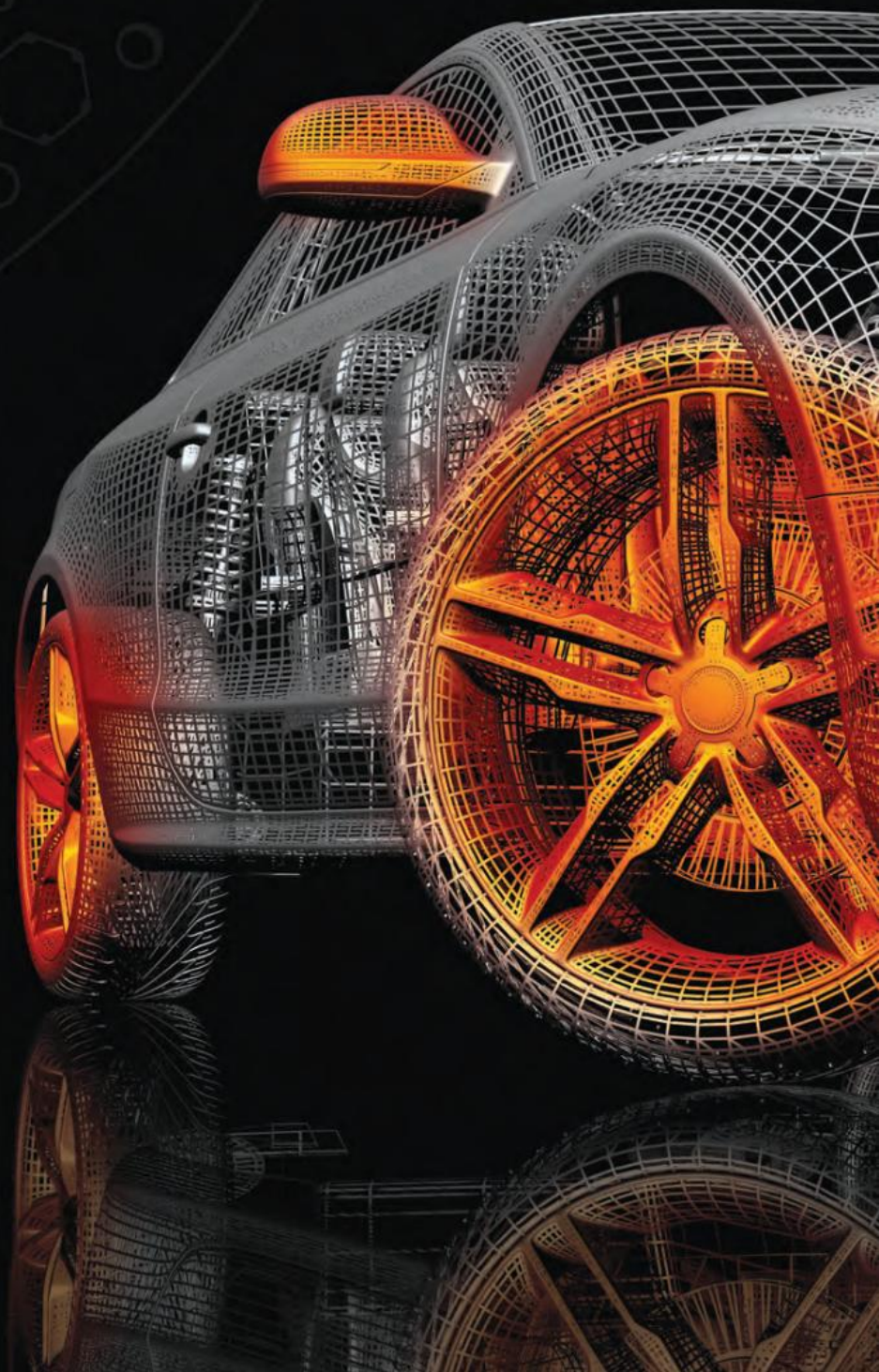
Automotive Mechanics

MAY | SIMPSON



10th Edition

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Competency grid

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AURATA001	Identify basic automotive faults using troubleshooting processes	Online content

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Any processes or procedures described are intended to be indicative of those generally used in the industry and information may or may not be appropriate for a particular make or model of vehicle.

For specific information on any servicing or repairs, the relevant service manual or manufacturer's information must be used.

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Contents in brief

Additional online chapters, including The Environment and the A utomotive Industry , are available in Connect.

Contents

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Preface

Automotive Mechanics 10e is a comprehensive blended learning package designed for today's automotive mechanics student. Now streamlined into a single volume, this tenth edition covers the core competencies for the Certificate II and III in Light Vehicle Mechanical Technology, as well as a range of the most popular electives. The single-column design of the new textbook provides an improved reading experience, with clear illustrations. The many new and revised topics throughout include:

- revised and condensed content to reflect the changes in the automotive industry and the needs of training providers
- clear objectives at the beginning of each chapter and summaries at the end to assist both teachers and students
- a new chapter on computer systems, including CAN Bus wiring repairs, diagnosis and testing
- information on the use of scan tools and other modern diagnostic equipment
- revised content on battery and charging systems, including smart chargers and stop-start systems
- new braking technology, including electronic park brakes and collision avoidance systems
- service and repairs to common-rail diesel systems.

To add to the list above, the *Connect* platform provides an interactive and meaningful learning experience. Its rich suite of online learning and assessment resources includes a web-based eBook with assessment tools, worksheets, interactive activities and PowerPoint summaries.

Automotive Mechanics 10e relates to passenger and light commercial vehicles and covers the principles, their applications, the construction of components and the basic servicing requirements. It is a valuable resource for all automotive students and deserves an important place in any automotive technician's library. While the resource does not attempt to replace vehicle manufacturers' manuals, it does provide a general resource that complements them.

Ed May and Les Simpson

About the authors

Les Simpson

Les Simpson has more than 35 years' teaching experience. He holds a Diploma in Teaching (Technical), a Certificate IV in Automotive Technology, a Certificate IV in Workplace Training and Assessment and is a member of the Institute of Automotive Mechanical Engineers. During his career, he has taught trade and farm mechanics in a small country college, plant and heavy equipment in a regional college, and light vehicle mechanics at metropolitan colleges.

Les has also worked overseas for TAFE NSW assisting the governments of Malaysia and the People's Republic of China to deliver vocational education and training (VET) programs.

Before joining TAFE NSW, Les served as a member of the Australian Army. During his army career, he completed his apprenticeship and gained experience working on a wide variety of vehicles and equipment.

Les is a keen supporter of WorldSkills Australia as a Sydney regional judge and team manager.

Ed May

Ed May has an automotive background that includes experience as a practising mechanic, aircraft fitter in the RAAF, technical representative for a major motor vehicle company, and TAFE teacher. He holds a Motor Mechanic's Certificate, a Diploma in Mechanical and Electrical Engineering, and also a postgraduate Diploma in Industrial Education and Training from the University of Manchester (UK). He has been an active member of the Queensland Division of the Society of Automotive Engineers Australasia (SAE) and is an honorary life member of the society.

As a TAFE teacher, Ed taught a wide range of automotive subjects at the South Brisbane College of TAFE. In addition to teaching, he has held the position of principal education officer, being involved in both curriculum development and administration. Before retirement he was the principal of the Ithaca College of TAFE.

In retirement Ed has maintained his lifelong interest in the automotive industry and in technical writing. While his writing has included other automotive titles, he has concentrated on the new editions of the very successful and widely used *Automotive Mechanics*.

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Ed May and Les Simpson

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PART 1

Introduction to motor vehicles

CHAPTER 1

Motor vehicle components

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 describe the four layouts of passenger and light commercial vehicles
2 identify the major components and systems of motor vehicles
3 state the purpose of the major components and systems of motor vehicles.

A motor vehicle consists of a large number of parts that are assembled during manufacture . Some parts are large , others quite small. Many are fitted together to form larger components. Some are bolted together while others, such as the body panels and subframes, are welded together .

The term motor vehicle can include passenger cars, station wagons, vans, utilities, trucks, buses and coaches.

Most of the information in this book relates to passenger vehicles and light commercial vehicles. However , its basic principles apply to all motor vehicles, including those that do not usually operate on roads, such as tractors and industrial and construct ion equipment.

1.1 Vehicle layouts

There are four basic layouts of the major mechanical components of passenger and light commercial vehicles: front-wheel drive, rear-wheel drive, all-wheel drive and four-wheel drive. These are shown in simplified form in Figures 1.1, 1.2 and 1.8, with their parts identified.

The main difference between them is whether the front wheels or the rear wheels drive the vehicle, and this can affect a number of other components, such as the mounting of the engine, the transmission, the drive line and the suspension.

Four-wheel-drive vehicles have additional transmission and drive-line components that carry the drive to all four wheels. In many four-wheel-drive vehicles, front-wheel drive is selected by the driver only when it is needed; other vehicles, referred to as all-wheel drives, operate in four-wheel drive at all times.

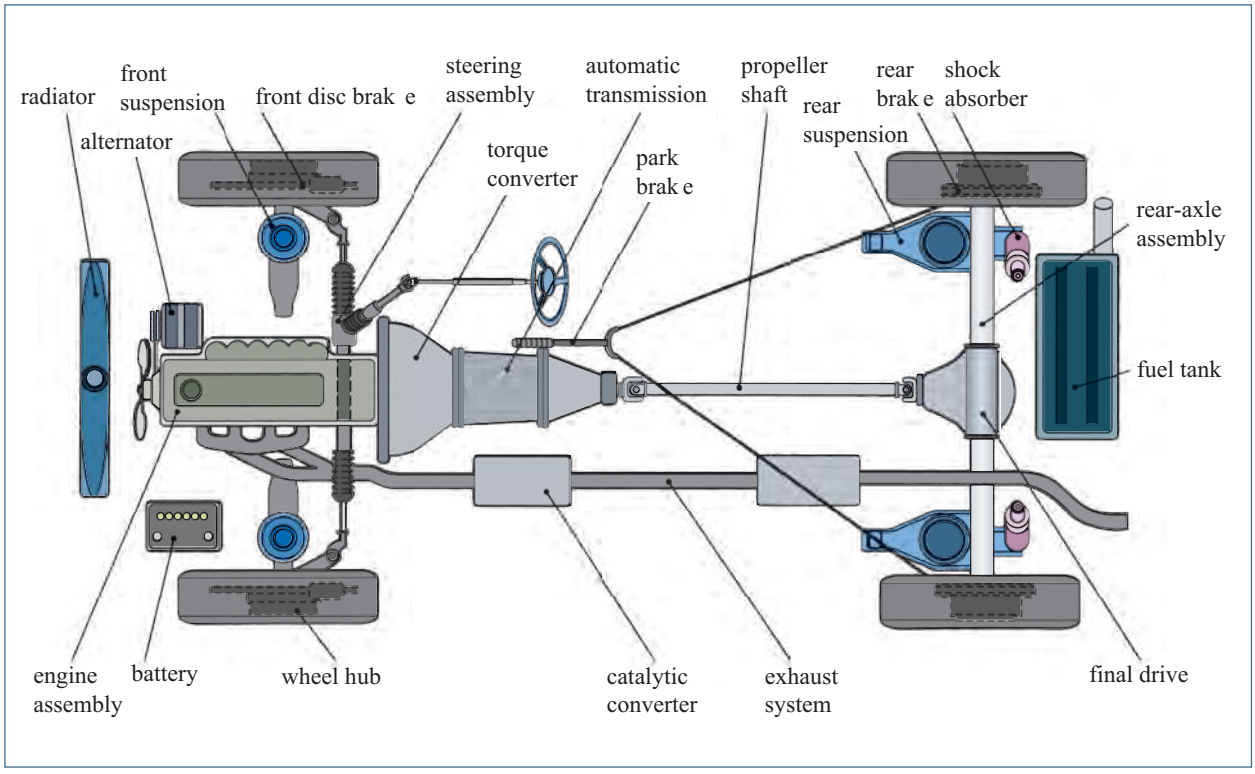


Figure 1.1 Skeletal arrangement of a rear-wheel-drive vehicle

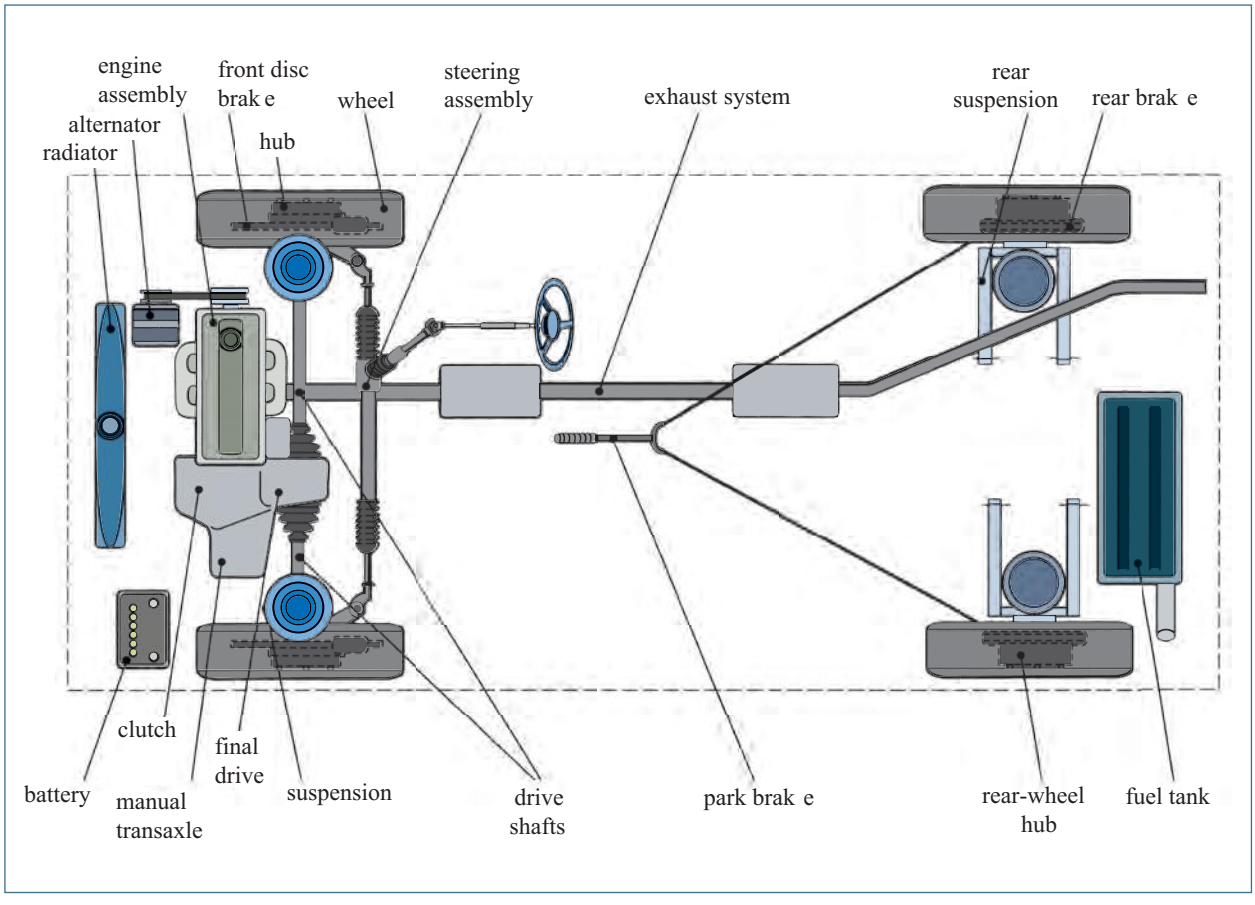


Figure 1.2 Skeletal arrangement of a front-wheel-drive vehicle

1.2 Sections of a motor vehicle

A motor vehicle consists of a number of sections that, for convenience, can be considered as follows:

1 Engine assembly . The source of power
2 Frame or chassis . The basic structure to support the engine and mechanical components
3 Drive train . Gears and shafts to connect the engine to the driving wheels
4 Running gear . The wheels, tyres, suspension, steering and brak es, for the vehicle to operate on the road
5 Electrical system . The battery , wiring, lights, starter , alternator , electronic controls and other electrical components
6 Body of the vehicle . Provides seating for the driver and passengers and, in commercial vehicles, carries loads.

To service these various parts, it is necessary to know their name, function and location. It is also necessary to understand how they operate and to be familiar with their construction and design. A knowledge of adjustments, servicing requirements and accepted methods of carrying out repairs is vital.

1.3 The engine assembly

The engine is the source of power that provides the torque or turning force that drives the vehicle. Engines in motor vehicles are called internal-combustion engines because fuel (petrol, distillate or gas) is burnt inside them.

Figure 1.3 shows a basic engine with its main parts identified. This is a four-cylinder petrol engine of the type fitted to passenger and light commercial vehicles. Figure 1.4 shows more details of an engine of this type.

Burning fuel inside the cylinders of the engine produces a high pressure that forces the pistons to move down their cylinders. Piston movement is transferred to the crankshaft by the connecting rods, causing the crankshaft to rotate. This rotary motion is then carried by the drive train to the driving wheels and used to propel the vehicle along the road.

The engine assembly includes the engine itself, as well as all the components and systems needed to make it start and run. These include the starting, charging, cooling, ignition, lubrication, fuel and exhaust systems.

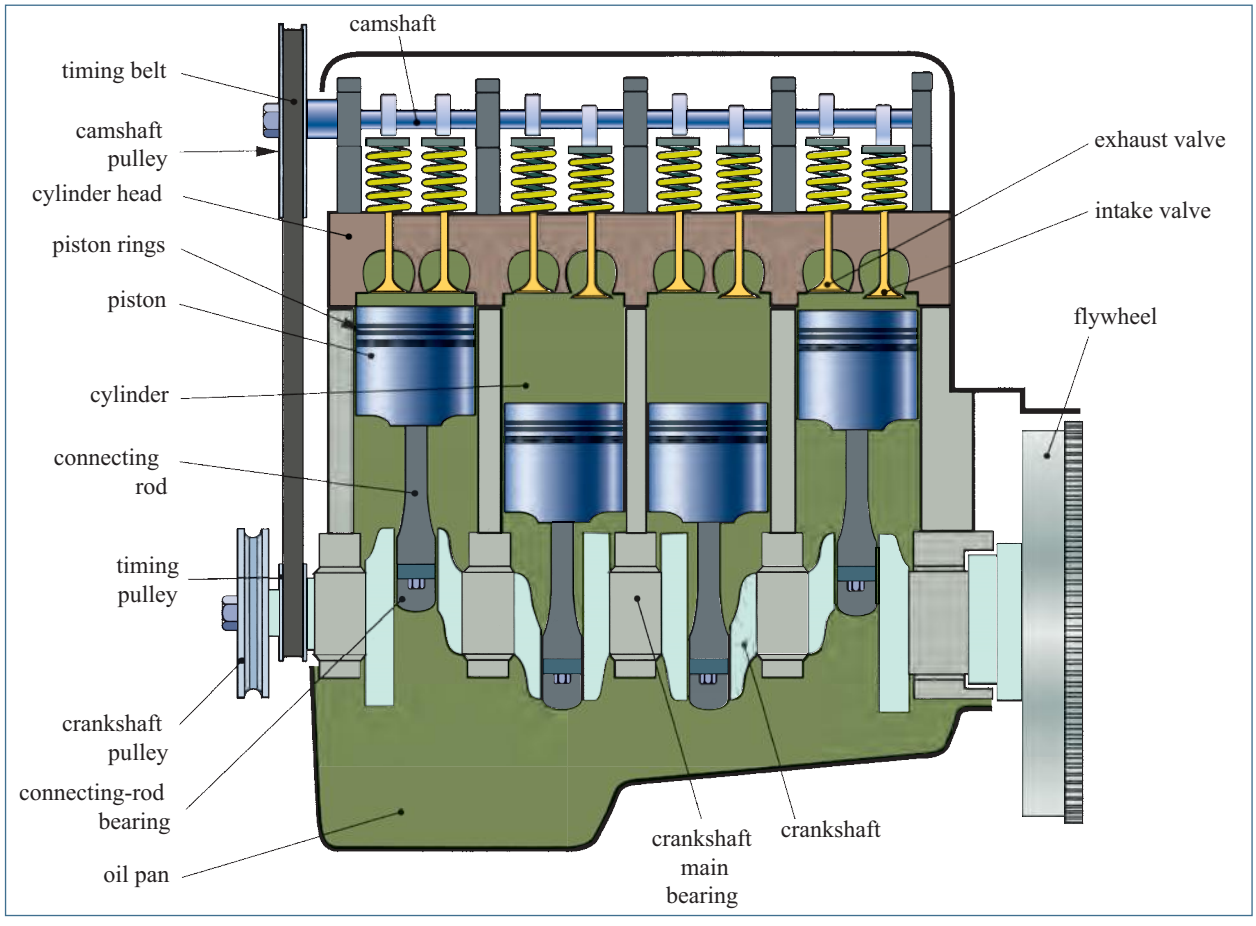


Figure 1.3 Basic construction of a four-cylinder engine

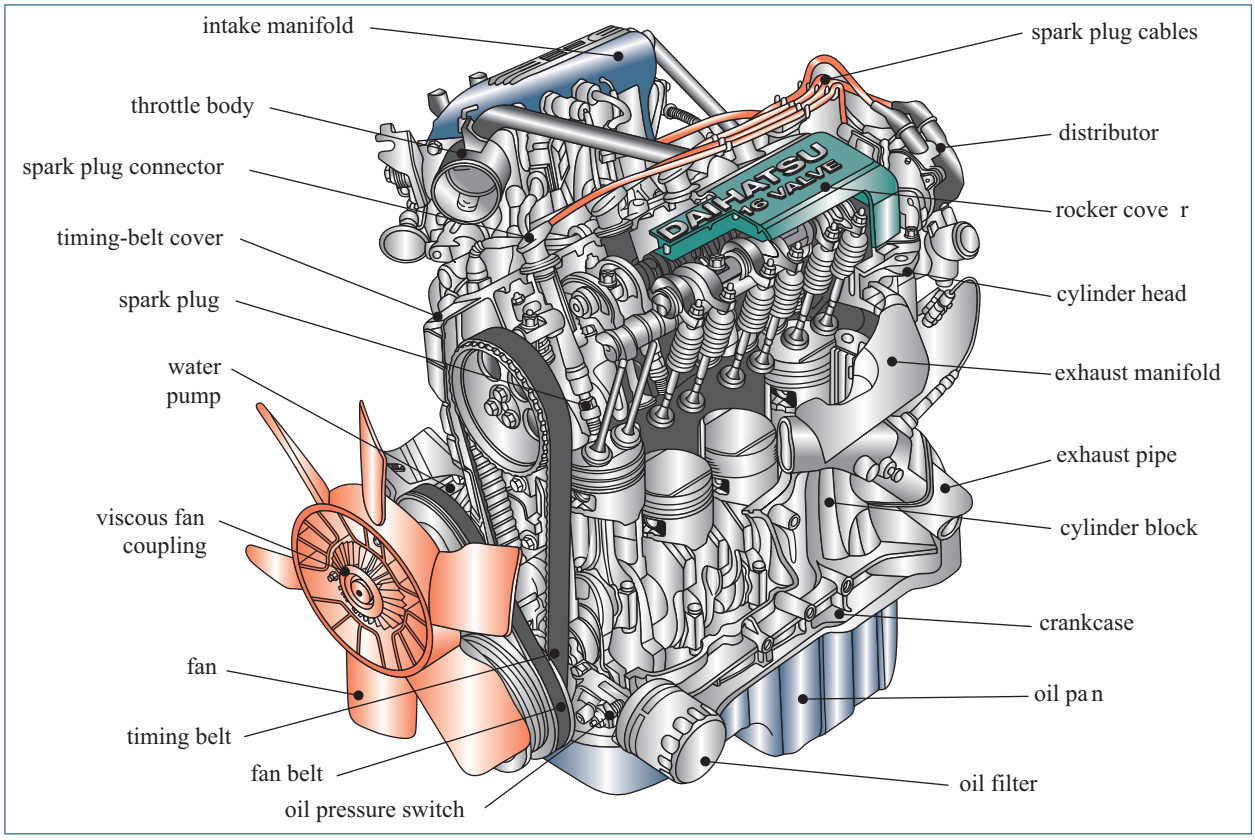


Figure 1.4 External components of an engine identified

1.4 Hybrid-drive vehicles

Hybrid-drive vehicles have an internal-combustion engine combined with an electric motor to provide the power that drives them. This is to improve fuel economy and reduce exhaust emissions (the electric motor produces no emissions). The engine can be designed smaller than usual and thus more fuel efficient.

The basic hybrid arrangement is shown in Figure 1.5, with its main parts identified. Depending on driving conditions, the power to drive the vehicle is delivered by the engine, the electric motor or a combination of the two. A fuel tank supplies petrol to the engine and high-voltage batteries provide power to the electric motor. The battery is recharged by a generator when the electric motor is not in use.

1.5 The drive train

The drive train, also called the power train, includes all the components that carry drive from the engine to the driving wheels of the vehicle. Different arrangements are used for rear-wheel drive and front-wheel drive (see Figures 1.1 and 1.2).

With rear-wheel drive, the drive reaches the rear wheels through the clutch, transmission, propeller shaft, final drive, differential and rear axle.

With front-wheel drive, the drive is carried by the clutch, transaxle and drive shafts to the front wheels. There are similar components to those of a rear-wheel drive but they are arranged differently and are more compact.

Vehicles with automatic transmissions have similar drive trains to those with manual transmissions but have a torque converter instead of a clutch. Automatic transmissions for front-wheel drive are known as automatic transaxles.

Handy hint: The term drive is commonly used, although what is actually being transmitted is torque , or twisting force .

1.5.1 Clutch

The clutch is a friction-type coupling that enables the engine to be connected or disconnected from the transmission. It consists basically of a large disc held against the engine's flywheel by spring force. The disc

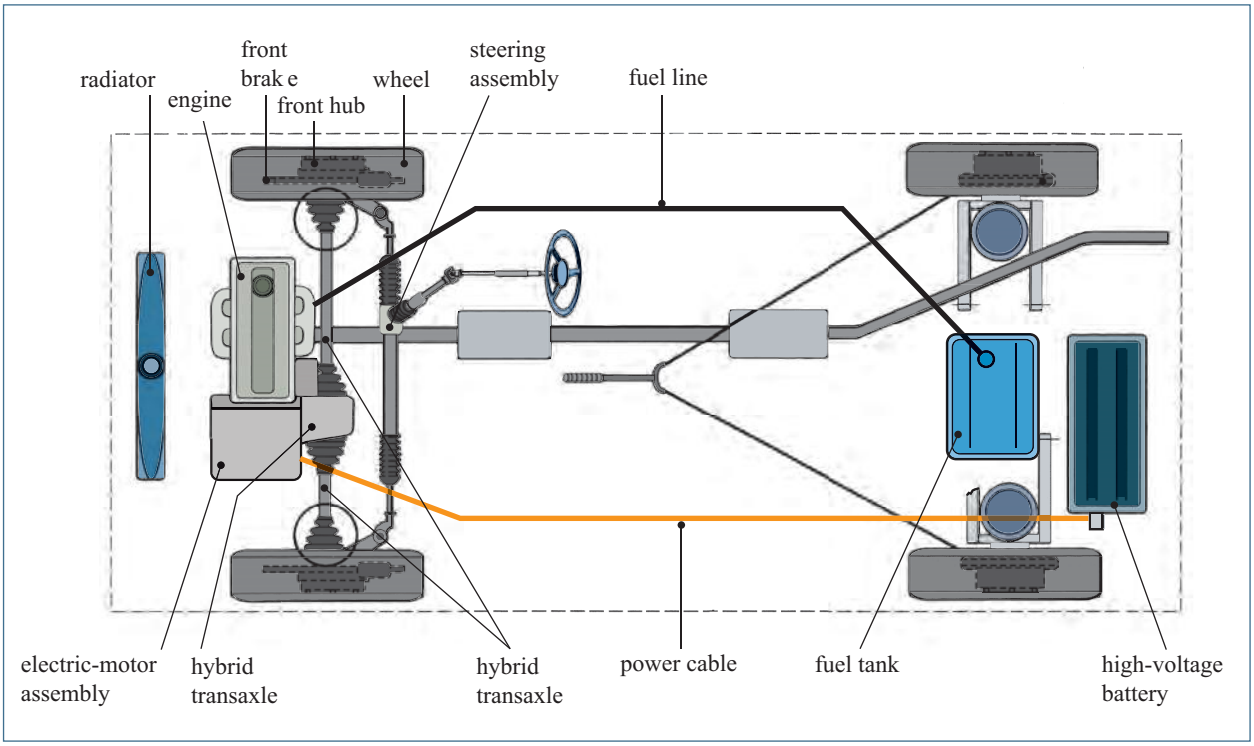


Figure 1.5 Skeletal arrangement of a hybrid-powered vehicle

is released by the driver pressing down the clutch pedal. This allows the gears to be engaged and gearshifts made. The clutch also enables the load to be applied gradually when starting the vehicle.

Figure 1.6 shows a simplified clutch arrangement. The clutch disc is held against the face of the flywheel by the diaphragm spring, but is released by the movement of the pedal being transferred through the cable to the release fork. The clutch shown is manually operated, its operation depending on the action of a cable and levers. Other clutches are operated hydraulically.

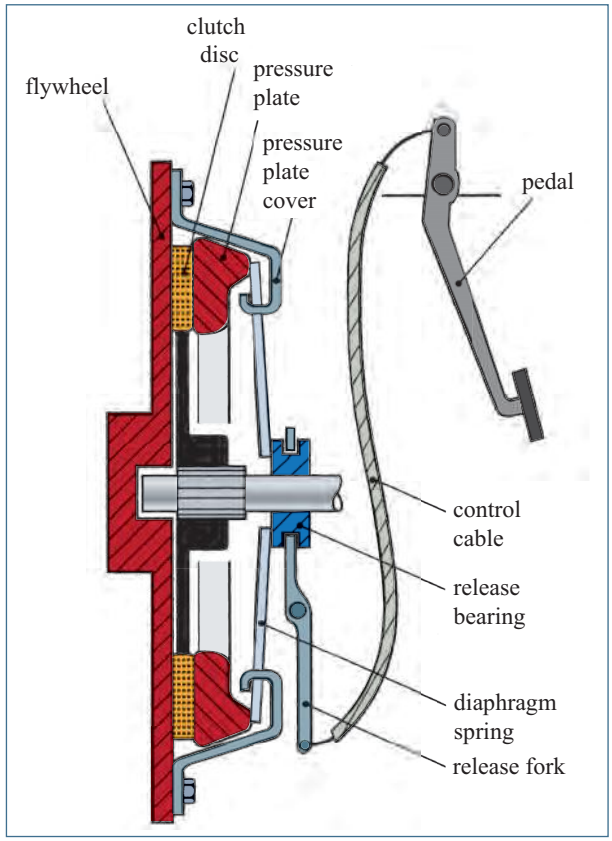


Figure 1.6 Simplified illustration of a clutch assembly

1.5.2 Rear-wheel drive

In rear-wheel-drive vehicles, a drive shaft, called the propeller shaft, carries the drive from the transmission to the rear-axle assembly. It has universal joints and a sliding spline which allows the shaft to change its length and 'angle' so that it can adjust to rear-axle and suspension movement.

Rear-axle assembly

The rear-axle assembly of a rear-wheel-drive vehicle contains the gears and axles that carry the drive from the propeller shaft to the rear wheels. The final-drive gears (the *crown wheel* and *pinion*) provide a gear ratio of about 4:1. They also change the direction of drive by 90°, from the propeller shaft to the rear-axle shafts and rear wheels.

The rear axle also houses the gears of the differential. When the vehicle is travelling in any direction other than straight ahead, one rear wheel must turn faster than the other. The differential allows this, while still delivering drive to both rear wheels.

Handy hint: With a 4:1 gear ratio in the final drive , the propeller shaft would rotate four times to turn the rear wheels once .

1.5.3 Front-wheel drive

The arrangement of a front-wheel drive is shown in Figure 1.7. The engine is mounted transversely, that is, across the vehicle. Therefore, there is no need to change the direction of drive before it reaches the driving wheels. Drive is transferred from the engine by the clutch to the gears of the manual transaxle, then through the final-drive gears and differential (which are in the transaxle housing) and then by the drive shafts to the front wheels.

The drive shafts have special types of universal joints called *constant-velocity joints*. Apart from allowing the shafts to adjust to suspension movement, the outer joints in the shaft must allow the front wheels to turn for steering.

1.5.4 Four-wheel drive and all-wheel drive

Four-wheel-drive vehicles have a final drive and axle at both front and rear. Figure 1.8 shows the basic arrangement of a larger four-wheel-drive vehicle. There is a propeller shaft from the transmission to both the front and the rear axles. This has a secondary transmission, known as a *transfer case*, located beside the main transmission. This is used to manually engage front-wheel drive.

All-wheel-drive vehicles operate in four-wheel drive all the time. They have a centre differential, or a special silicon coupling that allows for different speeds at the front and rear wheels. This is in addition to the differentials in the front and rear axles.

1.6 Transmissions

A transmission, usually called a gearbox, contains gears and shafts that provide a number of different gear ratios between the engine and the driving wheels. Gears are needed because an internal-combustion engine produces little power when running at low speeds.

To move a stationary vehicle, a low gear allows the engine to operate at a fairly high speed while the driving wheels turn at a low speed. This delivers a high torque to the wheels so the vehicle can move off easily. However, a low gear ratio is unsuitable for higher road speeds because the engine would have to operate at speeds far higher than it is capable of. For this reason, a transmission with a number of gears is used.

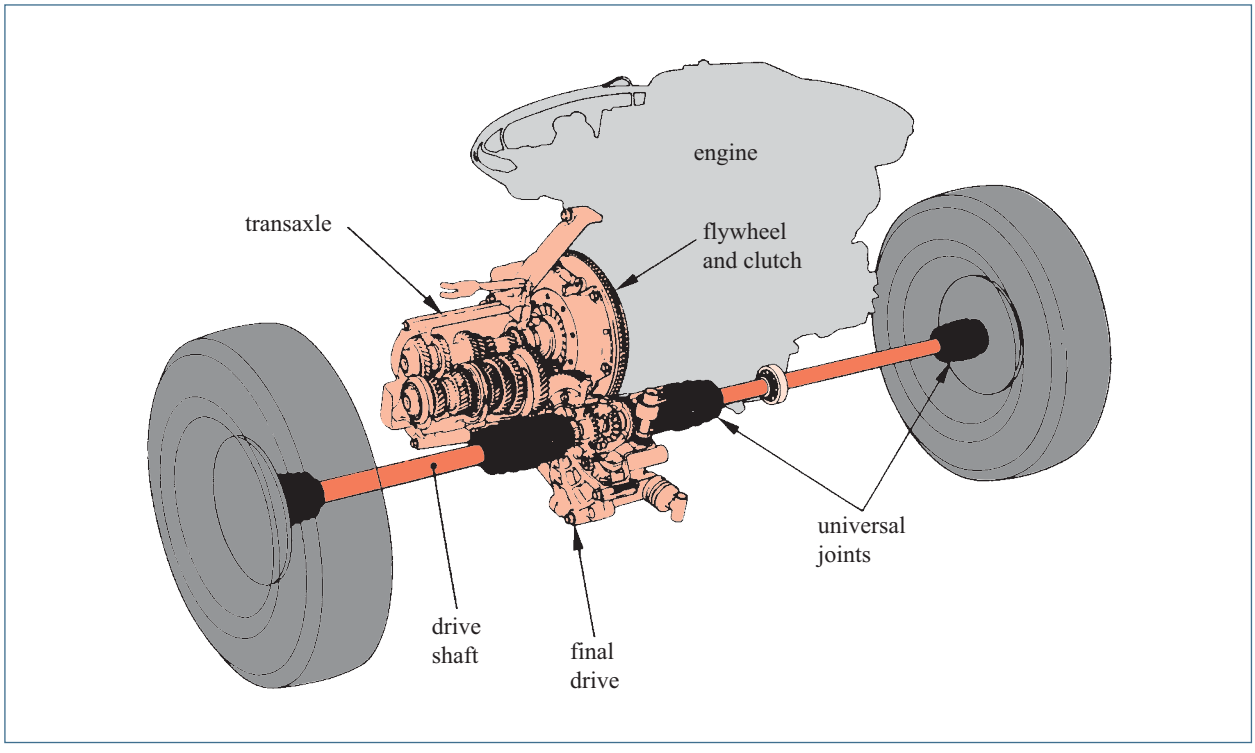


Figure 1.7 Arrangement of a transaxle and front-wheel drive FORD

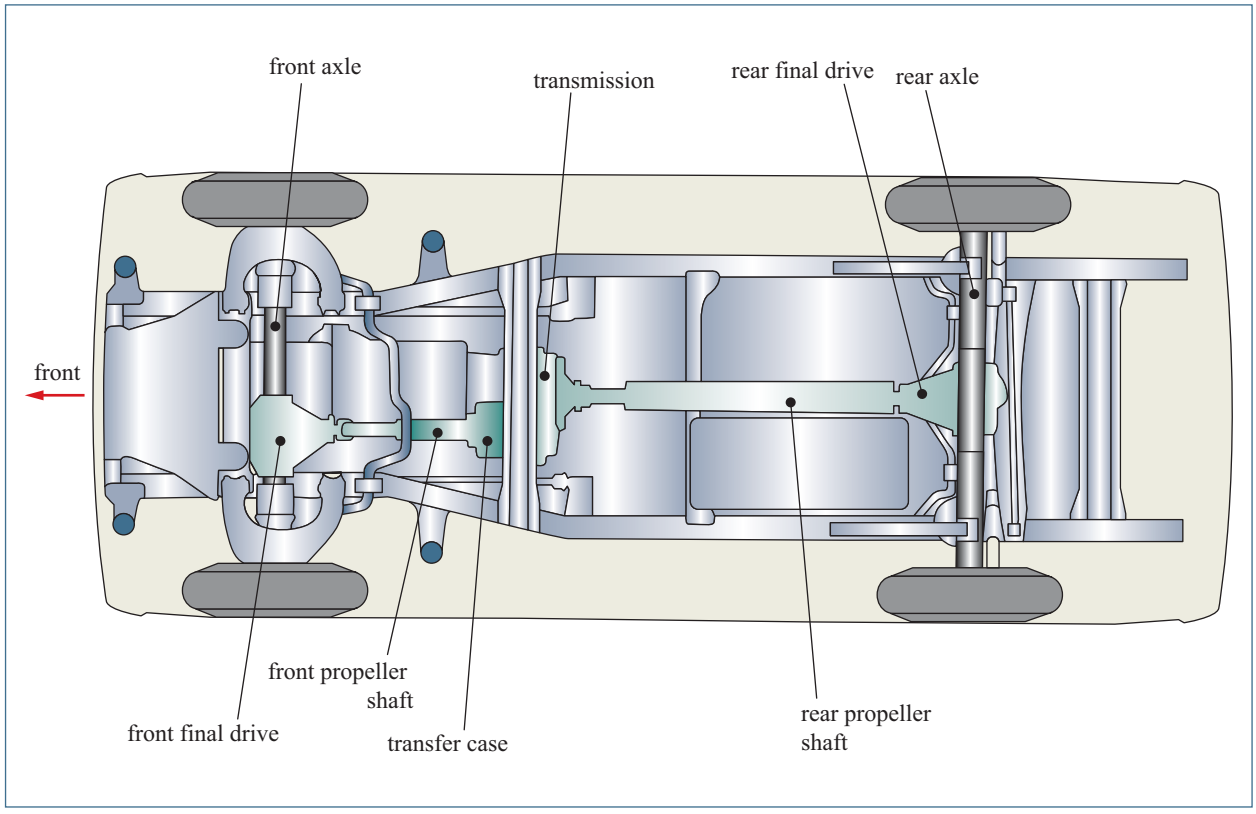


Figure 1.8 Arrangement of the drive line of a four-wheel-drive vehicle

Transmissions in passenger vehicles may have three, four, five or even six different gear ratios for forward movement as well as one for reverse. For light trucks, five or six gear ratios are often provided. Large trucks have an even greater number of gears.

In addition to the gear ratios within a transmission, a gear reduction also occurs in the final drive. In rear-wheel-drive vehicles the final drive is located in the rear-axle assembly, and in front-wheel-drive vehicles it is within the transaxle housing.

Handy hint: With front-wheel drive, the transmission is called a transaxle because it combines the functions of a transmission with those of an axle.

1.6.1 Manual transmissions

In a manual transmission or a transaxle, gears are selected by the driver moving the gear lever. When selecting or changing gears, it is necessary to isolate the engine from the transmission using the clutch. The overall gear reduction between the engine and the rear wheels is provided by the gears in the transmission and the gears of the final drive.

For example, if the first gears of the transmission provide a ratio of 3:1 and the gears of the final drive provide a ratio of 4:1, the overall effect would be a gear ratio of 12:1. The engine crankshaft would rotate twelve times to turn the driving wheels once.

Other possible transmission ratios are: second gear 2:1; third gear 1.5:1; fourth gear 1:1; and fifth gear 0.5:1. Changing up through the gears enables the road speed to be increased while maintaining reasonable engine speeds. Gears in the transmission also transmit torque, and so lower gears are used in conditions where the engine is operating under load.

Handy hint: Gear ratios similar to those shown could be used, but the actual ratios depend on the particular make and model of vehicle. An example of a low ratio is 3.166; even ratios are not used.

1.6.2 Automatic transmissions

Automatic transmissions (Figure 1.9) have a different type of gears, but they have similar ratios to a manual transmission. Gear shifting is done automatically without action from the driver.

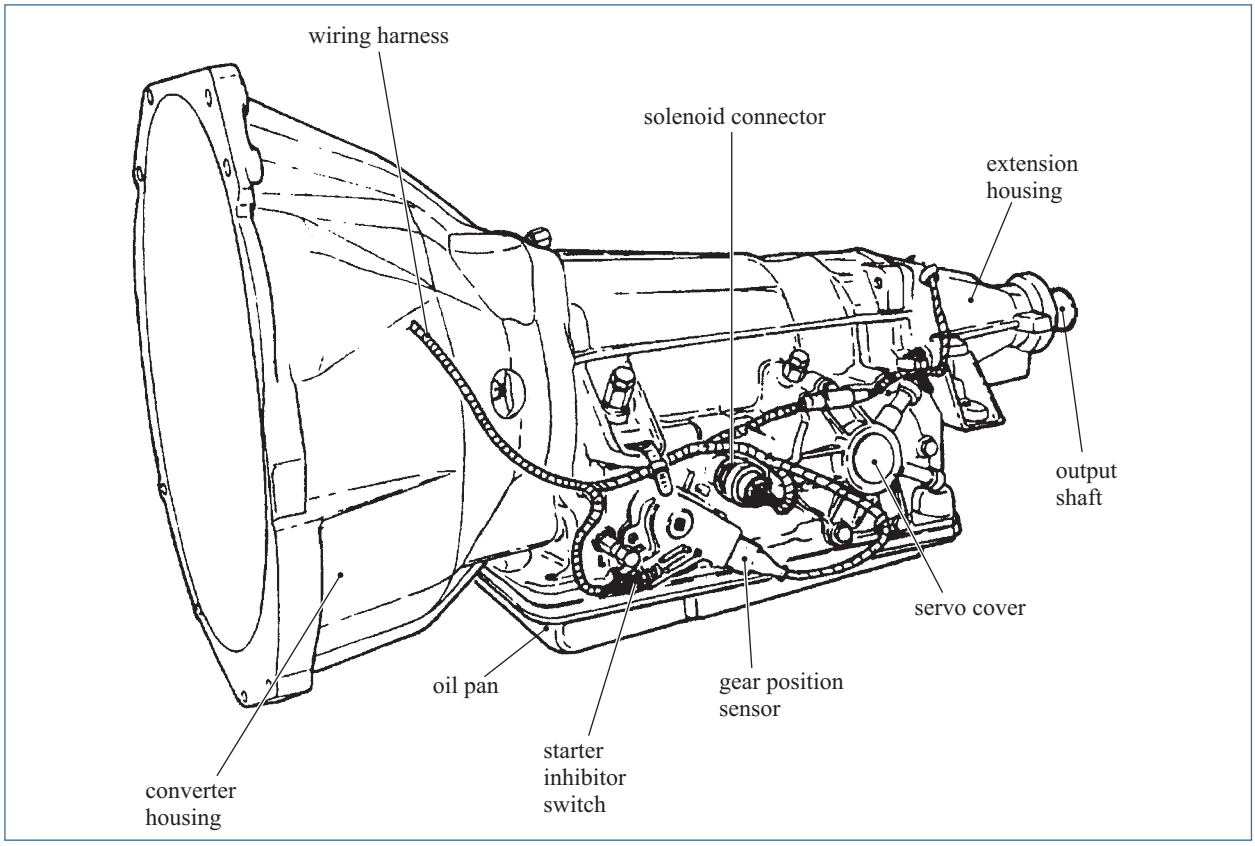


Figure 1.9 External parts of an automatic transmission FORD

Instead of a clutch, vehicles with an automatic transmission have a torque converter between the engine and the transmission. This is a hollow flywheel which is full of oil and attached to the crankshaft of the engine. Drive is transmitted through the converter by fluid being forced against vanes on the internal parts of the converter.

At engine idle speed, the fluid in the converter moves slowly and drive is not transmitted. When engine speed is increased, the fluid has sufficient force to carry drive through the converter to the transmission gears. There is slip between the parts of the converter, and this can provide a form of gearing under certain conditions. A clutch in the torque converter operates automatically in the higher gears to prevent slip.

1.7 Running gear

The running gear includes the suspension, wheels, tyres, brakes, steering and all the other chassis components that enable a vehicle to operate on the road. Separate chapters of this book are devoted to most of these, but a number of them will be considered briefly here.

1.7.1 Suspension

The suspension system supports the body of the vehicle and reduces the transmission of movement from the wheels to the body while keeping the wheels in correct alignment. The suspension system includes the wheels and tyres, axles, springs and shock absorbers. It also includes the arms and linkages that attach them to the chassis or subframe.

There are a number of different arrangements. Figure 1.10 shows a strut-type suspension unit. This consists of a coil spring mounted on a strut (a large shock absorber) and the axle spindle on which the wheel hub is mounted. This type of suspension is referred to as *McPherson suspension.* It is fitted to many passenger vehicles and can be used for both front and rear suspensions.

Springs

The wheels and axles are isolated from the chassis or subframe by the springs, which support the main parts of the vehicle. Springs allow the wheels to move up and down as they meet bumps or holes in the road, reducing movement that would otherwise be transferred to the body and passengers.

Figure 1.11 shows the action of a coil spring. When the wheel encounters a bump in the road, the spring compresses; when it meets a hole, the spring expands. This enables the wheel to follow the irregularities in the road. Linkages, or arms, connect the knuckle to the subframe and hold the wheel in position. There are various arrangements for both front and rear suspensions, which include coil springs, leaf springs and torsion bars.

Shock absorbers

Shock absorbers dampen out the action of the springs. Without them, the springs would continue to compress and expand (or oscillate), moving the body of the vehicle up and down. This repeated up-and-down movement would not only produce a very rough ride but would make the vehicle unstable. It would be difficult to control, particularly at higher speeds and on curves.

A shock absorber is fitted between the suspension and the body or frame near each wheel. Shock absorbers are filled with fluid which provides the damping action. McPherson struts have inbuilt shock absorbers and thus do not need separate ones.

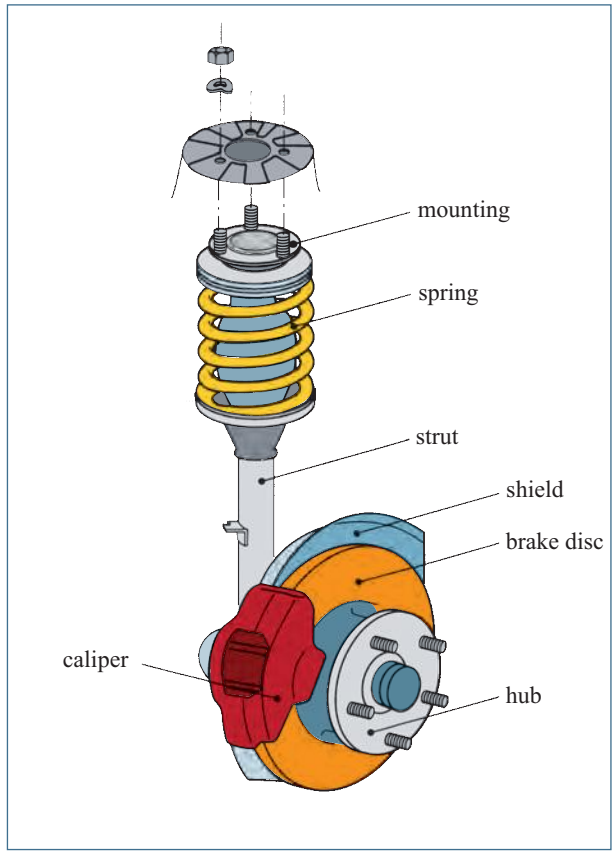


Figure 1.10 Strut-type suspension with its wheel hub and disc brake

1.7.2 Wheels and tyres

Wheels are made of pressed steel or aluminium alloy (the latter is used as it is lighter than steel and has cosmetic advantages). They consist of two sections: a rim and a flange. The rim provides a mounting for the tyre, while the flange has holes to allow the wheel to be bolted to the axle hub. Passenger vehicles use single wheels. Light trucks have single wheels at the front and dual wheels at the rear to increase their load-carrying capacity.

Pneumatic tyres

Pneumatic tyres support the vehicle and absorb shocks from smaller irregularities in road surfaces. Tyres with a separate inner tube were used for many years, but passenger cars now use tubeless tyres in which the air is retained by the airtight casing of the tyre and its fit on the wheel rim. Tyres provide cushions of air that enable them to flex slightly as bumps are encountered, giving a smooth ride. They also provide good frictional contact with the road surface for the driving wheels and braking.

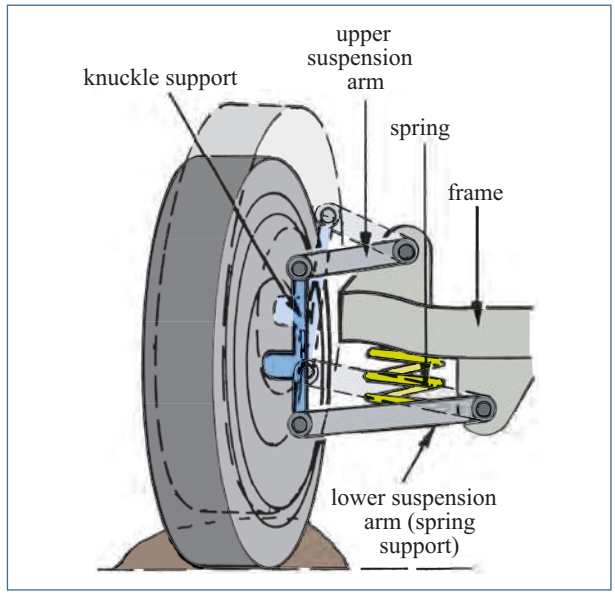


Figure 1.11 The coil spring compresses as the wheel encounters a bump in the road

1.7.3 Brakes

Brakes slow or stop the vehicle. With disc brakes, a disc attached to the wheel hub is clamped between two brake pads. Drum brakes have a drum attached to the wheel hub and braking is by means of brake shoes, which are expanded against the inside of the drum.

Both types are operated hydraulically. Hydraulic fluid in the system transfers force from the driver's brake pedal to the brakes at the wheels.

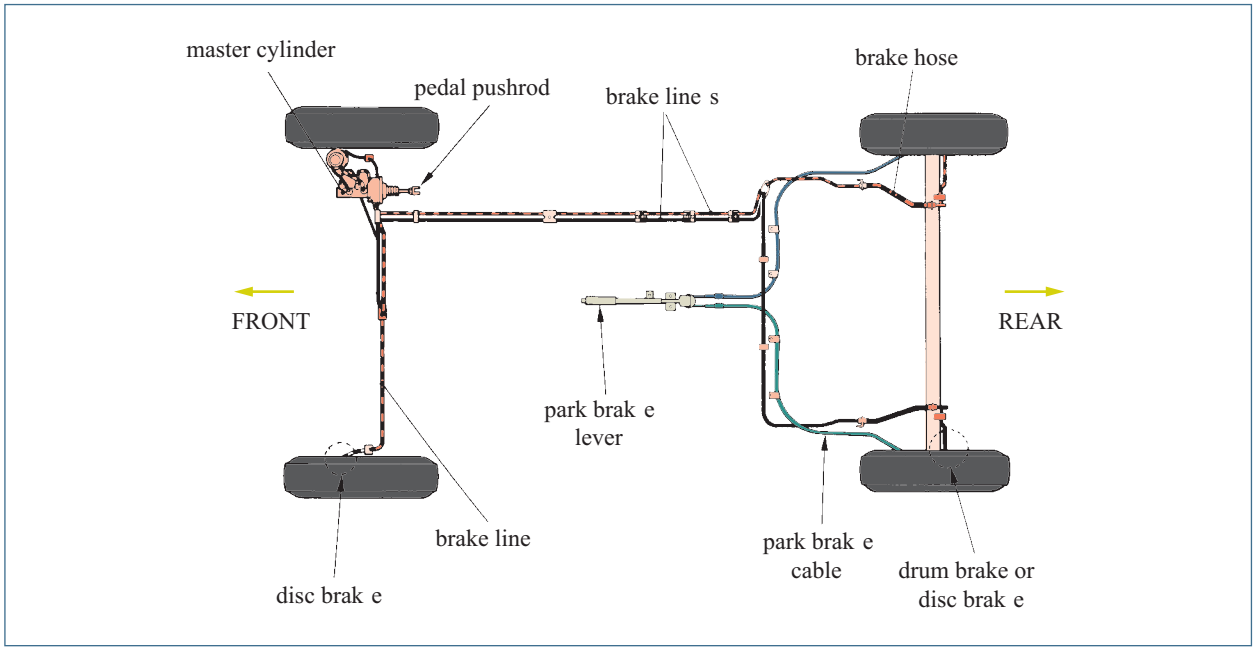


Figure 1.12 Braking system arrangement GM HOLDEN LTD

Figure 1.12 shows the arrangement of a braking system. The hydraulic system consists of a master cylinder, which is operated by the brake pedal, and hydraulic lines and hoses, which connect the master cylinder to the brake cylinders at the wheels. The system is filled with hydraulic brake fluid.

Brakes are power assisted, which reduces the force that the driver has to apply to the brake pedal. Some brakes are fitted with an anti-skid (or anti-lock) braking system (ABS). This prevents the wheels from skidding when the brakes are forcibly applied.

A parking brake can be applied by a foot- or hand-operated lever. The parking brake applies the rear brakes via cables located between them and the handbrake lever.

1.7.4 Steering system

The steering system permits the front wheels and hubs to be turned to the left and right so that the vehicle can be steered. The steering wheel is attached to a shaft connected to a steering box. Gears in the steering box are connected to the steering linkage, which is then connected to the front wheels. This arrangement turns the wheels in whichever direction the steering wheel is turned.

Figure 1.13 shows the steering arrangement for a rack-and-pinion steering box. Inside the steering box, a small gear on the end of the steering shaft is meshed with the gear teeth of a rack. This can be moved from side to side by turning the steering wheel, and this movement turns the wheels. This design of steering box is used extensively on passenger vehicles.

Most vehicles have power steering, where hydraulic pressure in the steering box assists the driver.

Handy hint: A rack is a bar into which gear teeth have been cut; a pinion is a small gear; a worm is a spiral-shaped gear.

1.8 Electrical system

The electrical system includes all the electrically operated parts of the motor vehicle, such as the battery, alternator, starter motor, switches, controls, lights and instruments. Figure 1.14 shows the location of various electrical systems.

The battery provides electrical energy when the engine is stopped. It operates the starter motor, ignition system and the other accessories necessary to start the engine. Once the engine is running, the alternator supplies the electricity. It also recharges the battery, replenishing the energy used in starting the engine.

The alternator has a grooved pulley and is driven by a belt from a similar pulley attached to the front of the engine's crankshaft. Its output increases with engine speed and so it is fitted with a voltage regulator. Electrical wiring installed throughout the vehicle connects the various parts of the electrical system.

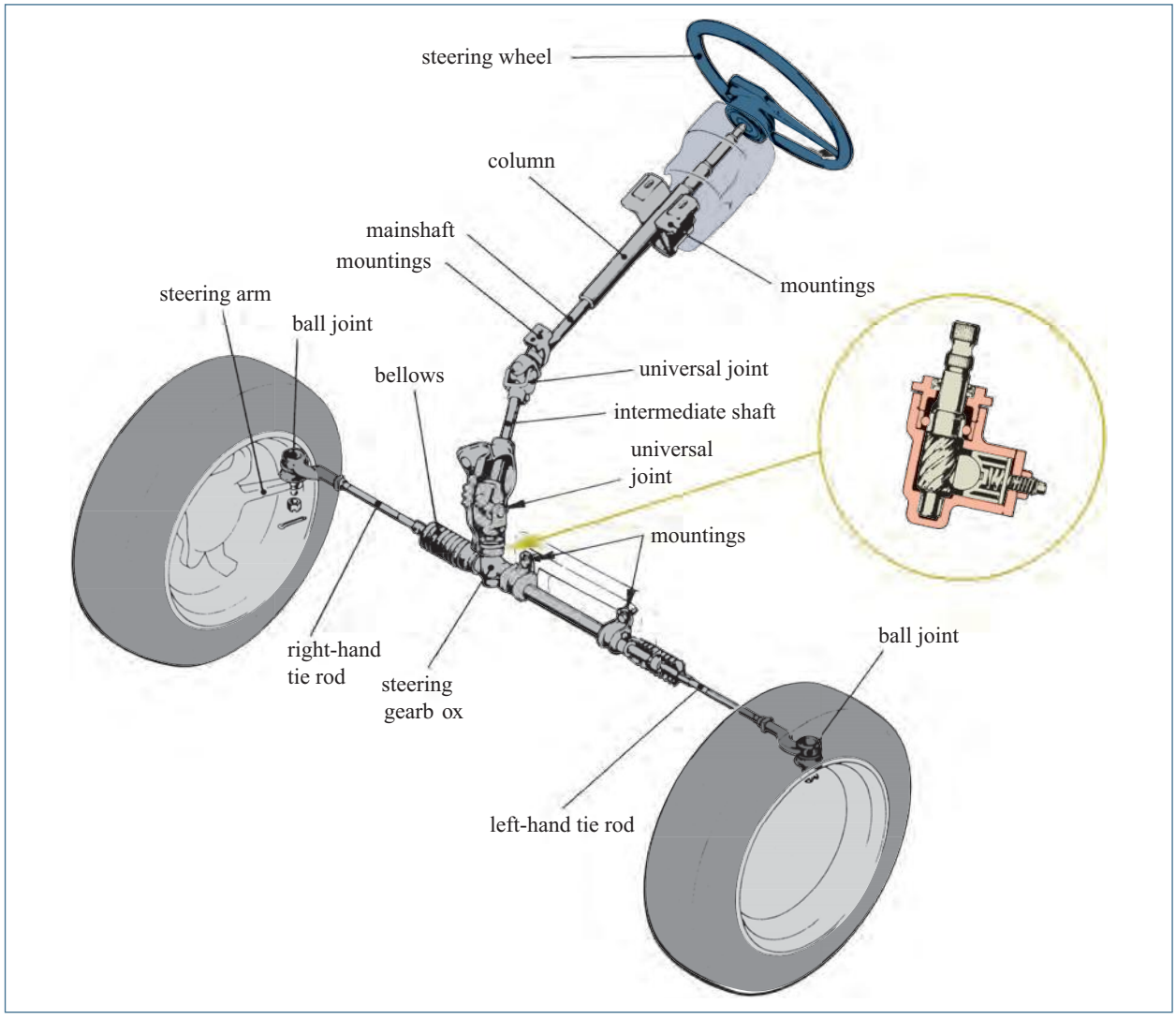


Figure 1.13 Rack-and-pinion steering system FORD

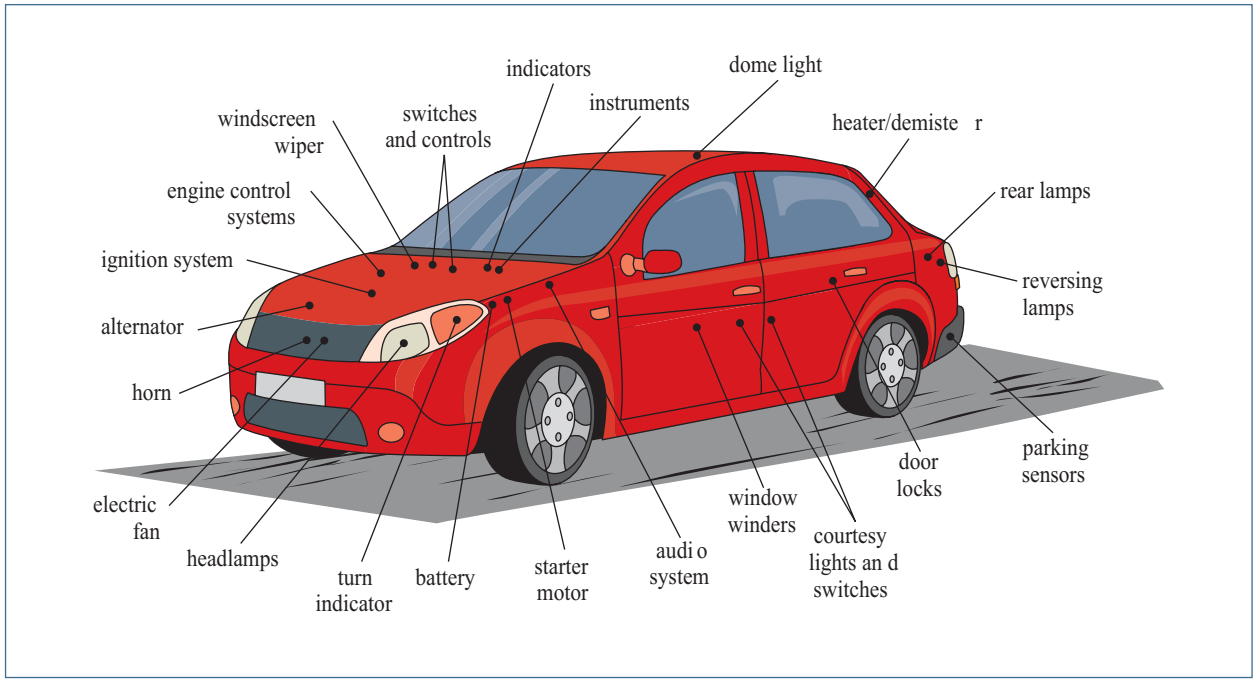


Figure 1.14 Location of various parts of the electrical system

1.8.1 Electronic controls

Electronic control units (ECUs) play a major part in the electrical system of motor vehicles. These are micro-computers with electronic components and circuitry that can monitor electrical components and perform a variety of tasks.

Many vehicles have a power control unit that looks after various engine functions and also automatic transmission controls. There is also a body control unit to control such items as lights, instruments, airbags, remote locking and entertainment.

Handy hint: While it is not necessary to understand exactly how electronic components and control units work, it is important to know why they are needed and what they do .

1.9 Body and associated parts

1.9.1 Vehicle construction

Passenger vehicles have a body of unitised construction. Reinforced panels and subframes are built into the body to provide the necessary strength and stiffness. A body of this type is shown in Figure 1.15.

Subframes for supporting the engine and transmission, the front and rear suspensions and other mechanical parts are built into the reinforced under-body panels. Strengthened sections of panels are used for mounting other components.

The subframes provide mountings for the engine, the transmission, the suspension and the steering. The engine has rubber mountings to prevent noise and vibration being transmitted to the vehicle body. Rubber bushes between the various parts of the suspension and the subframe also insulate against the noise and vibration that originate at the road and tyres.

Some light commercial vehicles have a cab and chassis. They have a driver's cab of unitised construction and a frame, or rear chassis, on which a tray-type body or a commercial body of some other design can be built.

Larger commercial vehicles have a full frame or chassis to which the body, engine, suspension, steering and other mechanical components are fitted. The chassis is made of steel channel or box section for strength, the parts being welded or riveted together. Cross-bracing makes the frame rigid enough to withstand the shocks, twists and vibrations that it will be subjected to during operation.

The body components include the metal panels of the body shell, the doors, bonnet (hood), boot lid, bumper bars, seating, soft trim, glass, body hardware, ornamentation, sound insulation and paintwork. Figure 1.16 identifies the main external parts.

1.9.2 Body panels

Body panels such as the roof and door panels are made from sheet metal that is pressed to shape between dies in large presses. The shaped parts are then welded together before being subjected to the finishing processes of sanding, priming and painting. While most structural parts are made of steel, aluminium alloy is used for panels in some vehicles because of its lighter weight.

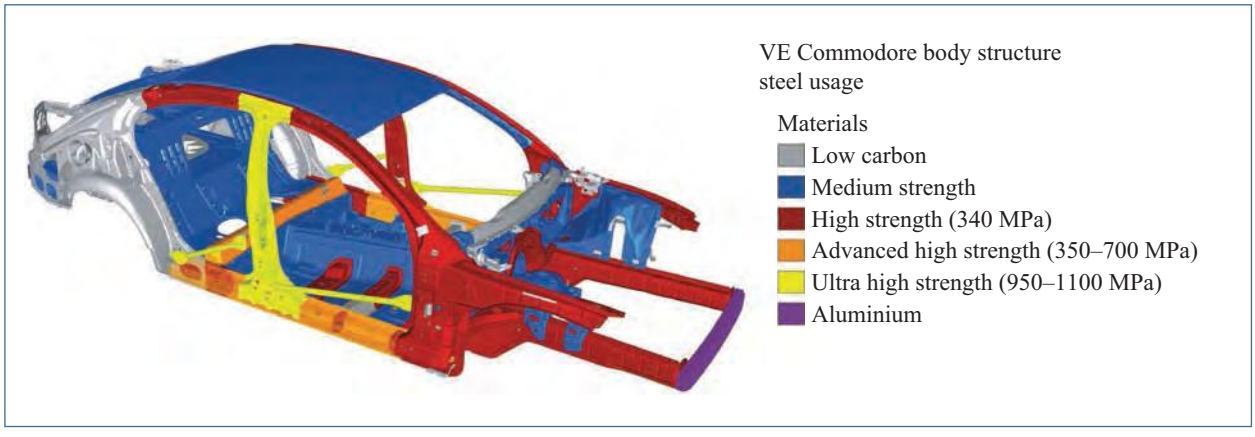


Figure 1.15 Body structure with different metals used. These pro vide light weight and strength GM HOLDEN LTD

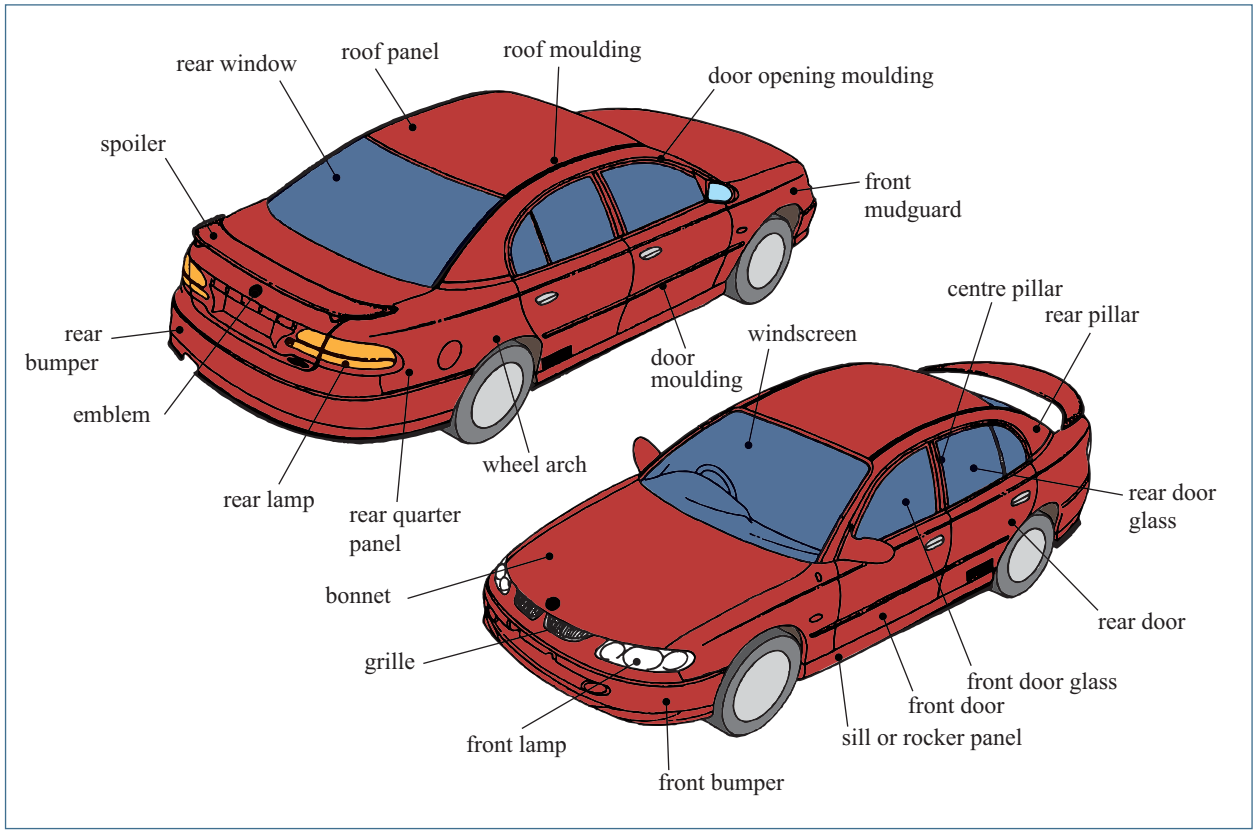


Figure 1.16 External body parts GM HOLDEN LTD

1.9.3 Glass

Windscreens are made of laminated glass. This has two thin layers of glass with a thin layer of clear plastic between them. If the windscreen is damaged, a layer of glass may chip or crack but will remain bonded to the plastic and the other layer of glass. Visibility is unaffected.

The glass in the rear window and doors is toughened safety glass. If this is damaged, it will crack into small pieces across the entire pane but will usually remain in position.

Handy hint: Safety glass is used as it breaks into granules instead of sharp pieces like ordinary glass. This makes it safer for the vehicle occupants.

1.9.4 Body hardware

Body hardware includes door locks, handles, hinges and window mechanisms. There are also smaller items such as bolts, screws and clips and other fasteners.

1.9.5 Interior trim

There are hard trim and soft trim parts. Hard trim items are metal fittings and plastic mouldings that finish off sections of the interior of the vehicle. Soft trim items include door linings, hood lining, floor mats, carpet, upholstery and other vinyl or fabric trimmings.

1.9.6 Ornamentation

The body has a number of small ornamental items such as the name of the vehicle, model badges or emblems.

1.9.7 Mouldings

Some vehicles have a plastic strip, usually called a moulding, along the belt line, on the mudguards and doors. As well as being ornamental, they also protect the panels.

1.9.8 Bumpers

Bumpers are fitted to the front and rear of the vehicle. They provide a small measure of protection against damage from collision, but only at very low speeds. The bumpers on passenger vehicles are in the form of

skirts, which are moulded to provide the finish to the front and rear of the body. Commercial vehicles have bumper bars of steel which gives more protection than plastic.

1.9.9 Grilles

A grille at the front of the vehicle allows air to reach the radiator. Some vehicles have a decorative grille; others have air-flow space in the front of the bodywork.

1.9.10 Paintwork

During manufacture, the body panels are given anticorrosive treatments. Some body panels are made from galvanised steel, which resists corrosion, while other panels and parts are sprayed with rust-preventative materials after assembly.

A bead of sealer is applied to joints between panels, and sound-deadening compound is applied to several places, such as the undersurface of the body and the inside of the door panels. Folds and seams, which could trap moisture and dust, are treated with anticorrosive material that penetrates between the surfaces. The exterior of the body undergoes a surface-preparation treatment before being primed and is then sprayed with its finishing coats of paint of the required colour.

1.10 Components and part names

All motor vehicle parts have names, with replacement parts also having part numbers. Some names relate to the part's location, often with the words *upper* or *lower* added. Others are combined with *left* or *right,* or *front* or *rear,* for example *upper radiator hose* and *right front wheel.*

Some parts are obviously named according to their function, such as *filter, spring* or *shock absorber.* The derivation of other parts' names can be harder to establish. For example, the *diesel* engine takes its name from its creator, Dr Diesel.

Names of components and parts can vary from country to country, as can spelling. For example, *clutch disc* can be spelt *disc* or *disk.* However, the reason for the names can usually be worked out, and this helps in remembering them.

1.10.1 Larger components

Larger components consist of a number of small parts: for example, the gearbox can be considered as a component and the gears that are fitted inside the gearbox as parts. Many components that contain other parts are referred to as *housings* or *boxes,* such as the *clutch housing* and *gearbox.*

In other cases, parts can be considered to form a system which consists of a number of components or parts; for example, the fuel system includes the fuel tank, fuel pump, fuel lines and fuel injection components. The diagrams in Figures 1.1 and 1.2 show the components in simple form and enable various components that make up the mechanical section of a motor vehicle to be identified.

Handy hint: The terms components, parts, units and items are all used in relation to motor vehicle parts.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify the sections of a motor vehicle
- identify the drive train, which has gears and shafts to drive the wheels
- state the different types of transmissions
- name the basic electrical components, such as the battery, alternator and starter motor
- state the operation of the internal combustion engine.

REVIEW QUESTIONS

1 Name the main sections of a motor vehicle .
2 Why is the engine referred to as an internal-combustion engine ?
3 What types of fuel are used in automotive engines ?
4 What is the purpose of shock absorbers ?
5 Why are tyres necessary ?
6 What are the parts of the power train ?
7 Why is a clutch necessary ?
8 Why is a transmission fitted to a vehicle ?
9 What is a transaxle ?
10 What is the function of the universal joints ?
11 What does the differential do ?
12 What are the two designs of brakes ?
13 What is the purpose of the suspension ?
14 Name some of the parts in a rear-axle assembly .
15 Name some of the electrical parts of a vehicle .
16 How is the alternator driven ?
17 What are the main differences between a front-wheel-drive and a rear-wheel-drive vehicle ?
18 Name the main external body parts of a passenger car . Refer to Figure 1.16.

CHAPTER 2

Workshop safety

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 state the requirements of workshop policies and procedures relating to personal safety
2 state the safe operation of equipment and safety around motor vehicles and their components, including engines and batteries
3 follow emergency procedures relating to fires, fire extinguishers, evacuation plans and first aid
4 contribute to workshop safety as a member of a team.

The type of work that takes place within an automotive workshop carries risks of severe injury or death from such activities as manually handling heavy or awkward components, vehicles slipping from hoists and jacks, or vehicles being moved in the vicinity of people working. Other less obvious risks include breathing in asbestos or the fumes from welding, soldering or solvents.

Workplace health and safety (WHS) is everyone's responsibility. Employers have an 'absolute duty of care' to provide and maintain a safe workplace, and employees have a duty to take reasonable care to protect their own safety and the safety of others. This includes knowing how to eliminate or control risks and hazards.

A proactive attitude towards identifying hazards and reporting them to relevant personnel is crucial. Everyone can adopt this attitude, which is key to creating and maintaining a safe, happy and productive workplace. Equally important is following up concerns and taking action. None of this can happen without effective management and communication and record-keeping skills.

Every state has legislation to protect an individual's health and safety at work. More information on WHS is available by visiting the national website, Safe Work Australia, www.safeworkaustralia.gov.au or the WHS authority's website in each state or territory.

2.1 Personal safety

Items of personal safety are referred to as *personal protective equipment* (PPE). These must conform to Australian standards; if they do, they will be marked accordingly. The owner of a business or workplace must display a list of the PPE required, and all individuals must comply with relevant regulations at all times. The following are the more common items of PPE (Figure 2.1).

2.1.1 Hearing protection

Continuous exposure to loud noise can cause permanent damage to hearing that may take many years to become apparent. Operating noisy equipment and using air tools are examples of activities that require the use of hearing protection, the nature of which is determined by the level of noise and length of exposure to it.

2.1.2 Skin protection

Gloves should be worn to protect the skin when handling hazardous materials such as refrigerants and solvents. The type of glove will depend on the task being carried out.

Application of a good barrier cream throughout the day will help protect the skin from cracking and minor irritations. Cuts and abrasions should be attended to immediately to prevent infection.

2.1.3 Clothing

Suitable clothing should always be worn in the workshop. Loose sleeves and other loose clothing can catch on parts of a vehicle or become tangled in equipment. Rotating parts such as fans, belts and drills are particularly dangerous as they could, for example, catch a loose sleeve and quickly pull a hand into them.

Long hair can become entangled in rotating parts.
Tie long hair back or wear a cap or other headgear.

2.1.4 Footwear

Sturdy footwear—especially that fitted with reinforced toecaps—will protect feet from hazards at floor level and falling objects.

2.1.5 Safety glasses and shields

Eyes need special protection. Clear safety glasses should be worn whenever there is a risk of eye injury, for example when using a grinding wheel or for any workshop job involving dust or metal particles.

Dark glasses must be used during gas (oxy-acetylene) welding. These enable the weld to be seen and also protect the eyes against the intense light, heat and sparks.

Arc welding produces rays that can permanently damage the eyes and burn the skin, so a special protective face shield with a dark-glass window face shield should be used and adequate clothing worn. It is dangerous to operate a welder or watch somebody else doing so without this equipment.

Figure 2.1 PPE is a vital element of workshop clothing
SHUTTERSTOCK

2.2 Other personal safety issues

2.2.1 Housekeeping

Keeping the workshop clean and well organised makes it safer, especially by minimising the risk from trip and slip hazards. Good housekeeping makes for a more efficient working environment (Figure 2.2).

Work benches, portable benches and tool boxes make it much easier to store tools and components that have been removed from vehicles. Keeping cleaning products and tools close at hand helps manage small spills and blemishes as soon as they occur.

Attention to housekeeping also shows an attitude of professionalism and respect for the vehicle owner.

Figure 2.2 A clean and tidy workshop is safer , more efficient and reflects a professional attitude SHUTTERSTOCK

Vehicles should be treated with care. They should be protected by covers (interior and exterior), and any dirty marks cleaned before the vehicle is returned. This is an expectation in, and of, workshops today.

2.2.2 Personal hygiene

Personal hygiene should be strictly observed when working in automotive workshops. While working with chemicals like solvents, oil, grease and petrodiesels, it is important to avoid contamination of skin, eyes and lungs. Washing hands before meal breaks and wearing appropriate PPE when dealing with these chemicals is vital.

When affected by any contagious illness such as flu, it is very important to avoid passing it on to others in the workplace. Using tissues and handkerchiefs helps to prevent airborne contagion, and it is helpful to the self and others to consider staying at home when sick.

Figure 2.3 Demonstrating a safe lifting posture
SHUTTERSTOCK

2.2.3 Manual handling

Manual handling is any activity that requires a person to lift, lower, push, pull or carry an object. Incorrect manual handling causes many workshop injuries. Good handling habits that reduce the risk of injury include:

1. Use lifting equipment for heavy loads.
2. Seek help from others to reduce the effort required.
3. Lift correctly, using leg muscles rather than back muscles (Figure 2.3).
4. Plan your work and store heavy items at waist height.
5. Always lift within your comfort zone .

2.2.4 Safety and tools

Small hand tools should be kept clean and tidy and be used correctly. Hammerheads should be secure, screwdrivers and chisels kept ground to the right shape, and drills and punches sharpened correctly.

Larger tools should be kept under control and not scattered about. Keep equipment out of aisles and working spaces where they would become a hazard, taking particular care with jack handles and creepers.

2.2.5 Using compressed air

Use air pressure carefully. Never point an air gun or hose at yourself or another person as particles of dirt can be blown at sufficient speed to enter the eyes or penetrate the skin. High-pressure air forced against the skin is very dangerous as it can enter the bloodstream. Also, rust from the compressor can cause blood poisoning.

2.3 Machine and equipment safety

Equipment includes things like safety stands, floor jacks and engine-lifting cranes. Machines normally have rotating or cutting components and are externally powered by electricity, hydraulics or compressed air. Workshop equipment is expensive and must be treated with care—the operator is responsible for using it safely. Safe operation of machines and equipment means using them correctly. Following manufacturers' instructions will reduce the risk of injury and ensure the most efficient use of the machine.

2.3.1 Use of machines

Standard operating procedures (SOP)

Every piece of machinery in the workplace must have its standard operating procedures (SOP) attached with, at a minimum, the following information:

- manufacturer' s operating instructions
- associated safety hazards
- any recommended PPE.

Figure 2.4 A range of safety signs that may be found in an automotive workplace SIGN TECH

Mobile equipment such as jacks and stands can have their SOP attached to the wall nearest to their storage location. Safe Working Loads (SWL) are found on the jack and stands decals, subject to Australian Standards.

Machine guards

Guards should be fitted to machines with external moving parts. They protect the operator, who should make sure that they are correctly in place.

Grinders should have covers over their grinding wheels to prevent grindings from being thrown towards the operator. The tool rests should always be adjusted close to the edges of the wheels. This will prevent a particle that is being ground from jamming between the tool rest and the grinding wheel. This could injure the operator, damage the wheel or ruin the article being ground.

Figure 2.5 Portable electrical tools should be tested and tagged regularly COURTESY COMPLETE TEST & TAG

Wheel balancers also require the use of safety guards. A guard over the tyre will protect the operator from dust or small stones that might be dislodged from the tread while spinning.

2.3.2 Electrical tools

When using electrical tools, always read and follow the operating procedures, keeping hands and clothing away from moving parts.

Every 240-volt power tool should have a tag attached to its cord (see Figure 2.5), showing when it was last tested for electrical safety. When equipment is found to be faulty and at risk of harming somebody, it is important to immediately isolate it and attach a tag that shows clearly that the item is faulty and not to be used. The workplace supervisor and all potential users of the equipment should also be informed. The equipment should be repaired or replaced as soon as possible.

2.4 Motor vehicle safety

Mechanics should appreciate the value of the motor vehicles in their care. A motor vehicle is a complex piece of machinery and should be treated as such, whether being worked on or driven.

Responsible driving protects mechanical parts, prolongs vehicle life and prevents accidents. When parking, make sure that the vehicle is safe: that is, apply the parking brake and place a manual transmission in the correct gear, or an automatic transmission in park.

2.4.1 Protecting the vehicle

When working on a vehicle, the paintwork and upholstery must be protected from being marked or damaged. Covers should be used on mudguards, seats and floor mats.

The final part of any workshop job should be to ensure that the vehicle is clean and ready for use. The tyres, engine oil, coolant, brake fluid and fuel should be checked, whether they were part of the repair or not, before the vehicle can be considered ready for delivery.

2.4.2 Spills, leaks and splashes

Clean up spills and splashes when they happen. Hydraulic brake fluid will remove paint and must be dealt with immediately: wash the area with plenty of water straight away. No wiping is required. Hydraulic brake fluid can cause skin irritation if it comes into contact with hands or other parts of the body; if this happens, the fluid should be washed off with soap and water. Engine coolant will also remove paint—spills should be removed by flushing with water.

Fuel leaks are a fire hazard and should be corrected as soon as they are discovered. Oil leaks make a mess and a severe oil leak from the engine could cause engine failure, with permanent damage to engine parts. Spillages of these chemicals also contribute to the contamination of our environment and waterways, and all work should involve practices to minimise this.

Sustainability: More information on the environmental impact of spills and leaks is available at www.epa. vic.gov.au.

2.4.3 Preparing the vehicle for the customer

When the service or repairs are completed, a vehicle should be thoroughly cleaned and inspected before being returned to the customer. All fluid levels should be checked, as should tyre pressures. Fault codes when repaired should be deleted and service indicators re-set where required.

2.4.4 Jacking and raising vehicles

Jacks must be placed securely under vehicles and used only at the correct jacking points (Figure 2.6). An incorrectly placed jack will not only damage the vehicle, but could also slip, allowing the vehicle to fall and cause injury.

Stands should be used to support a vehicle after it has been raised by a jack. These must also be placed under jacking points to prevent damage. Stands must be used for work under a vehicle—never work under a vehicle that is supported only by a jack.

Vehicles being raised on a hoist should be suitably positioned, with lifting arms or pads correctly placed. Failure to do this will create an unsafe situation and could also cause structural damage to the vehicle.

All lifting and supporting equipment should have the *safe working load* (SWL) marked on them in kilograms or tonnes. Never exceed the limit.

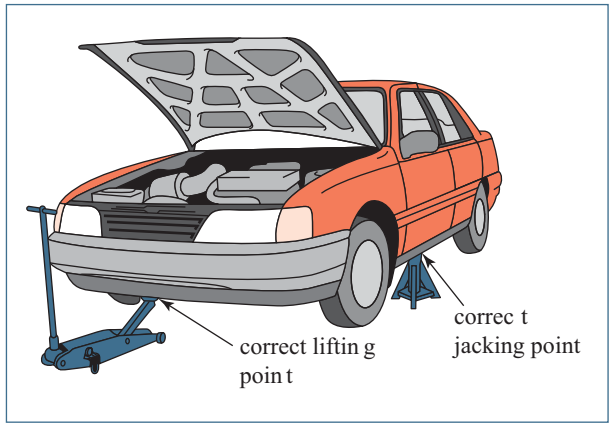


Figure 2.6 Jack a vehicle safely and place lifting stands in the right places

2.5 Safety with vehicle components

Some components that are being dismantled are under load and require special precautions to prevent injury. For example, care is needed with compressed springs, particularly suspensions, where correct jacking is required to relieve the load before the spring is removed. Special tools are sometimes used to hold the spring during replacement of the strut (Figure 2.7).

2.5.1 Brake and clutch dust

Dust should not be blown from brake or clutch parts. Airborne dust can be inhaled, presenting a health hazard particularly, lung cancer. Use only brake and clutch cleaner to clean.

2.5.2 Airbag precautions

The vehicle manufacturer's procedures and precautions should always be followed when working on vehicles that have airbags. When an airbag is deployed, it suddenly inflates (Figure 2.8). There will be a loud noise, some smoke and white powder. As the airbag deflates, it will release nitrogen gas, which is harmless. The metal parts will be hot.

⚠ Safety: Airbags will deploy if the crash sensors are disturbed or voltage wrongly applied to the airbag wiring.

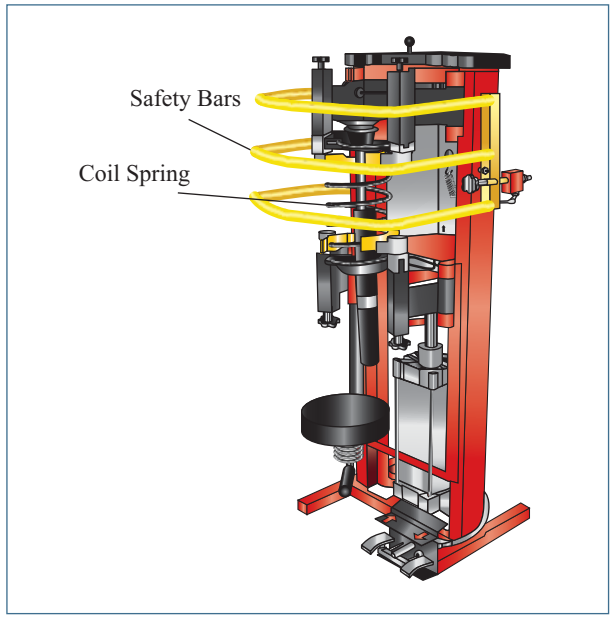


Figure 2.7 Tool being used to hold a suspension spring safely during removal and replacement

2.6 Engine safety

The engines of vehicles manufactured before 1986 will produce dangerous exhaust emissions including hydrocarbon (HC), oxides of nitrogen (NOx) and carbon monoxide (CO). Carbon monoxide is a deadly gas, and a vehicle's exhaust should be connected to an exhaust extraction system. Vehicles manufactured after 1986 still produce emissions, so adequate workshop ventilation is required.

2.6.1 Engine moving parts

If an engine is running, make sure that hands or clothing do not affect any moving parts. Pay particular attention to drive belts, pulleys and fans. Many engines have a long belt driving a number of pulleys, while others have two or more belts which must be avoided.

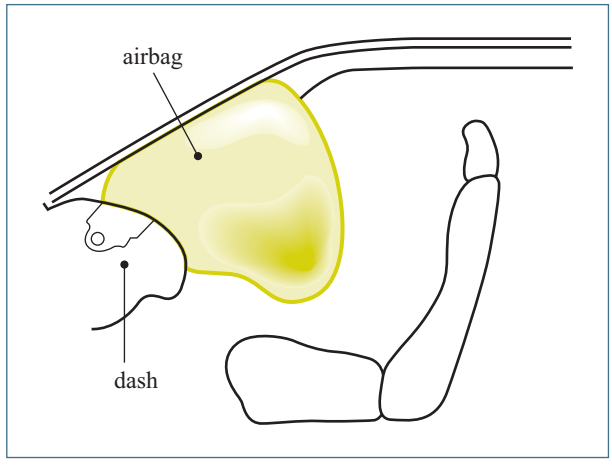


Figure 2.8 An airbag that has been deployed

Care is needed with electric fans. They are temperature controlled and do not run continuously. With the ignition switch on and the engine running, a stationary fan could start up when least expected. With hybrid vehicles, the engine may start at any time if the vehicle is in the 'ON' position. Always check the instrument cluster before working on the vehicle.

2.6.2 Cooling system

The coolant in the engine and radiator reaches temperatures above the boiling point of water. The coolant is also under pressure and scalding coolant will be forced from the radiator if the radiator cap is removed when the engine is hot.

To avoid scalding of hands, face or arms, the radiator cap should be removed only when the engine is cold. If it has to be removed before an engine has cooled down, it should be covered with a heavy pad of rag. The cap should be turned only as far as its first stop, until pressure has been relieved. Then it can be completely removed.

2.6.3 Exhaust system

The exhaust manifolds and the other parts of the exhaust system reach high temperatures. To prevent burns, the engine and associated parts should be allowed to cool before working on them.

2.6.4 Ignition system

Make sure that the ignition switch is turned off and the engine stopped before working on or near the ignition system. The ignition system produces exceedingly high voltages, and these can be dangerous. Contact with any part of the ignition system while the engine is running should be avoided. People with heart pacemakers should be particularly careful of the high voltages that could affect the pacemaker's operation.

2.6.5 Petrol fuel system

Petrol spills and leaks around the vehicle are dangerous because petrol vaporises at room temperature and is easy to ignite. Small spills will happen when the fuel line is disconnected during normal servicing and repairs (for example, replacement of the fuel filter or connecting a pressure gauge). These operations are safe if properly prepared for in the following way:

1 Depressurise the fuel system by running the engine with the fuel pump fuse removed until the engine stops. Some systems have a fitting for depressurising.
2 Disconnect the battery . See handy hint below .
3 Keep drip trays and rags handy .

2.6.6 Gas fuel systems

Vehicles that use gas as a fuel require different safety precautions from petrol or diesel systems. Liquid petroleum gas (LPG) is heavier than air and will collect in low places such as drains or pits. Natural gas for vehicles (NGV) is lighter than air and will collect in roof spaces. The work area should be well ventilated in case of a gas leak.

In both cases, the valve must be turned off at the tank and the fuel lines purged of gas before any components are removed. Naked flames or sparks must also be removed from the work areas.

2.7 Battery safety

Care is needed when working with or near batteries. They should be handled and maintained correctly as they can cause corrosion, produce gas and sparks and inflict burns (Figure 2.9). The following should be remembered:

Safety: Wash off any battery acid that comes into contact with the skin. For eyes, flush with plenty of clean water and seek medical advice .

1 Batteries contain sulphuric acid, which can irritate the skin, damage clothing and corrode metal parts.
2 Burns can result if contact is made with the battery terminals, or between the 'live ' terminal and the engine or body . Take care when using tools on or near battery terminals.
3 The battery can be isolated by disconnecting the cable from the negative terminal.
4 Disconnect the battery if work is to be done on any electrical component or circuit. Failure to do this could damage the electrical system.
5 Disconnect the battery if it is to be recharged in the vehicle . This will prevent possible damage to electrical components.
6 During charging, a battery produces an explosive (hydrogen) gas that will damage the battery if accidentally ignited. Keep sparks and flames away from batteries that are being recharged.

Safety: Remove all jewellery before working on vehicle electrical systems. Electricity tracking through jewellery can cause serious burns.

Handy hint: Most modern vehicles need to have an alternative electrical source before their battery is disconnected. This prevents loss of memory and settings in electronic components.

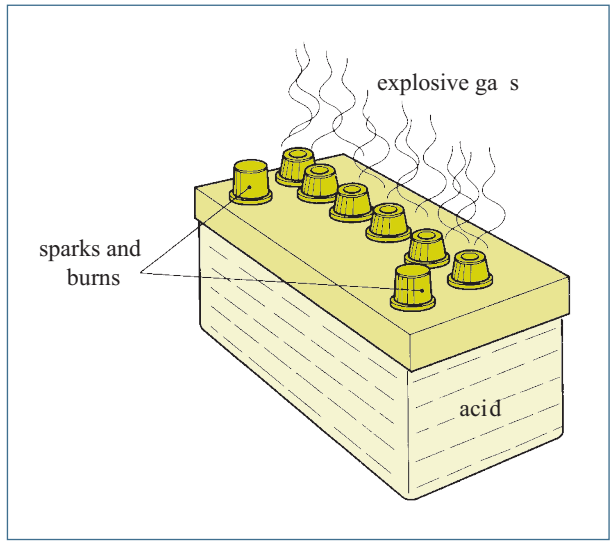


Figure 2.9 Possible hazards when working with batteries

2.7.1 High-voltage systems

Vehicles are now being produced that operate on higher voltage than 12V DC. Some components also operate on alternating current (AC) internally at high enough voltages to cause injury or even death. Some examples are diesel injection, traction control, anti-lock brakes (ABS) and hybrid vehicles. High-voltage cables are coloured orange and red and may be live up to five minutes after disconnecting the battery or removing the fuse. The manufacturer's instructions should always be followed.

2.8 Hazardous materials

Many of the materials used every day in the workshop can be hazardous to people or the environment if they are not used, stored and handled correctly.

All chemicals classified as dangerous or hazardous must be stored properly and clearly labelled. The label should show the class of hazard posed by the chemical, and how it should be stored, used and disposed of safely. Figure 2.10 shows petrol stored in a flammable liquids storage cabinet. The following are points about particular hazardous materials:

Figure 2.10 Flammable liquids storage cabinet PBA SAFETY

1. Oils should be stored away from flammable sources and in a protected bunded area (this is an area with a secondary containment system) to limit environmental contamination. They should be stored in their appropriately labelled containers and sealed.
2. Brake fluid should be stored in a sealed container , specifically labelled and in original packaging. It must be kept away from sunlight and moisture and in a bunded area.
3. Brake dust can contain asbestos and should be treated with every precaution as it is extremely dangerous. Under no circumstance should dust be inhaled or allowed to come into contact with the body . Items contaminated by asbestos should be double-bagged and disposed of at approved sites only . Vehicles built after 2004 will not have been manufactured with asbestos.
4. All chemicals have different compositions and should be treated with caution. Information on storage , use , dangers, medical treatment and firefighting techniques can be found in the SDS (safety data sheet, see next section) on manufacturers ' websites.
5. Cleaning products ' SDSs will indicate the risks associated with them. Chemicals that are biodegradable are safer for the environment and should be used where possible . All cleaning chemicals have special purposes and these should be understood before use .

2.8.1 Safety data sheet (SDS)

Manufacturers of chemicals and other products used in the workplace must provide a safety data sheet (SDS). This contains more detailed information than can be provided on a label. An example of a safety data sheet is shown in Figure 2.11. The data sheet contains the following information:

- manufacturer' s details and product name
- dangerous goods classification
- physical properties such as boiling point and ingredient concentrations
- hazard information such as health effects, first aid and advice for medical professionals
- precautions for use , including exposure limits and protective equipment required during handling
- safe handling, storage and spills, and emergency services.

Copies of SDS should be kept in a central location to which everyone in the workshop has access.

Handy hint: Safety data sheets can be easily updated from manufacturers ' websites and added to the workplace folder for quick reference in an emergency .

SAFETY DATA SHEET

Castrol Brake Fluid DOT 3

Section 1. Identification

GHS product identifier	Castrol Brake Fluid DOT 3
Product code	467148-AUXX
SDS no.	467148
Relevant identified uses of the substance or mixture and uses advised against	
Use of the substance/ mixture	Brake fluids. For specific application advice see appropriate Technical Data Sheet or consult our company representative.
Manufacturer	
Supplier	Castrol Australia Pty Ltd Level 17, 717 Bourke Street Docklands, Victoria 3008 ABN 87 008 459 407 www.castrol.com.au Tel: +61 (03) 9268 4111 Fax: +61 (03) 9268 3321
EMERGENCY TELEPHONE NUMBER	+61 2801 44558 (or 1800 14 14 74 within Australia)
OTHER PRODUCT INFORMATION	Technical Advice Helpline Number: 1300 55 7 998

Section 2. Hazard(s) identification

Classification of the substance or mixture	SERIOUS EYE DAMAGE/EYE IRRITATION - Category 1
GHS label elements	
Hazard pictograms	
Signal word	DANGER
Hazard statements	H318 - Causes serious eye damage.
Precautionary statements	
General	P103 - Read label before use. P102 - Keep out of reach of children. P101 - If medical advice is needed, have product container or label at hand.
Prevention	P280 - Wear eye or face protection.
Response	P305 + P351 + P338 + P310 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER or physician.
Storage	Not applicable.
Disposal	Not applicable.
Supplemental label elements	Not applicable.
Other hazards which do not result in classification	Defatting to the skin.

Figure 2.11 Safety data sheet CASTROL

2.9 Emergency procedures

Everyone in the workplace should know what to do in case of an emergency. Likely emergencies could include fires, chemical spills, serious accidents and personal injury. If the emergency requires the evacuation of the building, everyone should immediately go to a predetermined assembly area outside the building. Key staff in the workplace should be trained to handle the evacuation and signs placed throughout the building showing the location of exits and assembly points. It is important that everybody knows the ambulance, fire and police emergency contact number. Throughout Australia this number is 000.

Workshops and businesses are required to keep various safety- and emergency-related documents. These include injury registers, accident registers, risk assessments, incident reports, operational and safety policies and procedures. It is important that all employees understand how to fill in these reports and also have a clear understanding of operating procedures in their workplace.

2.9.1 First aid

The objective in all workshops should be to remove hazards and so prevent workshop accidents. However, if an accident does occur, correct and appropriate first-aid treatment is needed.

First aid means rendering immediate assistance in the event of an accident or sudden sickness. The most important actions are those which save life, for example, resuscitation, stoppage of severe bleeding and treatment of poisoning.

All workshops should have at least one person who is fully trained in first aid and who knows what to do in an emergency. If an accident occurs in a workshop, or there is a case of sudden illness, a person with first-aid training will know how to handle the situation.

In all cases of serious accident, professional medical aid should be sought immediately.

2.10 Fires and fire safety

For a fire to occur (combustion), three things must be present:

1. Fuel. This can be any combustible material—a liquid, a solid or a gas.
2. Air. This provides oxygen, which is required to sustain combustion.
3. Heat. This is needed to bring the fuel to a temperature at which it will start to burn.

All combustible materials must be converted into a vapour before they will burn, and it is the vapour that actually burns. Different fuels, or combustibles, will vaporise at different temperatures. Those that vaporise at low temperatures, such as petrol, are classed as *flammable* materials.

Fire safety means being aware of the potential fire hazards in a workshop and minimising them. It means having appropriate firefighting equipment available and knowing how to use it. It also means knowing how to contact emergency services.

2.10.1 Fire hazards

Petrol, distillate, cleaning solvents, oily rags, welding and smoking represent particular fire hazards in an automotive workshop. Petrol is a highly flammable liquid that must be handled and stored carefully. At room temperature, it gives off vapours that are easily ignited by a spark or flame, and so safety precautions must be observed wherever petrol is used. For this reason, ‘No smoking’ signs are displayed in many workshops.

Distillate is not as volatile as petrol. It requires higher temperatures to produce vapour and so is less of a hazard.

Oily rags and waste are a potential source of fire. As they can be ignited by spontaneous combustion, they should be placed in covered metal containers.

Welding creates heat and sparks that could start a fire and ignite liquids such as petrol, cleaning fluids and solvents. Welding should be confined to a welding bay, as far as possible. When welding on a vehicle, precautions should be taken in relation to the closeness of fuel, whether it is in the fuel tank, fuel lines or in the engine compartment.

Gas fuels (LPG and NGV) have special safety precautions and there are particular regulations that apply to vehicles with gas fuel systems.

2.10.2 Extinguishing fires

Figure 2.12 shows a triangle of combustion. Each side of the triangle represents one of the three elements needed for combustion–*fuel, air* and *heat.* The principle of extinguishing a fire is based on the following:

1 Removing fuel. If the fuel is removed, the fire will starve and go out.
2 Excluding air . If air is excluded by smothering the fire, there will be no o xygen and combustion can no longer tak e place .
3 Reducing the heat. If heat is reduced, the temperature will drop and combustion will cease .

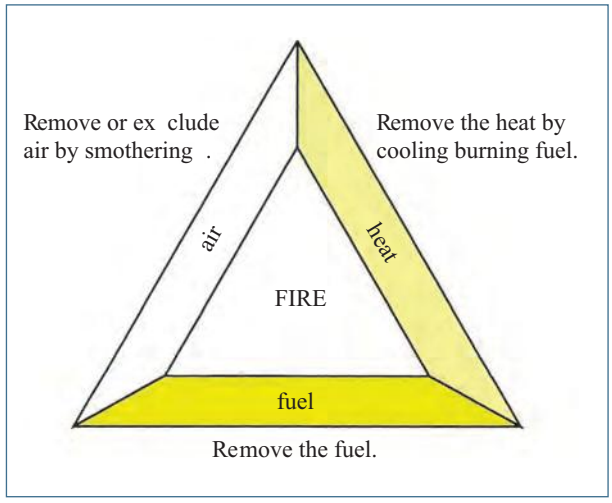


Figure 2.12 The triangle represents the three elements of a fire—air, fuel and heat. R emove one side of the triangle and it will collapse , just as removing one element of the fire will extinguish it

2.10.3 Classes of fires

The various types of fires are separated into *classes*:

1 Class A fires. Solid materials, such as paper , wood or cloth.
2 Class B fires. Flammable liquids, such as petrol, kerosene , methylated spirits and paints.
3 Class C fires. Flammable gases, such as LPG and NG V.
4 Class D fires. Burning metals, such as magnesium, sodium and lithium.
5 Class E fires. Live electrical equipment, such as in switchboards, motors, switches or appliances.

Handy hint: Electricity is not a fuel, but it can generate heat and high temperatures that can cause a fire (and still be present during a fire).

2.11 Fire extinguishers

There is no single type of extinguisher that would suit all classes of fires, so fire extinguishers are designed for use on particular classes of fires. This is necessary because burning liquids require different treatment to burning solids, and conducting materials cannot be used on electrical equipment.

When a solid material is on fire, it can usually be cooled down with water to a temperature where it will no longer burn.

To control a liquid fire the air supply must be blocked off. Air contains oxygen, which is necessary to sustain all forms of combustion. When air is blocked off, burning can no longer take place.

An electrical fire should have the power supply isolated and then the fire smothered.

2.11.1 Extinguisher identification

The different types of fire extinguishers are identified by colour. They can also be identified by the class of fire (A to E) for which they are suitable. The extinguishers commonly found in automotive workshops are foam, carbon dioxide and powder (Figure 2.13).

The types of extinguishers are described below. The best way of becoming familiar with them is to check the extinguishers in your workshop and read the instructions on the labels.

Foam extinguishers

These are used for class A and B fires. They must not be used on electrical fires. They are red with a blue band and eject foam, which can be used on petrol and similar liquid fires. The foam blankets the liquid, cutting off the air supply. If the fire is in a container of liquid, the foam should be directed to the side of the container so that it spreads across the surface of the liquid.

Carbon dioxide extinguishers

These are suitable for class B and E fires. They are red with a black band and consist of a pressure cylinder which contains carbon dioxide. When directed at a fire, the gas removes the oxygen and cools the burning material to below combustion temperature.

Figure 2.13 Fire extinguishers for automotive workshops FIREQUIP

Safety: Do not allow the discharging gas to come into contact with your fingers as it can cause frostbite . Hold the discharge nozzle by the plastic handle .

Powder extinguishers

These are suitable for class B, C and E fires. These are red extinguishers with a white band. They expel a fine powder which smothers the fire and also absorbs some of the heat.

Water extinguishers

These are coloured red and are suitable for class A fires only. They are not suitable for automotive workshops but may be found in office and reception areas.

2.11.2 Water and other methods

Water can be used as a jet to reduce the temperature, or as a spray to restrict the air.

Sand thrown over most small fires will extinguish them. A sack or similar cover can be used to blanket the flames in small fires.

Fire blankets

Clothing that is on fire can be extinguished by wrapping the wearer in a special fire blanket (see Figure 2.14). This cuts off the air supply.

Figure 2.14 Fire blank et FIREQUIP

Safety: Prompt, appropriate action at the start of a fire can stop it spreading.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- state the importance and demonstrate correct use of PPE
- apply safe manual handling procedures
- demonstrate the safe use of machines and power tools
- work safely around engines and vehicle components
- demonstrate how to store and dispose of hazardous materials
- state what to do in an emergency
- demonstrate fire prevention techniques and the correct use of fire extinguishers.

REVIEW QUESTIONS

1 Identify five important items of personal protective equipment.
2 How can you help to ensure the safety of other people ?
3 What precautions should be tak en when using compressed air?
4 List some precautions that are needed in relation to workshop machines.
5 Before using a machine , what general check should be carried out?
6 What safety precautions relate to portable electric tools ?
7 What precautions should be tak en when parking a vehicle ?
8 When working on an engine , how could the bodywork be protected?
9 Why are the jacking points of a vehicle important?
10 Why should special care be tak en when working with batteries ?
11 Why is it necessary to tak e care with airbags ?
12 Name some of the hazards associated with a running engine .
13 What is a flammable liquid and how should it be stored?
14 Name four items of important information that can be found on a safety data sheet.
15 What is spontaneous combustion ?
16 What are combustible materials ?
17 How does air affect a fire ?
18 What is meant by the classes of fires ?
19 What type of extinguisher should be used on an electrical fire ?
20 When would a foam-type extinguisher be used?
21 What is first aid?

CHAPTER 3

Workshop practices

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify general processes, practices and procedures that are carried out in a mechanical repair workshop
2 explain the meaning of specific terminology associated with motor vehicle servicing and repairs
3 describe operations and processes associated with motor vehicle servicing **and repairs.**

Many different tasks are carried out in an automotive workshop . These range from general servicing and maintenance to major repairs and complete overhauls of mechanical and electrical systems. Regardless of the job, all tasks must be completed safely while also observing the correct procedures to protect the environment.

3.1 Automotive service and repair procedures

Service and repair procedures are likely to include the following tasks.

3.1.1 Measuring

Measuring is carried out on motor vehicle systems and components. The length, thickness, diameter and angle of components are checked to determine serviceability. Pressure, vacuum, voltage and revolutions are also measured. The correct care, use and maintenance of measuring equipment is vital to ensure that all procedures are carried out to the required standard.

3.1.2 Dismantling

Motor vehicle systems are made up of a range of components which need to be removed for either repair or replacement. The level of dismantling or repair tasks ranges from basic to significantly complex, the latter requiring a high level of skill and knowledge. Manufacturer service manuals provide detailed information on the correct way to carry out these tasks.

3.1.3 Cleaning

Cleaning mechanical systems and components is important and must be carried out effectively. Failure to do so can result in personal injury, damage to components and the environment.

Cleaning options include the use of:

1. Parts cleaner . A tank filled with a cleaning solution. It has a flexible metal spout which pumps the solution into a tray , and parts are then cleaned with a brush.
2. Ultrasonic frequency . Parts are placed inside a tank and cleaned using ultrasonic frequency .
3. Heavy-duty spray washers. Operating lik e a dish washer , these are large enough to clean components such as engine blocks, transmissions and differentials.
4. Hot tanks. Parts are placed inside a large tank filled with cleaning solution. Some of these tanks are fully automatic, have an agitator , operate on a rinse cycle and recycle the solution.
5. Pressure cleaner . A high-pressure water cleaner .

Once cleaned, components can be inspected and prepared for reassembly.

Sustainability: When choosing cleaning fluid, always consider using a product that is non-to xic, biodegradable , water-soluble and has no hydrocarbons. A material safety data sheet (MSDS) will outline the correct usage of , and disposal methods for , cleaning fluids. Where possible , recycle all unwanted parts.

3.1.4 Inspecting

Motor vehicle systems and components are subjected to wear and can also be damaged by poor workmanship. During servicing, repairs and overhauls, components are checked for correct specifications to determine if they can be reused. Inspection procedures are vital in this process.

Handy hint: Parts that are suitable for reuse are classed as serviceable . Parts damaged or worn beyond specified limits are classed as unserviceable .

3.1.5 Replacing

Routine servicing, repairs and major overhauls of systems and components often require new parts to be fitted to vehicles. Some parts need to be replaced, while others, such as engines and transmissions, can be reconditioned and reused.

3.1.6 Reassembling

The system being repaired must be reassembled to manufacturer specifications. Attention to detail and knowledge of the system's function and operation are required, as is the correct use of tools and equipment.

3.1.7 Installing

In the automotive industry, the term *installing* refers to the fitment or replacement of a part or component.

Handy hint: Special tools are sometimes needed to install parts such as oil seals and bearings.

3.1.8 Adjusting

Various parts of a motor vehicle require some form of adjustment as part of servicing and repair. Adjustments compensate for wear and restore the original specifications of the manufacturer. Some parts can be manually adjusted (Figure 3.1), while other parts require complete disassembly, accurate measurement and adjustment by the fitting of specified shims.

Figure 3.1 Adjusting—adjusting screws enables the valve clearance to be set to the thickness of the feeler gauge

3.1.9 Lubricating

The correct lubrication of mechanical components in a motor vehicle is vital. Due to the effects of friction and extremely close tolerances, engine, transmission and driveline components require a high-quality oil to lubricate and protect all surfaces. Other moving parts within a motor vehicle (such as wheel bearings) are filled with grease that lubricates their surfaces. Without effective lubrication, moving parts within a motor vehicle will not be able to withstand the effects of heat or friction under continued operation.

3.1.10 Diagnosing

The complexity of modern vehicle systems means that systematic checks need to be carried out to identify and rectify faults. This is often referred to as *troubleshooting* or *fault finding*. While electronic fault diagnosis equipment can identify specific problems within a system or component, the automotive technician must have an exceptional understanding of how mechanical systems and components operate in order to diagnose problems and recommend solutions.

3.2 Workshop operations

Other tasks that an automotive technician will perform include repairing or reconditioning parts which have been dismantled, modifying parts, manufacturing a tool or a fitting or carrying out regular maintenance of workshop equipment. Some of these are indicated below.

3.2.1 Fitting

Some repairs require using basic hand tools which include hand-fitting operations such as drilling, threading, cutting, filing, grinding or reaming.

3.2.2 Machining

Automotive machining includes valve and valve seat grinding and cutting, brake disc and drum turning and cylinder honing.

3.2.3 Grinding

Grinding is part of some general repair and fabrication tasks. It is also used to sharpen and maintain small workshop tools. Reconditioning of engine parts is performed using specialised grinding machines. Examples include valve-refacing and a crankshaft-grinding machines.

3.2.4 Turning

A lathe manufactures specialised parts, and its effective operation requires a high level of skill. The part is mounted in the lathe and turned, or rotated, while a cutting tool removes metal to produce the required shape and size.

3.2.5 Drilling, boring and honing

Portable electric drills drill holes. Drill presses, which are permanently mounted on a bench or a frame, are also used as they provide greater accuracy and stability. Holes that are too large to be drilled are bored. For example, cylinders are rebored with a boring bar. This has a bar with a rotating cutter that is fed down the cylinder so that it cuts a small amount of metal from the cylinder wall as it rotates.

Honing is an abrasive process that uses a rotating hone with abrasive stones attached. When inserted into a cylinder, the stones press against the cylinder wall. Using a drill, and applying the correct speed and movement, the rotating motion of the hone creates the finished pattern within a cylinder.

3.2.6 Welding

A range of welding options are available. These include:

1. Arc welding. A process where metals are welded using heat generated from an electric arc. This is the most basic type of welding.
2. TIG welding. Tungsten inert gas (TIG) uses a tungsten electrode to create the weld. This type of welding can produce a high-quality finish.
3. MIG welding. Metal inert gas (MIG) uses a combination of Argoshield gas and a seamless wire electrode to create a weld.
4. Gas welding. A flame is created using a combination of oxygen and acetylene gas and is used to weld and cut metals.

Welding safety

While using welding equipment or observing welding tasks, it is vitally important to wear appropriate personal protective equipment (PPE); welding produces rays that damage eyes and burn skin. Safety glasses, welding shields, leather aprons, leather gloves, welding caps and flame-resistant cotton clothing that covers the entire body should be worn to prevent injury.

Safety: Special safety precautions must be taken with all welding to prevent burns or damage to eyes (see Chapter 2).

3.2.7 Fabricating

This is the process of manufacturing components from a range of materials including sheet metal, steel or plate. Fabrication includes processes such as cutting, drilling, bending, welding and machining.

3.2.8 Soldering

Soldering is sometimes referred to as *soft soldering* to differentiate it from some forms of *brazing*. (Brazing is a process whereby two pieces of metal are joined by being bonded by a molten alloy.) Soldering is used for electrical connections and for the manufacture and repair of older-style radiators. Solder consists of tin and lead, and melts at a relatively low temperature.

3.3 Production processes

A motor vehicle consists of a large number of parts, which vary in size and complexity. Smaller parts are assembled to form components. Parts are made in numerous ways such as being cast, formed, pressed, machined, forged and ground. They are then fastened together by a number of different methods such as welding, bolting, riveting or bonding.

Figure 3.2 shows a section of a rear suspension. The various parts are labelled with the processes that produce them. The following outline of production processes explains more about how parts are produced.

3.3.1 Casting

Casting is a process where molten metal is poured into a shaped mould made of sand or metal. It is typically a production process for large parts such as an engine block, cylinder head and transmission housings.

With *diecasting,* molten metal (usually a copper/zinc alloy) is forced under pressure into shaped metal dies. This produces smooth castings which require little or no finishing. Examples of parts produced by diecasting include small engine accessories and body hardware.

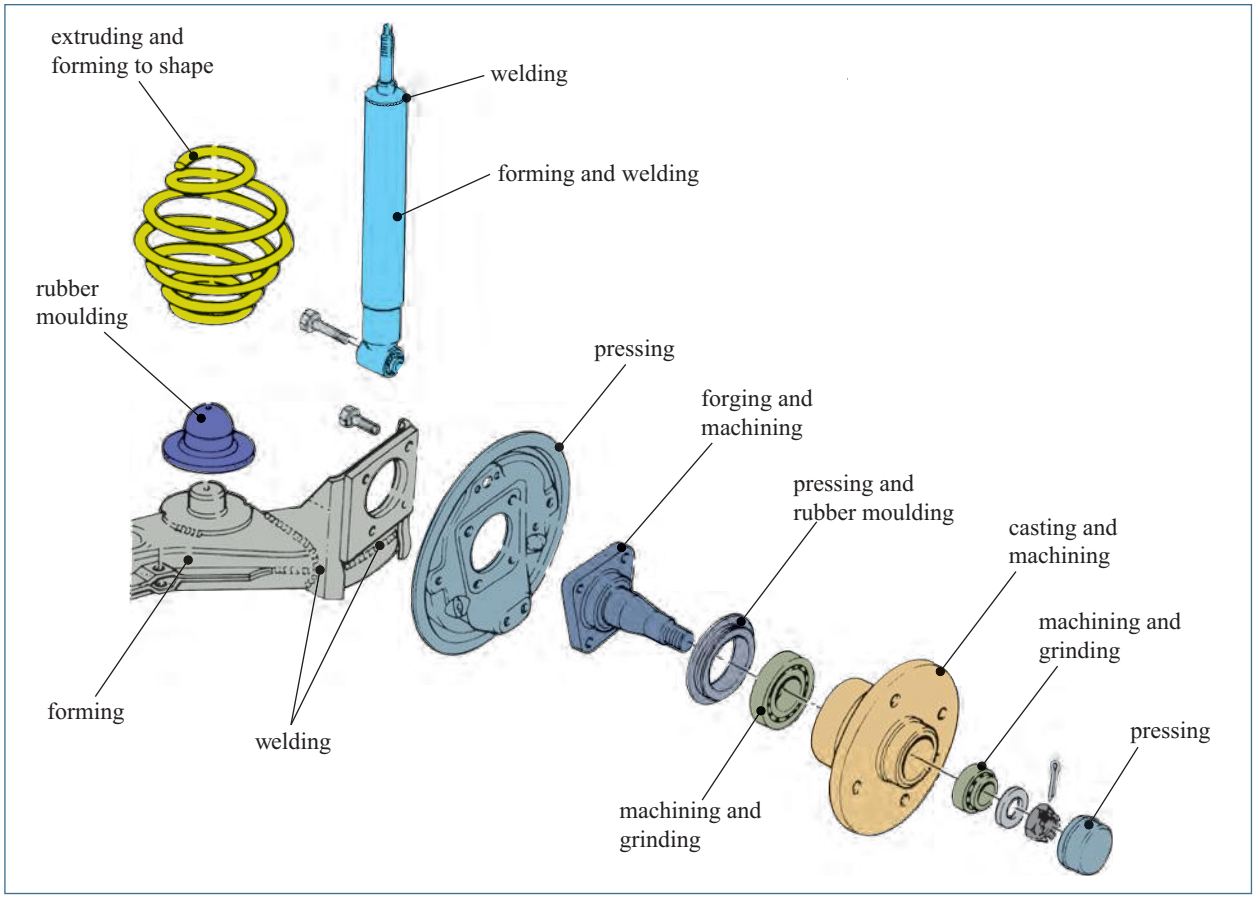


Figure 3.2 Part of a rear suspension, showing the manufacturing processes that produce the various parts GM HOLDEN LTD

Handy hint: A die is a block of metal that is shaped or patterned to a required specification. It is used to apply a standardised shape or pattern to other pieces of metal.

3.3.2 Moulding

Moulded plastics are made by shaping plastic within a mould or die. This is a simple and relatively cost-effective process. Grilles, dash panels, centre consoles, door trimmings and bumper bars are examples of the moulded plastics that are used in vehicles. Plastic parts are much lighter than the equivalent metal parts.

Fibreglass parts, which are made of glass fibres impregnated with special resins, are also produced by a type of moulding. Tough, lightweight and durable, fibreglass is used mainly for special body parts.

3.3.3 Extruding

This is a process of forcing metals such as aluminium or plastic through a shaped die. When the material emerges, it has the same shape as the die opening. Moulded plastic and aluminium strips are made by this method.

3.3.4 Forming and pressing

The term *forming* describes the process of bending heavy metal sections to a specific shape. For example, parts of a truck frame are made from steel, which is cut to size and then *formed*, or bent, into channels or other suitable shapes. The parts are then joined together by welding or riveting.

Pressing is used for body panels that are produced from sheet steel or, in some cases, sheet aluminium. This is done with large presses which press the metal between dies. Pressing operations can include shaping, folding, bending and hole punching.

3.3.5 Production welding

A range of mechanical components are combined and welded together during the manufacturing process. These include mountings, brackets, suspension parts and subframes.

In modern vehicles, body panels and other components are spot-welded together by automated robotic systems. Spot welding involves the overlapping of thin sections of metal and applying pressure via an electric current, which fuses the metals together. A number of spot welds side by side can form a continuous weld.

3.3.6 Forging

Some parts are produced by *forging,* where metal (usually steel) is heated until it is white-hot and then hammered to shape. Front axles on trucks are an example of what is called a *large forging*; open-ended spanners are an example of a *small forging*.

3.3.7 Machining operations

A machine tool is a specialised machine that shapes or machines a range of the mechanical parts of a motor vehicle. Machining operations include drilling holes, threading, boring, grinding or cutting. Machined parts include shafts that are ground to size, gears with various forms of teeth, cylinder blocks and surfaces, bored cylinders, pistons, wheel hubs, axles, pulleys, pins and bearings.

3.4 Fasteners

Fasteners used on motor vehicles include studs, bolts, nuts, screws and rivets, as well as associated parts such as washers, snap rings, keys and cotter (split) pins. The application of bolts and studs is shown in Figure 3.3.

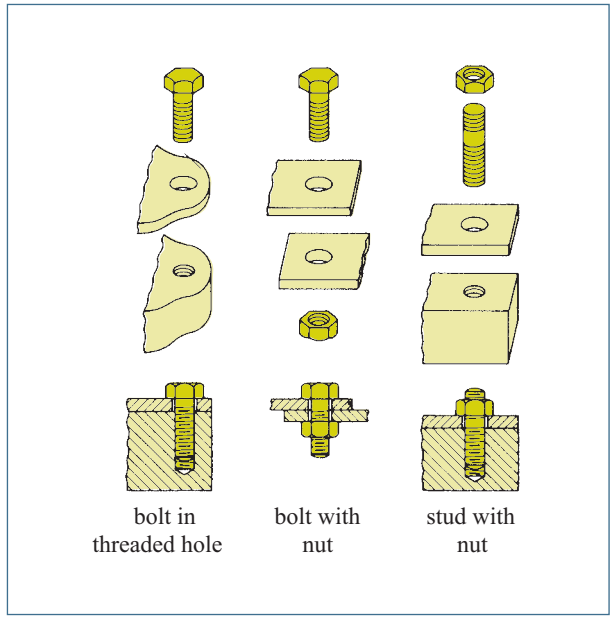


Figure 3.3 Methods of using bolts and studs

Handy hint: The terms bolt, stud and screw sometimes overlap . The meanings that follow are the ones usually given to these parts.

3.4.1 Bolts

Most bolts have hexagonal heads and are threaded for only part of their length. They are often fastened by a nut, but can be used in threaded holes. Zinc- or cadmium-plated bolts and nuts are used where there is widespread corrosion.

Some bolts have to sustain a greater load than others, so their diameter will vary. As bolts are made from different types of metals, they have different load ratings. They are categorised into either metric or imperial sizes and are classed according to their strength. Metric bolts have their heads marked for identification.

Figure 3.4 shows differently classed bolts and their head markings. For those with numbers marked on the head, the higher the number, the stronger the bolt. Bolts with recessed heads have embossed lines. For these, the more lines, the stronger the bolt. For example, two lines represent class 5 and three lines represent class 7. Bolts with a plain head are usually class 4.

Bolts should always be refitted in their original location; replacement bolts should be of the same class as the original.

3.4.2 Studs

Studs have no head and are threaded at both ends. One end is often a coarse thread, which is screwed into a threaded hole in a casting. The other end of the stud has a finer thread fitted with a nut.

3.4.3 Nuts

Although nuts vary in shape and design, most are hexagonal (Figure 3.5). Plain hex nuts are often combined with a lock washer to prevent them from working loose. An acorn or dome nut provides a neat finish and protects the threaded end of a bolt.

Slotted and castle (or castellated) nuts have slots, and the bolt or shaft on which they fit is drilled to allow a split pin to be inserted. This provides an effective locking device so the nut cannot work loose. When fitting a split pin, the head should fit neatly into the slot on one side of the nut. One end of the pin is bent over the end of the bolt; the other end is bent back onto the flat of the nut. The ends should be trimmed neatly to length.

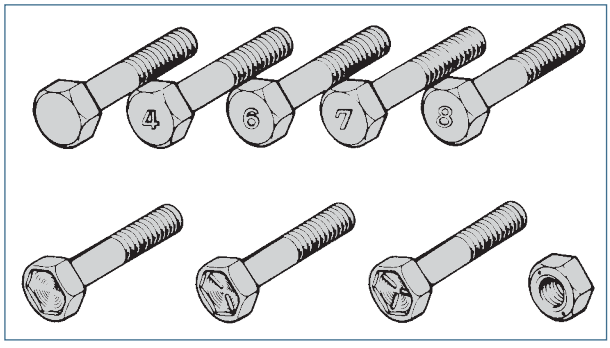


Figure 3.4 Classes of bolts are identified by markings on their heads

Self-locking nuts

Some nuts have a built-in locking feature that helps to prevent them from working loose (Figure 3.6). The nut in Figure 3.6(a) has a slot cut in the side which has been partly closed to distort the top two or three threads. These bind on the bolt and prevent the nut from loosening.

The interference nut in Figure 3.6(b) has a collar of nylon or soft metal. This binds against the thread

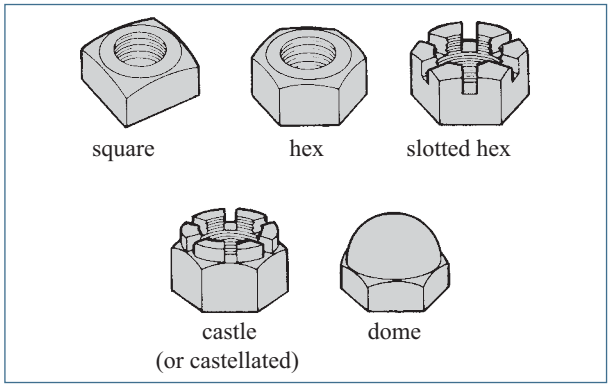


Figure 3.5 Various types of nuts

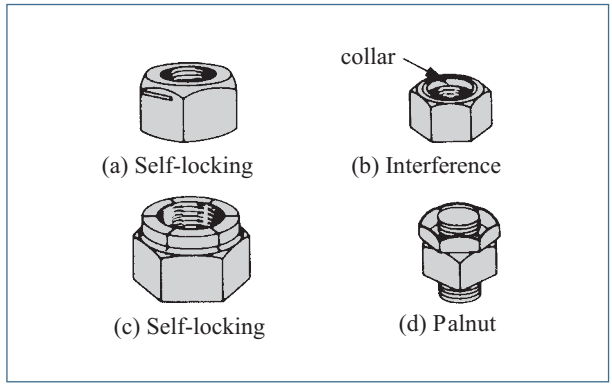


Figure 3.6 Types of self-locking nuts

of the bolt and prevents the nut from unscrewing. The self-locking nut with vertical slots in Figure 3.6(c) is constructed so that its top threads are tight on the thread of the bolt. This holds the nut in position. The palnut in Figure 3.6(d) is a thin nut that is screwed tightly onto the larger nut. The palnut acts as a lock nut to prevent the larger nut from loosening.

Handy hint: Some nuts and bolts are secured with thread-sealing compounds which are applied before the nut is tightened.

3.4.4 Screws

Screws are versatile fasteners which secure a range of components. The screws in automotive applications generally have a thread that is the entire length of the shank (Figure 3.7). Specific tools are required to remove or install some screws as the heads have various shapes with different styles of slots.

Certain bolts with hexagonal heads are also threaded for their full length and classed under the broad heading of *screws*. These are sometimes referred to as *setscrews* or *capscrews*.

The points or ends of screws (as shown in Figure 3.8) vary in design according to their application. For example, a grub screw secures a pulley or collar onto a shaft. This requires the cone point to fit into a small hole in the shaft, whereas a cup point could be used to grip *against* a shaft.

Self-tapping screws

These have coarse, tapered threads that are hardened so they can cut their own thread through sheet metal parts. A hole is drilled or punched through the sheet metal that is large enough for the point of the self-tapping screw to enter, and the screw cuts a thread in the metal as it turns.

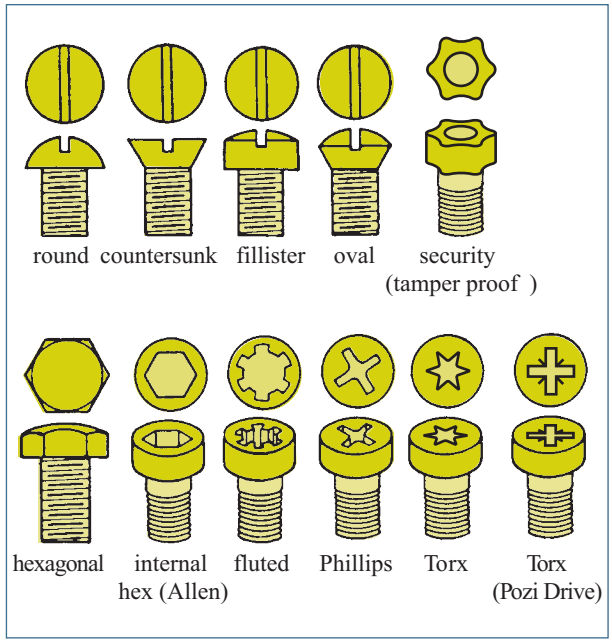


Figure 3.7 Types of screw heads

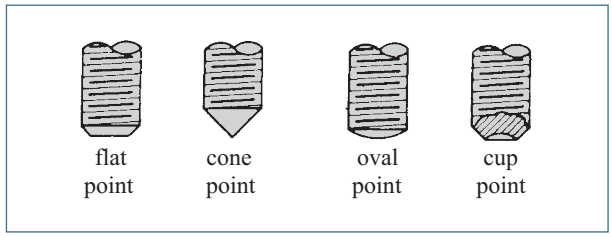


Figure 3.8 The points of screws or bolts can be shaped for particular purposes

3.4.5 Rivets

Rivets hold together parts that normally do not have to be dismantled. Generally used on thin materials, a pop rivet is placed in pre-drilled holes in the metal that needs to be joined. A riveting tool applies pressure to the rivet shank, which causes the rivet to spread. This forces all parts together before breaking off the rivet shank.

Solid rivets have a head that is either flat, countersunk or oval in shape. After being installed in the hole, the end of the rivet is formed to shape. There are special tools to form oval heads, but a ballpein hammer is generally suitable. Forming the head also spreads the rivet in the hole, and this helps to hold the parts securely together.

3.4.6 Keys

Keys and splines are used, in conjunction with other fasteners, to secure gears, pulleys, collars and similar parts to shafts (Figure 3.9). The key fits into a recess or slot in the shaft, while also projecting above it. The collar or other part has a keyway that fits over the key.

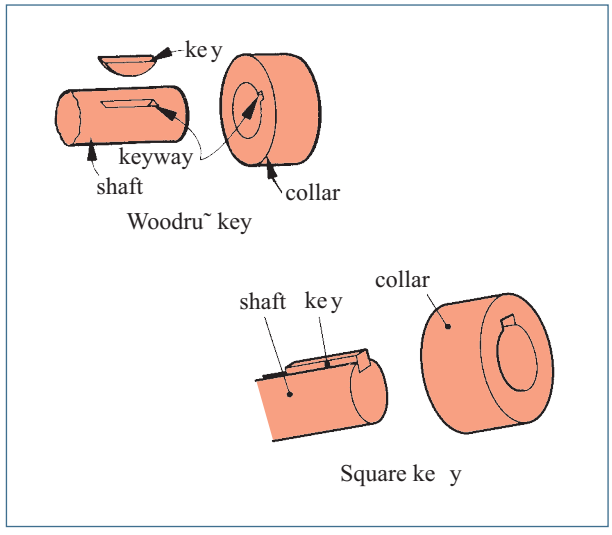


Figure 3.9 Keys used between a collar and a shaft

A Woodruff key fits into a recess in the shaft. Square-section keys are also used. With these, the shaft has a long groove (or keyway) to accommodate the key and a corresponding groove in the collar that fits onto the shaft. A nut or bolt and washer on the end of the shaft keeps the collar or part in place.

3.4.7 Splines

Splines are external grooves cut into a shaft that mesh with the internal grooves of another mating shaft. A parallel spline allows a shaft to slide, accommodating variations in shaft length. A tapered spline ensures that all parts are held firmly together.

3.5 Locking devices

Locking devices prevent nuts and bolts from working loose. Various types of locking devices can be used, and the type applied will depend on the level of locking security required.

3.5.1 Lock washers

Lock washers (Figure 3.10) are used under nuts and under the heads of bolts. Spring washers are a type of lock washer. They are strong, flat spiral springs which are placed under a nut or the head of a bolt. When the nut or bolt is tightened, the spring compresses. This places a load under the nut or head of the bolt, preventing either item from working loose. Other types of lock washers have small teeth so when placed between the head of a bolt or nut and the component being fitted, they grip or bite together and prevent the nut or bolt from loosening.

3.5.2 Snap rings or circlips

These are internal or external rings of spring steel that spring or snap into place when installed. Smaller rings, often called *circlips,* are made of round wire; larger snap rings are usually flat (Figure 3.11).

External snap rings are used on shafts to hold bearings, gears or collars in place. They fit into a groove in a shaft and are expanded with special circlip pliers when being installed or removed.

Internal snap rings are used within the grooves that are machined into housings that retain bearings or other parts. They have to be contracted when being installed or removed so that they can fit inside the housing and then be fitted into the groove.

3.5.3 Other locking devices

Other locking devices include:

1. Tab washers. Fit under the bolt or nut and have a tab that can be bent against a flat side of the bolt or nut.
2. Locking wire . Threaded through holes in two or more adjacent bolt heads so they hold each other .
3. Locking plates. Have tabs and are used between two bolts or nuts.
4. Staking. Using a small chisel or centre punch to mark or groove into the ends of the threads of a nut and bolt. The punch mark or staking locks both items together . The stak ed nuts are only used once .

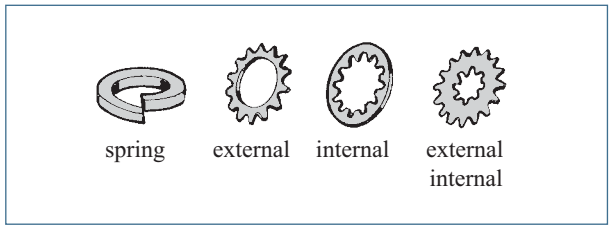


Figure 3.10 Lock washers

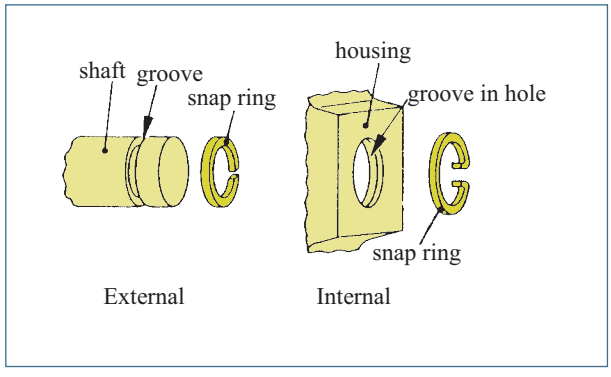


Figure 3.11 Snap rings or circlips

3.5.4 Locking compounds

To prevent nuts or bolts from loosening, a small quantity of locking compound is applied to the thread or other part during assembly. Locking compounds are available in a range of strengths, and are suitable for various purposes. They can be used to lock the threads of bolts, nuts and studs or to help retain pulleys or gears on shafts.

3.6 Screw threads

There are two types of threads: *external threads* and *internal threads*. Screws, bolts and studs have external threads while nuts and threaded holes have internal threads. Most threads are right-hand, where the nut can be screwed onto a bolt, or a bolt screwed into a hole, with a clockwise turn. Left-hand threads are used for special purposes where a right-hand thread could work loose, such as on some axles and some truck and van wheel nuts. Wheel studs will have L and R, for left and right, stamped on them.

Handy hint: Threads are used not only for fastenings but also for transmitting motion or power , as in a screw-type jack, a bearing puller or for adjustments such as some valve tappets.

3.6.1 Basic thread forms

There are four common screw thread forms. Their names relate to the shape of their particular thread section (Figure 3.12).

1 V-thread. This is the most common, and is used for bolts, nuts and other fastenings. It is easily produced in the workshop by using taps and dies.
2 Square thread. Rugged in design, this is used for screw jacks, vices, clamps and similar tools.
3 Acme thread. This is used particularly on lathe lead screws. The sloping sides of the thread allow the half-nuts, which are used as a form of clutch, to be easily opened and closed on the thread.
4 Buttress thread. Where there is a thrust against the screw in one direction only , a buttress thread can be used. Some vice threads and clamp threads are of this type .

3.6.2 Thread terminology

Special terms describe the various parts of threads. These are illustrated in Figure 3.13 and explained below.

1 Thread form. The shape of the particular thread.
2 Crest. The top of the thread. This can be flat or round for the particular thread form.
3 Root. The bottom of the thread. This can also be curved or flat for a particular thread form.
4 Angle. The angle of a V -thread.
5 Major diameter . The outside diameter .
6 Minor diameter . The smallest diameter of the bolt (measured at the root of the thread).
7 Pitch. The distance from a point on the crest of one thread to a corresponding point on the crest of the next thread.

A number of different forms of threads have been used for bolts, nuts and similar fastenings. Many countries developed their own thread systems, which resulted in a range of different thread forms that were not interchangeable.

The heads of bolts and nuts also presented issues as their size was directly related to the particular thread system. Different spanners were therefore required for use with these different systems.

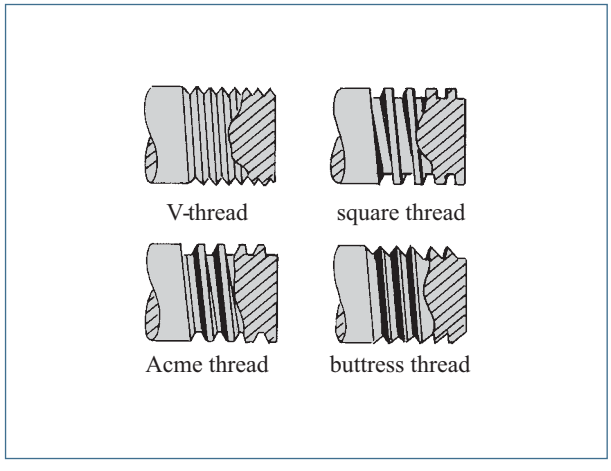


Figure 3.12 Types of threads

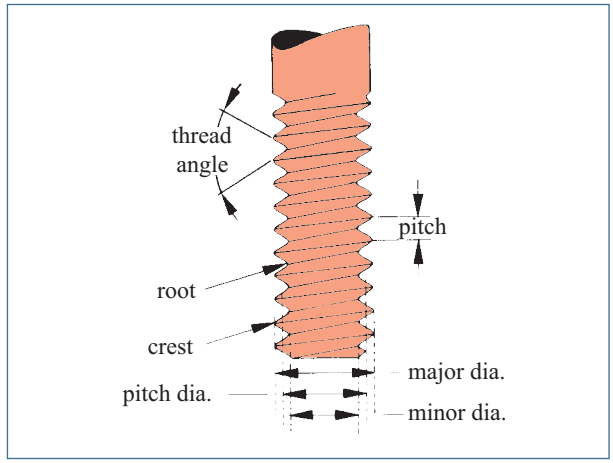


Figure 3.13 Parts of a screw thread

3.6.3 Coarse and fine threads

The use of fine and coarse threads can vary, depending on the required application. Coarse threads are commonly used for threaded holes in castings. As casting metal is brittle, it requires a larger amount of metal within the thread. Fine threads are mostly used for bolts and nuts where the material is tougher. Greater strength is obtained by utilising a greater number of fine threads.

Metric threads

The metric thread system is an international standard system for V-threads that is now used on most vehicles. Table 3.1 shows the pitch, the tapping size and the spanner size for various bolt diameters. All sizes are in millimetres.

Unified threads

Prior to the introduction of a standard metric thread system, a *unified* thread system was used in English-speaking countries. Vehicles manufactured in the United Kingdom, North America and Australia all used this type of thread.

There are two types of unified thread classifications: Unified National Coarse (UNC) and Unified National Fine (UNF), as shown in Table 3.2. Originally, both the United Kingdom and the USA had their own standard thread systems, while vehicles produced in parts of Europe other than the United Kingdom used metric threads.

American National Fine (ANF)

Developed by the Society of Automotive Engineers (SAE), this was originally known as the SAE thread. It was later adopted as an American standard and is similar to the UNF system.

Pipe threads

Threads on pipes are referred to as *gas threads*. They are often tapered throughout their length. The taper forms a seal between the pipe joints. Some plugs on transmissions and rear axles used tapered threads.

3.6.4 Thread-pitch gauge

A thread-pitch gauge measures the pitch of threads (Figure 3.14). It has a number of blades with teeth that are the shape of various threads. The blades are marked with the pitch of the thread and can be used on external and internal threads. When the correct blade is selected, it will fit neatly into the thread.

Handy hint: A bolt can be used in a similar way to a thread-pitch gauge . Place the threads together and hold them up to the light. If they have the same pitch and thread, they should be a neat fit.

Table 3.1 Metric threads, international pitch showing sizes in millimetres

Bolt diameter	Pitch	Tapping size *	Spanner size
4	0.70	3.5	7
5	0.80	4.0	8
6	1.00	5.0	10
8	1.25	7.0	13
10	1.50	8.5	17
12	1.25	10.0	19
12	1.75	10.0	19
14	1.50	12.0	21
16	2.00	14.0	24
20	2.50	17.5	30
24	3.00	21.0	36

*approximate size for workshop use

Table 3.2 Unified threads showing threads per inch

Bolt size (inches)	Threads per inch	
	UNC	UNF
1/8	30	–
3/16	24	32
¼	20	28
5/16	18	24
3/8	16	24
7/16	14	20
½	13	20
9/16	12	18
5/8	11	18
¾	10	16
7/8	9	14
1	8	12

Figure 3.14 A thread-pitch gauge has a number of blades for different threads

3.6.5 Thread repair methods

Damaged threads can be repaired using a range of different methods. The most common method is to use a Helicol. A HeliCoil is a coiled-wire type of insert that restores the threaded hole to its original size. This method requires the worn or damaged thread to be drilled out; then, using a specialised tap, a HeliCoil is inserted into the hole and allows the original-sized bolt to be used.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify workshop procedures such as cleaning, dismantling, inspecting, adjusting, measuring and reassembling components
- apply reconditioning and repair operations that involve grinding, welding, machining and fabrication
- identify a range of bolts and fasteners
- maintain a productive, safe and environmentally sustainable workplace.

REVIEW QUESTIONS

1 Outline a number of basic servicing procedures
2 If you were to install something, what might you be doing?
3 Name a range of commonly used replacement parts
4 What is the difference between serviceable and unserviceable?
5 What are specifications and how do they apply to automotive workshop practices?
6 What would you be doing if you were diagnosing something?
7 If a part requires machining, what needs to be done to it?
8 What is a casting?
9 Name some parts produced by casting.
10 What is an extrusion?
11 What process might be used to produce a body panel?
12 Name three common methods of welding.
13 Explain the basic safety precautions required when welding.
14 What is a forging?
15 Name some parts produced by forging.
16 What systems or components might you be repairing if you were soldering?
17 Outline a range of locking devices and explain where each is used.
18 What is a spline?
19 What is a snap ring?
20 Explain the four basic thread forms and what they refer to.
21 What is the pitch of a thread?
22 Using the appropriate table, find the pitch of the threads for a 10 mm bolt.

CHAPTER 4

Tools and their uses

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify a range of automotive workshop tools and equipment
2 select and safely use those tools and that equipment
3 service , maintain and store common automotive workplace tools and equipment.

A mechanic 's personal tool kit may include items such as spanners, ratchets, sock ets, screwdrivers, pliers, hammers and punches. To ensure a safe and productive working environment, all tools and equipment must be cared for and used correctly . Tools can be kept on tool boards or in a tool box with trays or compartments to k eep them sorted and ready for use .

Other tools and equipment in the workshop include those used for turning, holding, bending, hammering, cutting, forming, drilling, grinding, threading, pulling and lifting. Workshop professionalism involves using the correct tool for the required task, carrying out the work in reasonable time and observing good safety practices.

4.1 Tools for turning

Tools used for turning include spanners, screwdrivers and wrenches. Other specialist equipment is used for tightening or loosening bolts, nuts and screws, or for turning other threaded parts.

4.1.1 Spanners

Many types of spanners are available: open-end, socket, ring, combination open-end and ring, adjustable and so on. Each has its particular use.

Open-end spanners

These are the most common spanners (Figure 4.1). Their openings, or jaws, are set at an angle, allowing the spanner to be used in a restricted space. The bolt or nut is turned as far as the space will allow and the spanner is then turned over to permit further movement.

Handy hint: For greater control, a spanner should be pulled rather than pushed. If a spanner has to be pushed, do so with the open palm of the hand.

Ring and ratchet spanners

Ring spanners (Figure 4.2) have a ring at each end that fits completely around the head of the bolt or nut being turned. Ratchet spanners (Figure 4.2) have angled teeth cut into them.

Figure 4.1 Open-end spanners SNAP-ON

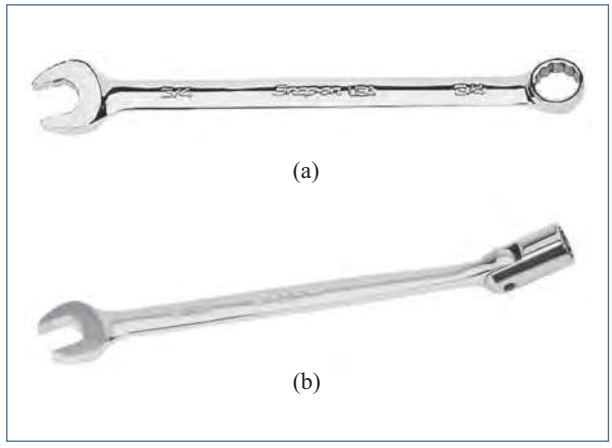


Figure 4.3 Combination spanners (a) open-end and ring spanner (b) open-end and sock et spanner SNAP-ON

Figure 4.2 Ring and ratchet ring/open-end spanners SNAP-ON

Figure 4.4 Sock et spanners SNAP-ON

Ring spanners can be used in restricted spaces because of the thin section of material at the ring. The double-hexagonal ring allows a bolt or nut to be removed or installed where there is a swing of only 30°.

Combination spanners

Combination spanners can be open-end and ring or open-end and socket (see Figure 4.3). The socket or ring end is used to loosen the bolt or nut where all-round contact is required. The open end can be used where access is difficult above the nut or bolt.

Socket spanners

These are tubular-type spanners that fit over the nut (Figure 4.4). They are used with a detachable handle. Most sockets are a double-hexagonal shape internally, so the bolt or nut being turned can be moved one-twelfth of a turn at a time, if necessary. The drive-end of the handle has a square end which fits into a square hole in the socket.

Socket accessories

Handles and other accessories are used with socket spanners. They include ratchet handles, speed braces, extension pieces and universal joints (Figure 4.5). The square driving end of the extension can be 6.4 mm (¼ inch) for small sockets and up to 25 mm (1 inch) for large sockets.

Special spanners

Some spanners, like those in Figure 4.6, are designed for special purposes. C-shape and S-shape ring spanners can be used for manifold bolts and nuts and in other places that are hard to reach with a normal ring spanner.

A flare-nut spanner is used on pipe fittings. The jaws are wider and stronger than an open-end spanner and less likely to damage the fitting.

Adjustable spanners

Spanners with adjustable jaws (often referred to as *shifting spanners*) are particularly useful for irregular-sized bolts and nuts. They should be used for special work only and are not substitutes for all spanners. They must be used correctly, with the jaws adjusted firmly (Figure 4.7).

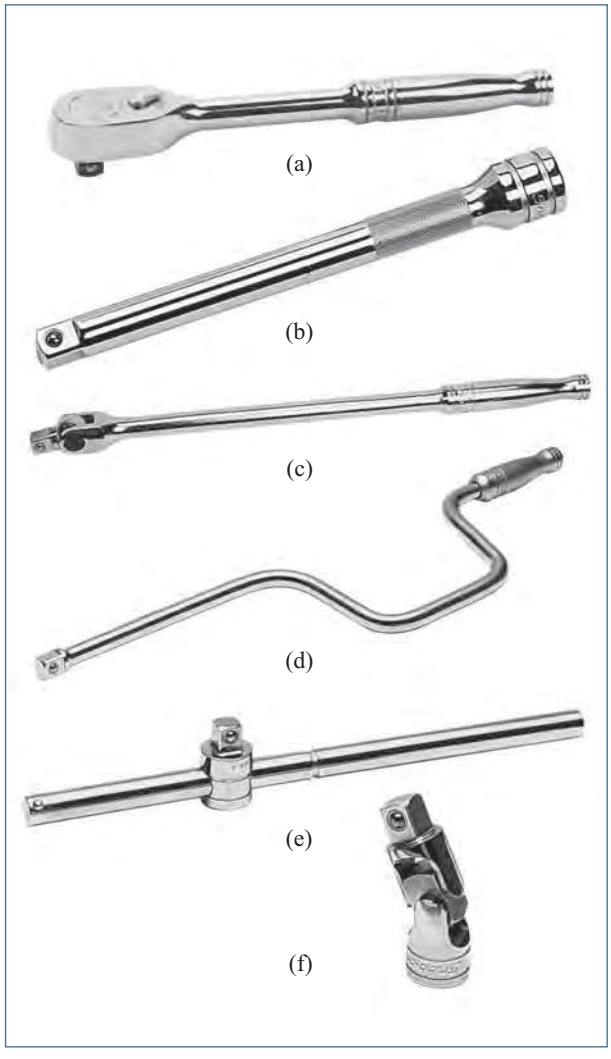


Figure 4.5 Socket accessories (a) ratchet (b) extension (c) breaker (d) speed brace bar (e) sliding handle (f) universal joint SNAP-ON

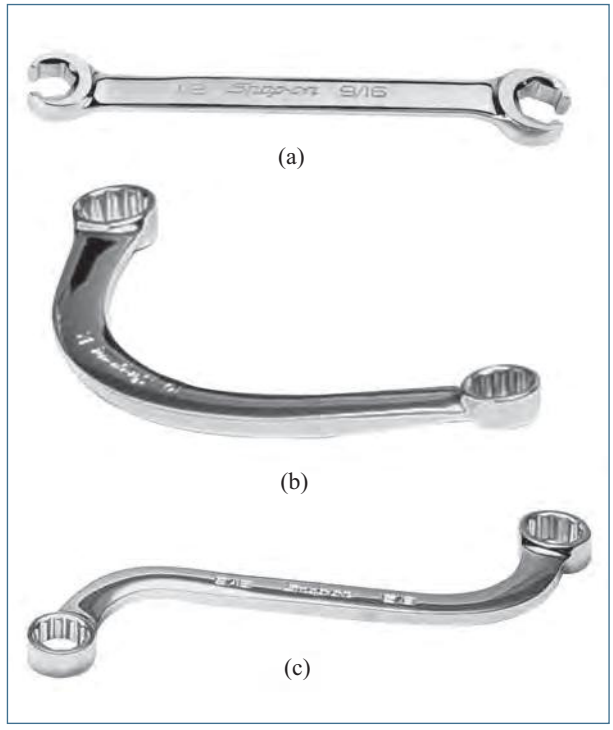


Figure 4.6 Special ring spanners (a) flare nut (b) C-shape (c) S-shape SNAP-ON

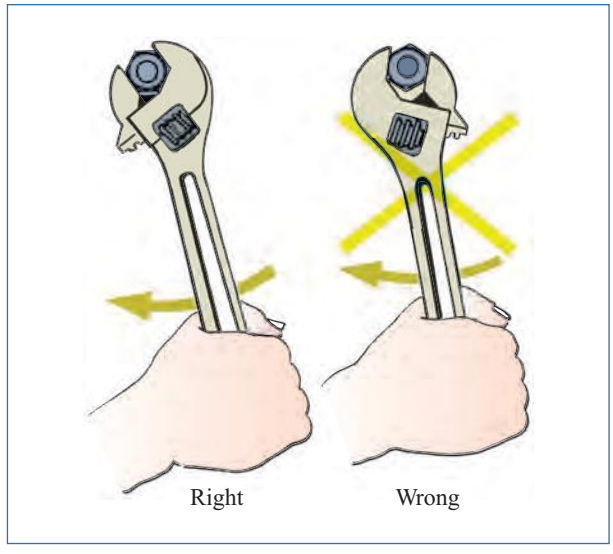


Figure 4.7 Use of adjustable spanner

4.1.2 Spanner sizes

Spanners are marked with the size of the nut or head of the bolt on which they will be used. This is the dimension across the nut or bolt head from one flat side to the other, sometimes referred to as *across the flats*. For open-end spanners, this is the width of the jaw opening.

Metric spanners are marked in millimetres, and a typical set could range from 6 mm (in steps of 1, 2 or 3 mm) up to 32 mm.

Spanners for bolts with Unified Threads are marked in fractions of an inch. (The Unified Thread Standard (UTS) mainly applies to screw threads used in the United States and Canada.) A set of spanners for these bolts could range from ¼ inch to 1 inch.

4.1.3 Torque wrenches

Torque wrenches tighten bolts and nuts to a specified torque. Figure 4.8 shows two common varieties. The 'click' type (a) has a preset scale that makes a click noise when the nut or bolt reaches the preset torque.

Torque wrench (b) has a dial gauge that reads the torque applied as it is being turned. It can be used for measuring bearing preload.

Some torque wrenches could have both metric and imperial scales, so be careful to use the correct one. Table A.8 in the Appendix is a conversion table for torque.

When bolts are tightened, they are placed under tension, the force of which is determined by the torque applied. The tighter the bolt, the greater the tension.

Torque wrenches are used because overtightening could cause distortion of parts, stripped threads or broken bolts; insufficient tension could allow a bolt or nut to become loose.

Manufacturers specify the torque for important bolts and nuts. Using a torque wrench enables the torque to be measured while tightening. Torque specifications for bolts and nuts are usually stated in newton metres (N. m) but may be in kilogram metres (kg. m).

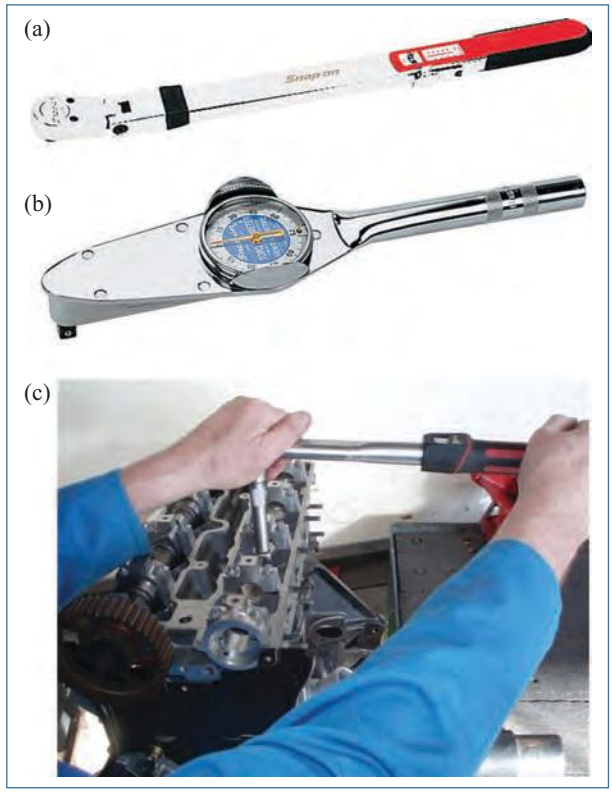


Figure 4.8 Torque wrenches (a) click type (b) dial gauge type (c) using a torque wrench to tighten a cylinder bolt SNAP-ON

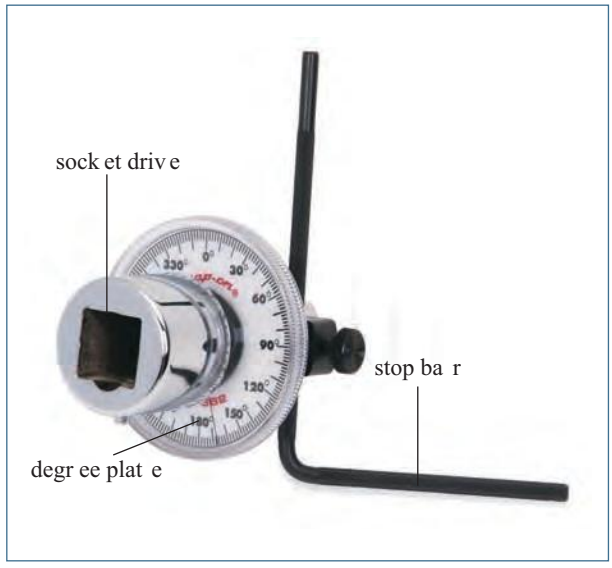


Figure 4.9 Angular torque gauge and sock et drive SNAP-ON

Angular torque gauge

An angular torque gauge (see Figure 4.9) is used on vital bolts such as cylinder-head bolts. It is used in conjunction with a torque wrench. The torque wrench applies the initial torque on the bolt and then the stop bar is engaged to stop the degree plate from turning. The pointer is then set to zero and the bolt turned through a specified angle to reach the final torque.

4.1.4 Other wrenches

Allen keys and Torx wrenches

Figure 4.10 shows an Allen key and a Torx wrench. Allen keys fit into the hexagonal recess in the head of special bolts and screws. Large Allen keys are referred to as 'Allen wrenches'.

Torx wrenches are similar but have flutes that fit into a recess in the head of Torx screws and bolts.

Both Torx and Allen bolts are used on engine parts. Allen and Torx tool sizes are now widely available as sockets in varying drive applications (Figure 4.11).

Pipe wrenches

These have an adjustable jaw to enable the wrench to fit a range of sizes of pipes or tubes. The hardened jaws are serrated to enable them to grip the pipe, but the serrations can mark and damage the surface of the pipe if the wrench is not used carefully. Figure 4.12 shows this type of wrench.

Strap wrench

Damage to components can be avoided by using a strap wrench (Figures 4.12 and 4.13). It has a soft, urethane-coated nylon strap that can be adjusted from 25 mm to 250 mm. A strap wrench can be used in various applications such as the removal of oil or fuel filters and other irregular-shaped objects.

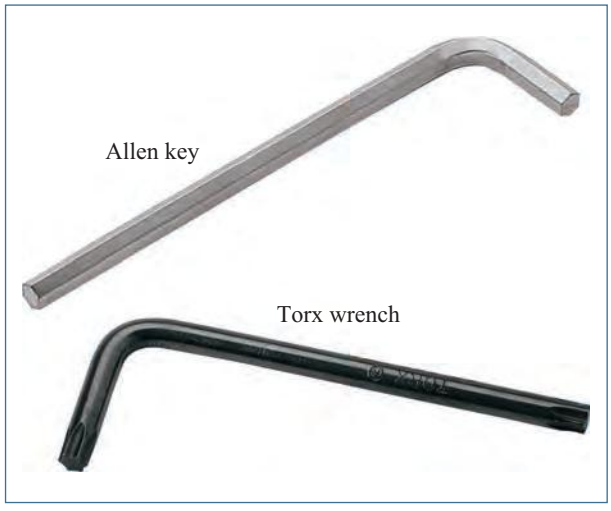


Figure 4.10 Allen key and T orx wrench SNAP-ON

Figure 4.11 Torx bits and sock ets AFRANK99 SHARED UNDER CC BY-SA 3.0

Figure 4.12 Pipe and strap wrenches SNAP-ON

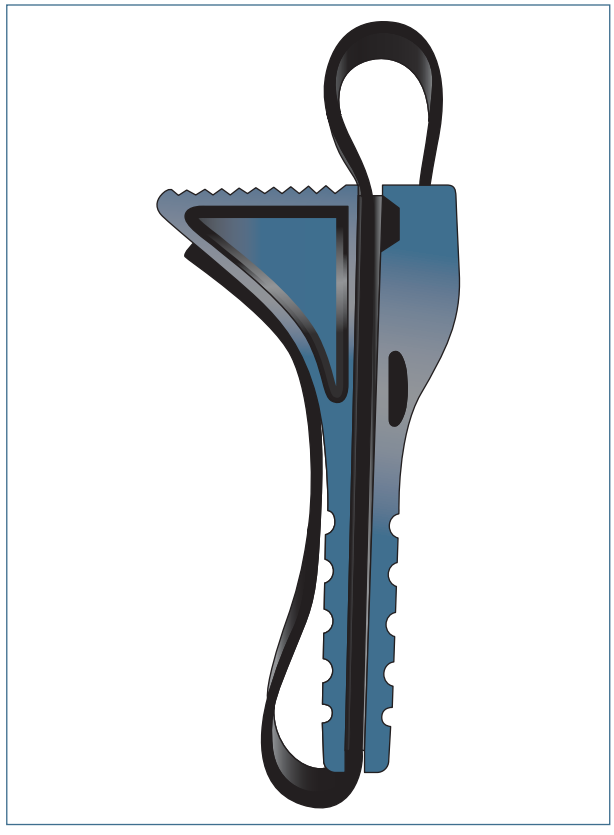


Figure 4.13 Strap filter wrench

Figure 4.14 Large swivel grip oil filter wrench

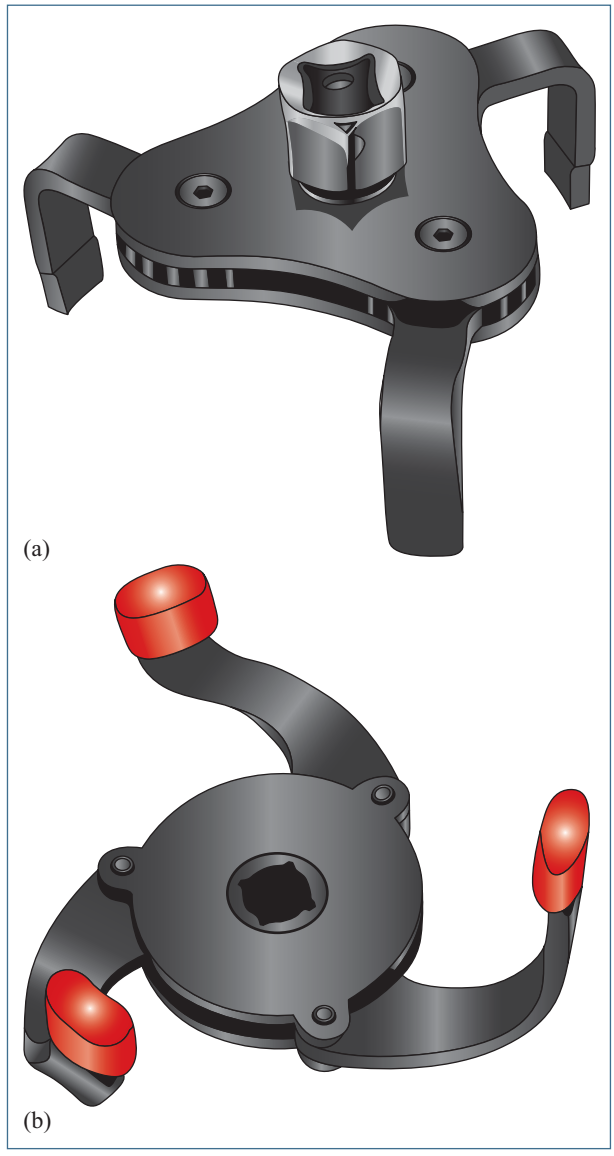


Figure 4.15 3-jaw oil filters

Oil filter wrenches

Oil filters are often in difficult-to-reach places that make the use of a strap-type wrench unfeasible. In these situations, a more compact and versatile 3-jaw-style wrench can be used (Figure 4.15a). Some oil filter wrenches (as shown in Figure 4.15b) are made specifically to suit a certain vehicle or application.

4.1.5 Screwdrivers

Screwdrivers are identified by the length of their shank or shaft and the shape of their drive. The screwdriver in Figure 4.16(a) is a flat-tip, general-purpose screwdriver with a 150-mm shaft to fit single-slot screws. Figure 4.16(b) has a Phillips tip for use on cross-slot screws. The screwdriver in Figure 4.16(c) has a POZIDRIV tip (this resembles a Phillips tip but has a different taper). The two types are not interchangeable as Phillips tips tend to ride out of POZIDRIV screws, causing damage.

There are also specialist screwdrivers for electrical, electronic and instrument use. Figure 4.16(d) shows a screwdriver with an insulated shank for electrical use. Screwdriver sets with interchangeable tips have a number of tip types and sizes that can be used with the one handle (Figure 4.16(e)).

Care of screwdrivers

The tip of a screwdriver for slotted screws must be correctly shaped, with the sides almost parallel (Figure 4.17). If the sides are tapered, the tip will be forced out of the slot as it is being turned, causing damage to the slot and making the screw difficult to tighten or remove.

The blade of a damaged screwdriver can be put back into shape using a grinding wheel.

Handy hint: Select a screwdriver that fits snugly into the screw head. One that is too large or too small will be difficult to use and will damage the screw slot.

Impact screwdrivers

Impact screwdrivers are used to loosen screws that cannot be removed by a conventional screwdriver (see Figure 4.18). When struck by a hammer, the impact driver supplies a strong downward twisting and turning force that rotates the tip of the impact driver. If required, the direction of the impact driver can be reversed; this tightens screws to a greater torque than a screwdriver.

Figure 4.16 Screwdrivers (a) flat tip (b) Phillips (c) POZIDRIV(d) electrical (e) ratchet set SNAP-ON

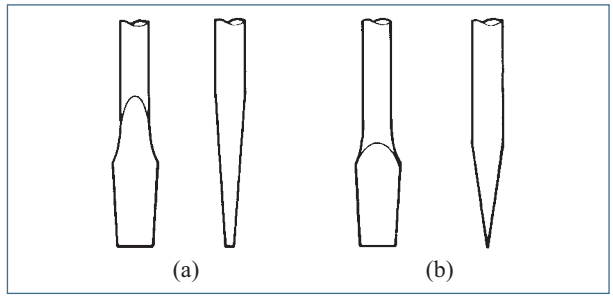


Figure 4.17 Screwdriver blades (a) correctly ground (b) badly ground

Figure 4.18 Impact screwdriver set

4.2 Tools for holding and gripping

In many workshop jobs, one part of a component has to be held while working on another part. Various tools can be used for this, including pliers, clamps, vices and fixtures.

1 Pliers. Pliers, shown in Figure 4. 19, are designed for various purposes—to hold, cut, bend and so on. They should not be used on the heads of bolts or nuts because this will cause damage and spanners will no longer fit.
2 Circlip pliers. These special pliers (Figure 4.20) remove and replace circlips or snap rings. Circlips (or snap rings) fit into grooves in shafts or housings. External circlip pliers expand the circlip for removal from a shaft, while internal pliers contract the circlip for removal from a groove in the bore of a housing.
3 Vice-grip pliers. These pliers (Figure 4.21) have a double-lever action that gives the jaws a very tight grip . The size of the jaw opening can be adjusted with a knurled screw on the end of the handle .

4.2.1 Clamps

Clamps are used for holding parts together while they are being assembled, drilled or welded. For example, two pieces of steel that are to be drilled and bolted together would be clamped together during the drilling operations to ensure that the holes in both pieces are in correct alignment. There are many different designs of clamps, some of which are shown in Figure 4.22.

4.3 Tools for hammering and driving

These include hammers and tools such as punches and chisels that are used in conjunction with them.

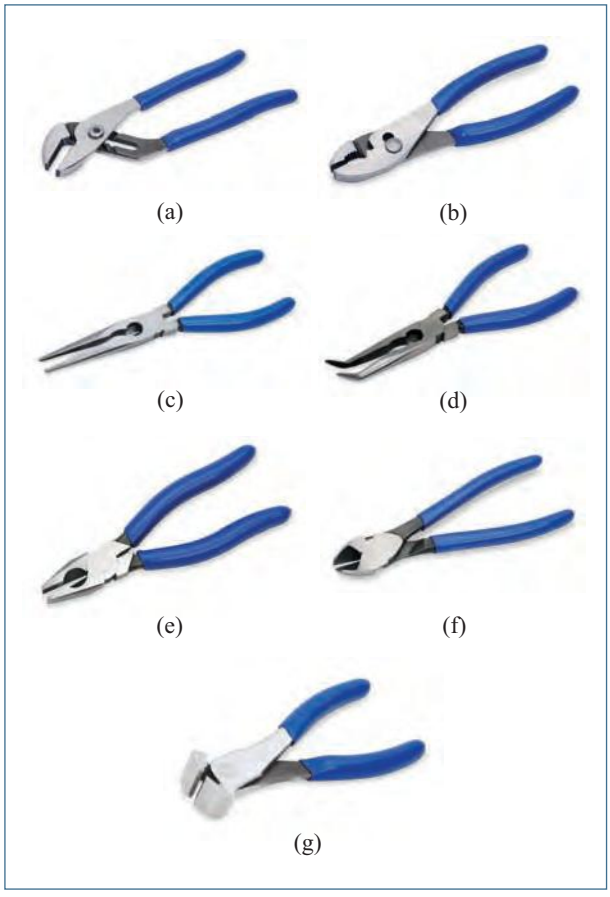


Figure 4.19 Various pliers for gripping and cutting (a) multi-grip (b) slip joint (c) long-nose (d) bent-nose (e) combination (f) diagonal-cutting (g) end-cutting SNAP-ON

Figure 4.21 Types of vice-grip pliers (a) standard grip (b) long-nose SNAP-ON

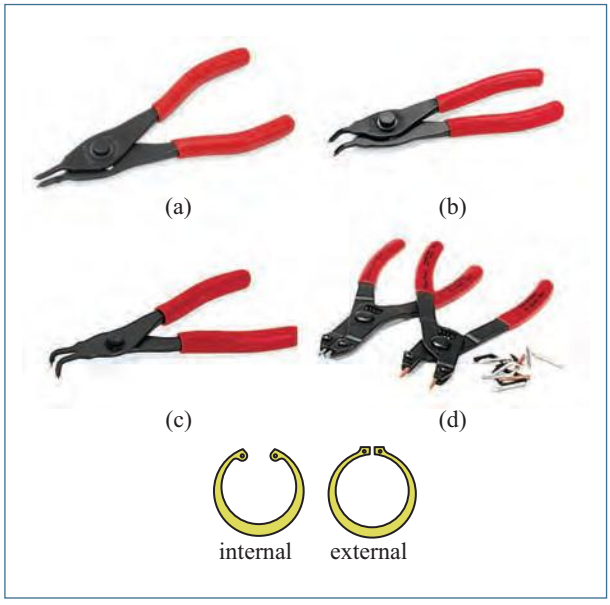


Figure 4.20 Circlip pliers (a) straight (b) curved external (c) curved internal (d) kit with replaceable tips SNAP-ON

Figure 4.22 Clamps (a) G-clamp (b) pipe clamp (c) welding clamp (d) sheet metal clamp SNAP-ON

4.3.1 Hammers

Hammers should be gripped at the end of the handle, not near the head. The face of a hammer should strike the object squarely, as in Figure 4.23.

All hammers must be used with care. Careless use of a steel hammer will bruise or injure the surface being hammered, and large hammers can cause considerable damage.

Some types of hammers are shown in Figure 4.24. These include:

1 Ballpein hammer . This is the type most commonly used in workshops. The flat face of the hammer is used for striking punches and chisels and also for general work. The ballpein is round and is used for riveting.
2 Crosspein hammer . This has a wedge-shaped pein instead of a ball. It is useful for work in corners that would not be accessible with a ballpein.
3 Panel hammer or panel beater . This is a specially shaped hammer that is used with a dolly for beating out damaged body panels.
4 Bronze-tip hammer . This strikes metal components that may be damaged using hardened hammers.

Handy hint: The faces or heads of soft hammers can be made of rubber , plastic, lead, brass or copper .

Another type of hammer is the soft-head hammer. This is used for striking surfaces that can be easily damaged or marked. When reassembling parts, a soft-faced hammer is sometimes used (Figure 4.25).

Safety: The use of personal protective equipment (PPE) should always be considered when using a hammer and punch: safety glasses to prevent debris from injuring eyes; gloves to protect hands from hammer strikes; and ear plugs to prevent hearing damage .

4.3.2 Punches

Various punches are used to drive out rivets or pins, align parts for assembly and mark locations of holes to be drilled. These are shown in Figure 4.26.

1 Centre punches. These mark a hole location prior to drilling, with the punch mark starting the drill in the right place . With no punch mark, the point of the drill will wander over the surface of the work and could start drilling in the wrong place .

Centre punches are also used for marking parts before they are dismantled. A light punch mark on mating parts enables them to be reassembled in the original position.

2 Starting and pin punches. Starting punches are tapered and are used to start a pin from a hole . Once the pin has been started, a pin punch is then used to drive it from the hole .

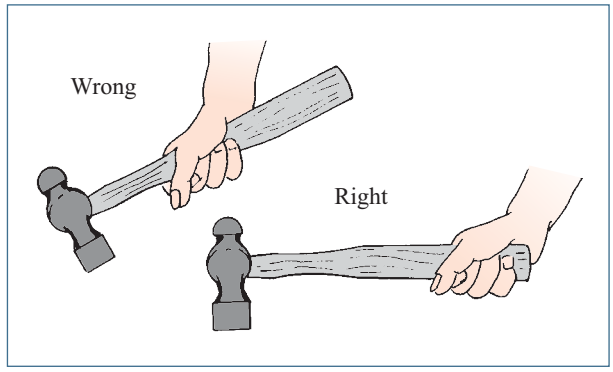


Figure 4.23 The wrong and right ways to grip and use a hammer

Figure 4.24 Various types of hammers (a) ballpein (b) crosspein (c) bronze-tip (d) panel beater SNAP-ON

Figure 4.25 Hammers with rubber and plastic heads SNAP-ON

The shank of a pin punch is either hexagonal or round, and the end parallel. For automotive work, pin punches range from about 3 mm to 12 mm in diameter. Starting punches are used because they are less likely to bend than long pin punches.

3 Drifts. Drifts are larger-sized punches that remove shafts. These are made by cutting a length of about 150 mm to 200 mm from a piece of round stock. This could be mild steel, brass, copper or aluminium as softer materials prevent damage to the end of the shaft that is being removed or replaced.

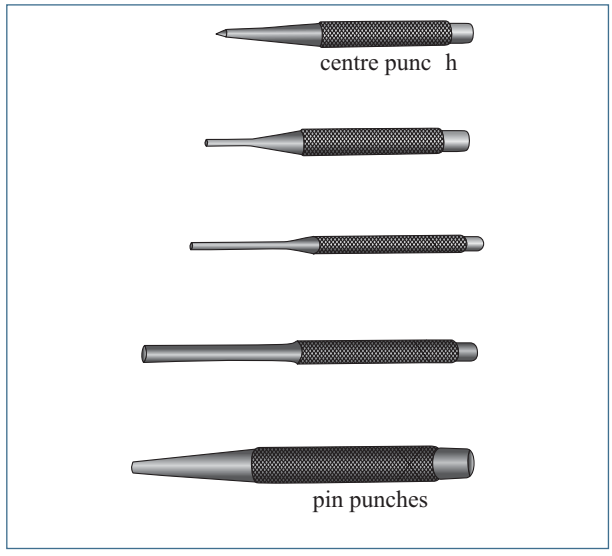


Figure 4.26 A centre, drift and pin punch set

4.4 Tools for cutting and forming

Tools under this heading include hacksaws, chisels, files, drills and tinsnips. There are also air, battery and electric-powered tools that are used for cutting and forming.

4.4.1 Hacksaws

Hacksaws cut metals. Two types are shown in Figure 4.27. They have replaceable blades and a frame that is adjustable for various blade lengths.

Blades are made with different numbers of teeth (see Figure 4.28). Using a blade with the wrong number of teeth will not only make the job more difficult but will damage the teeth or break the blade. The blade should be placed in the hacksaw frame and tightened to the correct tension. Insufficient tension will cause the blade to bend and break.

Handy hint: The teeth of the blade should point away from the handle so that they will cut when the hacksaw is pushed forward.

Figure 4.27 Hacksaws SNAP-ON

Cutting

A hacksaw should be used at around 60 cutting strokes per minute and the full length of the blade should be used wherever possible. On the forward or cutting stroke, move the hacksaw evenly and with even pressure. Lift the blade very slightly on the return stroke to avoid wear on the back of the teeth. Do not twist or bend the blade when cutting as this could cause it to break.

Figure 4.28 shows blades with the correct and incorrect pitch for different types of work. The teeth should be flat across the work. A blade with the correct number of teeth will provide *chip clearance.*

A general rule is that two or more teeth should always be in contact with the work. If a coarse blade is used on a thin section, the teeth will straddle the work, making cutting difficult and causing the teeth to break.

4.4.2 Cold chisels

Cold chisels are made in different shapes, the flat chisel being the most common. The other chisels shown in Figure 4.29 are for special purposes, such as cutting grooves and chipping in corners or other inaccessible places. A flat chisel can be used to cut off the heads of rivets or rusted bolts by holding it at a suitable angle to start the cut under the head to be removed.

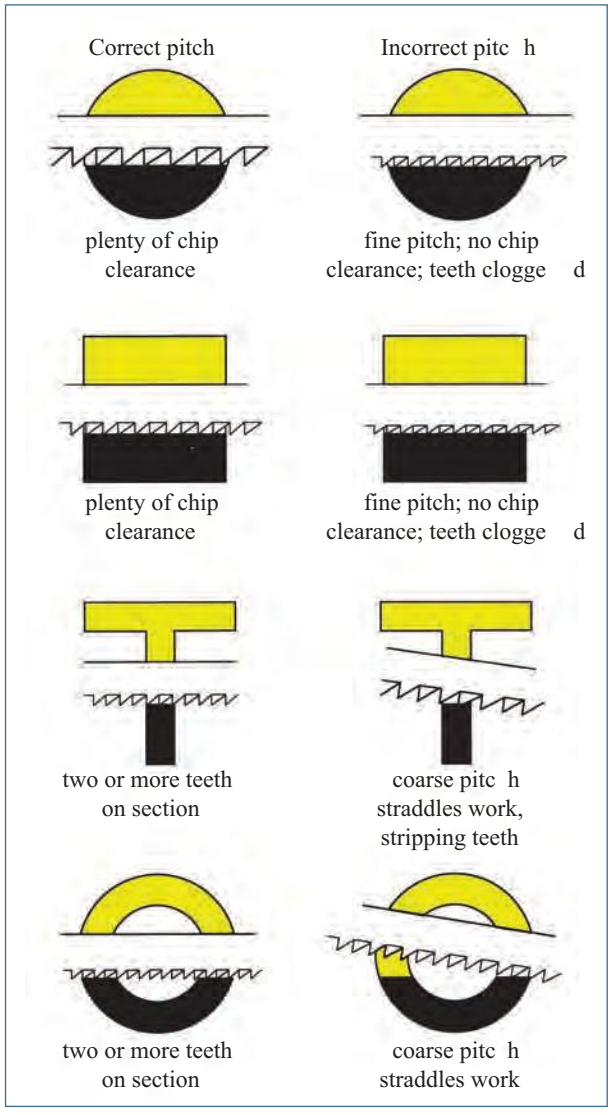


Figure 4.28 Hacksaw blades for various cutting jobs – blades with the correct tooth pitch are on the left and those with incorrect tooth pitch are on the right

Figure 4.29 Chisel and punch set SNAP-ON

To cut thin steel plate up to about 4 mm thick, the plate is gripped vertically in the jaws of a vice and the chisel held at about 30° to the horizontal. The cutting point should rest on the vice jaws at an angle of about 45° to the work. The cut is commenced from the edge of the work, and the chisel moved along the vice jaws as the metal is sheared through.

Care of chisels

The end of a chisel has a long taper and its point is sharpened by grinding it. The head is dressed to a slight taper.

A chisel that has mushroomed because of repeated hammer blows should be dressed on a grinding wheel to remove the turned-over metal (Figure 4.30).

4.4.3 Wad punches

These are hollow punches used for cutting holes in gasket materials and thin metal such as shim brass or shim steel. To cut a clean hole, the material is placed on a piece of wood or block of lead and the punch hit sharply with a hammer. Wad punches come in a range of sizes for various diameters of holes.

4.4.4 Files

A typical file with the various parts named is shown in Figure 4.31. Files are cutting tools with a large number of cutting teeth.

The term *cut* refers to the cuts that have been made across the face of the file to form the file teeth. When the cuts are relatively far apart, the file is termed a 'rough' or 'coarse' file. When they are close together, the file is called a smooth file. The coarser the file, the more metal it will remove with each stroke.

Figure 4.32 illustrates four different file cuts. When only one series of cuts is made across the face of the file, it is known as a single-cut file. When the file has two series of cuts across its face, it is known as a double-cut file (Figure 4.33).

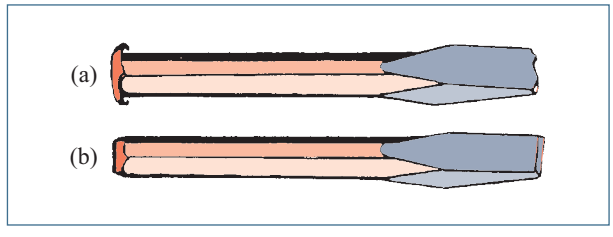


Figure 4.30 Cold chisels (a) chisel requiring grinding (b) chisel after grinding

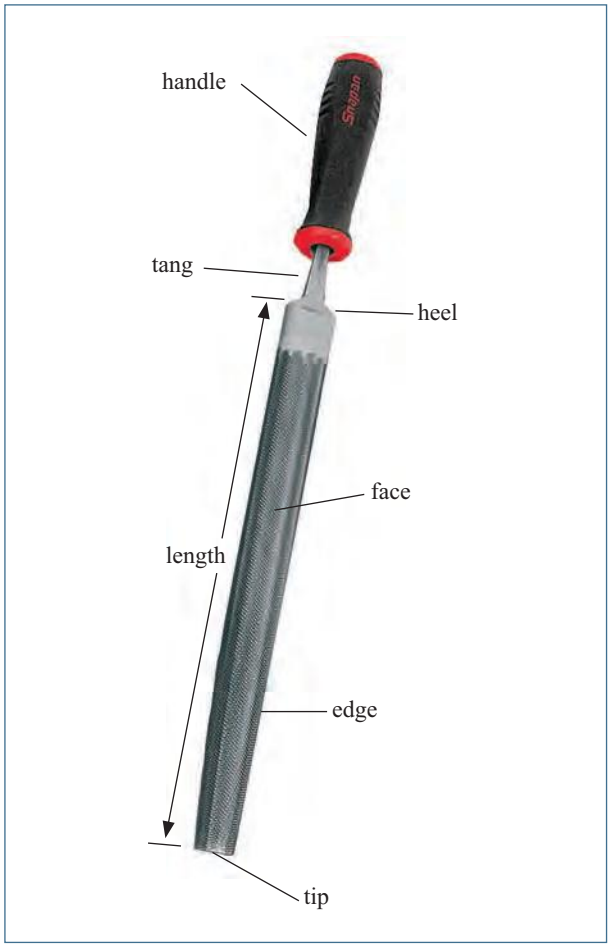


Figure 4.31 A typical file SNAP-ON

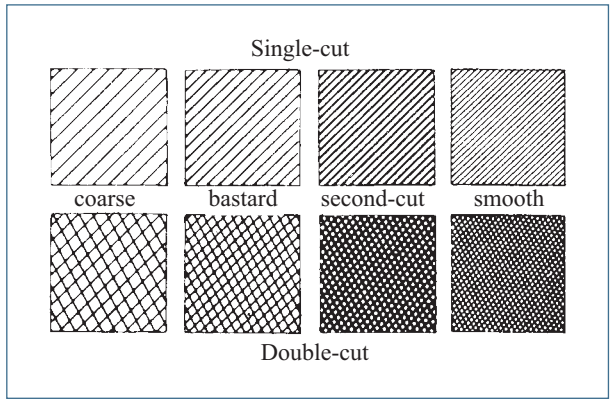


Figure 4.32 Types of file cuts

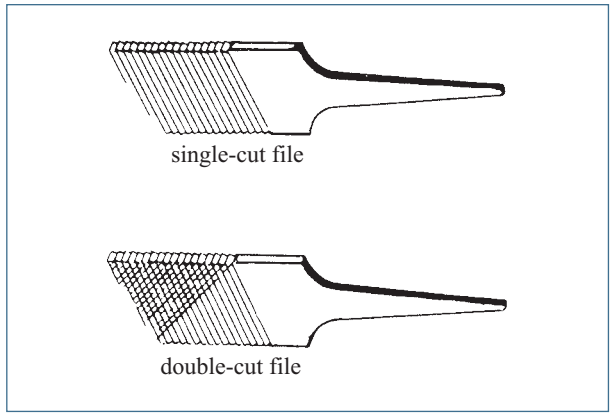


Figure 4.33 Single-cut and double-cut files

Files are also classified according to their shape. They may be flat, triangular, square, half-round or round. They can be either parallel or tapered from the heel to the tip.

Safety: The handle on the file should always be securely fastened to the tang (the main part of the file body). Never use a file that does not have a handle fitted.

4.5 Tools for drilling

Drills are used to make holes in all types of material. They are used with portable electric drills or bench-mounted drilling machines. The most common type is the twist drill. Reamers are used to finish holes to size after they have been drilled.

Safety: The use of personal protective equipment should always be considered when using tools associated with drilling. Ensure that safety glasses are worn to prevent debris from injuring eyes and that any loose clothing or hair is restrained.

4.5.1 Drilling machines

Bench drills have a cast-iron base that is bolted to the bench top (see Figure 4.34). A vertical column supports the electric motor and drill head at the top of the machine. The column has an adjustable work table, which can be moved up and down the column to suit various work heights.

The drilling speed can be adjusted by selecting different gears or, in some cases, by changing the drive belt on stepped pulleys. The feed is applied with a hand lever.

Figure 4.34 Bench drill and vice SHUTTERSTOCK

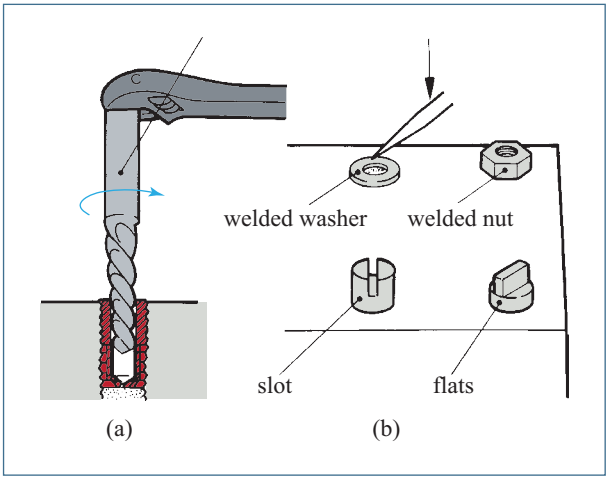


Figure 4.35 Removing a brok en bolt (a) with an extractor (b) other workshop methods

4.6 Tools for removing studs and broken bolts

Screw extractors remove bolts that are broken below the surface (Figure 4.35 (a)).

The first step in using an extractor is to centre-punch the end of the bolt and then drill a hole of the correct size for the extractor. The hole must be as close to the centre of the bolt as possible.

The extractor is tapered and has spiral flutes with sharp edges that form a coarse left-hand thread. It can be turned with a tap wrench or spanner, as shown.

4.6.1 Broken bolt removal

When the extractor is placed in the drilled hole in the broken bolt and turned, it screws itself down into the hole. The sharp edges of the flutes bite into the bolt so that it can be turned with the extractor and screwed out of its threaded hole.

Other methods that can be used are shown in Figure 4.35 (b). If part of the bolt is above the surface and the thread is free, it might be possible to turn it with a pair of pliers. Flats can be filed so that it can be turned with a spanner, or a slot cut with a hacksaw so that a screwdriver can be used.

Depending on the location, and if the break is flush with the surface, a spot-welded washer or nut could be used. If the bolt is large enough, it can be tapped on alternate sides with a hammer and a sharp punch. Tap on one side and then the other until the bolt loosens.

Handy hint: Where the thread is damaged, thread inserts can be fitted to restore the threaded hole .

4.6.2 Stud removal

In situations where a stud has broken off and left part of the shank or thread above the mounting surface, a stud remover (or extractor) can be used (see Figure 4.36). This is a tool that has an off-centered, knurled wheel and two holes ranging from approximately 12 mm to 19 mm in diameter. Selecting the most appropriate hole in the tool, the stud remover is placed over the broken stud. When turned, the stud extractor grips tightly against the broken stud, causing it to undo. A ½ inch drive ratchet or breaker bar is used to turn the stud extractor.

4.7 Tools and materials for grinding

Grinding wheels mounted on bench or pedestal grinders are used for general grinding jobs and for sharpening drills, punches and chisels. When fitted with a wire-wheel brush, a grinder can be used for cleaning.

Abrasive stones, or oilstones, are used for honing, sharpening and smoothing. Abrasive-coated discs and sheets are used during automotive body and paint repair work.

4.7.1 Grinding wheels

Grinding wheels come in a wide range of shapes and sizes including plain, bevel and cupped. Plain wheels are used on bench and pedestal grinders. Grinding is performed on the edge of the wheel. Cupped wheels are cupped to provide a grinding face on the side of the wheel.

In addition to the size and shape, grinding wheels are classed as either fine, medium or coarse and are selected to meet specific requirements.

Handy hint: A soft-grade wheel will wear away more quickly than a hard one , but will not clog as easily .

4.7.2 Replacing a grinding wheel

When a new wheel is to be fitted to a grinder, it must be specifically designed for the machine being used. Check to see whether any printed markings are visible on the old wheel that can be used for identification.

Before mounting a new grinding wheel, inspect all components for cracks. This includes the drive spindle on the grinder, locking washers, retaining nut and the new grinding wheel.

Clean the mounting spindle and flanges so that the wheel fits easily. Fit a clean blotter disc on each side between the wheel and the flanges.

Figure 4.36 Stud extractor tool (KINCROME)

Tighten the nut to hold the wheel firmly, then replace guards and adjust the work rests so that they are close to the wheel. Start the wheel, allow it to reach its full speed and run it for a minute or two. Stop the wheel and reinspect before using it.

4.7.3 Using a bench grinder

To grind a small tool, such as a punch, chisel or screwdriver, it is held against the edge of the wheel. The correct and incorrect methods are shown in Figures 4.37. The grinder should have clear shields to help protect the user from sparks or debris. Safety glasses should always be worn while grinding.

The tool should be supported on the tool rest with the point upwards against the edge of the wheel and should be moved slowly across the wheel, using its full width. Flat articles are held flat on the tool rest.

When grinding, do not apply too much pressure to the work, or hold the tool against the wheel too long without cooling it in water. Grinding generates heat, and this will quickly affect the temper of small tools.

Handy hint: Overheating will be shown by discolouration of the metal being ground, particularly the points of drills and the ends of punches and screwdrivers.

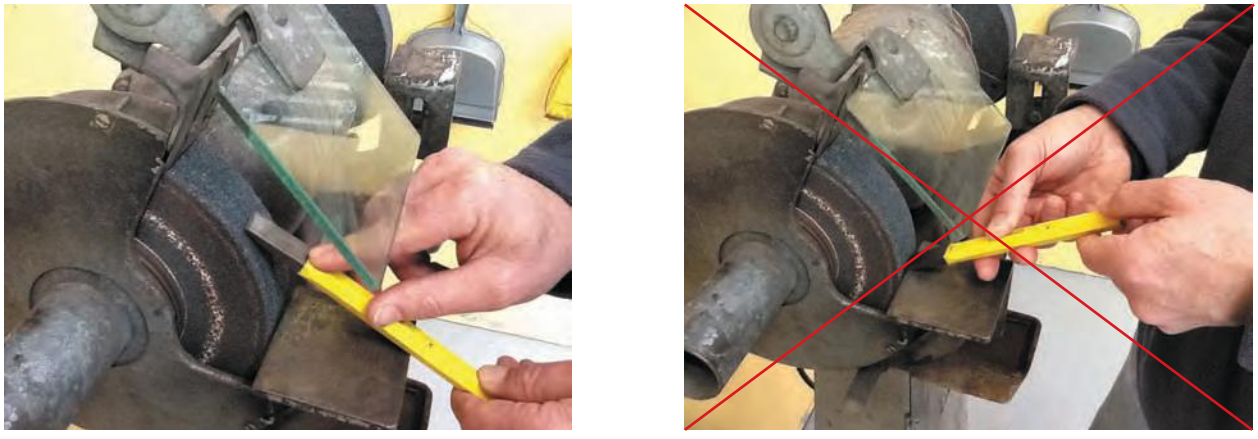


Figure 4.37 Grinding a tool (a) correct method of holding the tool against the wheel (b) incorrect method that could jam the tool between the rest and the wheel

4.7.4 Safety with grinders

Observe the following safety rules:

1 Inspect the equipment to ensure that it is in safe operating order .
2 Check that it has been correctly tested and tagged for electrical compliance .
3 Wear safety glasses or a shield.
4 Adjust the safety shields on the machine .
5 Check that the work rest is correctly adjusted close to the wheel.
6 Keep the wheel nuts tight.
7 Look closely for wheel damage .
8 Allow the wheel to reach full speed before use .
9 Stand to the side of the wheel if possible .
10 Do not overload the wheel by using ex cessive force on the work.
11 Hold small objects with pliers, not with hands.
12 For heavy grinding, wear leather gloves.

Grinding wheels can be *dressed* when the grinding edge becomes worn or grooved. A special wheel-dressing tool is used across the wheel edge.

4.8 Tools for pulling and pushing

Many parts, such as ballraces, collars and gears, are a tight fit on their shafts. Force is needed to remove and replace them, using pullers and presses.

4.8.1 Pullers

Figure 4.38 shows three types of pullers. The large puller in Figure 4.38 (a) is arranged as an external puller; that is, the legs or claws fit over the outside of the part being pulled. The puller in Figure 4.38 (b) is of similar design, but with three legs. The puller in Figure 4.38 (c) is a small, universal type. The legs of most pullers of these designs can be reversed so that the claws on their ends can be used internally as well as externally.

4.8.2 Presses

Mechanical presses, or arbor presses, are often used instead of a puller where the component is removed from the vehicle. Hydraulic presses are also used (Figure 4.39). These can apply much greater force than a mechanical press or puller.

To remove a bearing from a shaft by means of a press, the bearing must be suitably supported on the bed of the press so that it will not be damaged. Force is then applied to the end of the shaft by the ram of the press so the shaft can be pressed from the bearing.

Larger presses have a bed that can be raised or lowered to accommodate articles of different sizes.

Figure 4.38 Three types of pullers SHUTTERSTOCK

When removing or installing a bearing on a shaft using a puller or press, be careful that the force does not damage the bearing or shaft.

4.8.3 Hydraulic bearing puller

Hydraulic power tools are particularly useful for pressing bearings and collars on or off a shaft. The multiplication of power that is produced by a hydraulic tool means they can provide a great deal of force. Figure 4.40 shows a portable hydraulic bearing puller for general workshop use. The larger centre screw thread is filled with oil. The smaller screw, when turned, acts like a hydraulic press and forces a piston out at the opposite end with increased force.

4.8.4 Slide hammer

A slide hammer is used where an object cannot be struck by a conventional hammer and punch. The slide hammer has a long shaft, weighted handle and is attached to the object needing to be pulled by screws, a thread or hooks. The user quickly moves the weighted handle towards the end of the slide hammer which transmits an impact, causing the component to be pulled outwards.

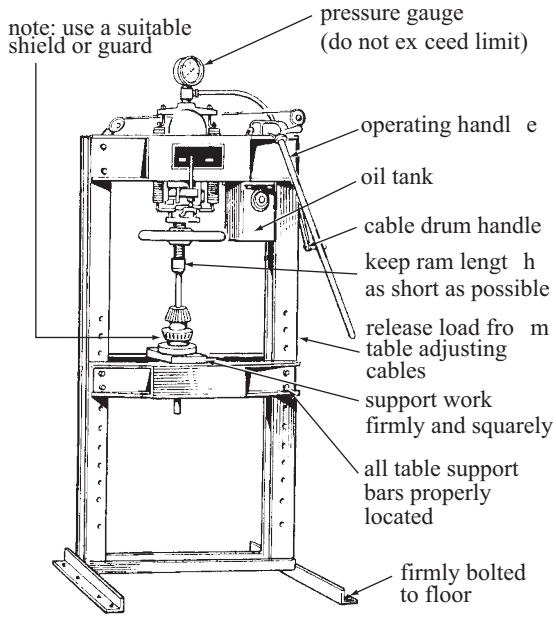


Figure 4.39 Working with a hydraulic press—a suitable guard or shield must be used

4.9 Portable power tools

A wide variety of power tools are available. They can be pneumatic (using compressed air), electric (mains voltage or battery operated) or hydraulic. Selection of the most suitable power tool will depend on a number of factors such as available power, amount of force required and safety issues.

4.9.1 Compressed air tools

Air-operated tools eliminate the possibility of an electric shock or sparks. Depending on the design and purpose of the particular air tool, they are capable of producing high torque or speed. Figure 4.41 shows several air-operated tools. They require a constant supply of clean, filtered air at a regulated pressure. Variations in this pressure will result in variations in torque and speed.

Figure 4.40 Hydraulic puller removing a bearing

Figure 4.42 shows a set of torsion bars that can be used with air tools to prevent over-tightening of the wheel nuts, studs, brake rotors and calipers. The torsion bars are colour coded for different-sized wheel nuts. The torque bar stops turning when the correct torque is reached.

Air tool maintenance

Air tools require special lubricants to maintain efficiency and long life. The lubrication can be added to the air supply line and automatically metered to the tool or added manually through the air inlet of the tool when required.

Safety: Be careful with the use of air supply lines as they can pose a trip hazard. Also , air tools are noisy so suitable hearing protection should be worn.

4.9.2 Electric power tools

Electric power tools are available with 240 volts mains supply or a low-voltage battery. Some can provide variable speed in both forward and reverse. A fast speed is usually selected for small drill sizes and a slower

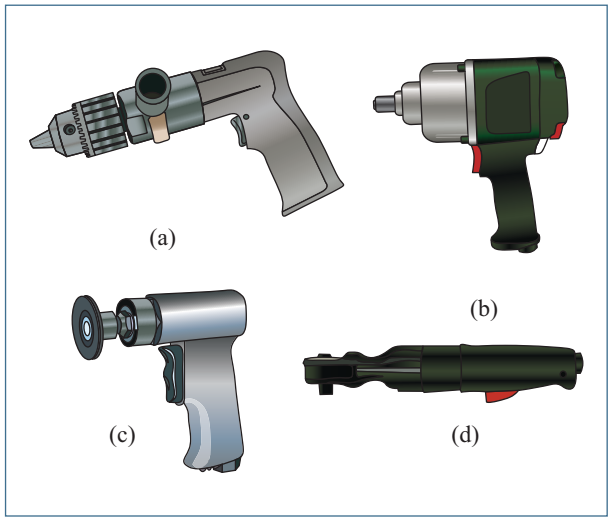


Figure 4.41 Portable air-operated power tools (a) air drill (b) air impact wrench (c) gask et sander (d) air ratchet

Figure 4.42 Torsion bar kit SNAP-ON

speed for larger sizes. Mains supply electrical tools have more power and torque than battery-powered tools and do not require recharging. Battery-powered tools can handle many jobs and have the advantage of being able to be used anywhere in the workshop without electrical leads or air lines.

Figure 4.43 shows different types of portable electric power tools.

Electric power tools should be maintained in good condition and used correctly. To ensure safety, each 240 V electric tool should be fitted with a tag that identifies that it has been tested, along with information about who tested it, the test date and when the next test is due. Any tool that is found to be faulty should be 'tagged out' by using a specified warning sign attached in a visible location on the tool.

4.10 Special service tools

Each workshop manual provides information on special tools designed for servicing particular parts of the vehicle. Many of the tools are essential, while others make it easier to do certain jobs. In some instances, a universal puller or other general item of workshop equipment can be used as a substitute for a special tool.

Special tools can include pullers, drivers, installers, guides, gauges, adaptors, adjusters and spring compressors. These tools are designed for use on parts of the engine, transmission, suspension, steering, brakes and many other components. Some examples are shown in Figure 4.44.

4.11 Jacks and lifts

Vehicles have specified jacking points so they can be easily lifted and supported. The locations of these jacking points vary with different models of vehicles but, in general, they are those parts of the body and suspension which are strong enough to support the weight of the vehicle without causing damage.

Jacking and lifting includes using workshop floor jacks, stands to support the vehicle and raising the vehicle on a hoist.

Figure 4.43 Portable electric power tools (a) 240 V drill (b) 240 V angle grinder (c) 240 V drill with handle (d) 18 V impact wrench MAKITA

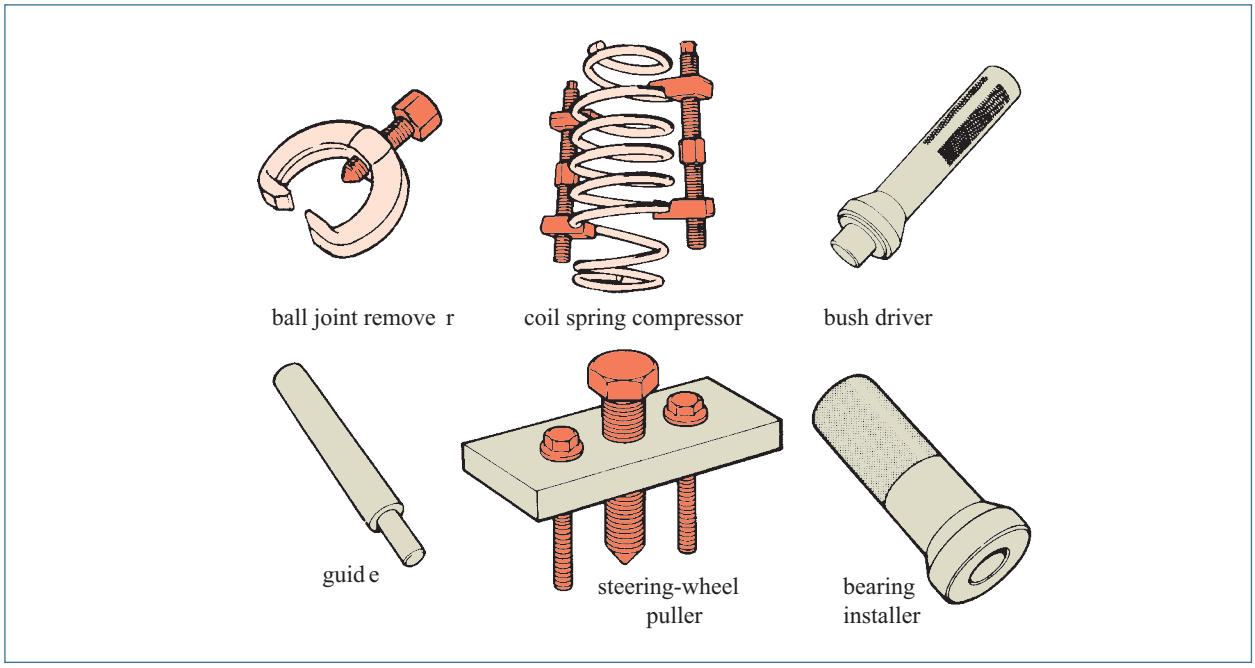


Figure 4.44 Examples of special tools

Examples of the use of jacks and hoists are included in the following sections, and can be used as a general guide. However, for particular vehicles, manufacturers' recommendations should always be followed.

4.11.1 Workshop floor jacks

A workshop jack can be used under sill panels at the same points as a vehicle jack, providing a suitable pad is placed between the top of the jack and the sill to prevent damage to the paint and crushing the panel.

The use of a workshop floor jack and safety stands is illustrated in Figures 4.45 and 4.46. If the complete vehicle is to be raised, then the rear of the vehicle should be raised and supported before the front is raised.

Figure 4.45 Jacking and support location (front)

Figure 4.46 Jacking and supporting location (rear)

1 Figure 4.45 shows the jack located at the centre of the front crossmember and being used to raise the front of the vehicle . The suspension lower control arms are not used as a jacking point. When the vehicle is raised, the safety stands are placed under the body subframe .
2 Figure 4.46 shows the rear of the vehicle being raised, with the workshop jack located at the centre of the rear crossmember . The rear of the raised vehicle is being supported by safety stands located under the body subframe .

Safety: Suspension components are not suitable for use as jacking points.

The jacking point for a rigid rear axle is shown in Figure 4.47. The jack is located under the centre of the rear-axle housing and is being used to raise both rear wheels. When raised, the vehicle can be supported by stands placed under each side of the axle housing.

Figure 4.47 A workshop jack located under a rear-axle housing SHUTTERSTOCK

Safety stands

Jacks are used to raise the vehicle. Safety stands should then be placed under the vehicle in suitable locations, as shown in Figures 4.45 and 4.46, and used to support the vehicle.

Safety: Using safety stands is a basic safety requirement when working on a raised vehicle . Always ensure **that the jack stands are placed in the correct position and will safely support the weight of the vehicle**.

4.11.2 Air jacks

Air jacks are a fast and easy lifting tool (see Figure 4.48). They reduce manual handling issues and come in a variety of shapes, sizes and lifting capacities. Another benefit of the air jack is that it is thin so it can fit under a very low vehicle. A constant supply of compressed air is required to operate this jack and, as with any lifting device, a jack stand must be used to support the weight of the vehicle.

4.11.3 Hoisting

A number of different types of hoists are used for lifting vehicles. A hoist can be designed with two side rails, platforms, arms or columns. The design of hoists can vary.

Single post hoist

These types of hoists are capable of lifting cars. However, they are mainly used to lift small-engine vehicles such as ride-on mowers, golf buggies and four-wheel motorbikes.

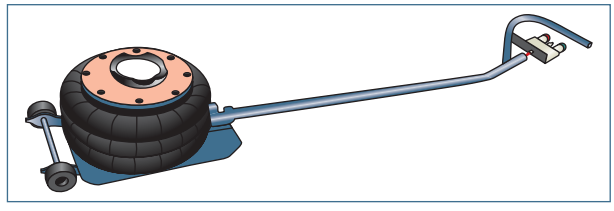


Figure 4.48 Air jack

Figure 4.49 2-post hoist

Figure 4.50 Locating pads for vehicle with a chassis

Figure 4.51 Pad of a hoist arm on sill panel SHUTTERSTOCK

Figure 4.52 The pads of a 2-post hoist located at the jacking points (viewed from underneath) SHUTTERSTOCK

2-post hoists

2-post hoists are designed to maximise workshop space and give easy vehicle access (Figure 4.49). They provide a versatile area in which a technician can work as all aspects of the vehicle are exposed when it is in the raised position.

When using a 2-post hoist, the lifting locations are basically the same as those used for jacking and supporting a vehicle. Vehicles with rigid axles at either front or rear can be supported by the hoist pads under the axle housings (Figure 4.50) or on the chassis rails (where fitted). Where the vehicle has coil springs and control arms at the front, the vehicle could be supported by the hoist pads at the outer ends of the control arms.

Passenger cars with independent suspension can be supported at four locations under the sill panels. An example of this is shown in Figure 4.51, where the pad on the arm of a hoist is located under the rear of a sill panel.

Figure 4.53 4-post hoist

Figure 4.54 Example of a workshop crane , load-leveller , correct lifting chains and shackles

With a 2-post hoist lift, the pads would be located in a similar manner at the front of the sill panels and also at their rear (Figure 4.52).

4-post hoists

Figure 4.53 shows a 4-post hoist. These are suitable for a wide range of vehicles as they include a ramp and platform onto which the vehicle drives. Once raised, the wheels remain on the platform; however, some 4-post hoists provide a feature including an air-jacking beam which raises the vehicle off the platform so the wheels are free for servicing requirements.

Mobile column hoist

Mobile column hoists are heavy-duty-style hoists that are used to lift trucks, buses and even rail equipment. In order to safely lift a truck or a bus, a number of these hoists are required as they are placed individually under the vehicle's wheels. These hoists are portable and can be set up to lift a range of different vehicles with various axle configurations and weights.

4.11.4 Workshop cranes

Heavy components can be lifted with a portable crane (see Figure 4.54). This is a device equipped with an extendable boom which is adjusted according to the weight to be lifted. For example, if the boom is fully extended, this will reduce the weight that can be safely lifted. When the boom is fully retracted, it will be able to lift the maximum capacity of the crane. Workshop cranes are very versatile and are particularly useful for heavy components such as engines and gearboxes.

⚠ Safety: Always ensure when using a workshop crane that any lifting chains, straps, shackles or load-levellers are in good operating condition and are correctly load-rated to suit the required task.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- select and use the appropriate tools, equipment and personal protective equipment (PPE) for workshop tasks
- apply pre-operational checks on all tools and equipment
- identify basic faults on a range of tools and equipment
- apply procedures for removing, tagging and reporting faulty equipment
- demonstrate basic repairs on equipment
- demonstrate the safe use of tools and equipment
- maintain and store tools and equipment in a clean and tidy manner .

REVIEW QUESTIONS

1 Name the sizes of some common spanners or wrenches.
2 What is an Allen key?
3 For what purpose is a torque wrench used?
4 Explain why a torque wrench has graduations on the main scale.
5 Explain how to correctly use an angular torque wrench.
6 Explain why it is vital to maintain a screwdriver tip correctly.
7 How would you select the correct screwdriver for the job?
8 Name three types of pliers and identify the correct use for each one.
9 Name other tools that are used for holding or gripping.
10 Where are circlip pliers used?
11 Name the various types of hammers.
12 What is a drift?
13 What are some of the common tools used for cutting and forming metals?
14 For what purposes can a centre punch be used?
15 If you were using a Torx socket, what tasks might you be performing?
16 What are soft jaws?
17 How can you identify a single-cut file?
18 Explain the correct procedure for refitting a blade in a hacksaw.
19 Why do hacksaw blades have different numbers of teeth?
20 Name the tools that can be used to remove broken studs.
21 Identify the benefits of using air tools as opposed to 240V electric tools.
22 For what purposes are jack stands used?
23 When using jack stands on a vehicle, identify where they should not be placed. Justify your answers.
24 Explain the benefits associated with using a 2-post hoist.
25 What are the key safety aspects to consider when using a floor jack to raise a vehicle?
26 Explain the benefits associated with using an air jack.
27 Identify the correct procedures for using a bench grinder

CHAPTER 5

Measuring and checking

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 select and use a range of measuring equipment
2 maintain, service and store measuring equipment.

Some of the components in a vehicle need to be measured and checked to ensure that they are still serviceable . Measuring and checking are important procedures that must be performed accurately , and at regular intervals, according to the specifications set down in the workshop manual. This ensures the safe and continued operation of the vehicle .

The specifications provide information about the type , size , capacity and dimensions of each component, and specify the clearance or setting of an adjustment. Wear limits, that indicate when a component must be replaced, are also provided in the workshop manual.

5.1 Measuring instruments

The complexity of systems in the automotive industry results in the use of a wide range of measuring instruments. Some are relatively simple and, when used correctly, provide accurate measurements and results. However, in situations where accuracy is critical, precision instruments are used. These require a greater level of understanding of their use. The following describes a range of common measuring tools.

5.1.1 Steel rule

This is the basic measuring instrument. It is used for general measurements where great accuracy is not required. Steel rules are usually 150 mm or 300 mm long, and are graduated in millimetres and half-millimetres. When turned on its edge, a steel rule can be used as a straightedge to check the flatness of a surface.

5.1.2 Feeler gauges

Feeler gauges are strips or blades of hardened steel that are fabricated to an accurate thickness. They are used to measure small clearances such as bearing clearances, valve clearances (Figure 5.1), piston ring and spark plug gaps. With the correct clearance, the feeler gauge should slide between the two parts with a slight resistance.

For ease of selection, feeler gauge blades are grouped together in order of size. The thickness of each blade is marked in millimetres, although some feeler gauges also include imperial measuring units. The blades can be used individually, but for larger measurements two or more can be used together.

Handy hint: To ensure that feeler gauges do not rust, they should be wiped clean with a rust preventative before storing.

When used with a steel rule as a straightedge, feeler gauges can be used to check that a component such as a cylinder head is not warped or that an oil pump gear has the correct end clearance (see Figure 5.14).

Figure 5.1 Checking valve clearance with a feeler gauge SHUTTERSTOCK

5.2 Micrometers

Micrometers are precision-measuring instruments that are designed to take extremely accurate measurements (down to one-hundredth of a millimetre, or 0.01 mm).

There are a number of different types of micrometers. The selection of the appropriate one will depend on the component being measured. The automotive service and repair industry generally uses the *outside micrometer* (for external measurements) and the *inside micrometer* (for internal measurements). Where more specialised measurements are required, a range of specialised micrometers can be used.

Handy hint: Micrometers are precision instruments. They must be treated properly to maintain their accuracy and to prevent them from being damaged.

5.2.1 Outside micrometers

Figure 5.2 shows the construction of an outside micrometer. It is a screw-type instrument consisting of a frame with an anvil and a threaded sleeve which carries the spindle. Turning the knurled part of the thimble screws the spindle towards or away from the anvil.

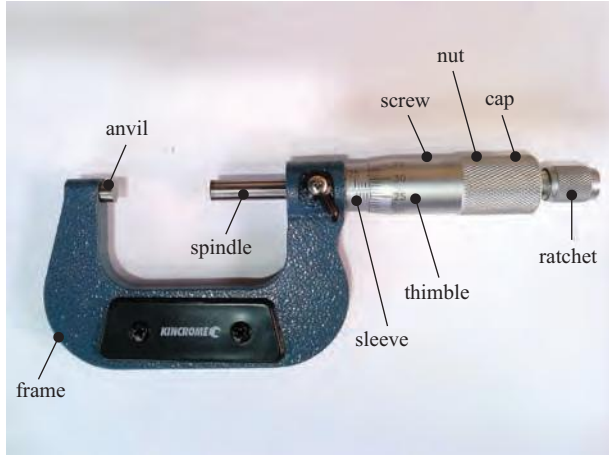


Figure 5.2 Parts of an outside micrometer

The correct use of an outside micrometer requires a number of steps:

1 Check for zero error (see ‘ Accuracy and care of micrometers ’).
2 Support the component to be measured
3 Hold the micrometer by the heat-resistant pad located on the frame .
4 Ensure that the micrometer is held squarely against the component.
5 Using the knurled cap on the end of the thimble , rotate the thimble in the desired direction.
6 When the spindle is in close contact with the component being measured, stop turning the thimble .
7 Turn the ratchet until the spindle and anvil are lightly in contact with the object being measured.
8 Read the measurement from the scales mark ed on the sleeve and the thimble (see ‘R eading micrometers ’).

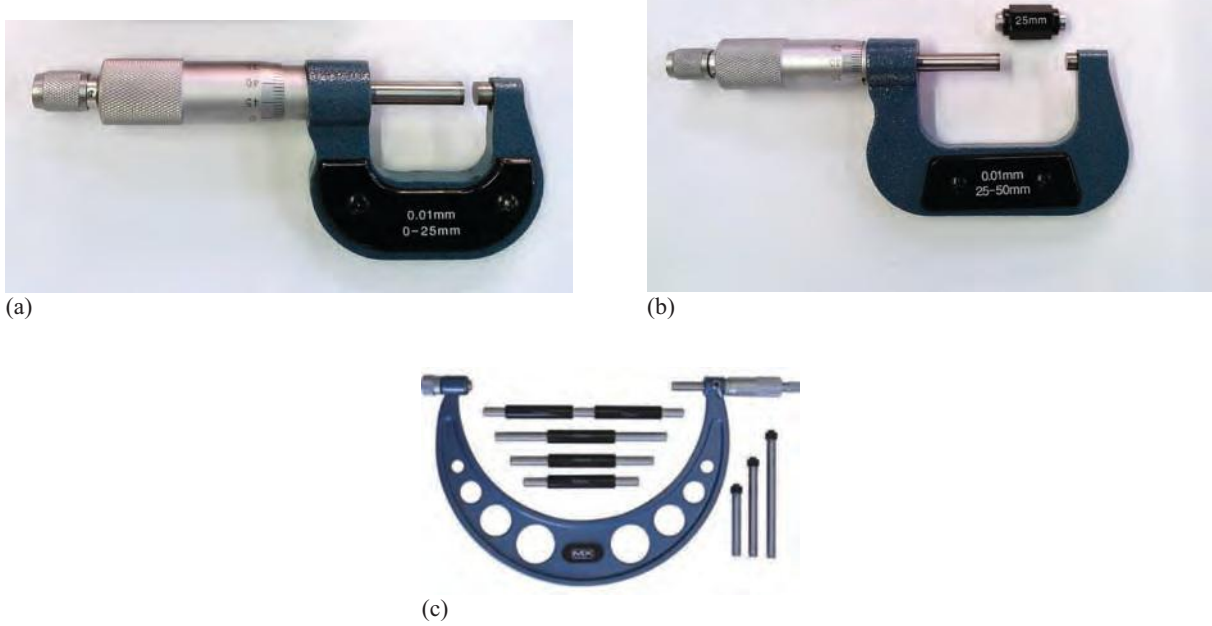
Sizes of outside micrometers

Outside micrometers are available in a variety of sizes. Three examples are shown in Figure 5.3. They are identified by their range of measurement. For example, Figure 5.3(a) is a standard 0–25 mm micrometer, Figure 5.3(b) is a 25–50 mm micrometer and is shown with the C spanner and setting bar that are required to check the device for accuracy. Figure 5.3(c) is an adjustable micrometer. It has four replaceable anvils, enabling it to measure a wide range of dimensions. Whenever the anvils are changed, the micrometer must be calibrated using setting bars for accuracy.

Handy hint: Setting bars are gauges that have been made to an accurate length.

5.2.2 Electronic digital micrometers

Most measurement instruments are available with electronic LED displays similar to the one in Figure 5.4. More accurate than standard micrometers, they can be calibrated to read metric or imperial dimensions.



(a) (b)

(c)

Figure 5.3 Three sizes of micrometers (a) 0–25 mm (b) 25–50 mm (c) 25–100 mm JUST TOOLS

Measurements are taken using the same method as for the outside micrometer. The micrometer is set to zero by a simple press of a button each time it is used.

Figure 5.4 Electronic digital micrometer with LED display in metric or imperial graduations SNAP-ON

5.3 Accuracy and care of micrometers

An outside micrometer must be checked for accuracy before use by testing for zero error. If the micrometer is not calibrated to zero prior to use, it will not provide an accurate measurement. The most common method of doing this is:

1 Hold the micrometer by the heat-resistant pad on the frame .
2 Clean the anvil and spindle surfaces with a soft cloth.
3 Using the knurled cap on the end of the thimble , rotate the thimble so the spindle moves towards the anvil. If calibrating a micrometer with a range of 25 mm and above, place the setting bar in between the anvil and spindle at this point.
4 When the spindle is in close contact with the component being measured, stop turning the thimble .
5 Turn the ratchet until the spindle and anvil are lightly in contact.
6 With the anvil and spindle closed, the 0 reading on the sleeve should align with the 0 reading on the thimble .
7 If the 0 readings do not align between the spindle and thimble , use the adjusting spanner to rotate the sleeve so that the 0 on the datum line aligns with the 0 on the thimble .

Micrometers should be handled carefully and stored correctly to preserve their accuracy. They should be kept clean and not be overtightened or strained.

Handy hint: Outside micrometers should always be left with a gap between the spindle and the anvil when not in use .

Proper care of a micrometer ensures accurate measurements. This includes the following:

1 Clean the micrometer before and after use .
2 Do not touch the measuring surfaces.
3 Store the micrometer properly .
4 Never use a micrometer as a clamp or tighten the measuring surfaces too tightly around the object being measured.
5 Do not drop the tool.
6 Always check the calibration before use .

Handy hint: If a micrometer (or any type of measuring equipment) is found to be faulty , it should be removed from service immediately and tagged for repair .

5.4 Reading micrometers

A micrometer has two scales that provide the measurement: one on the sleeve and the other on the thimble. The sleeve of an outside micrometer has the main scale marked on the datum line. (The datum line is the horizontal base line.)

The thimble has the secondary scale marked around its edge. As it is rotated, the main scale line moves, proving the reading.

5.4.1 Metric micrometer

With a metric micrometer (Figure 5.5), the main scale on the sleeve has a datum line running through its middle which shows both 1 mm and 0.5 mm divisions. The millimetre divisions are above the datum line and each fifth division is identified by the respective number. The half-millimetre divisions are below the datum line and are not numbered.

The scale marked around the thimble has fifty divisions, each representing 0.01 mm. Therefore, one full turn of the thimble represents 0.50 mm.

One full turn of the thimble moves the datum line 0.50 mm along the main scale; two full turns move it 1 mm.

Reading a metric micrometer

The main scale is read to the edge of the thimble and the thimble reading is added. The procedure is as follows:

1 From the sleeve , read the number of whole-millimetre divisions which are visible on the main scale above the datum line .
2 Add to this a half-millimetre division if one is visible on the main scale below the datum line .
3 From the thimble , note the division that coincides with the datum line and add this to the previous readings.

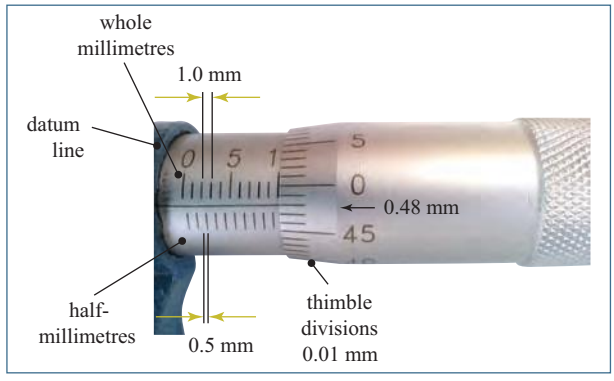


Figure 5.5 The divisions of a standard metric micrometer

Example 1

For the micrometer shown in Figure 5.5, the readings taken in order are:

9 whole millimetres = 9.00 mm
1 half-millimetre = 0.50 mm
48 thimble divisions of 0.01 = 0.48 mm
9.98 mm

Example 2

The scales of the micrometer in Figure 5.6 show the readings of:

main-scale 100 mm divisions: 10.00 mm
main-scale 0.50 mm division: 0.50 mm
thimble divisions: 0.16 mm
10.66 mm

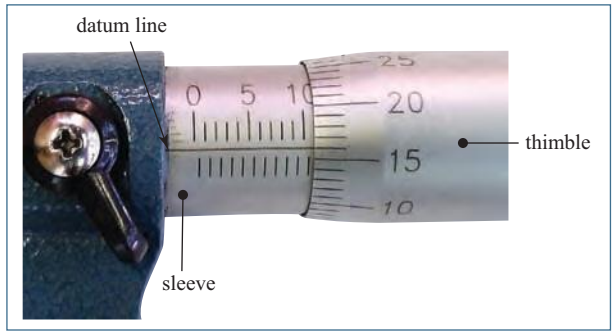


Figure 5.6 Metric micrometer scales—the reading shown is 10.66 mm

5.5 Vernier calipers

Vernier calipers are precision instruments that provide readings in steps of 0.05 mm or, in some instruments, 0.02 mm. The measuring scale on a vernier caliper consists of a graduated bar with both a fixed and a sliding jaw. The frame includes the main scale and the outside sliding jaw includes the vernier scale. The parts of a vernier caliper are shown in Figure 5.7.

The object to be measured is placed between the two jaws, and the sliding jaw carefully adjusted until both jaws are in contact with the object (Figure 5.8). The measurement can then be read directly from the scales of the instrument.

Both external and internal measurements can be taken. For internal measuring, the ends of the jaws are shaped to suit. Some calipers have scales for both external and internal measurements. The sliding jaw has a small rod which extends or retracts from the end of the frame, and this can be used to measure the depth or height of a component.

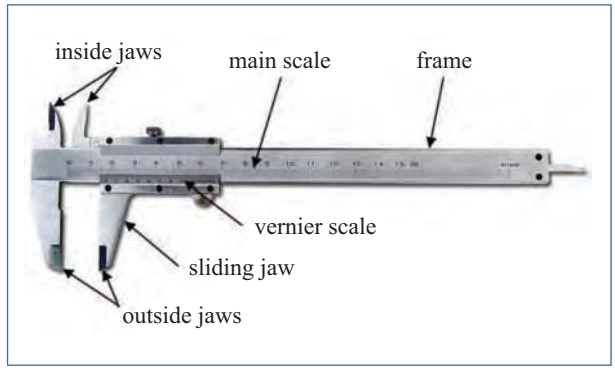


Figure 5.7 Parts of a vernier caliper SIMON A. EUGSTER

Figure 5.8 Using vernier calipers to measure the length of a valve spring

5.5.1 Reading the scales

Figure 5.9 shows the main scale that reads in whole millimetres and the vernier scale that reads in increments of 0.02 mm.

To read the measurement shown on the vernier caliper in Figure 5.9, the following steps can be applied:

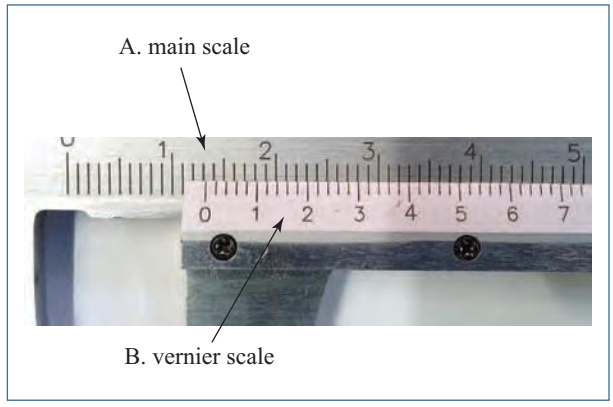


Figure 5.9 Scale of vernier A – main scale , each division is 1 mm; B – vernier scale , each division is 0.02 mm; the reading shown is 13.40 mm

1 Look at the main scale .
2 Identify the increment number that the 0 on the vernier scale has either stopped on or gone past. In this example , the 0 on the vernier scale is between 13 and 14 mm. So the reading is above 13 mm but under 14 mm.
3 Identify the vernier scale reading which will provide a reading to the nearest 0.02 of a millimetre (0.20 mm). On this vernier scale , the divisions are numbered 1 through to 10 and each division has a value of 0.02 mm.
4 Determine the value on the vernier scale by identifying a vernier graduation that lines up precisely with one of the graduations on the main scale.
5 In this example , the vernier scale is exactly lined up with the 4, which determines that it is 0.40 mm.
6 Add the 13 mm and 0 .40 mm to provide a measurement totalling 13.40 mm.
7 Therefore , the measurement shown in Figure 5.9 is 13.40 mm.

If the depth gauge function on the vernier caliper is being used, the same steps apply to obtain the measurement reading.

Example

For Figure 5.9, this is:

main-scale divisions:	13.00 mm
vernier divisions:	0.40 mm
	13.40 mm

5.5.2 Care of vernier calipers

Vernier calipers are an easy measuring device to maintain. After use, wipe the vernier caliper with a soft cloth to remove any contaminated residue. Lubricate the sliding frame to ensure that the vernier scale slides smoothly. Ensure that the locking screw on the vernier is secure and store the vernier caliper away from moisture. Most vernier calipers are supplied in a protective case, and this is an ideal storage method.

5.6 A dial gauge and its use

A dial gauge is a versatile device that can be used for checking a range of automotive systems and components. It has a face, or dial (Figure 5.10(a)), plunger and pointer. As the plunger is moved up or down, both the main and secondary dials in the face of the gauge move, displaying how far the plunger has

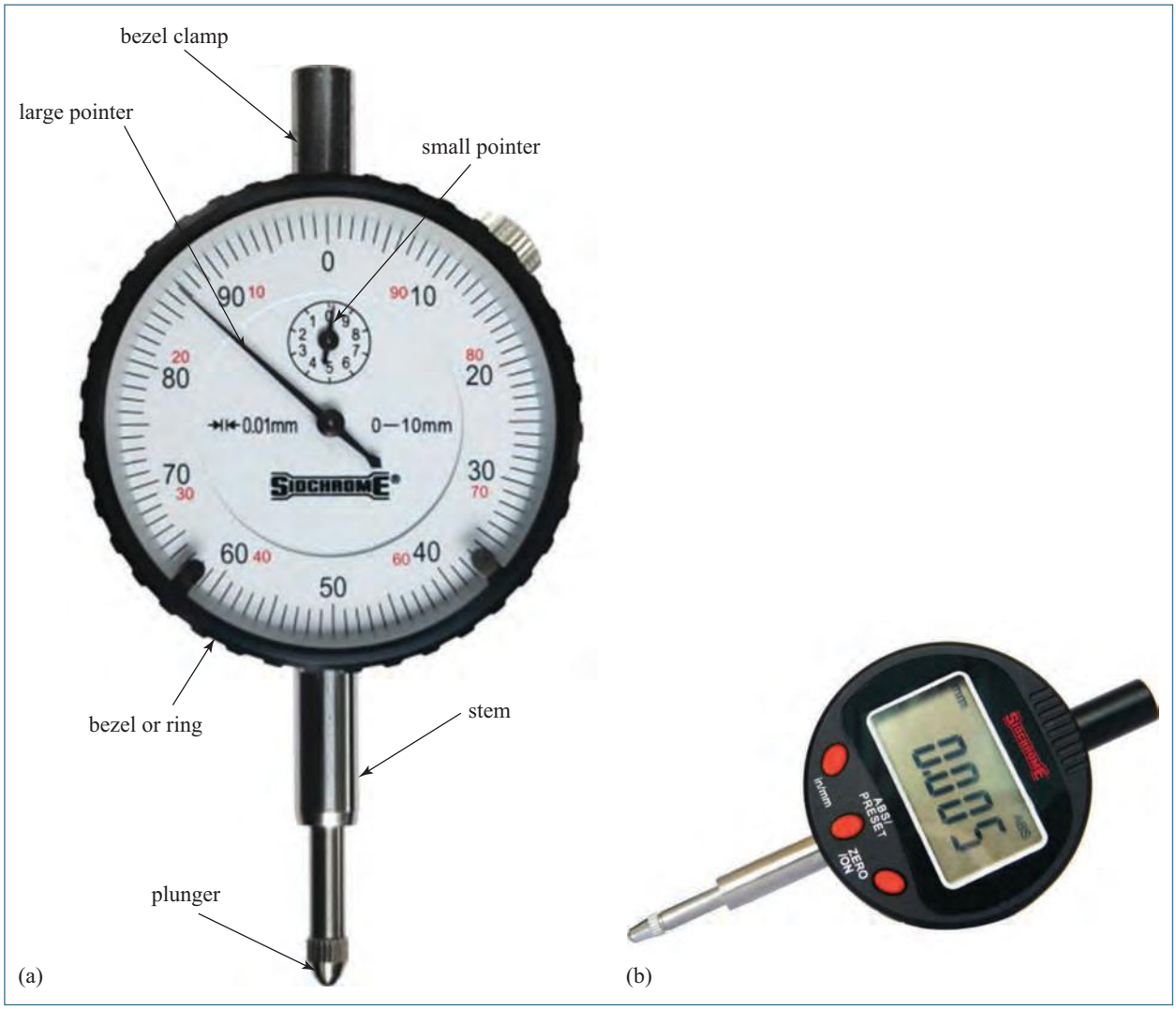


Figure 5.10 Dial gauges (a) analog (b) digital JUST TOOLS

travelled. Digital dial gauges offer the benefit of a very simple zero function and can also read in both metric and imperial units.

Gear backlash, end play in shafts, cylinder block deck clearances and runout of a rotating part can all be measured using a dial gauge. Figure 5.11 shows one being used to check flywheel runout. With the dial gauge mounted by a magnetic base, the gauge is set to zero, the flywheel rotated and the changes in gauge readings are noted.

A cylinder-bore gauge is a special arrangement of dial gauge that enables readings of the cylinder bore to be taken (Figure 5.12). The gauge is used to check both ovality and taper within the bore to determine the amount of cylinder wear. The cylinder bore dial gauge has a long extension, and movement of the plunger at the lower end of the gauge is transferred up through the extension to the dial gauge at the top. Plungers of different lengths can be fitted to suit different-sized cylinder bores.

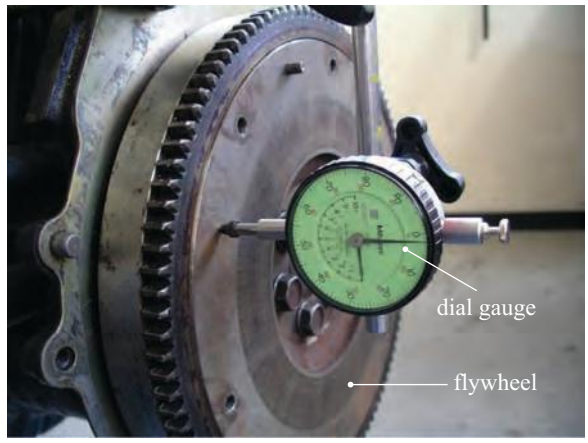


Figure 5.11 A dial gauge being used to check flywheel runout

Figure 5.12 Using a dial gauge to check cylinder bore for wear

5.6.1 Reading the scales

The dial is marked with divisions of 0.01 mm, and a pointer, operated by a plunger, is moved around it to indicate the reading. A smaller pointer on the face of the dial gauge counts the number of full rotations of the large pointer in 1 mm divisions.

The instrument is clamped or supported so that the plunger can be set against the part being checked. The bezel (ring) on the edge of the dial is then turned to set it to zero (that is, the '0' on the dial is set in line with the pointer).

A dial gauge shows variations in movement from the zero setting. These variations are transferred from the plunger to the pointer or display.

Handy hint: The pointer will show a plus reading on one side of zero and a minus reading on **the other**.

To set up and read a dial gauge, follow these steps:

1 Mount the dial gauge on the magnetic base , tool post and holding frame . Accuracy will depend on the stability with which the dial gauge is mounted.
2 Position the indicator so that the plunger is parallel to the direction of the component being measured.
3 Make adjustments to the magnetic base , post and arm so that the plunger and stem will detect any motion in the component.
4 The plunger of the dial indicator can determine movement in both directions. Move the dial gauge towards the component being measured so that it provides a reading midway within the measurement scale on the dial.
5 Calibrate the device to zero . This is done by rotating the ring on the edge of the dial face so that the '0' on the dial is set in line with the large pointer .
6 Move the component being measured and record the reading on the dial. Depending on the movement in the component, the dial gauge will record measurements in either a positive or negative direction.

5.6.2 Care of dial gauges

Dial gauges are precision instruments and it is important to maintain them correctly. After using the device, wipe it with a soft cloth to remove any contaminated residue. Lubricate the plunger to ensure that it slides smoothly. Store the dial gauge away from moisture, preferably in a protective case.

5.7 Tools for checking

There are occasions—such as carrying out a modification or fabricating a component—that require marking or measuring. The following are some commonly used tools.

5.7.1 Rules and tapes

Steel rules are usually 150 mm or 300 mm long, and are graduated in millimetres and half-millimetres. They are used for all normal workshop measurements. For longer measurements, such as obtaining the *track* or *wheelbase* of a vehicle, a steel tape is used. Its flexibility means it can measure curved surfaces or larger round objects.

5.7.2 Steel try square

A steel try square checks right angles. A try square has a stock with a blade at 90°. It is used when a line is to be scribed at right angles to the edge of the work. It is also used for checking internal and external right angles.

To check an external angle, the inside of the stock of the try square is held firmly against one finished surface, with the blade slightly clear of the work. The work is held up to the light, and the blade of the square brought slowly down to contact the surface being checked. An internal angle is checked in a similar manner with the outside of the square.

Handy hint: If the two surfaces being check ed are square , no light will show under the blade of the square .

5.7.3 Combination set

A combination set (Figure 5.13) has three separate heads, each of which can be fitted to a graduated steel blade to form a combination square, a centre square or a protractor.

1 Combination square . The square head, when fitted to the blade , can be used to mark out or check angles of 90 ° and 45 °. The head can be moved along the blade and so used as a depth gauge , with the measured depth shown directly on the blade .
2 Centre square . This head is V -shaped and, when fitted to the blade , the 'V' is bisected by the edge of the blade . To locate the centre of a round bar or disc:
   (a) place the blade flat on the end of the bar with the V -head in contact with the bar .
   (b) scribe a line along the edge of the blade (this is the diameter of the circular end).
   A second line scribed appro ximately at right angles will intersect the first line at the centre of the circle .
3 Protractor . The protractor head has a scale graduated in degrees so that the blade can be set at any angle to it. Angles can be mark ed out or check ed by using the protractor in a similar manner to a try square .

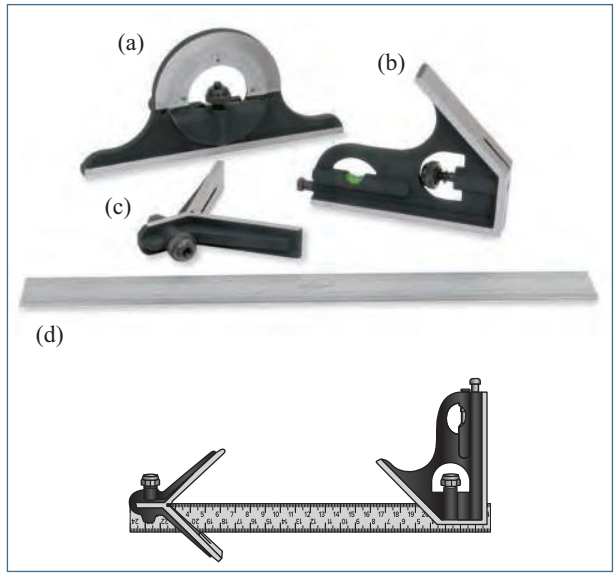


Figure 5.13 Combination set. The upper illustration shows the four components of the set (a) protractor (b) square (c) centre square (d) steel blade . The lower illustration shows the squares fitted to the blade SNAP-ON

5.7.4 Straightedge

A straightedge is used for checking the flatness of a surface. For a small surface, a steel rule or the blade of a try square may be used. The clearance between the steel rule and the component is checked to see if light can be seen under the steel ruler.

For larger surfaces, a long steel straightedge is used. This is placed on its edge and a feeler gauge used to measure any irregularities between the straightedge and the surface. Surfaces such as the face of a cylinder head are checked along their length and also diagonally in this way (Figure 5.14).

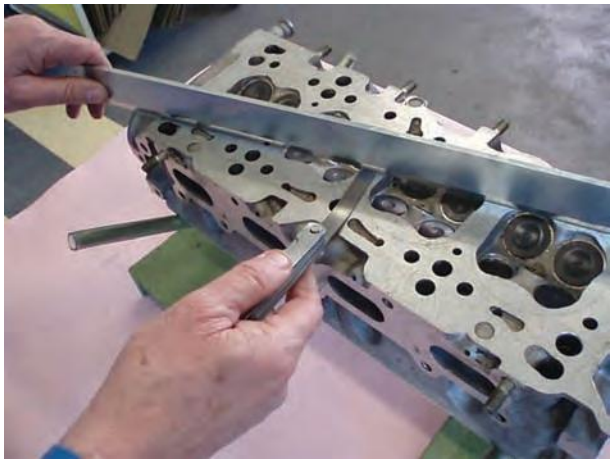


Figure 5.14 Using straightedge and feeler gauges to check the flatness of a cylinder head

Figure 5.15 Digital thermometer used to check exhaust manifold temperature

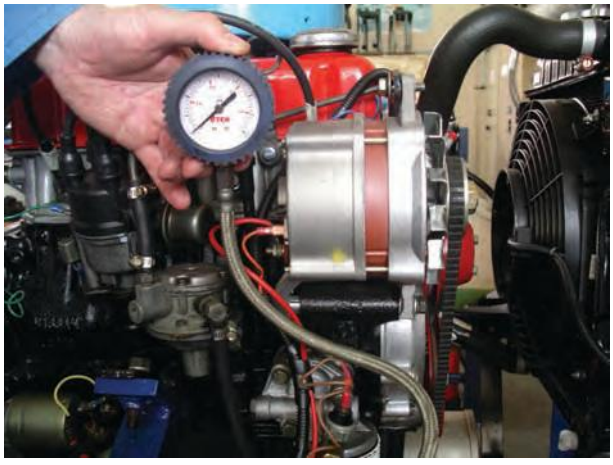


Figure 5.16 Pressure gauge connected to check the engine oil pressure SHUTTERSTOCK

Figure 5.17 Performance testing an air-conditioning system using a vacuum gauge SHUTTERSTOCK

5.7.5 Temperature measurement

Many systems and components rely on a change in temperature for their correct operation. An air-conditioning system, for example, reduces cabin temperature during operation and a shock absorber increases temperature. Degrees Celsius (°C) is the temperature scale used in the metric system.

Many other systems and components can have their operation checked using a thermometer (Figure 5.15). These include:

- cooling system thermostats
- intercoolers/heat ex changers
- tyres and wheel alignment
- transmission oil.

5.7.6 Pressure measurement

Pressure applied in vehicle systems is measured in two forms.

1 Pressures above atmospheric pressure such as oil pressure in Figure 5. 16 are measured in positive kilo pascals (+kPa). (For positive pressures, the ‘ + ’ symbol is not normally used.)
2 Pressures below atmospheric pressure such as in air-conditioning systems in (Figure 5.17) are measured in negative kilo pascals (−kPa) or mm of Hg (mercury).

Handy hint: Negative pressures are normally called a vacuum.

The pascal (Pa) is the basic unit of pressure measurement in the metric system. It is the force of 1 newton (N) applied to an area of 1 metre squared (m^2).

Therefore 1 Pa = 1 N m^2

In practice, this a very small unit of measurement and the unit pascals × 1000 (or kPa) is used.

Atmospheric pressure

Atmospheric pressure varies with altitude and temperature. Air pressure decreases above sea level and increases below sea level. Cooler air is denser than hot air and would have a higher air pressure.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- select the correct measuring device for the required task
- demonstrate the correct use of the measuring device
- demonstrate the correct way to read a range of measuring devices
- identify basic maintenance requirements for measuring equipment
- demonstrate the correct way to store measuring equipment.

REVIEW QUESTIONS

1 What is a feeler gauge and what might it be used to measure ?
2 For what purposes would a vernier caliper be used?
3 What would it mean if a micrometer had a zero error ?
4 What is the name of the section on the micrometer which shows 1.0 mm and 0.5 mm divisions ?
5 Provide three examples of the components that can be measured using an outside micrometer .
6 Explain how to correctly calibrate an electronic micrometer .
7 Provide three examples of items that can be measured using a dial gauge .
8 For what purposes are dial gauges used?
9 What is the purpose of the small pointer on a dial gauge ?
10 Which measuring instrument has a steel rod that can be used as a depth gauge ?
11 For what purposes would a try square be used within the automotive repair industry ?
12 Explain the use of a straight edge . What other measuring instrument can be used to assist with checking manufacturer specifications ?
13 How would a surface be check ed for flatness ?
14 What are vee blocks ?

CHAPTER 6

Friction and bearings

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 explain the effects of friction in relation to bearing surfaces
2 identify a range of bearing types and their applications
3 describe the correct installation and removal procedures for bearings
4 apply procedures to inspect, service and lubricate bearings.

The internal working components of a motor vehicle are complex. In systems such as engines, transmissions and differentials, metal surfaces such as shafts, gears and bearings are constantly in contact with each other. This creates friction, which results in heat and the wearing of metal surfaces. Bearings are used in mechanical components to reduce this friction and consequent wear. While all bearings have the same purpose, they differ in application and servicing requirements.

6.1 Friction

Friction is the force which opposes movement of one surface over another. It is always present, even between stationary surfaces; however, it only becomes noticeable when one surface is moved over another. Friction is affected by the type of surfaces that create it, and rough surfaces will produce more friction than smooth surfaces.

6.2 Types of friction

Friction has various functions in a motor vehicle. Bearings and gears are used to reduce its effects, whereas in the case of brakes and clutches, friction is increased to improve their efficiency. Different types of materials are used to create different levels of friction.

There are five main types of friction: static, limiting, sliding, rolling and fluid. The types that apply mostly to motor vehicle parts are sliding, rolling and fluid friction.

6.2.1 Static friction

Static friction holds things stationary. When any object is resting on a level surface, it will remain there because of static friction.

6.2.2 Limiting friction

Limiting friction is the friction between two surfaces when one is about to slide over the other. Gradually increasing the force on a surface in an effort to make it slide over another surface increases friction.

This limits (or prevents) movement. However, a point is reached when the friction can no longer prevent movement. The friction at this point is the limiting friction.

6.2.3 Sliding friction

Sliding friction is the resistance to movement that occurs when one surface is sliding on another. Sliding friction is slightly less powerful than limiting friction as less force is required to keep an object sliding than it is to start it. Sliding friction occurs when a shaft rotates in a plain bearing, or wherever one vehicle component slides in relation to another.

6.2.4 Rolling friction

Rolling friction is where surfaces are separated by balls or rollers. In these cases, they do not slide but roll on each other. Rolling friction is less dominant than sliding friction. In the context of motor vehicles, it applies to ball and roller bearings.

Handy hint: Ball and roller bearings are used to reduce friction, and for this reason are often referred to as being in the antifriction bearings category .

6.2.5 Fluid friction

Fluids also have friction, but this is less than the other types of friction previously mentioned. This is because, if two sliding surfaces are separated by a film of oil, friction will be greatly reduced; but there will be some. This friction is not caused by the surfaces being in contact but by the oil between them.

Handy hint: A fluid can be a liquid or a gas, but liquids have much greater friction than gases.

6.3 Using friction

Brakes use composite brake pads or linings, which are forced against cast-iron discs or drums. The composition material and cast iron operating together have a high *coefficient of friction,* and this is required for brake materials.

Brake lining and pad material is often referred to as *friction material* because of its high-friction properties.

The composite material and cast iron can both withstand the effects of the heat generated by friction when the brakes are applied. Tyre operation depends on the friction between the rubber tread and the road surface. The term *traction* represents the effect of friction when the wheels are driving; *adhesion* is the friction effect when the vehicle is cornering.

6.3.1 Coefficient of friction

The condition, material and force applied to a surface will affect the amount of friction generated. The coefficient of friction is a way of measuring the friction of two materials in contact. Different types of materials require a greater force to move than others. Therefore, they will have different coefficient ratings. An example of how these types of ratings apply to friction within a motor vehicle is shown in Figure 6.1 which compares the operation of brakes that produce high a coefficient value (0.3) with a lubricated plain bearing (0.01) and a roller bearing (0.001) that produces a low coefficient value.

Handy hint: An easy way to understand the coefficient of friction is simply to think of it as a way of measuring the friction between two surfaces. The greater the friction, the higher the coefficient.

6.4 Bearings

Bearings are used in many parts of a motor vehicle. Some are required to carry only a light load and therefore only need minimal lubrication. Where loads are heavy and constant, bearings are much more important and their lubrication critical.

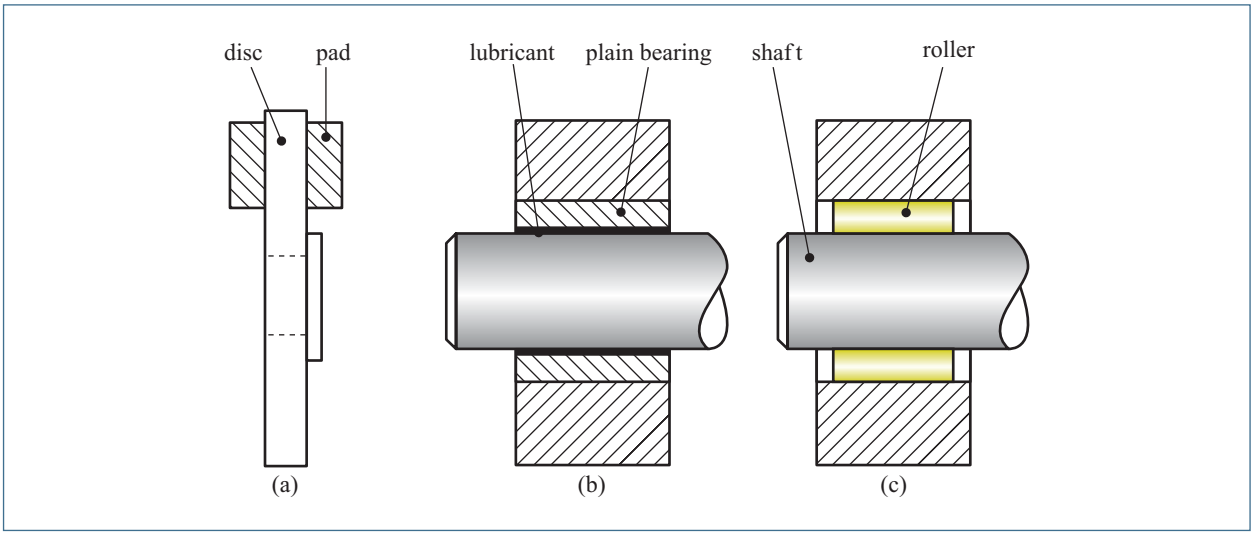


Figure 6.1 Locations with different coefficients of friction (a) brake disc and pads (b) lubricated plain bearing (c) roller bearing

6.4.1 General types of bearings

Bearings can be divided into two types: plain bearings, where the shaft runs directly on the bearing surface, and antifriction bearings, which have balls or rollers as part of the bearing. Although all bearings have some friction, it is reduced by the balls and rollers and, in the case of plain bearings, by special antifriction metals.

6.4.2 Application of friction to bearings

Understanding friction and how it applies to bearings is helpful when diagnosing faults. A plain bearing is a simple type of bearing and has no rolling components. It is subjected to sliding friction, where its surface slides over a shaft. This friction is reduced by lubrication. When the shaft is stationary in the bearing, or under heavy load, oil is squeezed out, and wear is caused by friction.

Ball and roller bearings have much less friction than plain bearings. However, when a ball or roller moves across the bearing surface, it is likely to form a groove, which increases rolling resistance. With a ball or roller bearing, rolling resistance tends to occur with both the inner and outer race surfaces and, though it may be minimal, a cold-flow of the metal surface results. This causes the races within the bearing to become deformed under load and produce excessive friction. Normally, this deformation is very small. However, if the bearing is excessively loaded, it can cause damage to the hardened surfaces and pitting will result, with subsequent bearing failure.

6.4.3 Bearing loading

Depending on the application, bearings are required to withstand certain loads. There are three types of loads (Figure 6.2).

1 Radial load. The load is applied at right angles to the shaft and the bearing carries the load along its radius.
2 Thrust load. The load is applied lengthwise to the shaft, and the bearing accepts this as a side thrust.
3 Combination load. This is a combined radial and thrust load, and certain bearings are designed to produce this. Many bearings designed for radial loads will also accept light thrust loads. This applies to most ball bearings.

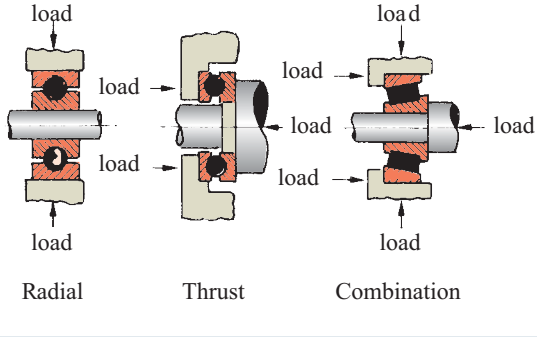


Figure 6.2 Three types of loads can be applied to bearings

6.5 Plain bearings

A plain bearing can simply be a hole drilled in a casting or component. This type of bearing is usually restricted to pins or shafts that have limited movement or rotate at slow speed. A smear of oil or grease may be the only lubrication required to lubricate a plain bearing.

Plain bearings are also used in components where a shaft is rotating at high speeds. In the case of the engine camshaft and bearings, both bearing and shaft are provided with pressurised lubrication.

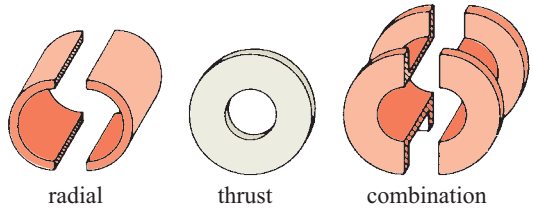


Figure 6.3 Plain bearings can be designed to carry both radial and thrust loads—thrust washers are a form of bearing that tak e thrusts

6.5.1 Sleeve bearings and bushes

Sleeve bearings are plain bearings in the form of a sleeve, which is pressed into holes bored into castings or other parts. Some sleeve bearings consist of a steel tubular backing with an antifriction metal lining. Camshaft bearings for overhead-valve engines are sleeve bearings that fit into bores machined into the cylinder block.

For other applications, such as pins and smaller shafts, bronze or nylon bushes are used. These types of bushes are called ‘sleeves’ and are used as bearings.

Moulded rubber or polyurethane bushes are used in suspension components. They move in relation to the body or wheel hub.

6.5.2 Split-sleeve bearings

Split-sleeve bearings are plain bearings that are made in two halves (Figure 6.3). They can also be referred to as bearing shells or bearing inserts.

Normally, split-sleeve bearings will only accept radial loads; however, when constructed with flanges, they will also accept thrust loads. Figure 6.3 also shows a thrust washer. Also a type of bearing, it takes thrust loads only. Thrust washers are sometimes split so that they can be easily installed over a shaft.

Figure 6.4 shows part of an engine crankshaft and one of its bearings. This bearing will accept both radial and thrust loads. Crankshaft and connecting-rod bearings are of a split-sleeve design. Due to the shape of the crankshaft, the bearings must be made in two pieces to enable them to be installed on the crankshaft journals.

6.5.3 Antifriction metal

Steel-backed bearings are lined with soft metal, which is referred to as *antifriction metal*. The steel backing provides rigidity and the lining provides the bearing surface. The antifriction metal is an alloy mixture which may contain lead, tin, copper or aluminium. Engine bearings can have three thin layers of bearing metal on a steel backing.

Handy hint: Bearings with antifriction metals must be well lubricated, which is why engine bearings receive a constant supply of oil from the lubricating system.

6.6 Antifriction bearings

Antifriction bearings include ball and roller bearings of various designs. As previously indicated, friction is greatly reduced due to the rolling action of the balls or rollers within a bearing. Steel balls have *point* (or *spot*) *contact* with the surfaces of the bearing, and rollers have *line contact* (Figure 6.5).

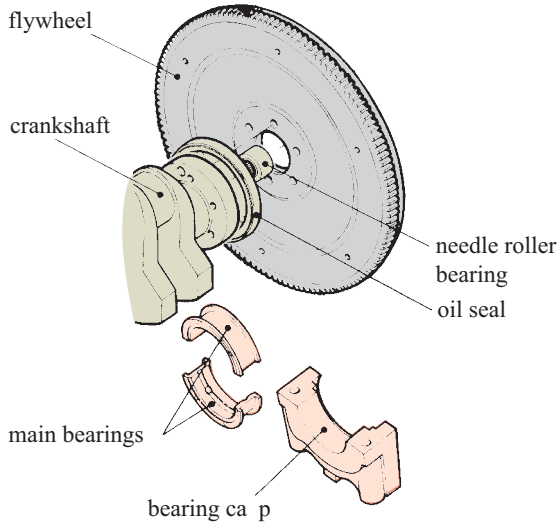


Figure 6.4 Rear end of a crankshaft showing a main bearing, oil seal and needle roller bearing

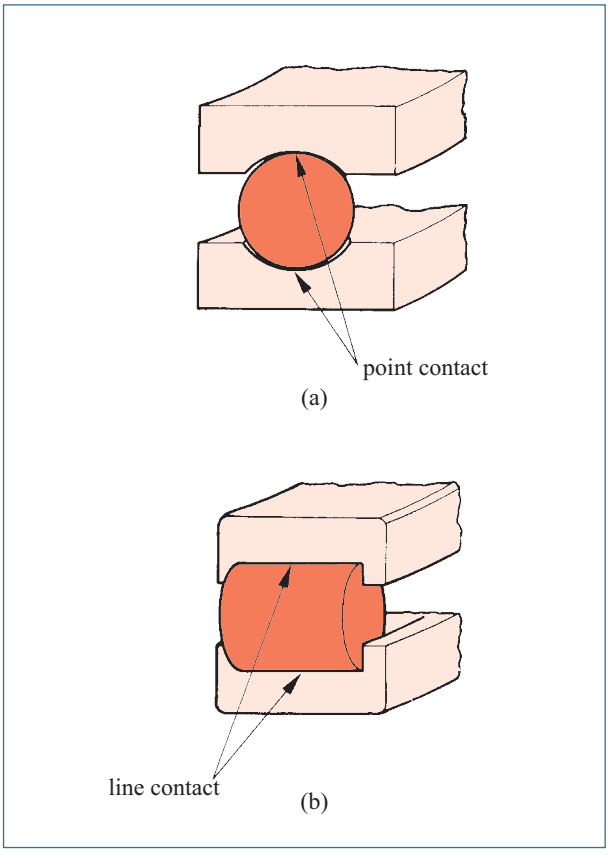


Figure 6.5 Ball and roller bearings (a) point contact of a ball bearing (b) line contact of a roller bearing

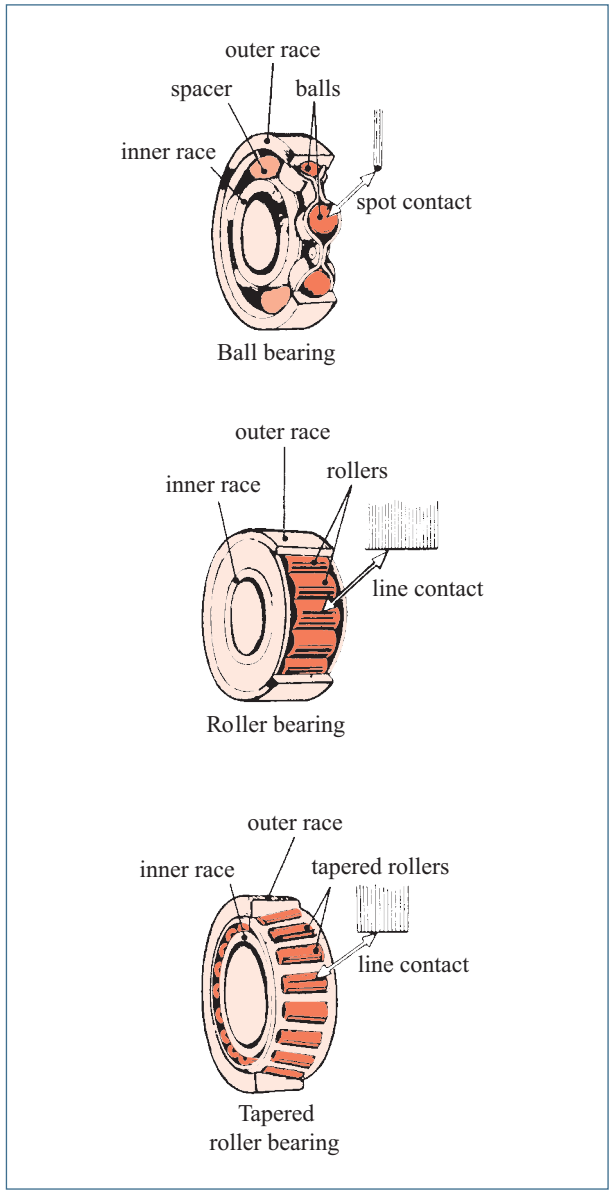


Figure 6.6 Three common types of antifriction bearings

As a result, roller bearings produce higher levels of friction than ball bearings. However, roller bearings are able to carry a greater load than ball bearings.

Three basic designs of antifriction bearings are shown in Figure 6.6. These are ball bearings, roller bearings and tapered roller bearings. There are a number of variations to these.

6.6.1 Ball bearings

The ball bearing in Figure 6.6 is a single-row ball bearing, which can also be referred to as a ballrace or annular bearing. It consists of an inner and an outer race with grooves or tracks in which the balls roll. The balls are held in place by a cage or retainer, which spaces them evenly around the bearing inner and outer race. This type of bearing cannot be dismantled and is not adjustable. It will carry radial loads and light thrust loads.

This is one of the most commonly used types of antifriction bearings.

Types of ball bearings

The following are common types of ball bearings (Figure 6.7).

1 Single-row ball bearing. This is similar to the ballrace , but has a circlip in its outer race . The circlip acts as a retainer to locate the bearing in its housing. Some ball bearings are designed with deep grooves. A deep groove on one side of the outer race and on the opposite side of the inner race enables the bearing to accept thrust loads in one direction.
2 Double-row ball bearing. This has two rows of balls that enable it to carry heavy radial loads. It will accept light thrust loads in either direction.
3 Thrust bearing. A ball bearing of this type will accept heavy thrust loads but cannot accept radial loads.
4 Cup-and-cone bearing. This has an inner cone and an outer cup , and the balls are separated and retained by a cage . These three parts are separate . Cup-and-cone bearings must be used in pairs and have to be

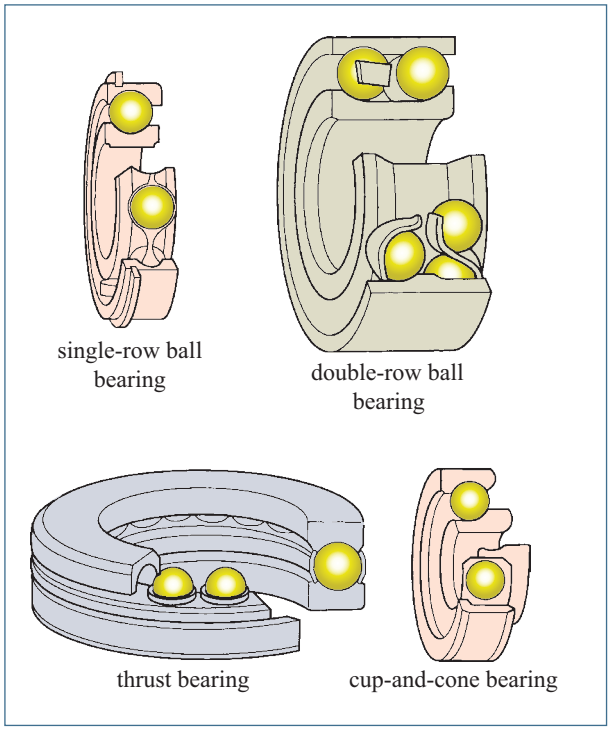


Figure 6.7 Types of ball bearings

adjusted when they are installed. A pair of these bearings will accept both radial and thrust loads. However , as tapered roller bearings can carry a greater load, they are generally used instead of cup-and-cone bearings.

6.6.2 Roller bearings

There are six main types of roller bearings, as follows:

1 Straight roller bearing. Also known as a cylindrical roller bearing or plain roller bearing, this has parallel rollers which run in grooves within the inner and outer races. The rollers are held in place by a cage . The surfaces on which they roll are referred to as raceways.

Straight roller bearings are deployed in similar locations to ball bearings. They are used to carry heavy radial loads, although some designs, with suitable flanges, will carry light thrust loads in one direction. While most bearings cannot be dismantled, some are made without flanges so that the parts can be separated.

2 Roller assembly . This consists of a number of straight rollers held in a cage . A roller assembly has no inner or outer race of its own but is fitted between a hardened shaft and the bore of a gear (or similar part). Due to the design of the roller assembly , they are only suitable for radial load applications.

3 Caged needle rollers. Small roller bearings are referred to as needle rollers or needle bearings. They can be used loose or held in some form of cage , (Figure 6.8.) Like roller assemblies, they have no races and are used between a hardened shaft and a hardened bore .

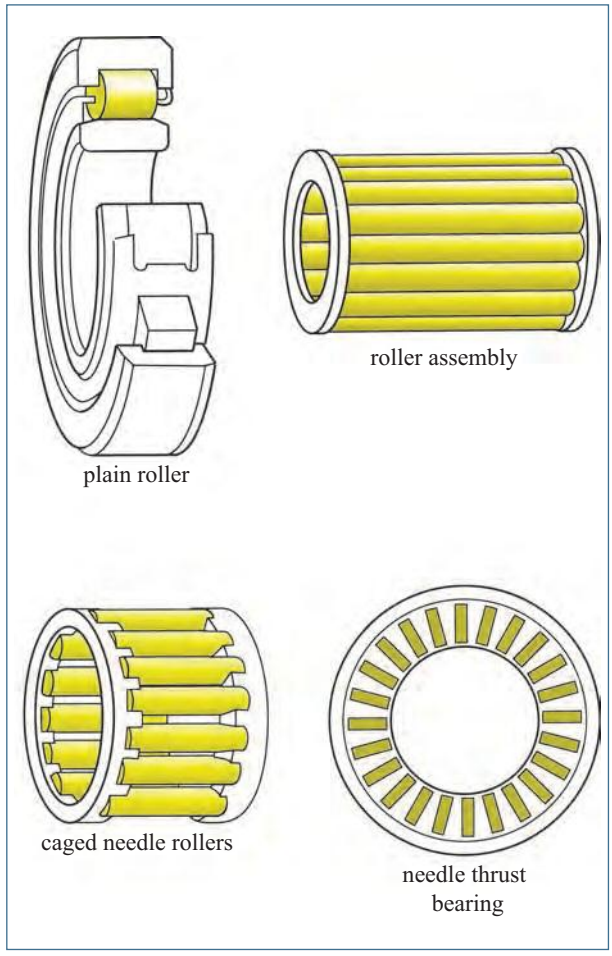


Figure 6.8 Types of roller bearings

4 Needle thrust bearing. A needle thrust bearing has its needles mounted radially in a washer-type retainer and used as a thrust washer . It can be installed on a shaft between two hardened surfaces to tak e the thrust load between parts or used with a hardened steel washer on each side .

5 Loose needle rollers. Needle rollers can be used without a retainer , as shown in Figure 6.9, where a number of rollers have been installed within the bore of a gear to provide a bearing. The rollers operate directly on a hardened shaft and thrust washers are fitted at each end of the gear to keep the needles in place .

6 Tapered roller bearings. These can be separated into two parts (Figure 6.10). The inner race , complete with the rollers and retainer , is known as the cone , and the outer race is called the cup . The cup and cone are held together when the bearing is installed and adjusted.

Some tapered roller bearings are designed to be used individually, however standard tapered roller

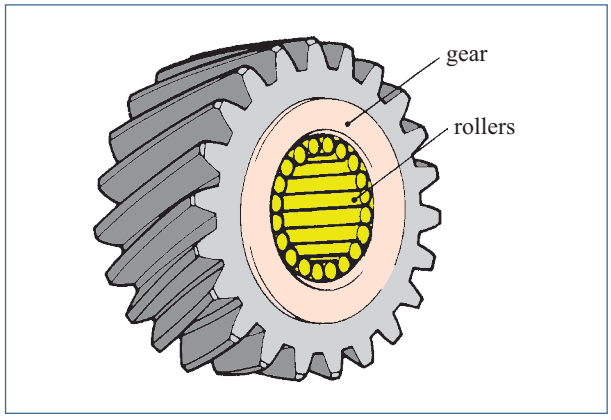


Figure 6.9 Needle rollers in the bore of a gear—the rollers run directly on the shaft and in the gear

Figure 6.10 Tapered roller bearing

bearings are used in pairs. When mounted back-to-back, they can carry heavy radial loads as well as thrust loads in both directions.

6.6.3 Bearings with shields and seals

In some applications, bearings are made with shields or seals. These arrangements are shown in Figure 6.11.

Shields can be on one or both sides of a bearing. They keep out dirt and restrict the flow of lubricant through the bearing.

Seals are used in bearings which are prepacked with lubricant. Bearings of this type are usually used in hard-to-access locations, and the seal is required to retain the lubricant for the duration of the bearing's life.

6.6.4 Clutch release bearing

The clutch release bearing, which is located inside the clutch housing, is a special thrust bearing (Figure 6.12). It is lubricated and sealed during manufacture, and its lubricant will normally last until other parts of the clutch require servicing.

6.6.5 Self-aligning ball bearings

Self-aligning ball bearings are used where alignment is difficult. They have a wide groove in the outer race, which allows the inner race and balls to tilt so that the bearing aligns itself to suit the alignment of the shaft.

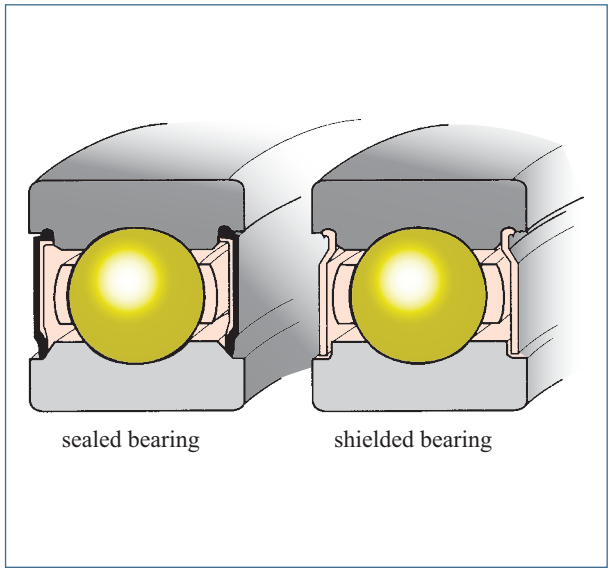


Figure 6.11 Sections through a ballrace show the seals and shields

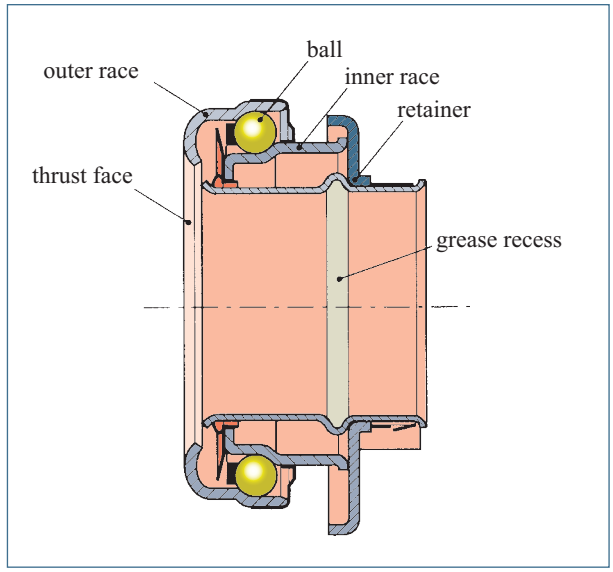


Figure 6.12 The clutch release bearing is a special thrust bearing

6.6.6 Other bearings

The composition of bearings varies according to the different purposes for which they are to be used. Steel pins may have bushes of bronze, rubber or nylon. Other bushes may be of steel with steel pins. Generally, a soft and a hard metal are used together for a plain bearing and shaft, though there are many examples of hardened steel parts working together (these need to be well lubricated).

Sintered bronze bushes are used in smaller components such as starter motors and electric motors. Powdered metal is fused together in the manufacturing process to form a very porous material which will retain oil to provide good lubrication.

6.7 Removing and installing bearings

During dismantling and repair of components, bearings must be removed from shafts and housings. Where they are fitted tightly to shafts and housings, force is required to remove them. However, any force must be applied correctly. No force should be applied through the balls or rollers of the bearing as it will break the bearing apart.

Handy hint: Force must always be applied to the inner part of a bearing when removing it from a shaft, and to the outer part of a bearing when removing it from a housing.

Many manufacturers recommend special tools for removing and replacing bearings, and these should always be used if available. Figure 6.13 shows a special puller removing a taper roller bearing from a differential carrier. These pullers apply pressure under the bearing cone, not under the retainer and rollers.

Universal puller kits are also available. These contain a range of fittings and adaptors that suit a variety of tasks. In many instances, an arbor press or a hydraulic press is used for removing and replacing bearings.

6.7.1 Using a press

To remove a bearing, the inner race is placed on metal press plates or on a pressing tool. This must adequately support the inner race on the bed of the press. The shaft is then pressed out of the bearing. The outer race should not carry any load during this operation.

The bearing can be replaced by using a piece of tube which fits over the shaft and against the inner race. The tube can also be used with a hammer to carefully drive the bearing on to the shaft.

6.7.2 Using a hammer and drift

A soft steel punch and hammer are often used to tap a bearing from a housing. A punch can also be used to remove (or replace) a bearing from a shaft (Figure 6.14).

Figure 6.13 Use of a puller that fits behind the bearing cone

Figure 6.14 A drift being used to replace a bearing on a shaft

The end of the punch should be shaped to fit against the shaft and be flat against the bearing race, as shown. Punching should be carried out alternately on opposite sides of the bearing to keep it straight, and care should be taken to prevent damage to the cage.

A mild steel punch should be used (a hard steel punch would be unsuitable). A brass punch is definitely unsuitable for bearings because brass chips can break off and become lodged in the bearing.

Safety: Whenever removing or replacing bearings, all hand and power tools must be used correctly to avoid damaging components. To reduce the risk of personal injury, the appropriate PPE should always be worn.

6.7.3 Retaining compound

A retaining compound can be applied to a bearing inner or outer race during assembly. A limited amount of retaining compound is used to prevent a bearing from moving or spinning on a shaft or within a housing. The compound does not affect the removal of a bearing and can also be used for bushes, sleeves and oil seals.

6.8 Cleaning and checking bearings

Prior to dismantling any component, thorough external cleaning should be carried out. This helps to prevent contaminants entering internal parts. The following procedure should be observed when cleaning bearings:

1. Thoroughly wash the bearings in clean solvent.
2. Hold ball bearings stationary while drying them with compressed air. Do not spin the bearing as this is dangerous and will damage it.
3. Lubricate the bearing immediately after drying with compressed air.
4. Re-check the bearing for cleanliness (they will often need a second clean).
5. Turn the bearing slowly by hand and check for any roughness or unevenness. With thrust bearings, apply pressure in the thrust direction.
6. Examine the balls or rollers and the bearing surfaces for defects. Look closely while rotating the bearing so that all surfaces are examined.
7. Sealed bearings should not be washed. Wipe the outside clean and check for roughness as previously described.
8. Never place a clean bearing on a dirty surface.
9. If a bearing is to be re-used, but not immediately, it should be lubricated and then wrapped in oiled paper or lint-free cloth. This will keep out dirt and prevent rusting. Never set a clean bearing down on a dirty surface.

Sustainability: A material safety data sheet (MSDS) should be used to gather information about the correct storage, handling and environmental requirements for all cleaning products. Failure to follow these procedures can result in personal injury and environmental damage.

6.8.1 Bearing lubrication

Bearings that are either completely or partly immersed in oil are well lubricated. Lubrication occurs as the bearing rotates and carries oil throughout the bearing surfaces. Engine bearings are supplied with oil by the lubricating system, which pumps oil to all the engine bearings and other parts that require lubrication.

It is common to pack wheel bearings with grease before they are installed. This must be done correctly to ensure they are lubricated appropriately and can go long periods without requiring new grease.

6.8.2 Packing bearings with grease

A bearing is packed by forcing grease in between the rollers, balls and races (thus it should be completely filled with grease).

This can be done by forcing grease into one side of the bearing with the palm of the hand until it comes out of the other side. Grease must be fully applied between all rollers and not just smeared around the outside of the bearing.

6.9 Bearing adjustments

Most tapered roller bearings have to be adjusted during installation. There are two types of adjustments: *screw adjustments* and *shim adjustments*.

6.9.1 Screw adjustments

The front-wheel bearings of a rear-wheel-drive vehicle are an example of bearings with a screw adjustment (Figure 6.15). The bearings are mounted back-to-back, with the cups in the wheel hub and the cones on the axle spindle.

The spindle has a locking nut which also provides bearing adjustment. When adjusting, the nut is first tightened until all free play in the bearing is removed. The locking nut is then backed off approximately one-sixth of a turn to provide the rollers with a small running clearance.

Handy hint: As the nut is being tightened, the wheel hub should be rotated so that the bearings seat correctly .

6.9.2 Shim adjustments

Adjusting shims or spacers can be fitted behind the cup or cone of a roller bearing. Shims can be selected for thickness so that the required clearance within the bearing is obtained. Adding shims will reduce clearance and provide a tighter adjustment, while removing them will increase clearance and give a looser adjustment.

Figure 6.16 shows one use of shims. Fitted between the bearing cups and the housings, they are used to adjust the differential case bearings. These are tapered roller bearings that, in this context, are usually given a preload. This is done by selecting shims of suitable thickness.

6.9.3 Unitised bearings

Unitised bearings are used for wheel bearings. The outer race, inner race and balls or rollers are designed as a unit and do not require adjustment.

Shims, selective-fit snap rings or spring-type washers are often used. However, they do not adjust the bearing itself but position it on a shaft in a housing. They can also be used to remove end-float from a shaft. Some bearings contain a groove in the outer race for a snap ring. This retains the bearing in the housing.

6.9.4 Bearing preload

Preload is an adjustment that is applied on a bearing by the installer to ensure that all bearing components are in full contact with their surfaces. This is only required where bearings are subjected to a thrust and

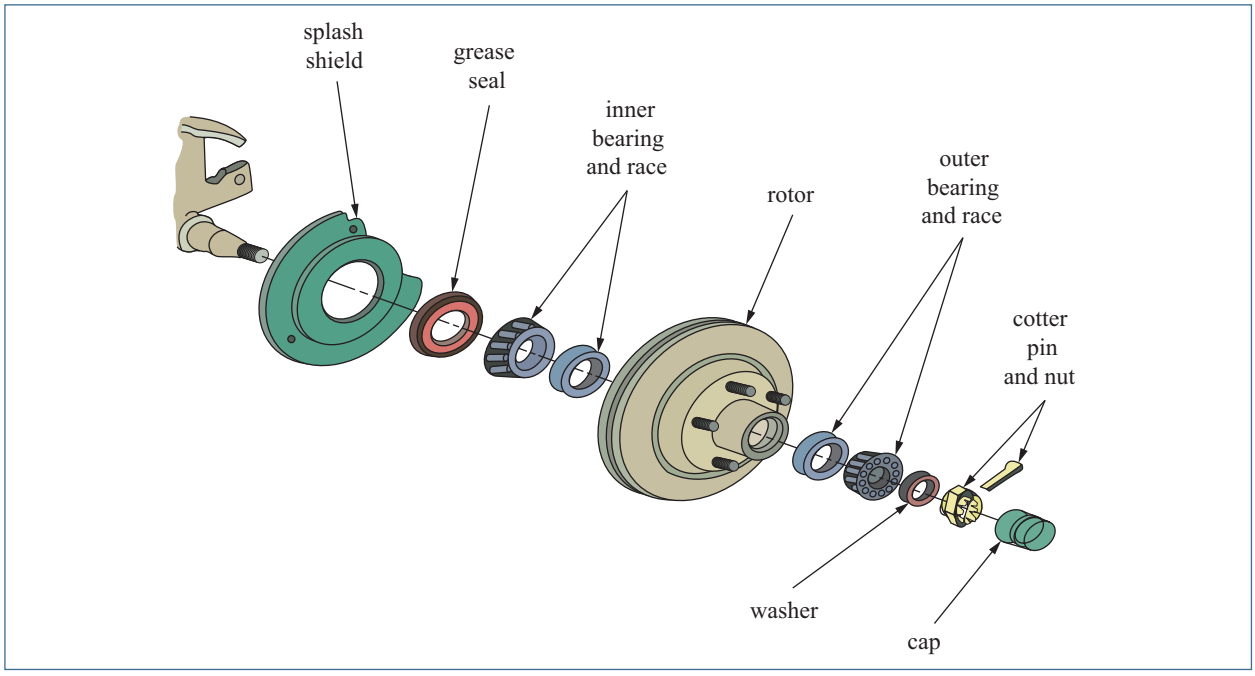


Figure 6.15 A conventional front wheel, hub and bearings for a r ear-wheel-drive vehicle

radial load. For example, the tapered roller bearings in a pinion of a differential are preloaded on assembly. Without the initial preload, this could cause one bearing to be loose and the pinion would have insufficient bearing support.

Handy hint: Some wheel bearings are tapered roller bearings, but are not preloaded.

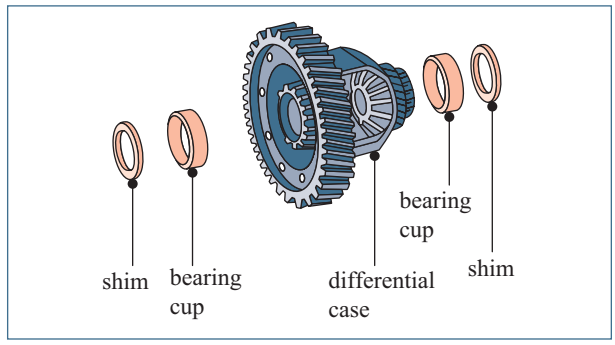


Figure 6.16 Differential case bearings with adjusting shims

6.10 Bearing failures and defects

Ball and roller bearings have a long life as long as they are not overloaded, incorrectly adjusted, poorly fitted or permitted to run without sufficient lubrication. As a bearing can be easily damaged when being removed from a shaft or housing, it is important to determine whether it actually needs to be removed. Removing a bearing to simply clean it can result in unnecessary damage.

Handy hint: Suitable bearing-removing tools are essential, and must be used properly to prevent damage .

6.10.1 Causes of bearing failure

Careful examination of bearings is necessary when seeking reasons for a bearing failure. The following are some of the causes of this.

Abrasion

Contaminants such as dirt or grit entering a bearing will damage the roller surfaces. This results in their surfaces taking on a dull (rather than polished) appearance.

Lack of lubrication

Excessive heat causes discoloration of the balls, rollers or bearing surfaces. Heat can also cause metal fatigue, which leads to metal particles contaminating the bearing. Insufficient lubrication in plain bearings will result in excessive wear; and complete bearing failure will occur if engine bearings operate without oil. Pins and bushes such as those in suspension components will seize if not correctly lubricated.

Corrosion

Water or moisture will cause corrosion. This is evidenced by pit marks or rust on the bearing. Incorrect cleaning, handling or storage procedures can result in surface corrosion, so bearings must be lubricated and stored appropriately.

Faulty fitment

A range of issues can affect the correct fitment of bearings. Common fitment faults include:

1 Incorrect interference fit between the bearing, shaft or housing . Care must be tak en to ensure that a shaft or housing diameter is compatible with the inner and outer bearing races to be fitted.
2 Shaft damage resulting in distortion of the race and consequent bearing failure . The shaft should be clean and smooth to allow the bearing to fit correctly .
3 Not ex amining all components carefully for damage and cleanliness .

Faulty adjustments

Common adjustment faults include the bearing being either too loose or too tight. Either can result in scored bearing surfaces and broken or chipped balls and rollers. When adjusting bearings, always follow manufacturers' specifications.

6.10.2 Antifriction bearing defects

A number of defects can occur in antifriction bearings. When inspecting bearings, look for signs that will identify a defect. Figure 6.17 (upper illustrations) shows the parts of roller and ball bearings that should be inspected. The following terms are used to describe bearing defects. The lower part of the figure illustrates some of these:

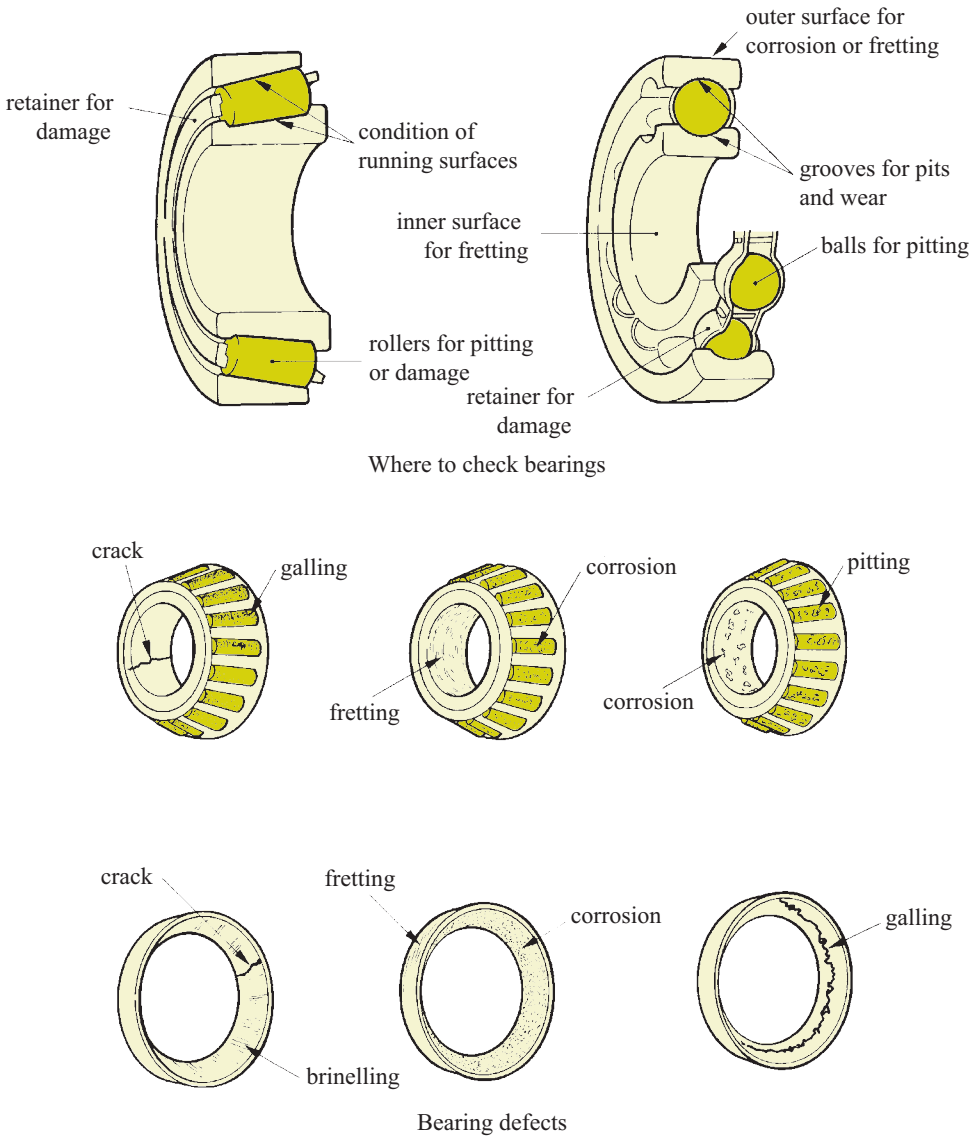


Figure 6.17 Types of bearing defects

1 Galling. Wear of the bearing surfaces with some small pitting. This is caused by poor lubricant or lack of lubrication.
2 Spalling. Badly pitted surfaces on both the inner and outer raceways, and possibly on the balls or rollers. This is due to the metal being overstressed and is known as metal fatigue . This could be caused by either overloading or a loose adjustment, which allows impacts or shock loading of the bearing surfaces.
3 Corrosion. Etch marks on any part of the bearing caused by water or moisture .
4 Pitting. Pit marks in the bearing surfaces. This could indicate an advanced state of corrosion caused by water or moisture .
5 Discolo uration . The surfaces of the bearing are discoloured by ex cessive heat. This is most lik ely due to lack of lubrication or the bearing being adjusted too tightly. Continued operation will cause galling and spalling.
6 Fretting. Rub marks on the outside of the outer race and the bore of the inner race . Marks on the outer race are caused by the bearing being loose within its housing. Rub marks on the inner race are caused by the bearing being too loose on its shaft.
7 Crack ed races. Bearing races can crack if either the shaft or housings they are fitted to are ex cessively tight on the races. Tightness such as this can also result in overheating.
8 Brinelling. This is a series of indentations or marks on the raceways. It is caused by shock loading or poor installation.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- explain that the purpose of a bearing is to assist with the reduction of friction so that components can operate efficiently and reliably
- identify excessive friction so that it does not lead to premature component failure
- understand the importance of correct bearing selection and maintenance procedures
- identify bearings, how they reduce friction and their correct application
- explain how abrasion, lack of lubrication, corrosion and faulty fitment or adjustment can cause bearing failure
- describe the process to correctly remove and install bearings using a press or a hammer and drift
- apply environmentally sustainable cleaning processes
- demonstrate how to apply correct adjustment or preload of bearings as required.

REVIEW QUESTIONS

1 Explain what is meant by friction.
2 Identify the five types of friction that apply to automotive systems.
3 Name a range of vehicle systems that use friction as an advantage.
4 Why is it important to limit the effects of friction in many vehicle components?
5 What is meant by the coefficient of friction?
6 How can friction be reduced?
7 Name the three types of loads that bearings can carry.
8 What is a plain bearing and where might it be used?
9 What type of bearing could be considered as an anti-friction bearing?
10 What are thrust bearings and where are they commonly used?
11 What are the advantages of double-row ball bearings?
12 Name four types of roller bearings.
13 What are needle roller bearings?
14 Explain why some bearings are sealed.
15 For what purpose would a self-aligning bearing be used?
16 How should a bearing be supported when pressing it from a shaft?
17 Explain how a ball bearing would be cleaned and checked.
18 Where are tapered roller bearings likely to be found?
19 Why should a bearing be subjected to bearing preload?
20 Describe briefly how you would adjust the bearings on a standard car trailer.
21 Identify a range of possible causes of bearing failure.

CHAPTER 7

Seals, gaskets and sealants

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify types of seals and gaskets and their applications
2 install and remove gaskets and seals
3 inspect and service gaskets and seals
4 use sealants and adhesives safely
5 demonstrate awareness of safety and environmental issues when working with seals and gaskets.

Seals and gaskets are commonly used in motor vehicle systems to prevent the loss of fluid, grease, gas or air. The reliability and durability of these systems is dependent on effective seals and gaskets. These ensure that all components are adequately lubricated while being protected against contaminants such as dirt and water.

Each system component may require a different seal or sealant, depending on issues such as heat, pressure, speed and the potential corrosiveness of the fluid or grease being contained.

7.1 Types of oil seals

7.1.1 Cased oil seals

Often referred to as lip-type seals, these consist of a moulded synthetic rubber seal enclosed in a metal case (Figure 7.1). The seal is made with a lip which forms a sealing edge against the shaft.

Some seals have a circular spring (sometimes called a *garter spring*) fitted behind their lip to hold it against the shaft and increase their sealing ability. Other seals do not have a spring but depend on the shape and resilience of synthetic rubber material to maintain contact between the lip of the seal and the shaft. Sometimes a double-lip seal is used.

Another type of seal has a metal casing that fits directly against the bore of a housing in which it is mounted. Others have a rubber coating over the metal which seals against the bore of a housing.

Most lip-type seals are effective at sealing in one direction only; when installed, the lip of the seal must face towards the inside of the housing. This results in any internal pressure from fluid or grease tending to

force the lip of the seal against the shaft, producing a more effective seal.

Handy hint: If a seal is installed incorrectly, its lip will lift off the shaft and the seal **will leak.**

Multi-lip oil seal

A multi-lip oil seal has three sealing lips moulded around a metal case. Each is a different shape, and the centre lip is made of Teflon™.

Multi-lipped seals are mainly used at the front and rear of the crankshaft as the Teflon™ compound within them reduces friction against the shaft.

Advanced automotive technology uses lip seals that only seal when pressure is applied to them. The purpose of this type of seal is to reduce friction and prolong the lifespan of components. These seals are mainly used in transmission, differential and axle systems.

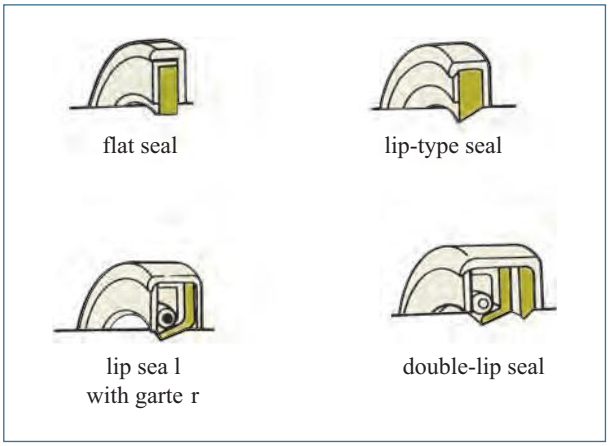


Figure 7.1 Metal-cased oil seals – the sectional views show the shapes of the seals

7.1.2 O-rings

O-rings are synthetic rubber rings that fit into grooves that have been machined in shafts and other components. When the O-ring is installed into its groove, it protrudes above the shaft. When the shaft and its mating part are assembled, the O-ring is compressed slightly, forming a seal between the two parts (see Figure 7.2). O-rings are simple and efficient. They rely on the durability of their synthetic rubber construction to maintain an effective seal.

O-rings are used in a variety of locations. In hydraulic systems, they provide a seal between a sliding shaft and a housing or between a piston and a cylinder. They can also be used instead of a gasket to seal between two mating faces: the O-ring fits into a groove in one face and, when the parts are assembled, is compressed against the mating face. This forms a seal between the two surfaces.

Figure 7.3 shows a drive unit that is used for speedometers and some sensors. It has two O-rings, each being used for a different purpose. The larger O-ring seals the housing in its mounting on the transmission; the smaller one is used as a seal between the drive shaft and the housing.

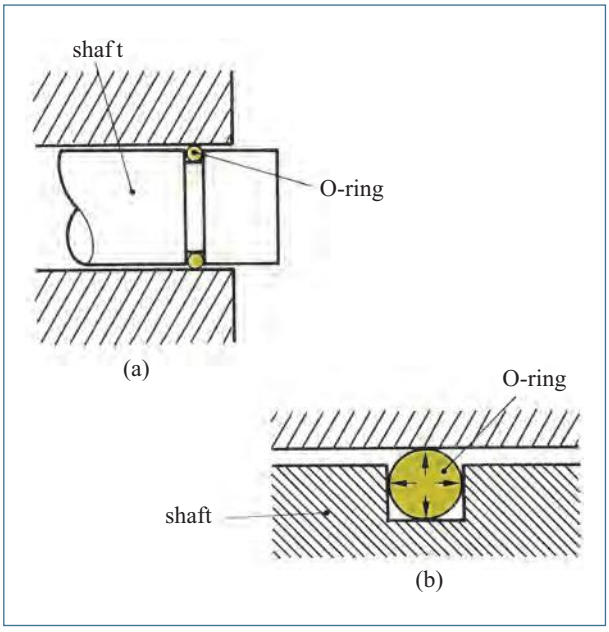


Figure 7.2 O-ring (a) installed on a shaft (b) forming a seal

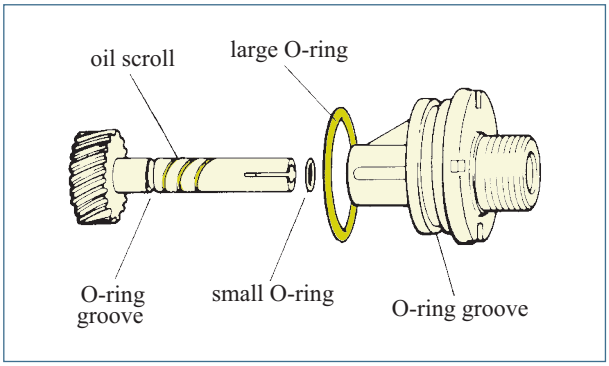


Figure 7.3 Speedometer or sensor drive with O-rings and an oil scroll MITSUBISHI

7.1.3 Sealing strips and blocks

These types of seals are made of rubber or a composition of various fibres. They are designed specifically for use at the front and rear of the crankshaft. Figure 7.4 shows where sealing strips are used on each side of the bearing cap to seal the end of the crankshaft.

7.1.4 Oil scroll

An oil scroll is a spiral groove that is machined into a shaft. The scroll is not the seal, but is used to reduce the amount of oil that reaches the main seal (see Figure 7.3).

The scroll winds in the opposite direction to shaft rotation. Oil is wound back away from the seal, reducing the saturation of oil at the seal.

7.1.5 Oil slinger

This is a dished washer that can be used on a shaft that fits through a housing. Oil reaching the slinger tends to work outward to its edge and is then thrown back away from the shaft. Oil slingers are supplementary seals whose function is to reduce the amount of oil that reaches the main seal.

7.1.6 Cup-type seals

Cup-type seals, two of which are shown in Figure 7.5, are used in the cylinders of hydraulic brake systems. The primary cup fits against the head of the piston, its lip sealing against the cylinder walls. When the brakes are applied, pressure in the cylinder forces the cup lips against the cylinder walls to form a more effective seal.

The secondary cup is made in the form of a ring which is fitted into a groove within the piston. The cup has lips on both its inner and outer edges so that it seals against both the piston and the walls of the cylinder.

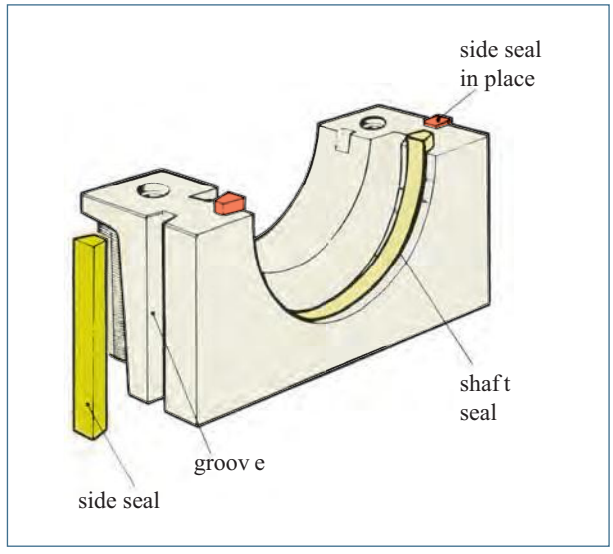


Figure 7.4 Seals in a main bearing cap at the rear of a crankshaft

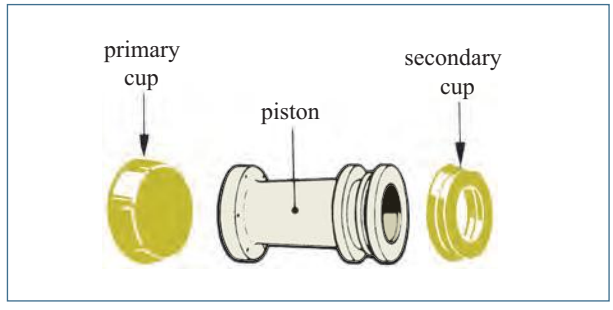


Figure 7.5 Seals used with a hydraulic brak e piston

7.1.7 Boots

Boots are fitted to various steering, suspension, drive shaft and hydraulic components. They are designed to either retain fluid or grease within the component or protect it from contaminants such as dirt or water.

Two different types of boots are found on the steering tie rod. The telescopic boot is fitted between the end of the steering box and the tie rod. It can expand and contract to accommodate movement of the tie rod as the vehicle is being steered. The smaller boot on the ball permits joint movement while retaining grease and excluding dirt and water.

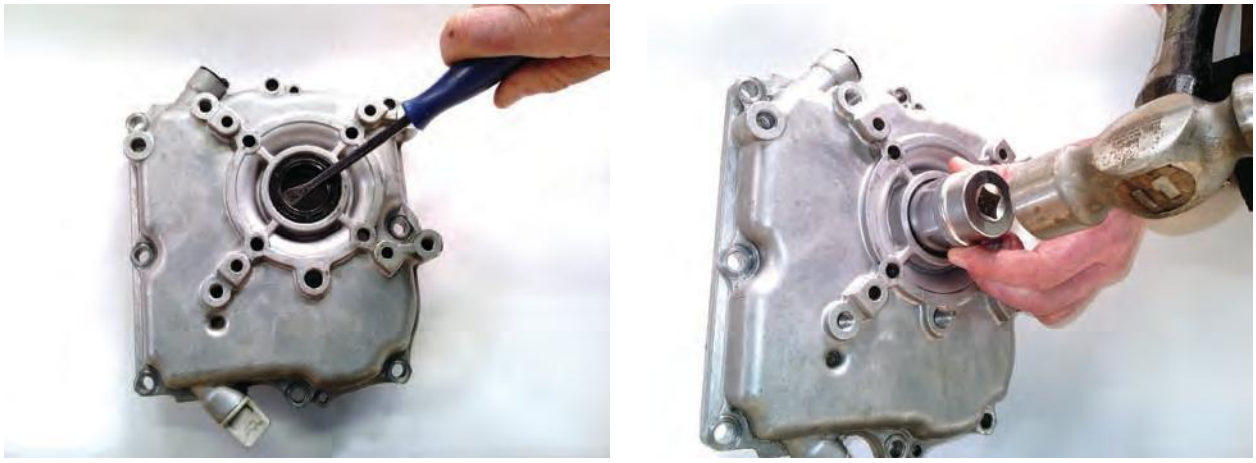
7.2 Servicing oil seals

If a seal is removed, a new one should always be installed. When fitting a seal, ensure that it is not damaged or distorted by an inappropriate installation method. For example, lip-type seals must have their lips facing in the right direction, otherwise they will leak.

7.2.1 Removing and replacing seals

Some seals, particularly those with a rubber coating on the outside, can be removed by levering them from the housing with a screwdriver or pry-bar. Care must be taken to protect the housing from damage.

Figure 7.6 shows a small seal being removed and replaced. The pry-bar is moved around the seal, levering it from the housing. The new seal is fitted into its bore within the housing. It is then tapped into place. While doing this, ensure that the seal is being pushed in squarely. Failure to do so could result in damage to the seal.



(a) (b)

Figure 7.6 A small seal in a housing (a) removal (b) replacement

Larger oil seals

In some instances, tools such as levers and slide hammers are suitable for removing seals. However, due to factors such as type, location and complexity of the seal, specific tools are often necessary. In most cases, a kit can be purchased that includes a range of seal removal and replacement tools.

7.2.2 Installing metal-cased seals

When fitting an oil seal to a housing, force must be applied to the outside metal edge. If force is applied anywhere else, it will distort the case and damage the seal. Wherever available, a special tool should be used so that force is applied to the correct section.

If such a tool is not available, a suitable piece of tubing could be used. If a drift is used, it should have a flat end and only be deployed against the outer edge of the seal. Tap the seal alternately on opposite sides while making sure that it is entering squarely.

Alternatively, an old seal can be used as a pressing or fitting tool. Being the same size as the new seal, it will apply force to the correct spot on the outer edge of the replacement.

Protecting seals

Before installing a seal over a shaft, inspect any keyways, threads or splines. Look out for sharp edges or burrs that could damage the seal during installation.

A tapered sleeve can be placed over the shaft to prevent damage to a seal while it is being fitted. Alternatively, wrap a strip of masking tape around the shaft for protection. To assist with fitment, lubricate the contact surfaces and rotate the seal or shaft as the former is being fitted.

Lubricating seals

Synthetic rubber seals and the shafts on which they operate should be coated with lubricant before being assembled. A dry seal operating on a dry shaft will damage the sealing lips. A dry oil seal can produce a loud whining noise, which indicates that the seal and shaft surfaces are insufficiently lubricated and the seal is being damaged.

With cased seals, grease should be placed behind the rubber seal as well as on the lips to provide initial lubrication.

Handy hint: Teflon ™ seals are ex ceptional in that they are usually installed dry .

Checking sealing surfaces

Before installing a seal, check the surface of the shaft against which it fits for scores and burrs. If necessary, give the surface a light polish. A new seal will not prevent a leak if the surface it is running on is damaged or worn.

7.2.3 Removing and installing O-rings

An O-ring can often be removed from its groove by squeezing it and stretching it above the groove. If the O-ring cannot be removed in this way, a small screwdriver or similar tool can be used to lift it out. This must be done carefully to avoid damaging the groove.

When installing an O-ring, lubricate the shaft and the groove where it is to be located. The O-ring can be rolled along the shaft and into the groove. Once installed, check that it is straight within the groove and not twisted. This is done by placing a small screwdriver under the O-ring and rotating it around its circumference. This will remove any twist that may be in the O-ring. Ensure that no damage is done to the surface of the O-ring during this process.

7.2.4 Hydraulic brake seals

When installing hydraulic brake seals, ensure that they are coated or dipped in hydraulic brake fluid. Other hydraulic brake parts can be lubricated with a special rubber grease (always refer to manufacturers' specifications). Brake fluid and rubber grease are the only lubricants that can be used: other oils or grease will swell the rubber, resulting in serious problems.

Safety tip: Rubber brake parts will be ruined if they become contaminated by mineral (engine) oil, grease or solvents.

7.2.5 Oil filter seals

The oil filter has a synthetic rubber ring which seals against the flat surface of the filter housing on the engine block. This is an important seal that has to withstand engine oil pressure. An undetected leak at the oil filter could empty the engine sump of oil, causing extensive engine damage.

When installing an oil filter, provide a light coat of oil or grease to the seal and tighten it firmly onto the filter housing. The correct tensioning procedure is often provided with the new filter, and the manufacturer can provide the correct specifications. After running the engine, the filter should be checked to make sure that it has been tightened correctly and that there is no oil leaking past its seal. Never overtighten an oil filter.

7.3 Gaskets

Motor vehicle systems and components are made up of a number of parts of different shapes and sizes that are bolted together. Although the surfaces of these parts are machined flat during manufacture, gaskets are required to seal the joints to prevent leaks.

Most gaskets are made from materials that are slightly compressible. This compensates for small irregularities in the surfaces and provides a seal. Gaskets come in a variety of shapes and sizes and are made from a number of different materials.

The material from which the gasket is made will depend on:

- the type of surfaces being sealed
- the pressure of the liquid or gas
- the temperature the gasket must withstand.

Compounds and sealants are also used to seal joints. Only in certain instances is it acceptable to use both a gasket and sealant together, and care should be taken to clarify what these instances are. Most modern engines and other system components use sealants rather than gaskets as they provide a more effective and efficient means of sealing components together.

Handy hint: Some compounds and sealers are designed to be used between parts without a gasket.

7.3.1 Gasket construction

Figure 7.7 shows some of the different types of gaskets covered in this section:

1 Plain gaskets. These are cut to shape from sheet materials which include special jointing papers, cork, cork composition and synthetic rubber.
2 Layered gaskets. These have a layer of composition material sandwiched between two thin sheets of steel. The metal is rolled over the holes for reinforcement.

3 Bonded gaskets. These are made of a composition material that is bonded to a perforated metal core. The holes in the gasket are often reinforced with metal ferrules.
4 Embossed steel gaskets. These are made from a single sheet of hard steel. Corrugations or beads are pressed into the steel around the holes to assist sealing.

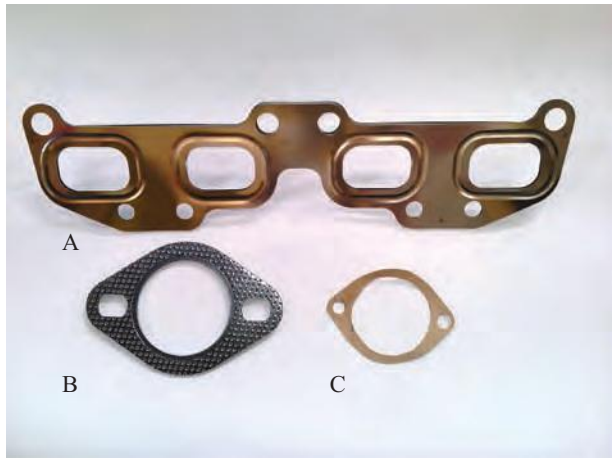


Figure 7.7 Types of gaskets A steel manifold gasket B bonded gasket C plain gasket

7.4 Gasket materials

The materials that gaskets are made from depend on the particular function they will perform.

7.4.1 Cork and cork composition

Cork gaskets are cut from sheets of granulated cork or sheets of cork and rubber composition. They compress easily and are often used on pressed-metal parts such as timing covers and engine sumps. A thick and compressible gasket is required on these as they do not have rigid surfaces.

Handy hint: The term composition refers to a gasket material made from manufactured fibres, graphite and other bonding materials.

7.4.2 Special jointing materials

Gaskets containing special papers and jointing materials are used in multiple locations to seal water, fuel or oil. Water pumps, some fuel pumps, transmissions and rear axles use these types of gaskets. Various thicknesses are available, and some of these gaskets are more compressible than others.

7.4.3 Fibre and nylon

These materials are used mainly as washers under plugs, bolts or nuts to prevent oil leaks. The material can be slightly compressed and is strong enough to allow the plug to be tightened without damaging the washer.

7.4.4 Synthetic rubbers

Synthetic rubber is made up of a range of different compounds. It is very compressible and resilient and can be moulded to form O-rings, circular seals and gaskets of various shapes. Most synthetic rubbers are resistant to both oil and water. The valve cover shown in Figure 7.8 has a moulded synthetic rubber gasket which fits into the recess of the plastic cover.

7.4.5 Steel core and composition

Often used for cylinder heads and manifolds, these consist of a perforated steel core with a special composition material bonded to each side. The steel core provides reinforcement and holds the composition material in place under pressure. Material of this type is resistant to oil, water, heat and corrosion.

Composition gaskets

Composition gaskets are used in locations that are subject to high temperatures. These are locations such as cylinder heads, manifolds and exhaust systems. Composition gaskets are usually made from sheet material and have a layer of composition between two outer layers of steel.

Figure 7.8 Valve cover with a moulded synthetic rubber gasket

7.4.6 Metal gaskets

Embossed metal gaskets are used for some cylinder heads and exhaust manifolds. The embossing consists of a series of beads or ridges that are stamped into the gasket metal around the cylinder bores and coolant holes. This ensures that the gasket will compress when tightened between metal surfaces and therefore provide an effective seal in these areas.

Metal gaskets are very resistant to heat and pressure. They can be a single layer, or be made of two or more layers. For example, an exhaust manifold gasket could be made of two layers of stainless steel and one thin layer of aluminium. Exhaust manifold gaskets are generally fitted with the steel layer against the cast-iron manifold and the softer aluminium layer against the aluminium cylinder head.

7.5 Handling and storing gaskets

Incorrect handling and storage of gaskets prior to fitment can result in them not being suitable for use. The following points outline some basic procedures to avoid this.

1 Store gaskets flat to prevent them from becoming twisted or damaged.
2 Gaskets are packaged with a cardboard backing for protection. Keep the package intact until the gaskets are required for use.
3 Some kits provide additional gaskets as they are often made to suit more than one model of vehicle. Ensure that the correct gaskets are used for the specific application.
4 Compare replacement gaskets with the originals to make sure that they are both the same shape and size.

7.6 Sealants and sealing compounds

There are a number of different grades of sealants or adhesive compounds that have a wide range of applications. Each sealing compound has a different adhesive effect and is not suitable for all applications. It is important to ensure that the correct sealing compound product is being used for the specific task. The following describes three different sealing compounds.

1 Thread sealants. Sealants are applied to threads to prevent fluid that is under pressure from leaking past the thread. They are commonly used on bolts that come into contact with the cooling system, such as cylinder head bolts.
2 Gasket sealants. Some gaskets can be coated with a sealant while being assembled. This fills the small spaces between the component and the gasket. Generally, the sealant is only applied to the removable component, and it helps keep the gasket in place during assembly.
3 RTV silicone sealants. Room temperature vulcanisation (RTV) silicone sealants cure or vulcanise at room temperature and can be used instead of a gasket to produce formed-in-place gaskets (Figure 7.10).

Handy hint: Parts that are assembled with sealants or sealing compounds can be dismantled with normal tools, provided the correct grade of sealant or adhesive was used during assembly.

Sustainability: Sealing and adhesive compounds require correct storage, use and disposal methods. Failure to follow the correct procedures can result in personal injury and environmental damage. To ensure that appropriate safety and environmental practices are followed, always refer to the material safety data sheet (MSDS) for the particular product.

7.7 Installing gaskets

Some important points for the installation of new gaskets are:

1 Treat gaskets with care to avoid damage; carelessness can ruin a new gasket before it is used.
2 The surfaces of the parts against which the gasket seats should be clean, with all traces of the old gasket removed. Cast-iron and aluminium alloy surfaces can be checked for flatness, and burrs can be removed by lightly draw-filing them with a smooth flat file or carefully rubbing them with fine-grade wet and dry sandpaper.
3 During installation, small gaskets can be held in place by a light coating of grease or oil. Both sides of the gasket are sometimes coated to assist with initial sealing.
4 Where a gasket is fitted between two parts, the bolts that hold the parts should be tightened gradually and evenly. A torque wrench should be used to tighten the bolts where torque specifications are provided.

Handy hint: Residue from cleaning should be completely removed before parts are assembled as foreign matter entering the engine will cause damage .

7.7.1 Housing gaskets

Flat machined surfaces such as housings often use thin gasket paper to seal fluids or grease. Alternatively, rubber gaskets are used. These offer a greater amount of compressibility when under tension. It is more common in modern vehicles to use a coating of sealing compound on mounting surfaces rather than a traditional style of gasket.

Handy hint: To prevent distortion and damage , the bolts securing a housing should be tightened **progressively in a diagonal pattern (see Figure 7.9).**

7.7.2 Engine sump gaskets

Some engine sumps and other parts are made from pressed steel. These are not as rigid as cast parts and therefore require a gasket that is thicker and more compressible than others. Cork or cork-composition gaskets are often used in these cases. Additionally, sealing compounds are used instead of a gasket to create a seal, and are referred to as *formed-in-place* gaskets.

Figure 7.10 shows sealant being applied to an oil pan. The sealant must form a continuous bead around the flange of the oil pan and be applied inside the bolt holes to prevent leaks.

A different type of gasket often used on an oil pan is made of aluminium and has a coating of silicon which acts as a seal. This gasket is used between an aluminium oil pan and the crankcase of an aluminium engine.

Handy hint: It is vitally important when applying a sealing compound or adhesive that the correct amount of sealant is used. An insufficient amount will result in an ineffective seal while an ex cessive amount of compound will result in sealant bulging out from the join. If ex cess compound breaks away from the bead when it has hardened, it can block oil galleries and result in catastrophic component failure .

7.7.3 Manifold gaskets

Intake manifold gaskets have to seal against vacuum leaks. Therefore, to ensure stability of the gasket, they are often made from composition materials.

Exhaust manifold and turbocharger gaskets are subjected to extreme heat. Therefore, they are manufactured from reinforced composition material, thin steel, laminated aluminium or a composition material between thin steel sheets.

Figure 7.9 Tightening bolts that secure a retainer to a housing—the bolts should be tightened progressively

Figure 7.10 Continuous bead of sealant being applied to an oil pan

7.8 How to make a gasket

Gaskets are readily available as spare parts. The gaskets supplied should be of the correct shape and are constructed from the correct material for the particular function they are to perform.

In instances where a gasket has to be made, the following suggestions may be helpful:

1 Select a material of the same type and thickness as the original.
2 Mark the shape of the gasket by tracing around the edges with a pencil. Scissors are then used to cut the shape and wad punches to cut the holes.
3 An alternative way of marking gasket paper is to coat the surface lightly with bearing blue and press the gasket material onto it. This will expose the shape that needs to be cut out.
4 For a casting, the gasket material can be placed on the face and a small ballpein hammer used to lightly tap around the edges and holes. This will provide an outline of the gasket, which can then be cut out with scissors.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- explain the role of gaskets and seals in automotive systems
- apply the appropriate selection of seals and sealant adhesives
- identify the results of the incorrect selection of seals and sealants
- explain the storage, handling, installation and safety and environmental considerations that apply to seals and sealing compounds.

REVIEW QUESTIONS

1 For what purposes are seals used within vehicle systems and components?
2 Name and explain how a range of oil seals function.
3 What issues can occur if an oil seal is incorrectly fitted?
4 What precautions would be taken to protect an oil seal during installation?
5 Explain the operation of an oil scroll.
6 Where are cup-type seals used?
7 What type of tools can be used to remove an oil seal?
8 Boots are fitted to various steering, suspension, hydraulic and drive shaft components. What is the main purpose of the boots fitted to these components?
9 What is a gasket?
10 Why are gaskets or sealants required in vehicle systems and components?
11 What are exhaust manifold gaskets made of and why?
12 Name some of the common types of gasket materials.
13 Manufacturers are reducing the number of gaskets in systems and components. What are they using in their place?
14 What issues may arise if excessive sealant is used when creating a gasket?
15 What precautions would be taken when tightening a part fitted with a gasket?
16 Explain the method you would use to cut a gasket.

CHAPTER 8

Fuels, fluids and lubricants

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify a range of fuels, fluids and lubricants that are used in motor vehicles
2 demonstrate how to handle lubricants, fuels and fluids according to safety and environmental requirements.

Automotive engines use a variety of fuels and fuel blends. These include petrol, diesel fuel, biodiesel, liquid petroleum gas (LPG),natural gas and ethanol. Petrol, diesel and LPG fuels are a refined product of crude oil; biodiesel is renewable and can be produced from plant oils or animal fat; natural gas is recovered from beneath the earth's surface; ethanol is a blend of petrol and other fuel that is produced by the fermentation of vegetable matter.

⚠ Safety: Incorrect handling or use of fuels, fluids and lubricants can cause serious personal injury, death or irreversible environmental damage. Always refer to a material safety data sheet (MSDS) for the correct handling, storage and disposal methods.

8.1 Crude oil and its products

Crude oil is a form of unrefined petroleum that is created from the remains of ancient plants and sea animals. Over millions of years, as this organic matter accumulated, it was covered by mud, sediment and other organic materials. Pressure and heat beneath the earth's surface converted it into crude oil or natural gas. Crude oil is extracted by drilling into the underground reservoirs that contain it. It is then transported to a refinery.

8.1.1 Products from refined crude oil

Refining crude oil includes a process called *fractionation* or *fractional distillation.* This is where the crude oil mixture is separated into parts called fractions. The fractions are determined by the temperature at which the various particles of oil transform into products such as petrol, diesel or lubricating oils. Figure 8.1 illustrates the basic process of fractional distillation and the products it produces.

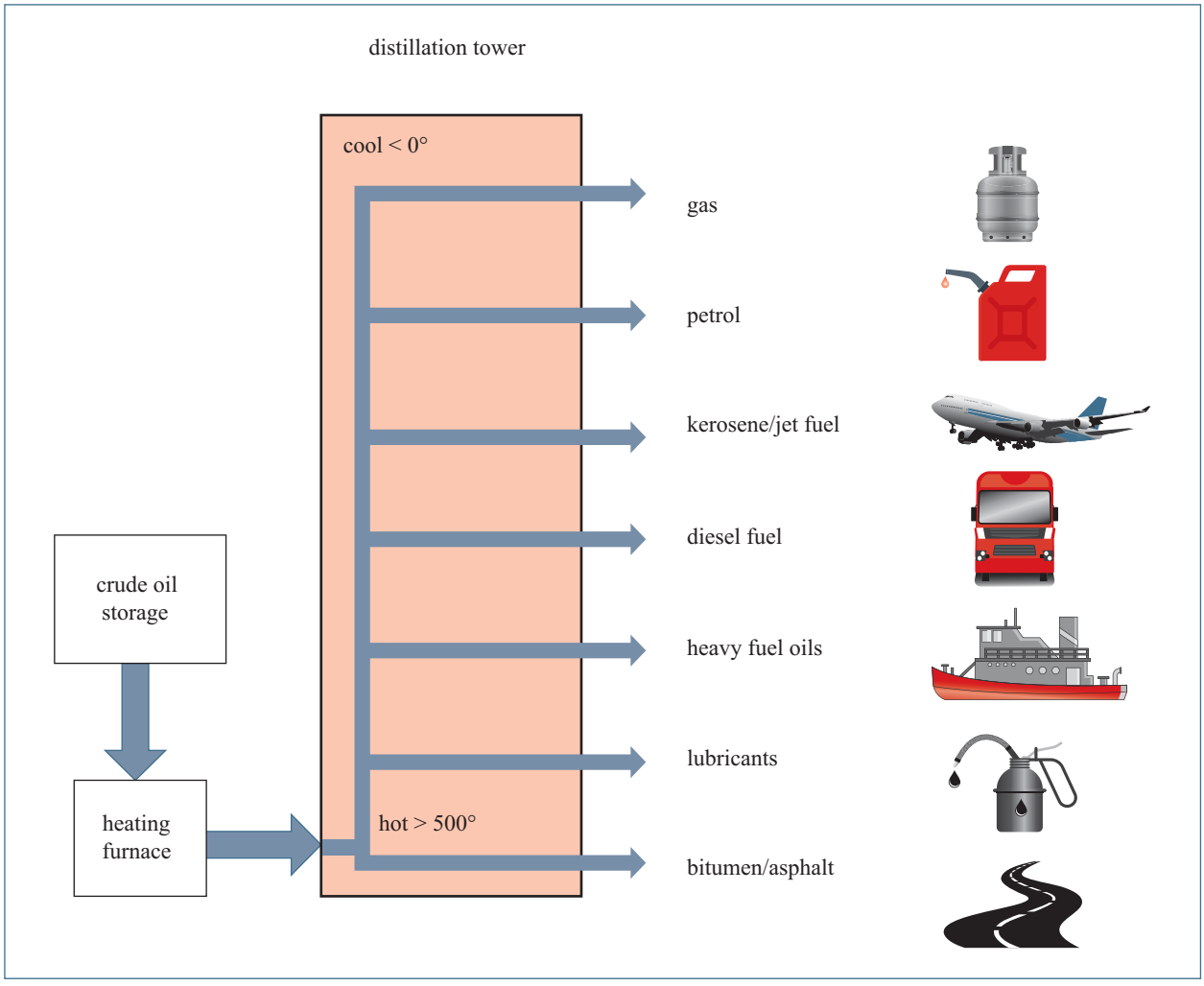


Figure 8.1 Distillation process and products

8.2 Petrol

Petrol is made up of a number of different hydrocarbons. This makes it a very volatile liquid that vaporises at a low temperature. When ignited, it generates a large amount of heat, making it an ideal fuel source for a petrol engine. Petrol is highly flammable, and extreme caution should be taken to ensure that all ignition sources are removed when handling or storing it.

Handy hint: Petrol is a complex fuel, being a blend of various lighter fractions of crude oil and chemicals and dyes.

8.2.1 Knocking

During the power stroke of an engine, the pressure in the combustion chamber should increase evenly as the air-fuel mixture burns. If it burns too rapidly, there will be a sudden increase of pressure which will cause a 'knocking' effect within the combustion chamber. This prevents the fuel from burning efficiently and, if is not rectified, the engine can be damaged.

Causes of knocking

During combustion, the spark at the spark plug starts the ignition process. A wall of flame spreads rapidly in all directions from the spark and travels throughout the compressed air–fuel mixture until the charge is burnt. This is called flame propagation.

1 Figure 8.2(a) shows the normal movement of the flame wall through the combustion chamber . During combustion, the pressure increases rapidly , but steadily .

2 Figure 8.2(b) shows the effect of the flame travelling too fast. Ex cessive pressure will build up towards the end of combustion and this will cause the last part of the charge to explode suddenly instead of being burnt. The explosion is referred to as detonation and causes knocking that can actually be heard. The sudden shock due to detonation can damage engine parts if the knocking is severe .

Knock sensors

Knock sensors are fitted to engines with electronic fuel injection as part of the engine management system. Knock sensors detect knocking and adjust the ignition and fuel systems to stop it. This results in a loss of engine power but prevents the damage caused by knocking.

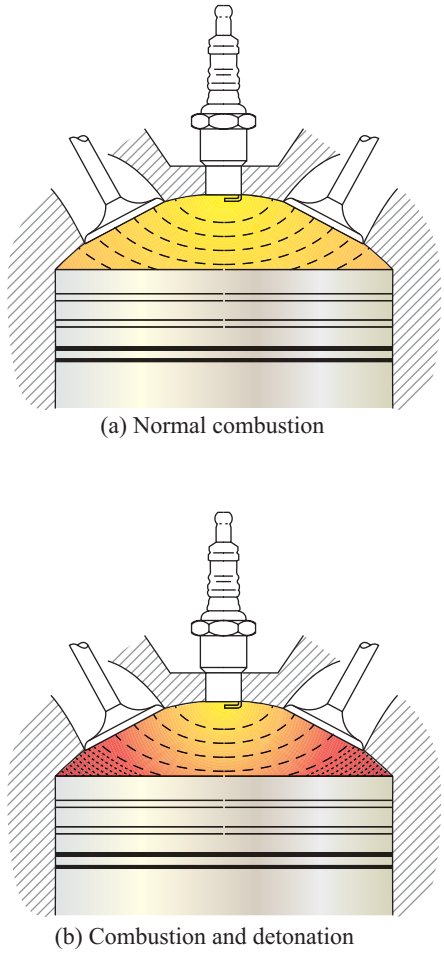
8.2.2 Octane rating of petrol

Fuels are tested to determine how they will perform in an engine and are given a *research octane number* (RON) to denote their resistance to knocking. A high-octane fuel resists knocking; a low-octane fuel knocks easily.

Handy hint: The RON (research octane number) is used for petrol sold in service stations in A ustralia.

8.2.3 Grades of petrol

Petrol is available in at least two grades: Unleaded Petrol (ULP) and Premium ULP. Some outlets provide higher grades of fuel, but the main ones are:


(a) Normal combustion

(b) Combustion and detonation

Figure 8.2 Combustion (a) normal combustion with the mixture burning evenly (b) the last part of the charge tends to explode and produce detonation

- ULP: 91 RON
- Premium: 95–98 RON
- Premium extra: 100 RON
- E10: A blend of appro ximately 10% ethanol and 90% unleaded petrol, it is appro ximately 94.5 RON .

Unleaded petrol was introduced in 1986 to help reduce harmful emissions. Additionally, catalytic converters are used in vehicle exhaust systems to remove dangerous emissions, such as carbon monoxide, nitrogen oxide and hydrocarbons.

Handy hint: Pre-1986 vehicles may need an upper cylinder lubricant when refuelling to prevent engine valve damage .

8.2.4 Petrol additives

A range of additives are used in petrol and include:

1 Oxidation inhibitors . Help prevent the formation of gum while the petrol is in storage .
2 Antirust agents . Protect the vehicle fuel system from corrosion.
3 Detergents . Clean the fuel injectors.
4 Phosphorus compounds . Reduce fouling of spark plugs.
5 Dye. Helps with the identification of fuels.
6 Octane improvers . Increase the octane rating.

The refining process is also controlled to keep sulphur compounds and gum-forming substances to a minimum. Excess sulphur compounds form sulphuric acids that can damage metal parts and bearings. Gum-forming substances could result in contamination of the fuel system and damage valves, pistons and rings.

8.2.5 Combustion of fuel

During combustion of the air–petrol mixture, water (H_2O) and carbon dioxide (CO_2) are produced. However, during combustion not all of the fuel charge burns completely, resulting in the production of carbon monoxide (CO). This is a colourless, odourless and tasteless gas that is extremely poisonous. It is a major source of air pollution and is dangerous to breathe. High exposure levels can lead to paralysis and death so engines should always be operated in a well ventilated area.

Safety: Enough carbon mono xide can be produced in a few minutes in a closed one-car garage to cause death. Never run an engine with the garage doors closed.

8.3 Ethanol

Ethanol is a renewable fuel made from a mixture of ULP, wheat, sugar cane, sugar beet and molasses. Fuels with ethanol will be marketed at the fuel pump as:

- E5. Consists of 5% ethanol and 95% ULP . This is used in some European vehicles .
- E10. Consists of 10% ethanol and 90% ULP . This is the A ustralian standard for ethanol-based fuels .
- E85. Consists of up to 85% ethanol and 15% ULP . This is not yet available at all fuel stations .

Ethanol in its pure state is alcohol. When mixed with petrol, it increases the volatility of the blend, which makes the fuel burn more efficiently, with lower emissions and an octane rating between 94.5 and 129 RON. While ethanol is comparatively environmentally friendly due to the reduction in greenhouse emissions, it is relatively expensive to produce and is generally not suitable for use in older vehicles as it can damage rubber seals and cause vapour locks in carburettor-style engines. Also, due to the cleaning effect ethanol has on the fuel system, when used for the first time it can dislodge old fuel deposits, causing filters to become blocked.

Handy hint: A list of vehicles that can operate on E5, E10 or E85 petrol can be found on the website of the Federal Chamber of A utomotive Industries at www .fcai.com.au/environment/can-my-vehicle-operate-on-ethanol-blend-petrol.

8.4 Gas fuels

The two gas fuels that are used for motor vehicles are liquefied petroleum gas (LPG) and natural gas for vehicles (NGV). Both of these gases are hydrocarbons, as is petrol, but LPG and NGV have different chemical compositions.

8.4.1 LPG

LPG consists mainly of propane and butane. It is normally a gas, but when compressed it becomes liquid. It is stored in liquid form at a pressure of approximately 750 kPa (kilopascals). Pure LPG is colourless, odourless and tasteless, so a chemical is added to give it a pungent odour. This enables its presence to be identified by smell if there is a gas leak.

Safety: The density of LPG is almost twice that of air so leaking gas will tend to flow downward and follow the ground. It could concentrate in low areas, such as work pits and drains, resulting in possible asphyxiation of personnel and an explosion.

8.4.2 Octane number of LPG

The octane requirements of LPG are defined by the *motor octane number* (MON) fuel rating method. This provides octane numbers that are different from that of the RON. Automotive LPG has a MON of approximately 92, which is comparatively higher than some ULP.

8.4.3 NGV

Natural gas vehicles (NGV) offer an alternative option to petrol-, diesel- or LPG-powered engines. Natural gas consists primarily of methane and includes the variants of compressed natural gas (CNG) or liquefied natural gas (LNG).

The natural gas is compressed into a high-pressure cylinder, but it will not change into a liquid unless it is also reduced to an extremely low temperature. This is not practical, so the gas is compressed to around

20 MPa and stored in heavy steel cylinders. In this state it is referred to as compressed natural gas, or CNG. Natural gas should not be confused with LPG.

Safety: Always keep ignition sources away from gas cylinders, gas fuel lines and components. Gas is stored under high pressure and failure to observe appropriate work practices may result in serious injury **or death. Only suitably qualified personnel are permitted to service or maintain an LPG or LNV system.**

8.5 Automotive diesel fuels

8.5.1 Diesel fuel

Diesel fuel (distillate) is made up of a mixture of hydrocarbons. The chemical composition of the fuel and the way it is refined (Figure 8.1) enhances its effectiveness. Firstly, the refining process provides the fuel with properties that ensure ease of atomisation and vaporisation when sprayed into the combustion chamber. Secondly, diesel is less volatile and provides a film of lubrication that will adhere to the injection pump and associated injector parts. Without an appropriate level of viscosity, the injection process will be less effective.

8.5.2 Biodiesel

Biodiesel contains a mixture of diesel, along with either 5% (B5) or 20% (B20) of fatty acids extracted from vegetable oils and animal fat. Biodiesel is a substitute fuel for diesel fuel, but it is not compatible with all diesel engines as viscosity ratings can vary, affecting the vaporisation of the fuel.

8.5.3 Properties of diesel fuels

The properties of fuel for diesel engines are as follows:

1. Viscosity. This must be low enough for the fuel to atomise effectively when sprayed into the combustion chamber.
2. Heat value or energy. This is higher for diesel engine fuels than for petrol.
3. Flashpoint. The temperature at which fuel starts to emit a vapour that would instantly ignite when exposed to flame or a spark. The flashpoint for diesel is approximately 55 °C; this is much higher than petrol, which vaporises at normal atmospheric temperature.
4. Self-ignition temperature. The temperature at which the atomised fuel ignites and burns without the aid of a spark. A low self-ignition temperature means that the engine will start easily and run with less diesel knock. This temperature is approximately 250 °C for diesel fuels.
5. Sulphur content. All diesel fuels contain a certain amount of sulphur. Excessive sulphur content results in excessive cylinder wear due to acid building up in the lubricating oil. To reduce exhaust emissions, environmental regulations in Australia specify that the sulphur content in diesel fuel must not exceed 10 ppm (parts per million).

Safety: Because of its high flashpoint, diesel fuel is much safer to handle and store than petrol. However, it is still classed as dangerous goods.

8.5.4 Cetane number

Diesel fuel is measured on its ignition quality and how readily it burns within the combustion chamber. This results in it having a *cetane number (CN)* rating. Diesel fuels which have a low cetane rating will result in longer delays with ignition that ultimately lead to slower combustion times, diesel knock and increased emissions. Most diesel engines function effectively on a cetane rating of approximately 45, but faster revving engines may require a fuel with a higher cetane rating.

Handy hint: The aim is to provide an engine with a fuel that delivers power as a result of good ignition qualities. So, the highest possible cetane number is not the only requirement for diesel fuel.

8.5.5 Cleanness of diesel fuel

Due to precision tolerances within fuel injection parts, system contamination from water, dust, rust or scale must be prevented. Contaminants can cause catastrophic damage to fuel injection components within a very short time. The care and maintenance of the fuel system is vitally important.

Ideally, where possible, the fuel tank of the vehicle should be kept full and not be left partly empty for long periods of time. Fuel tanks made from steel or aluminium can result in moisture condensing on the exposed metal surfaces and allowing drops of water to enter the fuel.

Handy hint: Good maintenance of the fuel system is most important, with fuel filters and water separators being regularly serviced.

8.6 Engine lubricating oil

A satisfactory lubricating oil must be able to do the following:

1 Have the correct viscosity
2 Resist o xidation
3 Avoid carbon formation
4 Prevent corrosion
5 Resist extreme pressures
6 Avoid foaming .

A number of additives are introduced into oil during the manufacturing process to give it the above properties. Mineral oils are those produced from the refining of crude oil. Other oils are synthetic oil, which is artificially made from raw materials, and semi-synthetic oil (this is a blend of refined crude oil and artificially made oil).

8.6.1 Viscosity of oil

Viscosity refers to the resistance of oil to flow. A *thick* or *heavy* oil has a high viscosity. A *thin* or *light* oil has a low viscosity. Oil can be described by two characteristics: body and fluidity.

1 Body refers to the resistance of the oil to penetration during heavy loads.
2 Fluidity is the ease with which the oil flows through oil lines and spreads over bearing surfaces.

Viscosity is affected by the temperature of the oil. It is reduced when oil is hot and increased when it is cold. An engine oil needs fluidity when it is cold while retaining its body at high engine temperatures. Oil viscosity is measured by a viscometer. This is a device that determines the time that a specified amount of oil takes to flow through a hole of a particular diameter. Temperature is taken into account during the test.

8.6.2 Oil additives

Once crude oil has been refined into lubricating oil, it is improved by supplementing it with chemical additives. These are:

- viscosity-index improvers
- pour-point depressants
- oxidation inhibitors
- corrosion and rust inhibitors
- foam inhibitors
- detergents
- dispersants
- extreme-pressure additive s.

Viscosity-index improvers

As the viscosity of oil changes with temperature, a viscosity-index scale is used. An oil with a high viscosity index will have less viscosity change with temperature than an oil with a low viscosity index. Special additives are used to improve the viscosity index of oils. Oils with viscosity-index improvers have relatively little change in viscosity between low and high temperatures.

Pour-point depressants

At low temperatures, oil could become so thick that it would not flow at all. Supplements are added to oil to reduce, or lower, the temperature at which this happens so that there is adequate engine lubrication during cold-weather starting and initial operation.

Oxidation inhibitors

As oil is heated and agitated, oxygen in the air tends to combine with the oil and oxidise it. For example, as the engine pumps oil through the oil galleries to lubricate parts, it is heated and mixes with air (aeration). As a result, some oxidisation of the oil will occur.

Oil that is oxidised breaks down to form various harmful substances, some of which can coat engine parts with an extremely sticky, tar-like material. This can clog oil channels and tend to restrict the action of piston rings and valves. Oil oxidation can also coat engine parts with a varnish-like substance. During the oil manufacturing process, chemicals known as *oxidation inhibitors* are added so that engine oils have a resistance to oxidation.

Corrosion and rust inhibitors

At high temperatures, acids can form in the oil, corroding engine parts. Engine bearings are highly susceptible to damage caused by corrosion so corrosion inhibitors are added to help prevent this. Rust inhibitors work by displacing water from metal surfaces so that oil coats them, and by causing an alkaline reaction which helps neutralise combustion acids.

Foam inhibitors

The churning action in the engine crankcase makes the engine oil foam. If this occurs, the oil will not provide normal lubrication of bearings and other moving parts. Antifoaming additives are applied to the oil.

Detergents

The combustion process leaves deposits of carbon on pistons, rings, valves and other internal parts of the engine. Some oil oxidation may take place, resulting in the formation of other contaminated deposits. To prevent this, engine oils contain a detergent additive.

The detergent loosens the deposits of carbon, gum and dirt and the oil then carries the particles of material away to the filtering system. Larger particles drop to the bottom of the crankcase while smaller particles tend to remain suspended within the oil. These impurities, or contaminants, are drained out when the oil is changed.

Dispersants

A dispersant is added to prevent the oil particles from clotting and possibly blocking oil galleries or the oil filter. As well as preventing clotting, the dispersant increases the amount of contaminants that the oil can carry. Dispersants and detergents work together. If the dispersant can keep the contaminants suspended as small particles in the oil, they will not deposit on engine parts and therefore reduce the need for detergent action.

Extreme-pressure additives

Engine components such as bearings and the valve train are subjected to very high operating pressures. To prevent the oil from being forced out of these surfaces, extreme-pressure additives are incorporated into the oil. This provides a body to the oil that resists pressure.

8.6.3 Classifications of oil

There are two different classifications of oil. One is the *SAE rating* of its viscosity; the other is a *service classification,* which is related to its performance.

SAE ratings of oil

The SAE rating of oil was developed by the Society of Automotive Engineers (SAE) in the United States. It is based on the viscosity of the oil and is generally referred to as 'grades'. Grades of oil can vary, depending on the required application. For example, an oil with an SAE grading of 20 may be suitable for use within an engine while an oil with an SAE grading of 140 would be used in a differential.

Handy hint: The SAE grade does not relate to the quality of the oil, only to its viscosity.

Multigrade oils

Many oils are rated as multigrade. This refers to oil viscosity's ability to vary under different heat conditions. Multigrade oils are labelled with two different numbers. The first is followed with the letter 'W', which specifies the characteristics (viscosity) of the oil in cold (winter) conditions. The second number identifies the viscosity of the oil and its characteristics when operating at normal engine temperatures. An example of multigrade oils suitable for modern vehicles could include SAE 10W –30 or SAE 15W –40. The viscosity

of multigrade oils needs to ensure that the characteristics of the oil allow it to flow easily when cold, but not be too thick when heated.

Handy hint: Always refer to manufacturer's specifications when selecting the correct oil for a vehicle.

Service classifications of oil

In addition to a viscosity rating, lubricating oils are also given a service classification. This is based on the type of service for which the oil is suited. Classifications developed by the American Petroleum Institute are used. These have 'S' classifications for petrol engines and 'C' classifications for diesel engines.

Oil classifications for petrol engines

Oil classification provides a rating of how well oil protects against oxidation, high-temperature deposits, sludge and corrosion. These ratings are regularly updated. An example of a rating is SN, which specifies improved performance with regards to fuel economy, protection for turbochargers, compatibility with emission control system and suitable for use in engines operating on ethanol fuels up to a rating of E85.

Classifications for diesel oils

For diesel engines, classifications commenced at CA and have progressed to CK4. These classifications are regularly updated so are subject to change. Each classification is designed for more severe service conditions than the previous one.

Combined classifications

Some lubricating oils fulfil the requirements of both petrol and diesel classifications. These are given a dual classification, such as SJ/CF.

8.6.4 Oil sampling and analysis

Sampling and analysis procedures can be conducted to monitor the lubrication system of a mechanical system and its components. Regular sampling of the oil can determine if any contaminants are forming within it, which may provide crucial information on aspects such as internal component wear and condition. As a result, if irregularities are found within sampled oil, preventative maintenance can be carried out on components to rectify faults before they cause further damage.

Sustainability: Incorrect handling, storage and disposal of waste oil will lead to severe environmental damage. Never allow any oil or liquid waste to enter landfill, a storm water drain or a waterway. Used oil is recyclable, and most waste management stations will accept limited amounts of waste oil. Larger quantities can be collected by a licenced contractor for recycling.

8.6.5 Oil consumption

An engine in good operating condition will not need additional oil in order to maintain a full oil level over a period of time or distance. However, one that is not in good operating condition may 'use' engine oil. The term 'use' means that the engine will consume oil during its operation; over time, this will reduce the amount of oil in the engine. Two reasons for the loss of engine oil are burning or leakage. Causes include:

1. High speed. At high engine speeds, more oil is thrown around in the crankcase and onto the cylinder walls. Some of this can find its way past the piston to the combustion chamber, where it is burnt.
2. High temperatures. When heated, the oil becomes thinner and is more difficult for the piston rings to control. It is easier for thinner oil to find its way down the valve guides and into the combustion chamber.
3. Worn piston rings. Worn piston rings cannot control the oil on the cylinder walls. It bypasses the piston and rings and is burnt in the combustion chamber with the fuel charge.
4. Worn bearings. Worn connecting-rod bearings have increased clearances and throw more oil than normal onto the cylinder walls. If the piston rings are also worn, this amplifies the problem.
5. Worn valve seals or guides. Worn valve seals will allow oil to pass down the valve guides. This particularly applies to intake valves, where oil is drawn into the valve port each time the valve opens. Worn valve guides will aggravate the condition. The condition of the valve seals should be checked before assuming that the piston rings and bearings are the cause of excessive oil consumption.
6. Oil leaks. Oil can leak from worn seals, faulty gaskets or loose bolts or oil filter. The engine should be cleaned and the source of the leak located.

Handy hint: Oil leaks can result in the excessive loss of engine oil. All oil leaks should be rectified before diagnosing ring, valve or bearing wear.

8.6.6 Reasons for oil changes

From the time that fresh oil is placed into the engine crankcase, it gradually loses its effectiveness as a lubricant. This is due to the accumulation of various substances and the diminishing effectiveness of the additives. Gum, acids and lacquer-like substances are by-products of combustion, and can also be produced as a result of high engine temperatures. In addition, the air that enters the engine can carry a certain amount of dust. There are also fine particles of metal released from the engine parts as they wear.

As the engine operates, the oil accumulates more and more of these contaminants. After many kilometres of operation, the oil will have deteriorated to the extent that it needs to be drained and replaced. General recommendations are that oil should be changed every 15 000 km or every six months, whichever occurs first. Some newer vehicles have extended service intervals, so it is important to follow manufacturer specifications.

More frequent oil changes

Oil that is subjected to severe operating conditions will require replacement at more regular intervals. Such conditions might include:

1. Short trips. Where the engine does not reach normal operating temperature before it is turned off, allowed to cool down and then restarted and driven again for a short period of time
2. High-speed engine operation (revolutions). Where oil is subjected to higher temperatures
3. Heavy-load operation. Where the engine is subjected to increased load conditions such as a vehicle carrying or towing a heavy load.

8.6.7 Effects of incorrect oil

Problems can occur if the incorrect oil is used. In some cases, the rating of the oil is critical as some engines require a specific grade, otherwise they will not run or will intermittently cut out when reaching operating temperature. Other effects of using incorrect engine oil are excessive oil consumption, increased fuel consumption and damage to internal engine parts.

If engine oil is not renewed as part of a regular service schedule, the additives within it will become less effective. Oxidation of the oil will occur from contact with the air in the crankcase, and contamination will result from the combustion cycle.

8.7 Grease

Grease is a semisolid lubricant that is used in bearings, ball joints and in various components where oil is not suitable. Grease consists of two parts: the lubricant, which is the oil, and the base (or holder or soap), which carries the oil. The base is made from a compound such as sodium, calcium, lithium, aluminium or zinc mixed with animal or vegetable fat.

8.7.1 How grease lubricates

Grease is an important lubricant and must stay in contact with moving or rotating parts without seeping out as a result of weight or centrifugal force. It must also withstand high operating temperatures and extended service intervals.

The structure of grease varies, and different greases are used in different applications. A light grease is almost in liquid form and has a low-viscosity oil rating base content. This enables it to find its way into very small clearances. A heavy grease will contain an oil of higher viscosity, and its thicker base would make it suitable for slower moving parts with more clearance between the operating surfaces.

8.7.2 Properties of grease

Grease has the following properties:

1. Consistency. This is similar property to viscosity. It is a measure of the 'thickness' of solid and semisolid petroleum products.
2. Melting point. Grease softens when heated, and when it reaches its melting point it becomes a liquid.
3. Drop point. This is the temperature at which the first drop separates from a mass of grease when it is heated. The drop point of a grease is used by manufacturers to measure the effect of heat.

Consistency and temperature

Ensuring that grease has the correct consistency is vital. Using the wrong type or grade of grease can result in damage to components. If a grease that is too thin in its consistency is used, it will easily discharge from bearings and leak past oil seals. If a grease that is too thick is used in a bearing, it will *channel* between the bearing rollers. Channelling is a result of thick grease building up between the rollers and not having the required viscosity to move throughout the bearing and lubricate the bearing rollers, cup and cone. If channelling is not rectified, the bearing surfaces will not be sufficiently lubricated, which may result in bearing failure.

The selection of an appropriate grease should be based on its uniformity, which means how it can withstand issues such as thinning out at the temperatures likely to be encountered. High-melting-point greases have special additives and bases and will lubricate bearings up to 200°C.

Handy hint: The National Lubricating Grease Institute (NLGI) designates the consistency of grease with an NLGI number ranging from NLGI 000 as the thinnest grease to NLGI 6 as the thickest.

8.7.3 Multipurpose and other greases

Advances in technology are resulting in vehicle manufacturers reducing some aspects of vehicle maintenance requirements. This has brought about the development of a single-use grease that can be used across a variety of applications.

Lithium-based grease is a multipurpose product that has a high melting point and a high resistance to water. Most ball joints in cars and light commercial vehicles are factory sealed with grease, making further application of grease impossible. In some instances, steering and suspension ball joints can be greased as part of a scheduled service on items such as trucks and heavy machinery. Molybdenum disulphide is used as an additive to the grease to help it maintain its quality between the extended service intervals.

In instances where water ingress of a component is likely, water-repellent greases are made with a lime base, and water-soluble greases are made with a soda base. Table 8.1 shows some types of greases, along with other lubricants and their uses.

8.8 Transmission oils

Transmission oils (gear oils) are used in manual transmissions and final drives. They have to be able to effectively lubricate all parts while maintaining consistency and not being easily discharged from between the gear teeth. (If the oil is easily squeezed out from between gears, bearings or teeth, it may not lubricate the metal surfaces as required.)

Hypoid final drives require extreme pressure lubricants because the teeth of the crown wheel and pinion are subjected to heavy loadings. Limited-slip differentials also require specific oil types as they will not operate efficiently if the wrong grade of oil is used.

Transmission oils have a viscosity range from SAE 85W to SAE 140. The API classifications for gear lubricants (GL) are GL1 to GL5, with GL4 and GL5 being the most commonly used.

Handy hint: Transmission and engine oils use a different viscosity scale so they cannot be directly compared via their SAE viscosity ratings.

8.8.1 Automatic transmission fluids

Automatic transmission fluids have many similar compounds to those of engine lubricating oils; however, they have particular friction characteristics. The bands and clutches of automatic transmissions require lubrication, but they also need friction when they are being applied. These are two opposing requirements that automatic transmission fluids need to overcome.

There are varying specifications that have to be met for vehicle and transmission manufacturers. There is no single oil that is suitable for all automatic transmissions as manufacturers use different designs, parts and technology to develop their transmissions. Using an incorrect oil can cause extensive damage to transmission parts so it is vital that manufacturer's specifications are followed.

8.9 Hydraulic brake fluids

Different types of brake fluids are available, and each type can be used in varying situations. Brake fluid can be either glycol or silicon based. Glycol-based fluid is effective as it absorbs moisture, but increased moisture within the system will reduce the boiling point of the fluid. Silicone-based brake fluid is

generally only used in special applications and does not absorb moisture. Glycol- and silicone-based fluids must not be mixed.

Table 8.1 Lubricants for motor vehicles

Lubricant	Application
Engine oils	Engines, some manual transmissions, bushes, pins and linkages, general lubrication
Gear oils (EP)	Rear axles and manual transmissions where extreme loads are encountered
Gear oils (straight mineral)	Manual transmissions where moderate loads are encountered
Automatic transmission	Automatic transmissions, power fluids, steering
Multipurpose grease	Chassis lubrication, universal joints, wheel bearings, general
Molybdenum disulphide	Ball joints packed for extended service periods
Special-purpose greases	Constant-velocity joints, rack-and-pinion steering boxes
Zinc oxide grease	Brake backing-plate parts, brake linkage, bonnet catches, clutch parts
Rubber grease	Brake hydraulic parts
Dry lubricant	Door locks, striker plates
Penetrating oils	Stiff linkages, bolts and nuts, leaf springs
Hydraulic brake fluids	Brake and clutch hydraulic systems

8.9.1 Requirements of brake fluids

The main requirement of brake fluid is that it must reliably transmit force from the brake master cylinder to the wheel cylinders. For this to happen under varied applications it must possess properties such as:

1. Viscosity. Must be suitable for all climatic conditions so that it flows readily at low temperatures and is not too thin at high temperatures.
2. Boiling point. Considerable heat is generated in the braking system, and the fluid must be capable of withstanding temperatures that exceed normal boiling points. If the brake fluid boils, some of the liquid transforms into gas. This is like having air in the braking system, as the gas will compress when the brakes are applied.
3. Rubber swell. A chemical additive within the brake fluid reduces problems associated with the swelling of rubber seals. Seals will continue to swell over a long period, which compensates for wear.
4. Prevention of corrosion. Due to a build-up of condensation within the brake fluid, corrosion must be eliminated so that it does not damage metal components or rubber seals. Another characteristic of brake fluid is its ability to resist corrosion by lubricating all moving parts within the master and brake cylinders.
5. Compatibility. Although fluids of the same type and which meet the same standards can be mixed this is not generally recommended. Furthermore, it is vital that glycol- and silicon-based fluids are not mixed.

The standards to which glycol-based fluids must conform include a specific boiling point of the fluid so that it can resist a vapour lock when operating under extreme conditions. They also include viscosity and the ability to absorb moisture. This information is usually on the label of the fluid container.

Safety: Contact with brake fluid can cause skin and eye irritation, as well as breathing problems. Always wear appropriate PPE when using brake fluid.

Sustainability: Brake fluid is a corrosive substance that will damage paintwork and the environment. Always ensure that it is correctly handled and disposed of. A material safety data sheet (MSDS) will contain comprehensive information about the correct procedures for using brake fluid.

8.9.2 Brake fluid specifications

Hydraulic brake fluid can be rated in a number of different ways. It is tested against Australian Standards and must meet a range of specifications and guidelines. Also, a vehicle manufacturer may set the required specifications for the type of brake fluid required for use within the particular vehicle. The most common method of specification is by a *DOT number* – DOT 3, DOT 4 and DOT 5. DOT refers to the Department of Transportation (USA), and the number relates to its characteristics, particularly boiling point.

1. DOT 3 fluid. The standard for brake fluid that is used in most vehicles for disc brakes, drum brakes and hydraulically operated clutches. It is dyed blue/green for identification.
2. DOT 4 fluid. Has similar properties to DOT 3 but has a higher boiling point.
3. DOT 5 fluid. Meets more stringent standards than DOT 3 and 4, including a higher boiling point.
4. DOT 5.1 fluid. Has a higher boiling point than DOT 5 fluid.

8.9.3 Care with brake fluids

Care must be taken to avoid contamination of brake fluid. Mineral oil, kerosene or any other mineral oil product should not come into contact with fluid or hydraulic brake parts. Even small traces of these will cause the rubber seals to swell and deteriorate. If contamination of brake fluid is suspected, it should be drained. The system should then be flushed and all rubber parts such as cups and hoses renewed. A simple test for contamination is to place a small quantity of the suspected fluid in a clean glass container and allow it to stand. If mineral oil is present, the fluid will separate into two distinct layers. This test should be made only as a matter of interest, and not to determine if the fluid is suitable for use.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- explain the concept of crude oil refining
- list the fuels used in the automotive industry and how they affect vehicle performance
- describe the properties and classifications of oil
- explain the reasons for oil changes
- describe the procedures for the correct handling, storage and disposal of lubricants, fuels and fluids.

REVIEW QUESTIONS

1 Name the products created by refining crude oil.
2 What is meant by volatility?
3 Name the four grades of petrol, and their RON, available within Australia.
4 What is meant by flame propagation?
5 Detonation can cause engine knocking. Explain the process of combustion that leads to excessive detonation.
6 Explain the function of a knock sensor.
7 Ethanol fuel is a renewable fuel made up from a mixture of ULP and what other products?
8 Explain the benefits of a fuel that is rated at 98 RON compared to a fuel with a rating of 91 RON.
9 Identify six of the additives used in petrol and provide a brief explanation of their purposes.
10 Which two products are a result of the combustion of the air-petrol mixture?
11 Why should an engine not be operated in a confined space?
12 Describe some of the properties of a diesel fuel.
13 Explain what can occur in a diesel engine if the fuel contains an excessive amount of sulphur.
14 Diesel fuels are rated by a number. How does the rating impact on combustion?
15 Name some contaminants that destroy diesel fuel components.
16 What is meant by viscosity? Outline the reasons for different oil viscosity ratings.
17 Oils are supplemented with a range of chemical additives. List eight of these additives.
18 Explain the purpose and the benefits of dispersant additives in engine oils.
19 Why are oils given a service classification?
20 Explain in detail the main reasons why engine oil should be changed as per manufacturer recommendations.
21 Provide a range of reasons why an engine may 'use' oil.
22 With regard to bearings and grease, what is meant by channel? What impact does it have on lubricating surfaces?
23 Name five essential properties associated with brake fluid.

CHAPTER 9

Service and maintenance

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 explain how to prepare a vehicle for service
2 describe and apply service information and requirements
3 identify a range of safe vehicle servicing and maintenance procedures.

There are numerous makes and models of light and heavy vehicles that require service and maintenance . As a result, there are many different types of vehicle services and repairs outlined in this chapter .

9.1 Servicing new vehicles

Two services are performed on new vehicles. One is a pre-delivery service, where the vehicle is checked, cleaned and mechanically inspected prior to being delivered to the purchaser. The other, known as a *first service* takes place after the vehicle has been delivered to the customer and has travelled a specified number of kilometres. The exact determination of when the first service will occur depends on manufacturer recommendations. Some manufacturers provide the first service at no cost, while others provide an upfront agreed service schedule with pre-determined costs.

9.1.1 Pre-delivery service

The complete vehicle is checked to ensure that everything is operating correctly and that it is clean and ready for delivery. A pre-delivery service also includes a road test to check the vehicle's performance. A high standard of pre-delivery service is essential as new vehicle sales are competitive and manufacturers strive for excellence. Problems with new vehicles are not only inconvenient to the customer but costly to the manufacturer, with regard to profit and customer satisfaction.

9.1.2 Pre-delivery schedule

An example of what is required within a pre-delivery schedule is shown in Table 9.1. This lists items that should be inspected and rectified if issues are detected.

9.1.3 Warranty

New vehicles are covered by a manufacturer's warranty. The length of the warranty will depend on the manufacturer and the type of vehicle being sold. All are based on a specified period of months or years, or a maximum number of kilometres, whichever occurs first. For example, a passenger car might have a 3, 5 or

Table 9.1 Pre-delivery inspection list

Vehicle exterior
• Tighten wheel nuts • Adjust tyre pressures to specifications • Check wheel covers • Inspect body weather strips • Inspect glass and exterior bright parts • Check paint for damage • Check fit of doors and panels • Check operation of bonnet-release and lock • Check headlamps, parking lamps and rear lamps • Check turn-signal lamps and warning-hazard operation
Vehicle on hoist
• Check manual transmission oil level • Check rear-axle oil level (rear-wheel-drive vehicle) • Check tyres for damage • Inspect steering linkage and suspension • Inspect fuel lines and connections • Inspect hydraulic brak e lines, hoses and fittings • Check exhaust system mountings • Check all underside hardware for looseness or damage
Under bonnet—engine stopped
• Check engine oil level • Check brak e master cylinder reservoir and connections for leaks • Check clutch master cylinder reservoir (hydraulic clutch control) • Check manual transaxle oil level (front-wheel-drive vehicle) • Check radiator and coolant reservoir levels • Check cooling system and heater hoses and connections • Check oil level in steering bo x (where appropriate) • Check power-steering reservoir • Check all drive belts for tension • Check throttle linkage or cable • Check windscreen-washer reservoir level • Check battery terminals and electrolyte level • Check all other hoses, fittings and components

Under bonnet—engine running and at normal temperature
• Check automatic transmission fluid level • Check ignition timing • Check idle speed and CO at idle
Interior of vehicle
• Check operation of ignition switch and steering lock • Check operation of the parking brak e and gear lever • Check inhibitor switch (automatic transmission) • Check operation of interior lights from all switches • Check instruments, indicator and warning-light operation • Check operation of electric windows and mirrors • Check operation of window winders and door locks • Check horn, windscreen wiper and washer • Check operation of radio and antenna • Check other audio equipment as fitted • Check front-seat controls for operation • Check seat belts, retractors and emergency locking • Inspect upholstery , interior trim and finish
Road test
• Check clutch operation • Check brak e operation • Check steering of vehicle • Check gearshifts, manual and automatic transmissions • Check operation of meters and gauges • Check general engine performance • Check for squeaks, rattles or unusual noises • Check heater and defroster operation • Check air-conditioner operation
After road test
• Remove protective covers from interior • Check provision of handbook, tools and spare tyre • Check and clean vehicle as necessary

7 year/100 000 km warranty, whereas a manufacturer's warranty on a commercial vehicle may be limited to 2 years/100 000 km. Some manufacturers offer extended warranties of 200 000 km to the original purchaser of the vehicle; warranties vary in time, kilometres and what is covered.

During this warranty timeframe, the manufacturer will either repair or replace any parts found to be defective through faulty workmanship or material. Warranties do not cover damage or failures caused by negligence or lack of maintenance.

9.2 Scheduled maintenance services

The term *maintenance* refers to work that is performed to ensure that the various parts of the vehicle maintain their normal operating function. *Scheduled maintenance* refers to maintenance performed on a regular basis according to a specified schedule. Scheduled maintenance is important as it can prevent a vehicle from becoming unreliable while also extending the service life of its systems and components.

Maintenance schedules will vary depending on the vehicle, its use and what conditions it is subjected to. An example of the standard items that may be included within a service schedule for a passenger or light commercial vehicle is shown in Table 9.2.

The schedule shown is for each service to occur at 15 000 km or every 12 months, whichever comes first. However, other schedules could be completely different so always check the specific schedule of a vehicle. There will be variations for particular vehicles, depending on aspects such as whether it is a front- or rear-wheel drive, a manual or automatic transmission, or a petrol or diesel engine. The sections of the schedule show a number of related systems that require servicing.

9.2.1 Schedule codes

The schedule in Table 9.2 outlines the various tasks required for each service. These are designated by codes consisting of the letters A, I, L, R and T. They are interpreted as follows.

A – Adjust

Carry out recommended adjustments according to specifications. This can apply to precise adjustments such as engine valve adjustment, or resetting or repositioning a small part.

I – Inspect

Perform a visual inspection or check and correct any faults found by adjusting or renewing as necessary.

Handy hint: A visual inspection implies a close examination of the particular part for wear , deterioration or damage .

L – Lubricate

This applies to lubricating parts such as ball joints, tail shafts and linkages. It also requires that lubricant be applied to such items as cables and controls. The repacking of bearings with grease can also be covered by this code.

R – Renew or change

Parts such as air filters, oil filters and fuel filters are designed to be discarded and replaced at regular intervals. Engine oil is changed at regular intervals and, in some circumstances, transmission oil is also changed. Certain parts may have a limited service life, and manufacturers will recommend that such parts are renewed at a particular service period. Spark plugs, engine timing belts, cabin filters and EGR valves in diesel engines are examples of items that may require replacement under this service code.

T – Tighten

This applies mainly to the bolts and nuts in the chassis, body, steering and suspension systems. Nuts and bolts are checked for their tension; some have to be checked and tightened to a specified torque. In many instances, the tension of manifold studs and engine mounting bolts is recommended.

9.3 Maintenance items

The following outlines each of the items listed in the maintenance schedule (Table 9.2). The numbered paragraphs correspond with the item number in the maintenance schedule.

9.3.1 Engine

1. Valve clearance

Valve clearances are checked and adjusted to specifications. For example, some manufacturers recommend that the bucket shims for the valves are checked for clearance every 30 000 km. However, before starting any adjustment, always check with manufacturer guidelines about correct procedures.

2. Manifold bolts

Bolts or nuts that attach the manifolds to the cylinder head are checked for tightness to ensure that there are no leaks. The bolts or nuts that secure the exhaust pipe to the manifold flange are checked for correct tension.

3. Drive belts

Camshaft drive belts (timing belts) must be replaced at the correct service interval to avoid them breaking with consequent serious damage. Where a rubber timing belt is fitted, it must be replaced at a specific number of kilometres or months; this will be specified within the vehicle's service schedule.

Drive belts for components such as the engine cooling fan, water pump, alternator, air conditioner and power steering must be checked for wear, deterioration and adjustment. Belts in doubtful condition should be renewed. Check the tension of the belt at a point midway between pulleys. If the deflection is excessive and a manual tensioner is fitted, adjust the belt to required specifications.

4. Engine oil

The engine oil should be drained and the oil filter changed at specified scheduled intervals. Check the washer on the drain plug to ensure it will provide a positive seal when refitted. Then refill the crankcase (sump) with the correct quantity of new oil of the recommended grade and type. In some vehicles, the engine oil must be replaced within a specified timeframe after the oil has been drained. This is to help eliminate the possibility of the oil pump losing pressure and resulting in the engine oil not lubricating as required when the engine is restarted.

After refilling the engine with oil, start the engine and check for leaks around the oil filter seal. Allow the engine to idle for a short period of time before stopping the engine. The engine oil level should be checked and, if necessary, filled to the correct level.

The schedule in Table 9.2 shows that the oil should be changed at each 15 000 km or twelve months. As previously stated, the service intervals may vary for different manufacturers and vehicle models. More frequent oil changes are recommended for severe driving conditions.

5. Oil filter

The oil filter removes small particles that contaminate the oil as it circulates within the lubricating system. It should be replaced when the oil is changed, otherwise it may become restricted or even block up completely. After the engine oil has been changed and the engine started, the filter and the sump plug should be checked to ensure that there are no oil leaks.

6. Oil leaks

The engine should be checked for oil that could be leaking from areas such as the oil filter, valve cover, sump, head gasket, sump plug, timing cover, crankshaft and camshaft seals.

7. Cooling system

Check the coolant level in the reservoir or header tank and top up to the correct level if required. The coolant level should be above the minimum mark shown on the reservoir or header tank.

Inspect all cooling-system hoses, including the heater hoses and connections, to ensure that they are not leaking, swollen or cracked. Any faulty hose or connector should be renewed. Check the radiator core for obstructions such as dirt, dust or grass particles that could reduce air flow. To clean the core, air or water can be blown through it in the opposite direction of normal air flow. Extreme care should be taken as the radiator core can be easily damaged.

The water pump should be inspected for leaks and its drive belt checked for tension and cracks. If the drive belt is cracked, it must be replaced. Check the operation of the cooling fan; if it is electric, ensure that it automatically engages when the engine is running at operating temperature.

8. Engine coolant

The coolant inhibitor should be tested for the correct percentage of coolant additive as this will show whether the correct amount of anti-corrosion, anti-freeze or anti-boil chemicals are present in the system. It is important that engine coolant be replaced and the system flushed when scheduled. Failure to do so can result in serious internal corrosion and failure of cooling system components. When replacing the coolant, move the heater temperature control to the hot position so that coolant will drain from the heater core.

The system should be refilled with coolant consisting of deionised water or rainwater, with the correct amount of antifreeze and corrosion inhibitor added.

Handy hint: When topping up a cooling system, always use the correct mix of water and coolant inhibitor . It is not recommended that different inhibitors are mix ed.

Table 9.2 Maintenance schedule (general)

Service intervals											
Kilometres × 1000	2	15	30	45	60	Kilometres × 1000	2	15	30	45	60
Months		12	24	36	48	Months		12	24	36	48
Engine						**Emission controls***					
1. Valve clearance	A		A		A	26. Emission hoses	I	I	I	I	I
2. Manifold bolts	T		T		T	27. Charcoal canister		I		I	
3. Drive belts	A	I	I	I	I	28. PCV system	I		I		I
4. Engine oil	R	R	R	R	R	29. Other emission controls	I	I	I	I	I
5. Oil filter	R	R	R	R	R	30. Exhaust gas recirculation (diesel engine)		I		I	
6. Oil leaks	I	I	I	I	I						
7. Cooling system	I	I	I	I	I						
8. Engine coolant			R		R	**Brakes and transmission**					
Fuel system – petrol						31. Brake fluid	I	I	R	I	R
9. Idle speed	I	I	I	I	I	32. Brake lines and hoses	I	I	I	I	I
10. Air cleaner			R		R	33. Brake linings and pads	I	I	I	I	I
11. Fuel filter			R		R	34. Brake pedal	I	I	I	I	I
12. Fuel lines	I	I	I	I	I	35. Parking brake	I	I	I	I	I
13. Fuel tank cap	I	I	I	I	I	36. Clutch*	I	I	I	I	I
Fuel system – diesel						37. Manual transmission	I	I	I	I	I
14. Fuel lines	I	I	I	I	I	38. Automatic transmission	I	I	I	I	I
15. Fuel filters			R		R	39. Drive line	I	I	I	I	I
16. Air cleaner	I	I	I	I	I	40. Final drive	I	I	I	I	I
17. Injectors	I	I	I	I	I	**Steering and suspension**					
18. Injection timing	I		I		I	41. Steering linkage	I	I	I	I	I
Ignition system – petrol						42. Wheel alignment	I		A		A
19. Spark plugs	I	I	R	I	R	43. Steering box or housing*	I		I		I
20. Coil pack, distributor Distributor and cables	I	I	I	I	I	44. Front suspension	I	I	I	I	I
						45. Front-wheel bearings*			L		L
21. Ignition timing	A		A		A	46. Rear-wheel bearings*			L		L
Battery and electrical						47. Rear suspension	I	I	I	I	I
22. Battery	I	I	I	I	I	48. Tyres and wheels	I	I	I	I	I
23. Lighting	I	I	I	I	I	**Other items**					
24. Instruments	I	I	I	I	I	49. Bolts and nuts on body and chassis	T	T	T	T	T
25. Power windows and mirrors	I	I	I	I	I	50. Exhaust system	I	I	I	I	I
						51. A/C cabin filters	I or R as necessary				

Code: A = Adjust I = Inspect L = Lubricate R = Renew or change T = Tighten

* as appropriate for the particular vehicle

Note: After 60 000 km, the schedule is repeated

9.3.2 Fuel system—petrol

9. Idle speed

Check that the engine idles evenly at the appropriate rpm. If it is necessary to adjust the idle speed, set it according to the emission-control information for the particular vehicle.

10. Air cleaner

Visually inspect the air cleaner for excessive contaminants or damage. In some instances, an air cleaner can be cleaned by applying a light stream of compressed air in the opposite direction of normal air flow through the filter. This is not recommended in all situations: if the filter is dirty or damaged due to extreme operating conditions, it should be replaced. The service schedule will usually specify when a filter is to be replaced.

11. Fuel filter

Fuel filters should be changed as per the service schedule. This is important because of the complexity of the fuel system and the importance of maintaining reliable and efficient operation. Always ensure that all filters and fuel lines are secured and do not leak.

12. Fuel lines

Carry out a general check of the fuel system hoses, pipes and connections. Check for damage, deterioration and possible leaks.

13. Fuel tank cap

The fuel cap should be in good condition and of the correct type. The washer should seal on the filler neck of the tank. If a cap is replaced, the replacement must be the same type as the original.

9.3.3 Fuel system—diesel

14. Fuel lines

Check connections to the filter, fuel pump and injection pump. Check injector pipes for tightness and leaks. Due to the extremely high pressures associated with common rail diesel engines, do not remove injector fuel lines unless the correct tools are available and the correct procedures are followed.

15. Fuel filters

Replace the filters as per the service schedule and, if fitted, drain water from the sediment filter. Older mechanically operated fuel pumps will require air bleeding from the system; most common rail injection systems, however, are self-bleeding. Check the filter seals and any drain plugs for leaks.

16. Air cleaner

Renew or clean the air cleaner, including any pre-cleaner that is fitted. Check air hoses and intake ducting to ensure that unfiltered air cannot leak into the intake system.

17. Injectors

Check for excessive black smoke at the tail pipe. Diesel injection systems are extremely complex, and servicing or repairs to injectors should only be carried out by a specialist

18. Injection timing

Check as scheduled for the particular engine. This is not a routine procedure and should be performed by a diesel injection specialist

9.3.4 Ignition system—petrol

19. Spark plugs

Most vehicle manufactures fit spark plugs to engines that are designed for extended periods of service and may not need checking or replacing for approximately 100 000 km. Older-style engines need spark plugs to be cleaned, re-gapped or replaced more regularly.

Handy hint: New spark plugs must be of the same type and have the same heat range as the originals.

20. Coil pack, distributor and cables

Ensure that the coil packs are securely mounted and that all wiring, connectors and high-tension cables are securely attached. Older vehicles fitted with a distributor may require additional maintenance, including:

1. cleaning the outside of the distributor cap
2. cleaning the inside of the distributor cap and rotor button, and inspecting the distributor cap for cracks or damage

3 when refitting the distributor , ensuring that the ends of the spark plug cables are pushed firmly into the cap
4 checking the ignition timing with a timing light and adjusting as necessary .
5 checking the vacuum or other ignition advance mechanism for operation. This can usually be done in conjunction with ignition timing.

21. Ignition timing

Check the ignition timing, where specified (many ignition systems are controlled by the electronic engine management system and do not require service checks).

9.3.5 Battery and electrical

22. Battery

Inspect the battery case for damage and the terminals for looseness and corrosion. Clean the battery and carrier with a solution of baking soda and hot water, taking care that no solution enters the battery. Apply a coating of battery sealer to the battery terminals to help prevent corrosion.

If the battery is classed as maintenance free, check the colour indicator of the built-in hydrometer. This will indicate the condition of the electrolyte. If the battery is not maintenance free, check the battery electrolyte level and measure its density using a hydrometer. Check the level of the electrolyte and, if required, top up the cells with deionised water to the required level.

When working on a hybrid or battery electric vehicle (BEV), ensure that the correct procedures are followed to isolate the battery.

23. Lighting

Check the operation of all lights including park, indicators, brake, interior, fog or auxiliary lighting and high- and low-beam headlights. Where fitted, check the operation of daytime running lights.

24. Instruments

A visual check should be made to ensure that the dashboard warning lights are operational. These types of lights vary, depending on the age and model of vehicle and may include warnings about the incorrect operation of the airbag, ABS, charging system, seatbelts, engine service or diesel particulate filter.

25. Power windows and mirrors

Check the operation of the power windows, mirrors and door locks.

9.3.6 Emission controls

26. Emission hoses

Inspect the hoses and connections of the emission-control components for condition and correct fitting.

27. Charcoal canister

Check connections to the canister, or replace it if specified within the service schedule.

28. PCV system

Check for correct operation of the positive crankcase ventilation valve. Clean or replace as necessary.

29. Other emission controls

There are many variations in the design and range of emission controls. These include exhaust gas recirculating (EGR) and air injection systems. For this reason, information should be obtained from a relevant workshop manual.

30. Exhaust gas recirculation (diesel engine)

Check security of connections and valve operation.

9.3.7 Brakes and transmission

31. Brake fluid

Check the brake fluid reservoir for the correct fluid level. Brake fluid should be changed at specified service intervals, which will vary depending on manufacturer requirements.

32. Brake lines and hoses

Inspect the brake lines and hoses for leaks. Check that the hoses are correctly fitted so they do not make contact with any component that can damage them.

33. Brake linings and pads

Check disc pads for wear and the disc rotors for excessive scoring and the minimum required thickness. Where drum brakes are fitted, check the linings for wear and the drums for scoring. Adjust the brake shoes if an adjustment is provided. Replace any worn parts within the braking system as required.

34. Brake pedal

With the engine running, check both the brake pedal free play and pedal travel. Ensure that the brake pedal is fitted with a non-slip surface.

35. Parking brake

Slowly engage the park brake lever and count the number of clicks it takes before it becomes tight and the brakes lock. Compare this information with the manufacturer's recommendation. If the vehicle is fitted with an electric handbrake, check that it is operating correctly.

36. Clutch

Check the clutch-pedal free play, or the free play of the release lever at the clutch housing. Adjust if required. For a clutch with hydraulic control, check the fluid level within the master cylinder and top up if necessary. Check for hydraulic leaks and change the fluid as specified in the service schedule.

37. Manual transmission

Check the oil level within the transmission or transaxle and top up as required. Check for oil leaks and ensure that all transmission mounting rubbers, nuts and bolts are securely fastened. Refer to the manufacturer's service schedule for oil replacement intervals.

38. Automatic transmission

Where possible, check the level of the automatic transmission fluid. The checking process can vary as some manufacturers may use a dipstick while others might use an oil level plug; or the transmission may be sealed and the oil only accessed by removing the transmission sump.

Handy hint: Check the colour and odour of the fluid. Fluid that is dark in colour or has a burnt odour should be changed.

39. Drive line

Manufacturers will use different arrangements for rear-wheel-drive, front-wheel-drive and four-wheel-drive vehicles. Check propeller shafts' universal joints for looseness and wear. Check the condition of the boots of constant-velocity joints and inspect drive-shaft seals for signs of leaks. Universal joints on some light commercial vehicles and four-wheel-drive vehicles can be greased.

40. Final drive

Check the oil level of the rear axle. Check for oil leaks and that the breather vent on the axle housing or differential housing is clear. Some front-wheel drives have the final drive as part of the transmission assembly so it is serviced with the transmission. Others have a separate compartment with its own level and drain plug for checking.

9.3.8 Steering and suspension

41. Steering linkage

Check the rotational free play of the steering wheel. Check the tie rod ends for looseness, and rubber boots for damage. Lubricate the ball joints if there is provision to do so.

42. Wheel alignment

A wheel alignment should be performed if there is any sign of irregular tyre wear. Front-end alignment is also required if steering has become difficult or if steering or suspension parts are renewed.

Handy hint: The rear wheels should also be checked for alignment if there is irregular tyre wear.

43. Steering box or housing

Check a worm-type steering box for oil level and possible leaks. With a rack-and-pinion steering, check the condition of the rubber boots and any oil leaks or excessive wear in the joints of the rack ends.

For power steering, check the fluid level, condition of the drive belt and operation of the system. Manufacturer's instructions should be followed when servicing or maintenance is carried out on vehicles fitted with electric-assisted or full electric power steering.

44. Front suspension

Check suspension ball joints for wear and inspect the boots for damage. Where provision is made, lubricate the suspension ball joints. Check the shock absorber or strut for leaks, and check the condition of the shock absorber mountings. Inspect other parts of the suspension for wear and damage.

45. Front-wheel bearings

The service schedule will specify when the front-wheel bearings should be cleaned, inspected and repacked with grease. Many front-wheel bearings are packed with grease and cannot be dismantled for servicing.

46. Rear-wheel bearings

With some front-wheel-drive vehicles, the rear-wheel bearings can be cleaned and repacked in a similar way to the front-wheel bearings noted above. Other rear-wheel bearings cannot be dismantled. The rear-wheel bearings of rear-wheel-drive vehicles are usually sealed and cannot be serviced. This applies to both rigid rear axles and independent rear suspension.

47. Rear suspension

Check the bushes and mountings of the rear-suspension parts. Bounce the vehicle to check shock absorber operation. Inspect the shock absorber rubber bushes and look for signs of oil around a shock absorber that could indicate that it is inoperative. If necessary, disconnect or remove the shock absorber to check its operation.

48. Tyres and wheels

Inspect the tyres for cuts, bruises and for sharp objects embedded in the tread. Check tyre inflation, correct load rating, directional rotation and that all wheel nuts are fitted. The minimum legal tread depth requirement for a passenger tyre is 1.5 mm for a continuous band around the circumference of the tyre which normally contacts the road. Check for tyre wear and carry out a wheel alignment if required. Where recommended, or where the tyre wear is not uniform, rotate the tyres to even up the wear. Inspect the wheels for rim damage, and check the wheel nuts for tightness.

9.3.9 Other items

49. Bolts and nuts on body and chassis

Check and generally tighten all bolts and nuts which secure various parts to the body, chassis or subframes. Use a torque wrench where a torque is specified.

50. Exhaust system

Check the various parts of the exhaust system for condition and possible leaks at the pipe joints. Check the mountings for condition and ensure that there is clearance between the parts of the exhaust system and the body or suspension.

51. Air-conditioning cabin filters

Reset service indicators

9.4 Service intervals

A sample of servicing requirements is shown in Table 9.2. This table specifies that the service intervals are at either 15 000 km or 12 months, whichever occurs first. These are examples of general service intervals for a passenger or light commercial vehicle operating under normal conditions.

For a vehicle operating under what are classed as severe driving conditions, the service interval on some items is reduced to half of that shown in the schedule. Severe driving conditions can include the following:

1 Towing a caravan or trailer
2 Repeated short trips or infrequent use
3 Operating on dusty roads
4 Operating in rough, sandy or muddy conditions
5 Driving for a prolonged period in extremely cold weather .

Handy hint: Severe operating conditions could apply during a particular service period only , where a vehicle is being used in other than its normal conditions.

9.4.1 Items requiring more frequent service

Under severe operating conditions, some items within the schedule may require more frequent servicing.

Engine oil and filter

Engine oil deteriorates more rapidly under severe conditions, and both oil and filter should be changed more frequently. Even if not used regularly, it deteriorates over time due to chemical and moisture build up.

Air filter

The engine air filter is designed to collect dust and prevent contaminants from entering the engine. However, under severe conditions the filter could become restricted and reduce the flow of air into to the engine, resulting in a loss of power and a decrease in fuel economy.

Clutch

Depending on the type of vehicle and what it is used for, there may be different servicing requirements for the clutch. If a clutch has been subjected to heavy loads or frequent use, cables (where fitted) may need to be checked to ensure that the correct free play adjustment is applied. Hydraulic systems require that the fluid level, hoses and cylinders are not leaking.

Brakes

A number of factors can lead to more frequent servicing of the braking system, such as:

1. The vehicle being regularly subjected to carrying or towing a heavy load
2. The terrain over which the vehicle usually travels
3. The driving habits of the operator .

As a result, brake components will wear more rapidly and require more frequent inspections.

Steering and suspension

Steering and suspension components are subjected to increased shock loads during severe driving conditions. Therefore all steering and suspension components should be checked for damage and wear and, if required, should be lubricated or greased more frequently.

Transmission oils

Transmissions which are regularly exposed to abnormal loads will require additional servicing. The service schedule will specify the extra requirements and automatic transmission fluids should be changed before the oil becomes dark or develops a burnt odour.

Drive line and final drive

Universal joints should be inspected for looseness and wear that could result from increased loads. Lubricant in the final drive should be checked or changed as specified. Boots on universal joints of front-wheel-drive vehicles should be inspected for deterioration and damage.

Chassis and body bolts

Rough conditions can produce vibrations that can loosen bolts and nuts on the body or chassis.

Wheels and tyres

Wheel nuts should be checked for tightness and tyres should be checked for damage and abnormal wear.

9.5 Special services

Special services involve carrying out extra maintenance on systems and components due to a range of operating conditions. These may include:

1 General safety inspections prior to (or at the end of) long trips
2 Air-conditioning service in preparation for summer months
3 Cooling system service to ensure efficient operation in cold or hot climates
4 Battery inspections, especially during the colder months.

9.5.1 General service and repairs

This type of service will generally occur as a result of abnormal wear or failure of components. Additional services may be required due to a range of issues such as the vehicle being repaired as a result of crash damage, poor driving habits, lack of previous maintenance or severe operating conditions.

9.5.2 Vehicle recall service

Vehicles may be recalled by the manufacturer to rectify faults associated with defective or unsafe components. When a vehicle is recalled, the registered owner is contacted and it is repaired by the manufacturer at no cost to the owner. Refer to the Australian Competition and Consumer Commission website for a list of vehicle recalls.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain the steps needed to prepare a vehicle for service or maintenance repairs
- apply vehicle service schedules
- list the items covered in a service or repair maintenance schedule
- describe safe and efficient vehicle servicing and maintenance procedures.

REVIEW QUESTIONS

1 Explain the purpose of a pre-delivery service . List some items that would be check ed.
2 What aspects of vehicle servicing or repairs are generally not covered by manufacturer' s warranties ?
3 A number of schedule codes are listed in T able 9.2. Explain the various tasks required for each code .
4 Why is it important to ensure that a camshaft drive belt be replaced at the recommended interval?
5 Explain what type of faults you would be looking for on external engine drive belts.
6 Outline what checks should be conducted on both the cooling system and the engine coolant.
7 Referring to T able 9.2, indicate how frequently the following items would be given attention:
   (a) engine oil and filter
   (b) engine coolant change
   (c) battery
   (d) brak e fluid change
   (e) EGR valve.
8 Provide a detailed explanation as to the inspection required for the wheels and tyres.
9 What would be inspected as part of the drive line and shafts ?
10 What would be inspected in both a worm type steering bo x and a rack and pinion steering system ?
11 Explain what is meant by severe driving conditions . Identify and explain which items require more frequent servicing as a result.
12 How would automatic transmission fluid be check ed?
13 What are the possible causes of irregular tyre wear?
14 For what reasons might a vehicle manufacturer conduct a vehicle recall?

PART 2

Running gear

CHAPTER 10

Tyres, wheels and balance

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 interpret information to enable the selection of wheels and tyres for specific applications in vehicles
2 observe safety procedures and requirements to safely remove and refit wheels and tyres
3 safely balance wheel and tyre assemblies
4 service and inspect wheels and tyres for safety and serviceability in accordance with workplace and manufacturers ' requirements and specifications
5 accurately inspect, document and interpret wheel and tyre assemblies
6 analyse inspection results.

Tyres provide a cushion between the road and the vehicle to reduce road shocks. They also provide friction with the road surface . During acceleration, this is in the form of traction to propel the vehicle along the road. Friction also provides adhesion, which opposes the tendency to skid on turns and allows quick stops to be made during braking.

10.1 Tyre construction

Figure 10.1 shows the construction of a tyre. Its main body is referred to as the *casing,* and is made of a fabric with layers of cords impregnated with rubber. This is formed over a moulding device and rubberised, and the sidewall and tread materials are applied. The tyre is then subjected to a process which heats the rubber under pressure in a metal mould, processing the rubber and forming the desired shape of tyre and tread. The rubber used in tyres is mainly synthetic, being manufactured from the products of the coal and petroleum industries. Carbon is added for toughness and strength, particularly for the treads.

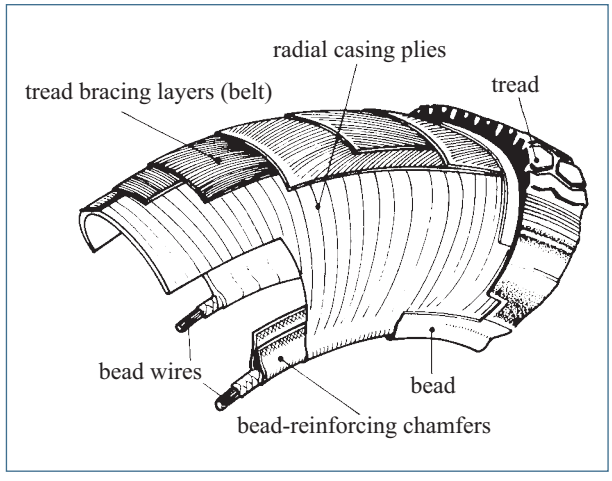


Figure 10.1 Tyre construction FORD

10.1.1 Plies and ply rating

The layers of cords in the fabric of the casing are called *plies.* Tyres were originally made with cotton

cords and were marked, for example, *4 ply* or *6 ply* to indicate the number of plies they contained. This showed the strength of the tyre. Development of higher-strength cords such as rayon, nylon, polyester and steel enabled the number of plies to be reduced while maintaining tyre strength. A passenger vehicle tyre could be constructed with two plies for the sidewalls and four plies under the tread.

Stronger cords led to the method of tyre marking being adjusted and the word *rating* being added so that a tyre was given, for example, a 4-ply rating or 6-ply rating. This does not reflect the actual number of plies used, but shows that the tyre is equal in strength to one with that number of cotton plies.

Handy hint: Light truck tyres usually have a specified ply rating; passenger vehicle tyres have speed and load ratings.

10.1.2 Tubed and tubeless tyres

A tubed tyre has a separate inner tube which is fitted into the tyre when it is mounted to the tyre rim. When inflated with air, the tube maintains the shape of the tyre under the load of the vehicle. Tubeless tyres do not have a separate inner tube but a soft rubber lining on the inside of their casing and beads that fit tightly against the wheel rim to form a seal. When the tyre is inflated, air is retained between the wheel and the casing. However, most tyres are tubeless.

A section of a tubeless tyre, mounted on a rim, is shown in Figure 10.2, with the tyre parts identified. Also shown is the air valve, which fits tightly in a hole in the rim. Passenger and light commercial vehicles have tubeless tyres. Putting a tube in a tubeless tyre that won't hold air is not recommended because of the extra heat generated by friction between the tube and the inner tyre wall.

Handy hint: There are two basic types of tyre construction: bias or cross-ply , and radial. The differentiating factor is the arrangement of **the cords in the plies.**

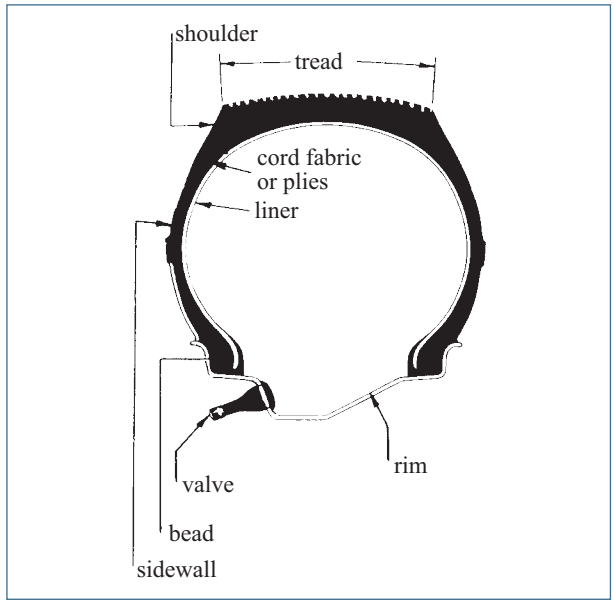


Figure 10.2 Sectional view of a tubeless tyre and rim

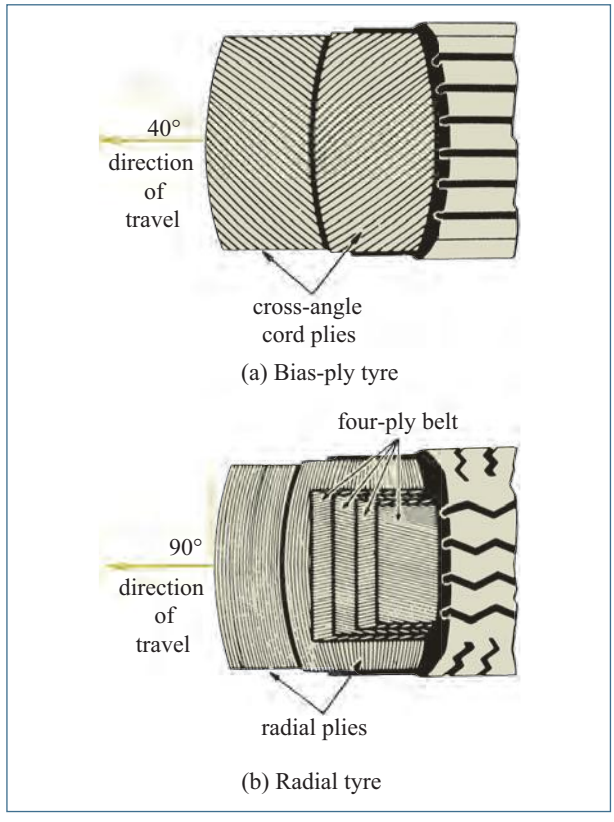


Figure 10.3 Types of tyre construction GOODRICH

10.1.3 Bias (cross-ply) tyres

Bias, or cross-ply, tyres have cords that run diagonally in alternate layers (Figure 10.3(a)). The terms *bias* or *bias-ply* are used because the cord fabric from which the plies are made is cut on a bias (at an angle) to the cords. The term *cross-ply* is used because the cords cross at an angle. Tyres of this design have stiffer sidewalls than radial tyres due to the cross-bracing effect of the diagonal cords.

10.1.4 Radial tyres

Radial tyres are the most common type. The cords in the casing of the tyre run in a radial direction, that is, straight across the tyre section without crossing (Figure 10.3(b)). Radial tyres also have a belt of reinforcing material between the casing and the tread, as shown in Figure 10.4. The belt, consisting of two or more layers of cords, runs around the circumference of the casing. The belt provides a firm base for the tread and holds it against the effects of the centrifugal forces that are present when the tyre is rotating.

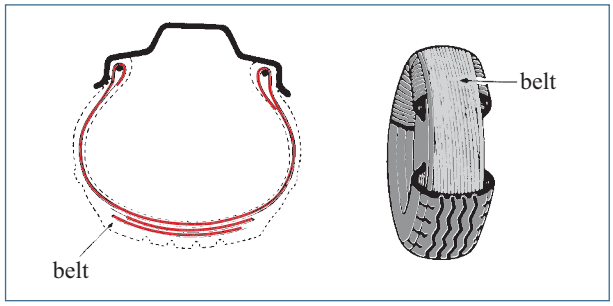


Figure 10.4 A radial tyre has a belt of cords around its circumference beneath the tread GOODRICH

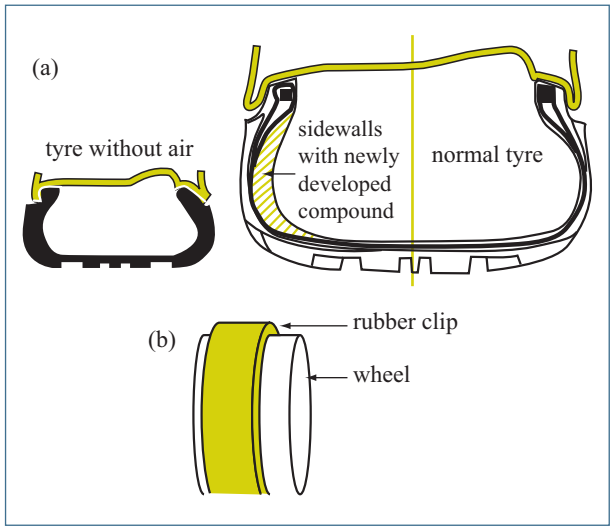


Figure 10.5 Run flat tyres (a) reinforced sidewall (b) rubber clip inside firm

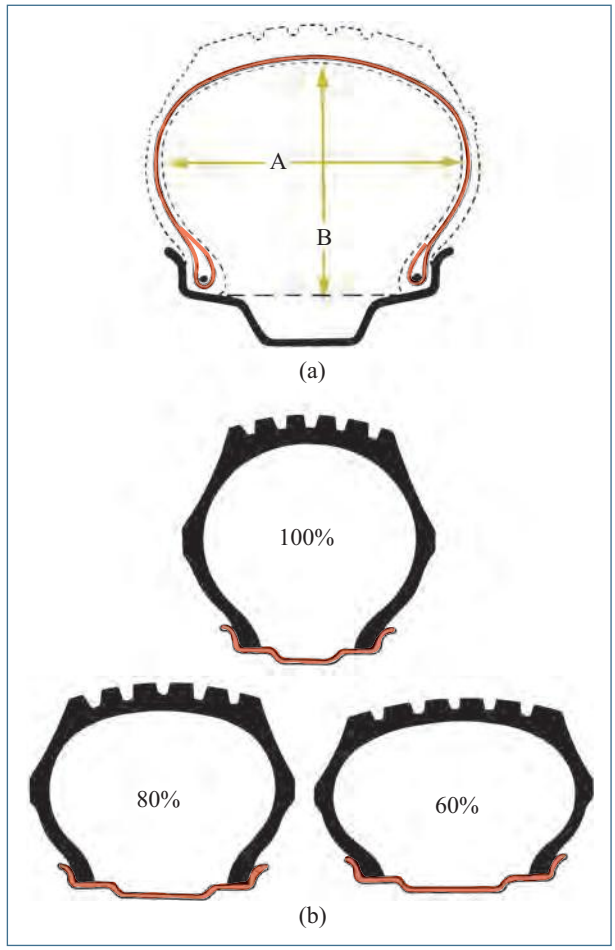


Figure 10.6 Tyre profiles (a) section through a low-profile tyre—height B is 80% of width A for the tyre shown (b) examples of tyre profiles and aspect ratios GOODRICH

10.1.5 Steel-belted tyres

Steel-belted tyres have cords of steel wire built into the reinforcing belt beneath the tread. This provides a strong belt that does not stretch under inflation pressure, giving the tread area greater stability while allowing flexible sidewalls.

10.1.6 Run flat tyres

Several manufacturers have developed systems that allow vehicles to be driven safely at restricted speeds with low or no tyre pressure. There are two types:

1 Reinforced tyre sidewall, as shown in Figure 10.5(a)
2 Rubber clip inside the rim, as shown in Figure 10.5(b).

Both systems operate in conjunction with tyre pressure monitors.

10.2 Tyre profiles

The tyre *profile* is the shape of the tyre section when it is mounted on the rim of the wheel. Tyres are produced in a number of different profiles, some fairly round and others much flatter. The *aspect ratio* of a tyre is the height/width ratio of the tyre section (Figure 10.6(a)). This is a way of measuring and comparing the profiles of tyres.

The aspect ratio is always less than one (for example, 0.80, but the decimal point is usually omitted) and is sometimes expressed as a percentage, with the percentage sign also often omitted. Tyres have different aspect ratios, such as 80, 75, 70, 65 and 60. For passenger vehicles, the trend is towards squatter and wider tyres with very low aspect ratios. Figure 10.6(b) compares three different tyre profiles.

10.2.1 Tyre footprint

The area of tread pattern in contact with the road is referred to as the 'tyre footprint'. When the vehicle is stationary or moving in a straight-ahead direction, the footprint will be uniform. A low-profile tyre will have a shorter and wider footprint than a high-profile tyre of similar size and load-carrying capacity, but the areas of the footprints will be about the same (Figure 10.7). Changes in the footprint will occur as a result of vehicle load, speed, cornering and tyre pressure.

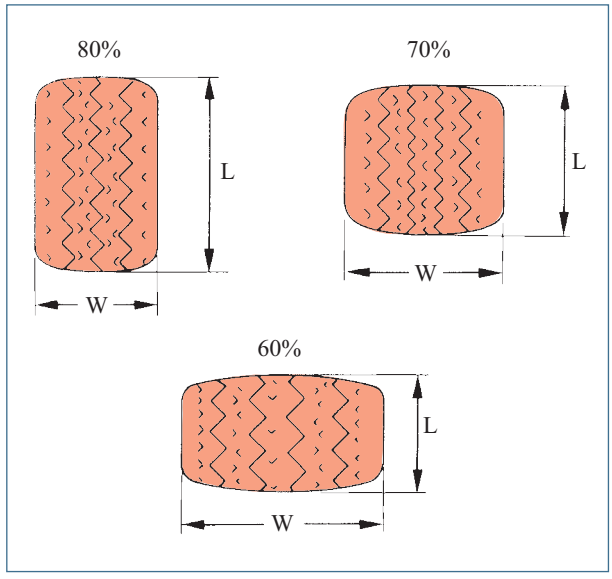


Figure 10.7 Tyre footprints on the road surface for different aspect ratios—L is contact patch length, W is contact patch width

10.3 Tyre sizes and identification

Information about a tyre is moulded into the sidewall. This information can include the manufacturer's name, tyre name, tyre size, type of construction, load index, speed category and country of manufacture (Figure 10.8). Some light-truck tyres are identified by 'LT'. Special types of tread may be identified, for example, 'M + S' indicates a tread suitable for mud and snow. The type of cord material may be identified by the words *rayon, nylon, polyester* or *steel.* 'DOT' appears on some tyres. This stands for Department of Transport (USA) and shows that the tyre conforms to United States standards.

10.3.1 Radial tyre sizes

For passenger vehicle-type radial tyres, two systems of sizes are in common use: metric and P-metric. The metric system originated in Europe, the P-metric in the USA.

Metric tyres

The following is an example of a metric marking for a tyre, with an explanation of what it means:

205/65 R16 92H

- 205 is the nominal section width of the tyre in millimetres
- 65 is the aspect ratio , i.e., height is 65% of width
- R means that it is a radial tyre
- 16 is the rim diameter in inches
- 92 is the load index number (see T able 10.1)
- H is the speed category symbol (see T able 10.2).

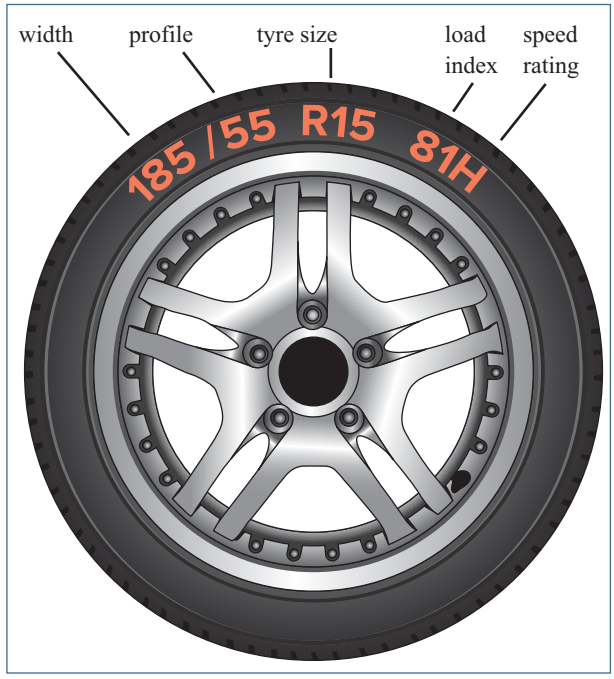


Figure 10.8 Information on the tyre sidewall

P-metric tyres

P-metric tyres are marked in the same way as metric tyres, with the prefix 'P' added. Following is an example of a P-metric tyre marking, with an explanation of what it means:

P175/65 R14 81H

- P stands for passenger car
- 175 is the tyre section, i. e. 175 mm wide
- 65 is the aspect ratio , i.e., height is 65% of width
- R means that it is a radial tyre

- 14 is the diameter of the wheel in inches
- 81 is the load index number (see Table 10.1)
- H is the speed category symbol (see Table 10.2).

The load index and speed category are referred to as the 'tyre description'. The *load index* is a numerical code for the maximum load that the tyre can carry; the *speed category symbol* is an alpha code for the speed rating of the tyre. Tables 10.1 and 10.2 show some of the more common load indexes and speed categories for passenger and light commercial vehicles.

Bias-ply tyres

Bias-ply tyres have their size shown in inches, such as 6.00–14, or 6.70–14. The first example shows that the width of the tyre section is 6 inches and the diameter of the rim is 14 inches. The ply rating is usually specified for light-truck bias tyres, and can be 6 or 8 ply.

Table 10.1 Load indexes for tyres

Load index	Kilograms
80	450
82	475
86	515
88	560
91	615
95	690
98	750
100	800

Table 10.2 Speed category symbols

Speed category symbol	Speed km/h
P	150
Q	160
R	170
S	180
T	190
U	200
H	210
V	240

10.4 Tyre tread patterns

Tyre treads are made in various patterns designed to suit different vehicles and operating conditions. These range from passenger vehicles operating at high speeds on constructed roads to tractors and earth-moving equipment operating under rough conditions.

10.4.1 Passenger vehicle tyres

The types of treads used on passenger vehicles are shown in Figure 10.9. These are designed to provide the necessary friction with the road surface for wet or dry conditions during acceleration, braking and steering. On wet roads, the various parts of the tread act like a squeegee, pushing the water away so that the tread can grip the road surface. Where there are pools of water on the road, the main tread pattern forces the water to the rear through its grooves, then shoves it aside. Small cuts or slots in the tread help to squeeze out water that remains on the road surface so the tyre runs on a relatively dry surface.

Figure 10.9 Types of treads for passenger vehicle tyres (a) symmetrical tyres (b) asymmetrical tyres (c) directional tyres

Apart from friction between the tyre and road being reduced by wet road conditions, a tyre can aquaplane on water. This is most likely to happen if the tyre is badly worn or subjected to severe braking. Under these conditions, a wedge of water under the tyre causes it to lift from the road surface. Tyre tread patterns are designed to minimise this possibility.

10.4.2 Directional tyres

Some tyres have tread patterns designed to rotate in only one direction, as shown in Figure 10.9(c). These tyres will have an arrow on the side wall that indicates the correct direction of rotation.

10.4.3 Tyre noise

Improvements in vehicle design, such as reducing wind noise and sound-proofing the cabin, have increased the need to reduce tyre noise. Tread patterns with uneven spacing between the gaps in the tread reduce the noise of a rotating tyre.

Table 10.3 Tyre placard

Tyre specifications & pressures				
Location	Front	Rear	Front	Rear
Wheel rim profile	5.5 J		5.5 J	
Recommended tyre sizes	175/65 R14 81H		175/65 R14 81H	
Recommended pressures				
To max. load	190 kP a		190 kP a	
High speed	28 p .s.i.		28 p .s.i.	

The tyres fitted to this vehicle must have a maximum load rating not less than 425 k g or a load index of 78 and speed rating not less than T

10.4.4 Australian Design Rules

Australian Design Rules (ADRs) are government regulations that cover safety and associated items for motor vehicles. The rules that relate to wheels and tyres for passenger vehicles deal with safety rims for wheels, and standards of strength, construction, pressure, load and tyre fitment. The rules apply to the manufacture of vehicles, but are also relevant to replacement tyres or wheels.

ADR 23 specifies standards of strength, construction, pressure and loads for tyres. This enables manufacturers to select appropriate tyres for their vehicles. ADR 24 concerns the tyres fitted to a vehicle, in relation to vehicle load capacity, rim size and tyre speed characteristics. It requires a placard to be permanently fixed inside the glovebox door (or other accessible location) that shows: the rims and tyres that can be fitted to the vehicle; the maximum load and speed ratings of the tyres; the recommended tyre pressures. Table 10.3 is an example of a tyre placard.

Handy hint: ADRs apply to replacement tyres and wheels as well as to original equipment. Replacements must be in accordance with the tyre and rim combinations specified on the placard.

10.5 Tyre inflation

Tyres should be inflated to the pressure recommended by the vehicle manufacturer, or as shown on the tyre placard on the vehicle. They should be checked regularly and inflated to the recommended pressure. Incorrect pressures can cause tyre wear as well as steering and braking problems. Figure 10.10 shows how correct and incorrect inflation affects tread contact with the road surface. Correct inflation holds the tyre in its correct shape, with the tread in full contact with the road surface. The tyre will act in the way it was designed to act, and there will be normal tyre wear.

Underinflation allows the tyre to become flatter. The edges of the tread will be in heavy contact with the road, but the centre will carry less load and will wear less than the edges. A tyre with low pressure can cause heavy steering and possible squealing on corners. Low pressure also increases the rolling resistance of the vehicle and therefore the energy required to drive it. Fuel economy will also be reduced as a result of low tyre pressures.

Overinflation gives a hard ride and subjects the tyre to road shocks because it does not flex normally. Uneven tyre pressures, particularly on the front wheels, tend to steer the vehicle to one side. The centre of the tread is in heavy contact with the road and will wear more than the edges.

10.5.1 Tyre pressure monitors

The tyre pressure can be monitored electronically using a device fitted around the rim inside it or in the tyre inflation valve. The pressure monitor uses wireless technology to send signals to the receiver about tyre pressure and temperature. The wheel and tyre combination is indexed to the location on the vehicle and should not be changed. Pressure monitors can come as standard equipment or be fitted as an accessory.

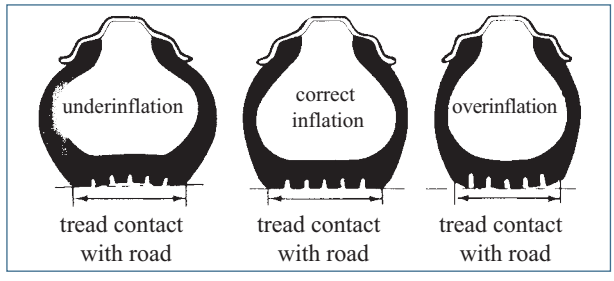


Figure 10.10 Effects of correct and incorrect inflation on the contact that the tread mak es on the road surface

Handy hint: Using nitrogen gas for tyre inflation is becoming more common in automotive applications. Nitrogen leaks through the rubber three times more slowly than oxygen, maintaining the tyre at the correct pressure for longer.

10.6 Tyre wear

Tread wear indicators are moulded into the tread pattern of passenger vehicle tyres. The indicators show up as plain bars across the tread when only 1.5 mm of tread remains. The tyre should then be replaced. Tyre wear can also be checked using a tread depth gauge (Figure 10.11). There are many factors that cause tyre wear. Where abnormal wear occurs, the type of wear can indicate the likely cause of the problem.

Figure 10.11 Checking tyre tread wear SHUTTERSTOCK

10.6.1 Underinflation

If a tyre is underinflated, its sides will bulge, lifting the centre of the tread away from the road. The load will be concentrated on the outer edges of the tread, causing excessive wear (Figure 10.12(a)). The centre of the tread will carry a reduced load and so will have less wear.

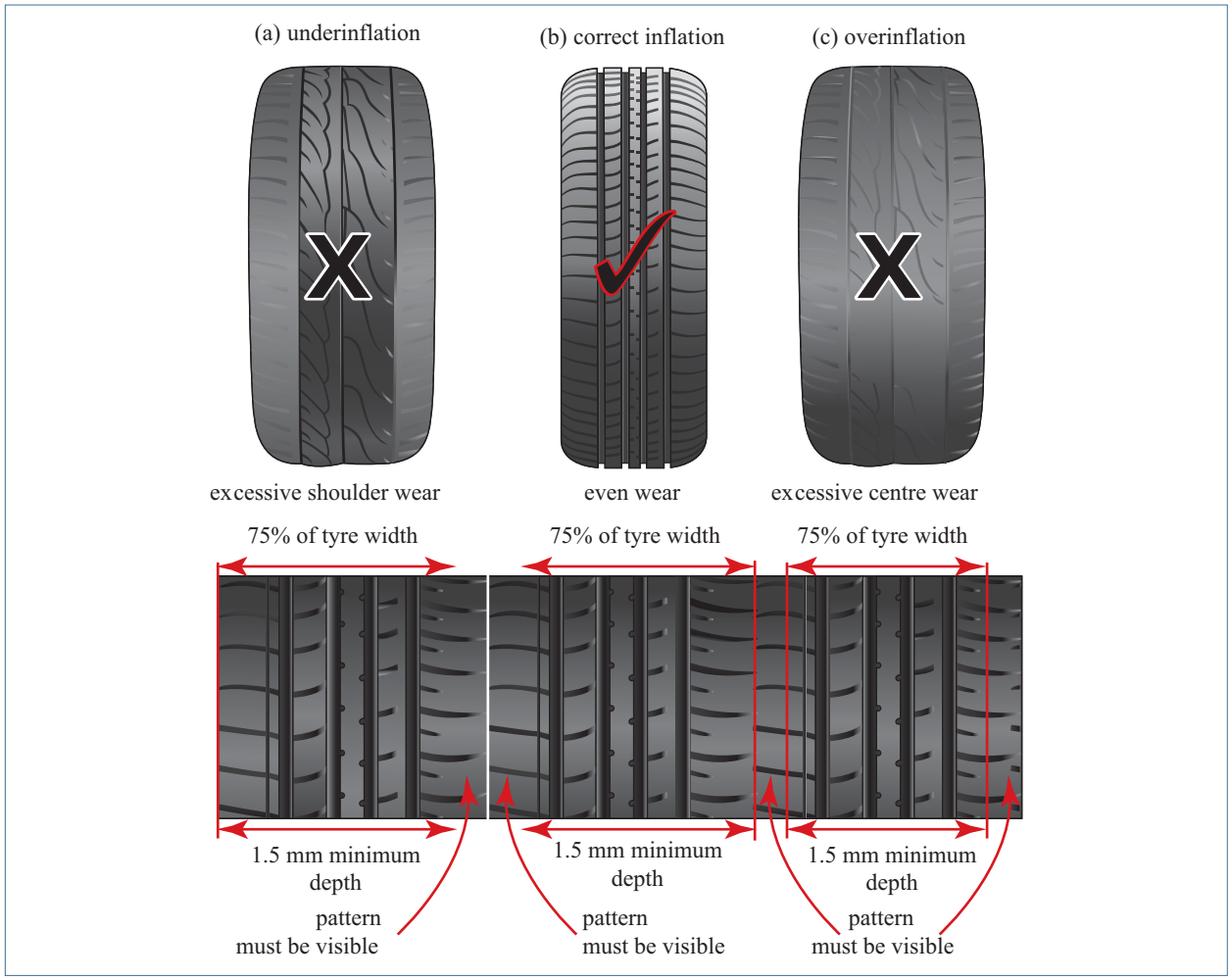


Figure 10.12 Tyre wear due to incorrect inflation (a) wear from underinflation (b) wear from correct inflation (c) wear from overinflation

Underinflation allows greater flexing of the tyre sidewalls, imposing higher loads on the cords. Also, excessive heat is generated, increasing the temperature of the tyre. High temperatures soften the rubber compounds and allow the plies or tread to separate from the casing. If an underinflated tyre strikes a kerb or a hole in the road, the sidewalls could be pinched against the rim. This could damage the tyre and cause it to deflate, or break some of the cords and cause early tyre failure.

10.6.2 Overinflation

An overinflated tyre has a reduced tread area in contact with the road surface. This increases the load on the centre of the tread so that it wears much more quickly than its sides (Figure 10.12(c)). The tyre will not flex as much as it should and the fabric will receive shock loads which, combined with high tyre pressure, can cause tyre failure.

10.6.3 Wheel camber

When viewed from the front, the front wheels of a vehicle are not vertical, but lean out a little at the top. This angle from the vertical is referred to as *camber*. If a wheel has excessive camber, its outer edge will wear more rapidly than its inner edge (Figure 10.13(a)). This occurs because the face of the tread does not sit flat on the road.

10.6.4 Wheel alignment

Front wheels have a small amount of *toe-in* or *toe-out,* but if this is excessive, the tyre will tend to drag sideways while it is being moved forwards. Characteristic of this type of wear are the feather edges that appear on one side of the tread (Figure 10.13(b)). Front wheels also have *toe-out on turns.* When cornering, the inside wheel is turned a greater angle than the outer one. Incorrect angles can cause the tyres to scrub.

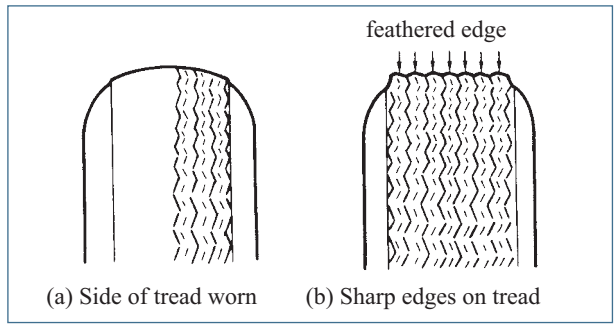


Figure 10.13 Tyre wear due to wheel problems (a) wear from excess camber (b) wear due to excessive toe-in or toe-out

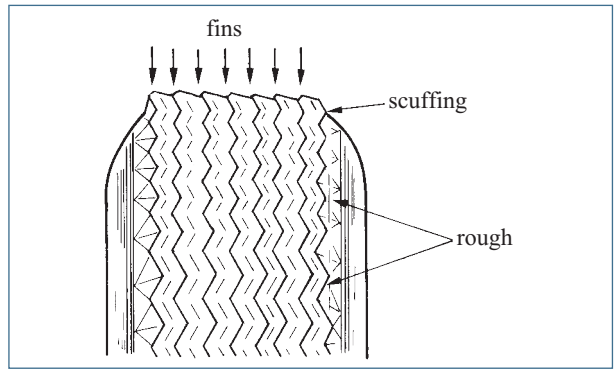


Figure 10.14 Wear from high-speed cornering

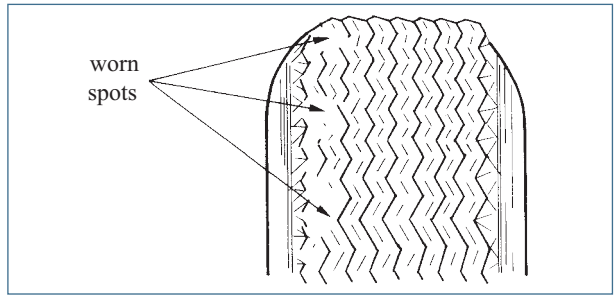


Figure 10.15 Uneven tread wear due to mechanical faults, unbalanced wheels or tread separation

10.6.5 Cornering and high speed

Tyre wear from taking corners at too high a speed can be similar to camber wear. When cornering, centrifugal force on the vehicle is resisted by the tyres on the road surface. At high speed, some side-slip of the tyre occurs, producing a diagonal type of wear which rounds the outer shoulder of the tyre. In severe cases, fins or sharp edges can be found on the inner edges of the treads (Figure 10.14). In general, tyres can have a faster rate of wear at high speeds because of the higher temperatures, greater scuffing and more rapid flexing to which they are subjected.

10.6.6 Mechanical conditions

Tread wear that is uneven or in spots can be caused by a number of mechanical conditions (Figure 10.15). These include misaligned wheels, out-of-balance wheels, defective brakes, inoperative shock absorbers and loose or worn steering or suspension parts.

10.7 Tyre rotation

Tyres do not wear uniformly on all four wheels. Rate and type of wear vary according to the location of the tyre on the vehicle. To equalise wear on all tyres, the wheels and tyres are rotated (interchanged) at regular intervals, or when wear is noticeable. Figure 10.16 shows three different sequences of tyre rotation.

1 Four wheels, same side . The wheels are moved from front to rear on the same side of the vehicle . This evens out tyre wear while k eeping the same direction of rotation (Figure 10 .16(a)).
2 Five-wheel sequence . Where all the tyres are in good condition, the spare wheel can be introduced so that wear is evenly distributed over five tyres (Figure 10 .16(b)).
3 Four wheels, diagonal. Diagonal rotation changes the wear pattern of the tyres and also changes the direction of rotation (Figure 10 .16(c)).

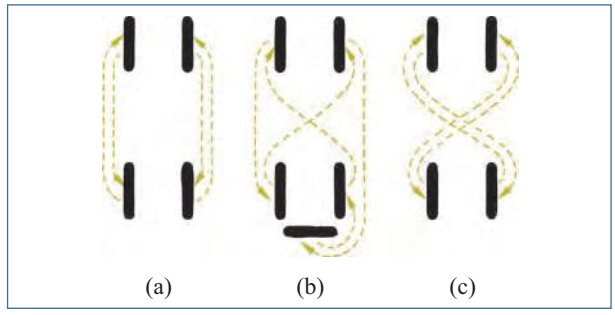


Figure 10.16 Three different sequences of tyre rotation (a) tyres on same side (b) using spare (c) diagonal rotation

The spare can be part of a normal sequence of rotation, or only introduced if one of the tyres has damage or abnormal wear. As far as possible, the spare should be paired with a tyre which has a similar amount of tread.

10.7.1 Reasons for tyre rotation

Front tyres have a wear pattern that is different from rear tyres. Tyres also wear differently, depending on whether they are on a front-wheel-drive or a rear-wheel-drive vehicle. With rear-wheel drive, the front tyres are likely to have more wear on the edges of the tread due to steering; rear tyres could have more wear on the centre of the tread because they are used for driving. With front-wheel drive, the front tyres are likely to wear faster than the rear tyres because they are used for both driving and steering. They also carry more of the vehicle load than the rear tyres.

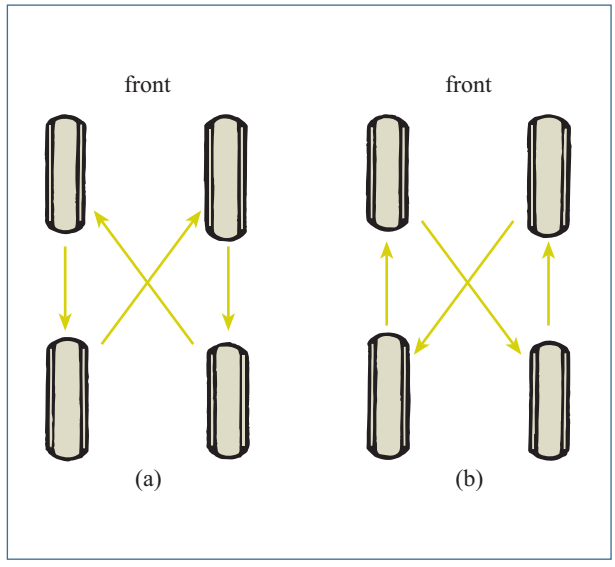


Figure 10.17 Tyre and wheel rotation (a) for front-wheel drive (b) for rear-wheel and four-wheel drive

There are various recommended sequences of rotation. Figure 10.17 shows a sequence for front-wheel-drive vehicles and a different one for rear-wheel-drive and four-wheel-drive vehicles. The different sequences take into account that the wear patterns of the tyres of front-wheel drive and rear-wheel drive are different.

Handy hint: Tyres with pressure monitors cannot be rotated without reprogramming the monitor ECU to the new location on the vehicle . Some modern vehicles cannot perform tyre rotation due to differing rim/tyre diameters and widths. Others have no spare tyre or a space-saver tyre .

10.8 Wheels

Passenger vehicle wheels are either pressed steel or cast aluminium-alloy construction. Wheels consist of two main parts: the flange (or disc) and the rim. Steel wheels have the rim formed separately from the flange; the two parts are then welded together to form the wheel. Ventilation holes in the flange allow air circulation to help dissipate heat from the brakes and associated parts.

Aluminium-alloy wheels are sometimes used for appearance, but they are also used because aluminium and its alloys are not as heavy as steel. Wheels can be cast in aluminium alloy with much thicker sections than steel wheels. This provides stiffness, allowing stresses to be distributed over a wider area. Also, aluminium alloy is a good conductor of heat and this helps to dissipate some of the heat generated by the brakes and tyres.

10.8.1 Wheel rims

Rims for passenger vehicles are of the *drop-centre* or *well-base* type. With these wheels, the centre of the rim is ‘dropped’, or reduced in diameter, to form a well which enables the tyre to be removed and replaced. A rim of this type is shown in Figure 10.18. The rim also has humps which hold the bead of the tyre in position against the edge of the wheel rim if a tyre fails.

Handy hint: Split-rim type wheel rims are mainly used on four-wheel-drive vehicles and light trucks.

Rim size

Rims are designated by their width and their profile (shape). For example, in a common passenger vehicle wheel with a rim of 5.5 JJ, the '5.5' represents the rim width in inches, and 'JJ' is a code for a particular rim profile. Any replacement should have the same sized rim as the original, or should comply with the rim size shown on the tyre placard attached to the vehicle (see Table 10.3).

The width of the rim will determine the spread of the beads of the tyre when it is mounted, so it must be correct for the size of tyre. If the rim is too narrow, the width of the tyre section will be reduced and the point where the tyre should normally flex will be closer to the tread. If the rim is too wide, the tyre will spread and the flex point will move closer to the rim. In both cases, the tyres will produce more heat than they should. Also, the contact between the tread and road will be altered.

An oversize tyre may not seat correctly; the bead area could be distorted and not seal properly against the rim. If the tyre has a tube, it will be overstretched around the beads of the tyre and could deteriorate much faster than it normally would.

Rim offset

The flange of the wheel is not in the centre of the rim, but is closer to the outside. This gives the rim offset.

The amount of offset is the distance from the mounting surface of the flange to the centre of the rim. Altering the offset will affect the steering geometry of the vehicle. A replacement wheel should have the same offset as the original and comply with the rim size on the vehicle placard.

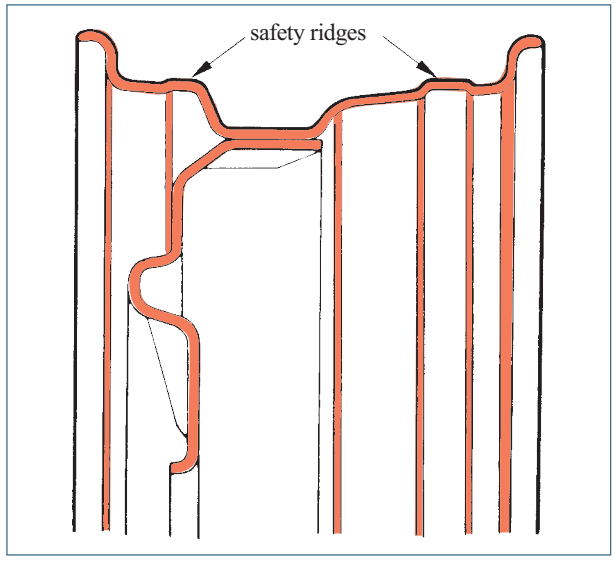


Figure 10.18 Wheel safety rims

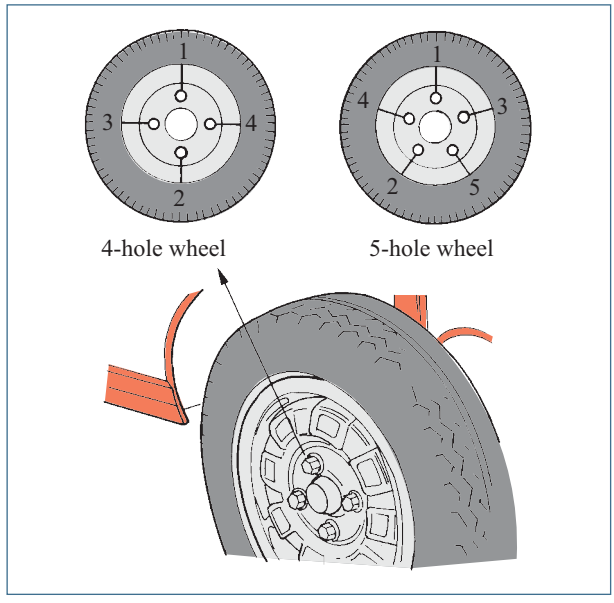


Figure 10.19 Sequence of tightening wheel nuts

10.8.2 Installing wheels

Wheel nuts have a taper which fits into a corresponding tapered hole in the wheel. When the nuts are tightened, the tapers centre the wheel on the hub. Wheel nuts or bolts should be tightened to the specified torque. To ensure that the wheels are seating correctly and not distorted, they should be tightened in the correct sequence, as shown in Figure 10.19.

10.8.3 Wheel covers and caps

Wheel covers and caps of various designs are fitted to the wheels of passenger vehicles. Figure 10.20 shows a steel wheel and an aluminium-alloy wheel. The steel wheel has a plastic cover. It is held to the wheel by lugs and a large spring ring. The alloy wheel is designed to be seen, but has a wheel cap which covers only the wheel nuts and hub.

Safety: Correct tools and equipment must be used when removing and fitting wheels and tyres. This includes lifting equipment such as trolley jacks **, axle stands and appropriate hand tools.**

10.9 Removing and fitting tyres

Tyres are removed from (and also fitted to) wheels with a tyre-changing machine (Figure 10.21). The wheel with its deflated tyre rests on the bed of the machine, which uses air-operated or electrically-operated tools to remove the tyre from the wheel. A flat-ended bead-breaking tool forces the beads of the tyre away from the rim. A lever or removing tool then levers or rolls the bead of the tyre off the wheel as the wheel is rotated.

While one side of the bead is being removed, the bead on the opposite side must be pushed hard into the well of the wheel. The tyre cannot be stretched over the rim and, unless the bead is broken away from the edge of the rim and held into the wheel well, the tyre cannot be removed.

10.9.1 Fitting tyres

Safety: Correct PPE must be worn at all times when removing and fitting tyres. Always read and follow tyre changing-machine operation and correct manual handling techniques.

Key points about fitting tyres include:

1. Before fitting a tyre, all dirt or rust should be removed from the wheel rim.
2. The wheel is placed on the machine, and the beads are rolled over the wheel rims. A coating of vegetable oil or soapy water will assist in fitting the tyre.
3. Red dots on the tyre and rim should be aligned (see 'Balance marks' below).
4. A tubeless tyre must be inflated quickly to force the beads onto the rim. The valve core can be removed temporarily to assist the flow of air.
5. When inflated to the correct pressure, check the tyre to see that the beads are seating correctly by checking the bead indicator in relation to rim of the wheel. The bead indicator is a moulded ring on the sidewall of the tyre. When the tyre is correctly installed, the bead indicator should be concentric with the edge of the rim.
6. To test for leaks, the complete wheel can be immersed in water. Leaks will be shown by air bubbles.

Handy hint: Alloy wheels are made of relatively soft material and must be treated carefully to avoid damage.

Balance marks

Tyres and rims are marked during manufacture to identify positions for balance. This allows the high harmonic point (heavy spot) of the tyre to be indexed with the low harmonic point (light spot) of the wheel. A tyre manufactured in Australia will

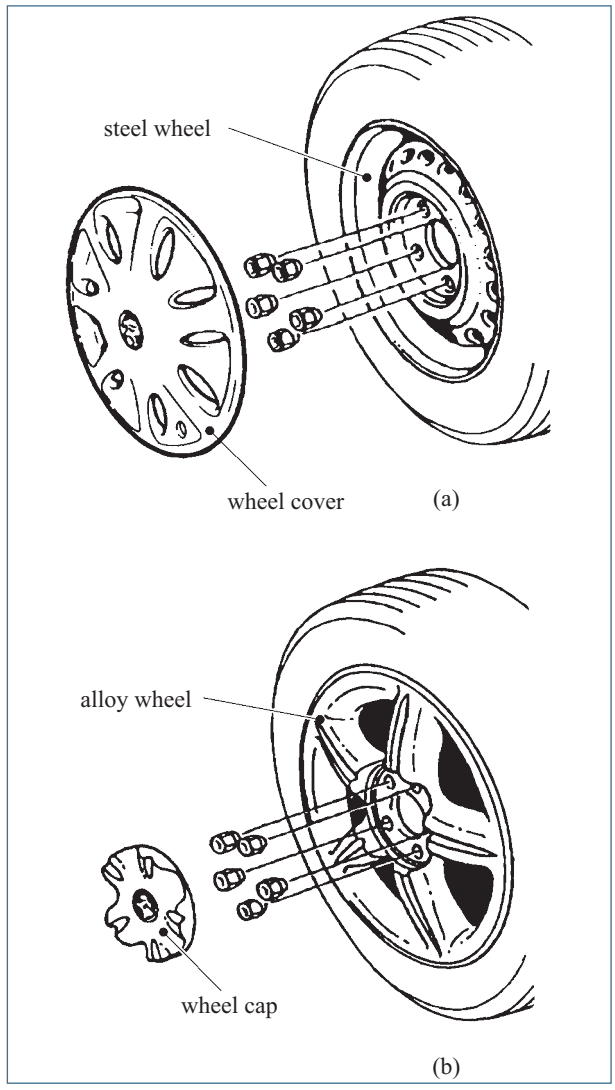


Figure 10.20 Wheels (a) 15-inch steel wheel (b) 16-inch alloy wheel

Figure 10.21 A wheel mounted on a tyre-changing machine CORGHI

have a red dot at the heavy spot. The flange of the wheel will have a coloured dot and a drill mark to identify the light spot. These marks should be aligned when the tyre is fitted to the wheel. Some imported tyres have a white dot for the light spot placed 180° from the mark on the wheel. A yellow spot can represent the static balance point.

Handy hint: For practical purposes, the high and low harmonic points can be considered as the heavy and light spots of the tyre .

Sustainability: Worn or 'end-of-life ' tyres must be recycled to lower their environmental impact **on landfill.**

10.10 Selecting tyres and wheels for specific applications

10.10.1 Tyre selection

When selecting special tyres, the first things to be aware of are the tyre specifications of the vehicle model (the load and speed rating). There is no need to stick to a particular brand, but tyres must fit the wheel properly and be of the size and type recommended by the manufacturer. It is also important that they are matched as pairs, front and rear. That is, both front tyres should have the same tread pattern and tread depth, and both rear tyres should have the same tread pattern and tread depth (although these need not be the same as the front tyres). With unmatched tyres, braking, steering and handling could be compromised.

10.10.2 Wheel selection

Only wheels and tyres that are shown on the vehicle's tyre placard or listed in the owner's handbook should be fitted. For specific applications, other combinations might be used. Wheels up to 26 mm wider than the largest optional wheel recommended by the vehicle manufacturer may be fitted. The overall diameter of the wheel-and-tyre combination must be no more than 15 mm over the largest diameter wheel-and-tyre combination specified for the vehicle, and not more than 15 mm below the smallest diameter wheel-and-tyre combination.

When fitting a larger wheel-and-tyre combination, the fitted unit must stay within the mudguard. Also, when viewed directly from the top of the mudguard to the ground, with the tyre and wheel facing in a straight-ahead position, the tyre and wheel must not be visible.

Handy hint: The wheel track must not be increased by more than 25 mm beyond the maximum specified by the vehicle manufacturer for the particular model. A ustralian Design Rules must **be followed.**

10.11 Wheel balance

Wheels and tyres need to be in balance to prevent vibration and minimise wear of tyres, suspension components and steering parts. Correct wheel balance is important for front wheels, where unbalance could cause steering problems.

When a wheel rotates, centrifugal force acts on each part of the wheel and tyre, and the effect is like a number of forces pulling outwards against the tyre. These forces become stronger as the rotational speed of the wheel increases. Where the mass is evenly distributed around the wheel and tyre, all the forces will be equal. The wheel and tyre are balanced, so centrifugal force has no obvious effect (Figure 10.22 left). However, if the tyre has a heavy spot, it will be unbalanced and the effect of centrifugal force will be greatest at the heavy spot (Figure 10.22 right). There will be a strong pulling force that rotates with the tyre and this will pull the wheel up and down or from side to side.

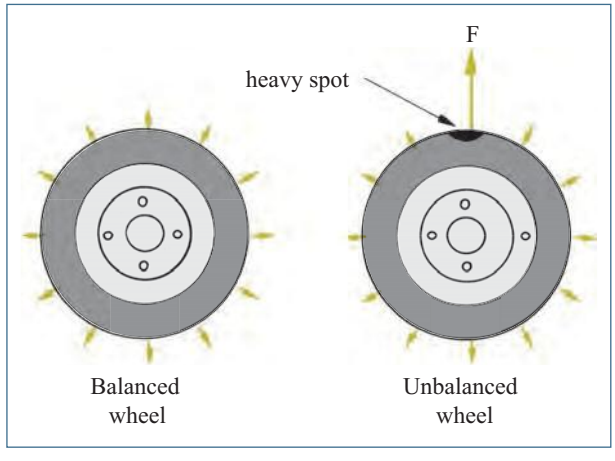


Figure 10.22 Centrifugal force acting on a balanced and an unbalanced wheel

10.11.1 Effects of unbalance

There are two types of balance (and unbalance): *static* and *dynamic*. Figure 10.23 shows the effects of both. Unbalance is caused by heavy spots on the tyre, but the position of those spots will determine whether the tyre has static unbalance or dynamic unbalance. A heavy spot in the centre of the tread will produce static unbalance and cause the wheel to move up and down. A heavy spot (or spots) on the side of the tyre will produce dynamic unbalance and cause the wheel to move from side to side. The difference between the two types of unbalance is shown in Figure 10.24.

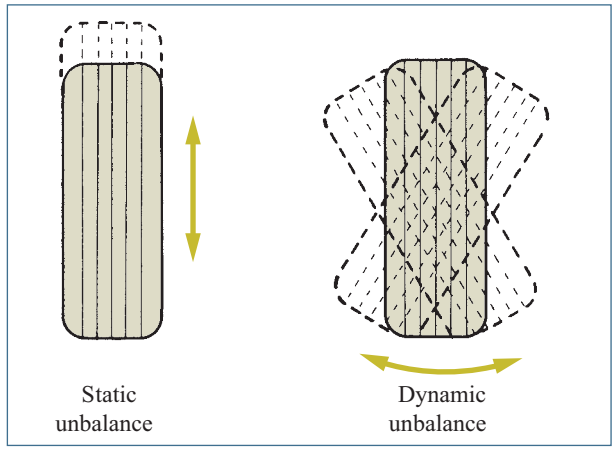


Figure 10.23 Effects of static and dynamic unbalance on a wheel

10.11.2 Static balance

A wheel (and tyre) that is in static balance and free to rotate on its axle will remain in any position to which it is turned. If it is out of balance, the heavy spot will rotate the wheel until it comes to rest at the bottom. In Figure 10.24(a), the heavy spot in the centre of the tread causes static unbalance. This can be corrected by fitting a weight to the wheel rim directly opposite the heavy spot. (Two weights are needed, each equal to half the mass of the heavy spot.) Without balance weights, the wheel would tend to be pulled up and down as it rotates, which is referred to as *tramp*. The force that rotates with the wheel would also try to pull it to the front and back, but this is prevented by the suspension.

The term *harmonics* is used in relation to vibration and unbalance. A single out-of-balance spot on a tyre would produce a vibration, referred to as the 'first harmonic'. A second heavy spot would produce a second harmonic, and so on. In simple terms, harmonics can be considered to be vibrations caused by a heavy spot on a tyre.

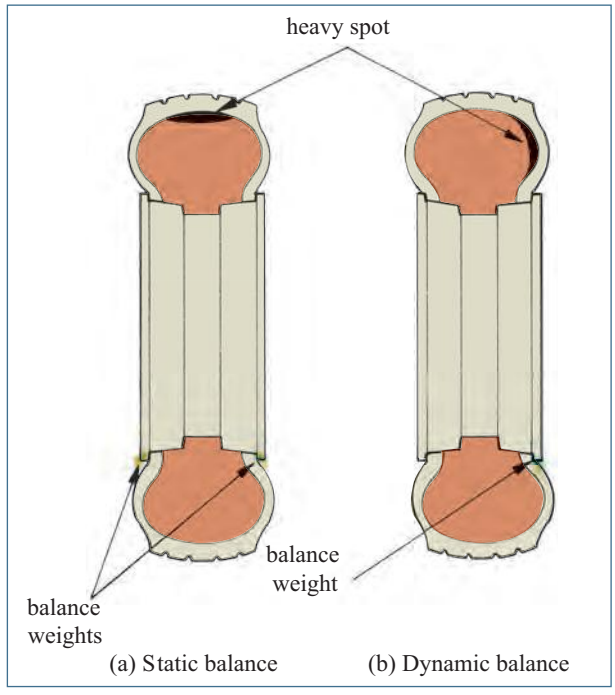


Figure 10.24 Difference between static and dynamic balance—corrective weights have been added

10.11.3 Dynamic unbalance

The tyre in Figure 10.24(b) has a heavy spot on its side. With front wheels, the force will pull the tyre and try to turn the wheel on its steering axis. As the wheel rotates, it will be pulled from side to side because the force changes its direction with each half-turn of the wheel. It pulls the front of the wheel, and then the back, to produce a side-to-side movement which is referred to as *wheel wobble* or *shimmy*.

The effect of the force is noticeable only at the front and at the rear of the wheel, where the steering allows it to pivot from side to side. When the forces are at the top or bottom, the wheel is held and so has no side-to-side movement, although it can have *tramp*.

Couple

The tyre in Figure 10.25 has two equal heavy spots which are diagonally opposite. The wheel is in static balance because one heavy spot balances the other. However, while the wheel has static balance, it has dynamic unbalance. When this wheel (without the weights) is rotating, centrifugal force acts on both heavy spots. A force will pull the front of the tyre and a force will also pull its rear. Together, they form a *couple* which produces shimmy. The balance weights give the wheel dynamic balance.

10.11.4 Correcting unbalance

Balance weights are fitted to the rim of the wheel to balance the heavy spot (or spots). Figure 10.26 shows a wheel with static unbalance. Two balance weights are used to correct it so that the mass is evenly distributed on the wheel. Figure 10.27 illustrates a wheel that has dynamic unbalance; a weight is needed for correction. When in dynamic balance, the mass is distributed evenly on each side of the wheel centreline. Most tyre-and-wheel assemblies that need balancing require a combination of static and dynamic balancing.

10.12 Balancing wheels

There are two general designs of wheel-balancing machines. One type spins the wheel with it off the vehicle, and the other spins the wheel while it is on the vehicle. They both use the vibrations that occur when the wheel is rotating to locate any unbalance in the wheel and tyre. They check both static and dynamic balance.

10.12.1 Off-vehicle wheel balancers

These are floor-mounted machines which spin the wheel after it is removed from the vehicle. The wheel is mounted on the spindle of the machine and spun by an electric motor (Figure 10.28). Balancers of this design have direct-reading instruments. With a single spin of the wheel, the machine will give readings for both static and dynamic balance. The instruments show the balance weights required and where they should be fitted to the wheel.

Machines of this type basically consist of a lightly mounted spindle for the wheel and electronic sensors to measure the vibrations of the spindle when the wheel is rotating. The vibrations are picked up by the sensors and then transferred to the instruments, which show the out-of-balance readings. A wheel assembly that is in balance produces no vibrations. Wheel balancing machines have electronic components and circuits that make them easy to operate. In most cases, the wheel size is selected by the operator and the machine then automatically provides readings to suit the size of the wheel being balanced.

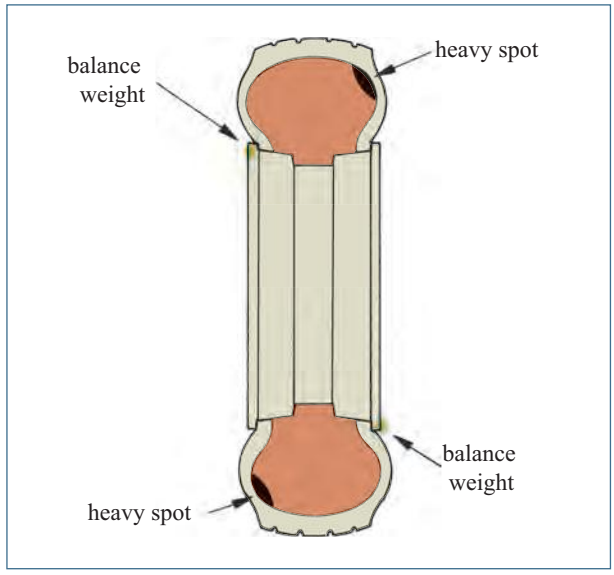


Figure 10.25 Couple—the wheel is in static balance but weights are needed for dynamic balance

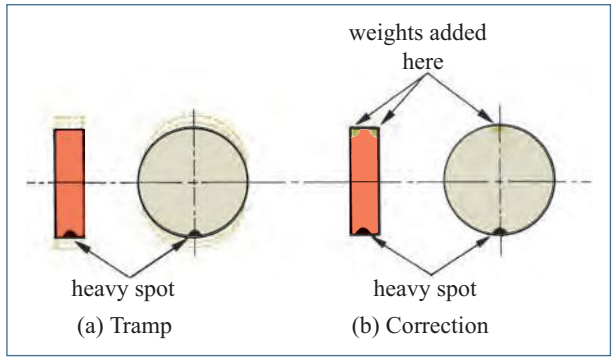


Figure 10.26 Correction of static unbalance (a) heavy spot causes wheel tramp (b) corrective weights added

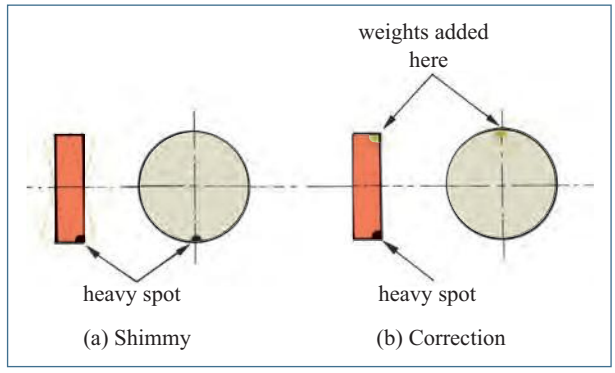


Figure 10.27 Correction for dynamic unbalance (a) heavy spot causes wheel shimmy (b) corrective weights added

Safety precautions

Wheel-balancing machines have a safety hood which covers the wheel while it is being spun. The wheel can reach high speed; covering the wheel protects the operator from a wheel weight that might fly off. Before spinning the wheel, stones should be removed from the tread. This is done to avoid possible injury to the operator and to obtain accurate balance.

10.12.2 Fitting balance weights

Balance weights are made in a number of different sizes; the mass, in grams, is shown on the weight. Balance weights have a spring clip which holds them on the rim of the wheel. They are fitted by being tapped into place with a hammer. When properly installed, they fit neatly into the shape of the rim (Figure 10.29).

Figure 10.28 Off-vehicle motorised wheel balancer with safety hood and digital instruments CORGHI

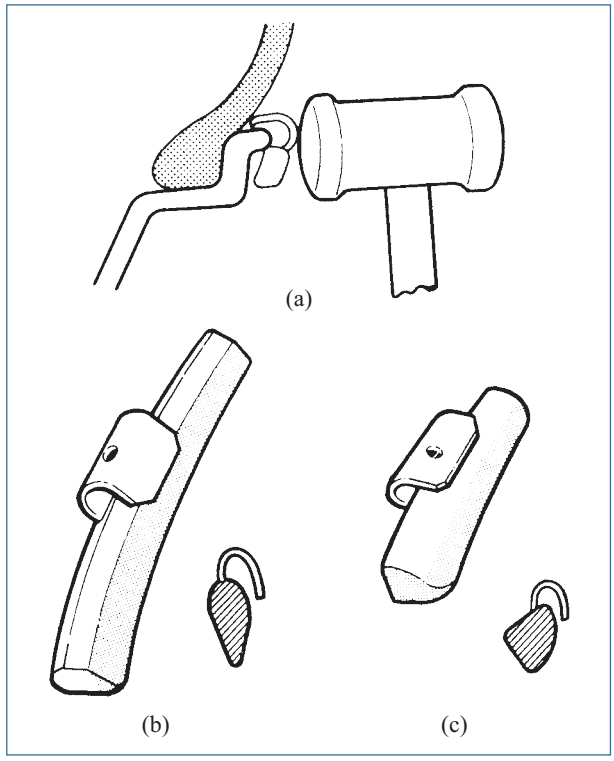


Figure 10.29 Balance weights (a) fitting a weight to a rim (b) weight for an aluminium wheel (c) weight for a steel wheel FORD

Different weights are used for aluminium and steel wheels. Aluminium wheels have a different-shaped rim from steel wheels, and so the weights need a different cross-section. Flat adhesive or 'stick-on weights' are also used for aluminium wheels. They are fitted on the inside of the rim; the surface must be clean to allow the stick-on weights to be secured (Figure 10.30).

10.12.3 Tyre and rim runout

Where a wheel is difficult to balance, the wheel and tyre should be checked for excessive runout. A dial gauge mounted on a base checks the rim (Figure 10.31). Generally, runout should not be more than about 2 mm. The tyre is checked at the centre of the tread for radial runout and against the sidewall for lateral runout. Before checking tyre runout, the vehicle should be driven to warm up the tyre and get rid of any flat spots on the tyre due to standing. Tyre runout and unbalance can sometimes be reduced by deflating the tyre and rotating it 180°.

Figure 10.30 Stick-on balance weights SHUTTERSTOCK

Figure 10.31 Checking tyre and rim runout

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain the importance of wheels and tyres to vehicle and occupant safety
- describe how wheels and tyres impact balance and alignment
- describe tyre construction, including profile , size and identification
- demonstrate the correct way to remove and refit tyres
- explain the reasons for balancing wheels and tyres
- demonstrate how to balance wheels and tyres.

REVIEW QUESTIONS

1 What are tubeless tyres ?
2 Name the various parts of a tyre .
3 What is meant by ply rating ?
4 What is a low-profile tyre ?
5 What is a radial tyre ?
6 What are safety rims ?
7 How can the correct-size tyres for a passenger car be determined?
8 What is meant by static balance ?
9 What is meant by dynamic balance ?
10 Name the types of wheel balancers and indicate briefly how each type operates.
11 What are some of the effects of a wheel that is out of balance ?
12 What is a tread wear indicator ?
13 How can tyre and wheel runout be check ed?
14 Indicate some of the precautions that are needed when using a wheel balancer .
15 How are wheel weights fitted?
16 Indicate the sequence for tightening wheel nuts.
17 What is a tyre placard ?
18 What is meant by load index ?
19 What is meant by speed category ?
20 What is a run flat tyre ?

CHAPTER 11

Brakes

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify brake system components, including their function, operation and location on modern vehicles
2 state the operating principles of hydraulic braking systems
3 safely carry out brake system service and maintenance in accordance with workplace and manufacturers' requirements and specifications
4 accurately diagnose and repair brake system components.

A brake system has two main sections: the brake assemblies at the wheels and the hydraulic system that applies the brakes. The system includes the service (foot) brakes for use when the vehicle is being driven, and a parking brake which is applied when the vehicle is parked. Some systems have disc brakes at all four wheels; some have discs at the front and drum brakes at the rear; others have drum brakes at all four wheels.

Brake service involves maintenance and repair of drum brakes, disc brakes and the parking brake or the hydraulic system. Servicing the hydraulic system includes checking the level of the fluid and renewing cups and seals if there is a leak. The brake linings of drum brakes and the pads of disc brakes gradually wear away and have to be replaced when they become excessively worn. Some brakes require adjustments to compensate for wear, although most systems have automatic adjustments.

11.1 Basic brake system

Figure 11.1 shows a hydraulic brake system. The parts are as follows:

1 Brake pedal—operated by the driver
2 Brake booster—makes the brakes easier to apply
3 Master cylinder—provides hydraulic pressure
4 Caliper and discs—slow or stop the wheels when the brakes are applied
5 Brake lines and hoses—connect the master cylinder to the brake calipers at the wheels
6 Brake fluid—transmits force from the master cylinder to the calipers at the wheels.

11.1.1 Operation

When the driver pushes the brake pedal, force is applied to pistons in the master cylinder. The pistons apply pressure to the fluid in the cylinder, and the brake lines transfer this to the calipers. The pistons in the hydraulic

cylinders in the calipers are moved to apply the brakes. When disc brakes are applied, brake pads are clamped against the disc. When drum brakes are applied, brake shoes are expanded against the inside of the brake drum. These different actions provide the friction between the parts that is needed for braking.

A moving vehicle has energy which must be absorbed by the brakes when they are applied. The energy is converted into heat as a result of the friction between the braking surfaces. The heat is then dissipated into the brake parts and the surrounding atmosphere. So, the brake pads and discs or the brake linings and drums, together with their associated parts, must be able to withstand high temperatures and high pressures.

Handy hint: Kinetic energy is converted to heat energy by the brak es through friction.

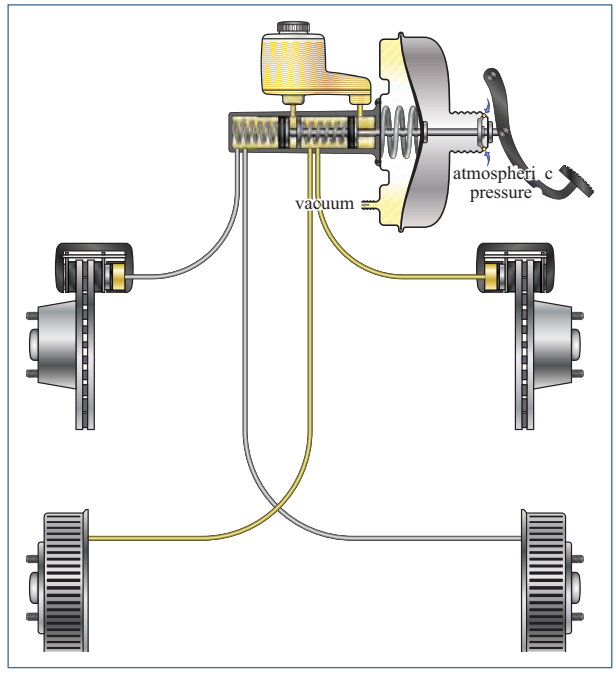


Figure 11.1 Arrangement of diagonally split brak e system SHUTTERSTOCK

11.2 Hydraulic principles

The hydraulic system transmits and increases force through cylinders and pistons of different sizes. Operation of the hydraulic system is based on Pascal's principle, a scientific law which states: *Force is applied to liquid and pressure is the result.*

11.2.1 Liquids will not compress

For all practical purposes, liquids are not compressible, and so hydraulic pressure represents a force applied to the liquid in an enclosed space. The cylinder in Figure 11.2 contains liquid and a piston. As a result of the force on the piston, the liquid applies pressure to the walls and bottom of the cylinder. The piston does not move as there is nowhere for the liquid to go.

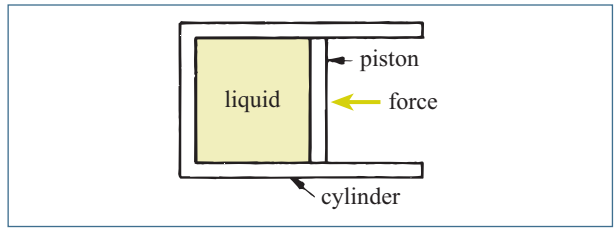


Figure 11.2 Force applied to a liquid transmits pressure

Handy hint: Gas can be compressed but, for all practical purposes, a liquid cannot be compressed.

11.2.2 Air will compress

If a cylinder contains both air and liquid, a force applied to the piston will compress the air and reduce its volume, and the piston will move down the cylinder (Figure 11.3). When the force is removed, the piston will return to its original position.

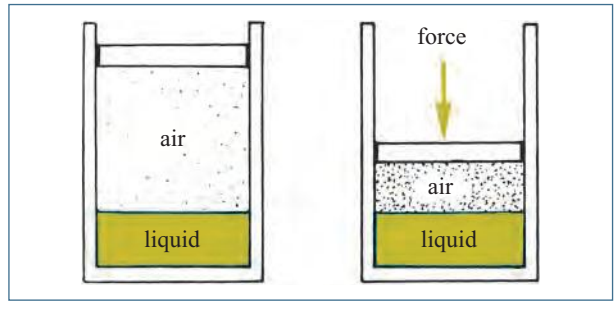


Figure 11.3 Force applied to the piston compresses the air but not the liquid

This arrangement of air and liquid would be unsatisfactory for operating hydraulic brakes, as the force would not be transmitted through the system. Much of the brake pedal movement would merely be used to compress the air without applying the brakes.

Handy hint: When work is done on hydraulic brak es, air can enter the system and the brak es then have to be bled to remove it.

11.2.3 Force and pressure

Figure 11.4 shows two cylinders of the same diameter. Force applied to one piston is being transferred hydraulically to the other. As the cylinders and pistons are the same size, the force applied to one piston

will be the same as the force delivered by the other. However, forces can be increased or reduced by having cylinders of different sizes.

Figure 11.5 is a simple hydraulic brake system with three cylinders of different sizes. The diagram explains force and pressure. When the brake pedal is pressed, the force against the piston in the master cylinder (A) will apply pressure to the fluid. The pressure will be the same in all parts of the system, but it will have a different effect on the pistons in the other cylinders. There will be different forces from the pistons, as follows:

1 Cylinder B is smaller than A, so the force from B will be less than the force applied to A.
2 Cylinder C is larger than A, so the force from its piston will be greater than the force applied to A.

In a hydraulic brake system, the master cylinder is smaller than the wheel cylinders, so the force at all the wheel cylinders is increased. The force can be varied by different-sized cylinders, and also from front to rear, for better braking (even though the pressure is the same in all parts of the system).

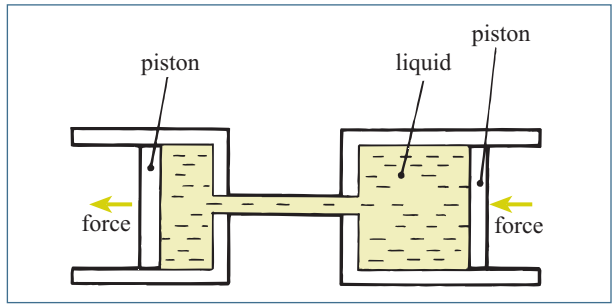


Figure 11.4 Force is transmitted by hydraulic means from one cylinder to another—equal cylinders, equal force

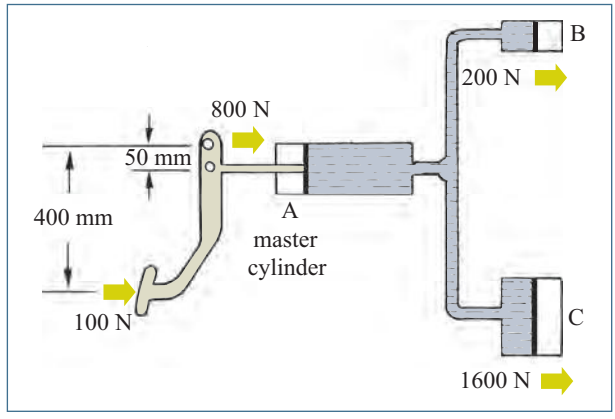


Figure 11.5 Basic principle of a hydraulic brak e system

11.2.4 Example of force and pressure

Figure 11.5 shows how forces can be increased. The area of the piston head in cylinder A is 80 mm^2, in B it is 20 mm^2 and in C it is 160 mm^2. The area of the piston head needs to be known, because pressure acts on the surface area, and the force on each piston is related to its area.

If a force of 100 N is applied to the brake pedal, lever action will increase this to 800 N at the master cylinder pushrod, producing pressure in the system. This pressure, by acting on the pistons of the other cylinders, will be converted back to a force. The force at B will be 200 N because the area of its piston is one-quarter the size of A and the force at C will be 1600 N, because its piston is twice the size of A.

Handy hint: Pressure is the same throughout the system, but there are different forces at the pistons.

11.3 Brake hydraulic systems

Brakes have a split hydraulic system. This is a dual system with a tandem master cylinder with two pistons. It is split into two hydraulic circuits (parts), each operating the brakes at two of the wheels. Some systems are split between the front and the rear, so the front brakes operate independently of the rear brakes. Other systems are split diagonally, so that there is one front brake and its diagonally-opposite rear brake in each of the hydraulic circuits. Split systems are a safety feature that prevents complete loss of brakes. If fluid is lost from one part of the system, emergency braking will be provided by the other part.

11.3.1 Front–rear split systems

In a front–rear split system, the front brakes are split from the rear brakes. If a failure occurs in the rear brake circuit, the front brakes will continue to operate for emergency braking, but it will be reduced. Braking will be even at the front, but the rear of the vehicle will be unstable.

If a failure occurs in the front brake circuit and not in the rear brakes, the rear brakes will provide all the braking, but it will be less effective than front-only braking.

11.3.2 Diagonally split systems

In the diagonally split system that was shown in Figure 11.1, the primary part of the master cylinder operates the left-front brake and also the diagonally opposite right-rear brake. The secondary part of the master cylinder operates the other two brakes as a separate circuit. With diagonally split brakes, a failure in one part of the system allows two diagonally opposite wheels to provide reasonably stable emergency braking.

11.3.3 Antilock braking systems

Antilock braking systems (ABS) are split differently. Each wheel or axle is referred to as a channel. There are two types; three- and four-channel systems.

In a three-channel ABS, hydraulic pressure is supplied to the front brakes individually, and to both rear brakes as one, although wheel speed is measured at all four wheels individually. This system is fitted to vehicles with a live rear axle system.

In a four-channel ABS, hydraulic pressure is supplied to all four brakes individually, wheel speed is measured at all four wheels individually and wheel lockup can be controlled on all four wheels individually. This system is fitted to vehicles with independent suspension, and is shown in Figure 11.6.

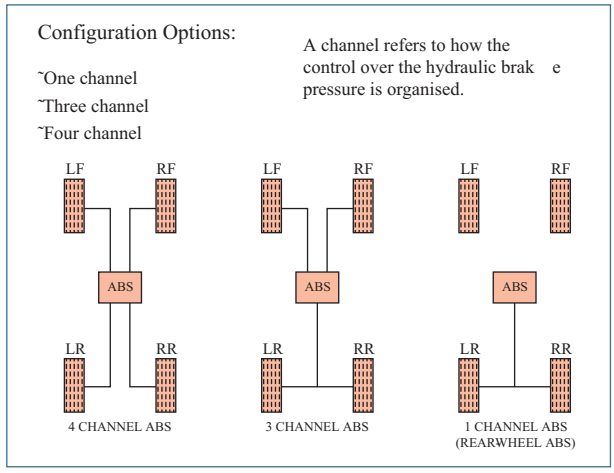


Figure 11.6 Three- and four-channel ABS systems

11.4 Master cylinders

Figure 11.7 shows a simple master cylinder connected to a wheel cylinder of a drum brake. This has only one piston, but dual, or tandem, master cylinders are now used. The basic system shown operates as follows:

1 The system is full of fluid, being supplied from the reservoir through the inlet port and the compensating port. When the pedal is pressed, the piston is moved on its downstrok e. This closes off the compensating port and traps fluid ahead of the piston. Fluid is forced past the check valve in the end of the cylinder into the brak e lines. Fluid displaced into the wheel cylinder moves the pistons apart and brings the brak e shoes into contact with the brak e drum.
2 When the pedal is released, the master cylinder piston is moved back by the return spring. Fluid now flows from the wheel cylinders towards the master cylinder and is returned to the reservoir via the compensating port and the inlet port.

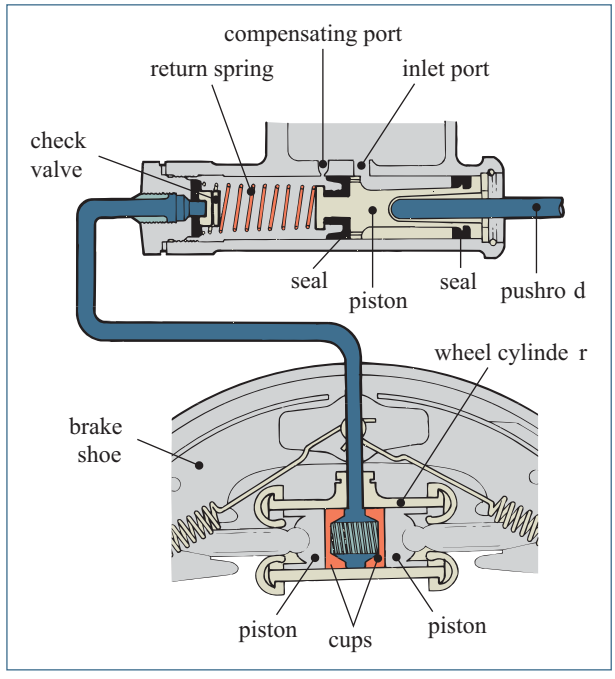


Figure 11.7 Basic master cylinder connected to a wheel cylinder

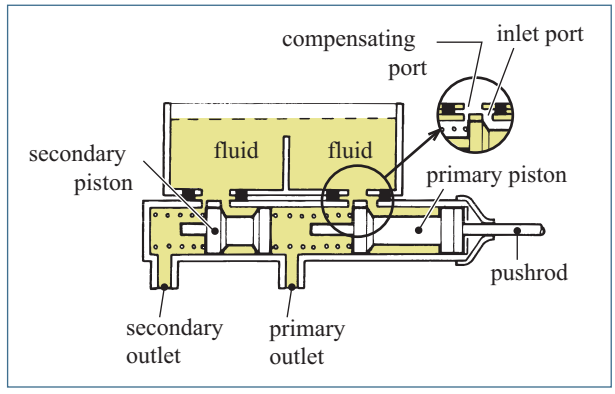


Figure 11.8 Basic tandem master cylinder

11.4.1 Tandem master cylinders

Figure 11.8 shows the basic design of tandem master cylinders. It has a cylinder with two pistons, which are referred to as the ‘primary’ and the ‘secondary’ piston. A reservoir on top of the cylinder supplies the brake fluid. The diagram shows the position of the pistons with the brakes released. There is fluid in the

reservoir and in the cylinder. When the brakes are applied, the brake pedal moves the pushrod, pushing the primary piston along the cylinder bore. This closes off the compensating port and creates pressure in the primary section of the cylinder and in the primary circuit of the hydraulic system.

The pressure in the primary section of the cylinder also acts against the back of the secondary piston, moving it down its bore. This closes off its compensating port and creates pressure in the secondary section of the master cylinder and the secondary circuit of the hydraulic system.

Handy hint: Pressure builds up simultaneously in both circuits to apply the brakes at all four wheels.

11.4.2 Master cylinder construction

Figure 11.9 shows the dismantled parts of a relatively basic tandem master cylinder. The reservoir is made of semi-transparent material, so the fluid level is visible without removing the cap. The reservoir is mounted on top of the cylinder, and there are seals between it and the inlet ports of the cylinder. The cylinder has a primary piston and a secondary piston. These have seals, each with a return spring. The pistons are retained in the cylinder by a snap ring.

Piston seals

Each piston has two seals. The primary piston has an L-type seal on its head and an O-ring on the opposite end. The secondary piston has an L-type seal on its head and another L-type seal in the opposite end. The L-type seals fit into grooves in the pistons. Their lips are forced against the cylinder wall when the brake is applied. The O-ring on the primary piston prevents fluid from leaking from the rear of the cylinder.

Each seal has a different purpose, as can be seen by considering the effects of faulty seals:

1. A faulty seal on the head of a piston will cause loss of pressure in a part of the cylinder.
2. A faulty L-type seal on the rear of the secondary piston will allow fluid under pressure to pass from the primary section of the cylinder to the secondary section.
3. A faulty O-ring on the primary piston will allow fluid to leak past the end of the piston and from the rear of the cylinder.
4. A faulty seal between the reservoir and the cylinder will allow fluid to leak over the outside of the cylinder.

Ports in the master cylinder

The master cylinder has two outlet ports to which the brake lines are connected externally. One is for the primary circuit, the other is for the secondary circuit (Figure 11.9). The internal ports can be seen in Figure 11.10, which is a sectional view of a master cylinder.

There is a compensating port and an inlet port between the reservoir and the cylinder in both the primary and secondary sections of the cylinder. These connect the reservoir to the cylinder, supplying the latter with fluid. The compensating ports are located just ahead of the piston seals. The inlet ports are behind the piston seals and they supply fluid to the outside area of the pistons (see Figure 11.8).

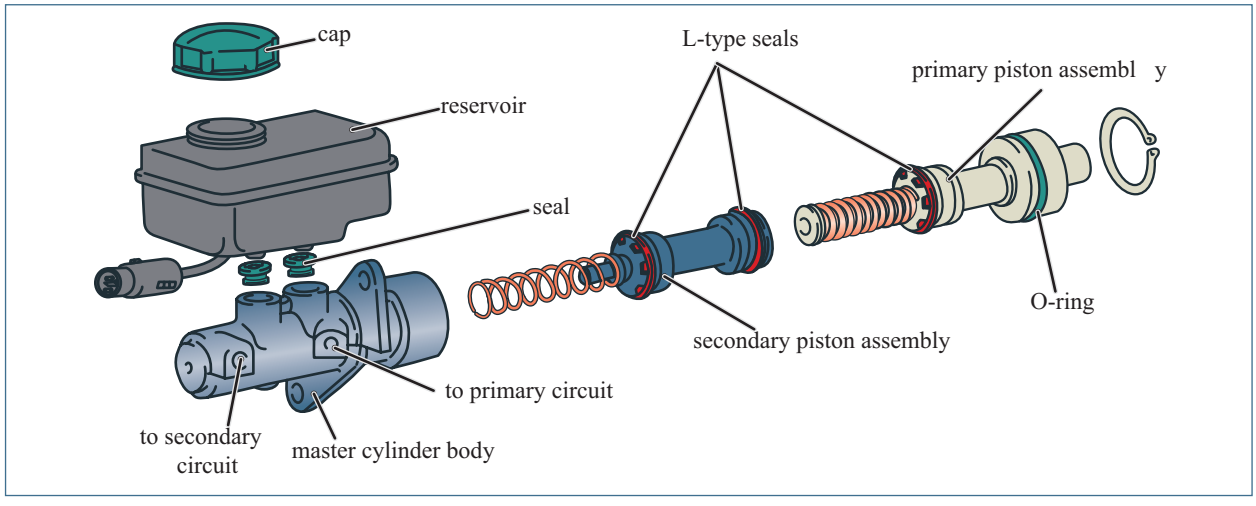


Figure 11.9 Dismantled tandem master cylinder

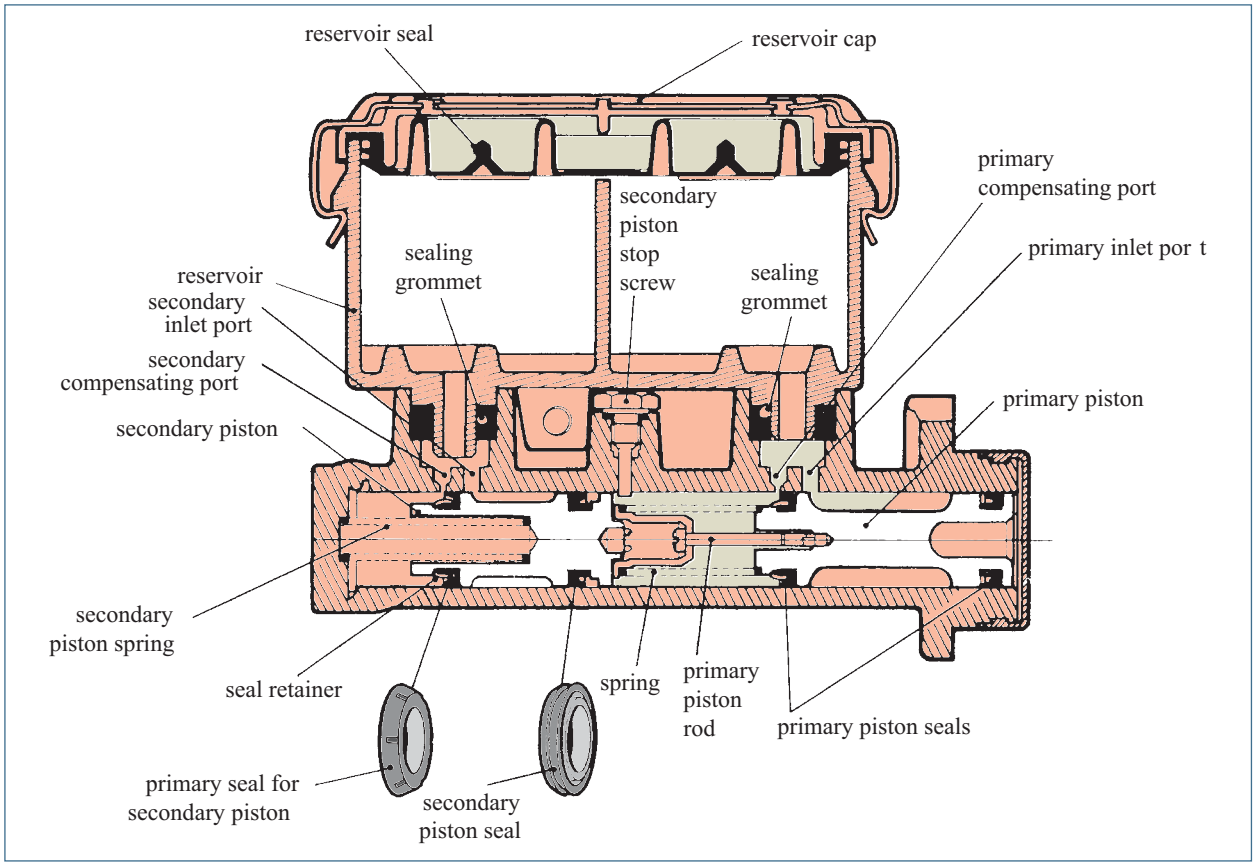


Figure 11.10 Tandem master cylinder

Handy hint: Because of its compensating ports, this design of master cylinder is referred to as a compensating-type master cylinder .

11.5 Compensating-type master cylinder

Figures 11.9 and 11.10 show compensating-type master cylinders. Internal compensating ports play an important part in their operation. Master cylinder operation can be related to Figure 11.10, as follows.

1 As the brak e pedal is pressed, the primary piston is moved along its bore . This closes off the primary compensating port so that fluid pressure develops in the primary circuit.
2 The fluid pressure created in front of the primary piston forces against the rear of the secondary piston, so that it also moves.
3 When the secondary piston moves, it covers the secondary compensating port and pressure builds up in the secondary circuit.
4 As the brak e pedal continues to be pressed, both pistons will move to displace fluid to their circuits and apply the brak es.

Handy hint: Although these operations have been described separately , they occur simultaneously to provide equal pressure to both the primary and secondary circuits.

11.5.1 Action when the pedal is released

On the return stroke, the cylinder has an action known as *recuperation*. This keeps the cylinder full of fluid, ready for the next brake application. This action for one piston is shown in Figure 11.11. It works like this:

1 When the brak e pedal is released, the piston is returned by its spring faster than the fluid can flow back into the cylinder .
2 This creates a low pressure in front of the piston so that, momentarily , the pressure in the reservoir is higher than the pressure in the cylinder .

3 This causes a small amount of fluid to flow from the reservoir , through the inlet port and past the seal on the head of the piston to the front part of the cylinder .
4 When the pedal is pressed, the extra fluid is trapped in front of the piston and pedal travel is reduced.
5 If the brak e pedal is pumped, extra fluid will be transferred to the front of the cylinder in this way . Each pedal strok e will reduce the travel, so that the brak es can be held on with a very small pedal movement.
6 When the pedal is released and the piston returns to its normal position, fluid will flow back to the reservoir through the compensating port so that all pressure is relieved from the system.

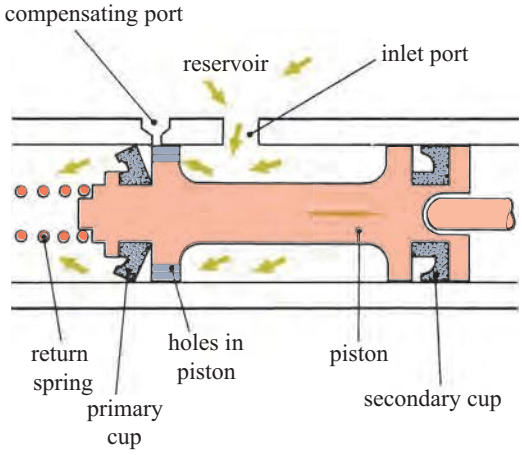


Figure 11.11 Master cylinder piston on a recuperating strok e—fluid flows past the primary cup

11.5.2 Fail-safe feature of tandem cylinders

With a tandem cylinder, one section of the master cylinder will still operate to provide emergency braking if a hydraulic failure occurs in one circuit. This is illustrated in the three diagrams in Figure 11.12.

1 Normal condition. In Figure 11.12 (a), the cylinder is full and the fluid is at the correct level in both sides of the reservoir . There is no loss of fluid.
2 Leak in secondary . In Figure 11.12 (b), fluid has been lost from the secondary circuit. When the brak e pedal is pressed, there will be no resistance from the secondary piston and it will bottom in the cylinder bore .
The primary piston will travel further down the cylinder bore , but will still develop pressure in the primary circuit to provide emergency braking.
3 Leak in primary . In Figure 11.12 (c), fluid has been lost from the primary circuit, so the primary piston will move along its bore until its piston rod contacts the secondary piston.

The secondary piston will now be operated mechanically by the primary piston, rather than hydraulically; the brakes operated by the secondary circuit will still function.

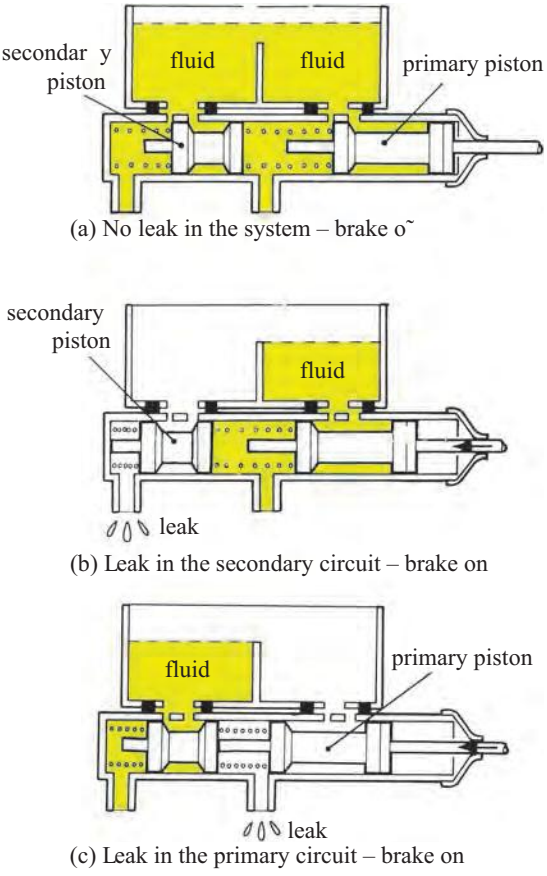


Figure 11.12 Tandem master cylinder and the effects of leaks (a) normal operation (b) loss of pressure in the secondary circuit (c) loss of pressure in the primary circuit

Safety: Loss of fluid in any part of the system will increase pedal travel and the brak es will operate on two wheels only .

11.6 Centre-valve master cylinder

Centre-valve master cylinders do not have a compensating port but have a centre valve in the piston which performs the same function. Figure 11.13 shows the parts of a master cylinder with a centre valve, and Figure 11.14 shows the same cylinder in cross-section. This master cylinder has a centre valve in the secondary piston and a fast-fill arrangement for the primary piston. The bore of the cylinder is stepped, with a large bore at the rear (open) end. The primary piston is also stepped to suit the cylinder bore.

The primary part of the cylinder has a compensating port and an inlet port, but there is a fast-fill valve fitted between these ports and the reservoir. This is a combination valve with a ball and a pressure seal.

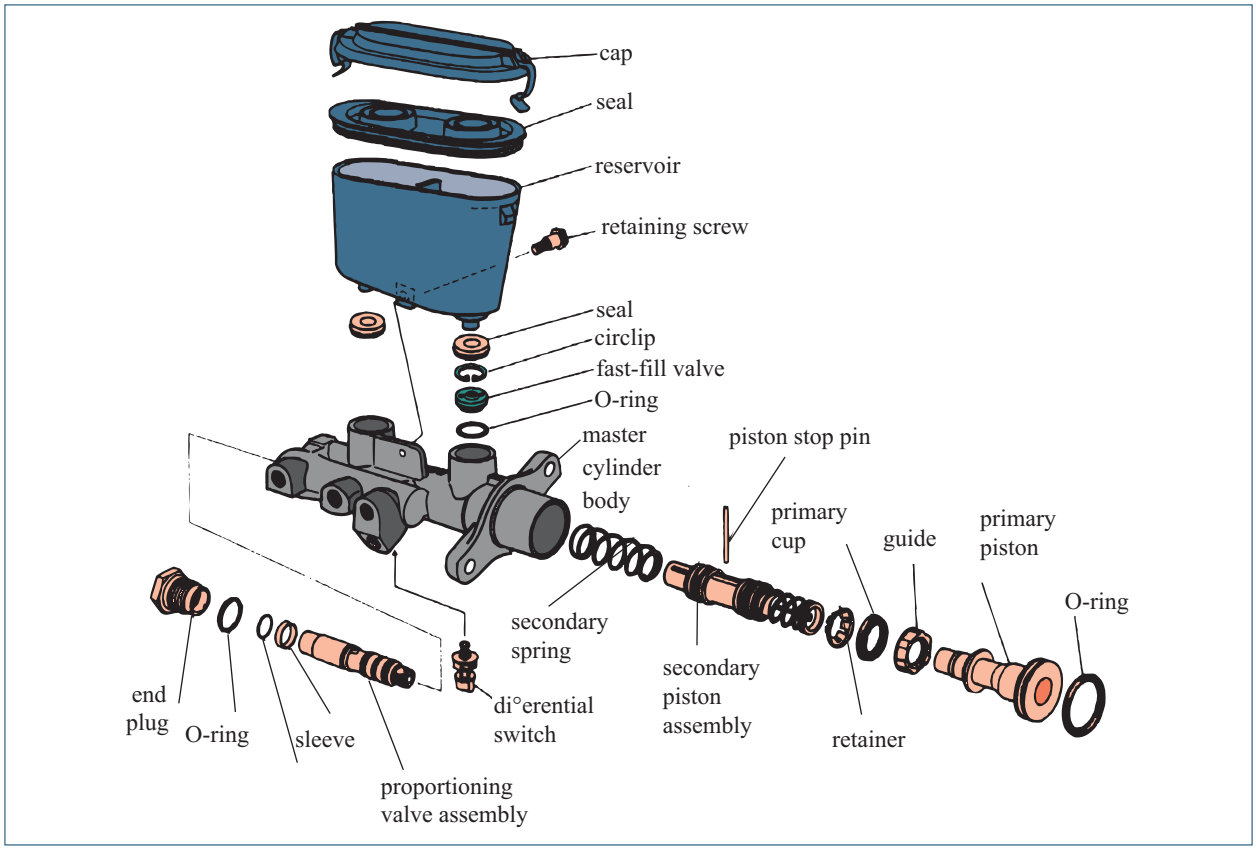


Figure 11.13 Tandem master cylinder assembly with a fast-fill valve FORD

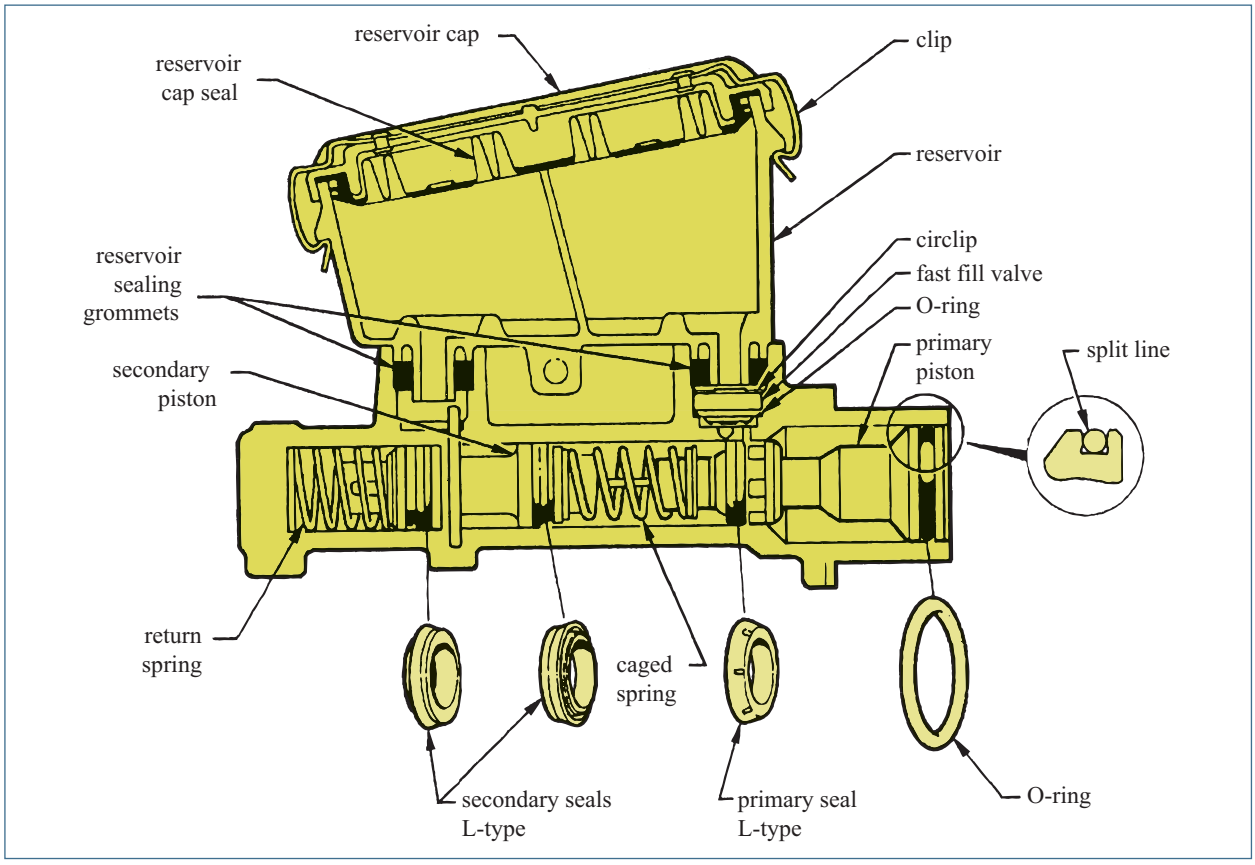


Figure 11.14 Sectional view of a tandem master cylinder with a fast-fill valve FORD

Depending on the pressure, it allows fluid to flow from the large bore of the cylinder to the reservoir, or vice versa.

The secondary part of the cylinder does not have a compensating port. Instead, the centre valve in the secondary piston performs the same function. The valve closes when the secondary piston is moved on the downstroke, so pressure builds up ahead of the piston. It opens when the piston is on the return stroke to allow fluid to pass through the piston and return to the reservoir.

Handy hint: The fast-fill arrangement enables the clearance between the pads and the brake discs to be taken up quickly when the pedal is pressed, and this reduces the pedal travel.

11.6.1 Master cylinder operation

1. When the brake is applied, the primary piston is moved in its bore and fluid is displaced by the piston. The ball of the fast-fill valve is held on its seat, so fluid is prevented from passing into the reservoir.
2. Because of its larger bore, there will be more fluid displaced by the rear part of the primary piston than by the front. This extra fluid flows past the L-type seal on the front of the primary piston and is added to the fluid that is being displaced by the front of the piston.
3. This produces a high volume of fluid, which quickly moves the brake pads to take up the clearance between the pads and the discs. This is a relatively high volume of fluid at a low pressure.
4. With continued movement of the piston, pressure builds up in the system ahead of the piston to apply the brakes.
5. There is also some pressure created in the large bore behind the head of the piston. This pressure opens the ball in the fast-fill valve so that fluid can flow from the large bore back into the reservoir.
6. Once the fast-fill valve has opened, the cylinder acts in the same way as a conventional master cylinder, with all the pressure being created in the small-bore section of the master cylinder.

Return stroke

When the brake pedal is released, the pistons will be returned by their springs. Fluid will flow from the primary section of the master cylinder back to the reservoir through the compensating port, the inlet port and the fast-fill valve. From the secondary section, fluid will flow through the centre valve and back to the reservoir through the inlet port.

The centre valve performs the same function as a compensating port. It is used in some master cylinders fitted to vehicles with antilock brake systems. These systems generally operate at higher pressures and have more piston movement than standard brake systems. Eliminating the compensating port from the cylinder helps to prolong the life of the secondary piston seal.

11.7 Valves in the hydraulic system

Figure 11.15 shows the valves that can be used in hydraulic brake systems, although they are not all likely to be fitted to one system. They are shown as separate valves but, in an actual system, may be designed as part of the master cylinder or as combination valves.

11.7.1 Pressure differential valve and switch

Figure 11.16 shows a pressure differential switch. This is a plunger-type switch that is operated by a spool valve connected between the two circuits of the hydraulic system. With equal pressure in both circuits, the valve is balanced and held in a central position. Normally, the plunger of the switch rests in a groove in the valve and the switch is off. However, if there is a pressure loss in one circuit, the valve will be moved by the pressure in the other circuit. This will raise the switch plunger to operate the differential switch and light the brake-failure warning indicator.

The spool valve in the illustration has different diameters at each end, but they are subjected to

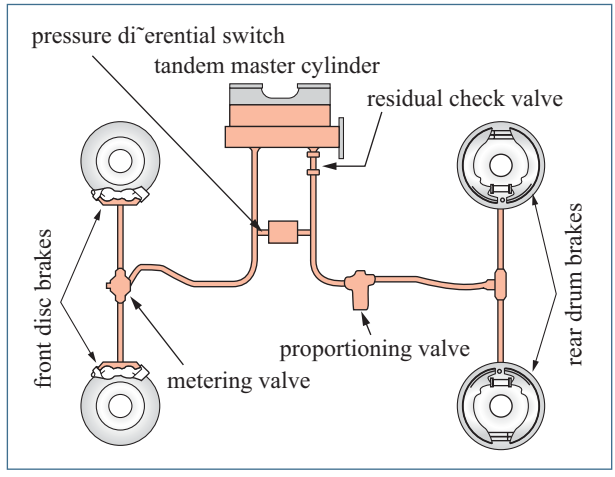


Figure 11.15 Location of valves in a hydraulic brake system

the same hydraulic pressure. The valve remains in balance because the pressure on the large end is opposed by the pressure on the small end, plus the force of the spring.

11.7.2 Proportioning valve

Proportioning valves regulate the hydraulic pressure to the rear brakes. Generally, front brakes require a greater pressure than the rear brakes, particularly during heavy braking. Disc brakes require higher pressures than drum brakes, so systems with disc brakes at the front and drum brakes at the rear need a proportioning valve.

The proportioning valve restricts the pressure to the rear brakes and provides the correct proportion of braking to the front and rear. Without this valve, the rear drum brakes could lock before the front disc brakes were fully applied. The pressure to the drum brakes is kept to about 75% of that of the disc brakes. However, if a failure occurs, full pressure is provided by the proportioning valve.

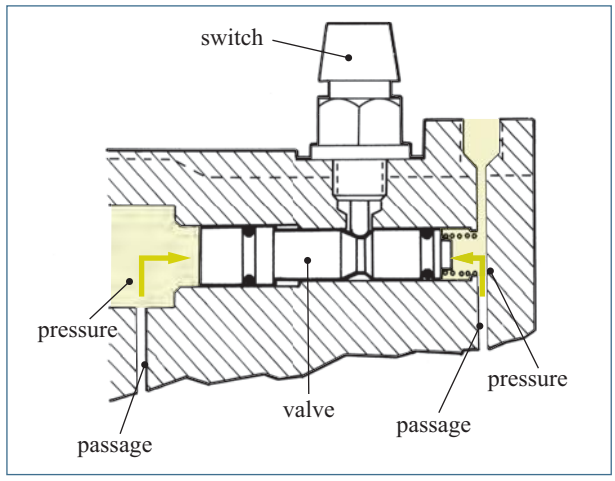


Figure 11.16 Arrangement of a spool valve and switch to operate a brak e warning lamp

Handy hint: The master cylinder in **Figure** 11.13 has a proportioning valve assembly . This valve has the combined functions of proportioning and pressure differential.

Principle of operation

Figure 11.17 shows a simple proportioning valve of the type called a *pressure-sensitive regulating valve*. It is shown as a separate valve, but this type of valve is often a part of the master cylinder. It is a stepped valve, operating in a stepped bore. The arrangement is shown for a front–rear split system. At lower pressures, the front and rear circuits operate at the same pressure. At higher pressures, the proportioning valve regulates the pressure in the rear circuit so that it is less than that of the front circuit.

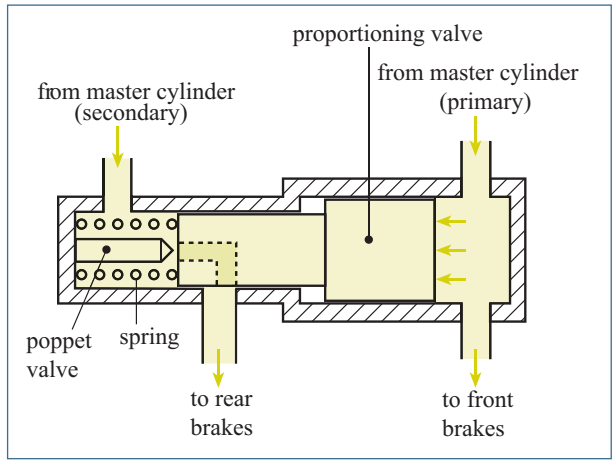


Figure 11.17 Principle of a proportioning valve

The following occurs when the brakes are applied:

1 Pressure from the primary side of the master cylinder passes through the large part of the bore to the front brak es.
2 Pressure from the secondary part of the master cylinder simultaneously passes through the smaller part of the bore via a passage in the valve to the rear brak es. To allow fluid to pass, the proportioning valve is held away from the poppet valve by the spring.
3 As pressure in the system is increased, pressure against the large end of the proportioning valve overcomes the spring force and the proportioning valve moves towards the poppet valve .
4 When a particular pressure is reached ('crack pressure '), the proportioning valve will have moved against the poppet valve to close off the passage to the rear wheels.
5 With the passage closed, pressure will act against the small end of the proportioning valve to oppose the pressure on the large end. The passage will be opened and closed as the proportioning valve moves against or away from the poppet valve .
6 Because of the different areas on the ends of the proportioning valve , a condition will exist where the rear brak e pressure will always be less than the front. Any increase in pressure from the master cylinder will affect both sides of the proportioning valve so that the pressure difference will always exist.

11.7.3 Arrangements of proportioning valves

There are various arrangements of proportioning valves. The proportioning valve can be part of the master cylinder (as in Figure 11.13), a valve (or valves) fitted to the master cylinder outlet, or a separate unit in

the system. Generally, a single unit is used where the system is split between the front and the rear. For a diagonally split system, the master cylinder can have two outlets to the rear brakes with a valve fitted to each outlet. Where a dual-proportioning valve is fitted into the system away from the master cylinder, this will have more than one valve as part of a unit.

Proportioning valve and brake failure

The type of proportioning valve in Figure 11.17 can also operate if brake failure causes a difference in pressure between the two circuits. If there is loss of pressure in the rear brake circuit, the proportioning valve is moved against the poppet valve to close off the rear circuit. If the loss of pressure is in the front circuit, the proportioning valve is moved away from the poppet valve by the spring so that full pressure reaches the rear brakes. This movement closes off the front brake circuit. These same actions can also operate a pressure differential switch for the brake-failure indicator lamp.

11.7.4 Load-sensing proportioning valve

Making the braking force applied to the front wheels greater than that to the rear is achieved by the size of brake components and the use of proportioning valves. Load-sensing valves reduce the braking effect on the rear wheels, increasing the braking effect on the front.

With load-sensitive proportioning valves, there is a mechanical connection between the valve and the suspension system. This 'measures' the displacement of the body due to load, varying the pressure accordingly. Load-sensing proportioning valves are used on some larger vehicles such as vans, which operate loaded and unloaded. They are also used on some small passenger vehicles where the load depends on how many people are in the vehicle. Figure 11.18 shows a typical location for the valve.

11.7.5 Check valve

Check valves were used in some drum-brake systems to maintain a residual pressure in the system. The low residual pressure was used to keep the wheel cylinder cups expanded. Residual pressure is not needed with the design of wheel cylinder cups now used in the wheel cylinders of drum brakes. It is not needed with disc brakes and, in fact, is undesirable. Any pressure remaining in the system when the brakes are released would prevent the brake pads from releasing fully.

11.7.6 Fluid-level warning

A fluid-level warning device can be fitted to the master cylinder reservoir. This consists of a float that operates a sensor. When the float level drops below a certain level, the sensor operates a warning light to indicate this to the driver. One design is illustrated in Figure 11.19.

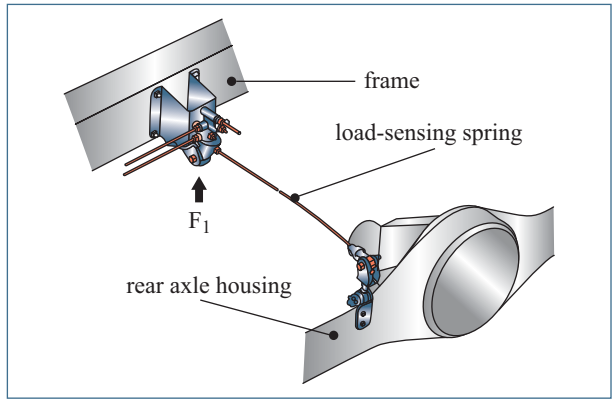


Figure 11.18 Load-sensing proportioning valve fitted to the frame of a light truck

11.8 Wheel cylinders

The wheel cylinders in both drum and disc brakes convert hydraulic pressure to a mechanical force. The wheel cylinders for drum brakes are bolted to the brake backing plate and are used to expand the brake shoes against the brake drum. Disc brakes have wheel cylinders that are part of the disc caliper. This straddles the brake disc and the wheel cylinders clamp the brake pads against the disc.

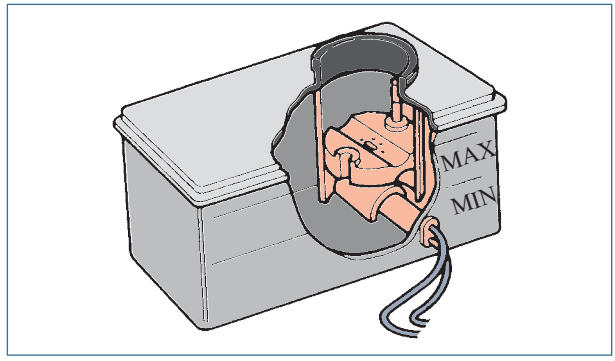


Figure 11.19 Level sensor in a brak e master-cylinder reservoir

11.8.1 Drum-brake wheel cylinders

There are two types of wheel cylinders used with drum brakes: *double piston* (or double acting) and *single piston.*

Double-piston cylinders

Figure 11.20 shows a double-piston cylinder in sectional view. Each piston has a rubber cup which fits into a groove in the inner end of the piston. A coil spring between the pistons acts as a return spring, and this keeps the pistons apart. When the brakes are applied, hydraulic pressure between the cups forces the pistons outwards, and this forces the brake shoes against the brake drum. A rubber boot is fitted to each end of the cylinder to exclude dirt and water. There is a bleeder valve which is used when bleeding the brakes to remove air from the system.

Figure 11.21 shows the parts of a dismantled wheel cylinder of the type commonly used for passenger vehicles. Wheel-cylinder cups are installed with their sealing lips pointing inwards. With the brakes released, and no pressure in the system, the cups have sufficient pressure against the cylinder to form a seal and hold the brake fluid in the system. With the brakes applied and pressure in the cylinder, the lips of the seals are forced outwards against the wall of the cylinder to increase the sealing action and hold the fluid under pressure.

Single-piston cylinders

The parts of a single-piston cylinder are shown in Figure 11.22. It also has a ring-shaped cup installed in a groove in the piston. This seals against the cylinder and also against the piston. Single-piston cylinders are used in pairs, with each cylinder being used to operate one of the brake shoes.

11.8.2 Disc brake cylinders

The cylinder of a disc brake is part of the caliper assembly. The caliper straddles the disc and carries the disc pads as well as the cylinder and piston (Figure 11.23). The parts of a caliper with a single piston are shown in Figure 11.24. This is a typical single-piston caliper for a passenger car. The cylinder is built into the caliper and the piston is much larger in diameter than those used with drum brakes. The larger piston provides a greater force, which is needed for disc brakes.

The piston seal, a ring with a square cross-section, is located in a groove machined in the cylinder. It fits around the piston to provide a seal between the piston and the cylinder. A boot fits into grooves in the piston and the cylinder. When the brakes are applied, fluid pressure behind the piston forces it against the brake pad and the pad is forced against the disc.

The pads have no return springs. The piston is returned in its bore by the springy action of the piston seal. This also prevents drag between the pad

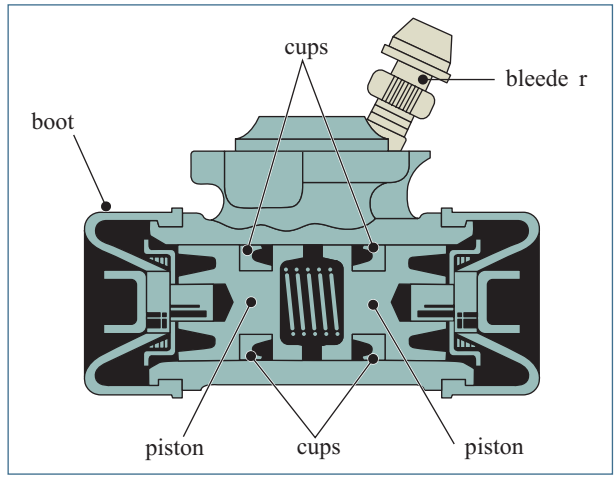


Figure 11.20 Double-piston wheel cylinder for drum brakes

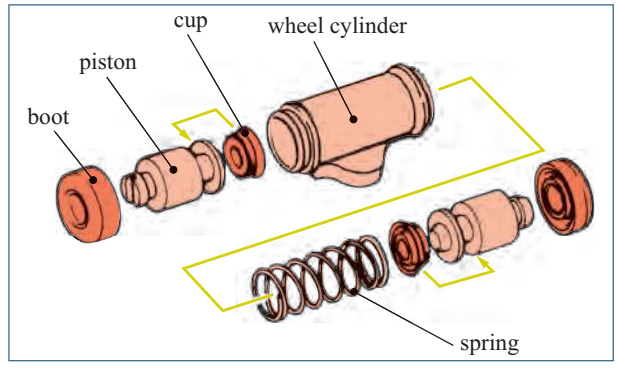


Figure 11.21 Dismantled wheel cylinder with two pistons GM HOLDEN LTD

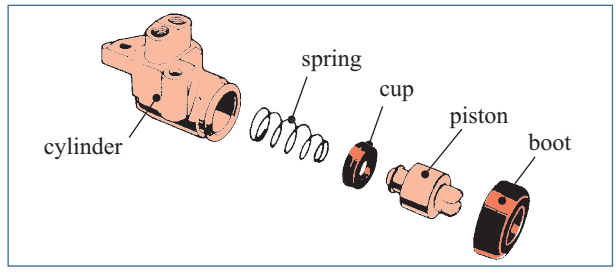


Figure 11.22 Parts of a single-piston wheel cylinder

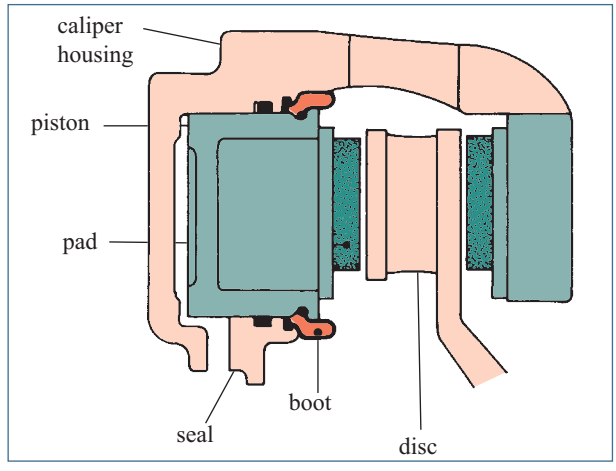


Figure 11.23 Section of a disc and caliper showing the cylinder, piston and pads

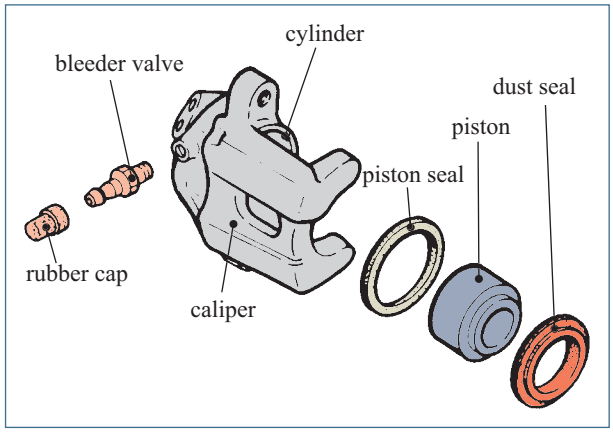


Figure 11.24 Disc brake caliper with its cylinder, piston and seals FORD

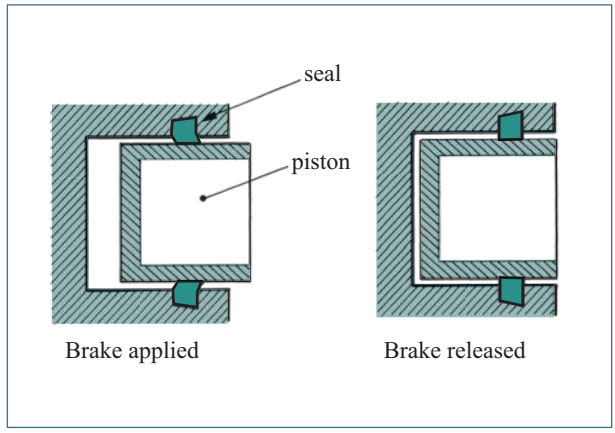


Figure 11.25 The action of the disc brake piston seal

and the disc. Figure 11.25 shows how the seal distorts when the piston is moved in its cylinder, and how it relaxes to withdraw the piston when the fluid pressure is relieved.

Handy hint: Some calipers have a single piston while others have two. The calipers of some high-performance vehicles can have four or six pistons.

11.9 Hydraulic brake fluid

Hydraulic brake fluid can be used only in hydraulic brake and clutch systems. Its main requirement is to transmit force from the master cylinder to the wheel cylinders, but it must also have other properties. Brake fluids must conform to set standards relating to viscosity, boiling point and compatibility with other brands of fluids of the same type and with brake-system parts. Although brake fluid is typically replaced at regular service intervals due to deterioration, it can be tested to establish its serviceability.

Handy hint: Brake fluids are classified by a DOT number, DOT being the acronym for the US Department of Transportation.

11.9.1 Brake fluid DOT specifications

The following are the DOT brake fluid specifications:

- DOT 3: boiling point—140 °C (284 °F)
- DOT 4: boiling point—155 °C (311 °F)
- DOT 5.1: boiling point—180° C (356 °F)
- DOT 5: boiling point—190 °C (374 °F).

Note: The polyglycol-based DOT 3, DOT 4 and DOT 5.1 brake fluids can all be mixed together, but they cannot be mixed with DOT 5 as it is silicone based.

11.9.2 Care with brake fluid

Even if they have similar base composition, fluids with different DOT ratings must not be mixed. Avoid contamination of the fluid. It must not be mixed with any other liquid and should be kept in containers that are perfectly clean and have not previously been used for oil, kerosene or any other mineral oil product. Contaminated or incorrect fluid will cause the rubber cups and hoses to swell and become unserviceable. Brake fluid spills should be cleaned up immediately, using plenty of water.

11.10 Bleeding brakes

Whenever any part of the hydraulic system has been disconnected, air will enter the system, causing the brakes to be spongy. The pedal will have a soft, springy effect because air in the system is compressed. Where a lot of air has entered the system, the pedal can be depressed right to the floor without any resistance.

To remove air trapped in the system, the brakes are bled. This involves drawing fluid from the bleeder valve at each wheel cylinder (or at each caliper) until the air is removed. Two methods can be used: manual bleeding and pressure bleeding. Manual bleeding uses the master cylinder to pump the fluid through the system. Pressure bleeding uses a pressure container to force fluid through the system.

Safety: **Always use correct PPE such as safety glasses when carrying out brake service work.**

11.10.1 Manual bleeding

Before starting the bleed, check the master cylinder reservoir. The fluid must be at a reasonable level during bleeding to prevent air from being drawn into the master cylinder. The procedure for manual bleeding is as follows:

1. Attach a plastic tube to the end of the bleeder valve at the caliper or wheel cylinder. Place the open end of the tube in a glass container that is partly filled with brake fluid. The end of the tube should be submerged in the fluid to prevent air from re-entering the system (Figure 11.26).
2. Unscrew the bleeder valve one-half to three-quarters of a turn. This will allow the fluid to flow from the wheel cylinder.
3. Have an assistant apply the footbrake slowly a few times. This will pump fluid through the system and out of the open bleeder valve, taking any air with it. The air will appear as bubbles in the fluid in the container.
4. When bubbles cease to appear and only fluid is being discharged, tighten the valve and remove the tube.
5. Before proceeding with the next wheel, check the fluid level in the reservoir and top up if necessary, but do not overfill. Do not reuse fluid that has been bled from the system.
6. When all the brakes have been bled, depress the brake pedal several times and then hold it down. If all the air has been removed, the pedal should feel firm and there should be plenty of pedal reserve. If the pedal is spongy, indicating that air is still in the system, bleeding will have to be done again.

Handy hint: It might be necessary to top up the reservoir several times before bleeding is completed.

Handy hint: The valve should be tightened during a pedal downstroke to prevent the possible entry of air.

Other points about bleeding

With some systems that are difficult to bleed, close off the bleeder valve at the end of each pedal downstroke. This ensures that air will not be drawn back into the system during the upstroke. The bleeder valve is reopened at the start of each downstroke. With split systems, each circuit is bled separately. The longest line of the circuit should be bled first, then the shorter line of that circuit. The other circuit is then bled in the same way.

Where the master cylinder has been dismantled, it should be primed on the bench. It can then be bled after being installed in the vehicle and before the line connections are tightened.

11.10.2 Pressure bleeding

Pressure bleeders have a container of fluid and a means of applying pressure, either a hand pump or a workshop airline. The pump has a plastic hose that is connected to an adaptor on top of the master cylinder reservoir. Fluid at low pressure is supplied to the reservoir, and this can be bled from the bleeder valves. The pedal does not have to be pumped.

With pressure bleeders, care must be taken that the fluid is not exposed to the atmosphere for long periods. There is some advantage in using small containers of fluid that can be easily closed with screw caps.

Figure 11.26 Bleeding the brakes with a tube connected to the bleeder valve on the caliper

11.11 Brake booster

The brake booster (Figure 11.27) assists the driver to apply the brakes and so reduces the effort needed on the brake pedal. Passenger and light commercial vehicles with petrol engines use a brake booster which is operated by the partial vacuum produced in the engine's intake manifold. Vehicles with diesel engines cannot use manifold vacuum and so have an engine-driven vacuum pump.

The brake booster operates whenever the brake pedal is depressed, and the amount of assistance is proportional to the pressure applied to the pedal. Should the unit fail, the driver can still apply the brakes, but a greater effort will be needed at the pedal.

Handy hint: Vacuum-operated units of this type are variously called brake boosters, vacuum boosters, vacuum servos and vacuum-assist units. They do not normally require service or adjustments but should be routinely inspected.

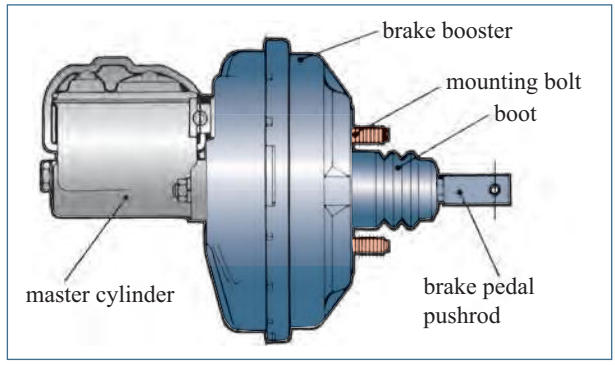


Figure 11.27 Arrangement of a brake booster and master cylinder

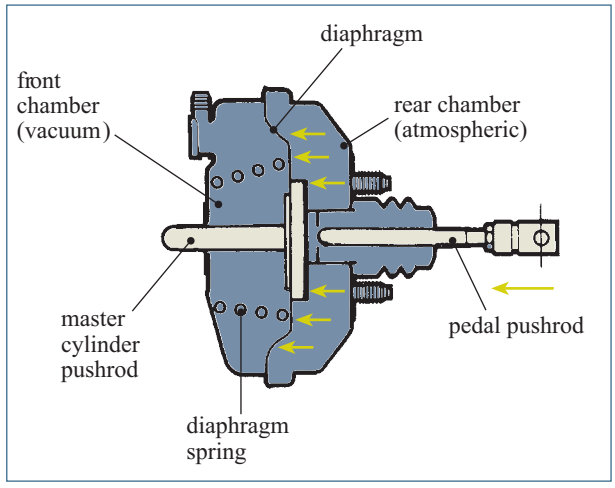


Figure 11.28 Principle of a brake (vacuum) booster with the brakes being applied

11.11.1 Basic parts and operation

The external parts of a basic brake booster are identified in Figure 11.27 and the main internal parts in Figure 11.28. The unit consists of two vacuum chambers separated by a diaphragm located between the brake-pedal pushrod and the master-cylinder pushrod. A spring against the diaphragm holds it in the released position. There is a control valve in the rear chamber that is operated by the brake-pedal pushrod. The valve can admit either vacuum or atmospheric pressure to the rear chamber.

With the engine running and the brakes released, there will be vacuum on both sides of the diaphragm, and the diaphragm spring will keep it to the right. When the brakes are applied, the brake-pedal pushrod operates the control valve. This shuts off vacuum from the rear chamber and opens it to atmospheric pressure. Atmospheric pressure in the rear chamber moves the diaphragm and the master-cylinder pushrod to the left. This pushes against the piston in the master cylinder to apply the brakes.

When the brakes are being held (applied), the diaphragm is kept stationary with vacuum on one side and a partial vacuum on the other. When the brake pedal is released, vacuum is readmitted to the rear chamber and the return spring pushes the diaphragm to its released position.

11.11.2 Operation of brake booster

The sectional views in Figures 11.29 to 11.31 show the various parts of a brake booster unit in detail, and also how it operates. There are three conditions shown: the released position, the applying position and the holding position.

Released position

Figure 11.29 shows the brakes in the released position, with vacuum on both sides of the diaphragm. Atmospheric pressure, shown by the dotted shading, is blocked off. The following relates to the released position:

1 The front chamber is connected by a hose to the intake manifold so, whenever the engine is running, there is vacuum in the front chamber.
2 The control valve is in the position where the vacuum port V is open and the atmospheric port A is closed. This allows vacuum to be admitted to the rear chamber so that there is vacuum on both sides of the diaphragm.
3 The diaphragm is held in the released position (to the right) by the large diaphragm return spring.

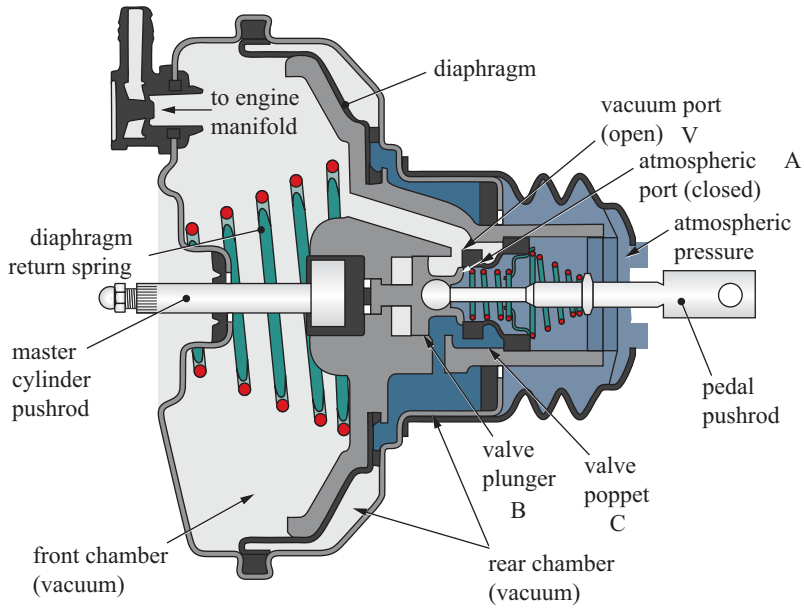


Figure 11.29 Brake booster—release position: the vacuum port V is open and the atmospheric port A is closed. Both sides of the diaphragm are under the influence of engine intake-manifold vacuum

With the valve in the position shown, the vacuum port V is open and both sides of the diaphragm are exposed to intake-manifold vacuum. Atmospheric pressure, shown by the shading, is blocked off at the atmospheric port A.

Applying position

Figure 11.30 shows the brakes being applied with atmospheric pressure on the rear of the diaphragm. This is shown by the shading of the rear chamber. The following relates to the applying position:

1. The brake pedal has been depressed and its pushrod has transferred movement through to the master cylinder.
2. Pressing the brake pedal also moves the plunger so that the poppet C closes off the vacuum port V.
3. At the same time, the plunger B is moved away from the poppet to open the atmospheric port A.
4. The atmospheric port A admits atmospheric pressure to the rear chamber as shown by the shading.
5. The diaphragm is moved to the left to assist in applying the brakes.

Holding position

Figure 11.31 shows the brakes in the holding position. There is intake-manifold vacuum on the front of the diaphragm and a partial vacuum (pressure less than atmospheric) on the rear. This is shown as light shading of the rear chamber. The following relates to the holding position:

1. With the brakes applied, pressure in the master cylinder pushes back against its pushrod and the valve plunger to close the atmospheric port A.
2. This retains a partial vacuum in the rear chamber with the diaphragm held suspended.
3. The diaphragm will remain in an applied position. The vacuum and the spring in the front chamber will be balanced by the partial vacuum in the rear chamber.
4. An increase in pedal pressure will move the plunger off its seat to admit atmospheric pressure to the rear chamber and apply the brakes harder. A decrease in pedal pressure will have the opposite effect.
5. When the pedal is released, the plunger and poppet will move back to the released position. This will open the vacuum port V to admit vacuum to the rear chamber and the return spring will move the diaphragm back to the release position.

Handy hint: The term vacuum indicates a negative pressure, which is a pressure below atmospheric. **A true vacuum would be a condition where there is no air and no pressure.**

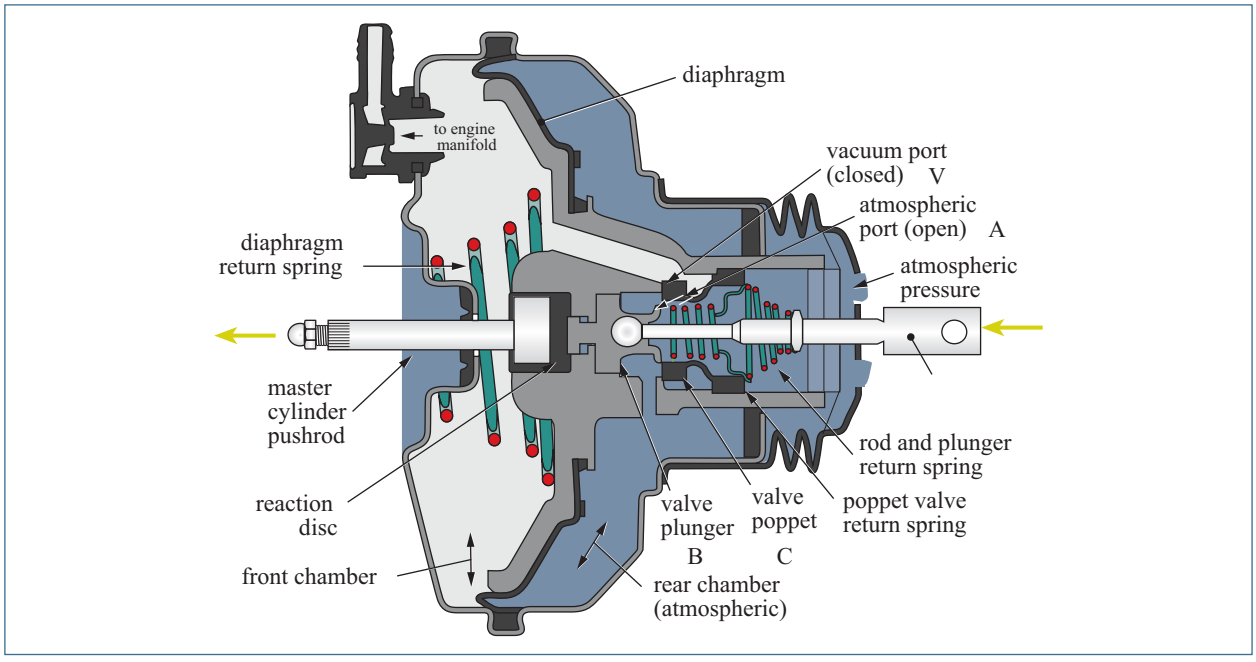


Figure 11.30 Brake booster—applying position: when the brake pedal is depressed, the valve-operating rod attached to the brake pedal moves the valve plunger forward so that the valve poppet C closes off the vacuum port V. The valve plunger B is moved away from the valve poppet to open the atmospheric port A

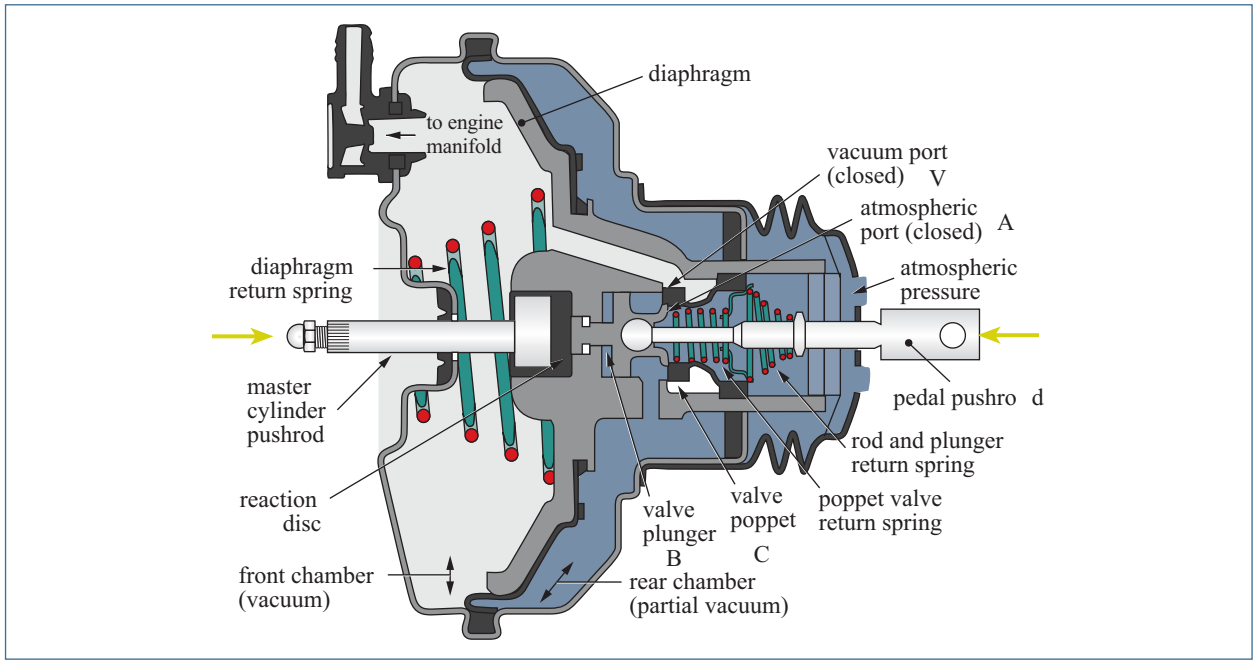


Figure 11.31 Brake booster—holding position: both the atmospheric port A and the vacuum port V are closed and the diaphragm is held suspended with the brakes applied. Partial vacuum is retained in the rear chamber to hold the diaphragm

Booster designs

The booster that has been discussed has a single diaphragm and one atmospheric chamber. Some larger vehicles have dual diaphragms and two atmospheric chambers. These operate in a similar manner to that described for a single diaphragm. The main difference is that, with atmospheric pressure acting against two diaphragms, there will be twice the assistance provided to apply the brakes. Figure 11.32 shows a dual-diaphragm brake booster in the brakes-applied position with atmospheric pressure action on both diaphragms (pistons in the Figure).

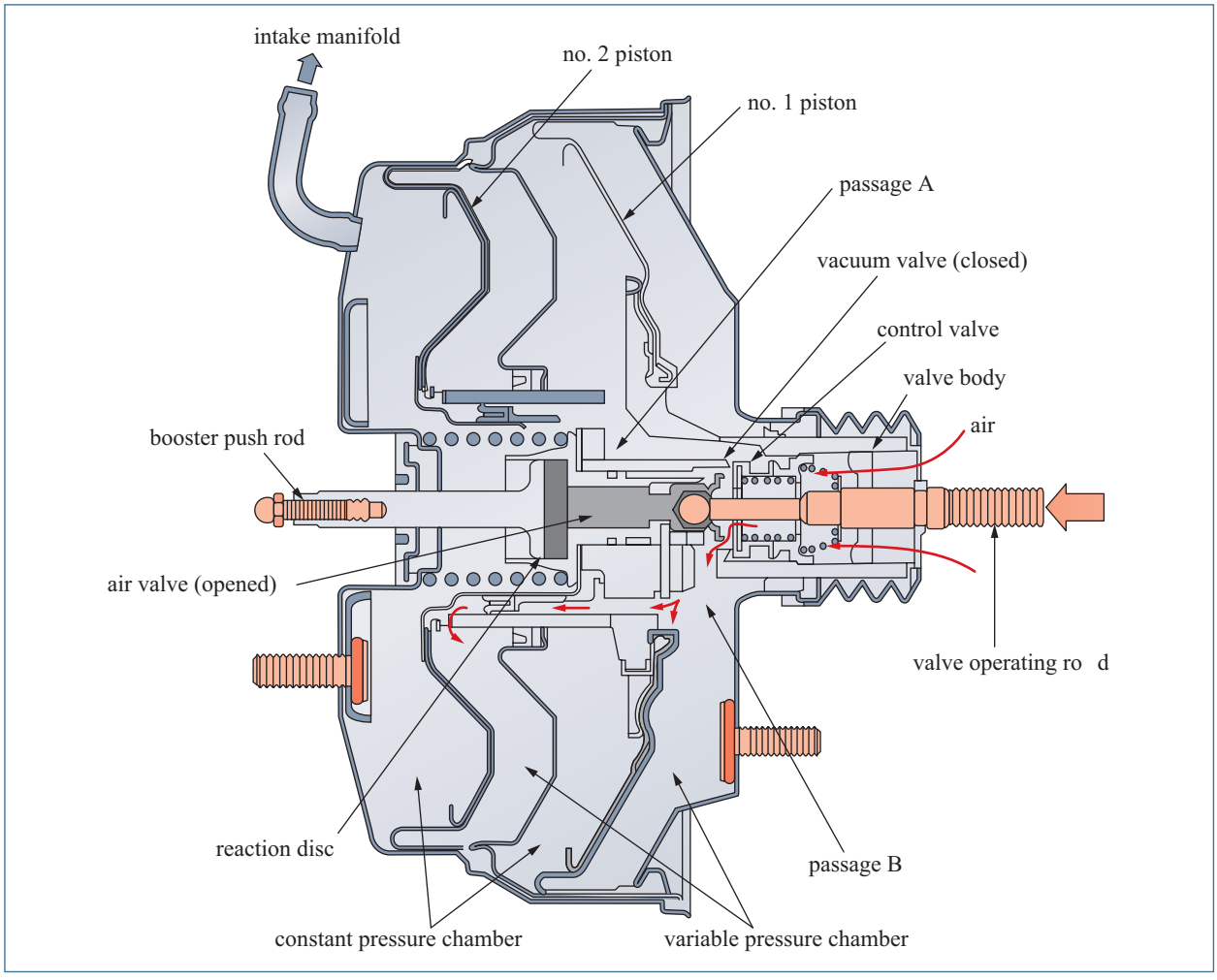


Figure 11.32 Dual-diaphragm brak e booster

11.12 Drum-brake assemblies

Safety: Use correct PPE and safe manual handling practices when removing wheels or dismantling and cleaning drum brak es. These should include precautions against inhaling brak e dust, which may contain asbestos.

There are two main parts to a drum brake: the cast-iron brake drum and the brake-shoe assembly. The latter includes the backing plate with the brake shoes, wheel cylinders and other associated parts. The dismantled parts of a drum-brake assembly for a passenger car are shown in Figure 11.33, and a drum-brake assembly for a light commercial vehicle is shown in Figure 11.34.

11.12.1 Brake drum

The brake drum provides a cast-iron braking surface against which the brake linings operate. The brake shoes are expanded inside the drum, so it must be capable of withstanding the force applied by them without distorting. The brake drum must be capable of absorbing the heat produced by friction between the shoes and the drum. It must also dissipate this heat to prevent excessively high temperatures developing in the brake assembly.

11.12.2 Backing plate

The backing plate for the front brakes is mounted to the steering knuckle, and the backing plate for the rear brakes is mounted to the axle flange. The backing plate carries all the stationary brake parts. It is a steel pressing whose outer edge is flanged to fit over the edge of the drum. It not only acts as a support for the brake shoes and associated parts, but also as a shield against road dirt.

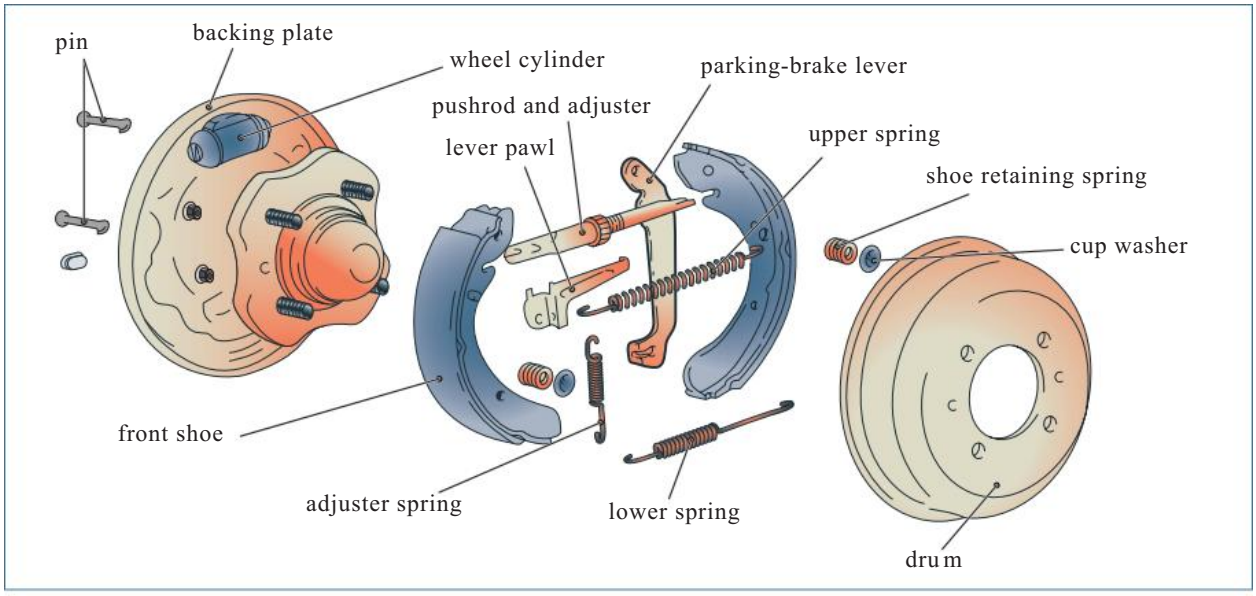


Figure 11.33 Dismantled rear drum-brake assembly with parking-brake parts for a passenger car

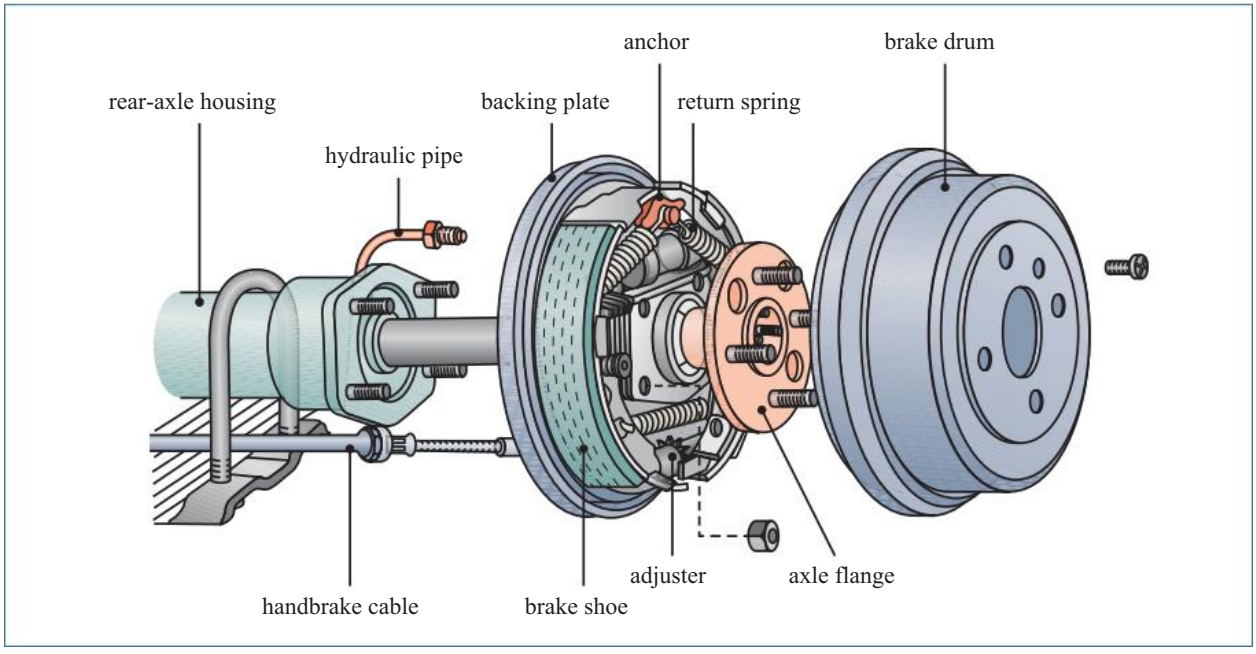


Figure 11.34 Drum-brake assembly of the duo-servo design for a light commercial vehicle

11.12.3 Brake shoes and linings

Two brake shoes are used, and these are shaped to fit the contour of the brake drum. A shoe consists of a web and a flange. The web stiffens the flange and prevents the shoe from distorting when it is expanded. The flange has a lining of friction material bonded to it. The lining is a compound consisting of various fibres, synthetic resins, friction materials and heat-dissipating materials.

To withstand the high temperatures generated during braking, linings must be able to transfer some of the heat to the brake shoes. Some of the fibres used in brake linings are insulators of heat and, to offset this, soft particles of metal, such as zinc, can be included in the lining material. The metal particles are good conductors of heat and so help to transfer it from the surface of the lining to the shoe.

11.12.4 Brake springs

Springs are fitted between the shoes, or between the shoes and the backing plate. These locate the shoes on the backing plate and return them to their normal position when the brakes are released. Retaining springs and clips hold the brake shoes against the backing plate. Other springs locate the shoes in position or hold

them together. Anchors locate the ends of the shoes by providing an abutment against which they can rest. Anchor pins hold the ends of some return springs.

Handy hint: Adjusters provide the working clearance between the brak e shoes and the drums.

11.12.5 Wheel cylinders

The wheel cylinders are bolted to the backing plates. Some backing plates carry one cylinder, others two. One end of each brake shoe abuts a piston and the shoes are expanded by the pistons when the brakes are applied. As previously indicated, some wheel cylinders have two pistons and others have only one piston.

11.13 Brake-shoe assemblies

Various arrangements are used to mount the brake shoes to the backing plate. Three general designs of brake-shoe assemblies have been used:

- leading and trailing shoes
- duo-servo
- two-leading shoes.

11.13.1 Leading and trailing shoe brakes

Figure 11.35 illustrates a basic brake assembly with leading and trailing shoes. The shoes rest against an anchor at their lower end (the heel of the shoe), and are expanded at their upper end (toe) by a double-acting wheel cylinder. They are held in position by the return springs. (The brake assembly in Figure 11.33 also has leading and trailing shoes.)

The hydraulic action of the wheel cylinder, when the brakes are applied, pivots both shoes about the anchor, forcing their upper ends against the brake drum. The direction of rotation of the drum, shown by the arrow, assists the movement of the leading shoe. Once the brake lining comes into contact with the drum, rotation gives it a wedging action against the drum. The lower end of the shoe can also move on the anchor, giving full contact between the lining and the drum.

Rotation has the opposite effect on the trailing brake shoe, which receives no assistance from drum rotation. However, when the vehicle is moving in reverse, the drum will rotate in the opposite direction and the rear shoe will have the wedging action.

Generally, the increase in braking gained by the leading shoe from drum rotation is offset by the loss suffered by the rear shoe. This can result in greater wear of the front shoe than the rear shoe. The leading-shoe lining is at times made longer than that of the trailing shoe to provide a greater area of lining to even up the rate of wear of the two linings. All brake-shoe assemblies have this type of wedging action, but certain designs have the brake shoes mounted on the backing plate to use the wedging effect to advantage.

Handy hint: This wedging effect is referred to as a self-energising effect or a servo effect.

11.13.2 Duo-servo brakes

Duo-servo brakes (Figure 11.36) have a self-energising or servo effect on both brake shoes. The shoes are linked together at their lower ends and are allowed to float—the lower ends are not anchored to the backing plate. For self-energising assemblies, the front shoe is known as the *primary shoe,* and the rear shoe as the *secondary shoe.*

On applying the brake, the primary shoe contacts the drum and is rotated slightly with it to transfer movement through the linkage to the secondary shoe.

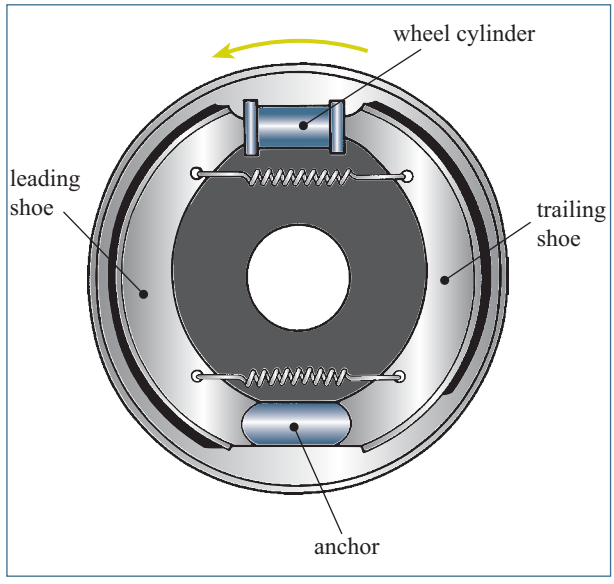


Figure 11.35 Basic brak e-shoe assembly with a leading and a trailing shoe

The secondary shoe receives force from both ends, that is, from the expansion of the wheel cylinder at the upper end and the transfer of movement from the primary shoe at the lower end. The combined effect causes the secondary shoe to be forced against the drum even harder than the primary shoe.

Handy hint: Because they operate differently, primary and secondary shoes can have different lengths of linings, or different types of linings.

11.13.3 Two-leading-shoe brakes

This design has two single-acting wheel cylinders (Figure 11.37) which produce a wedging action on both the front and the rear shoes. Each cylinder forces one end of its shoe outwards, and a self-energising effect is imparted to each shoe due to drum rotation (as previously explained). The other end of the shoe is located against the back of the wheel cylinder, which acts as an anchor. This means that both shoes provide equal braking, with a force greater than that which could be applied by normal means.

Some vehicles, with drum brakes at both the front and rear, have two-leading-shoe brakes at the front wheels and leading and trailing type brakes at the rear wheels. This provides the higher percentage of braking required for the front wheels of the vehicle.

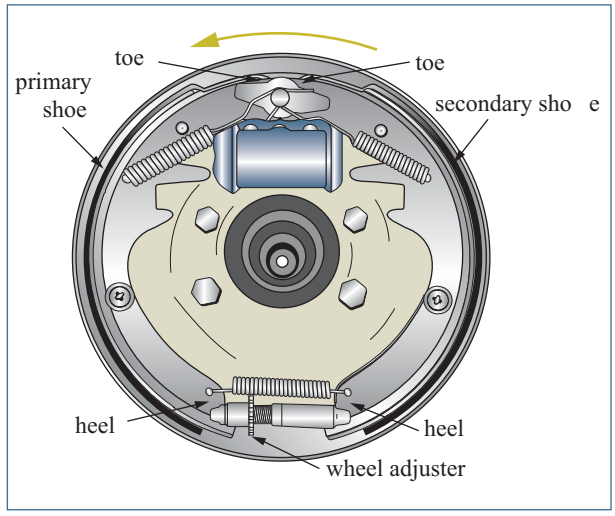


Figure 11.36 Brake assembly of the duo-servo type

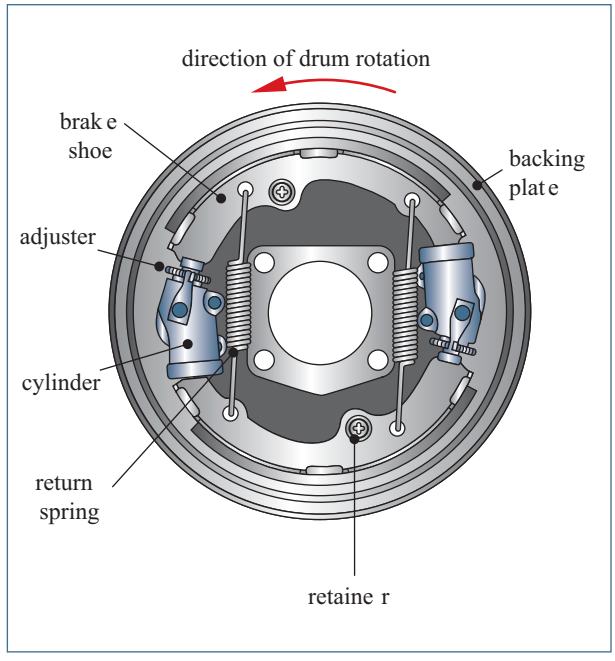


Figure 11.37 Two-leading-shoe brake assembly

11.14 Drum-brake adjustments

For efficient braking, the brake shoes must be centred in the brake drum with minimum clearance between the shoes and the drum. Front drum brakes have to be manually adjusted, but rear drum brakes have a self-adjusting mechanism.

Most brake shoes are self-centring, so that adjustment is provided only to spread the shoes and provide correct clearance between the linings and the drum. Self-centring is achieved in most brake designs by allowing the shoes a small amount of float, either by means of a link anchor or sliding abutment at the end of the shoe.

Centring can only be achieved if the correct lining has been fitted and the brake shoes are not distorted. Distorted brake shoes, or incorrect thickness or radius of brake linings where drums have been turned oversize, will result in partial contact only between the two braking surfaces.

11.14.1 Adjusting brake shoes

Brake-shoe adjustment consists of operating the adjustment to spread the shoes until they contact the drum. Adjustment is continued until the spreading of the shoes causes them to centre themselves in the drum. The adjustment is then backed off until the wheel rotates freely. Applying the footbrake momentarily during adjustment will force the brake shoes to their correct position in the centre of the drum, and assist adjustment.

Star wheel adjuster

This type of adjuster is fitted to the threaded link between the shoes of duo-servo brakes. Adjustment is carried out by using a special adjusting tool, or a suitable screwdriver. This is inserted through a slot

provided in the backing plate to turn the star wheel (Figure 11.38). The link is threaded so that the shoes are expanded when the star wheel is turned.

Screw adjustment at the wheel cylinder

With two-leading shoe brakes, a screw adjuster is fitted at each wheel cylinder. The backing plate has slots that allow a screwdriver or special tool to be inserted. Notches on the adjuster enable it to be turned to spread the shoes.

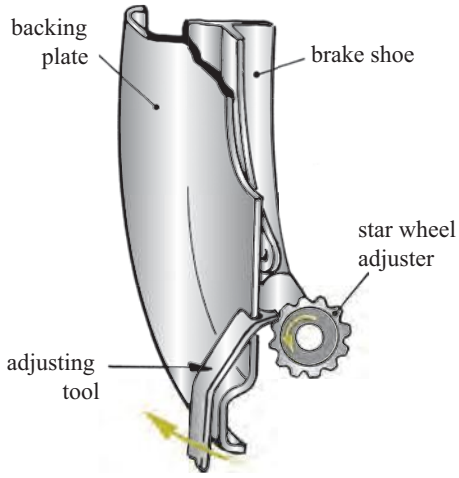


Figure 11.38 Star wheel or notched brak e adjuster

11.15 Self-adjusting drum brakes

The self-adjusting mechanism consists of a lever arrangement that operates the brake adjuster by movement of the shoes. When shoe movement increases to a certain point through wear, the lever operates the adjustment to spread the brake shoes in a similar manner to a manual adjustment.

11.15.1 Duo-servo self-adjustment

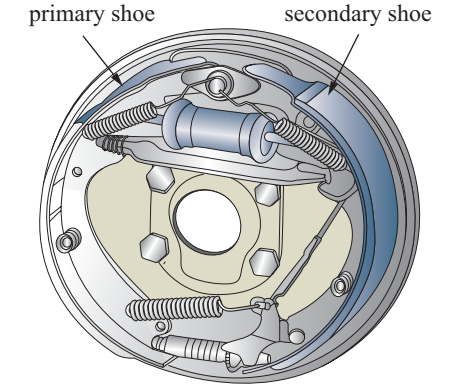
Figure 11.39 shows the self-adjusting arrangement for duo-servo brakes. A lever mounted on the lower end of the rear brake shoe operates the star wheel adjuster. A cable attached to the anchor at the top of the assembly restrains the adjuster lever, so that it pivots whenever the brake shoe is expanded.

Due to the self-energising effect of the brakes, the rear shoe has increased movement when the brakes are applied while the vehicle is reversing, so that the adjustment will operate, particularly when the brakes are applied in reverse.

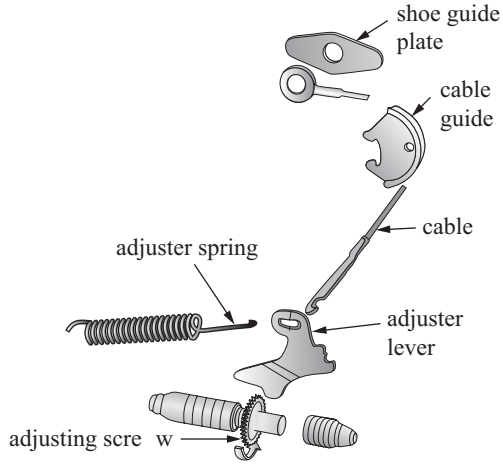
11.15.2 Operation

The automatic adjuster operates as follows:

1. When the vehicle is moving in reverse and the brak es are applied, the secondary shoe moves outwards and downwards due to rotation of the drum.
2. The cable guide , which is attached to the brak e shoe , pulls the centre of the cable , which in turn pulls the adjuster lever . This causes the end of the lever to move across the notches of the adjusting screw .
3. This action occurs whenever the brak es are applied in reverse , but the lever will not normally engage a notch of the adjuster . It will only move far enough to do this when the clearance between the brak e shoe and the drum becomes great enough to require adjustment.
4. When the brak es are released after the lever has engaged a notch, the adjuster spring will return the lever to its normal position, turning the adjusting screw one notch as it does so . In this way, the brak es are automatically adjusted whenever the lever can move sufficiently to pick up a notch in the adjusting screw .



Brak e with automatic adjuster (left rear shown)



Automatic-adjuster parts

Figure 11.39 Duo-servo brak e assembly with automatic adjuster

11.15.3 Leading–trailing shoe self-adjustment

Figure 11.40 shows one arrangement of a self-adjusting mechanism for a brake assembly with a leading and trailing shoe. Many rear-wheel brakes are of this type, but there are variations. The trailing shoe is fitted with the parking-brake lever, which operates the threaded adjusting strut. The strut has two parts: a threaded rod and a nut with ratchet teeth, or notches. The adjusting lever, which is attached to the parking-brake lever, is engaged with the teeth on the nut.

As the parking brake is applied and the brake shoes are moved outwards, the pawl moves over the ratchet teeth. If sufficient clearance exists between the brake lining and the drum (due to wear of the linings), the lever will move far enough to engage with one of the teeth. When the parking brake is released, the lever will be returned, turning the adjusting nut and spreading the brake shoes a little to adjust their clearance.

Self-adjusters maintain the small clearance needed between the shoes and the drum. However, when removing a brake drum, the clearance might have to be increased so that the drum does not snag on the linings. The adjuster is then backed off to contract the shoes. Figure 11.41 shows one method of doing this. A small screwdriver holds the adjusting lever clear of the adjuster teeth or notches, while another screwdriver turns the adjuster to shorten the strut.

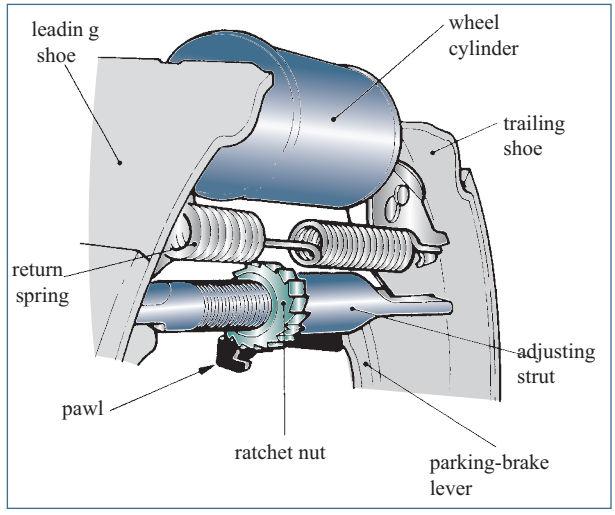


Figure 11.40 Self-adjusting mechanism on leading-trailing shoe brak es MITSUBISHI

11.16 Disc-brake assemblies

Figure 11.42 shows disc-brake assemblies, which consist of two main parts: the disc (also called the rotor) and the caliper assembly. The disc rotates with the wheel hub while the caliper, which straddles the

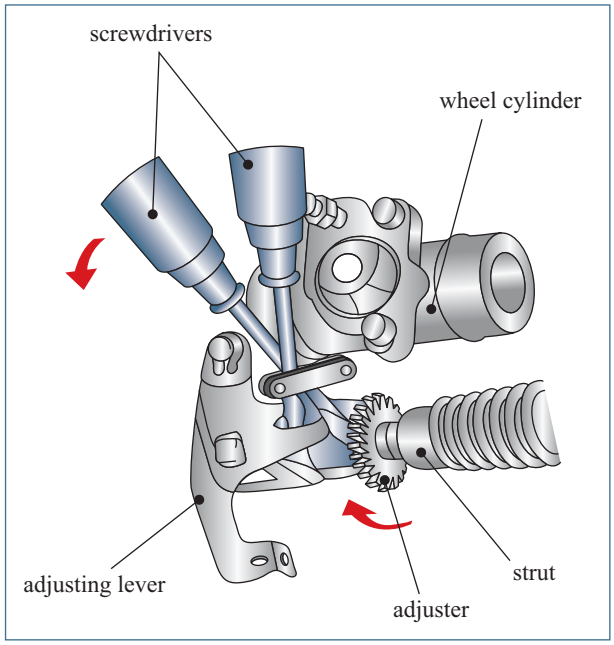


Figure 11.41 Releasing the automatic brak e adjuster to contract the brak e shoes—access is through a hole in the backing plate

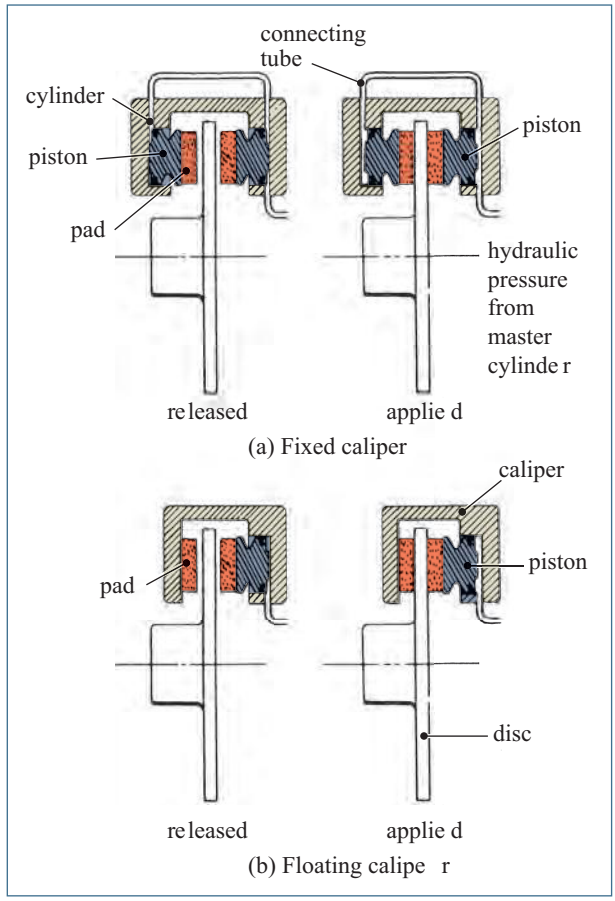


Figure 11.42 Disc-brak e arrangements for fix ed and floating calipers

disc, is held stationary. The caliper assembly includes the hydraulic cylinder, piston and the brake pads. Calipers for rear brakes also have a mechanism for applying the parking brake.

The diagrams show the principle of disc brake operation. With the brake in the released position, the pads are slightly clear of the disc which rotates between them. When the brake is applied, pressure from the master cylinder forces the pistons against the pads, which are then forced against the disc. This produces a clamping action, which slows or stops the disc.

When the brake is released, the pistons retract slightly to allow the pads to move away from the disc. The pads have no return springs, but the pistons are returned slightly in their bores by the resilience of the piston seals. A small runout of the disc moves the pads away from the disc surface to provide clearance and prevent wear.

Two different designs of calipers are shown: a *fixed caliper* and a *floating caliper.* The fixed caliper has a cylinder and piston on each side of the disc, while the floating caliper has a cylinder and piston on only one side of the disc.

11.16.1 Features of disc brakes

Some disc brake features are:

1 The surface of the disc is exposed to the atmosphere , and the heat can dissipate .
2 Higher pressures are required in the system to produce a large force against the small friction pad.
3 The disc is exposed to water and dirt, but these are easily shed from the brak e assembly because of its open construction.
4 A splash guard or backing plate is fitted to protect the disc from road dirt.
5 Balance of the disc is easy to achieve during manufacture because of its comparatively simple shape .
6 Braking is uniform under nearly all conditions, with little possibility of brak e grab or fade .

11.16.2 Brake discs

There are two designs of brake discs: *solid discs* and *ventilated discs*. Ventilated discs are often used on the front brakes and solid discs are used on the rear brakes. Brake discs are made of cast iron, with a ground surface on each side against which the pads are applied. The disc is shaped to fit over the wheel hub and has drilled holes to fit the wheel studs. Some performance vehicles use disc rotors made of composites such as reinforced carbon-carbon or ceramic matrix composites, as shown in Figure 11.43.

Figure 11.44 illustrates a ventilated disc. This is hollow and consists of two flanges separated by fins. The rotating disc acts as a form of air pump to maintain a flow of air through the disc, removing heat generated during braking. (See also Figure 11.49.)

Handy hint: Ventilated discs are used with front brak es because they are applied with greater force than the rear brak es, and so generate more heat.

Figure 11.43 Brake disc rotor in a performance vehicle SHUTTERSTOCK

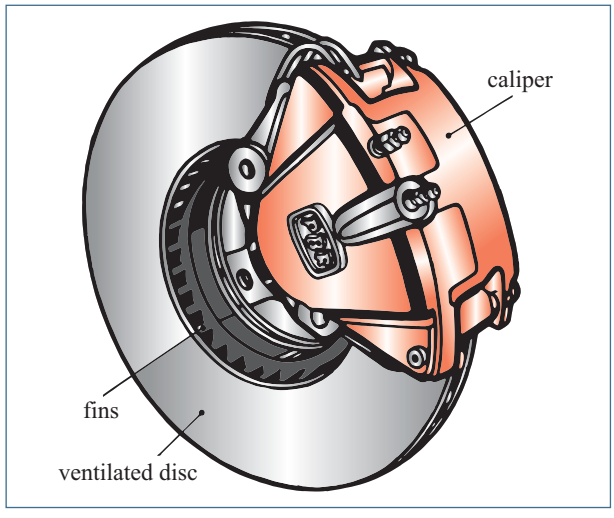


Figure 11.44 Ventilated disc and caliper

11.16.3 Fixed calipers

A fixed-caliper assembly and a solid disc are illustrated in Figure 11.45. A two-piece caliper is used, with the two parts being bolted together. The caliper has two cylinders, one on each side of the disc, so each piston operates its own brake pad.

When the brakes are applied, hydraulic pressure is applied to the pistons and they move the pads

against the disc with equal force. Only the pistons move—the caliper is fixed to the steering knuckle. Figure 11.46 shows a fixed caliper with four pistons. This type of brake is used on some high-performance vehicles.

11.16.4 Floating calipers

Figure 11.47 shows the dismantled parts of a floating-caliper assembly. The main parts are the caliper housing, the anchor plate, the piston and the pads. This type of caliper is made as a single part and has only one cylinder, which is built into the inner side of the caliper. The anchor plate is an iron casting and the caliper housing is a light alloy casting.

The caliper is mounted on the anchor plate, which is bolted to the steering knuckle. The caliper is not rigidly attached to the anchor plate—a machined surface on the caliper rests on a corresponding machined surface on the anchor plate.

Two guide pins, which are bolted to the caliper, pass through holes in the anchor plate. The guide pins position the caliper in relation to the anchor plate but allow it to slide sideways (float) in operation.

Floating-caliper operation

The operation of a floating caliper can be seen in Figure 11.48.

1 In Figure 11.48(a), with the brakes released, there is a small running clearance between the pads and the disc.
2 In Figure 11.48(b), hydraulic pressure in the cylinder has forced the piston against the inner pad, and the inner pad against the disc.

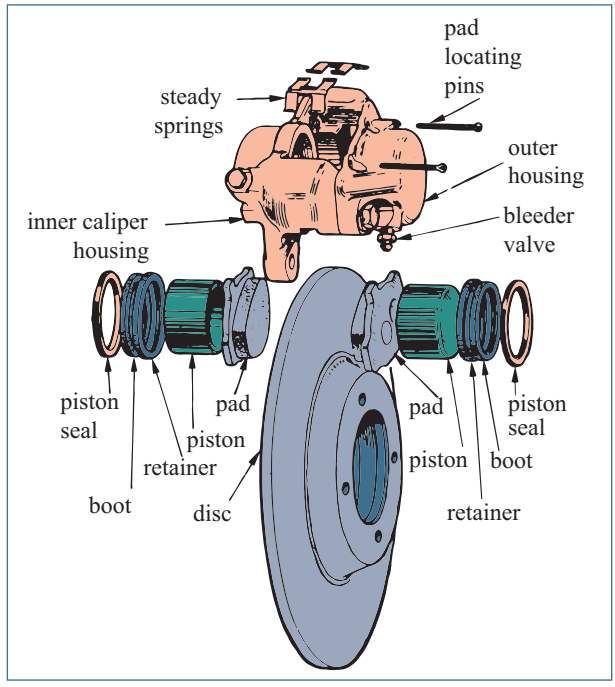


Figure 11.45 Disc-brake assembly with a fixed caliper

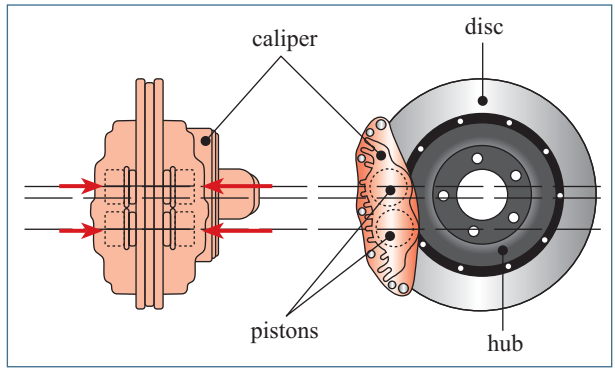


Figure 11.46 Front brake with a ventilated disc, a fixed caliper and four pistons

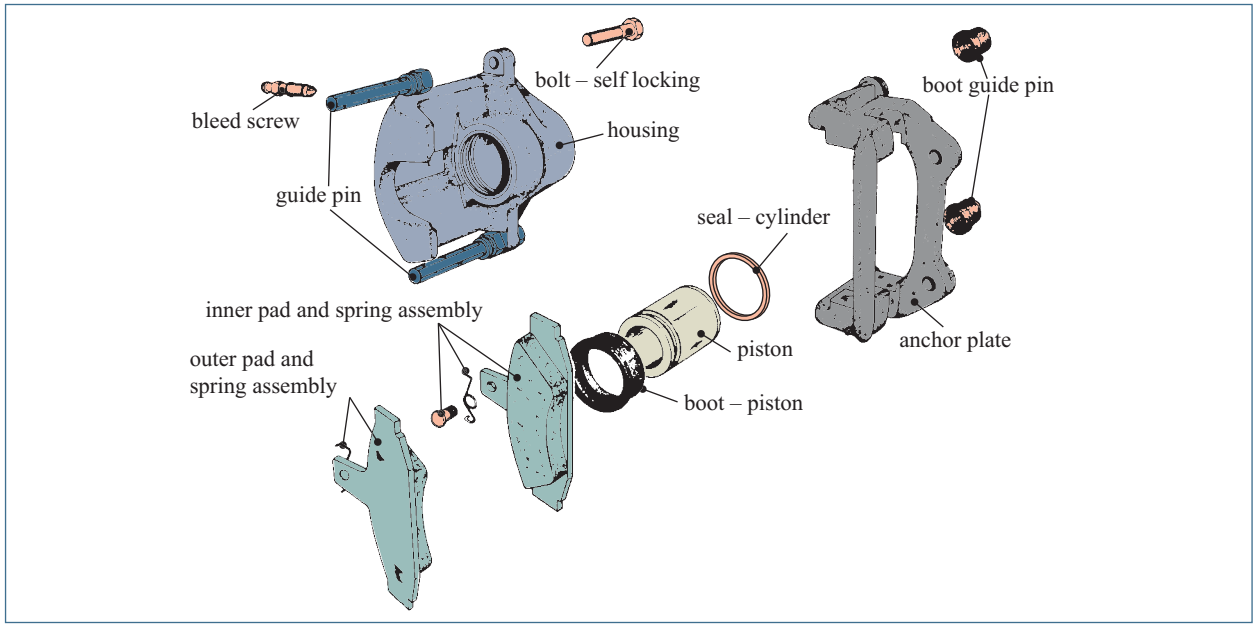


Figure 11.47 Disc-brake caliper assembly with a floating caliper GM HOLDEN LTD

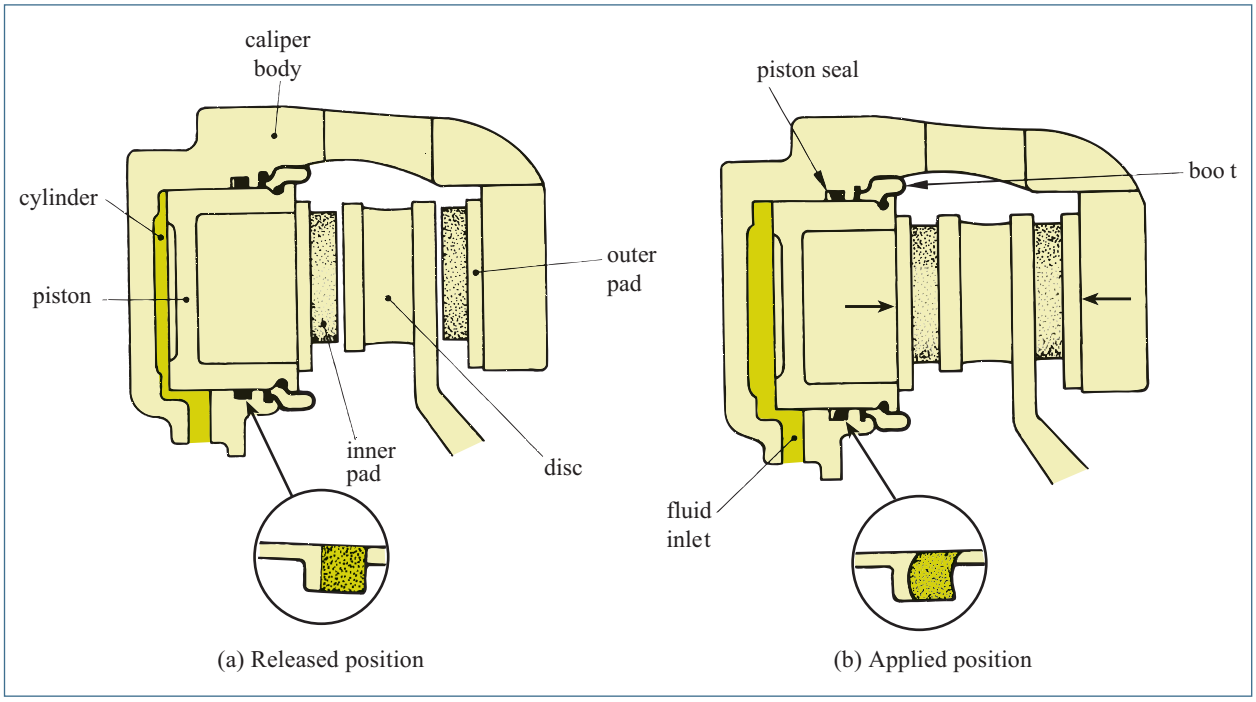


Figure 11.48 Floating-caliper operation (piston seal action is sho wn in the insert)

3 Hydraulic pressure acts against the back of the cylinder as well as against the piston, and this causes the caliper housing to slide inwards.
4 This movement is transferred through the caliper to the outer pad, which is also forced against the disc. Both pads are applied with equal force .

When the brake pedal is released and hydraulic pressure removed, the piston is withdrawn a little by the action of the piston seal. This removes pressure from the pads and provides running clearance between the pads and the disc.

The action of the piston seals is also shown. In the released position, the seal is relaxed, but it flexes when the brakes are applied. When the hydraulic pressure is relieved, the seal returns to its normal shape, taking the piston with it. This provides the small clearance that is needed between the brake pad and the disc.

Dual-piston brake caliper

The brake assembly in Figure 11.49 has a floating caliper with two cylinders and two pistons. It also has a ventilated disc. This design is often used with front brakes. Its operation is similar to that of a single-piston caliper, except that two pistons provide a greater braking force. Figure 11.49 show the caliper cut away so that the pistons and brake pads can be seen.

11.16.5 Disc pads

Disc pads are now manufactured from a variety of friction materials. These materials may be non-asbestos organic, low metallic, semi-metallic or ceramic.

The choice of compound depends on the application. Lighter passenger vehicles generate less heat in the brakes than heavy or high-performance vehicles. The optimum brake composition for any given use will be a combination of attributes that include:

- stopping power
- heat absorption and dispersion
- resistance to fade
- recovery speed from fade
- wear rate
- performance when wet
- noise in operation.

A disc pad consists of a steel backing plate with friction material bonded to its surface (Figure 11.50). The pad is positioned by guide lugs that fit into slots in the caliper or the anchor plate. Anti-rattle clips are fitted to the lugs to prevent the pad from rattling in the slots when the brakes are released. A steel shim is often fitted between the back of the inner pad and the piston. The parts shown are typical, but various shapes and sizes of pads are used in other installations. Different types of anti-rattle springs are also used.

11.17 Parking brakes

Most parking brakes are operated by a hand lever that is floor-mounted and located beside the driver. Figure 11.51 shows the layout of a floor-mounted parking brake (handbrake). This consists of the parking-brake lever with cables connecting it to the rear brake assemblies. The lever is connected to a yoke which carries the cables. This acts as an equaliser so that equal pull is applied to both cables. The front end of the cable is exposed, the rear ends enclosed by an outer cable. Brackets and guides locate the cable in relation to the bodywork and suspension.

11.17.1 Parking-brake levers

The parking-brake lever includes a ratchet mechanism which consists of a toothed quadrant on the mounting bracket and a pawl on the lever. When the parking brake is applied, the spring-loaded pawl engages with the teeth in the quadrant and holds the brake on. The brake is released by pressing the button to disengage the pawl.

Dash-mounted levers

Some vehicles have a dash-mounted parking brake. One design used in some light-commercial vehicles is shown in Figure 11.52. This has a T-shaped handle attached to a rod. When the handle is pulled outwards to apply the brake, pawls (located at position A) drop into ratchet teeth cut into the rod to hold the brake in the applied position.

The rod operates a lever that is attached to a front cable. The rear end of this cable is connected to an equaliser on the rear cables which transmit movement of the handle to the rear brakes. The brake is released by rotating the handle. This turns the teeth away from the pawls so that the rod can slide inwards to the released position.

Foot pedal

A foot-pedal-operated parking brake is used in some vehicles (these are not common). This is a small

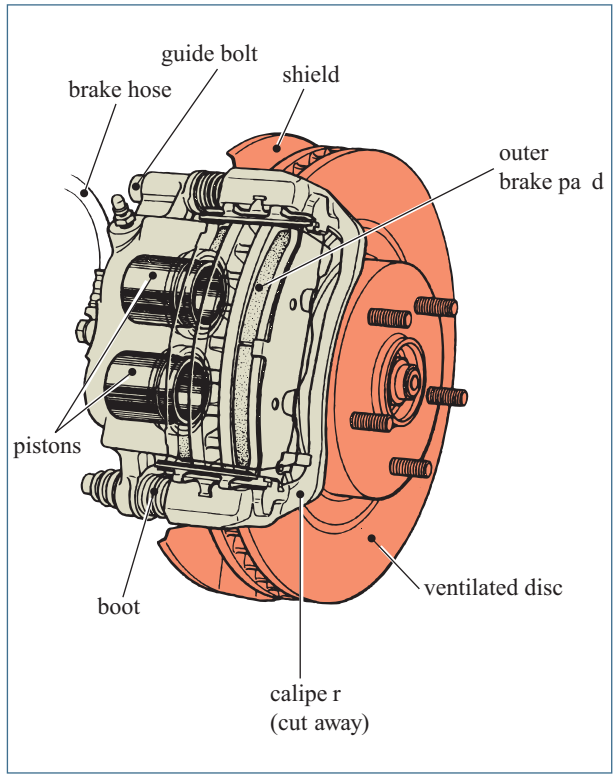


Figure 11.49 Cut-away view of a floating-caliper assembly with two pistons and a ventilated disc SUBARU

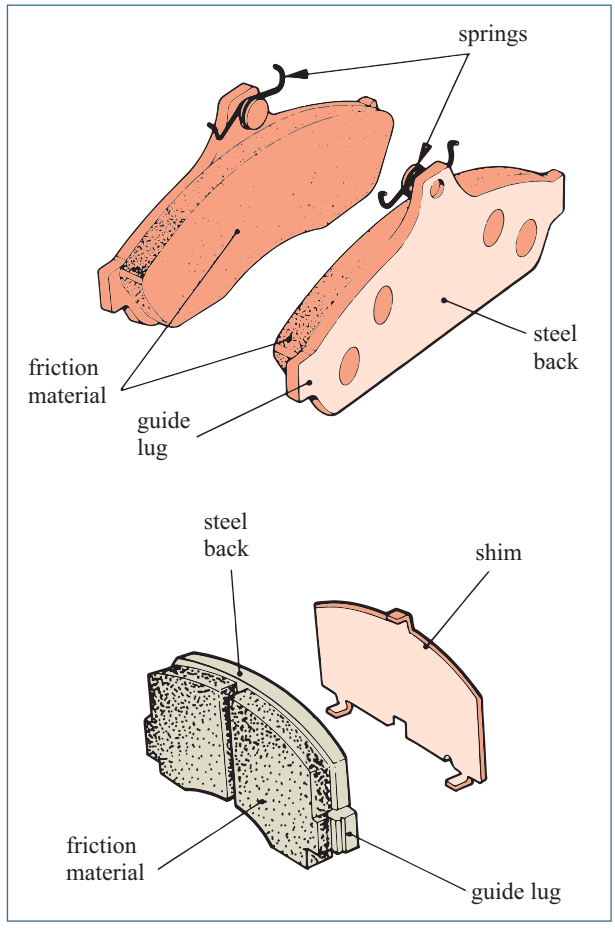


Figure 11.50 Disc-brak e pads

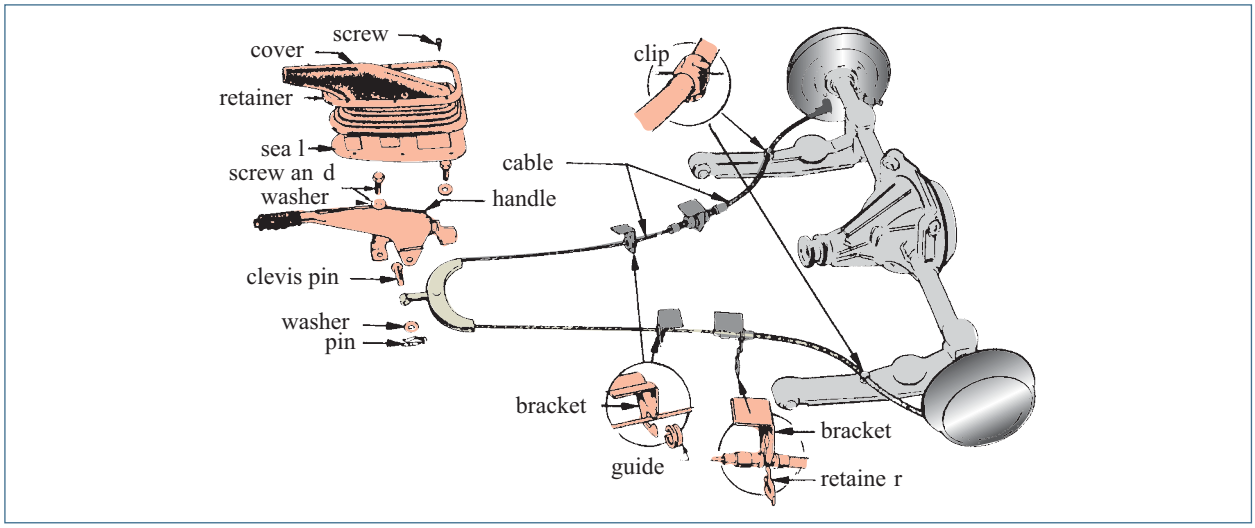


Figure 11.51 Parts of a parking-brak e assembly

pedal that operates the parking brake cable in the same way as a hand lever. It has no connection to the normal footbrake pedal. When the pedal is pushed to apply the parking brake, a pawl-and-ratchet device holds the brake applied. The parking brake is released by again pressing the pedal.

11.17.2 Drum parking brake

With drum brakes, the rear end of the parking-brake cable is attached to a lever at the brake assembly (Figure 11.53). One end of the lever is pivoted on a pin at the top of the rear shoe, and the other end is in the form of a hook to which the brake cable is attached. A pushrod, which sometimes incorporates the brake adjuster, is fitted between the lever and the front shoe.

When the lower end of the lever is pulled by the cable, the pushrod pushes the front shoe against the brake drum. The reaction of the lever against the rear shoe also pushes the rear shoe against the brake drum.

Handy hint: The brak **e assembly in Figure 11.53** is of the leading and trailing shoe design that is typical for a rear drum brak e.

11.17.3 Parking brake for disc brakes

There are two designs of parking brakes for disc brakes: *drum parking brakes* and *disc parking brakes*. One design has a combination of disc and drum, with the drum being used for a separate parking brake. In the other design, the parking brake uses the brake pads.

Disc with drum parking brake

Figure 11.54 shows a disc brake with a separate brake-drum assembly for the parking brake. A combined drum and disc is used. The disc brake operates in the

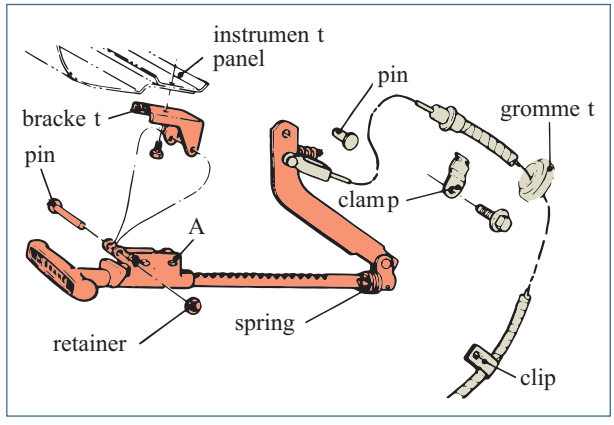


Figure 11.52 Dash-mounted parking brak e

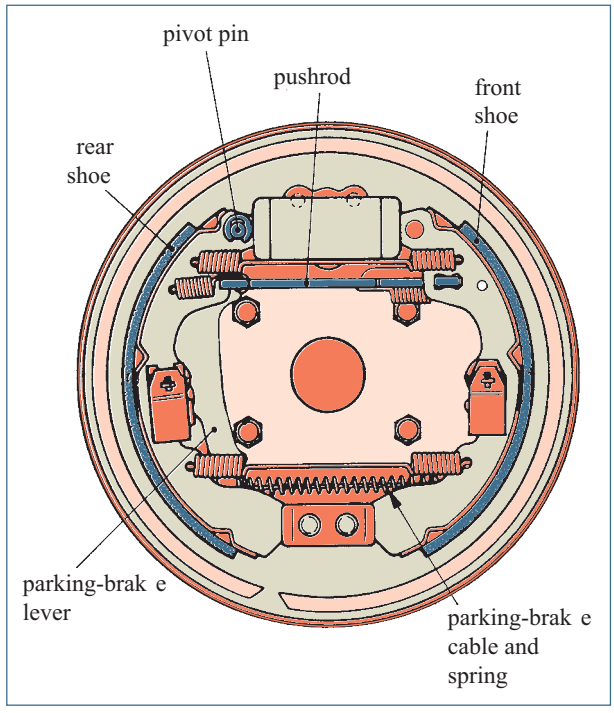


Figure 11.53 Rear drum-brak e assembly showing the parking-brak e parts

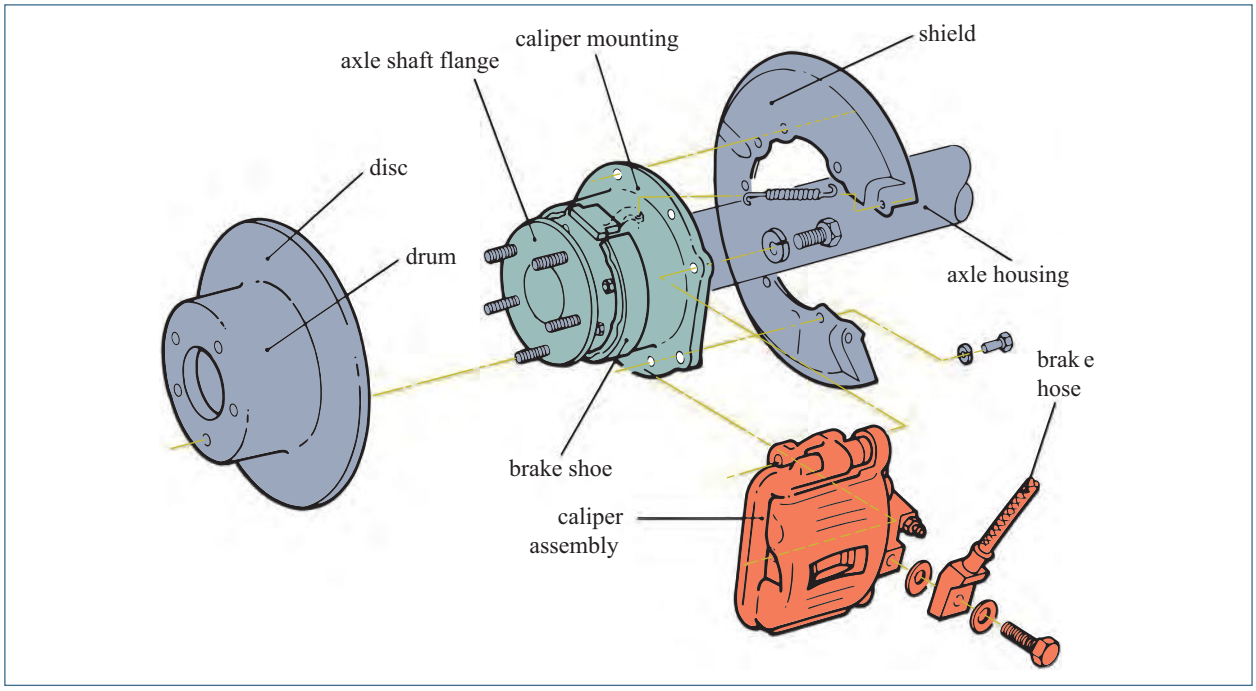


Figure 11.54 Disc brak e with a separate drum-type parking brak e GM HOLDEN LTD

usual way on the disc section. The parking brake operates inside the drum.

The parking-brake assembly is smaller than a normal drum brake. It is operated by the brake cable that is attached to a lever on the assembly. The lever expands the brake shoe against the inside of the drum. Some designs have a single-piece shoe; others have two shoes.

Disc parking brake

Figure 11.55 shows a rear brake caliper with parking-brake mechanism. With this arrangement as part of the caliper, the pistons are moved mechanically by the action of the parking-brake cable and the brake pads are held against the disc. The caliper has a lever to which the brake cable is attached. When the parking brake is applied, rotary movement of the lever is transferred through the caliper to the piston to apply the brake pads.

There are different arrangements for changing the rotary movement of the lever to axial movement of the pushrod. There are also different arrangements for the pushrod. The caliper shown uses a strut-and-pushrod arrangement with a self-adjusting screw included.

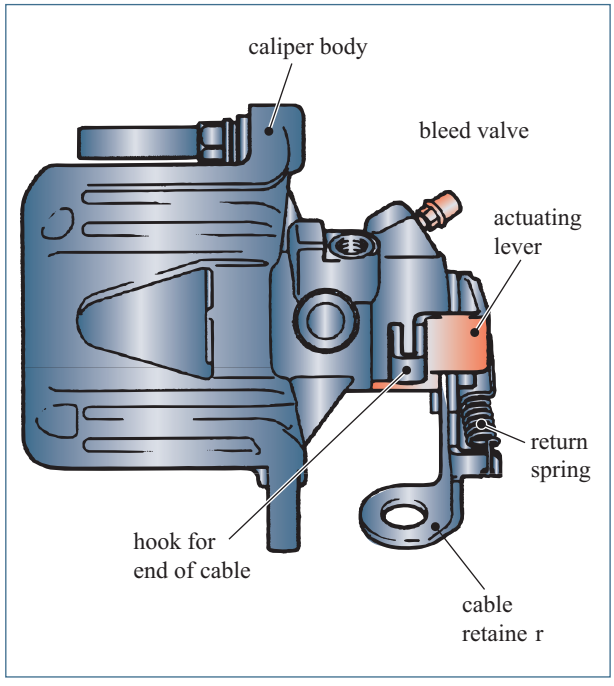


Figure 11.55 Rear brak e caliper with parking-brak e mechanism for applying the brak e pads GM HOLDEN LTD

The parts of a rear disc-brake assembly with a parking brake are illustrated in Figure 11.56. This has a different pushrod arrangement. When assembled, the actuating lever is bolted to the end of the lead screw, and the adjusting nut is threaded onto the lead screw.

The back of the piston is hollow, accommodating the tapered end of the adjusting nut. Movement of the lever rotates the lead screw, and this pushes the adjusting nut against the piston to apply the brake. The lead screw and adjusting nut form a self-adjusting mechanism.

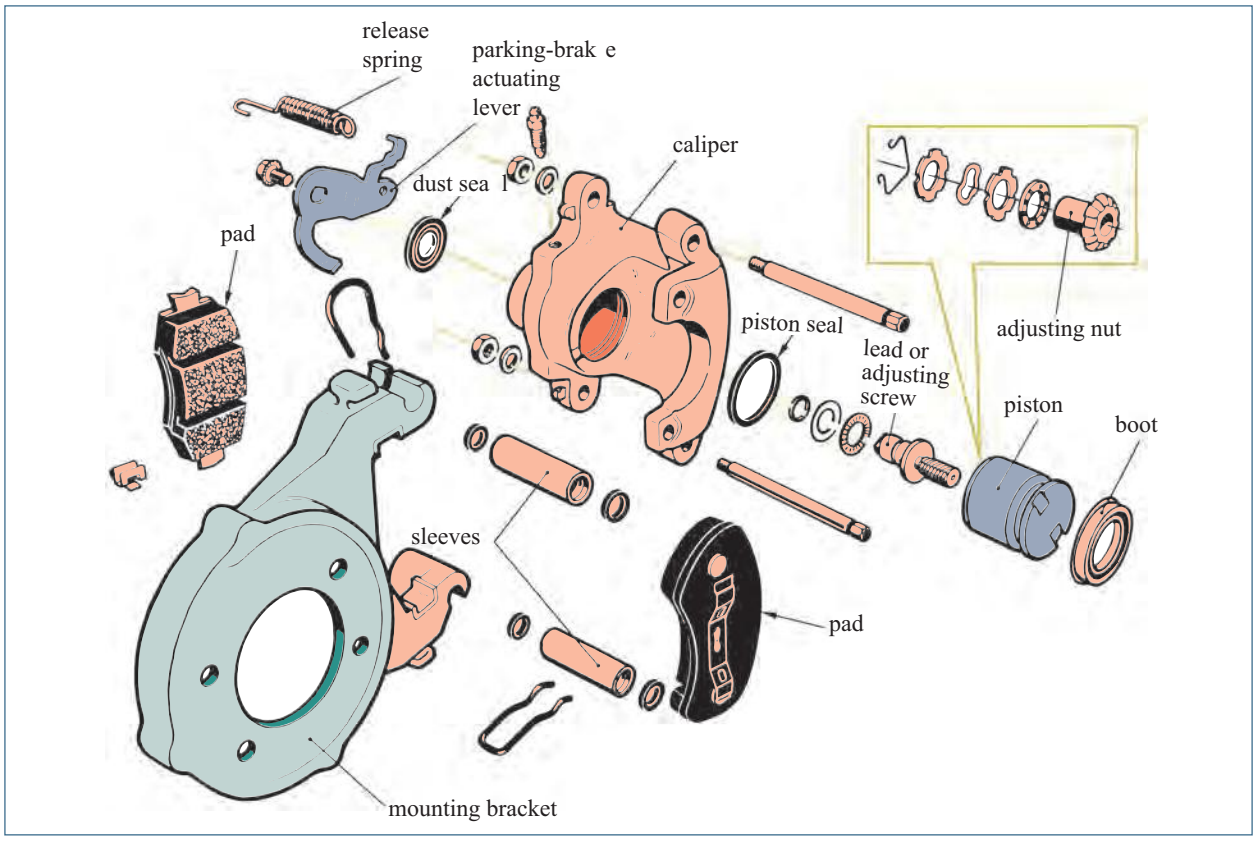


Figure 11.56 Rear disc-brak e assembly with a parking brak e FORD

11.18 Parking brake adjustments

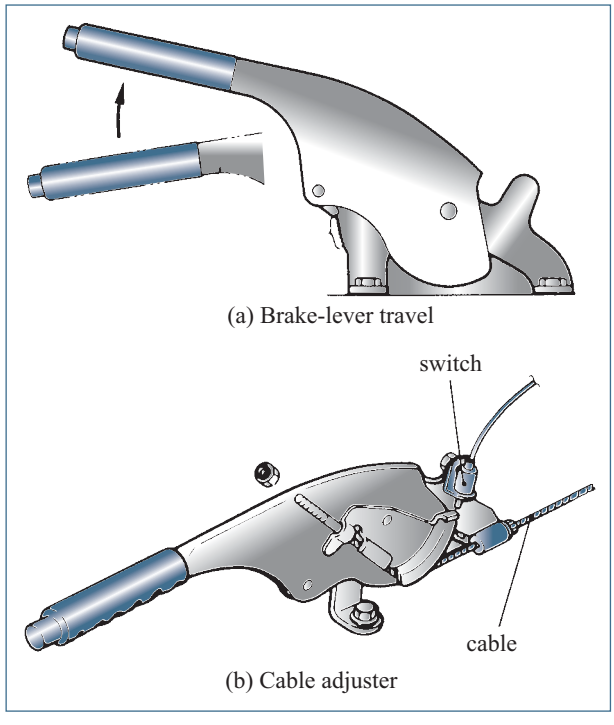
Most parking brakes (handbrakes) have some form of adjustment on the cable at the parking lever end. Figure 11.57 shows an example. Where parking-brake travel is excessive, the cable can be shortened to reduce movement. Most cables to the rear wheels have an equaliser, and so a single adjuster is sufficient. Other arrangements could have a separate adjustment on each cable.

11.18.1 Drum parking brake

With drum brakes, the self-adjusting mechanism automatically adjusts the clearance between the brake shoe and the drum. To a large extent, this also maintains the adjustment of the parking brake, and no further adjustments are needed at the wheel assemblies. Cable adjustment is made if the parking brake travel is excessive.

11.18.2 Disc parking brake

The caliper assembly in Figure 11.58 has a parking brake that operates the disc pads. The parking-brake cable is attached to a lever on the caliper. When the parking brake is applied, the lever turns a large screw to force the pads against the disc. In the illustration, the lever turns the screw which rotates in the nut. This pushes against the piston to apply the pads against the disc.



(a) Brake-lever travel

(b) Cable adjuster

Figure 11.57 Parking-brak e adjustment

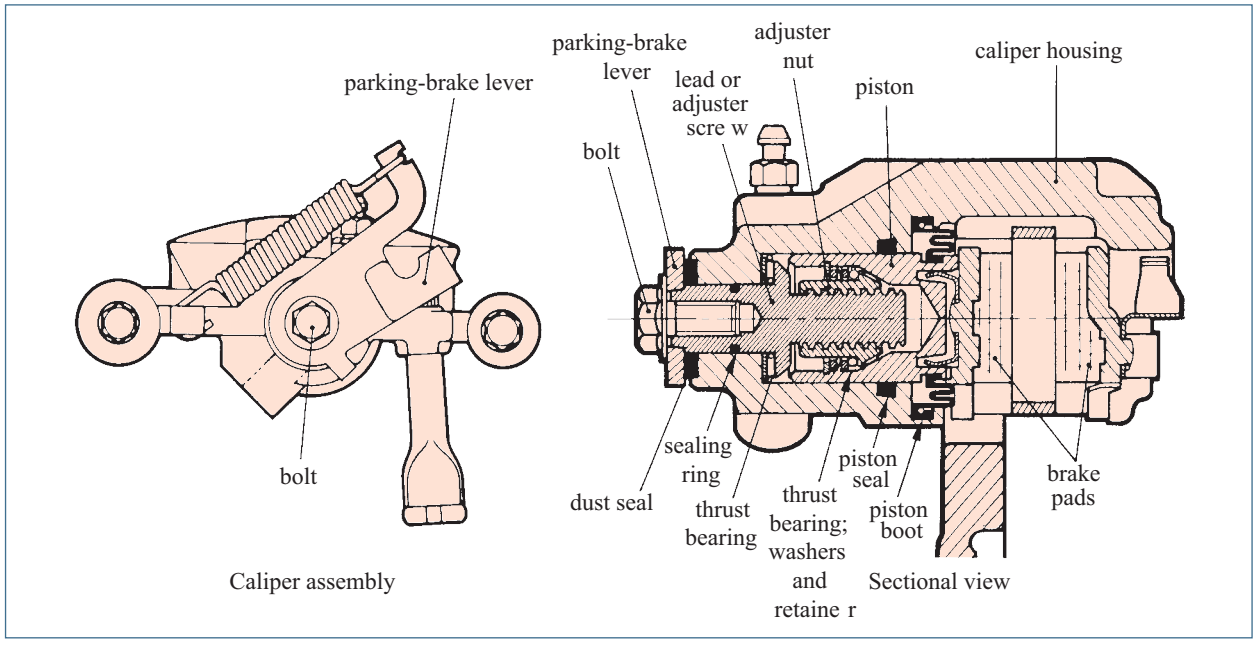


Figure 11.58 Rear disc caliper with parking brake MITSUBISHI

Effects of brake-pad wear

The service brakes need no adjustment because, like all disc brakes, the piston gradually moves further out of its bore as the pads wear. This maintains the normal clearance between the pad and the disc. The parking brakes do need adjustment, and an automatic adjuster is provided.

Disc parking-brake adjuster

In the disc parking-brake adjuster, the nut is allowed to rotate in the piston whenever the service brakes are applied. This winds the nut outwards on the screw and keeps it close to the piston. The nut has a thrust bearing to make it easy to rotate (Figure 11.58). Each time the service brakes are applied, the nut is pulled by the piston, and this tends to rotate it and wind it along the screw.

As the pads wear and the piston gradually moves further in its bore, it takes the nut with it. This increases the overall length of the screw and nut, preventing excessive movement of the parking-brake lever.

The nut can turn only when the service brakes are applied. It is prevented from turning when the parking brake is applied by the friction between its conical head and the piston.

11.18.3 Disc/drum parking brake

Construction

Figure 11.59 shows the dismantled components of a drum-type parking brake assembly that is used with disc brakes. It consists of a backing plate, an actuator and a single shoe with the brake lining. The actuator is bolted to the backing plate. It consists basically of the actuator body with two plungers operating in the bore. A pushrod and the end of the actuating lever are fitted between the plungers.

One plunger is referred to as the *tappet* and the other as the *adjuster nut.* The adjuster nut is notched and carries the adjuster screw. The tappet and adjuster screw both have slotted ends to accommodate the ends of the brake shoes.

Parking brake adjustment

The parking-brake shoes do not require regular adjustment. When necessary, it is done by turning the adjusting nut to either spread or contract the shoe. It can be adjusted with the brake drum removed, or with it in place.

With the brake drum removed, the diameter of the shoe is measured across the linings and the shoe is expanded to a specified dimension. After adjustment of the shoe, the drum is replaced.

With the brake drum in place, the notched adjuster is accessible through a hole in the brake drum. A flat-bladed screwdriver can be inserted through the hole and used in the notches to turn the adjuster (Figure 11.60).

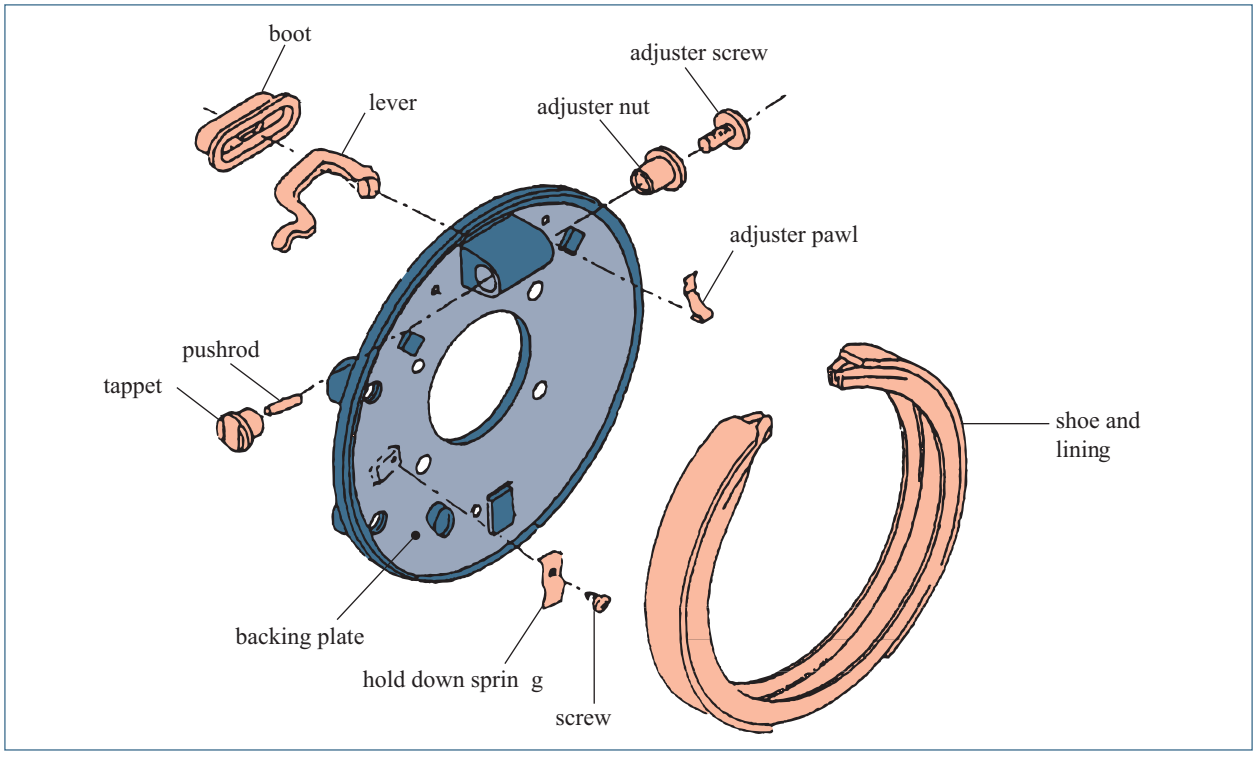


Figure 11.59 Components of a drum-type parking brak e that is used with a rear disc brak e FORD

The nut is adjusted to expand the shoe until it binds against the drum. The nut is then backed off until the brake drum can be rotated freely. The travel of the parking-brake lever is checked and, if necessary, adjusted at the cable adjustment. When fully applied, the parking-brake lever should not have more than five clicks of the pawl over the ratchet.

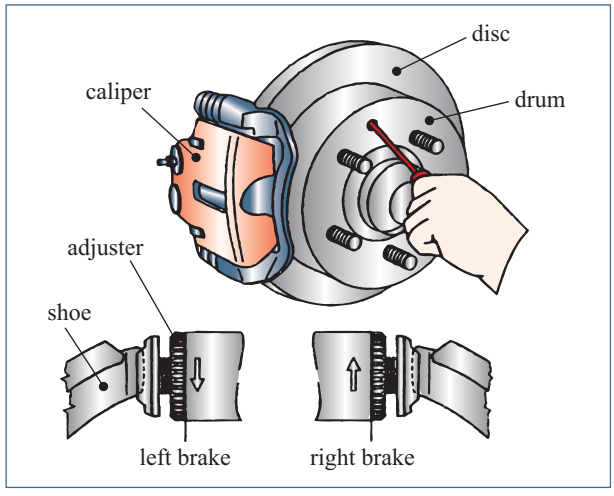


Figure 11.60 Adjusting the shoe of a drum-type parking brak e MITSUBISHI

11.19 Brake tools

Special tools are used to dismantle and service brakes (Figure 11.61). Most are for use with drum brakes, where springs have to be removed and replaced.

1 Return-spring tools —for removing and replacing return springs, preventing damage and distortion.
2 Brak e spring pliers —highly versatile , they have handles whose ends are shaped for levering springs into position.
3 Retaining-spring tools —for removing and replacing the retainers and springs. Their ends are shaped to fit against the retainer and over the pin, making it easier to compress the spring and turn the retainer .
4 Brak e-adjusting tool —a small lever with a flat blade , it fits through a hole in the backing plate to turn the star nut or notched adjuster .
5 Caliper piston expander —a tool for disc brak es, it is used between the piston (pistons) and the caliper after the disc pads have been removed. It is expanded to push the piston back into its bore so new pads can be fitted.
6 Brak e cylinder hone —has three abrasive stones which are held outwards on spring blades. It is used with an electric drill to hone wheel and master cylinders, and to remove light corrosion. It is used only on cast-iron cylinders.

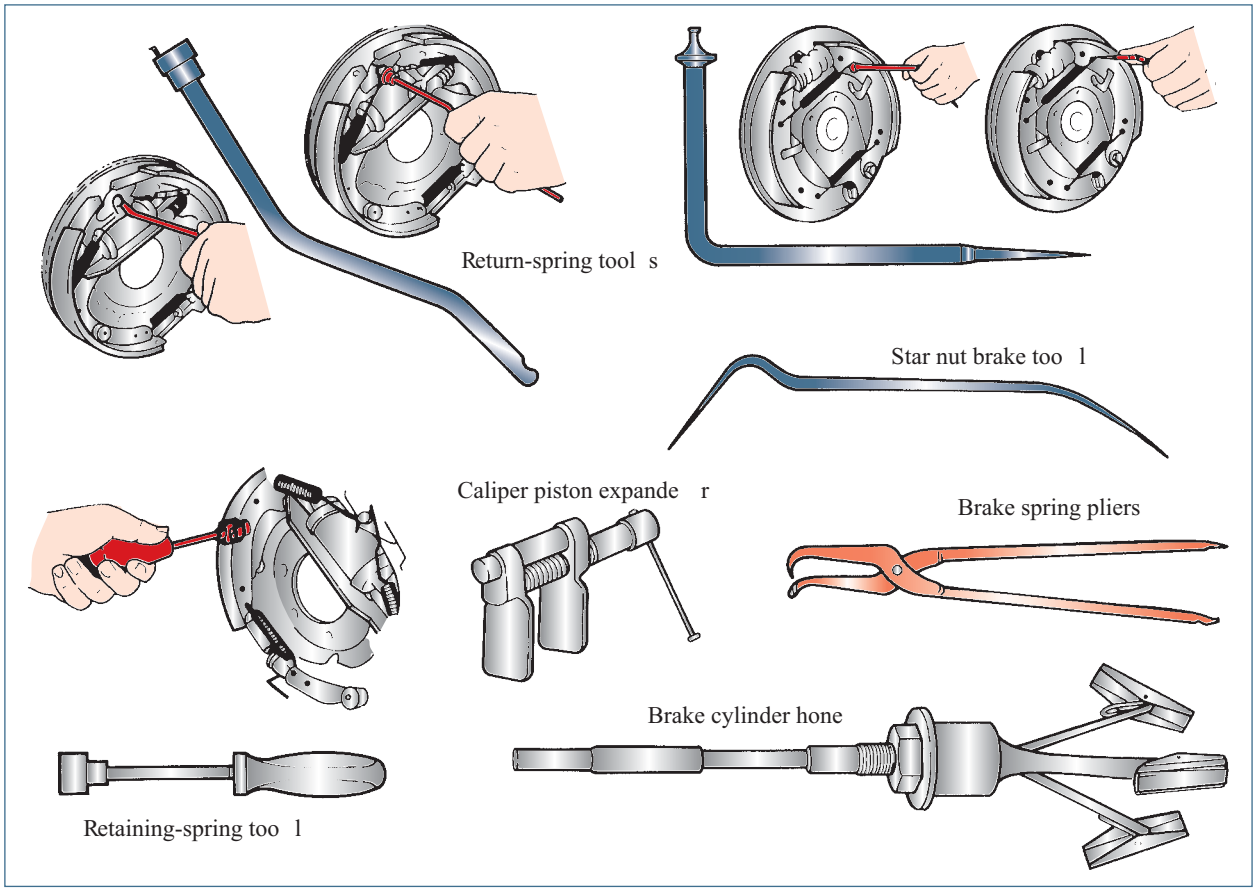


Figure 11.61 A range of brak e service tools

11.20 Brake system maintenance and inspection

The maintenance and inspection requirements of the various parts of brake systems are outlined the following sections.

11.20.1 Brake fluid level

The level of the hydraulic fluid in the master cylinder reservoir should be checked regularly. Reservoirs are made of transparent material and have maximum and minimum fluid level marks, so the fluid level can be checked without removing the reservoir cap.

The fluid in the reservoir should be maintained at the maximum level and should not require topping up. If frequent topping-up is necessary, the system should be checked for leaks. The cap and seal, or the cover and seal, should be refitted to the reservoir correctly so that the fluid will not leak or be exposed to the atmosphere.

Safety: Brak e fluid that is exposed to the atmosphere will absorb moisture from the air , and this will lower its boiling point.

Fluid leaks and spills

If fluid is being lost from the reservoir, the master cylinder, wheel cylinders, brake hoses, brake lines and connections should be checked for leaks. Any spilt brake fluid will damage paintwork. Should this occur, the area should be immediately washed with cold water.

11.20.2 Brake fluid change

Brake fluid should be changed every two years. Its condition can be checked using a fluid tester which is connected to the 12-volt battery and immersed in the master cylinder reservoir fluid. If this fluid does not pass the test, all fluid in the system should be replaced.

11.20.3 Brake pedal checks

Checks can be made of the brake pedal, as shown in Figure 11.62. They are as follows.

1. Free height. The free height, or distance of the pedal above the floor, is a specified dimension (Figure 11.62(a)). This can be adjusted by altering the length of the pushrod at the brake pedal.
2. Free play. The pedal should have a small amount of free play (3 to 6 mm) in the released position. This is the amount of movement at the pedal before any resistance is felt. If free play is insufficient, pressure will build up in the system and cause the brakes to be slightly applied. If the free play is excessive, this could reduce the effective pedal travel.
3. Pedal travel. This is the distance that the pedal travels when the brakes are applied (Figure 11.62(b)).
4. Pedal reserve. The depressed pedal height, or distance from the floor, is known as the pedal reserve.

11.20.4 Pedal reserve

Pedal reserve is related to pedal travel. If the pedal has normal travel, it will be well clear of the floor when the brakes are applied and there will be adequate pedal reserve. However, if there is excess pedal travel, there will be low pedal reserve. Its different causes are indicated below.

Handy hint: Pedal reserve must be checked with the parking brake off so that the brake shoes or pads are in the released position.

Low pedal reserve—firm pedal

Excessive pedal travel, but with a firm pedal, could signal too much clearance between the brake shoes and the drum. The brakes could need adjusting, or the self-adjustment mechanism might not be working. Worn brake linings or pads would also be a likely cause. In the hydraulic system, low pedal reserve could be the result of failure of one of the circuits of the split brake system.

Low pedal reserve—soft pedal

Excessive pedal travel, but with a soft or spongy pedal, could be caused by air in the hydraulic system, or by a shortage of brake fluid. Other hydraulic faults such as a defective master cylinder could be preventing pressure from being built up. If the pedal moves slowly down, under light-to-medium pressure, the fault is likely to be the seals in the master cylinder.

Safety: It is unsafe to operate a vehicle with low pedal reserve, and the system should be checked to find the cause.

11.20.5 Stop-light switch

The operation of the stop-light switch should also be checked. The switch is operated by brake pedal movement, being 'off' when the brake pedal is in the released position and switched 'on' as soon as the pedal is moved. The switch can be adjusted by altering its position in relation to the pedal. This can also be used to adjust pedal free play.

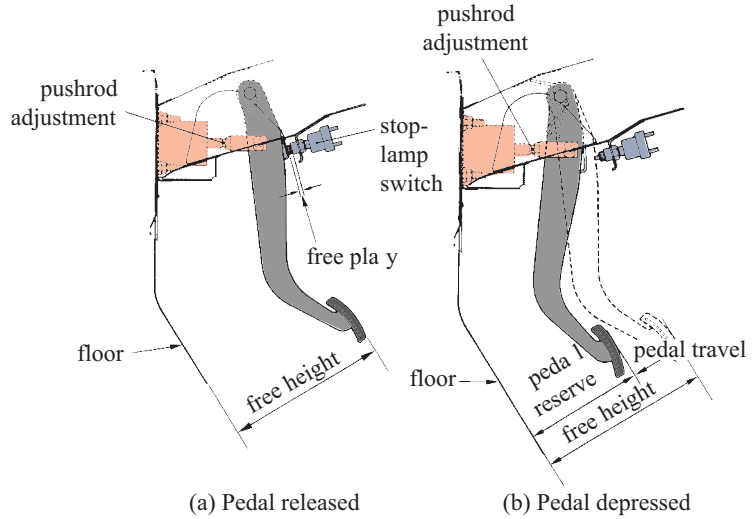
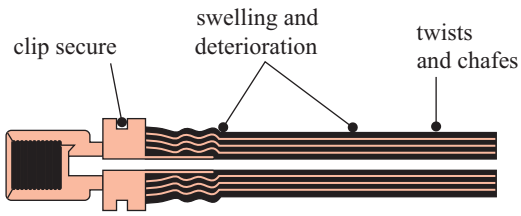


Figure 11.62 Brake pedal GM HOLDEN LTD



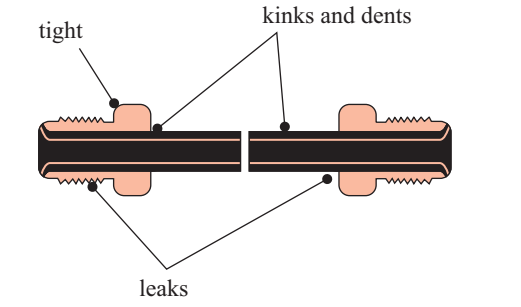
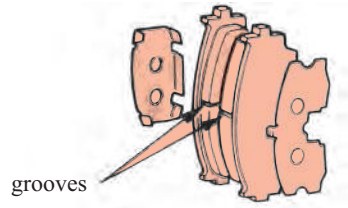


Figure 11.63 Inspection of hydraulic brak e hose and tubing



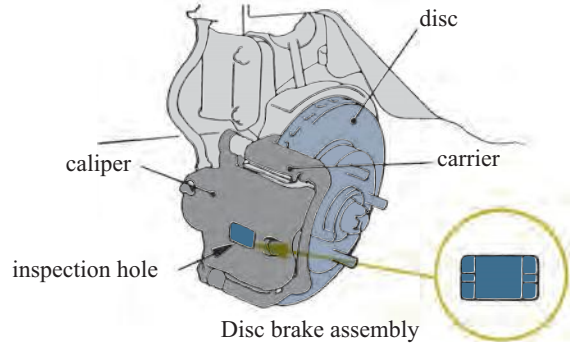


Figure 11.64 Disc-brak e assembly—the caliper has an inspection hole

11.20.6 Brake lines and hoses

The brake lines should be inspected for damage and the hoses for deterioration and signs of leaks (Figure 11.63). Hoses should be installed free of twists and sharp bends. They should be positioned so that they will not rub against parts of the suspension or be fouled by the tyre when the front wheel is turned. The nuts of brake-line connections should be tight. The tubing should be correctly secured and free of kinks and dents.

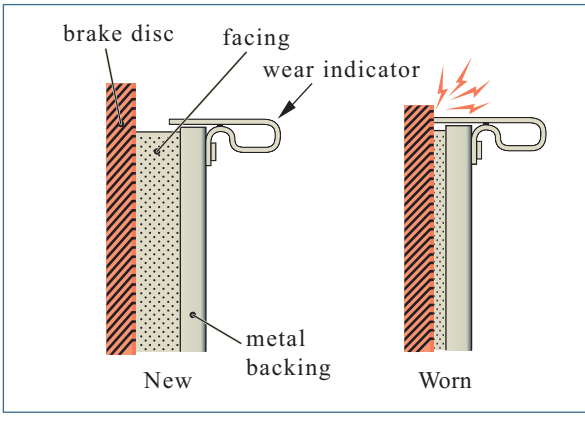


Figure 11.65 Operation of a pad wear indicator

11.20.7 Brake adjustments

Disc brakes do not require pad adjustment as they are self-adjusting. The pistons gradually move out of their cylinders as the pads wear to maintain a small clearance between the pads and the discs. Most drum brakes have self-adjusting mechanisms, but some have manual adjustments. These will require periodic adjustment to compensate for brake-lining wear.

11.20.8 Lining and pad wear

Brake use gradually wears away the friction material of the brake linings and the brake pads. Eventually, they have to be replaced. The thickness of brake pads can usually be checked visually without removing them from the caliper assembly. Calipers often have an inspection hole through which the edges of the pads can be seen (Figure 11.64).

Some brake pads have a metal spring which acts as a wear indicator (Figure 11.65). When only about 1.5 mm of facing is left, the spring makes contact with the disc when the brakes are applied. This produces a metallic sound that signals that the pad is near its wear limit. With drum brakes, the wheels and brake drums have to be removed to check the thickness of the brake linings.

11.20.9 Brake pad sensors

There are two main types of sensors; single-wire and two-wire. In the single-wire type a sensor is built into the brake pad at the minimum wear thickness. When the rotor contacts the live sensor, the circuit is completed to earth through the rotor and a warning light comes on in the instrument cluster.

A two-wire sensor is attached to the brake pad. When the wear limit is reached, the rotor connects the two contacts to complete the warning light circuit. The sensor is separate from the pad. It should be replaced at the same time as the pads.

11.20.10 Parking brake

The parking-brake lever, when fully applied, should only move about half its possible travel, as shown in Figure 11.66. As the lever is moved to the applied position, the pawl will click over the ratchet teeth. The maximum number of clicks is often specified, and is a gauge of lever movement. Excessive movement indicates the need for adjustment.

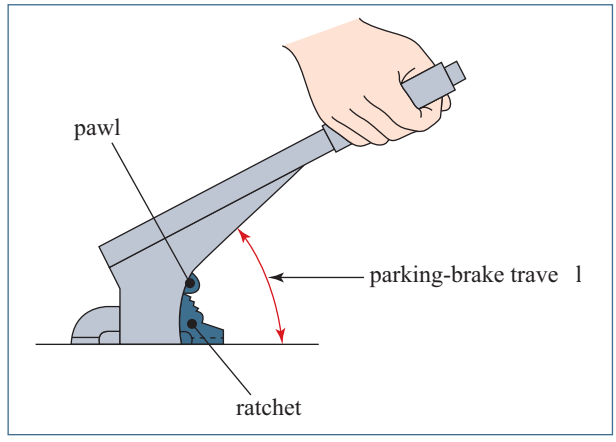


Figure 11.66 Parking-brake (handbrake) travel is checked by the number of clicks of the pawl over the ratchet teeth TOYOTA

11.21 Master-cylinder service

Figure 11.67 has four different views of the dismantled parts of a master cylinder. The following, which relates to Figure 11.67, outlines the main aspects of working on a master cylinder:

1 Proportioning valve. This is an assembly that is part of the master cylinder (Figure 11.67(a)). It fits into a bore in the cylinder body and can be removed after the end plug has been removed from the front of the cylinder.

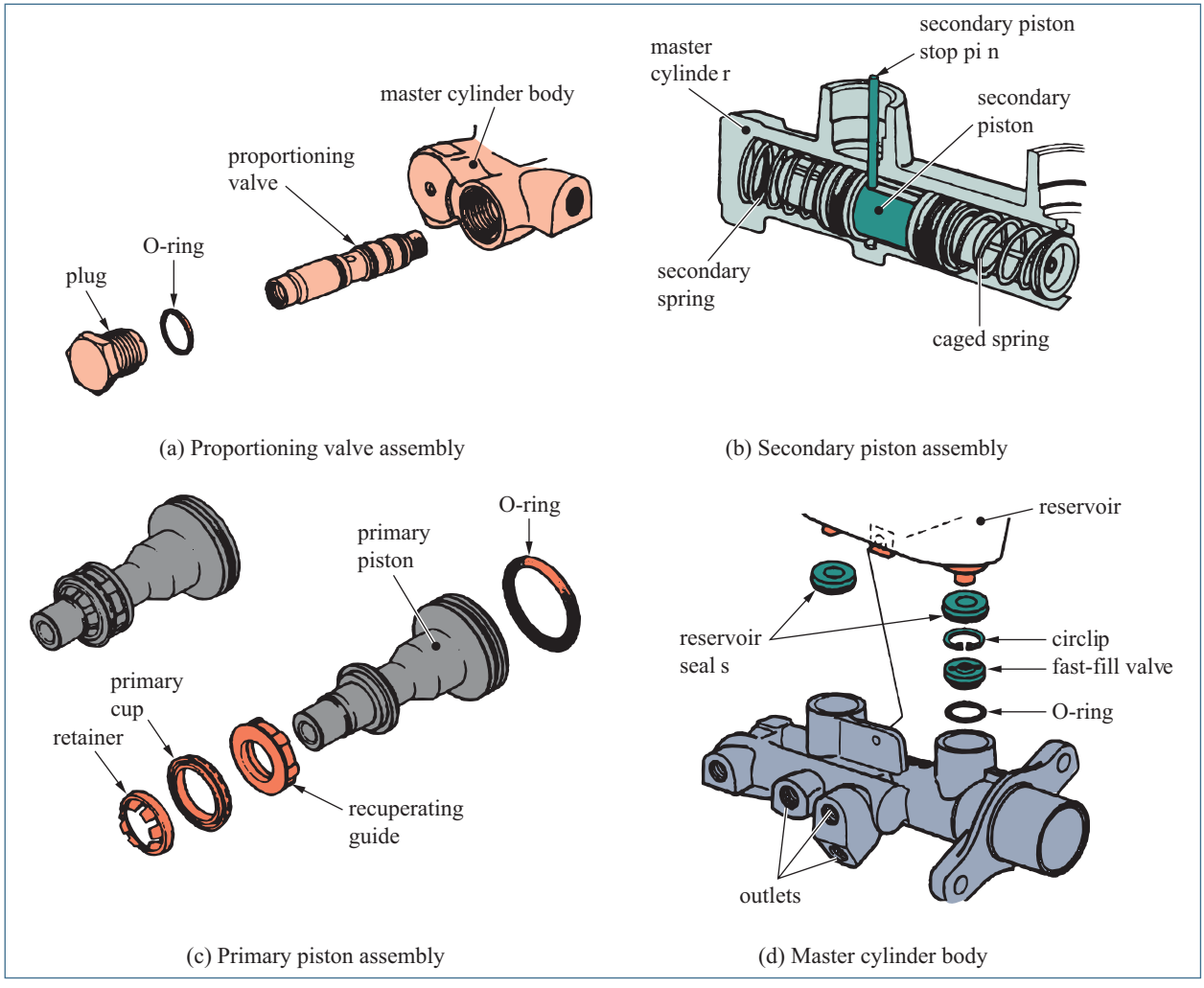


Figure 11.67 Dismantled parts of a tandem master cylinder FORD

The O-rings on the valve assembly can be renewed, but if the proportioning valve assembly has a fault, the complete valve assembly must be replaced. Care should be taken to prevent the O-rings on the valve from being damaged.

2 Secondary piston. The secondary piston assembly is not dismantled (Figure 11.67(b)). If the seals are worn or damaged, a new piston assembly has to be fitted.

When being installed in the cylinder, the assembly is pushed to the bottom of the cylinder bore with a soft wooden dowel. It is fitted with the caged spring towards the open end of the cylinder.

The piston is retained in the cylinder by a stop pin which is accessed through the reservoir front inlet port. The pin fits through a slot in the piston, which must be aligned with the pin holes in the cylinder during reassembly.

3 Primary piston. The parts of the primary piston assembly are shown (Figure 11.67(c)). The large O-ring is fitted in a groove in the large end of the stepped piston. The recuperating guide, L-type seal and seal retainer are fitted to the small end of the piston.

4 Master cylinder body. This shows the seals between the reservoir and the cylinder (Figure 11.67(d)). The reservoir is secured to the cylinder by a bolt. The fast-fill valve is located in the cylinder reservoir rear inlet port area, and is accessible with the reservoir removed.

Handy hint: During assembly and installation, the lips of the seal must face into the cylinder.

11.21.1 General master-cylinder service points

When dismantling a master cylinder, avoid damaging the parts. O-rings and seals should be carefully removed from pistons and valves so that the grooves into which they fit are not damaged. When cleaning a master cylinder, use special brake cleaning fluid to protect the rubber components. Rubber grease or clean brake fluid should be applied to the parts as they are being assembled. This will make it easier for the seals and O-rings to enter the bore of the master cylinder.

11.21.2 Removing and replacing a master cylinder

The procedure is as follows:

1 Remove the brake fluid from the reservoir and cylinder by bleeding the brakes, as previously shown.
2 Remove electrical connections and brake lines. Cover the pipes to keep them clean.
3 Remove the master cylinder.
4 Mount the new master cylinder in a vice and fit brake pipes that are bent to go to the bottom of the master cylinder reservoir, as shown in Figure 11.68.
5 Fill the reservoir with the correct brake fluid and bleed the air from the master cylinder by pushing the rear piston slowly in and out. Continue this procedure until no air bubbles rise to the surface of the brake fluid.
6 Remove the pipes, seal the outlets, top up the fluid level and replace the reservoir cap.
7 Fit the new master cylinder to the vehicle, ensuring that the mounting on the brake booster is clean.
8 Fit the brake pipes and electrical connections.
9 Apply the brakes and check for spongy pedal or leaks around the master cylinder. Bleed the brakes again if necessary.

11.22 Disc-brake service

Disc-brake service includes inspecting the brake pads for wear (and replacing them if necessary), checking the discs and making sure that there are no fluid leaks at the caliper. The piston boots and piston seals usually only need replacing when the vehicle has completed a lot of kilometres, or a long period of service.

11.22.1 Brake pads

Brake pads should be renewed when the friction material is worn to a minimum thickness of about 2 mm. In most cases, the caliper must be removed to enable the pads to be replaced. This also enables the condition of the boot to be checked and the cylinder inspected for possible leaks.

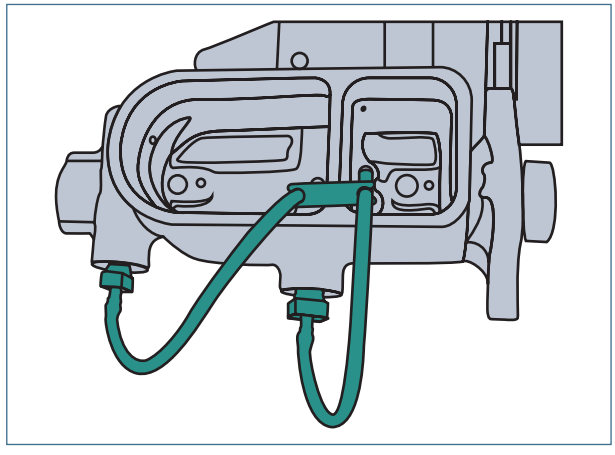


Figure 11.68 Master cylinder being bled

To gain access to the pads, the caliper housing is unbolted and lifted clear of the disc. The hydraulic hose does not have to be disconnected from the caliper unless the caliper requires servicing.

Safety: The caliper should not be allowed to hang by the hydraulic hose—it should be tied by a wire to a part of the suspension.

When fitting new pads, the piston has to be pushed back into its cylinder in the caliper. Doing this displaces fluid back into the reservoir, which could cause it to overflow if some fluid was not first removed. Fluid can be bled from the reservoir by loosening the hydraulic connections at the master cylinder, or from one of the bleeder valves.

Brake pads should always be replaced as a front or a rear set. If only one brake pad needs to be replaced, the other pads in the set also need to be replaced, irrespective of their condition.

Self-adjustment of pads

Disc brakes are self-adjusting. As the pads wear, the pistons will gradually move further from their bore to maintain the small clearance between the pad and the disc. The pistons will be retracted by the action of the seals each time the brakes are released, but only to a position which gives the normal pad clearance.

Also, with floating calipers, the caliper housing is being centred each time the brakes are applied. In this way, disc brakes adjust themselves. There is no service adjustment provided.

11.22.2 Caliper construction

The dismantled parts of a caliper with two pistons are shown in Figure 11.69. This type of caliper is commonly used for the front brakes of larger vehicles. Single-piston calipers are used for smaller vehicles and for the rear-wheel brakes.

11.22.3 Caliper service

To renew the piston boot and seal, the caliper assembly must be removed from its mounting. The hydraulic hose is disconnected so that the caliper can be taken from the vehicle to the bench. The pistons are accessible after the pads have been removed. Figure 11.70 shows the main dismantling and reassembling operations for a caliper.

Dismantling

1 The piston is removed by blowing it carefully from its cylinder (Figure 11.70(a)). A piece of wood or a pad of rag or cardboard about 20 mm thick should be placed in the caliper and air pressure gradually applied.

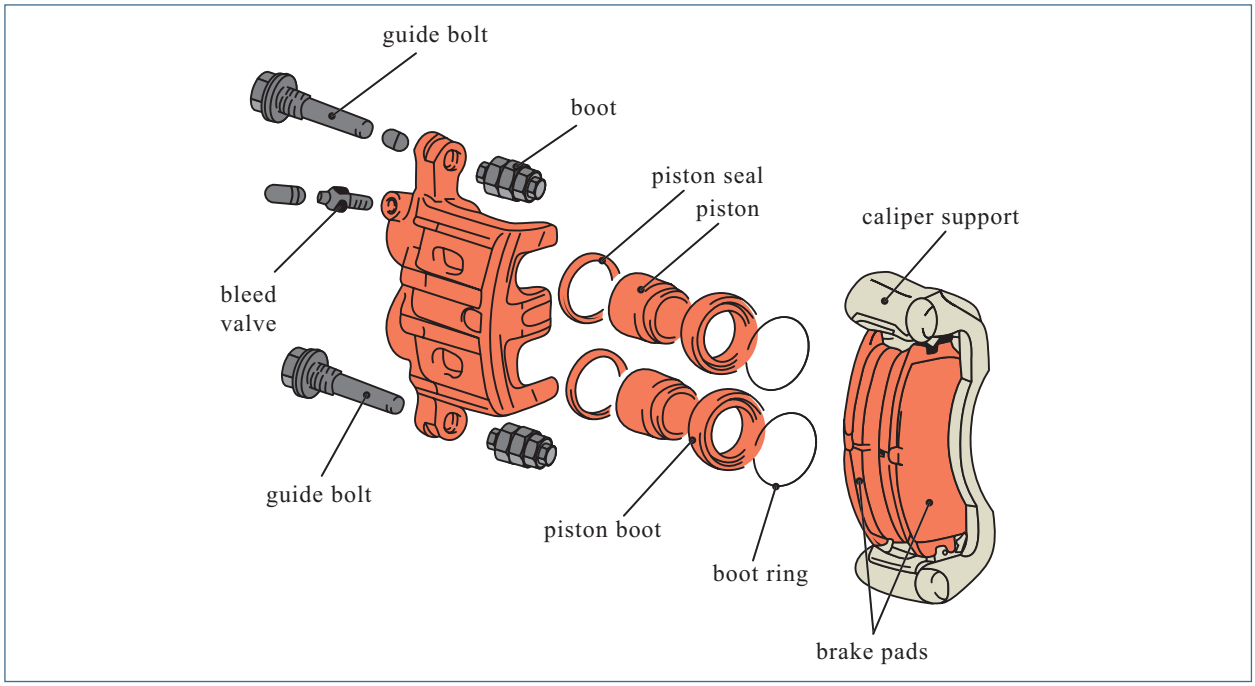


Figure 11.69 Floating-caliper assembly with two pistons

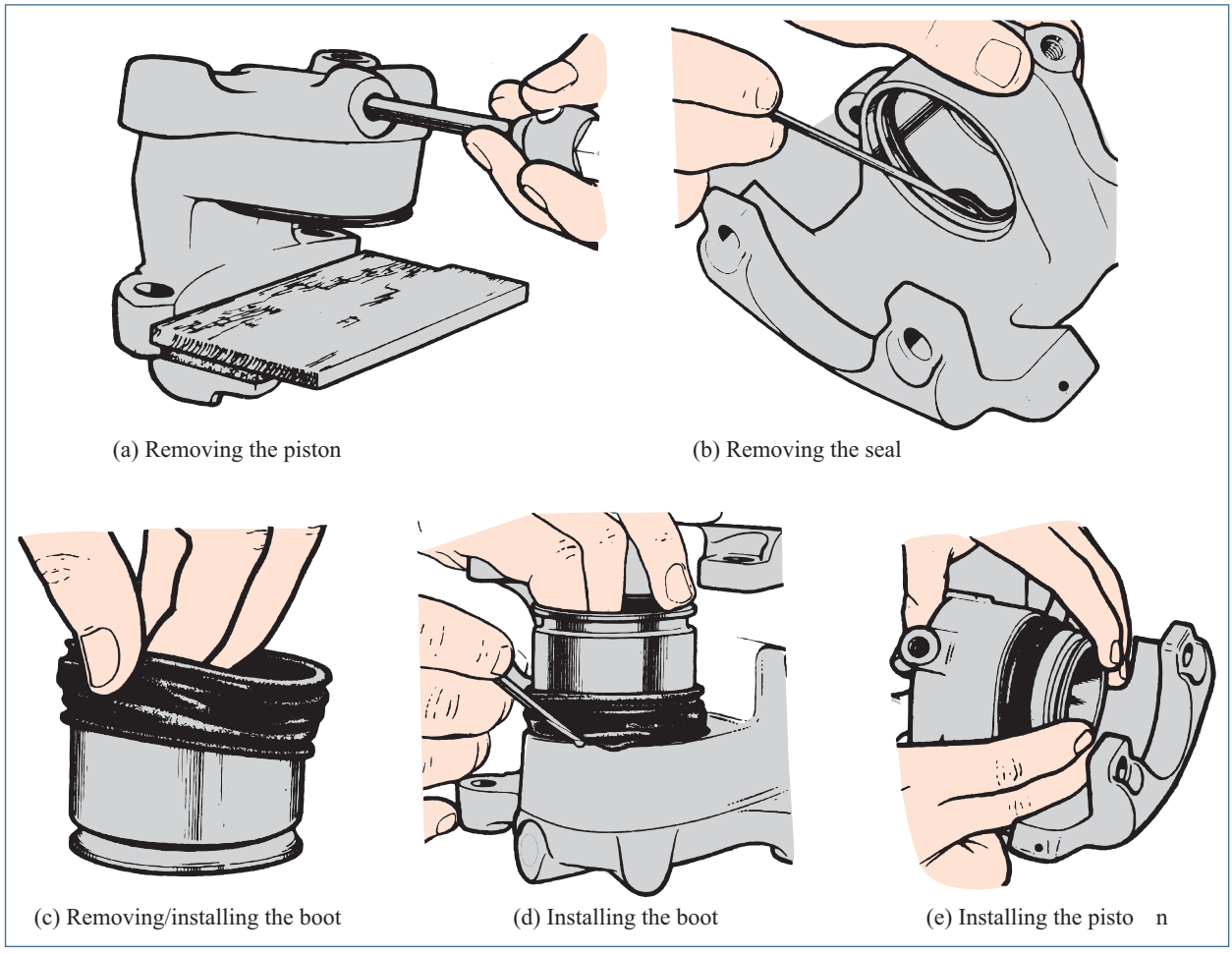


Figure 11.70 Servicing a piston and caliper assembly FORD

2 To remove the piston seal from its groove in the cylinder bore , a small plastic or wooden probe is used (Figure 11.70(b)).
3 With the piston removed from its bore , the rubber boot can be removed from its groove in the bore of the cylinder and from the groove in the piston (Figure 11.70(c)).

Handy hint: The probe must be of soft material to avoid damaging the groove and bore .

Inspection

1 The parts should be cleaned with methylated spirits and wiped dry . The caliper and passages in the caliper can be blown with compressed air , but pad dust should not be blown off with compressed air .
2 The cylinder bore should be check ed for scoring and corrosion. The cylinder cannot be honed; a caliper with a damaged bore should be replaced.
3 The piston should be check ed for pitting, scoring or loss of plating due to wear .

Reassembly sequence

The piston seal is installed in its groove in the cylinder bore, the boot is installed on the piston, and the piston is then installed in its bore in the caliper (Figures 11.70(d) and 11.70(e)).

1 When installing the piston seal, it should be dipped in fluid or coated with rubber grease and then fitted into its groove in the cylinder . The seal is of square section and care should be tak en to ensure that it is not twisted.
2 When reassembling the piston, a new boot and seal should be used.
3 The inside of the boot should be coated with rubber grease before it is installed on the piston. The piston should also be coated with rubber grease before being installed in its bore .

11.22.4 Discs

The disc should be checked for scoring. The disc is serviceable if only light scoring exists, but it will require machining in a disc brake lathe if scoring is excessive. It can also be checked for runout, thickness and parallelism.

Figure 11.71 shows the parts that are checked.

1 Disc runout is checked by mounting a dial gauge against the face of the disc and rotating it slowly to check the variation of the gauge reading. The maximum allowable runout is around 0.15 mm.
2 The thickness of the disc can be checked with a micrometer or vernier calipers. The thickness should be measured at a number of places to determine whether the faces of the disc are parallel. The maximum allowable variation in thickness is around 0.015 mm.

There are specifications for the minimum disc thickness. For ventilated discs, the minimum thickness of each flange is also specified. When a disc is resurfaced, there are limits to the amount of material that can be removed.

Handy hint: If the finished size of a disc is below the minimum specifications, it must be discarded and a new disc fitted.

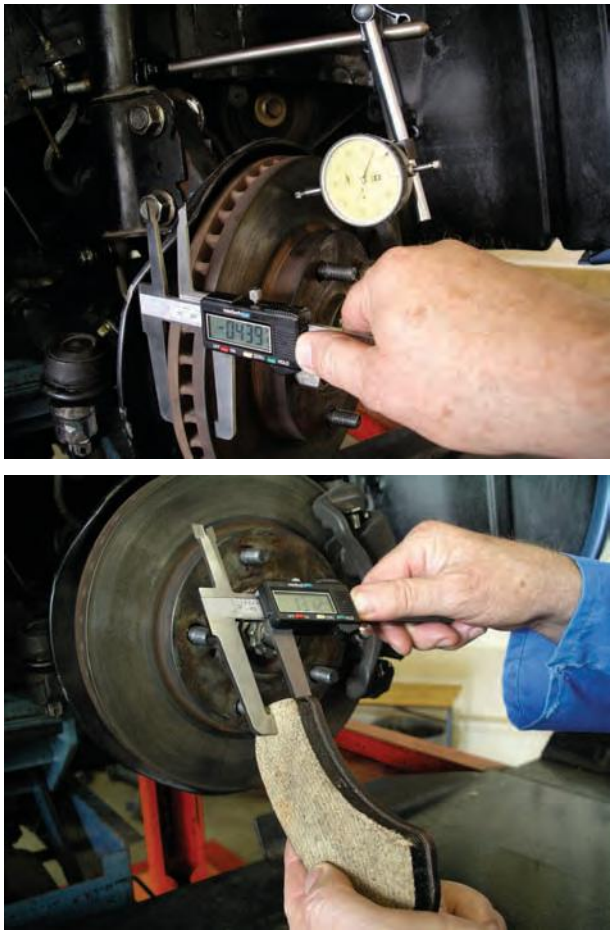


Figure 11.71 Checking the condition of the disc and pad

Table 11.1 Brake fault diagnosis

Possible fault	Likely cause
Excessive pedal travel	Brake shoe adjustment required Excessive disc runout Insufficient fluid, or leaks Air in the hydraulic system Loss of fluid in one hydraulic circuit
Spongy pedal	Air in the hydraulic system Insufficient fluid
Springy pedal	Incorrect shoe adjustment Distorted brake shoes Badly installed shoes
Pedal gradually goes to floor	Leak in hydraulic system Faulty cups in master cylinder allow fluid to pass
Hard pedal	Brake booster inoperative Pedal linkage damaged or dry Brake hoses or line restricted Wheel cylinder pistons seized Caliper piston stuck Wet brake linings
Pedal pulsates	Out-of-round or off-centre drum Excessive disc runout Normal effect of ABS
Brake drags	Incorrectly adjusted shoes No free play at pedal Fluid or grease on linings or pads Sticking piston in wheel cylinder or caliper Master cylinder fault Blocked compensating port Faulty brake hose or line Parking-brake cable binding
Brake grabs	Fluid or grease on linings or pads Faulty brake drum or disc Faulty return spring Piston sticking in wheel cylinder or caliper
Vehicle pulls to one side	Fluid or grease on linings or pads Faulty or incorrect return spring Seized piston in wheel cylinder Piston stuck in caliper Brake hose or line restricted One hydraulic circuit inoperative Low tyre pressure or worn tyre
Rear brakes lock	Proportioning valve inoperative Rear tyres worn Master cylinder faulty
Brake chatters	Fluid or grease on linings or pads Loose suspension parts Drum or disc out of round Loose mounting
Brakes squeal	Glazed or contaminated linings Type of friction material Dirty or scored drums

11.23 Fault diagnosis

Table 11.1 lists faults that can occur in brake systems and shows their likely causes. There are two general types of faults: those originating in the hydraulic system and those originating in the mechanical components.

11.24 Brake systems testing

There are two different types of brake testers which can calculate the braking efforts and efficiencies of a motor vehicle. Shown in Figure 11.72, these are:

1 Roller brak e testers —a chassis with a driven roller system
2 Decelerometer —a hand-held device for measuring dynamic braking forces during a vehicle road test.

(a)

(b)

Figure 11.72 Types of brak e testers: (a) roller brak e testers (b) a decelerometer SHUTTERSTOCK/AUTO TEST PRODUCTS PTY LTD

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- identify and understand brak e components
- apply the regular inspection and testing of brak e systems
- inspect, service and repair brak e system components
- examine and analyse brak e systems, using the correct tools and equipment to meet manufacturers ' requirements.
- diagnose brak e faults.

REVIEW QUESTIONS

1 What are the main parts of a braking system ?
2 Explain how force can be transmitted from the driver to the brak es at the wheels.
3 Why must air be ex cluded from the hydraulic system ?

4 What is a split brake system?
5 Name the two types of split braking systems.
6 What is a tandem master cylinder?
7 What is the function of the compensating port in the master cylinder?
8 What is a centre-valve master cylinder?
9 What is a fast-fill valve?
10 What is the purpose of a proportioning valve?
11 How does a fluid level warning operate?
12 List some of the different types of wheel cylinders.
13 State the main properties of brake fluid.
14 What is a brake booster?
15 Explain briefly how a brake booster functions.
16 Name the parts of a drum-brake assembly.
17 What is meant by leading and trailing shoes?
18 State some of the advantages of disc brakes.
19 Explain the difference between a fixed and a floating caliper.
20 Explain briefly how a drum parking brake operates.
21 Describe the two types of electronic parking brakes.
22 Why is it necessary to adjust drum brakes?
23 What is meant by a self-adjusting brake?
24 Describe how one type of self-adjuster works. Refer to one of the illustrations.
25 Where is the adjustment for the parking brake located?
26 How is brake disc runout checked?
27 Why must brakes be bled?
28 Give a brief outline of one method of bleeding brakes.
29 What adjustments are usually provided on a brake pedal?
30 How can the operation of a vacuum brake booster be checked?
31 How would a piston and its associated parts be removed from a caliper?
32 What could cause a spongy brake pedal?
33 The brake pedal of a drum-brake system has excessive travel. What is the likely cause?
34 What are the signs that disc pads need renewing?
35 When working on the vehicles brake system what safety and environment precautions must be followed?
36 What tool should be used when checking the measurement of disc rotors and where would you get information on minimum thickness?

CHAPTER 12

Suspension systems

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify the type, function, operation and location of suspension system components
2 observe safety procedures and requirements to safely carry out suspension system service and maintenance
3 diagnose and repair suspension system components and systems in accordance with workplace and manufacturers' requirements and specifications.

Suspension components include the springs, axle, shock absorbers, arms, rods and ball joints. These suspend the vehicle body and associated parts so that they are insulated from road shocks and vibrations which would otherwise be transferred to the passengers and load. Parts of front suspensions also perform steering functions.

Suspension servicing includes lubrication of ball joints, lubrication of wheel bearings, removing and replacing damaged or worn suspension parts, checks and adjustments for alignment and removing and replacing shock absorbers.

12.1 General suspension designs

There are two general designs of suspensions: those with rigid axles and those without. The latter are referred to as *independent suspensions.* Passenger and light commercial vehicles have independent suspension at the front. Many passenger vehicles also have it at the rear.

Rigid axles connect the wheels on each side of the vehicle so that some of the road movement of one wheel will be transferred through the axle to the wheel on the other side of the vehicle. Rigid axles are used on the rear of light commercial vehicles and some passenger vehicles. With independent front or rear suspensions, the wheels are able to move up and down independently of each other, reducing body movement to improve vehicle ride. Figure 12.1 shows the suspension of a passenger vehicle with independent coil suspension on all four wheels. This is only one example of how each wheel can be arranged to move independently of the others.

12.1.1 Sprung and unsprung mass

The terms *sprung mass* and *unsprung mass* relate to vehicle suspensions. Sprung mass is the mass of the vehicle that is supported by the springs. It includes the body, frame, engine and associated parts of the vehicle. The unsprung mass includes the wheels, tyres, brakes and the steering and suspension parts that are not supported by the springs (Figure 12.2).

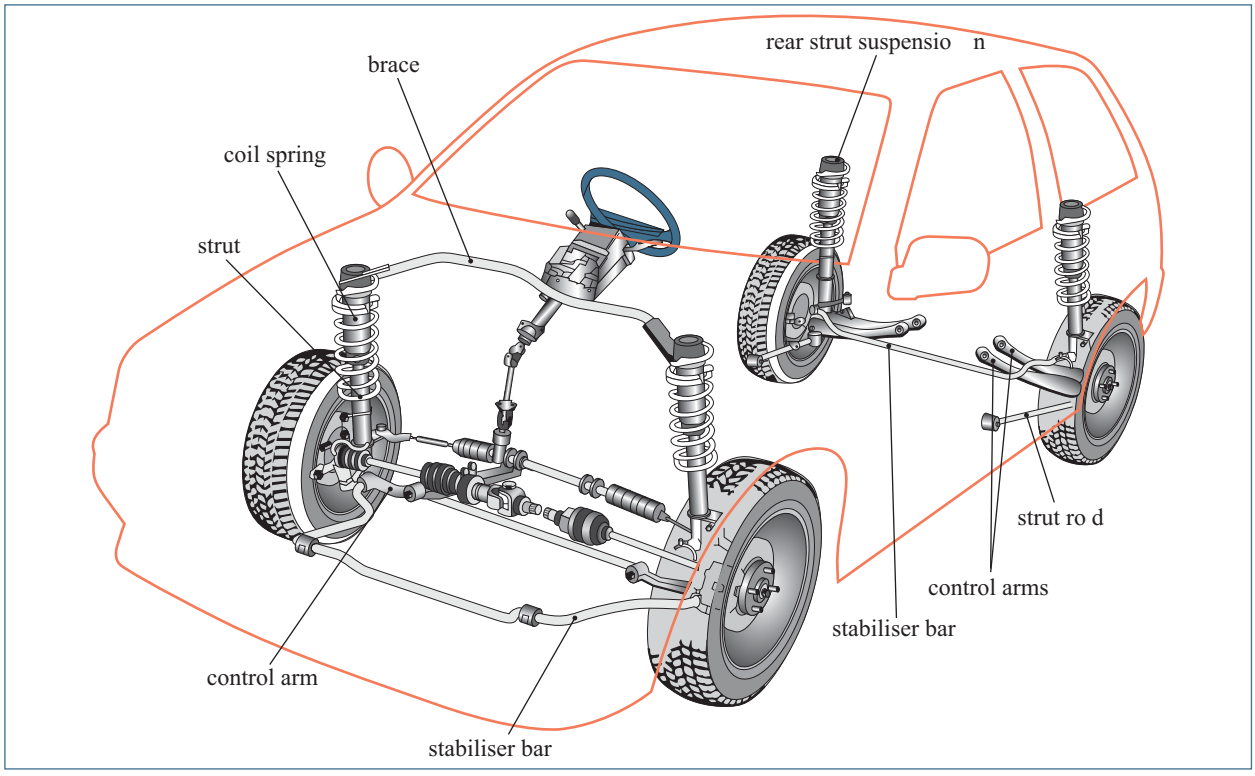


Figure 12.1 Passenger vehicle with independent suspension on a ll four wheels

Generally, the unsprung mass of a vehicle is kept as low as possible to improve the *ride* of the vehicle. A small wheel, with a low mass, will move up and down as it hits bumps in the road without much effect on the rest of the vehicle. However, a big wheel with a large mass would have a much more noticeable effect.

The ride of passenger vehicles is improved in the following ways: by springing as much of the suspension as possible; by using wheels of aluminium alloy instead of steel; by the type of shock absorbers used and by flexible springing.

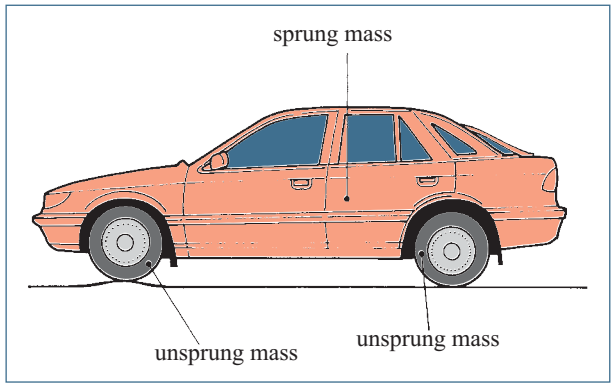


Figure 12.2 Sprung and unsprung mass—the body is sprung; the wheels and related parts are unsprung

12.1.2 Types of springs

The three basic types of steel springs are *leaf springs*, *coil springs* and *torsion bars.* The spring is the flexible component of the suspension and it is mounted in various ways. Other springing materials are rubber and gas.

Passenger vehicles have a variety of suspension systems. The common arrangements are coil springs at both front and rear, or coil springs at the front and leaf springs at the rear. Light commercial vehicles need heavier springs for load carrying and usually have coil springs at the front and leaf springs at the rear.

Handy hint: There are also air suspensions and hydraulic suspensions, and these are normally used as load-levelling systems on light vehicles.

12.2 Rear suspension with leaf springs

The ends of semi-elliptical springs are attached to the vehicle chassis or subframe, and the centre of the spring is bolted to the rear-axle housing. If the spring is mounted on top of the axle, it is said to be *overslung;* if mounted beneath the axle, it is *underslung.* Most leaf springs on passenger and light commercial vehicles are underslung.

12.2.1 Leaf springs

Leaf springs have one or more flat leaves made of special tempered steel. A multileaf spring (Figure 12.3) has a number of leaves of different lengths. These are held together by a centre bolt which passes through a hole in the centre of each leaf. Some springs have clips around the leaves to keep them in alignment.

The longest leaf, called the *main leaf*, is rolled at both ends to form eyes which mount the spring to the frame of the vehicle. Some springs have the ends of the second leaf rolled around the eyes of the main leaf as reinforcement. This type of leaf is referred to as a *wrap leaf*. The leaves of some springs have inserts of rubber or plastic between them. These act as insulators to prevent noise transfer and also reduce friction between the leaves.

12.2.2 Leaf spring designs

Various designs of leaf springs have been used, including elliptical, semi-elliptical, transverse and cantilever. The semi-elliptical spring is the design used today. The curved shape of the spring gives it camber, which is the distance between the top spring leaf and a line through the centre of the spring eyes.

12.2.3 Forces acting on a driving axle

Figure 12.4 shows the four forces acting on a driving axle. They are:

- longitudinal or front to rear
- vertical or up and down
- lateral or side to side
- torque or rotational

The direction of the force depends on whether the vehicle is braking, driving, cornering or driving over a bump. The main force is *torque reaction* which results from the traction between the tyre and the road. The axle housing tries to rotate in a direction opposite to wheel rotation and the suspension system must control this force through various suspension members. The main advantage of a leaf spring is that it can control all four forces acting on the axle

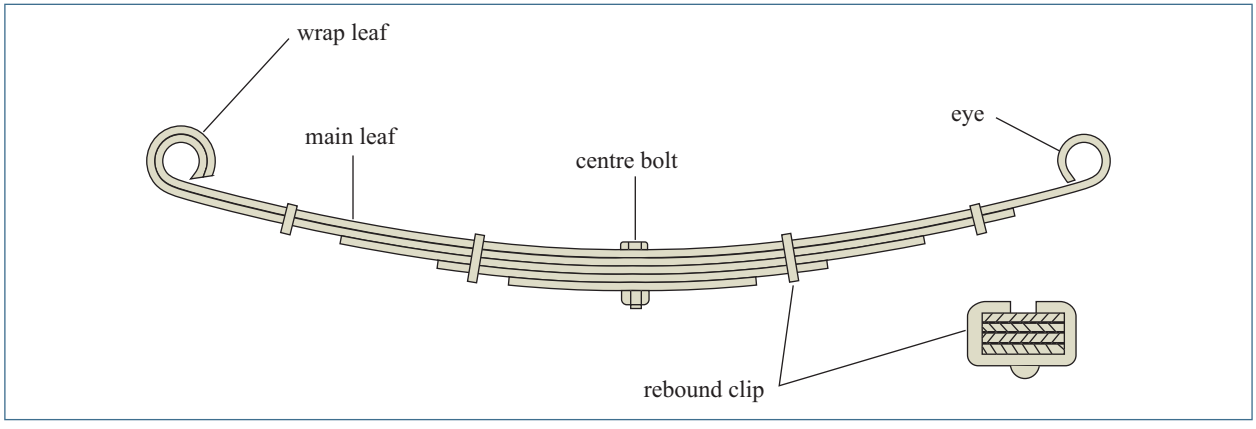


Figure 12.3 Leaf-spring construction

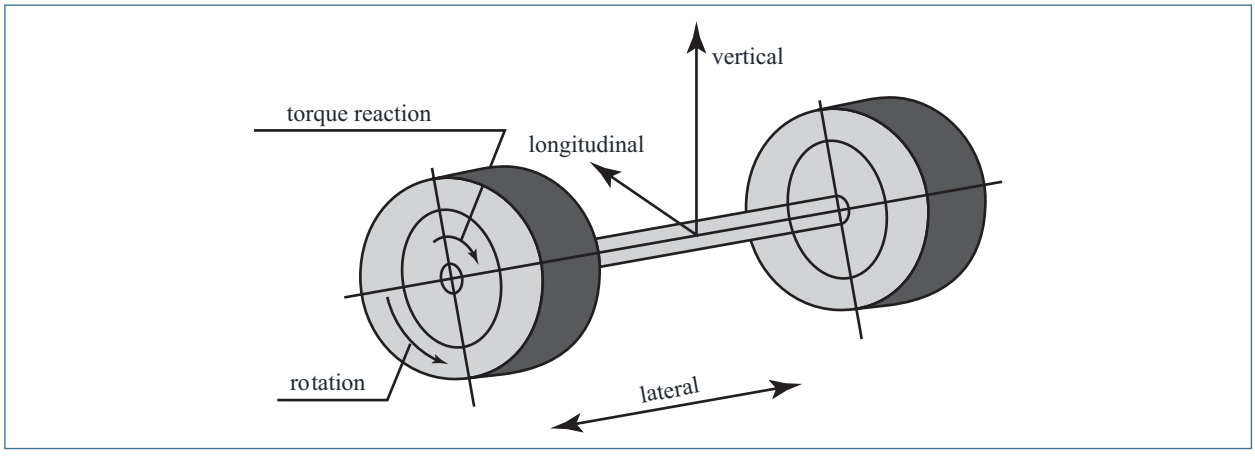


Figure 12.4 Forces acting on a driving axle

Handy hint: Torque reaction occurs only at the suspension of the driving wheels in both front- and rear-wheel drive .

12.2.4 Rear leaf-spring suspension components

Figure 12.5 shows the dismantled parts of a rear suspension with leaf springs. The arrangement is typical for rear leaf-spring suspensions. Its components are as follows.

Spring shackle and hanger

The front of the spring is bolted to a rigid spring hanger on the subframe, the rear being connected to it by a spring shackle. The shackle is a swinging link between the spring eye and a bracket on the subframe. A swinging link is needed because the distance between the spring eyes changes as the spring flexes. If both ends of the spring were rigidly fastened to the frame, the spring would not flex and there would be no spring action. A swinging shackle is therefore necessary at one end of the spring.

Spring bushes

The spring eyes are fitted with bushes (usually rubber), which insulate the spring from the frame to prevent noise and vibration from being transferred to the body. The rubber of the rear shackle bushes is compressed in the spring eye by the shackle bolts when the nuts are tightened. The bolts have a shoulder which comes up against the shackle side plate to prevent the nuts from being overtightened.

The eye in the front of the spring shown is elongated and is fitted with a large bush. The large bush at the front of the spring accepts all the forward thrust from the rear wheels that is being transmitted to the body. The shackle and hanger bushes are designed to flex within themselves and not to move on the bolt; if new bushes are installed, the nuts should be tightened with the load of the vehicle on the springs so that the rubber is in its normal working position and not under torsion.

Axle mounting

The axle has a flat spring pad that sits on the top of the spring and a spring plate under the spring. Two U-bolts straddle the axle housing and hold the axle in place. Rubber insulating pads are fitted between

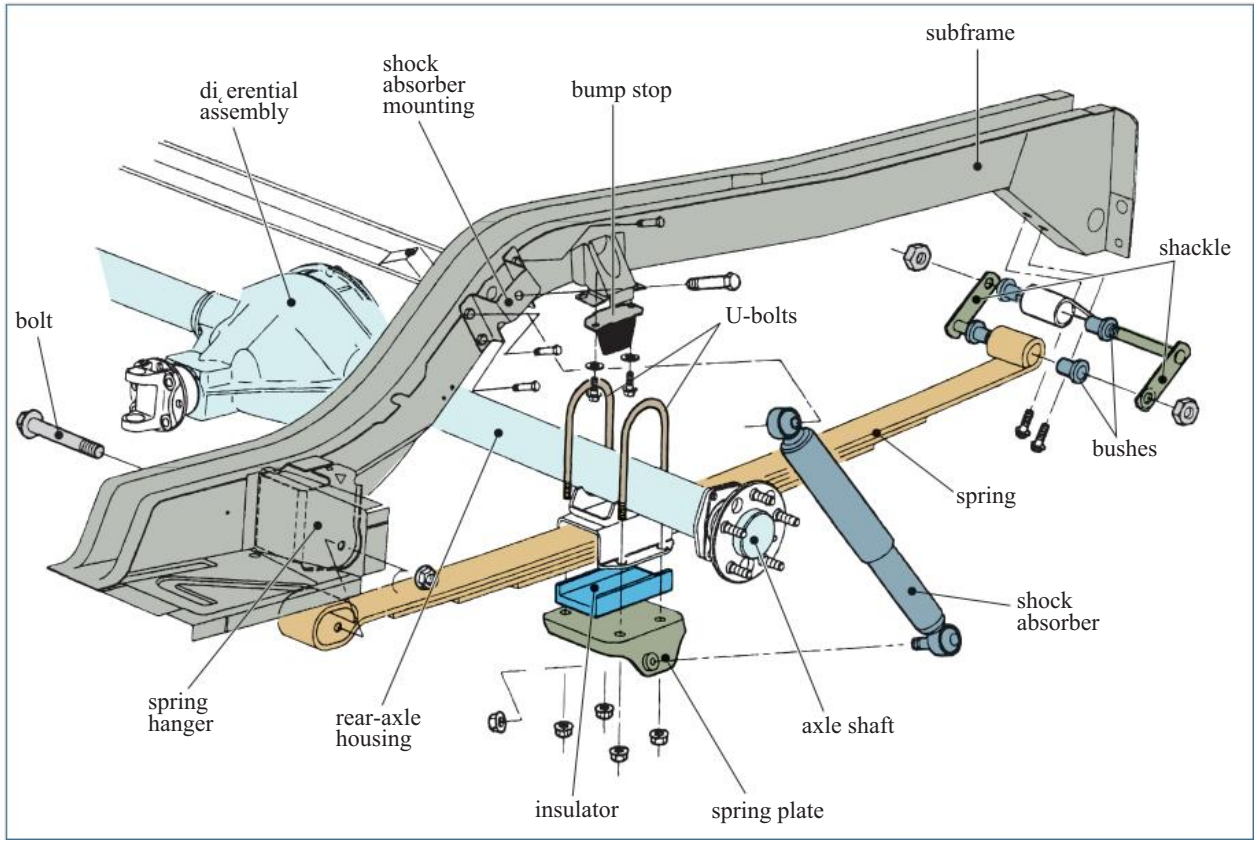


Figure 12.5 Rear-axle assembly with leaf springs FORD

the spring pad and the spring, and also between the spring plate and the spring. These reduce road, tyre and rear-axle noises that would otherwise be transmitted through the spring to the body.

Handy hint: The U-bolts must be tightened to the correct torque setting to prevent the axle from moving on the mounting pad.

Telescopic shock absorber and bump stop

The telescopic shock absorber, which dampens spring movement, is mounted between the spring plate and the subframe. The lower end has a rubber bush and a stud that secures it to the spring plate. The upper end also has a rubber bush, and this end is bolted to a bracket on the subframe. A moulded-rubber bump stop is bolted under the subframe above the axle housing. This will bottom against the axle housing if the wheel hits a large bump that causes maximum deflection of the spring.

12.3 Types of coil springs

Coil springs vary in shape, size and deflection rate. A light commercial vehicle would have springs that are robust and fairly stiff, while a small passenger vehicle would have much lighter and more flexible springs.

Three different types of coil springs are shown in Figure 12.6, but there are many variations. The coils can be evenly spaced (uniform pitch) or unevenly spaced (variable pitch). The rod that the spring is made from can be of uniform thickness throughout its length, or it can be tapered towards the ends of the spring. The shape of the spring can be cylindrical, barrel, conical or of some other design.

12.3.1 Deflection rate

Generally, a cylindrical spring of uniform pitch and uniform rod diameter will have a constant deflection rate; when the spring is being compressed, it will reduce in length in direct proportion to the load applied.

Other springs are designed to have variable deflection rates and provide a soft ride through ready deflection under light loads. Springs are often colour coded. They may look alike but have different load ratings.

There are a number of ways in which coil springs are mounted in suspension systems. Unlike leaf springs, coil springs can only control forces in the vertical direction and cannot hold the wheels in position. Therefore, control arms and rods of various designs are used in conjunction with coil springs as part of the suspension arrangement. These control the lateral and longitudinal movement of the wheel assembly and so keep it correctly located. They also control the torque reaction that occurs with driving wheels.

Handy hint: Lateral movement is side-to-side movement; longitudinal movement is front and rear movement.

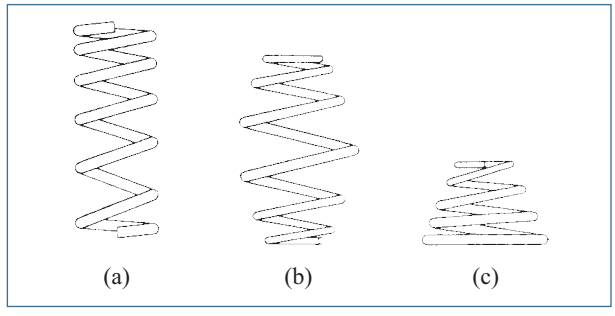


Figure 12.6 Types of coil springs (a) cylindrical with uniform-diameter bar (b) cylindrical with variable-diameter bar and variable pitch (c) conical with variable-diameter bar and variable pitch

12.4 Front suspension with coil springs

Figure 12.7 shows the basic arrangement of a coil-spring suspension. It has a centre crossmember that is fixed to the body subframe. The inner ends of the control arms are connected to the crossmember by bolts and bushes which allow the control arms to pivot. The outer ends of the control arms are connected to the steering knuckles by ball joints. The coil spring is mounted between the lower control arm and the crossmember. The arrangement forms a four-point linkage which allows each wheel to move up and down independently, under the control of the spring. The ball joints also allow the steering knuckle to be turned for steering.

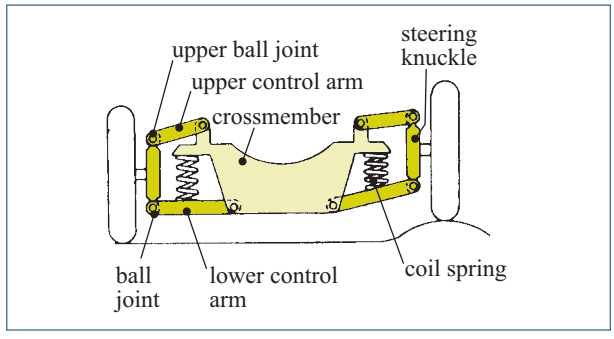


Figure 12.7 Basic arrangement of an independent front suspension with upper and lower control arms

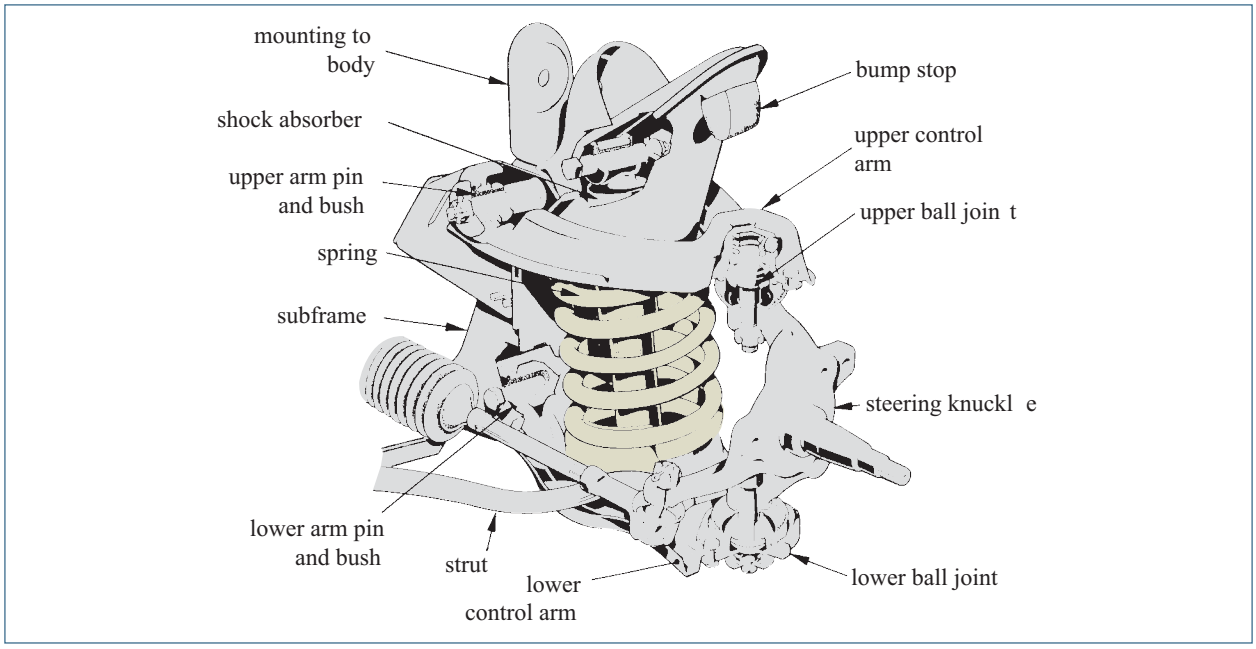


Figure 12.8 Arrangement of a front suspension with a coil mounted on the lower control arm FORD

Handy hint: Suspensions with ball joints at the top and bottom of the steering knuckle are known as ball joint suspensions. Earlier types of suspensions had a steering knuckle pivoted on a kingpin.

12.4.1 Ball joint suspensions

Three representative arrangements of ball joint suspensions are outlined here. There are many variations in actual design.

Coil spring on lower control arm

The ball joint suspension in Figure 12.8 has the coil spring located between the lower control arm and the subframe. The shock absorber is mounted inside the coil. The control arms are attached to the subframe by means of pins and bushes. The ball joints at the outer ends of the control arms are attached to the stub axle or steering knuckle. The control arms are of the 'wishbone' or 'A' design.

Coil spring on upper control arm

The suspension illustrated in Figure 12.9 is also a ball joint suspension, but in this design the coil spring is located on top of the upper control arm. The spring is mounted between the upper control arm and a spring tower built into the mudguard.

The upper control arm has a two-point mounting to the subframe, and this restrains both lateral and longitudinal movement. The lower arm, with only one mounting, restrains lateral movement but has a strut (rod) to restrain its longitudinal movement. The shock absorber is located inside the coil spring, with one end attached to the spring tower and the other end attached to the upper control arm.

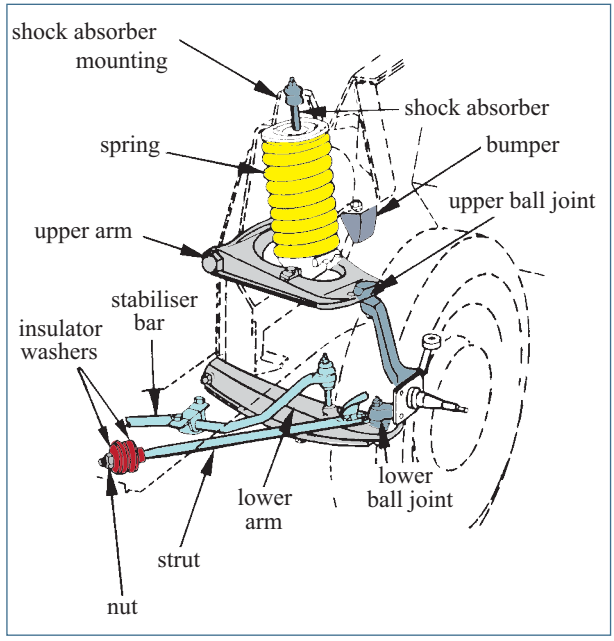


Figure 12.9 Front suspension system with a coil spring mounted on the upper control arm FORD

Load-carrying ball joints

The ball joints on suspension systems with upper and lower control arms carry different loads. The ball joint on the control arm that supports the spring is referred to as the load-carrying ball joint. It supports the vehicle and carries all of the road shock

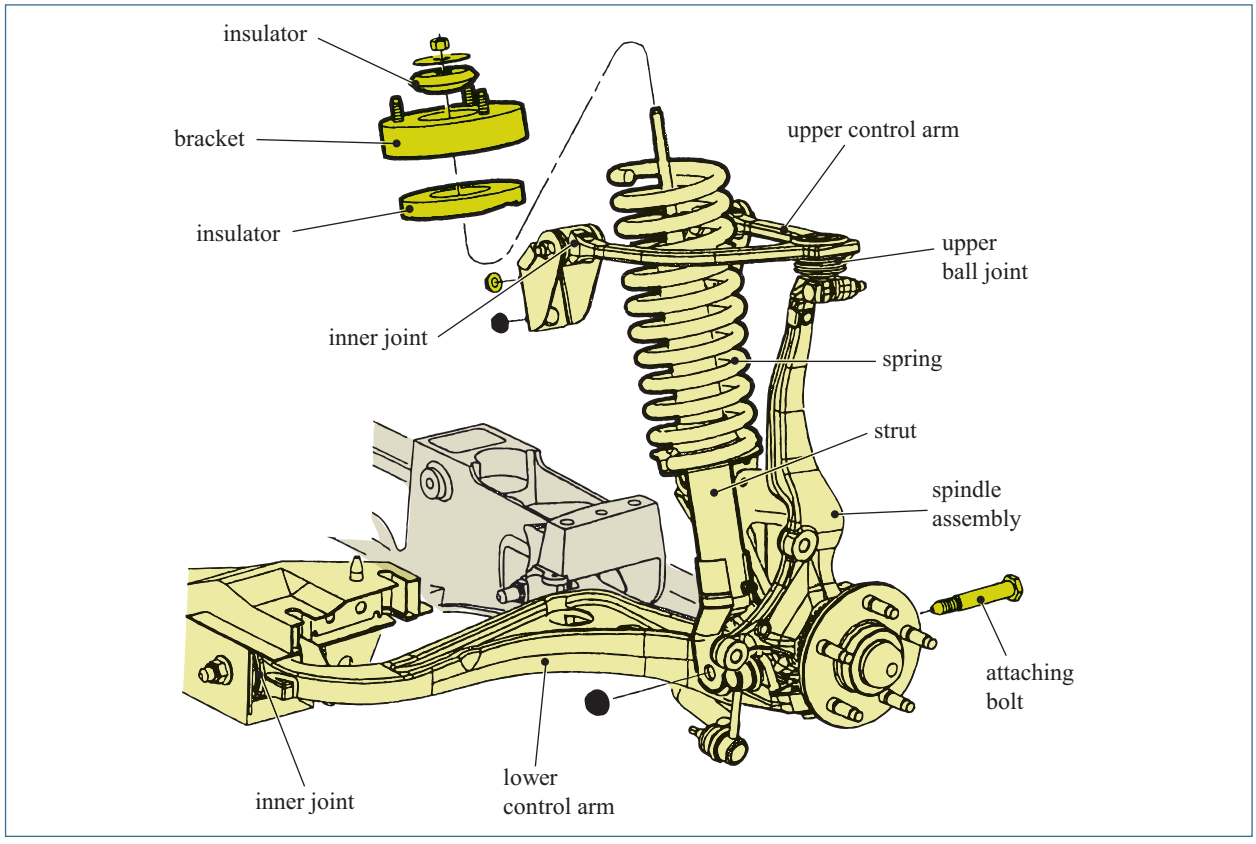


Figure 12.10 Front suspension with a strut and upper and lower c ontrol arms FORD

to the spring. In Figure 12.8 the load-carrying ball joint is on the lower control arm, but in Figure 12.9 it is on the upper control arm. The load-carrying ball joint wears out much faster than the other ball joint, which is referred to as the locating ball joint.

Strut with upper and lower control arms

Figure 12.10 illustrates a front suspension that has a strut and also upper and lower control arms. As it is a wishbone type, the inner mountings of the arms are wide apart, so the control arms control both lateral and longitudinal movement of the wheel.

The lower end of the strut straddles the outer end of the lower control arm, and the upper end of the strut is attached to a mounting on the body. The coil spring is located over the strut.

The axle spindle assembly (steering knuckle) has a ball joint at the top and bottom to enable it to be turned for steering. It has a spindle that carries the wheel hub and bearings.

12.5 Strut or McPherson suspension

This type of independent suspension incorporates a vertical shock absorber in conjunction with a coil spring. The suspension unit is mounted between a ball joint on the end of the lower control arm and a reinforced body mounting at the top of the mudguard, as shown in Figure 12.11.

The upper mounting assembly consists of a thrust bearing supported in a moulded rubber mounting.

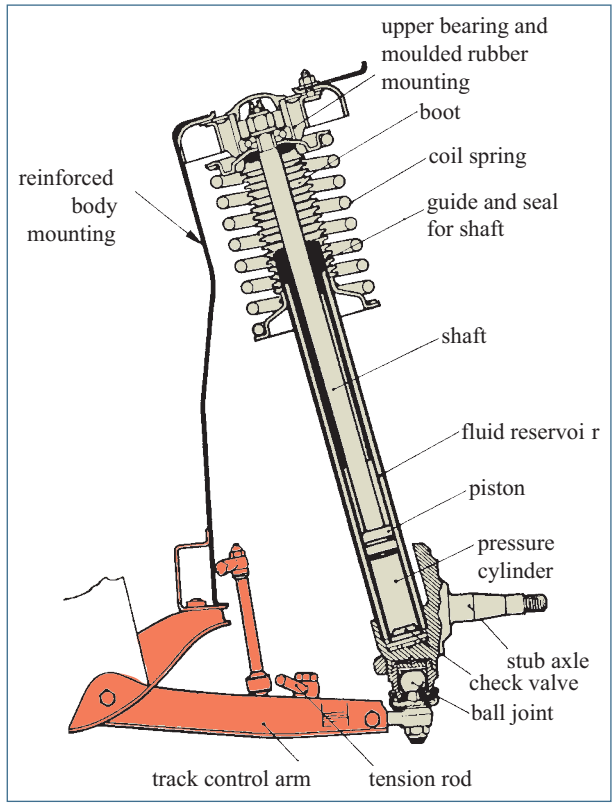


Figure 12.11 Basic arrangement of a strut or McPherson suspension

For steering, the strut pivots about its axis on the bearing in the top mounting and on the ball joint in the lower control arm. The lower control arm controls lateral movement of the bottom of the strut to prevent changes in wheel track. A control rod, referred to as a tension rod, controls longitudinal movement. The wheel is allowed vertical movement (dampened by the shock absorber), but is correctly positioned by the track control arm and the tension rod.

The shock absorber is a double-acting type, dampening out the oscillations of the spring. A stabiliser bar is fitted between the subframe and the track control arms to reduce body roll.

12.5.1 Strut suspension for front-wheel drive

Figure 12.12 shows the detail of a strut suspension for a front-wheel-drive vehicle and identifies the various parts. In this design, provision is made for a drive shaft to connect the transaxle to the front wheels. The shock absorber unit is bolted to a knuckle which is mounted by a ball joint to the control arm. The drive shaft passes through the knuckle, being supported in a bearing. The wheel hub is splined to the outer end of the drive shaft.

The A-shaped control arm has two mounting joints to the frame and these are fitted with rubber bushes. As this type of control arm has two mountings spaced well apart, it is able to prevent both lateral and longitudinal movement of the wheel.

12.5.2 Stabiliser bar

A stabiliser bar (sway bar or roll bar) is used on many vehicles with independent suspension. This is a long, U-shaped bar located across the vehicle. It is mounted to the crossmember or subframe in rubber bushes, with its ends attached to the lower control arm on each side of the vehicle (Figure 12.13).

The stabiliser bar reduces body roll by opposing body movement. When cornering, the body tends to lean outwards on turns or to roll, due to centrifugal force. This compresses the outer spring and expands the inner spring. The stabiliser bar is twisted, but the torsion of the bar resists this, reducing body roll.

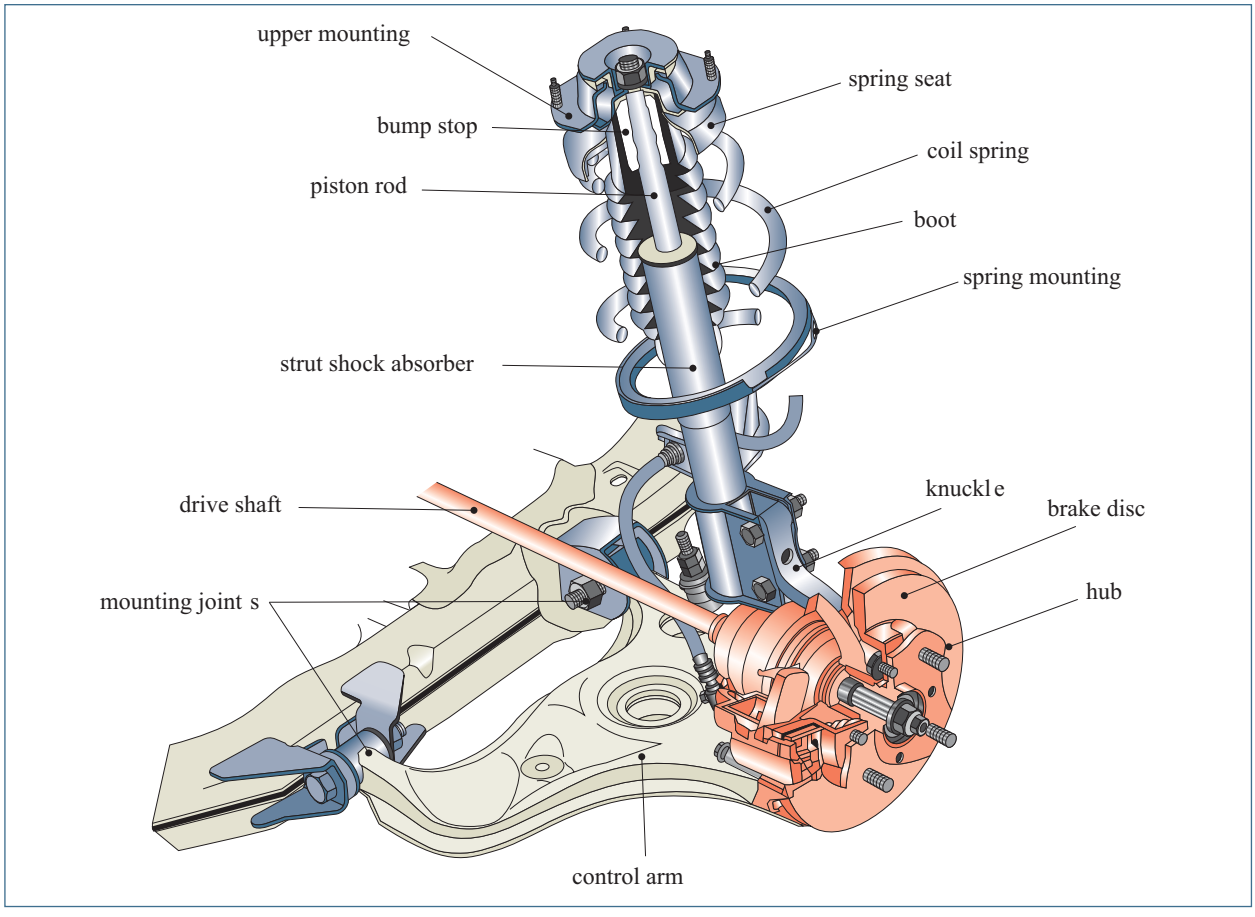


Figure 12.12 Strut suspension for a front-wheel-drive vehicle

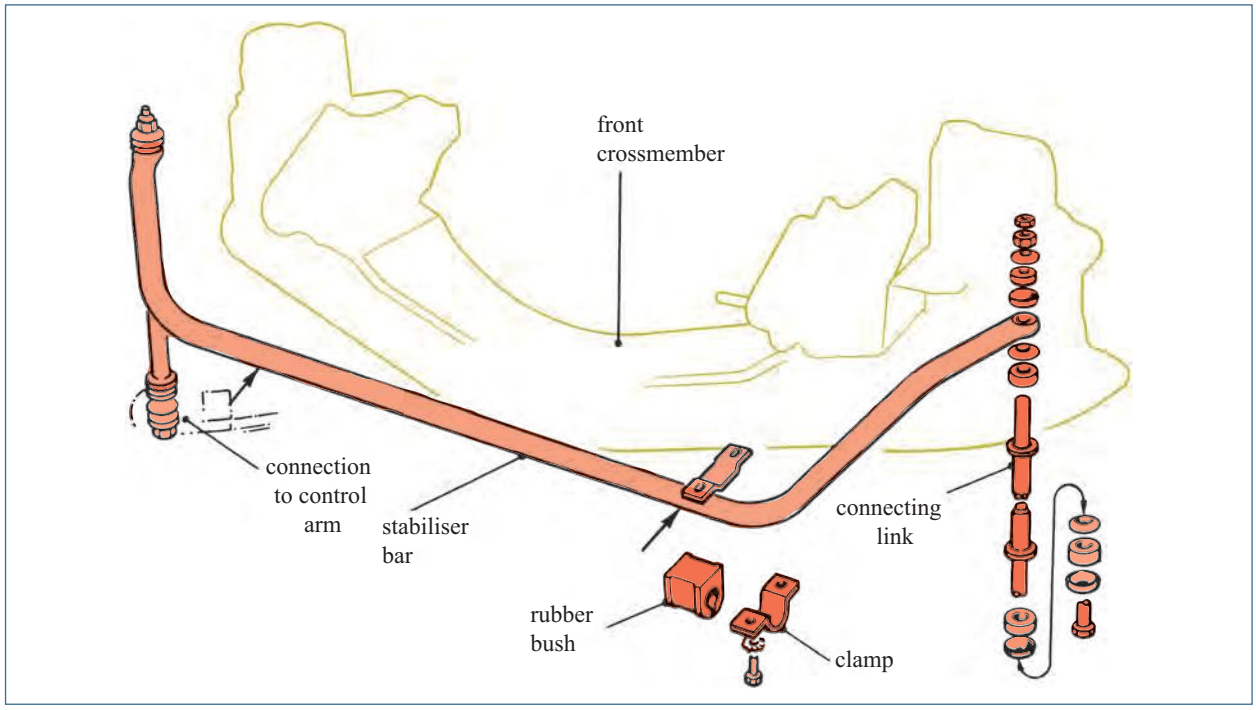


Figure 12.13 Stabiliser bar—arrows indicate locations of mountings to subframe

Handy hint: The stabiliser bar only becomes effective when the vehicle leans to the side . It has no effect when the vehicle is level.

12.6 Rear suspension with coil springs

There are a number of different arrangements for rear suspensions that use coil springs. Some coil-spring suspensions have rigid axle housings and others have independent suspension. Independent rear suspensions have arms and rods that are used in a similar way to independent front suspensions to hold the wheels in their correct position. Rear suspension designs are outlined under the following headings.

12.6.1 Rigid axle with trailing arms

Figure 12.14 shows a rear suspension with a rigid axle housing and coil springs. The springs are located between spring mounting plates on the trailing arms and spring seats on the subframe. Upper control rods between a bracket on the axle housing and the subframe prevent twisting of the axle housing by torque reaction.

The trailing arms, together with the upper control rods, prevent longitudinal movement of the axle housing.

Lateral movement is prevented by a track rod, also referred to as a *Panhard rod.* This is located at the rear of the axle across the vehicle. One end is anchored to the subframe and the other to the axle housing.

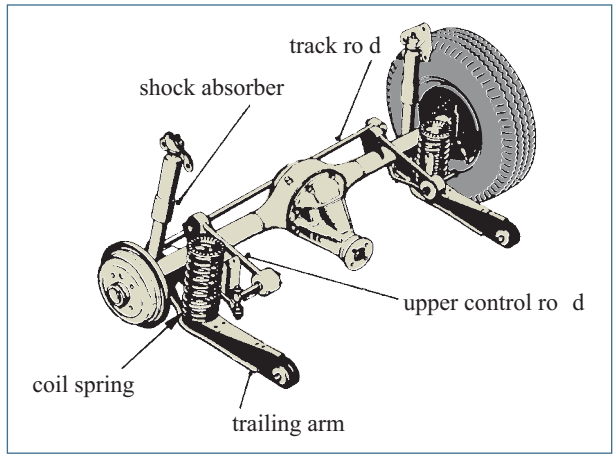


Figure 12.14 Rear suspension system with rigid-axle housing, coil springs and trailing arms

12.6.2 Rigid axle with Watts link

A rigid rear axle with a stabilising linkage known as a *Watts link* is illustrated in Figure 12.15. This is a similar arrangement to the track rod of the suspension just described, except that a linkage arrangement is used between the subframe and the axle housing instead of a single rod.

The Watts link consists of two rods and a lever which has a rocking action. The lever is mounted near the centre of the axle housing, and the links are connected between the ends of the lever and the subframe on each side of the vehicle. The arrangement prevents lateral movement of the axle housing but allows vertical movement. It also reduces body movement by transferring forces through the linkage from one side of the vehicle to the other.

The suspension is also fitted with a stabiliser bar to reduce body roll, and telescopic shock absorbers. A lower control rod and an upper control rod prevent longitudinal movement. They also prevent axle housing movement from torque reaction of the driving wheels.

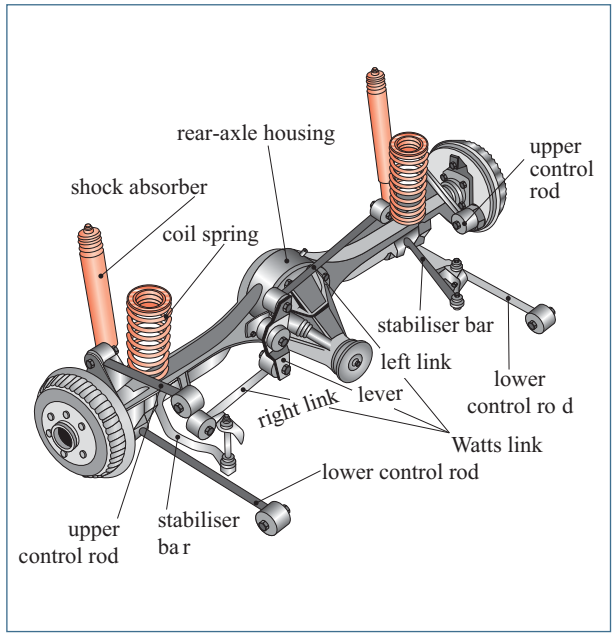


Figure 12.15 Rear suspension with a Watts link

12.7 Independent rear suspensions with struts

Figure 12.16 illustrates an independent rear suspension with a McPherson strut. It consists of the McPherson strut, two lateral arms (lower control arms), a trailing arm, a knuckle which carries the spindle for the rear wheel and a stabiliser bar. The lower end of the strut is bolted to the knuckle which

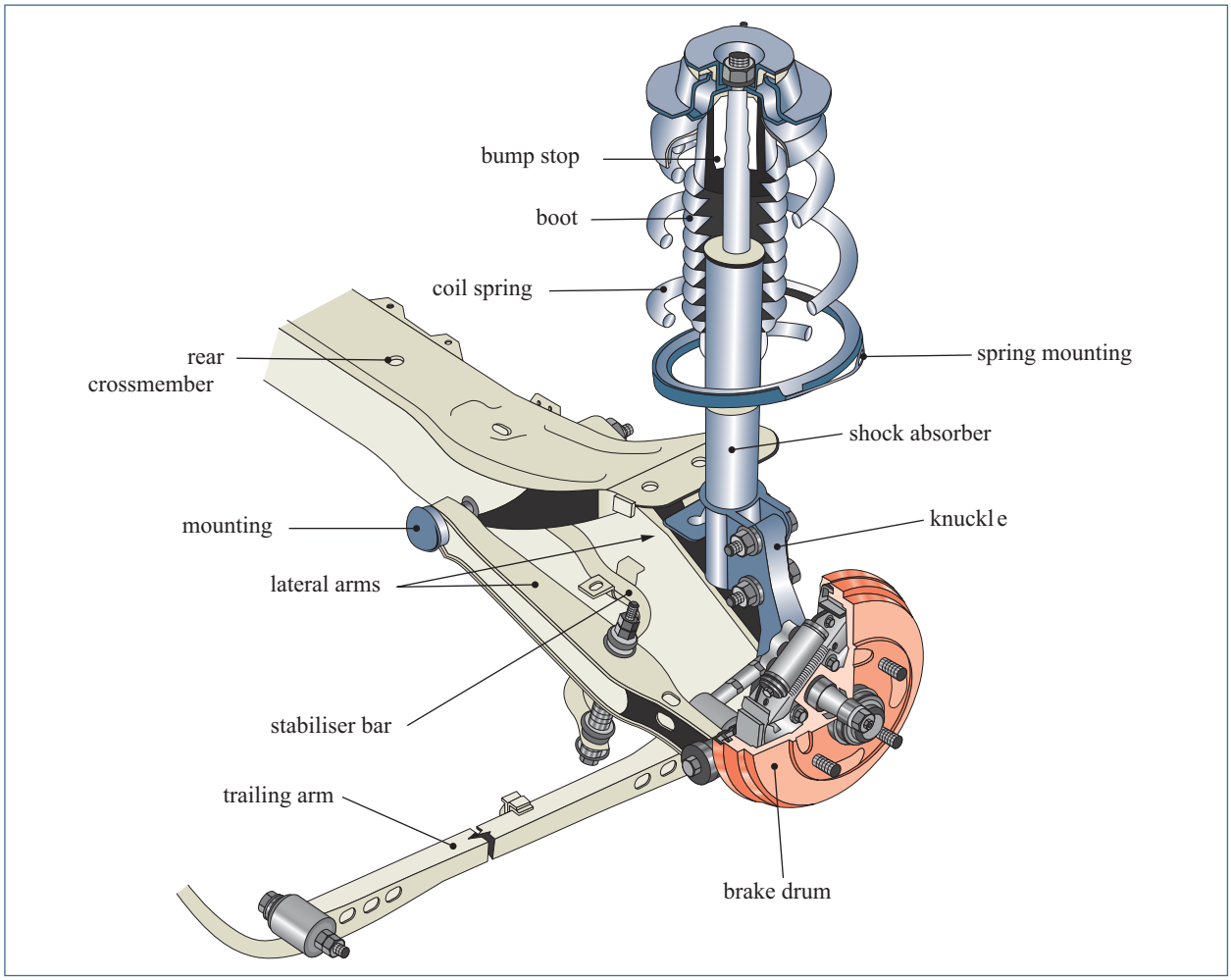


Figure 12.16 Independent rear suspension with a strut and trailing arm (front-wheel-drive vehicle)

has the spindle and bearings for the wheel hub. This type of suspension is fitted to the rear of many front-wheel-drive vehicles.

The upper end of the strut is bolted to a mounting in the wheel well. A boot inside the coil spring covers the upper end of the strut and protects the piston rod. A rubber bump stop is fitted over the piston rod to limit maximum travel.

The lateral arms between the lower end of the knuckle and the rear crossmember prevent changes in wheel track. The trailing arm is connected between the bottom of the knuckle and the vehicle subframe to prevent longitudinal movement of the wheel. The mountings at the ends of the arms are rubber-bushed to allow movement.

12.8 Rear suspension with swing axles

Rear-wheel-drive vehicles with independent rear suspension (IRS) have a differential assembly, with open drive shafts to the rear wheels. The suspension can be designed with struts or coil springs.

12.8.1 Swing axles and struts

A suspension and rear-axle assembly with swing axles and struts is shown in Figure 12.17. The top of the strut has a mounting in the wheel well, and the bottom is located by upper and lower control arms and a trailing arm. These are connected to the crossmember with bolts and rubber bushes.

The rear wheels are the driving wheels, so the suspension is designed to accept forward thrust from the wheels as well as other forces from road conditions. The differential assembly is mounted on the centre of the crossmember and the crossmember is fixed to the subframe of the body at four mounting points. All this is part of the sprung mass of the vehicle.

Handy hint: The term swing axle relates to independent rear suspensions, where the drive shafts 'swing' from the differential assembly .

12.8.2 Swing axles and coil springs

Figure 12.18 shows an independent rear suspension assembly with trailing arms and coil springs. The basic structure of the assembly is the crossmember to which the other components are attached. The large trailing arms are Y-shaped, and each has two mountings (pivot points) which connect them to the crossmember.

The mounting points of the trailing arms are spread well apart, providing both lateral and longitudinal stability to the wheels. The coil springs are of the variable-rate type and are located between the trailing arms and the underbody of the vehicle.

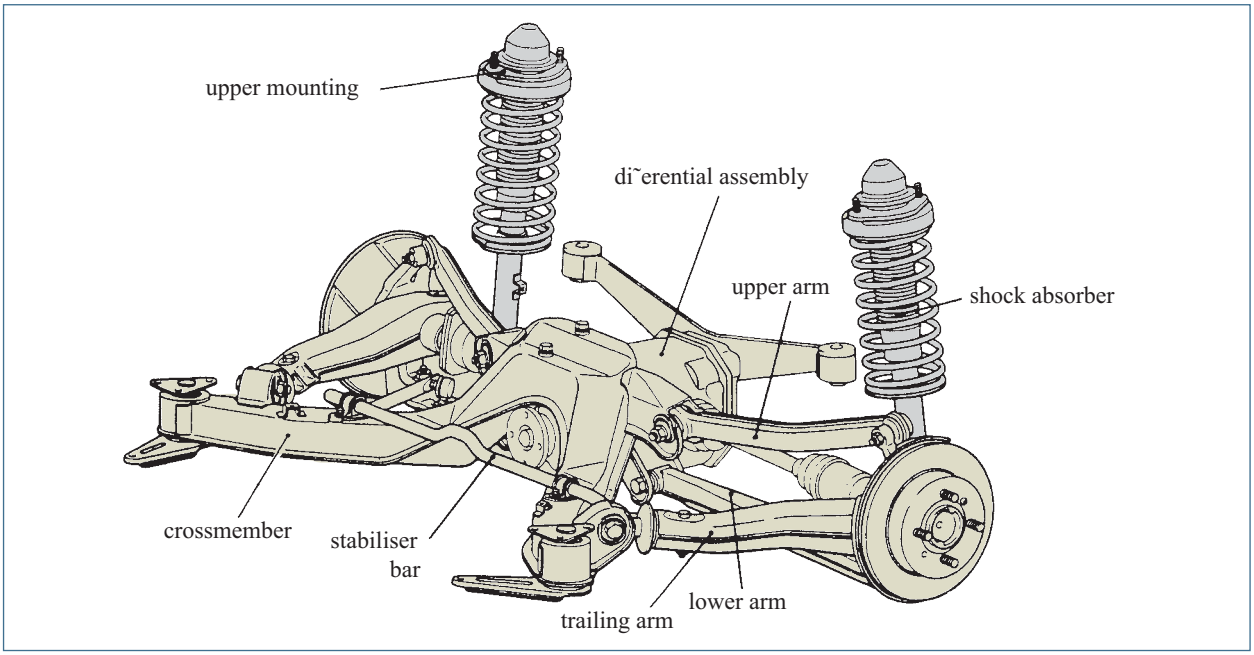


Figure 12.17 Independent rear suspension with trailing arms and struts (rear-wheel-drive vehicle) MITSUBISHI

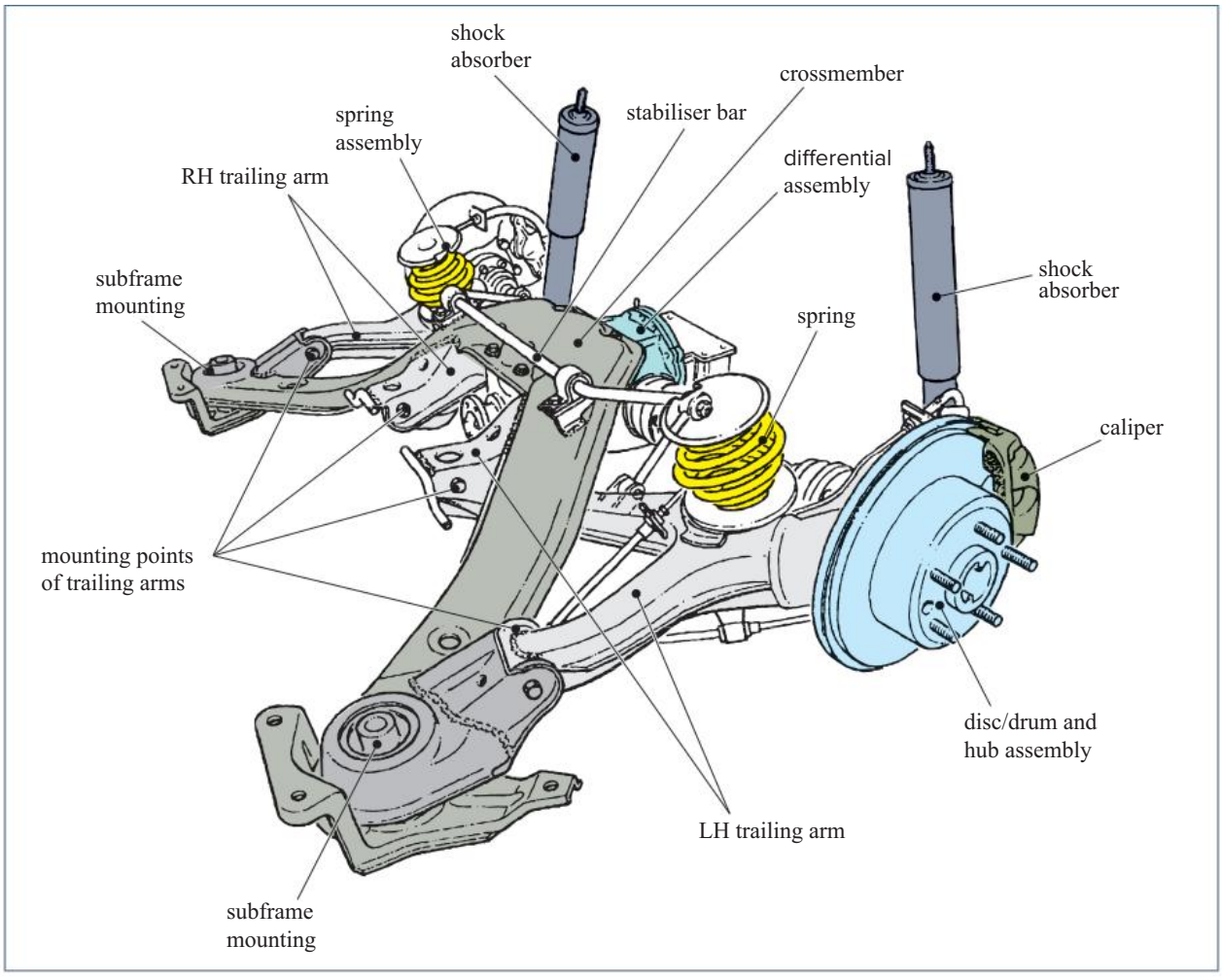


Figure 12.18 Rear-suspension crossmember assembly that includes trailing arms, coil springs and independent rear suspension GM HOLDEN LTD

A U-shaped stabiliser bar is mounted in brackets with rubber bushes on top of the crossmember. The ends of the stabiliser are connected to the trailing arms by links that are also fitted with rubber bushes.

Handy hint: Because of its shape, this type of trailing arm acts like a control arm as well as a trailing arm.

12.9 Torsion rear axle

The rear suspension in Figure 12.19 is used with front-wheel-drive vehicles. It has struts with coil springs, trailing arms and a lateral rod. It also has a torsion-type rear axle. This is a semirigid axle in which the axle beam and the torsion bar are an active part of the suspension. The axle beam has a U-shaped section (like an inverted U) with a torsion bar mounted inside it. The torsion bar is connected between the left and right sides of the suspension. The construction of the axle is shown in Figure 12.20.

12.9.1 Operation

The axle beam and its torsion bar both twist together with suspension movement. The axle is designed to reduce body roll or tilt. When the vehicle makes a turn, the body will tilt and cause one trailing arm to move up and the other to move down. This twists the axle beam and the torsion bar, which opposes the movement of the trailing arm. The torsion produced in the axle beam and bar limits the amount of body tilt.

The vertical forces are taken by the coil springs, the shock absorbers and the rubber bump stops. The longitudinal forces are taken by the trailing arms, and the side forces are taken by the lateral rod.

Handy hint: Although this suspension has a torsion bar, it would be classed as a trailing-arm suspension rather than as a torsion bar suspension.

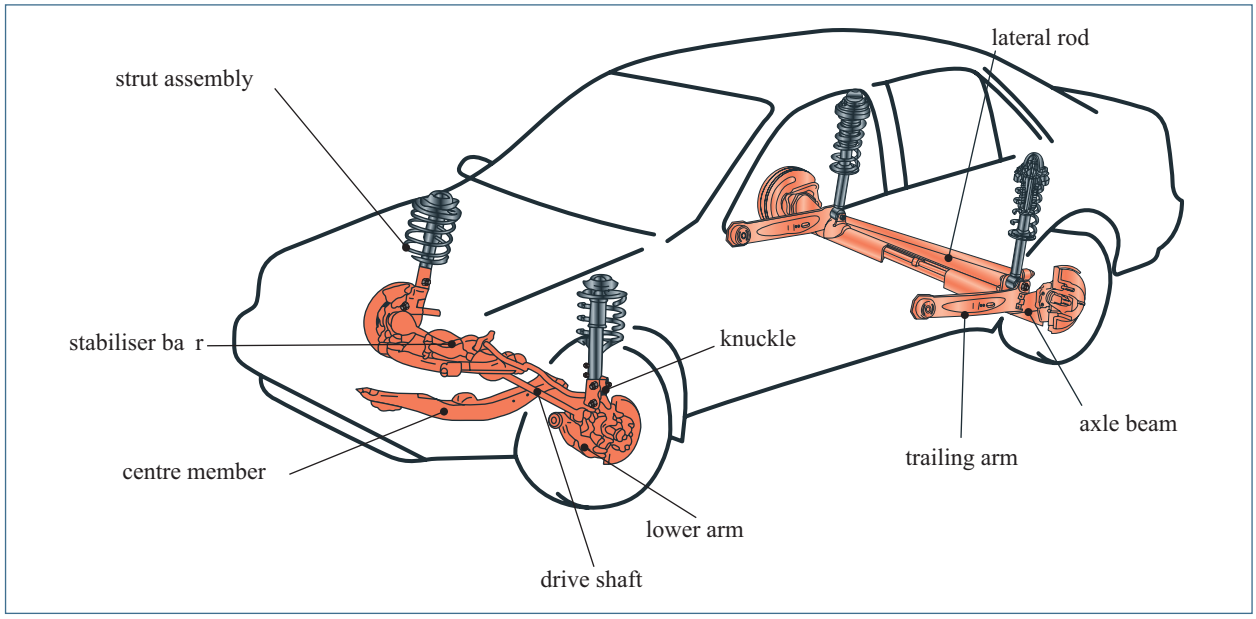


Figure 12.19 Coil suspension system with struts and torsion rear-axle assembly

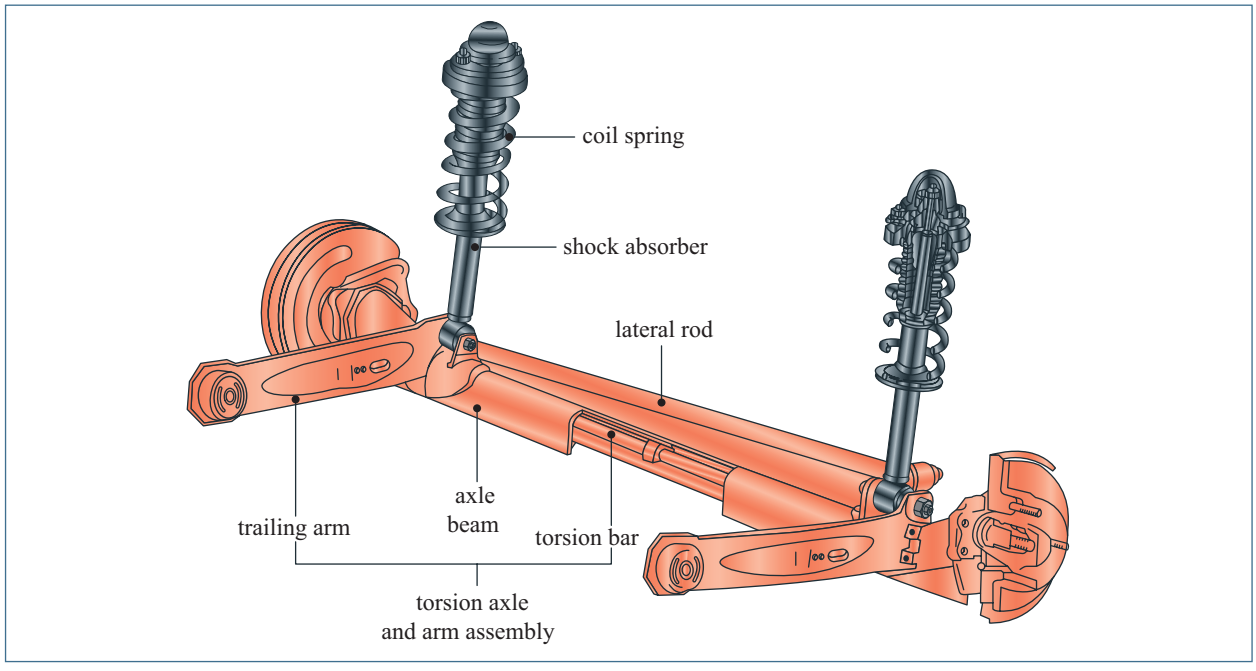


Figure 12.20 Torsion rear-axle and suspension assembly with a semi-rigid axle beam

12.9.2 Torsion rear axle with coil springs

Figure 12.21 shows the components of a torsion rear axle with coil springs. This is referred to as a *compound torsion-tube rear axle*. The axle beam does not have a separate torsion bar—the torsion requirement is provided by the design and the material of the axle beam.

The trailing arms are integral with the axle beam, and the wheel hub and bearing assemblies are bolted to the rear ends of the trailing arms. Variable rate springs are located between mounting pads on the trailing arms and the underbody.

The assembly has two mounting points to the vehicle—eyes at the front ends of the trailing arms have large damping bushes which are bolted to brackets on the underbody of the vehicle. Shock absorbers are fitted between the trailing arms and the body.

In operation, each trailing arm can move independently, with movement being controlled by the action of the coil spring, the torsion beam, the damping bushes and the shock absorber. At the same time, torsion can be transferred from one side to the other to help keep both sides of the vehicle level.

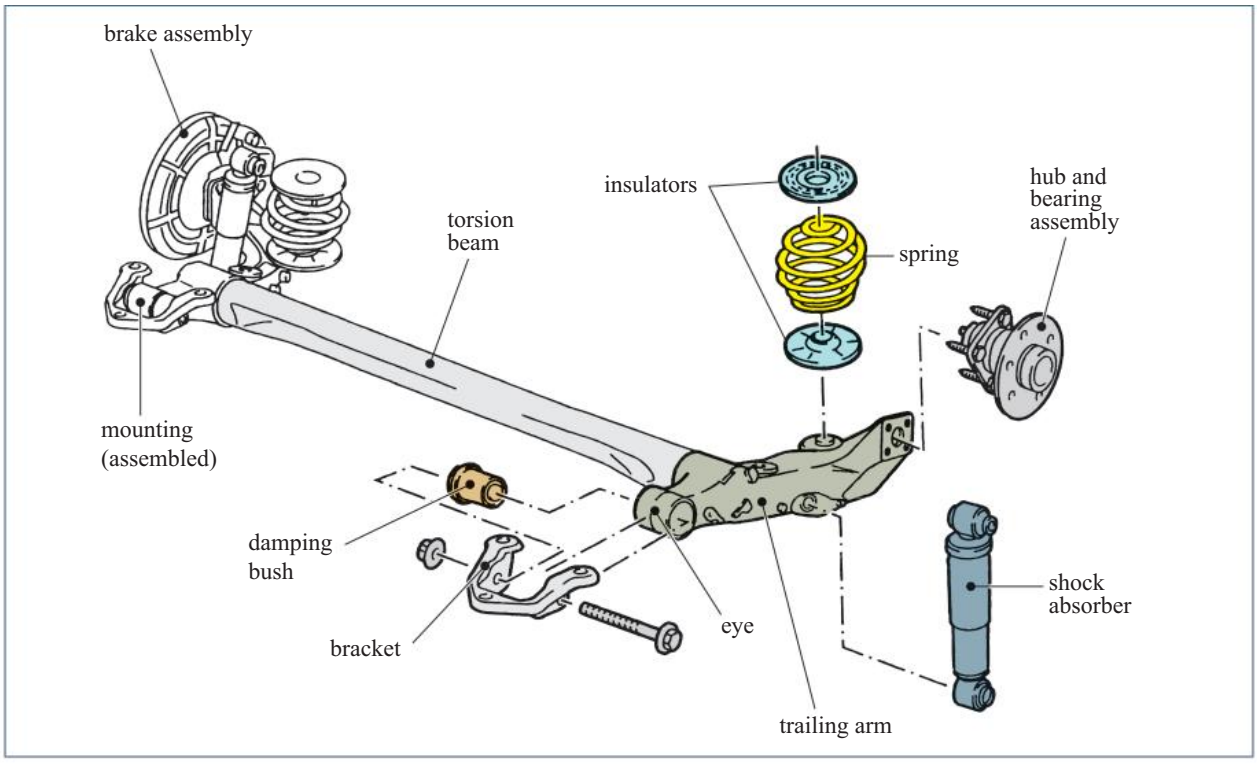


Figure 12.21 Torsion-type rear-axle assembly with coil springs and trailing arms GM HOLDEN LTD

Handy hint: If one trailing arm lifts, the torsion produced in the axle also tries to lift the other trailing arm.

12.10 Torsion bar suspension

In this system, the torsion bar acts as the spring, with linkage or control arms similar to those of coil-type suspensions. Spring action is produced by the torsion or twisting effect of a long alloy-steel bar. Figure 12.22 illustrates this suspension in simple form. The rear end of the bar is attached to the vehicle frame, and the front end is attached to the lower control arm. As the lower control arm moves up and down in response to the front wheel travelling over bumps or holes in the road, the torsion bar is twisted and untwisted to provide a spring action.

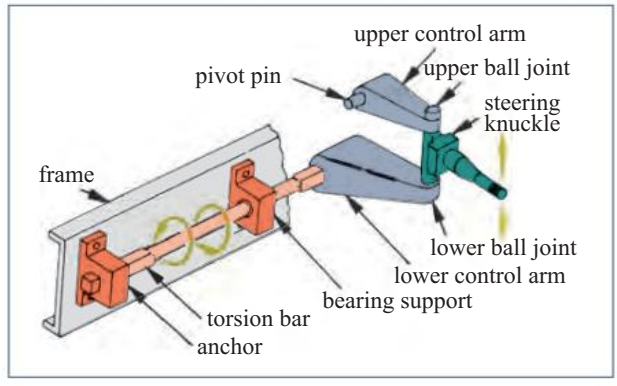


Figure 12.22 Schematic illustration of torsion-bar suspension

Handy hint: Torsion simply means twisting; the torsion bar is designed to withstand the twisting action.

12.10.1 Construction

The construction of a torsion bar front suspension is shown in Figure 12.23. This has upper and lower control arms and a long torsion bar extending towards the rear of the vehicle. The torsion bar is attached to the upper control arm at the front and fixed to the subframe at the rear. Suspension movement twists the torsion bar and this provides the spring action. Most torsion bars are mounted longitudinally like those shown, but they can be mounted laterally.

12.11 Shock absorbers

Springs alone are not satisfactory for a suspension system. A spring must be flexible so that it can absorb road shocks but, if it is too flexible, it will continue to compress and rebound. However, a spring that is too

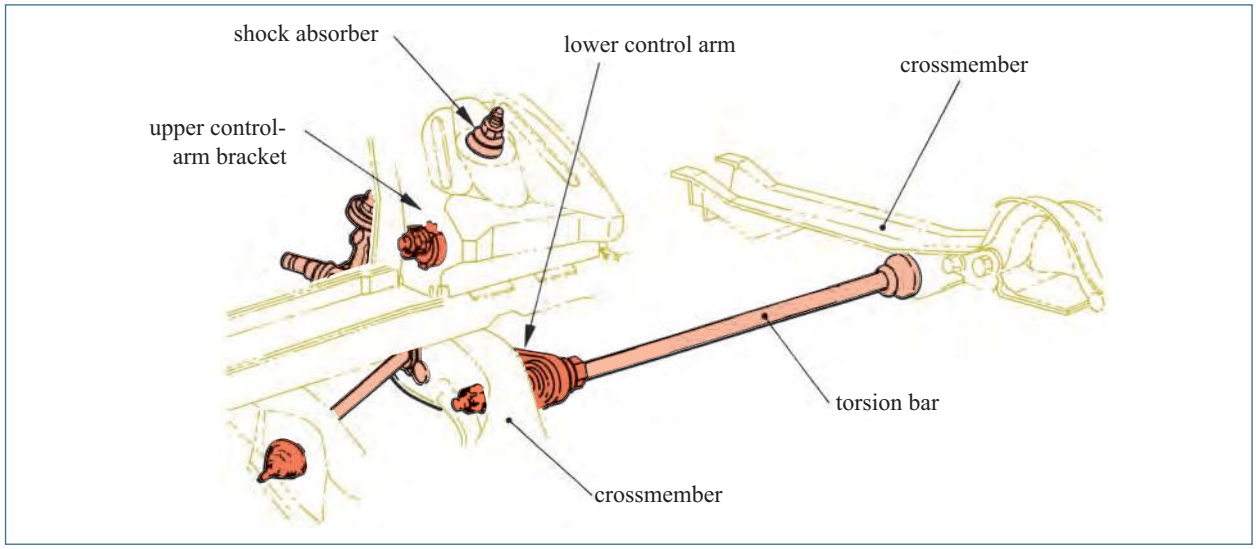


Figure 12.23 Front suspension with a lower control arm and a to rsion bar—the torsion bar is mounted between crossmembers

stiff will give a hard ride because it will transmit road shocks to the vehicle. A relatively flexible spring, in conjunction with a shock absorber, gives a smooth ride.

The action of a spring without a shock absorber can be seen in Figure 12.24. A mass suspended on a coil spring has been stretched and then released. The spring does not immediately return to its original position, but continues to expand and contract (or oscillate), moving the mass up and down. The oscillations will gradually decrease, unless the mass is again disturbed, when more oscillations will be set up.

Without shock absorbers, the springs of a motor vehicle would act like this simple spring. Apart from providing an unsatisfactory ride, the vehicle would be unstable.

Handy hint: Shock absorbers not only dampen out spring bounce but also k eep the vehicle stable on turns by opposing body roll.

12.11.1 Shock absorber operation

The telescopic shock absorber illustrated in Figure 12.25 is of tubular construction and partly filled with oil. The inner tube, or pressure tube, contains a piston attached to a rod, which in turn is attached to the upper mounting. The outer tube encloses the inner tube and carries the lower mounting. A tubular shield is fitted over the outside to protect the piston rod. When the shock absorber is compressed, the piston moves downwards.

Oil is forced from the lower chamber of the inner tube to the upper chamber through the piston valve and restricted passages in the piston. Oil also flows through a restriction in the check valve at the base of the tube into the reservoir. This is because the piston rod will displace oil equal to its volume as it moves down the inner cylinder. On the upstroke or rebound, the oil flow is again restricted through the passages in the piston, but this time the oil flows from the top to the bottom of the inner cylinder through the piston valve.

Oil also returns from the reservoir through the check valve (which is now open) into the lower chamber. This compensates for the loss of the volume of the rod which has moved out of the top of the cylinder as the shock absorber expands. The resistance caused by the flow of oil through the restrictions causes a drag on the movement of the vehicle springs, and this quickly dampens out spring oscillations.

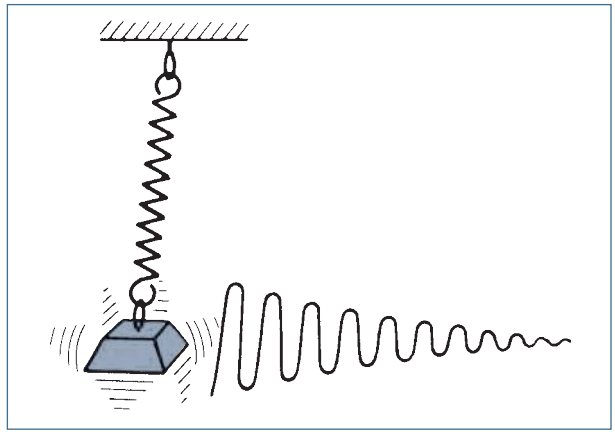


Figure 12.24 Oscillations produced by a mass hanging on a spring

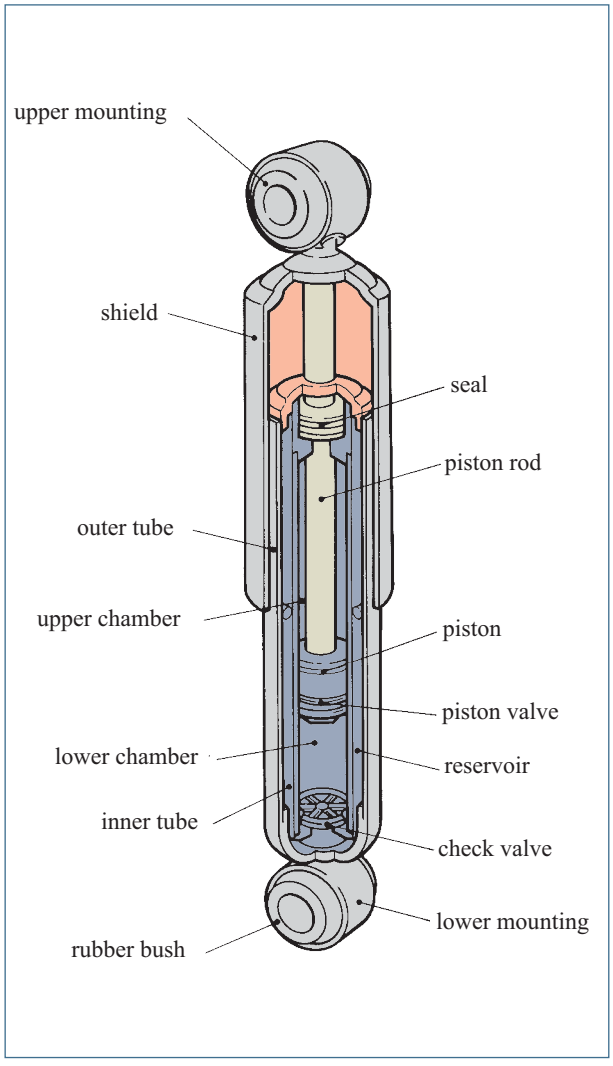


Figure 12.25 Sectional view of a telescopic shock absorber

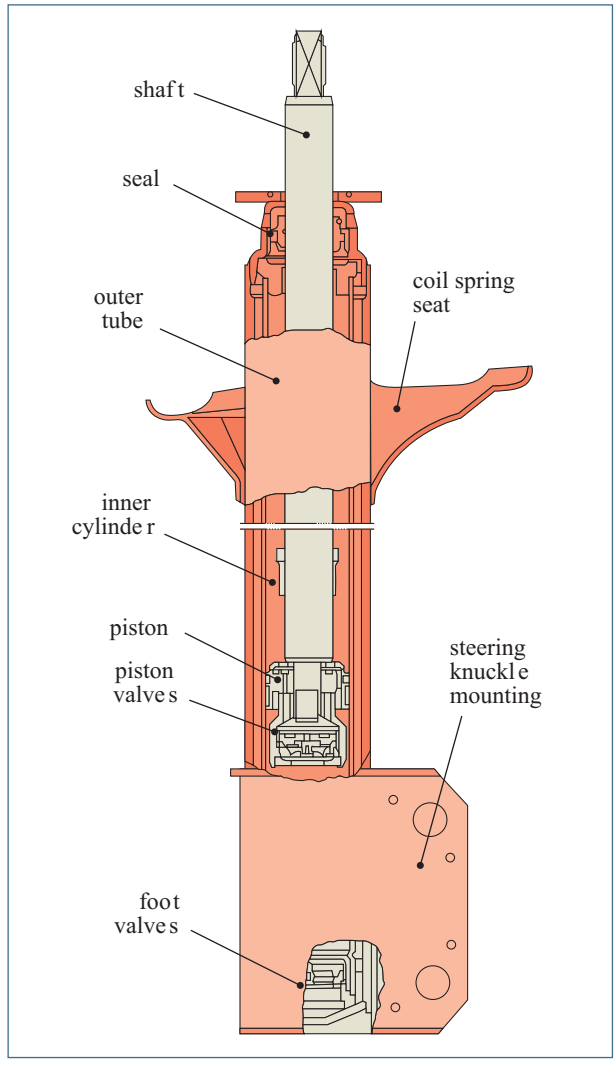


Figure 12.26 Construction of a strut for a front suspension

12.11.2 Gas-filled shock absorbers

Shock absorbers are not completely filled with oil; air occupies a space in the reservoir above the oil. Many shock absorbers have gas instead of air and are known as gas-filled shock absorbers. Nitrogen gas sealed within the shock absorber during manufacture reduces aeration and improves shock absorber operation.

Handy hint: Aeration occurs when air mix es with oil. The air bubbles affect shock absorber operation.

12.11.3 Strut shock absorbers

The shock absorbers that are a part of McPherson-type struts operate like a telescopic shock absorber, but are larger. Most struts are gas-filled and sealed, and cannot normally be dismantled. The construction of a strut can be seen in Figure 12.26, which shows part of the strut shown in section. The strut has a spring seat for the base of the coil spring that fits over the strut. The upper end of the shaft is threaded for the upper mounting and the lower end has a mounting for the steering knuckle.

Struts with variable shock absorbers

The arrangement of a variable shock absorber that is part of a suspension strut is shown in Figure 12.27. The shaft of the shock absorber is hollow and has a control rod that passes down its centre to a selector valve under the piston. The selector valve alters the oil flow through the piston and this affects the damping action of the shock absorber.

An electric actuator at the top of the shaft turns the control rod to open or close the selector valve. The damping action of the shock absorber can be changed by a switch on the dash which operates the actuator.

The oil flow in the illustration is shown with the shaft moving upwards. The selector valve is in the normal position, where oil flows through the orifice at the bottom of the piston as well as through restrictions in the piston. In the hard position, oil flow through the orifice is blocked off by the selector valve to reduce the oil flow through the piston. The switch can also be set for automatic operation. A sensor and an electronic control unit then determine the shock absorber action.

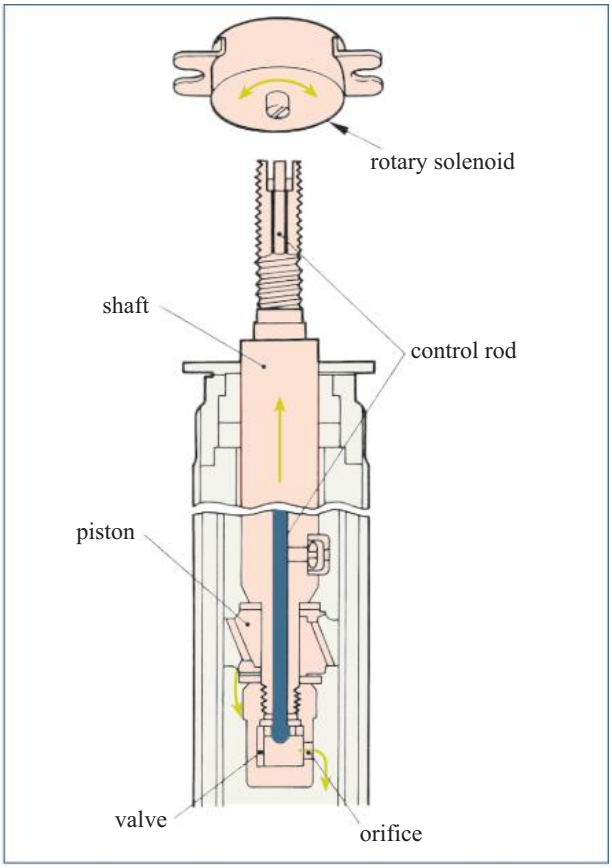


Figure 12.27 Strut with a variable shock absorber FORD

Magnetic shock absorber

Magnetic shock absorbers are filled with magnetorheological fluid, which is controlled by a magnetic field created by an electromagnet. The damping features of the shock absorber are controlled by varying the power of the electromagnet. Fluid viscosity within the shock absorber increases as electromagnet intensity increases.

This type of shock absorber has a number of different applications. Most of these are in semi-active vehicle suspensions which can adapt to road conditions. These are monitored via sensors in the vehicle. Figure 12.28 shows some examples.

12.11.4 Energy-regenerative suspension

In operation, a conventional vehicle suspension is subject to mechanical vibration. This produces energy in the form of heat, which is dissipated into the atmosphere, and so becomes wasted energy. To make use of this, an energy-regenerative suspension has been developed. This converts the vibration energy of the suspension into regenerative energy that can be used to improve the vehicle's fuel efficiency. Instead of dissipating the vibration energy into heat waste, the damper in a regenerative suspension will transform it into electricity and store it in the vehicle's electrical system. Some of

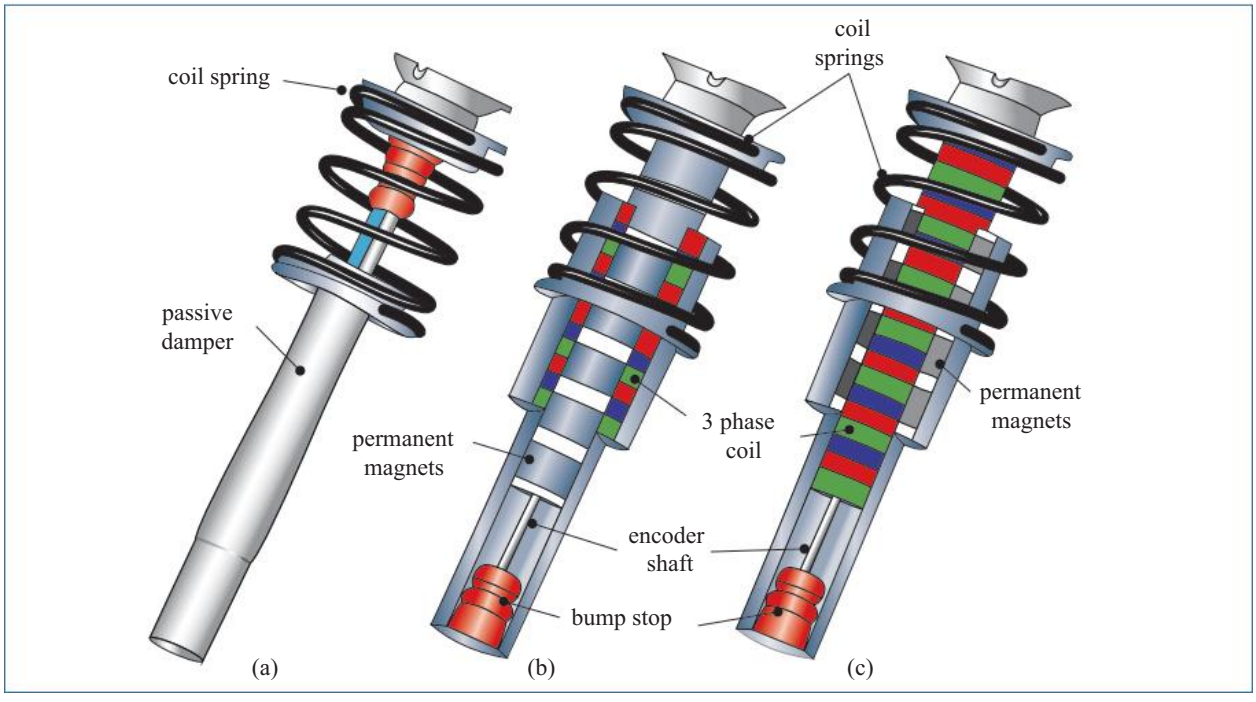


Figure 12.28 Magnetic shock absorber (a) passive (b) active interior magnet (c) active exterior magnet

the electrical energy produced can be used to tune the suspension damper to improve the suspension performance, and some can be used in the general electrical system of the vehicle. Energy regeneration increases fuel efficiency.

12.12 Height-control suspension

The struts used with a height-control suspension (HCS) have air cylinders at the top that operate as air springs. Air is injected into the cylinder to increase the vehicle height, or discharged from the cylinder to reduce the height. This is done through the air-injection port in the top end of the strut ram.

The high and low positions of the cylinder are shown in the composite illustration in Figure 12.29. The difference between these positions is around 60 mm. The rolling diaphragm seals the cylinder to the outside of the strut and allows the strut to move up and down. The height setting is controlled by a switch on the dash panel, and indicator lights show whether the suspension is set to the high or low position.

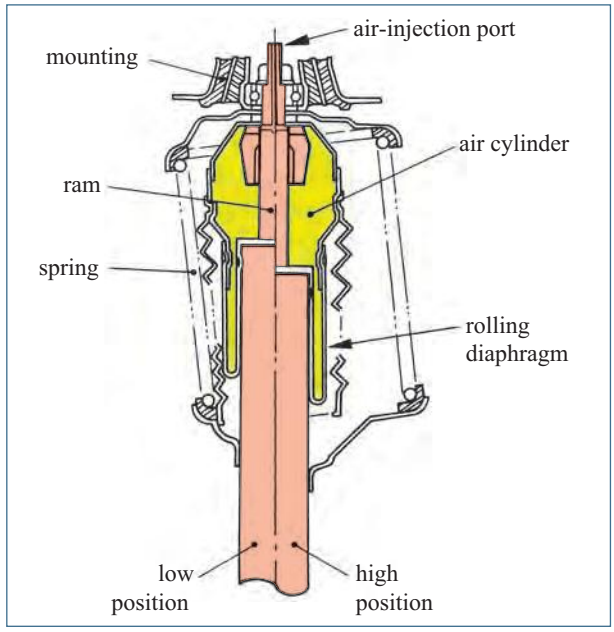


Figure 12.29 Upper part of a strut used with height-control suspension—half the strut is shown in the low position and half in the high position FORD

Figure 12.30 shows the location of the components of a height-control system. The system controls the height and ride of the vehicle by air pressure. It also has an automatic levelling function, which keeps the vehicle level if it is unevenly loaded with passengers or goods. The system consists of an electrically driven air compressor, a dryer, an air tank, control valves, an electronic control unit and an air cylinder on the top of each suspension unit. There are height sensors at the front and rear of the vehicle.

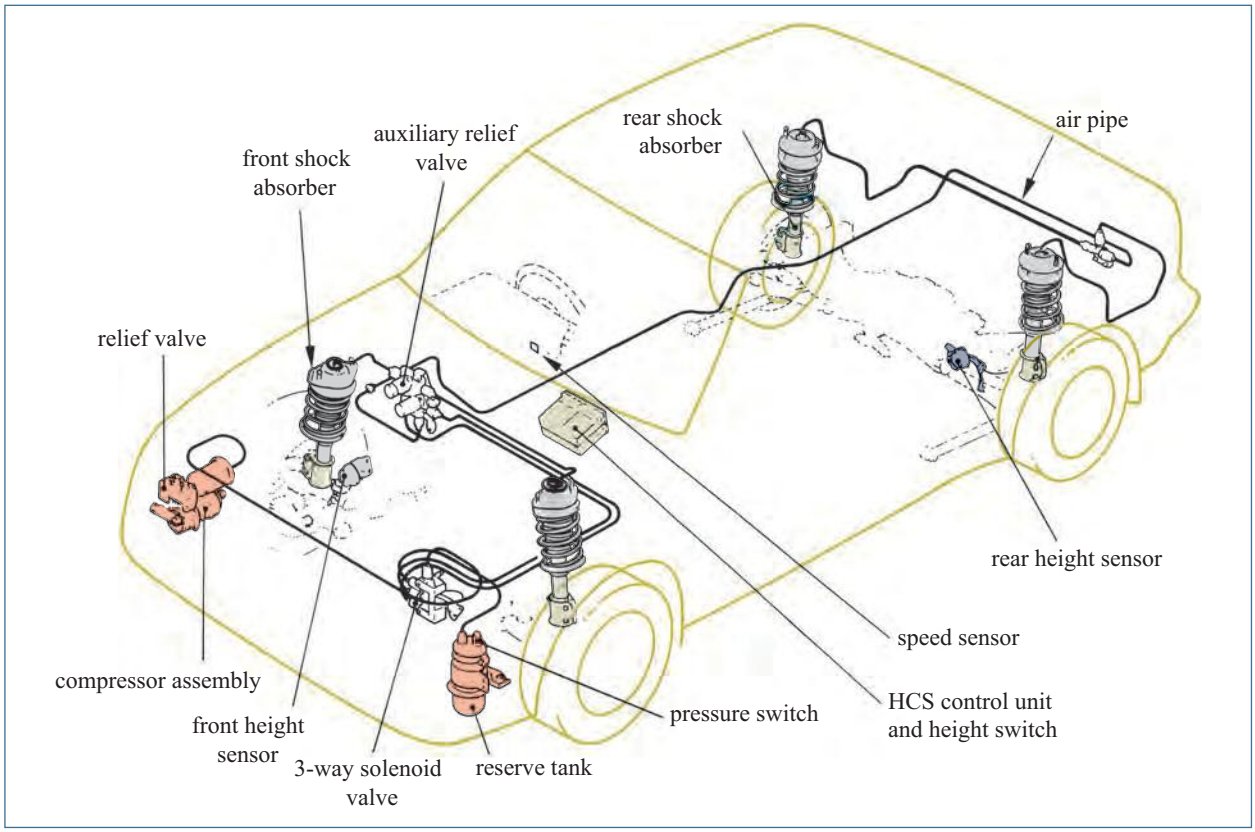


Figure 12.30 The components of a height-control suspension system FORD

Handy hint: The term kerb height refers to the distance between the vehicle body frame or specific suspension points and the road surface .

12.13 Electronically controlled suspension (ECS)

ECS can adjust the suspension of the vehicle to the driving conditions by taking into account vehicle speed, road surface, cornering, stopping requirements and acceleration (Figure 12.31). It increases driver safety and comfort, allowing the driver to choose between sport, normal or auto mode (see Chapter 48).

Figure 12.31 Electronically controlled suspension
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12.14 Suspension maintenance

Suspension maintenance consists of checks and, in some cases, lubrication. Arms and linkages are checked for looseness, rubber bushes for wear, ball joints for wear and rubber boots for deterioration. Suspension plays an important part in steering, so it is checked during a wheel alignment.

Ball joints are packed with grease during manufacture and usually need no further lubrication. However, they can be lubricated by partially filling the boot with grease. Some ball joints in the front suspension of light commercial vehicles can be lubricated with a grease gun. The bearings in some wheel hubs have to be dismantled for servicing, but others normally do not need servicing.

Sustainability: Always dispose of used suspension parts in accordance with sustainable practice guidelines.

12.15 Dismantling and reassembling procedures

The dismantling procedure will vary for different types of suspensions, but supporting the vehicle correctly and relieving the force of the spring are the first steps. With some suspensions, the spring is removed separately; with others, it is removed with other components. Reassembling is, in general, the reverse of dismantling. The text that follows relates mainly to the latter. A number of different types of suspensions show the types of operations that are carried out on suspension systems.

Safety: When working on suspension components, always be aware of the dangers of stored energy in compressed springs. Follow safe working practices and use appropriate PPE.

12.15.1 Supporting the vehicle

With the wheels on the ground, the springs and other suspension components are under load. Before the suspension can be dismantled, the load must be relieved by having the vehicle correctly supported. The vehicle is raised with a floor jack and stands placed at the correct jacking points under the sill panel or subframe. When the jack is lowered, the stands will support the body and let the wheels hang free. This takes the load off the parts of the suspension that are to be dismantled (Figure 12.32).

With the vehicle correctly supported, the spring will be extended, and the suspension will be sitting on its rebound bump stop or hanging on its shock absorber. This will depend on the type of suspension. A jack can then raise or lower the suspension as required. Suspension work can be done with the vehicle on the floor with the aid of jacks and stands; it can also be done with the vehicle on a hoist, provided it is suitably supported.

Handy hint: There are many variations in suspension design, so refer to workshop manuals for actual procedures.

Safety: It is dangerous to try to remove any suspension component unless the vehicle is correctly supported.

12.15.2 Preliminary work

Preliminary work has to be done before suspension parts can be dismantled. This includes:

1. Removing the wheel to gain access to the suspension components
2. Disconnecting the shock absorber by unbolting its mountings
3. Disconnecting the stabiliser bar from the control arms
4. Removing brak e components from their mountings
5. Disconnecting steering connections.

Handy hint: The actual parts that have to be removed will depend on the particular design of suspension.

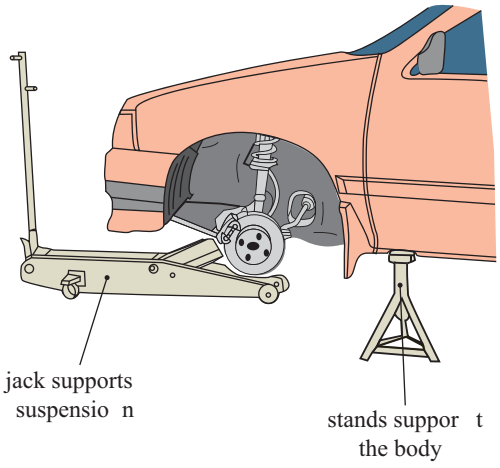


Figure 12.32 The vehicle must be supported correctly when working on the suspension

12.15.3 Finalising after reassembling

After reassembling a suspension, the bolts securing arms and linkages are tightened to the specified torque. Springs should be checked to ensure they are in their original positions and correctly fitted into their seats. Incorrectly fitting springs will affect ride height and wheel alignment. Before being finally tightened, the vehicle should be resting on its wheels and free of jacks and stands. Bounce it up and down a number of times to allow rubber bushes to settle and then carry out the final tightening.

The position of any parts that have a bearing on wheel alignment or adjustment should be marked before dismantling to assist with reassembly. For example, a steering knuckle and its mounting on the strut might be marked so that they can be reassembled in exactly the same position (Figure 12.33). After reassembling and before finally tightening the mounting bolts, the marks can be accurately aligned so that the wheel camber will not be affected.

Figure 12.33 A strut and knuckle are mark ed before dismantling

Handy hint: Some suspension bolts are not designed to be reused. Check the workshop manual if you are unsure .

12.16 Ball joint front suspension

With ball joint suspension of the design shown in Figure 12.34, the coil spring sits on the lower control arm, and its upper end has a mounting on the front crossmember. To remove the spring, the outer end of the control arm has to be lowered so that the spring will extend fully.

The shock absorber is mounted inside the coil and will have to be removed first. The outer end of the control arm is freed by removing the stud of the lower ball joint from the steering knuckle. The end of the control can then be lowered with a jack to free the spring. With the spring no longer in compression, it can be safely removed. During dismantling, the vehicle is supported under the front crossmember or subframe, and a jack supports the lower control arm and lowers it to extend the spring.

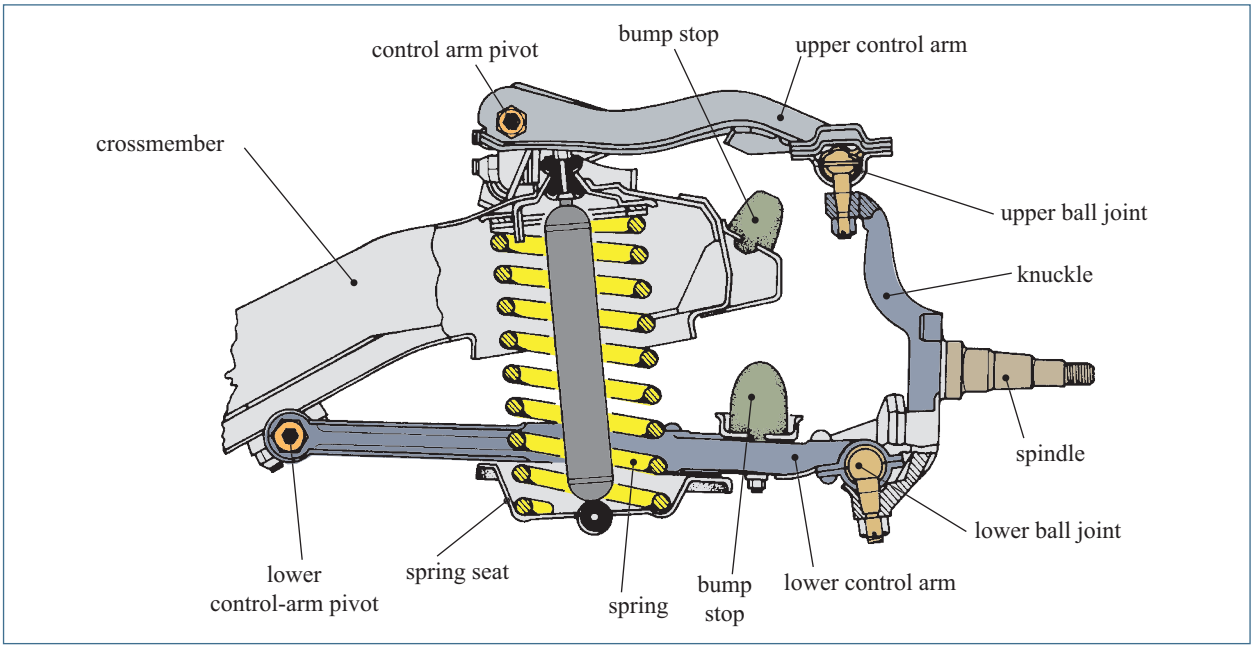


Figure 12.34 Coil suspension with upper and lower control arms

12.17 Strut (McPherson) suspensions

Struts are used for both front and rear suspensions. They are used in conjunction with rear-wheel drive, front-wheel drive and all-wheel drive. The strut and spring arrangements are basically the same wherever they are used, but there are different considerations when a strut is to be removed. Some of these are:

1 Arms and link ages. These are not the same for all suspensions, and this can vary the dismantling procedure .
2 Steering parts. With front-wheel drive , there are steering parts and also the drive shaft from the transaxle to consider .
3 Steering knuckle . With front struts, the steering knuckle is attached to the strut. This is usually bolted, but it can be part of the strut. (The steering knuckles are different for driving and non-driving wheels.)
4 Wheel hubs. With both front and rear struts, the arrangement of the wheel hub and/or axle spindle for driving wheels is different from non-driving wheels.
5 Springs. In almost all cases, the strut and spring are removed together , with the spring held compressed with a special tool.
6 Mountings. Similar mountings are used at the top of all struts, but the lower mounting can be different.

12.17.1 Front strut (rear-wheel-drive vehicle)

The components of a strut-type front suspension are shown in Figure 12.35. The suspension is for a rear-wheel-drive vehicle. The following parts can be identified:

1 Strut. The strut contains the shock absorber components. It has a seat for the lower end of the spring.
2 Spring. The coil spring is mounted over the strut and sits on the spring seat. It is held in a compressed state between the spring seat and the upper mounting.
3 Upper mounting. When installed in the vehicle , the top of the strut is bolted to the reinforced mounting of the spring tower .
4 Lower mounting. The lower end of the strut is bolted to the ball joint on the lower control arm.
5 Lower control arm. The lower control arm carries the ball joint and is connected to the front crossmember by bolts and rubber bushes.
6 Tension rod. The tension rod is connected between the front crossmember and the lower control arm. There are rubber bushes at each end of the rod. The threaded rod allows limited adjustment.

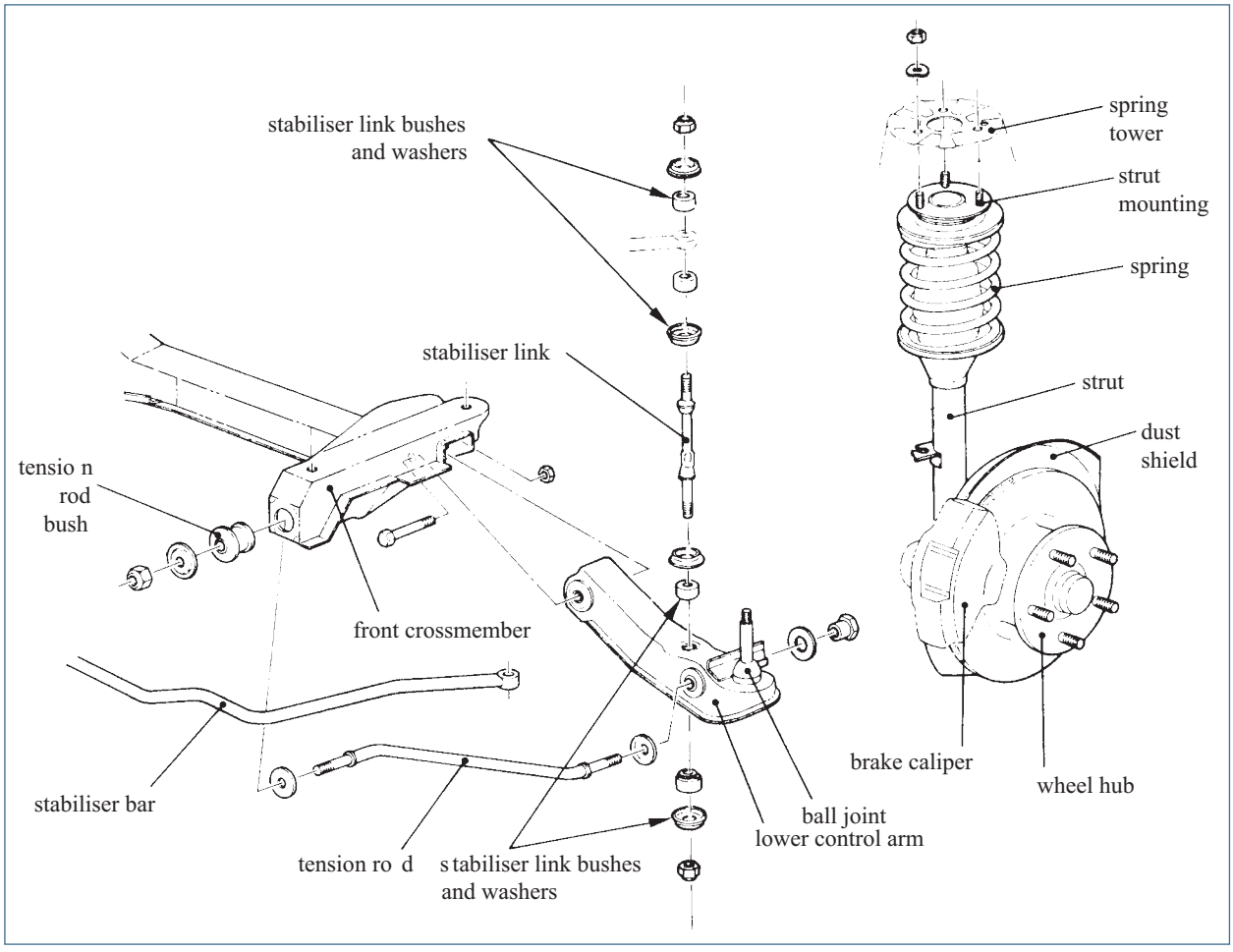


Figure 12.35 Strut-type suspension for the front wheel of a rear-w heel-drive vehicle GM HOLDEN LTD

7 Stabiliser bar . A link connects the end of the stabiliser bar to the lower control arm. The top of the link fits into the eye in the stabiliser bar and the lower end fits into a hole in the lower control arm. Rubber bushes are fitted at the top and bottom of the link.

8 Wheel hub assembly . The strut has a fix ed spindle on which the wheel hub and bearings are mounted. Other parts are the brak e disc, the brak e caliper and the dust shield.

Handy hint: Suspension parts can be replaced without removing the strut from its upper mounting, provided the vehicle and components are correctly supported. If the spring or strut require service , they are removed as an assembly .

12.17.2 Front strut (front-wheel-drive vehicle)

Figure 12.36 shows the lower end of a strut, the steering knuckle and the associated components for a front-wheel-drive vehicle. The strut itself is similar to the one in the previous illustration, but it has a knuckle that is bolted to the strut that is quite different.

The knuckle is designed with a boss with a large hole to carry the hub and bearing for the front wheel. The bearing is a unitised bearing with a double row of balls. It is not adjustable and is retained in the knuckle by a snap ring. The knuckle is connected to the control arm by the ball joint, which allows the knuckle and strut to be turned for steering.

A boss on the hub fits into the bearing. The hub has internal splines, which accommodate the splines on the end of the drive shaft. The hub is retained in the bearing and the shaft is retained in the hub by a nut and washer on the end of the drive shaft.

The dust shield and the brake caliper are mounted on the steering knuckle. The brake disc is bolted to the wheel hub.

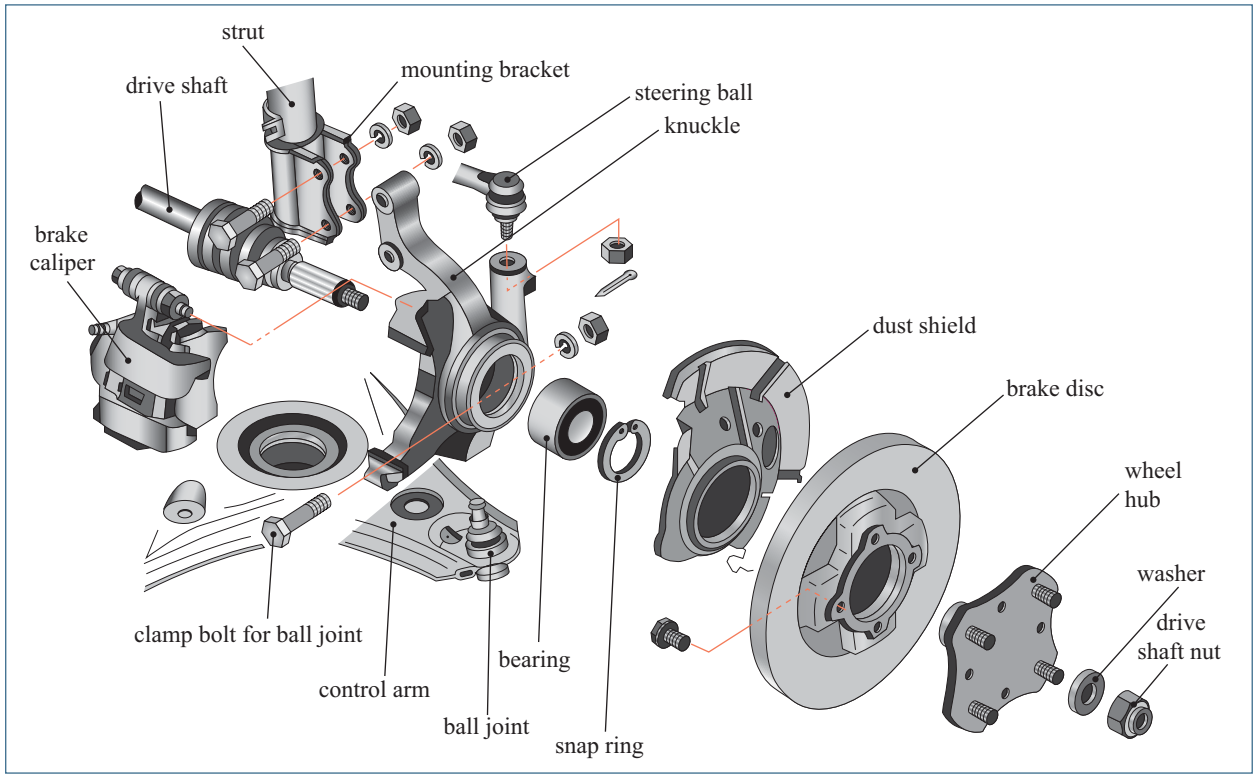


Figure 12.36 Components of a hub assembly for a strut suspension (front-wheel-drive vehicle)

12.17.3 Rear strut (front-wheel-drive vehicle)

When dismantling a rear strut suspension for a front-wheel-drive vehicle, a floor jack is used. Stands are then placed under the jacking points at the rear of the sill panel to support the body of the vehicle, as shown in Figure 12.37. The lower mountings of the suspension are accessible with the wheel removed, and the upper strut mounting is accessible from the interior of the vehicle.

Figure 12.37 Position of jack and stands for dismantling a rear suspension with struts

Dismantling points

The general dismantling sequence for this type of suspension is to disconnect the lower end of the strut, then the upper end so that the strut can be removed complete with the spring. The trailing arm and lateral arms can then be dismantled as required.

In some cases, the strut is too long to be easily removed and has first to be compressed. The jack is placed under the lower control arm and the strut and spring are compressed. The compressing tool is then fitted to hold the spring in this condition. The compressed strut is short enough to enable it to be removed.

Safety: Safety precautions should be **followed when handling and compressing springs.**

12.18 Rigid rear axle with coil springs

There are several different arrangements of rigid rear axles with coil springs, one of which is illustrated in Figure 12.38. One side of the suspension is shown assembled and the other dismantled. The suspension has upper and lower control arms. (The lower control arm is a trailing arm.) It has a Panhard (lateral) rod.

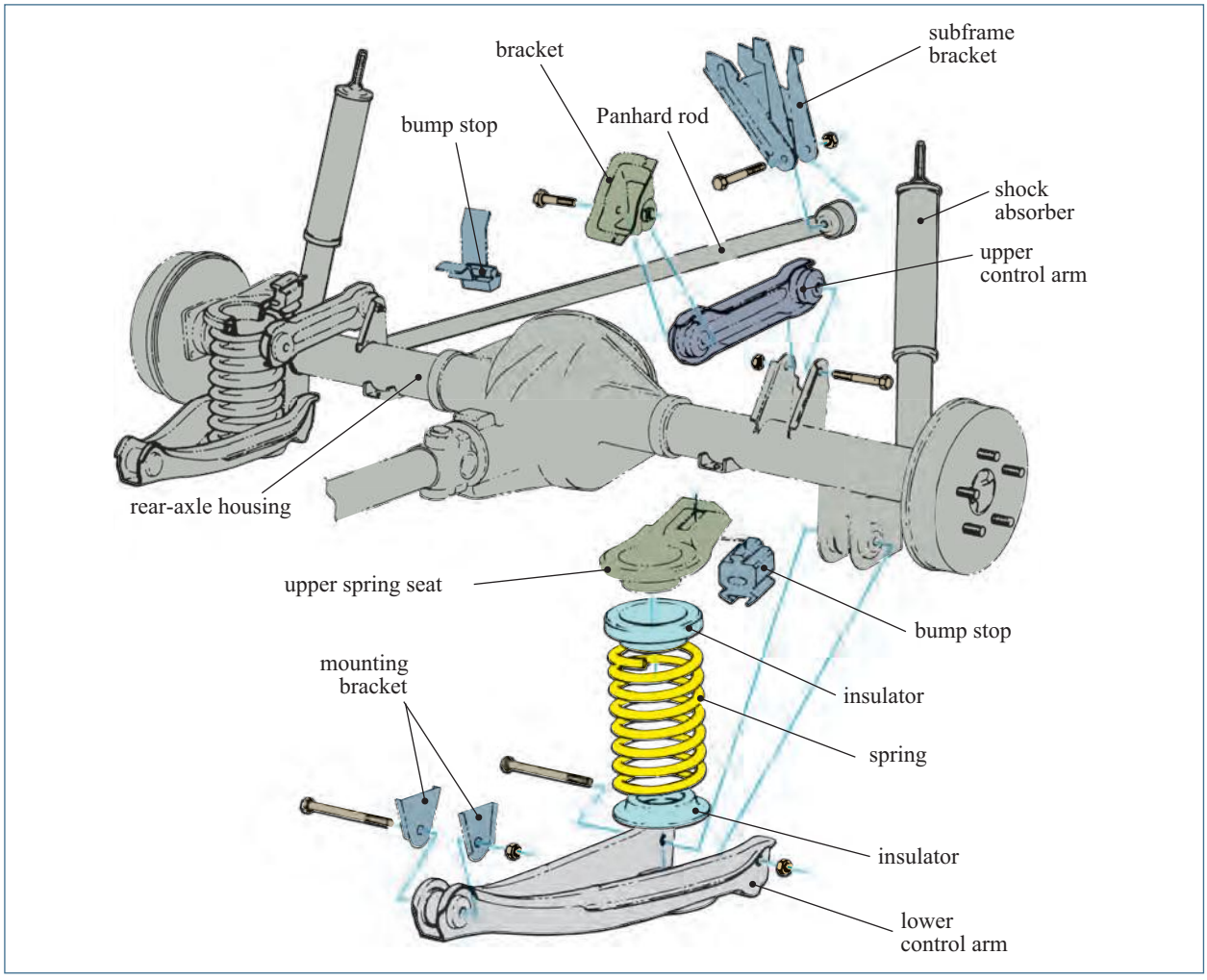


Figure 12.38 Rear suspension with a rigid-axle assembly and coil springs GM HOLDEN LTD

12.18.1 Removal of parts

1 A floor jack raises the rear of the vehicle , and stands are placed under the rear jacking points.
2 The jack remains in place to support the rear-axle housing.
3 The Panhard rod is disconnected or removed.
4 The lower ends of the shock absorbers are disconnected from their mountings.
5 The jack and axle housing are lowered. This allows the coil springs to extend so that they can be removed.
6 With the springs removed, there is no loading on the remaining suspension parts and further dismantling can be carried out.
7 The lower control arms are disconnected from the axle housing, or removed.
8 After the control arms are disconnected, the axle housing is free as far as the suspension is concerned.

Some of the dismantling points for a suspension with a rigid axle and coil springs are illustrated in Figure 12.39.

Handy hint: If the axle housing is to be completely removed, the propeller shaft will have to be disconnected at the pinion flange .

12.19 Independent rear suspension (rear-wheel-drive vehicles)

There are two general designs of independent rear suspension (IRS) for rear-wheel-drive vehicles. These are strut-type suspension and trailing-arm suspension. Both have swing axles, or open drive shafts, between the differential assembly and the rear (driving) wheels.

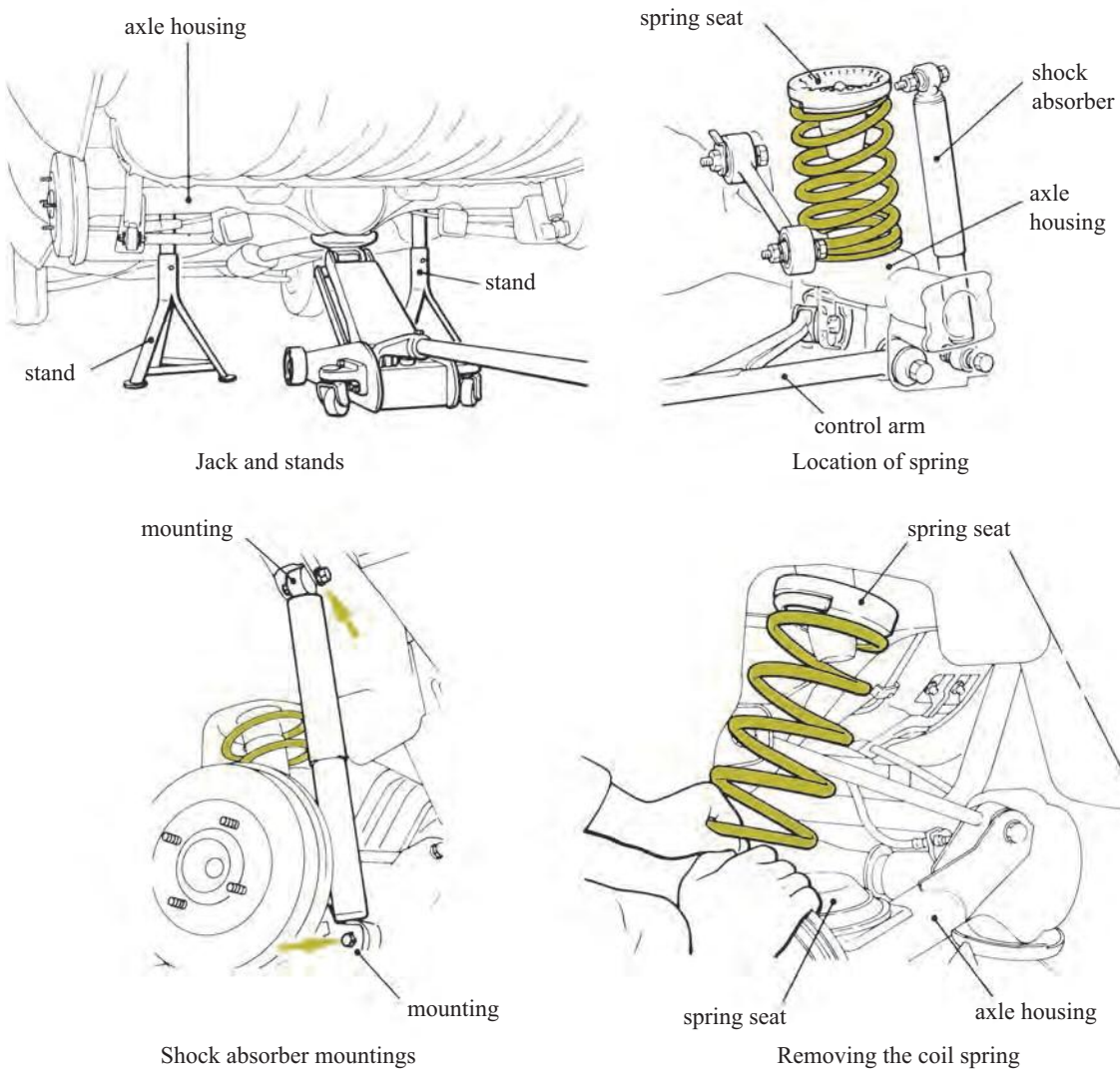


Figure 12.39 Service points on removing a rear axle and coil-spr ing suspension MITSUBISHI

12.19.1 IRS with struts

Figure 12.40 shows a rear-axle crossmember assembly with a strut-type suspension system. The struts are inside the coil springs. The differential assembly is bolted to the centre of the crossmember, which is bolted to the subframe of the vehicle.

The suspension has upper and lower control arms that are mounted to the crossmember. The coil springs fit over the struts. The struts have an upper mounting to the body and a lower mounting to the lower control arm (see also Figure 12.44).

The upper strut mounting is accessible from inside the vehicle. The lower strut is accessible from the rear. With the vehicle supported on stands, the suspension can be lowered enough to remove the strut complete with the spring and upper mounting.

12.19.2 IRS with coil springs

Figure 12.18, earlier in this chapter, illustrates an independent rear suspension with coil springs and trailing arms. The dismantling procedure is similar to that previously outlined for a rigid axle with coil springs, except that the drive shaft has to be considered. The same applies to the arrangement of the wheel hub, if that part of the assembly is to be dismantled.

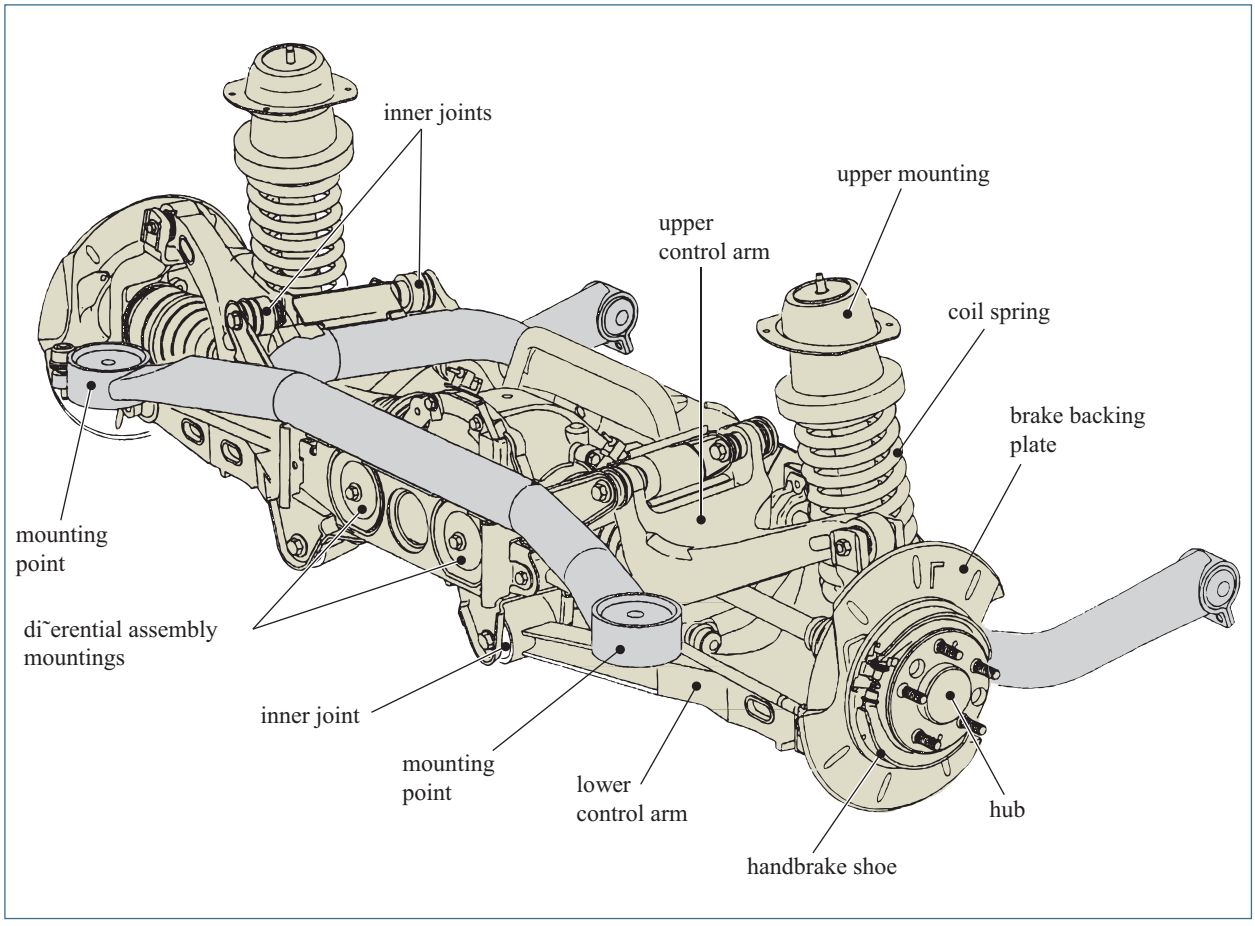


Figure 12.40 Rear-axle crossmember and suspension assembly for a rear-wheel-drive vehicle with independent rear suspension FORD

The drive shaft and the wheel hub are connected by flanges that are bolted together. To separate the drive shaft, the flange bolts are removed (Figure 12.41). The drive shaft can then be moved away. The drive shaft should be tied up to the cross-member and not allowed to drop. This prevents damage to the constant-velocity (CV) joint boot.

12.20 Rigid rear axle with leaf springs

Figure 12.5, earlier in this chapter, shows the components of a leaf spring suspension, a type used with some station wagons and light commercial vehicles. To remove the spring, the axle housing has to be lifted away from it. The spring can then be disconnected, first at the rear end and then at the front. The procedure is:

1 Raise the vehicle with a jack under the centre of the rear-axle housing and place stands under the subframe to support the rear of the vehicle .
2 Remove the wheel to mak e the spring more accessible .

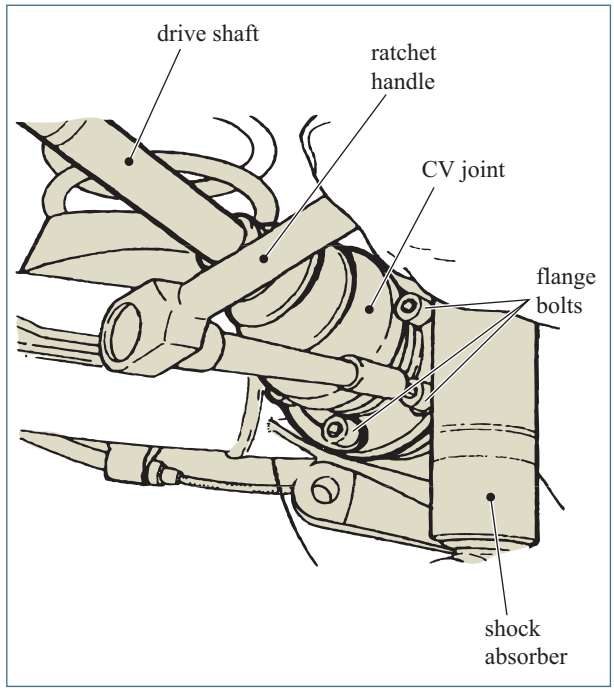


Figure 12.41 Disconnecting the drive shaft of an IRS at the wheel hub GM HOLDEN ITD

3 Disconnect the shock absorber at its lower mounting, or at both mountings if it is to be removed.
4 Lower the jack so that the springs hang.
5 Remove the nuts from the U-bolts and remove the spring plate and insulator from under the spring.
6 Remove the U-bolts and raise the jack until it lifts the rear axle from the spring. The jack now supports the rear-axle housing.
7 Disconnect the rear shackle and lower the end of the spring to the floor.
8 Remove the bolt from the spring hanger at the front of the spring and remove the spring.

12.21 Dismantling and reassembling struts

Figure 12.42 shows a dismantled front strut (rear struts are the same, except for the upper mounting). With the spring compressed, the strut can be dismantled as shown. The shaft nut at the top keeps the parts in place. Once that is removed, the upper mounting can be removed, followed by the spring seat, the upper insulator, the coil spring, the bump stop and the dust cover.

The shock absorber part of the strut cannot be dismantled; if it is faulty it has to be replaced with either a new or a reconditioned unit.

12.21.1 Rear suspension strut

Figure 12.43 shows the mountings for a rear-suspension spring and strut. This particular strut has its lower end mounted to the lower control arm.

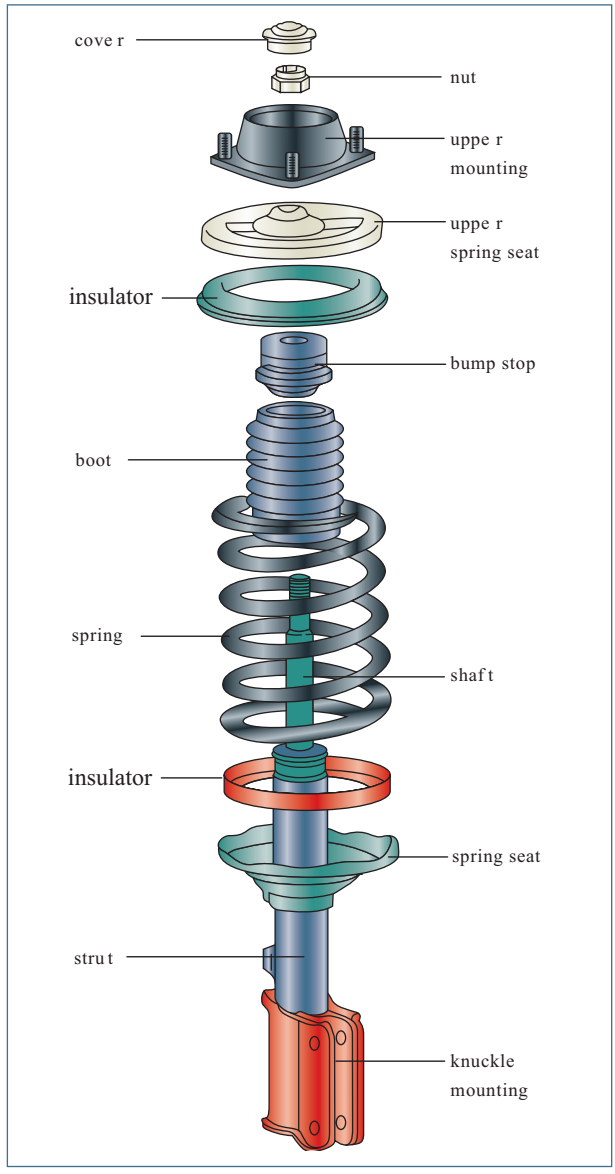


Figure 12.42 Parts of a McPherson strut for a front suspension

1 Figure 12.43 (a) shows the dismantled parts of the strut.
2 Figure 12.43 (b) shows how the upper end of the coil is located in the insulator , which is shaped to fit.
3 Figure 12.43 (c) shows the lower end of the spring and how it fits on to the spring seat on the strut.
4 Figure 12.43 (d) shows how the strut is mounted to a reinforced part of the body above the rear wheel arch. The nuts securing the strut are accessible from inside the body .

12.22 Servicing components

The following are some of the service operations that are carried out on components of various suspension systems.

12.22.1 Compressing strut springs

The coil spring of a strut-type suspension must be compressed before the strut can be dismantled. A compressing tool is fitted over the coils and draws them together. With most suspensions, the strut can be removed from the vehicle as an assembly and the compressing tool then used. However, sometimes the compressing tool has to be fitted to the spring to reduce the length of the strut before it can be removed.

Spring compressing tool

Figure 12.44 shows one design of compressing tool. Each of its two pieces has a long bolt that screws into jaws that fit over coils of the spring. Screwing the bolts compresses the spring so that the shaft nut can be removed.

Safety: The tool must be fitted correctly and the spring compressed evenly by tightening **each side a little at a time**.

Compressing tool for coil spring

Figure 12.45 shows a compressing tool for a coil spring mounted above the upper control arm. This consists of a threaded rod and tube. It is used inside the spring after the shock absorber has been removed.

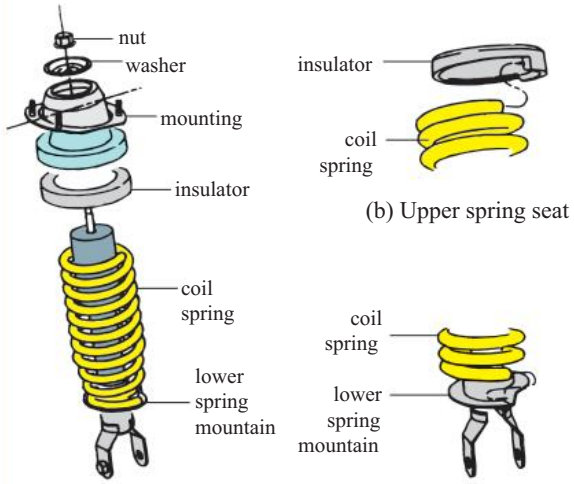
The lower end of the tool is bolted to the shock absorber mounting (shown in the inset of the diagram) and a collar is used at the top of the spring tower. With the spring seat bolts removed from the control arm, operating the tool will compress the spring.

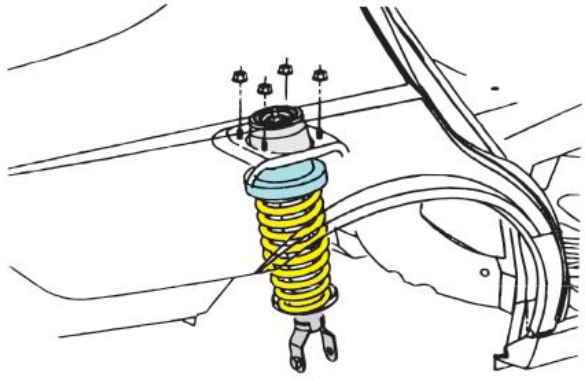
12.22.2 Removing and replacing suspension bushes

The rubber bushes in suspension components can be pressed in or out with a press, or with special tools. In Figure 12.46, pressing tools are being used with a large vice. In Figure 12.46 (a), the pressing tool is being used to push the old bush from the eye into the socket. In Figure 12.46 (b), the new bush is being installed with the help of the guide.

12.22.3 Removing and replacing ball joints

Some ball joints are bolted to control arms; others are pressed in. Still others are not replaceable,





(d) Strut mounting—upper

Figure 12.43 Mountings for a rear strut and spring FORD

Figure 12.44 Compressing the coil spring of a strut-type suspension

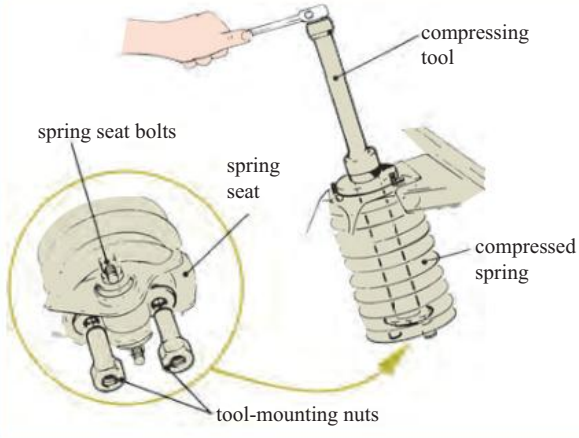


Figure 12.45 Tool being used to compress a coil spring FORD

so a new arm and ball joint will have to be fitted if the ball joint is faulty.

Ball joint removing tool

Figure 12.47 is one example of a special tool that removes the ball joints from a steering knuckle. The ball studs fit into tapered holes and need force to remove them. The threaded tool is installed as shown and expanded against the ends of the studs. Removal is assisted by tapping the knuckle around the stud area with a hammer.

Ball joint pressing tools

Pressing tools are needed to remove and replace some ball joints, as shown in Figure 12.48. The type of ball joint shown is a press fit in the control arm and so has to be pressed out if it is to be replaced. The new ball joint has then to be pressed into the control arm. When correctly in place, it has a flange that fits into a recess in the control arm.

Handy hint: There are two parts to the pressing tools—one part for pressing, the other for supporting.

12.22.4 Replacing stabiliser bar bushes

Stabiliser bars and links have rubber bushes where they are connected to the control arms and other parts. There are also shaped washers. These parts must be assembled correctly so that the rubber parts separate the metal parts and act as insulators. The way in which bushes and washers are assembled can be seen in Figure 12.35 (earlier in this chapter).

12.22.5 Replacing leaf-spring bushes

The shackle bushes at the rear of the spring are in two pieces and are easy to remove from the spring eye. On reassembly, the parts of the bush are inserted from each side and the shackle assembled. Tightening the shackle bolts clamps the bushes in place. The rubber bush at the front of the spring usually has a metal case. With the spring removed, the old bush can be pressed out of the spring eye and a new one pressed in.

Without completely removing the spring, bushes can be removed and installed with a bush-removing tool, as shown in Figure 12.49. The tool consists of an adaptor and a socket with a through bolt. The nut on the bolt is tightened to pull the old bush out of the spring eye.

Handy hint: The tool is used in a similar way to pull a new bush into the spring eye .

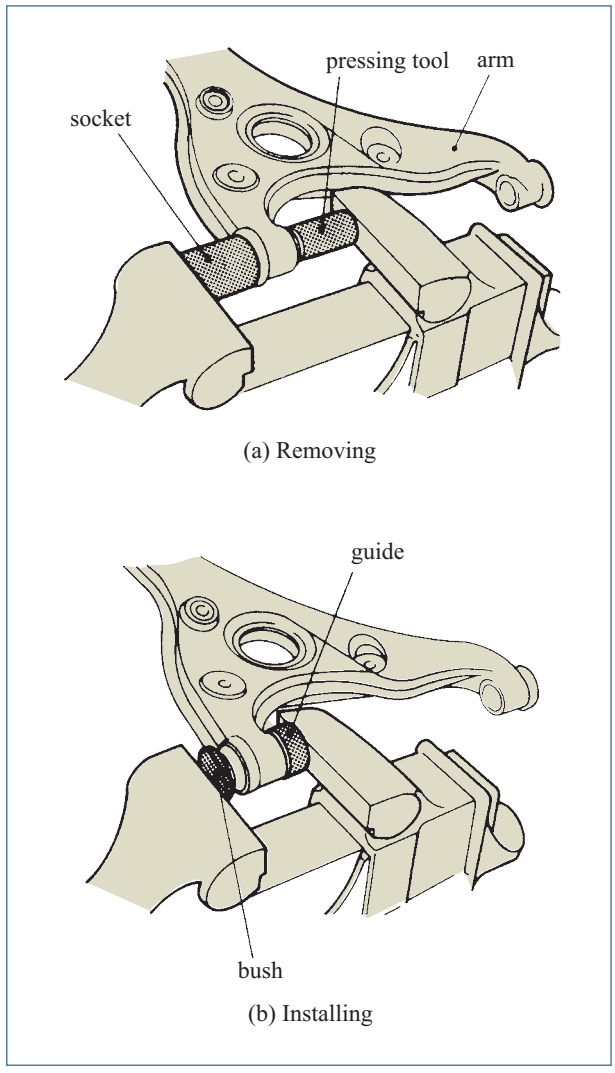


Figure 12.46 Removing and installing a bush in a suspension arm FORD

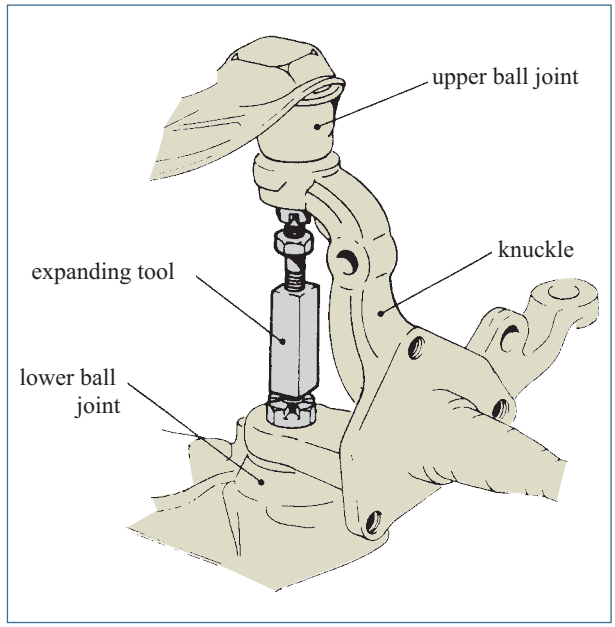


Figure 12.47 Ball joint removing tool

12.23 Servicing hubs and bearings

A number of different types of bearings and hubs are used with suspension systems. The main differences are caused by the location of the driving wheels; that is, whether the vehicle has front-wheel drive or rear-wheel drive. Vehicles with four-wheel drive combine some of the features of both rear-wheel drive and front-wheel drive.

Tapered roller bearings, plain roller bearings and ball bearings are all used for wheel hub bearings, but there are many different arrangements. Some of these are able to be lubricated and adjusted, but others are not. Unitised bearings, which have a double row of rollers or balls, are used extensively. They are not adjustable and need no servicing.

12.23.1 Rear-wheel drive

Rear-wheel-drive vehicles conventionally have tapered roller bearings in the front hubs. Front-wheel bearings of this type require periodic servicing. Roller bearings or ball bearings are used at the rear, and do not require servicing.

Many passenger vehicles now have unitised bearings at both the front and rear, and some have unitised hubs. These designs of bearings do not require servicing.

12.23.2 Front-wheel drive

There are a number of different bearing arrangements for front-wheel-drive vehicles. These usually have unitised bearings at the front and they can have either ball or roller bearings of conventional design at the rear, although unitised bearings and hubs are extensively used.

There are some hubs and bearings that require periodic service, but most front-wheel-drive hubs have bearings which, under normal conditions, do not require servicing. The bearings in the hub are usually referred to as 'wheel bearings'.

12.24 Other bearing arrangements

Figure 12.50 shows the hub and bearing arrangement for the rear wheels of a light truck. This has a full-floating rear axle. The axle shaft can be withdrawn from the housing after removing the nuts from the axle studs. This gives access to the nuts that hold the bearings and retain the hub. The hub and bearings are removed from the rear-axle housing for servicing. The bearings are serviced in the usual way for tapered roller bearings.

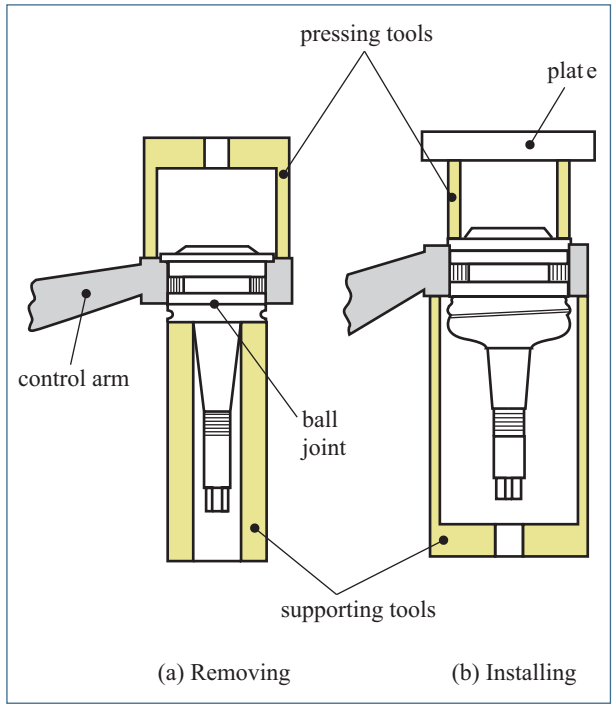


Figure 12.48 Removing and installing a control arm ball joint FORD

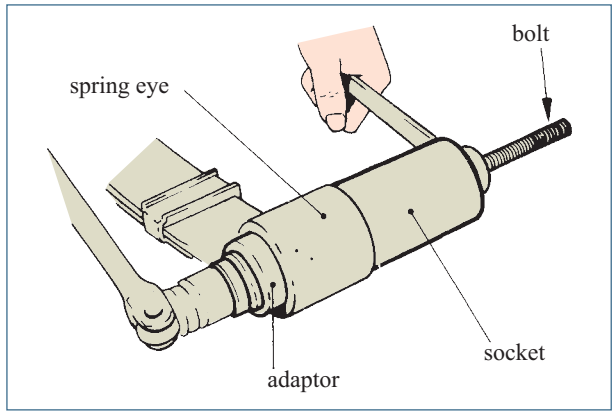


Figure 12.49 Tool for removing and replacing a bush in a spring eye FORD

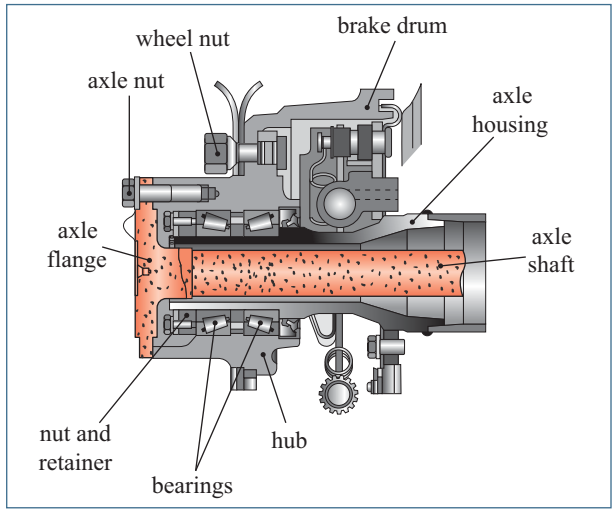


Figure 12.50 Rear-wheel hub of light truck with a full-floating rear axle

12.24.1 Hub with ball bearings

Figure 12.51 shows a rear-wheel hub with ball bearings. This is for a front-wheel-drive vehicle. The hub is mounted on a short stub axle, which is bolted to the axle carrier. The hub has an inner and an outer bearing. These are conventional ballraces. The bearings can be removed for servicing or replacement, the examples shown being two separate ballraces. They are serviced by cleaning and repacking with grease. They are not adjustable and the axle nut, which retains them, is tightened to a specified torque.

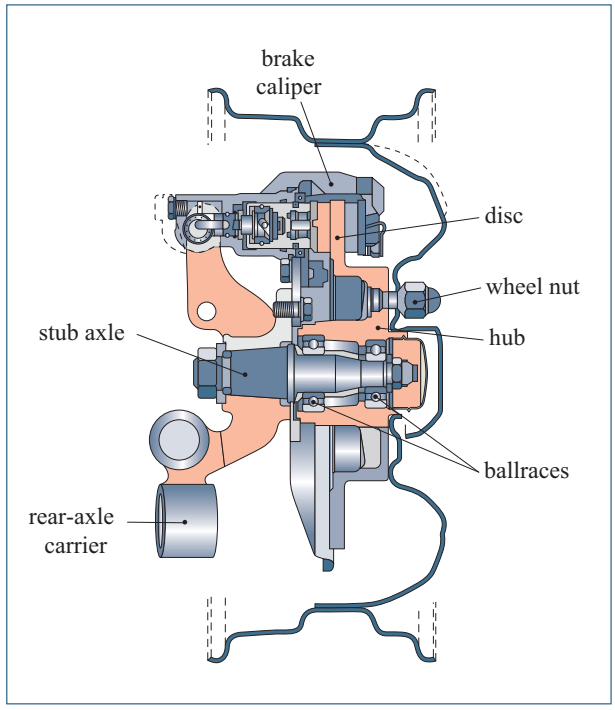


Figure 12.51 Rear-wheel-hub assembly with ball bearings

12.25 Hubs with tapered roller bearings

Figure 12.52 shows the arrangement of a front wheel, the hub and the bearings for a rear-wheel-drive vehicle. This is a conventional arrangement that has two tapered roller bearings. The bearing cups are fitted into the hub and the bearing cones mounted on the spindle. The bearings are retained on the spindle by a nut and washer. An inner oil seal and an outer cap retain grease in the hub and exclude dirt and water.

12.25.1 Rear hub for front-wheel drive

Figure 12.53 shows a rear-wheel hub and spindle assembly for a front-wheel-drive vehicle. The spindle has a flange that is bolted to the trailing arm of the suspension, and the hub is mounted on the spindle on tapered roller bearings.

The arrangement of the hub and bearings is the same as that of the front wheels of most rear-wheel-drive vehicles. The bearings are serviced in the same way and the bearing adjustment is similar, although some bearings are adjusted with a light preload.

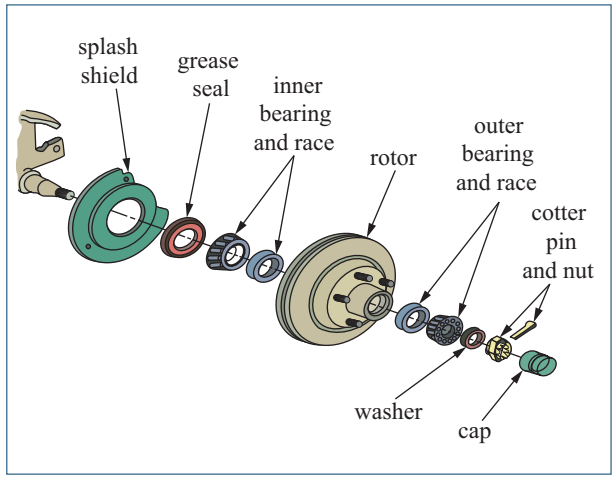


Figure 12.52 Front hub , bearing and grease retainer of a rear-wheel-drive vehicle FORD

12.25.2 Front-wheel hub with unitised bearing (front-wheel-drive)

Figure 12.54 shows the dismantled components of a hub assembly for the front wheel of a front-wheel-drive vehicle. The hub has provision for the splined end of the drive shaft and includes a unitised ball bearing.

The sequence for dismantling the parts of the hub assembly is generally as shown in the illustration, from right to left. The strut remains in the vehicle and the hub and associated parts are dismantled from it. Dismantling starts with the removal of the lower control arm ball joint. This allows the lower part of the strut to be pulled outwards to free the drive shaft from the hub. With some suspensions, the bearing is a press fit in the knuckle and the hub is a press fit in the bearing. An extractor pushes the drive shaft from the hub.

Handy hint: The actual sequence for dismantling this, or any other suspension, should be obtained from the appropriate workshop manual.

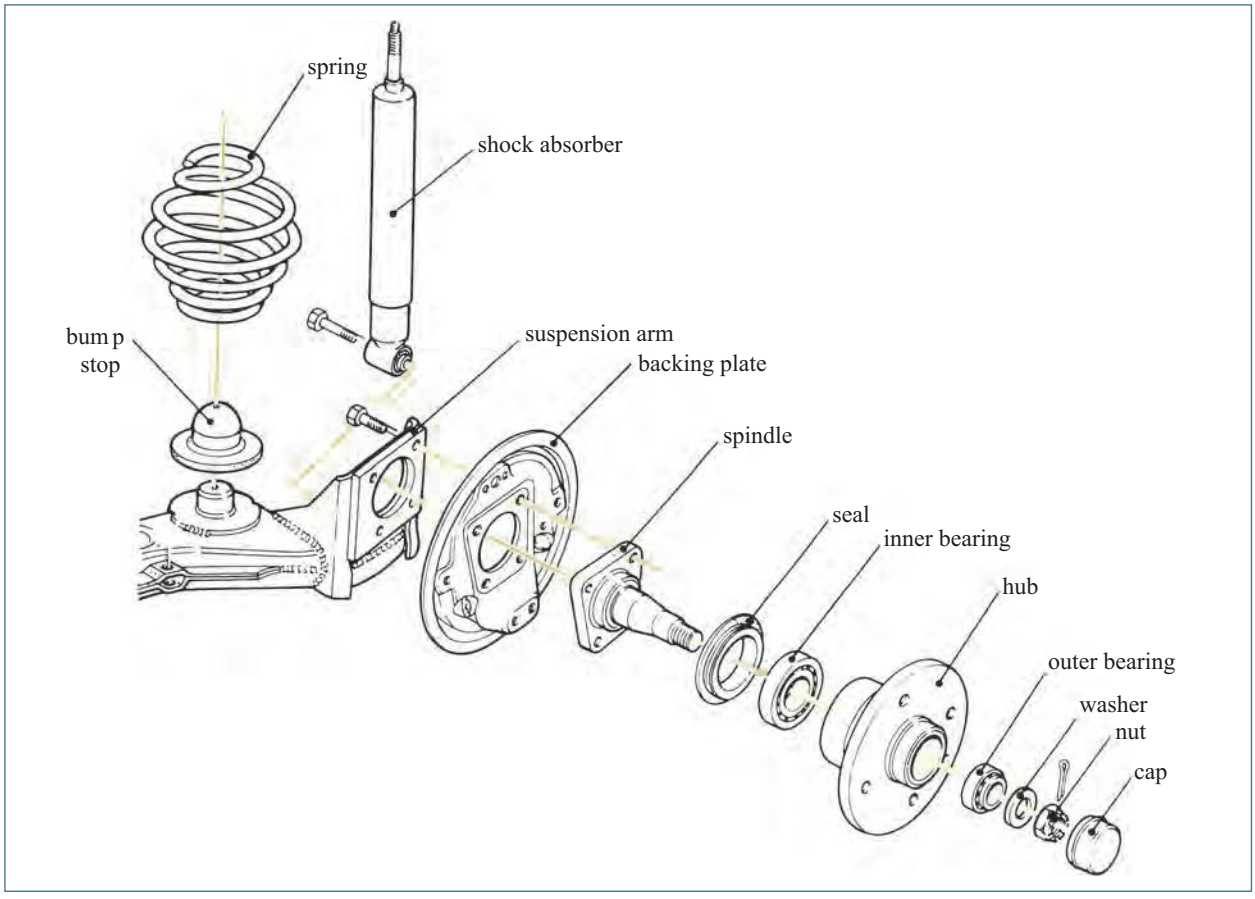


Figure 12.53 Rear-wheel assembly with tapered roller bearings (fron t-wheel-drive vehicle) GM HOLDEN LTD

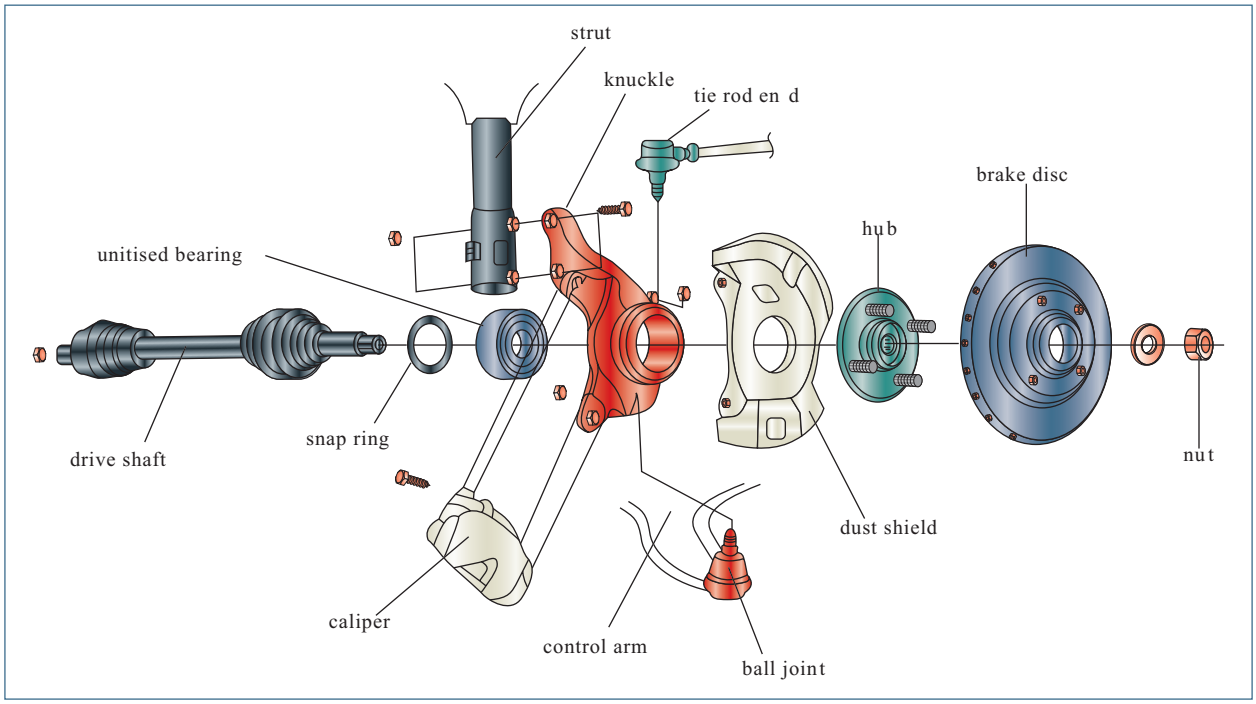


Figure 12.54 Front suspension and drive components of a front-w heel-drive vehicle

12.25.3 IRS with rear-wheel drive

Figure 12.55 shows the arrangement of a rear-wheel hub assembly with a unitised bearing. This assembly is for a rear-wheel-drive vehicle with independent rear suspension (IRS). The unitised bearing fits into the trunnion housing and is retained by a snap ring. The trunnion shaft fits through the bearing and is splined to

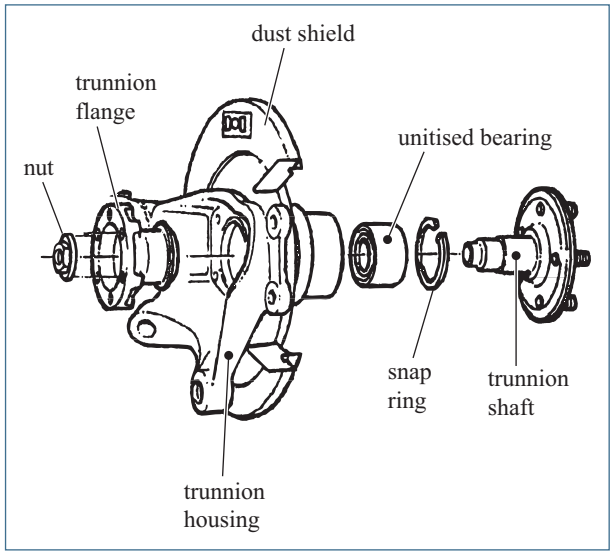


Figure 12.55 Rear-wheel hub assembly for an IRS (rear-wheel-drive vehicle)—it has a unitised bearing
GM HOLDEN LTD

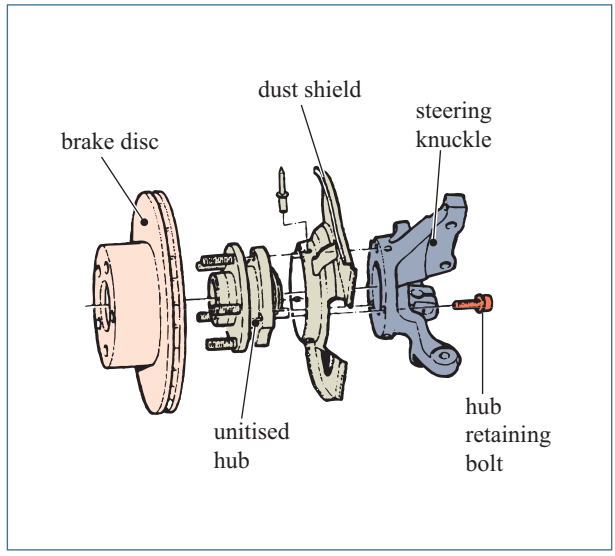


Figure 12.56 Unitised wheel hub for the front wheel of a rear-wheel-drive vehicle GM HOLDEN LTD

the trunnion flange. When assembled, the parts are held together by a nut that is threaded on to the end of the trunnion shaft.

12.25.4 Unitised hub assembly

Some hubs are designed as a unit, with the bearing being lubricated and sealed within the unit. They cannot be dismantled, require no lubrication and there is no service adjustment. Figure 12.56 shows one design of this type of hub and its associated components. This is used on the front suspension of a rear-wheel-drive vehicle.

The hub consists of three parts: the inner hub, the outer hub and the bearings between the two parts. The inner hub includes the flange with the wheel studs. The outer hub is bolted to the steering knuckle. If the bearing should become unserviceable, the hub can be unbolted from the steering knuckle and a replacement hub fitted.

12.26 Servicing shock absorbers

Shock absorbers must be fitted correctly. There are a number of different types of mountings, two of which are shown in Figure 12.57.

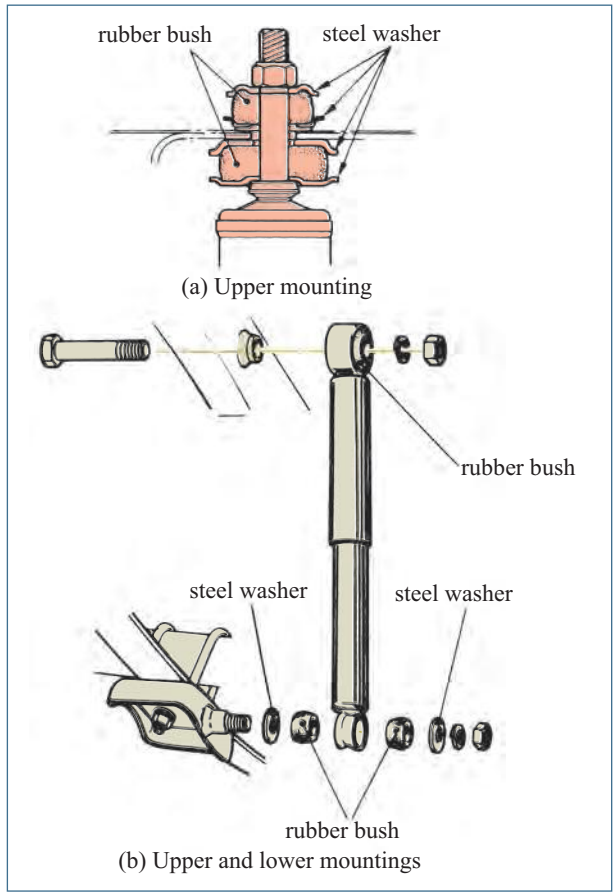


Figure 12.57 Shock absorber mountings

1 Upper mounting. Where the mounting bolt passes through the crossmember or body as shown in Figure 12.57(a), the washers and rubber bushes must be installed correctly to prevent rattles and squeaks. The cup-shaped washers centre the bolt in the hole and also act as retainers for the rubber bushes.
2 Eye mounting. Where the shock absorber has an eye mounting, as shown in Figure 12.57(b), the rubber bushes must extend on each side of the eye so that metal-to-metal contact between the shock absorber and its mounting brack et is prevented.

Handy hint: With all types of mountings, the rubber bushes must be installed so that they act as insulators between the shock absorber and the body or suspension.

12.26.1 Checking shock absorbers

Shock absorbers can be checked for leaks, for looseness of mountings and also for operation. Bounce each side of the vehicle in turn (front and rear). If the shock absorbers are in good condition, the vehicle will resist and will settle as soon as pushing stops. If the shock absorbers are poor, the vehicle will be easy to bounce and will not settle quickly.

On a road check, indications of poor shock-absorber operation are:

1 The vehicle bounces ex cessively .
2 The vehicle continues to bounce and will not settle after passing over bumps.
3 The vehicle does not corner well, but leans.
4 The front end of the vehicle dips ex cessively when braking.

Handy hint: These checks apply to the shock absorbers of struts as well as to individual shock absorbers.

Figure 12.58 Checking shock absorber operation by compressing and expanding

Bench test

With a shock absorber removed from the vehicle, it can be checked for resistance by holding it in its normal position and extending and compressing it fully (Figure 12.58). If the resistance is uniform for the full length, the shock absorber is satisfactory. If it has resistance at the start and then extends freely, the fluid might be low or the valve faulty. Any air trapped in the inner cylinder of the shock absorber can be expelled by extending and compressing the shock absorber a number of times. Resistance indicates that air has been removed.

12.27 Checking suspension parts

Table 12.1 is a guide to possible suspension problems, including possible causes.

12.27.1 Checking ball joints

A ball joint consists of a body, a ball stud and a ball seat. Some ball joints have a spring or moulded rubber ring which holds the ball against its seat; others have a moulded seat. These give the ball preload. Some ball joints are not preloaded because they are used in a location where the weight of the vehicle or spring will naturally hold the ball on its seat.

To check a ball joint for wear, the suspension must be supported so that the ball joint has no load. The jacking point will depend on the type of suspension. With the load removed from the ball joint, grasp the wheel and rock it to check for free play. Check for radial movement of the ball (in and out) and for axial movement of the ball (up and down).

With strut-type suspensions, the ball joint should have no free play and, if loose, will have to be replaced. With ball joint suspension, some balls are preloaded and others are not. Make sure that any movement found is actually in the ball joint and not in the wheel bearing or some other part of the suspension.

Table 12.1 Suspension problem guide

Problem	Possible cause
Squeaks	Spring mountings Lack of lubricant Worn bushes in control arms Leaf spring insulators worn or damaged Shock absorber mountings worn
Rattles	Worn or loose shock absorber mountings Stabiliser bar mountings worn or loose Stabiliser bar bushes worn Ball joints worn and loose Control arm bushes worn
Vibration	Tyre pressures high Wheel out of balance Shock absorber inoperative
Other noises	Lack of lubrication Loose wheel nuts Loose or faulty wheel bearings Tyre noises
Worn tyres	Misaligned suspension Bushes worn in control arms or other suspension parts Inoperative shock absorbers Damaged or bent suspension parts
Vehicle bounces	Shock absorbers weak or inoperative Spring weak
Vehicle steering	Tyre pressure low on one side Sagged spring Incorrect wheel alignment Bent steering or suspension part Worn or loose bearing

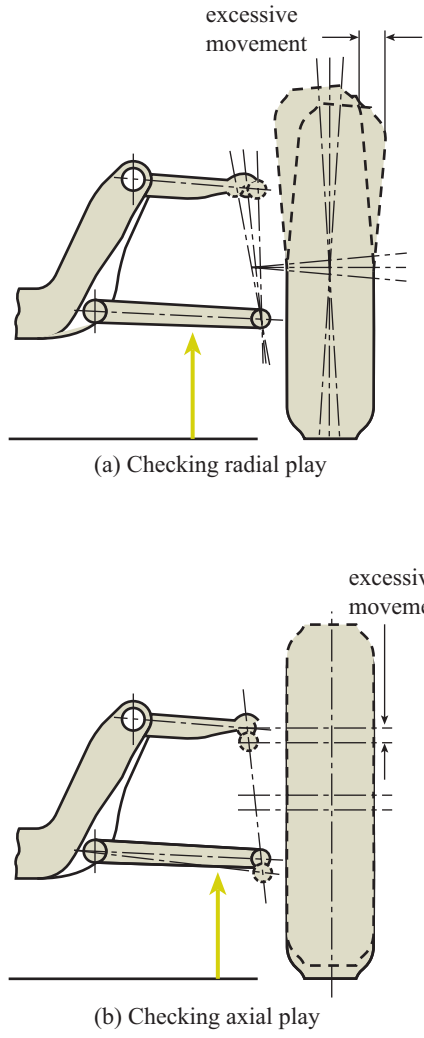


Figure 12.59 Checking the condition of suspension ball joints

Handy hint: When checking a ball joint, ascertain whether or not it has preload—otherwise, normal looseness could be mistaken for wear.

Check with ball joints installed

Figure 12.59 shows how to check a ball joint suspension. A jack is placed under either the crossmember or the lower control arm to raise the wheel. To check the ball joints of a suspension of the type shown in Figure 12.34, the jack is placed under the lower control arm to raise the wheel. This lets the wheel hang and relieves the load on the ball joints. Both radial play and axial play of the balls can be checked.

Where the suspension has its coil spring mounted on top of the upper control arm, the jack would be placed under the crossmember to raise the wheel. This allows the wheel to hang down and relieve the load on the ball joints.

With strut-type suspension, the wheel would need to hang so that the load on the ball joint is relieved. The vehicle would be supported at the body jacking points or possibly under a cross-member. An appropriate place would need to be selected to suit the particular suspension arrangement.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe the suspension system 's provision of steering stability , handling and comfort
- apply the correct procedures for inspecting, removing, diagnosing and repairing a vehicle 's suspension system
- explain the impact of worn suspension components on vehicle stability , driver control and other suspension system components.

REVIEW QUESTIONS

1 What is meant by sprung mass and unsprung mass ?
2 Name the three main types of springs.
3 Name the parts of a leaf spring.
4 Name the various parts of a leaf-spring suspension.
5 What is meant by torque reaction of the rear-axle housing ?
6 What is the main difference between a front and a rear suspension ?
7 What is meant by deflection rate ?
8 What is meant by lateral and longitudinal , as far as suspension is concerned?
9 What are control arms ?
10 What is strut suspension ?
11 What is the purpose of a stabiliser bar?
12 What are trailing arms ?
13 What is a Watts link ?
14 Name the main parts of an independent suspension for a rear-wheel-drive vehicle .
15 Name the main parts of a suspension for a front-wheel-drive vehicle .
16 What is a torsion rear axle ?
17 What is torsion bar suspension ?
18 Why are shock absorbers fitted?
19 What is a variable shock absorber ?
20 Why must a vehicle be correctly supported when working on a suspension ?
21 How would a coil spring be compressed on a strut-type suspension ?
22 Why is final tightening of suspension parts usually done with the wheels on the floor?
23 Name some of the different types of hub and wheel bearings.
24 How can suspension ball joints be check ed for wear when removed from the vehicle ?
25 What are some of the possible causes of rattles in a suspension system ?
26 What parts of a suspension system could produce squeaks ?
27 What are the indications of faulty shock absorbers ?
28 How can shock absorbers be check ed?
29 What is electronically controlled suspension ?
30 When diagnosing an electronically controlled suspension systems fault , what specialised tool will you need to use?

CHAPTER 13

Steering systems

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify steering system components, including type, function, operation and location
2 state safety procedures and requirements to safely carry out steering system service and maintenance
3 diagnose and repair steering system components and systems in accordance with workplace and manufacturers' requirements and specifications.

For a vehicle to be steered, the front wheel spindles (with their hubs and wheels) are turned in the direction of travel. This arrangement, where the centre part of the axle or suspension is fixed and the outer parts pivot, is known as the Ackermann principle of steering. It is the basis of all motor vehicle steering systems. Steering systems on passenger vehicles generally require no periodic lubrication, although worm-type steering boxes do require a lubricant check. Most ball joints are lubricated and sealed during manufacture and normally do not have to be lubricated in service.

Some light commercial vehicles with ball-joint suspension have grease nipples on the tie-rod ball joints; others have plugs that can be removed so that grease nipples can be fitted and the ball joints lubricated with a grease gun. Vehicles with power steering require a check of the oil level at normal service periods.

13.1 Steering systems

The main parts of a steering system are:

- steering column assembly with a steering wheel.
- steering box with its gearing.
- linkage connecting the steering box to the front wheels.
- *front suspension parts. These are the ball joints or strut mountings that allow the steering knuckles to pivot.*

There are two basic types of steering systems: those with rack-and-pinion steering boxes and those with worm-type steering boxes. *Rack-and-pinion* and *worm* refer to the type of gearing in the steering box. Gearing is needed so that the driver can turn the steering wheel against the resistance of the wheels.

The linkage holds the front wheels parallel while the vehicle is moving straight ahead, turning the wheels through the correct angle when the vehicle is turning. When the vehicle is on a turn, the inside front wheel is turned a greater angle than the outside wheel, allowing each wheel to roll around the correct path without scuffing the tyres.

Figure 13.1 illustrates the position of the wheels on a turn. All four wheels roll about a central point, but each follows a different arc. The difference in the angles of the front wheels is designed into the steering system.

Four-wheel steering (or all-wheel steering) offers tighter turning circles and improved agility when cornering, as well as greater stability at speed. Rear-wheel steering systems supplement what the driver is doing with the steering wheel by turning the rear wheels in the opposite direction to the front wheels at low speed, before switching them to the same direction as the front wheels at highway speeds (Figure 13.2).

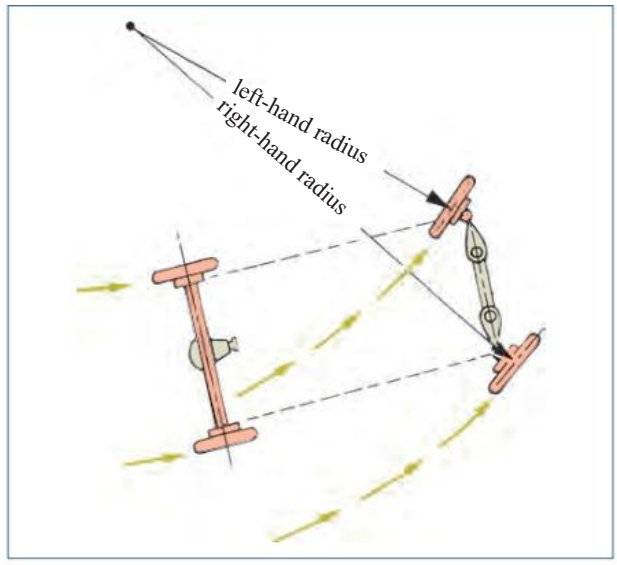


Figure 13.1 Path of the wheels on a turn—the inner front wheel pivots through a greater angle than the outer front wheel GM HOLDEN LTD

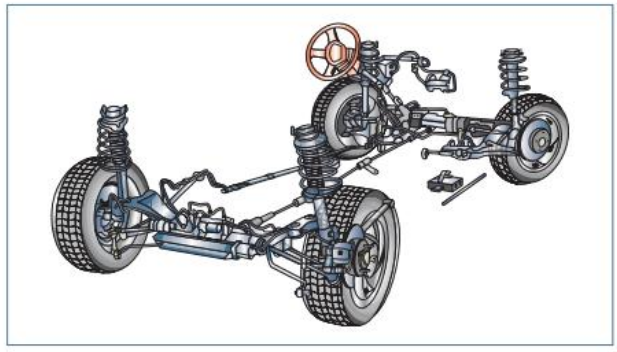


Figure 13.2 Four-wheel steering mechanism

13.2 Rack-and-pinion steering systems

Figure 13.3 shows a rack-and-pinion steering system which consists of the following parts:

- steering wheel
- steering column
- mainshaft
- intermediate shaft and universal joints
- steering box
- tie rods and ball joints
- steering arms.

The steering wheel is attached to the mainshaft, which fits inside the steering column. Steering movement is transferred through the mainshaft and intermediate shaft to the steering box. When the steering wheel is turned, rotary movement is transferred by the shafts to the pinion in the steering box. The pinion teeth are meshed with the teeth of the rack, so pinion rotation moves the rack from side to side.

The ends of the rack are connected to the steering arms by the tie rods, so rack movement pivots the knuckles and turns the wheels at an angle for steering. Ball joints at each end of the tie rods facilitate steering and suspension movement.

There are four mounting locations for the steering assembly: the mainshaft and the steering column are supported by a mounting at the dash and by a lower mounting to the body. The rack-and-pinion assembly has two mountings to the body.

Rack-and-pinion steering is used on many passenger vehicles. It is direct acting and so has fewer linkage parts than other systems. The intermediate shaft and universal joints allow the steering box to be mounted centrally on the body of the vehicle.

13.3 Steering systems with worm gearing

Steering systems like the one in Figure 13.4 have a worm-type steering box. This provides a gear reduction and a 90° change in direction of movement. The steering box has a pitman arm, which is connected by linkage to the idler arm and to the wheels. The various arrangements of linkages are as follows.

13.3.1 For independent front suspension

Figure 13.4 shows a typical steering system for independent suspension. Its steering parts are:

1 Pitman arm. Attached to the sector shaft in the steering box, it moves from side to side when the steering wheel is turned.
2 Idler arm. Mounted to the subframe, this moves with the pitman arm, to which it is parallel.

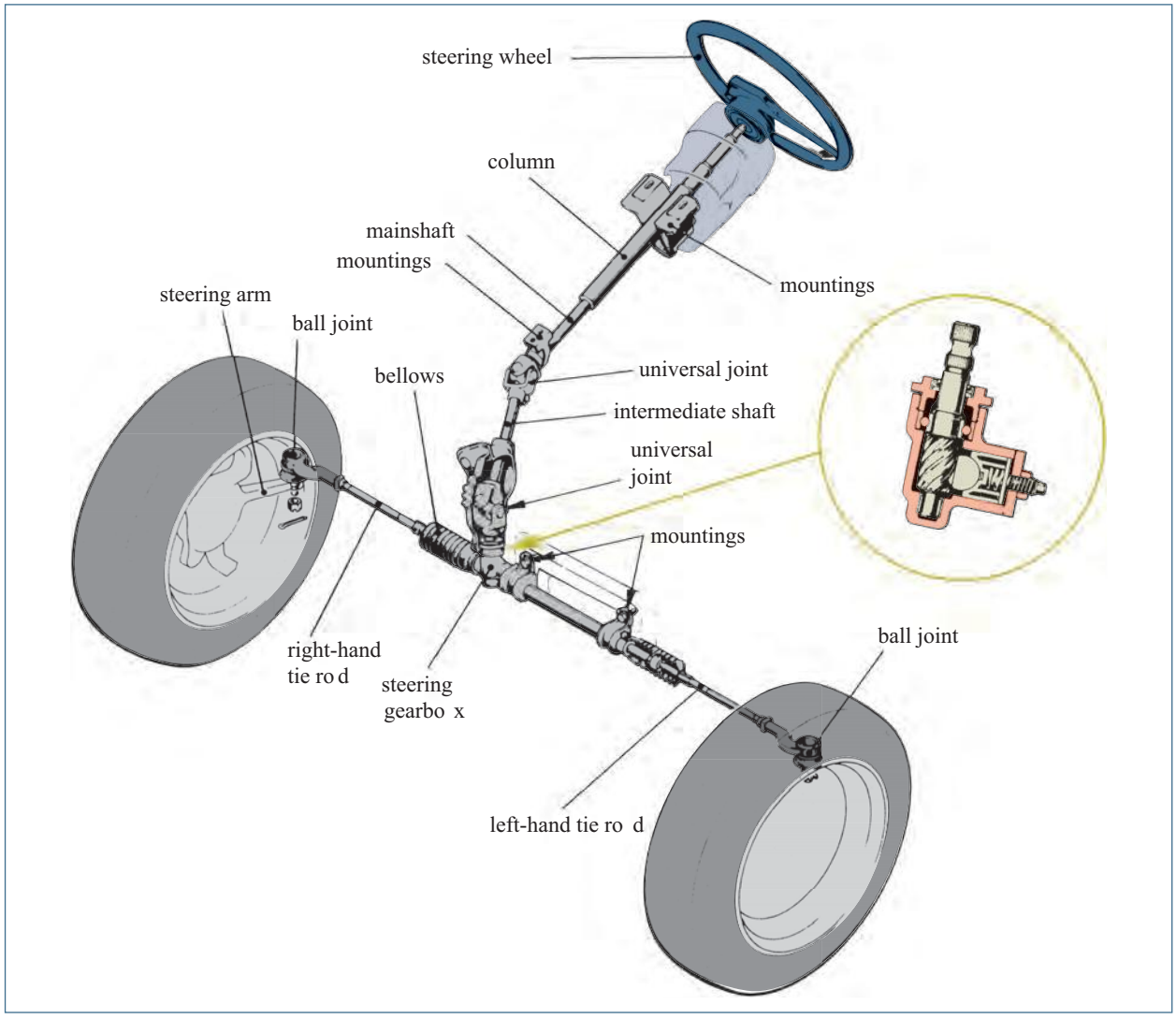


Figure 13.3 Rack-and-pinion steering system FORD

3 Track rod. Connects the pitman arm to the idler arm and relays movement from one to the other .
4 Tie rods. Connecting the track rod to the steering arms on the steering knuckles, they transfer movement of the pitman arm to turn the wheels.
5 Ball joints. Located on the ends of the track rod and tie rods, they facilitate steering and suspension movement.

13.3.2 For a forward-control vehicle

Figure 13.5 shows an arrangement for a van where the steering system is mounted in front of the engine and wheels. The steering box is mounted to the front of the subframe with the pitman arm vertical. A drag link connects the pitman arm to the relay lever. The relay lever has two arms; one is connected to the drag link, and the other is connected by the track

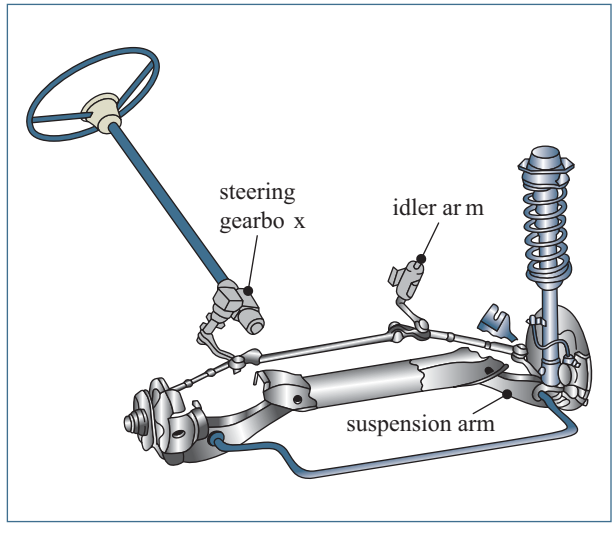


Figure 13.4 Steering arrangement for an independent front suspension

rod to the idler arm. Tie rods connect the track rod to the steering knuckles. Ball joints are fitted at all the connections.

13.3.3 For a four-wheel-drive vehicle

Figure 13.6 illustrates one type of steering arrangement for a four-wheel-drive vehicle. The steering knuckles are mounted on large ball joints on the ends of the front-axle housing so that they can pivot for steering purposes. The steering box is offset from the steering column, so two universal joints and an intermediate steering shaft are used.

In this arrangement, a hydraulic damper, similar to a shock absorber, is fitted between the track rod and the subframe. This prevents shocks from being transmitted through the linkage to the driver.

The drag link is connected between the pitman arm and an arm on the front of the left-hand knuckle. The track rod is connected between the steering arms on the knuckles, and this transfers movement from one knuckle to the other.

Handy hint: There are a number of different arrangements of suspension and steering systems for four-wheel-drive vehicles.

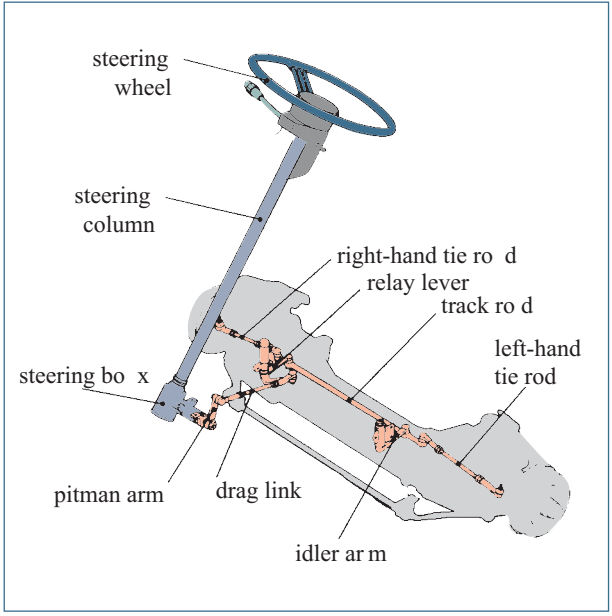


Figure 13.5 Steering system for a van with forward controls

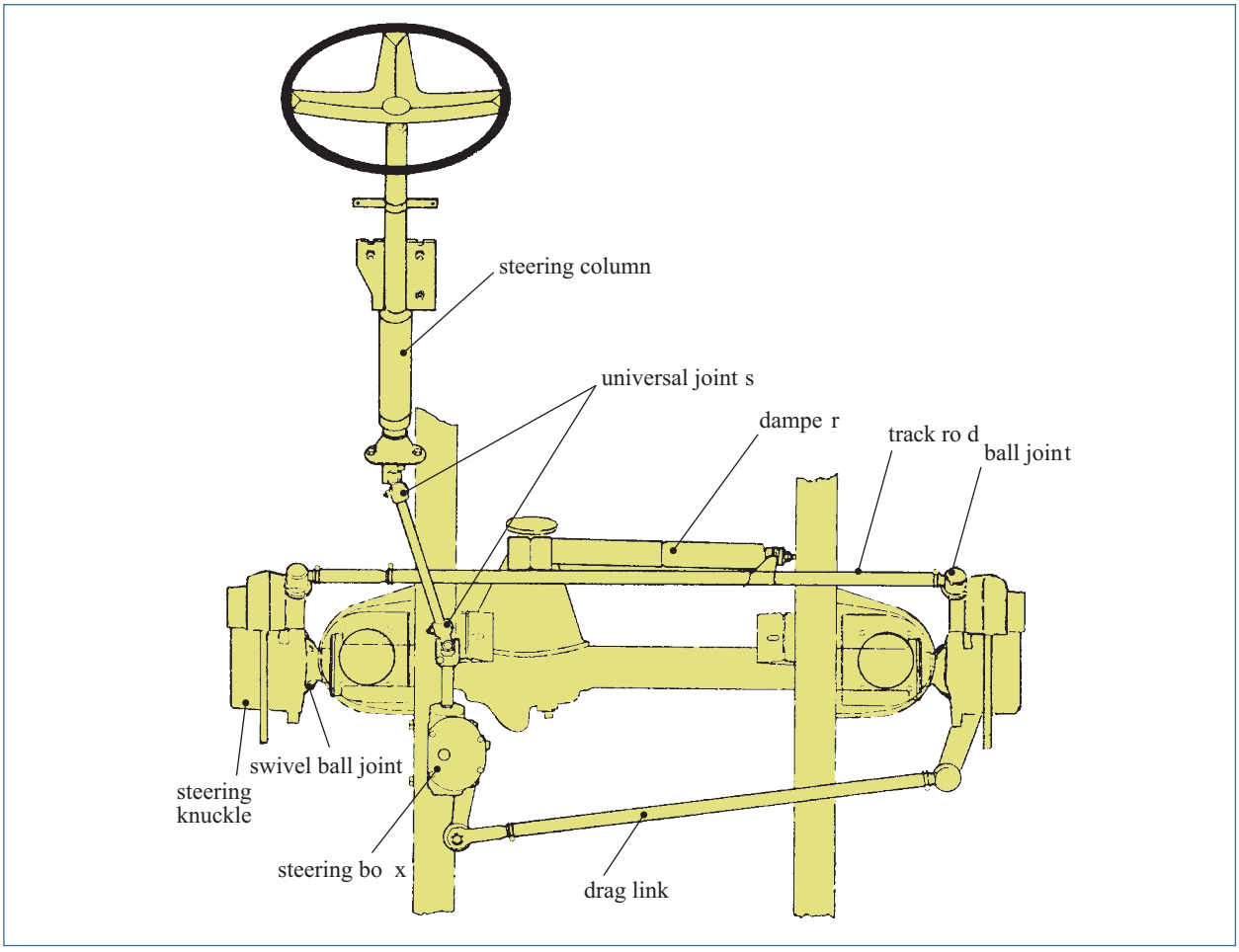


Figure 13.6 Front-axle assembly and steering arrangement for a four-wheel-drive vehicle

13.4 Steering wheels and columns

The steering column assembly transmits steering wheel movement through the steering shaft to the steering box. Functions of the steering column include:

- steering and ignition lock
- tilt and distance adjustment
- collapsible steering shaft and mounting brack ets
- steering wheel airbag
- lighting and wiper control
- cruise control
- audio control
- transmission control.

Figure 13.7 shows a steering-column assembly. It illustrates the following parts:

- steering wheel
- horn pad on the steering wheel
- combination switches for the headlamps, windscreen wipers and turn signals
- ignition switch and steering lock
- arrangement for tilting the steering wheel
- steering column
- intermediate shaft and universal joints.

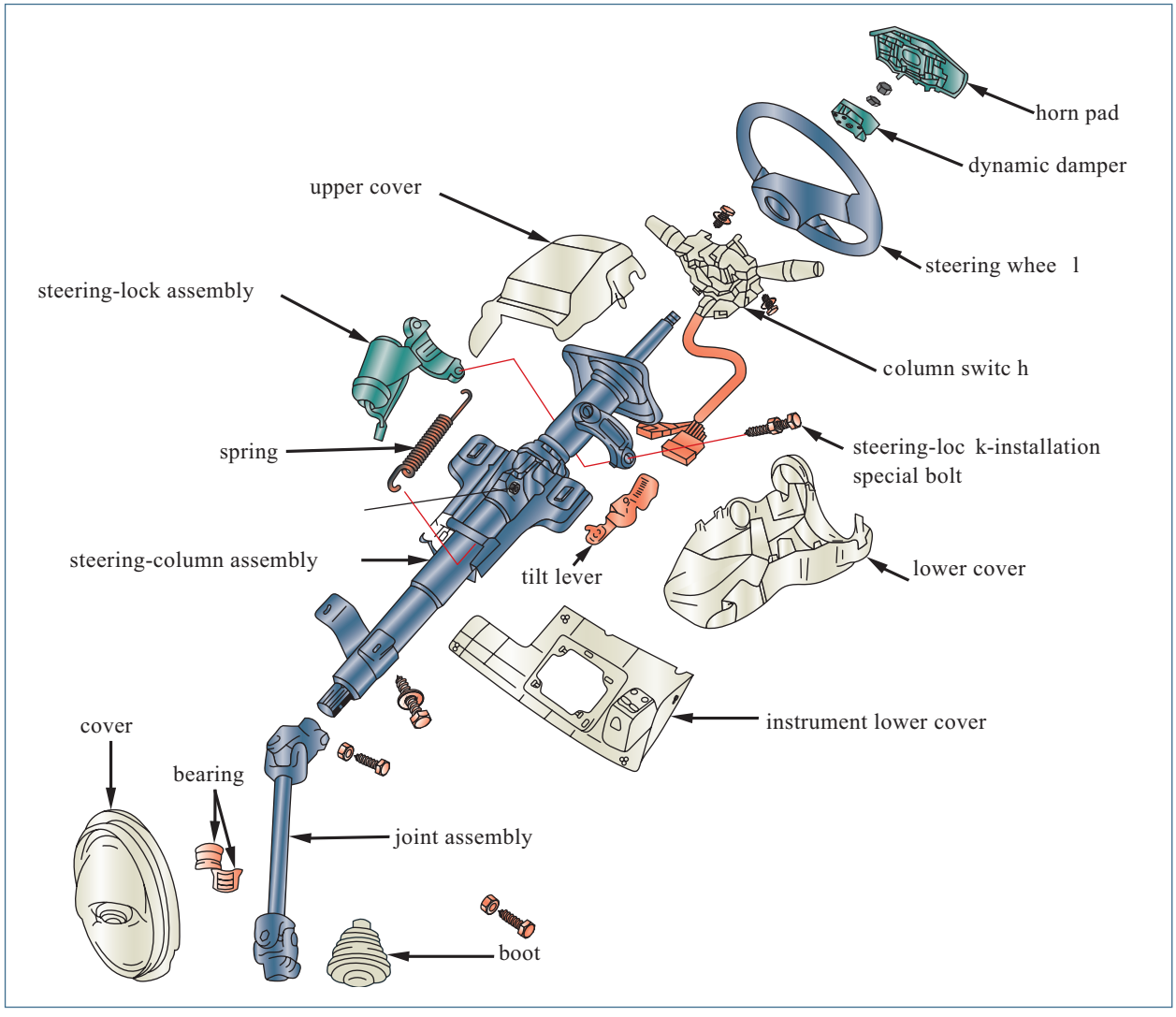


Figure 13.7 Parts of a steering-column assembly and associated components

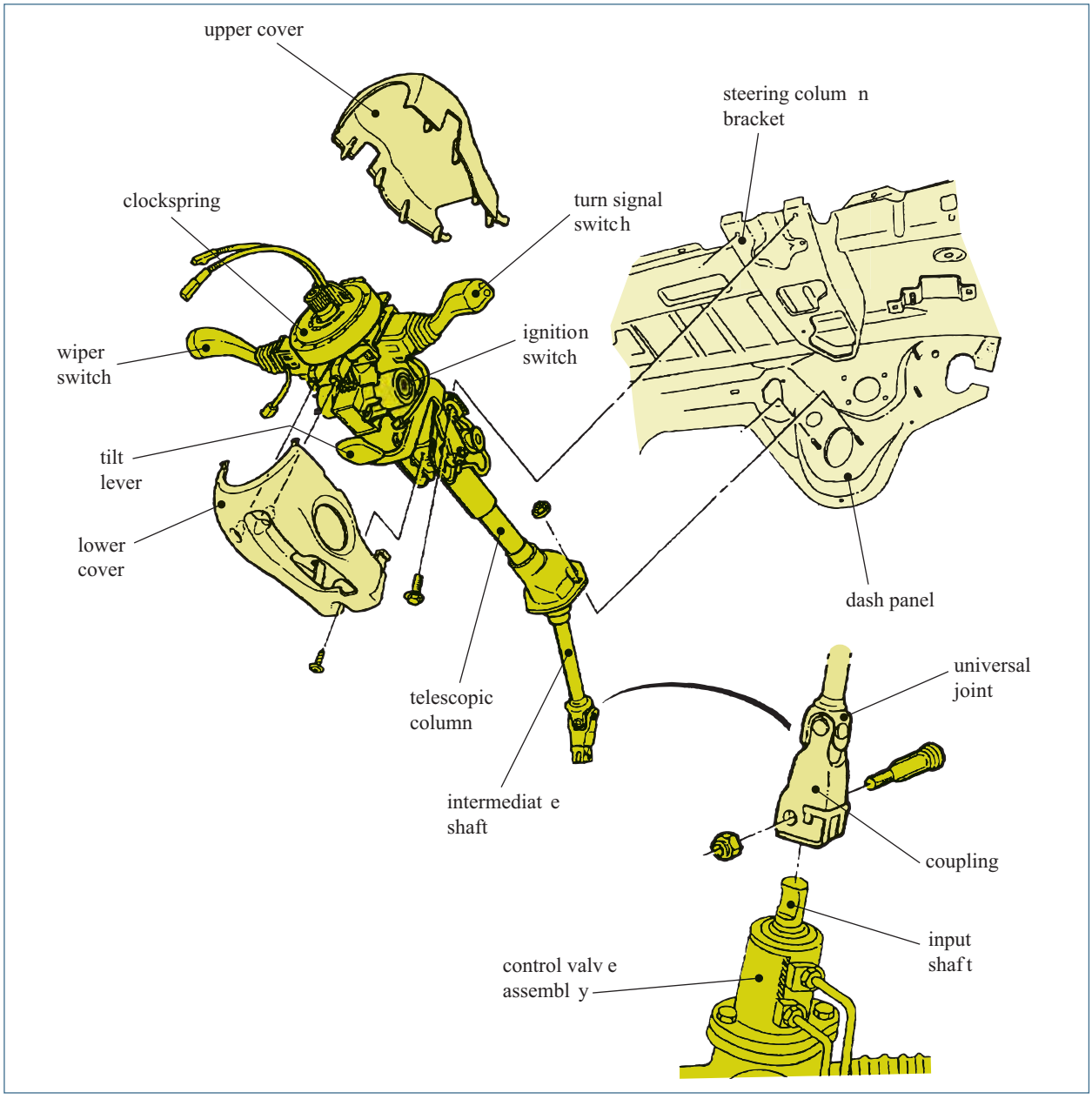


Figure 13.8 Steering-column assembly for a steering wheel with a n airbag GM HOLDEN LTD

The assembly is mounted to the body with two mountings. Plastic covers have to be removed to gain access to the upper mounting, the switches and other parts. (See also Figure 13.8.)

Steering column

Figure 13.8 shows a steering-column assembly with provision for a driver's airbag. This has a clockspring assembly at the top of the steering column which provides a flexible electrical connection. This device is like a large, coiled clock spring with connections for the airbag. The spring allows the steering wheel to be turned while it is still connected electrically to the wiring in the steering column.

Other identifiable features of this steering column are: its mounting to the dash; the electrical switches; the telescopic column and the coupling to the rotary valve of a rack-and-pinion power-steering assembly.

13.5 Steering boxes

A steering box is a small gearbox connected between the steering mainshaft and the linkage of the steering system. The gearing enables the front wheels to be turned easily from side to side, and prevents road shocks from being transmitted directly to the driver.

Gear ratios of steering boxes vary from about 12:1 up to about 18:1. With these ratios, the steering wheel is rotated about 2.5 turns up to 3.5 turns to pivot the front wheels from lock to lock.

There are two basic designs of steering boxes for passenger and light commercial vehicles—those with rack-and-pinion gearing and those with worm gearing. The rack-and-pinion and the recirculating-ball are the most common types.

13.5.1 Rack-and-pinion steering boxes

Figure 13.9 shows the dismantled parts of a rack-and-pinion steering box. The main parts are the housing, the toothed rack and the pinion. This is in mesh with the teeth of the rack, so its rotation moves the rack from side to side.

The pinion is carried by a ball bearing at its upper end and by a roller bearing in the housing at its lower end. The rack operates in bushes in the housing. A spring-loaded yoke supports the rack below the pinion, holding the rack in mesh with it to eliminate free play between the gear teeth. The spring loading on the yoke is adjustable by the threaded plug which screws into the housing.

The pinion preload of this particular steering box is adjustable by selective fit of the bearing snap ring. Other steering boxes may have threaded adjustments or shim adjustments. The inner ball joint is screwed to the end of the rack and is covered by the bellows which fits on the tie rod and over the end of the housing. Clamps at each end of the bellows retain it in place.

The ball joint on the outer end of the tie rod is threaded onto the tie rod, and this enables the tie rod to be adjusted for length. The housing is mounted to the body of the vehicle by two brackets (only one is shown).

Rack-and-pinion lubrication

Lubrication of the rack and pinion is via a semifluid grease or heavy-viscosity oil. This is transferred from side to side in the housing, to a certain extent, by rack movement. Where grease is used, rapid movement of the wheels from lock to lock with the wheels off the ground could create a pressure which would damage the bellows or force it off the housing.

13.5.2 Variable-ratio gearing

Many rack-and-pinion steering boxes have a rack with a variable gear ratio (Figure 13.10). This is achieved by changes in the shape of the teeth from the centre of the rack towards the ends. The teeth become closer

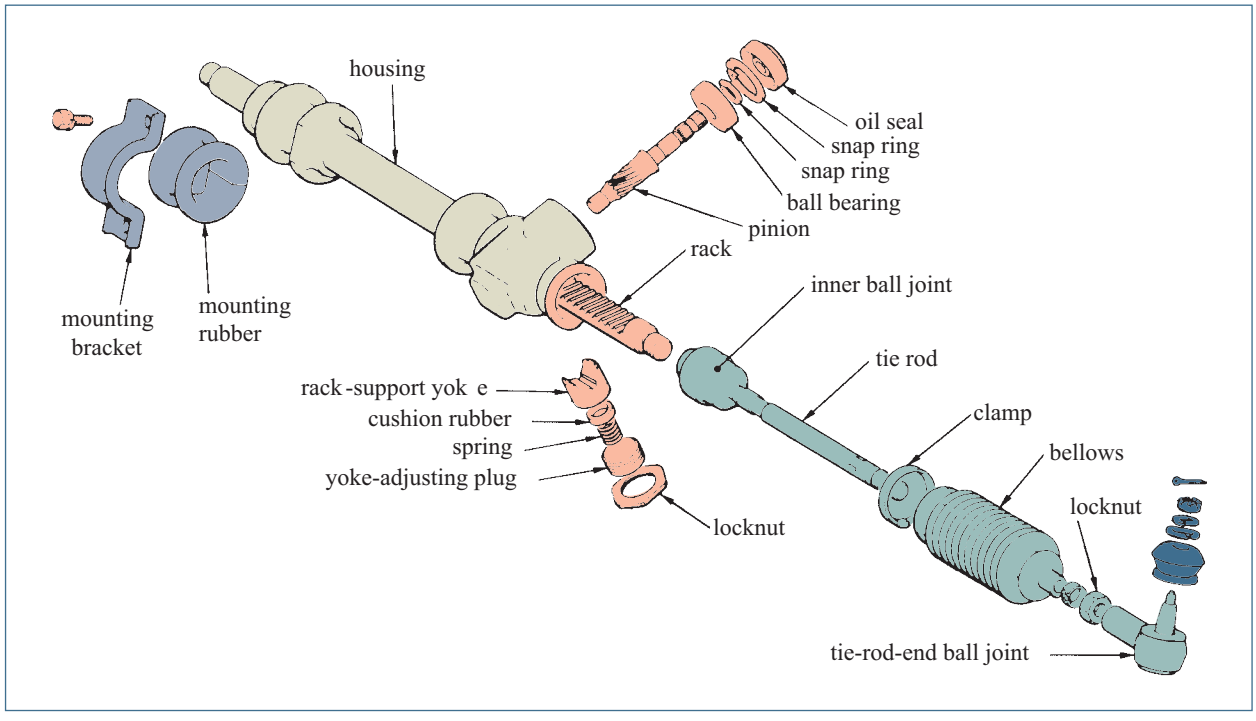


Figure 13.9 Rack-and-pinion steering-box components MITSUBISHI

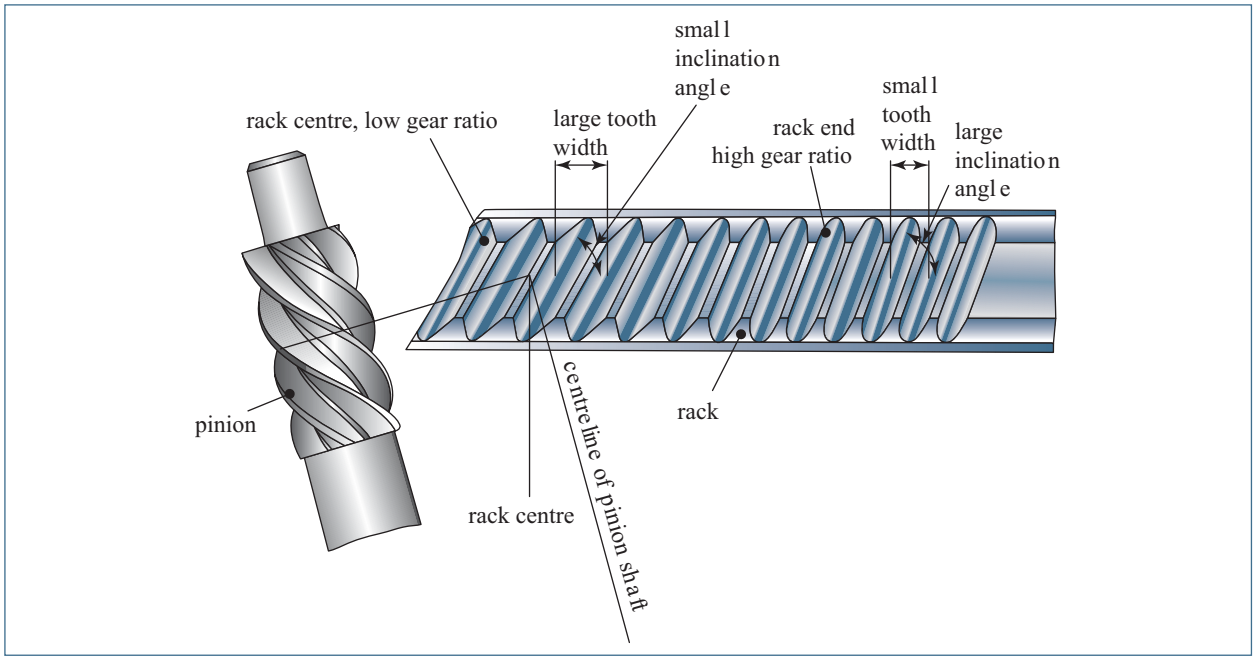


Figure 13.10 Rack-and-pinion with a variable gear ratio

together towards the ends of the rack, and this provides higher gearing when the wheels are turned towards full lock. This reduces the amount of steering wheel movement required when turning or parking the vehicle. As an example, a standard rack could require 3.5 turns of the steering wheel to turn the wheels from lock to lock, while an equivalent variable ratio rack could require only 2.7 turns.

13.6 Rack-and-pinion power steering

Figure 13.11 shows a rack-and-pinion power-steering system. It has the same mechanical parts as one that is not power assisted, and also a number of hydraulic parts. These are:

- oil pump and reservoir
- high-pressure line and hose
- return line and hose
- control valve assembly
- power cylinder .

13.6.1 Operating principle

The diagrams in Figure 13.12 show the basic operation of rack-and-pinion power steering. The pump produces hydraulic pressure; the flow-control valve controls the pressure; and the control valve directs pressure fluid to the piston which is attached to the rack. A simplified control valve is shown. It turns to open or close passages whenever the steering wheel is turned.

1 Steering straight ahead. In Figure 13.12(a), the control valve is in a neutral position. Fluid from the pump circulates through the flow-control valve , then through the control valve and back to the reservoir . There is oil on each side of the piston, but there is no pressure in the power cylinder and as a result, no power assistance .
2 Steering on a turn. In Figure 13.12(b), the steering wheel has been turned and so the control valve has also turned. The control valve now directs pressure oil to one side of the power cylinder and connects the other side to the return line .

   The oil on the pressure side of the piston assists rack movement, while oil displaced on the other side goes back to the reservoir through the return line .
3 Steering wheel held turned. When the steering wheel has been turned and held in position, the control valve will return to the neutral position. The pressure in the power cylinder will be relieved and there will be no power assistance .

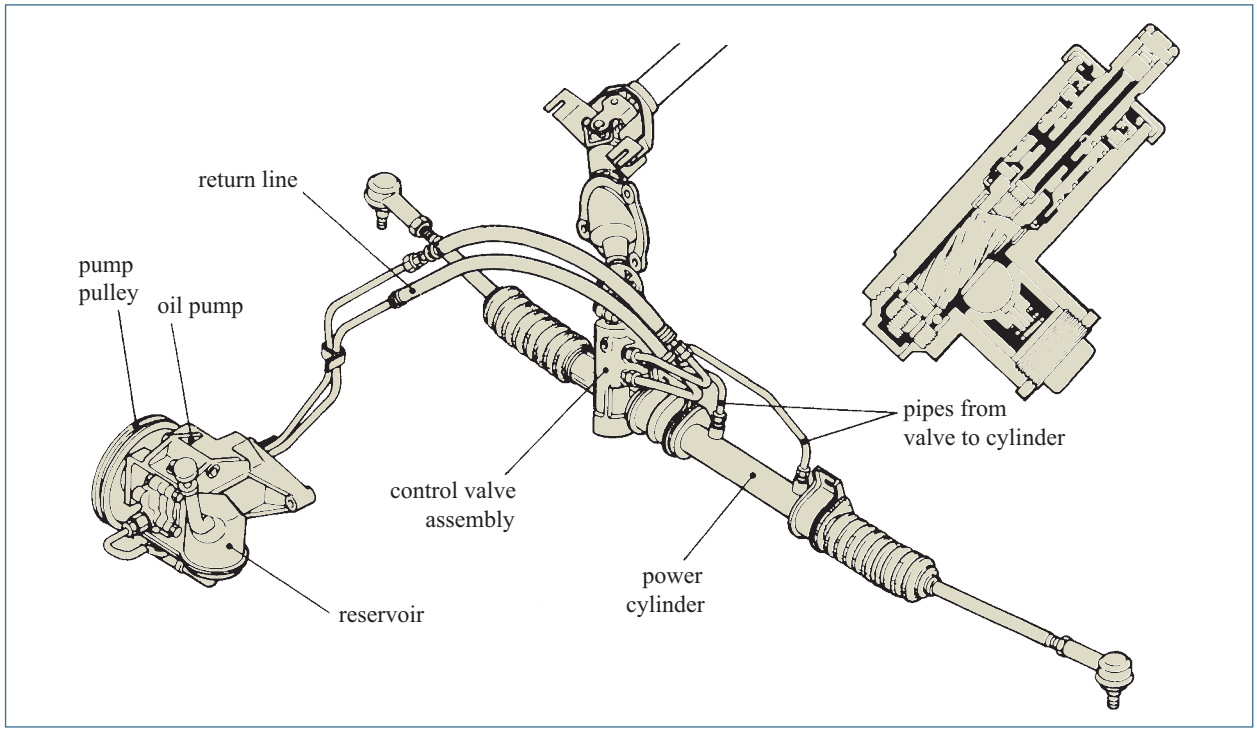


Figure 13.11 Rack-and-pinion power-steering assembly—a sectional view of the steering box is also shown FORD

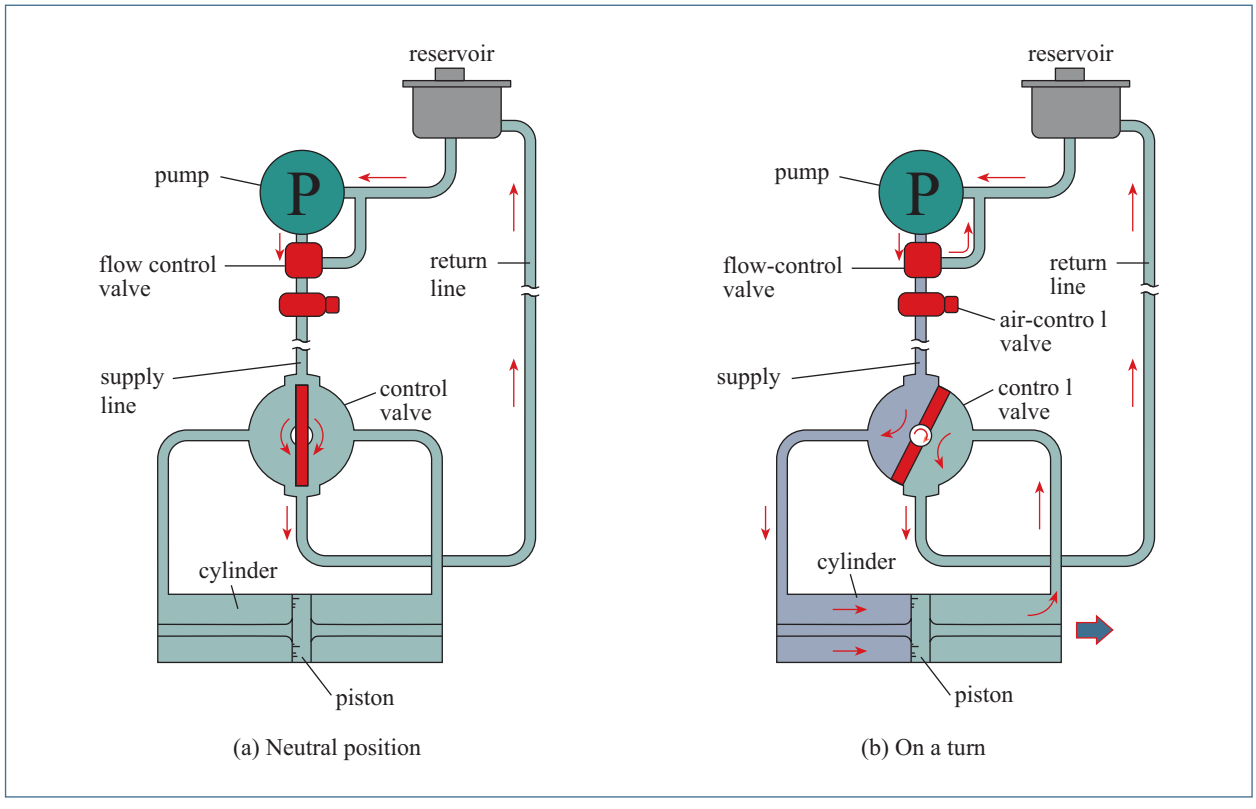


Figure 13.12 Rack-and-pinion power steering—principles of operation

Air-control valve

The air-control valve is a pressure-operated switch that increases the engine idle speed when the oil pump is under maximum load. This occurs when the steering wheel is turned to the full lock position. Oil pressure in the supply line operates the air-control valve switch to increase idle speed. It does this in an electronic fuel injection (EFI) system by allowing extra air to bypass the throttle valve.

Flow-control valve

The flow-control valve controls the flow of oil to the control valve by bypassing it to the pump intake. It also has a pressure-relief valve.

13.7 Rack-and-pinion power-steering components

13.7.1 Oil pump assembly

Vane oil pumps (Figure 13.13) are the most common type of power-steering pump. The rotor is in an oval- or elliptical-shaped housing, and vanes fitted to its outside diameter sit against the housing walls as it turns.

The *flow-control valve* controls oil flow by bypassing oil from the outlet side to the inlet side of the pump. This reduces oil flow in the system at higher speeds when the pump output would be much greater than required.

A *pressure-relief valve* is part of the flow-control valve. If the wheels are held on full lock, the pressure in the system quickly builds up. When a certain level is reached, the pressure-relief valve will be lifted off its seat to allow oil to pass, and so prevent the hydraulic system from developing excessive pressure.

13.7.2 Power cylinder

Figure 13.14 shows the power cylinder. It is formed in the steering-box housing, and the piston is attached to the rack. The control-valve assembly is located on top of the housing, and two tubes connect it to the cylinder, one to each side of the piston. The illustration shows oil under pressure being directed to the piston to force both it and the rack to the right to help the wheels to turn.

13.7.3 Control valve assembly

Figure 13.15 shows a sectional view of a steering box and control valve assembly. This has a rotary-type valve that directs oil flow to and from the power cylinder as the steering wheel is turned.

The control valve parts of the assembly are:

- torsion bar
- input shaft and the inner member of the valve
- valve housing
- valve sleeve
- pressure pipe from the oil pump
- oil-return line
- pipe to the power cylinder (right turn)
- pipe to the power cylinder (left turn).

The steering box parts of the assembly are:

- pinion
- rack
- yoke
- yoke adjuster .

Valve operation occurs when the inner member of the valve rotates slightly inside the valve sleeve. This opens appropriate ports between the two parts.

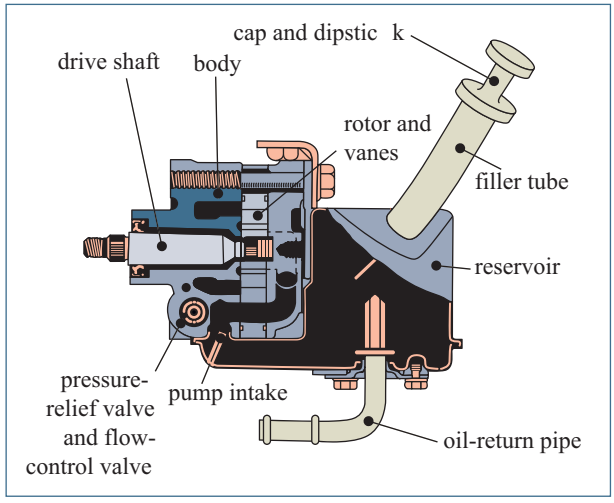


Figure 13.13 Vane-type power-steering pump

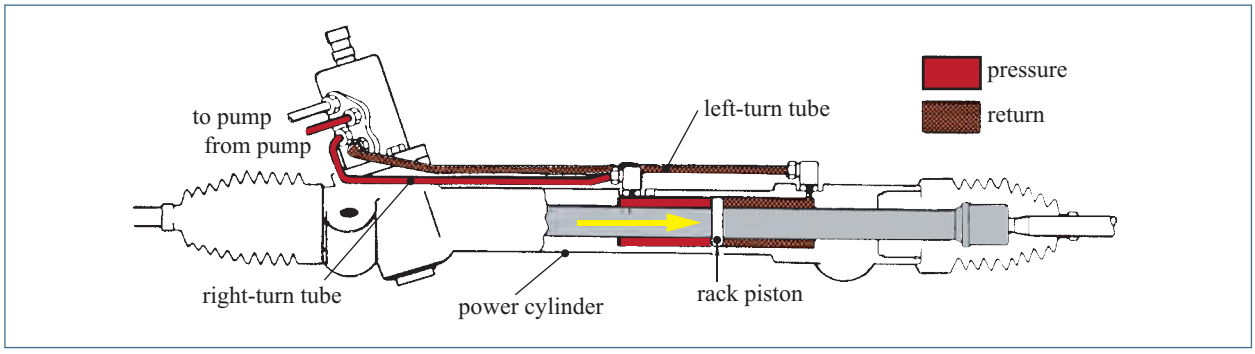


Figure 13.14 Power cylinder of a rack -and-pinion power steering GM HOLDEN LTD

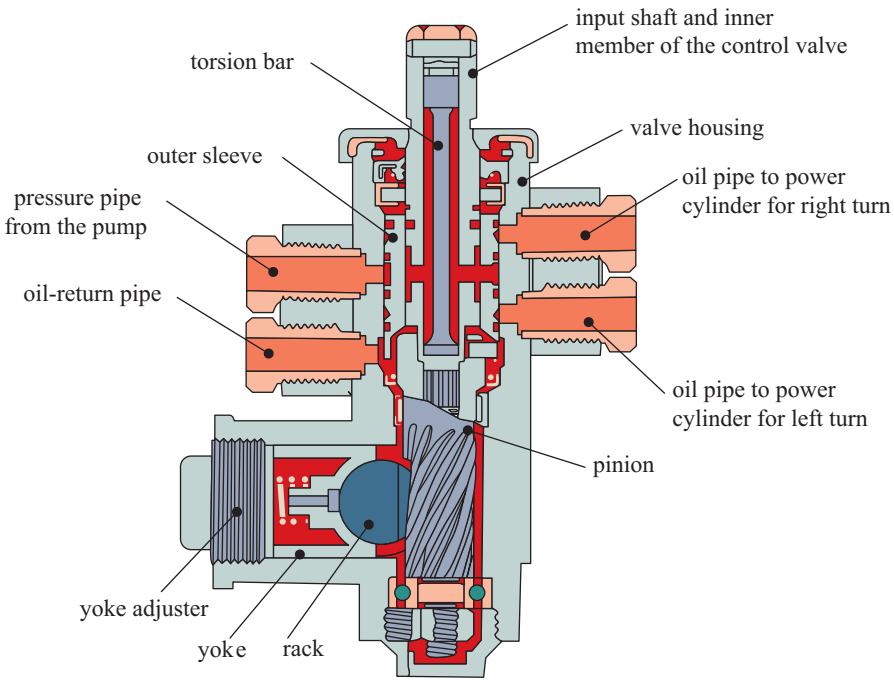


Figure 13.15 Rotary control-valve assembly of a rack -and-pinion power steering

Pressure oil from the pump is allowed to reach one side of the power cylinder, while oil from the other side is returned to the reservoir.

Valve operation

The inner member of the valve is attached to the input shaft and the outer sleeve is, in effect, attached to the pinion. Both parts turn when the steering wheel is turned, but the torsion bar twists a little under load and allows movement between the two parts to operate the valve.

Whenever the input shaft is turned, the torsion bar is twisted slightly as it turns the worm. Because the inner member of the valve is a part of the input shaft, and because the sleeve is attached to the worm, the sleeve always has a slight delay in response to steering-wheel movement. This causes ports in the valve to open and close.

The amount of twist of the torsion bar depends on steering conditions. For normal driving, where only light movements of the steering wheel are required, there is very little twist and therefore little valve operation or power assistance.

Under other conditions, such as when parking, a greater force is used on the steering wheel. This causes a much greater deflection of the torsion bar and greater movement of the inner member of the valve in relation to the sleeve; the valve ports open wider to provide a much greater flow of oil and more power assistance.

13.8 Speed-sensitive rack-and-pinion power steering

With power steering, most assistance is needed when parking, less when driving at lower speeds, and very little when driving at higher speeds. Speed-sensitive power steering modulates the oil pressure in the system so that it has more effect at low speeds than at high speeds. Active steering varies electronically how much the front wheels turn in relation to the steering input from the driver.

Figure 13.16 is a basic diagram of a speed-sensitive power-steering system. In addition to the normal hydraulic components, it has an electronic control unit and a solenoid valve. The solenoid valve is located in the supply line, where it can restrict the flow of oil to the power cylinder. This allows the pressure in the power cylinder to be varied, which means power assistance can be adjusted to suit different steering conditions.

The solenoid valve is controlled by the electronic control unit. At low speeds and when most power assistance is needed, the solenoid valve is opened to provide high pressure. At higher speeds, when power assistance is not needed, the valve is almost closed.

The ECU receives signals from three sensors: a vehicle-speed sensor, an engine-speed sensor and a steering-angle sensor. Determining how much power assistance is required, it sends signals to the solenoid, which is energised and de-energised to provide the right pressure to the power cylinder.

13.9 Electro-hydraulic power steering

Figure 13.17 shows an electro-hydraulic power-steering assembly. The main parts are:

- electro-hydraulic supply unit
- rack -and-pinion unit
- hydraulic lines
- wiring harness.

The rack-and-pinion assembly, with its control valve and power cylinder, is the same as those used in other power-steering systems, but the hydraulic pressure is provided by the electric motor and pump of the electro-hydraulic supply unit. This system is self-contained and operates independently of the engine.

13.9.1 Electro-hydraulic supply unit

The parts of the electro-hydraulic supply unit are shown in Figure 13.18. While the unit is shown dismantled, it is not repairable and has to be replaced as a unit if it becomes unserviceable. The parts and their functions are as follows:

1 Reservoir . To hold the fluid
2 Resonator . To reduce pulsations from the pump

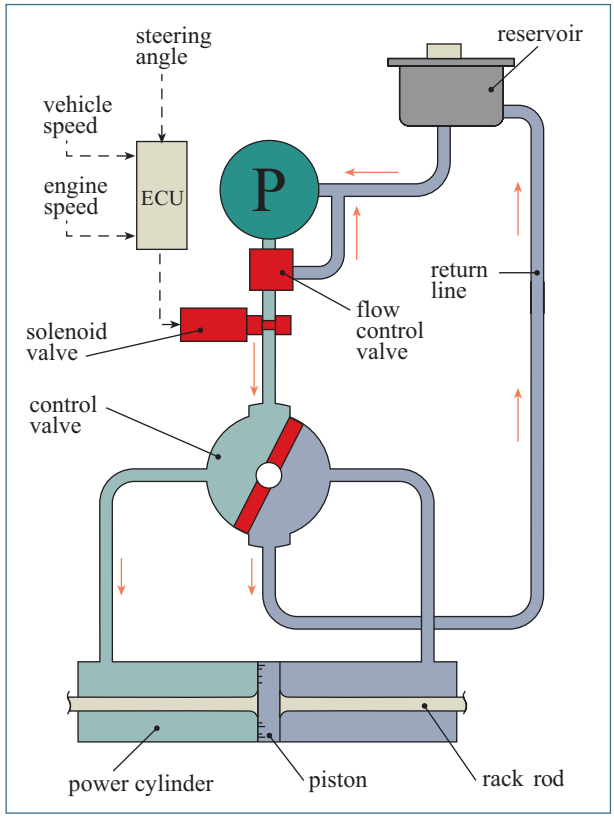


Figure 13.16 Speed-sensitive steering—principle of operation

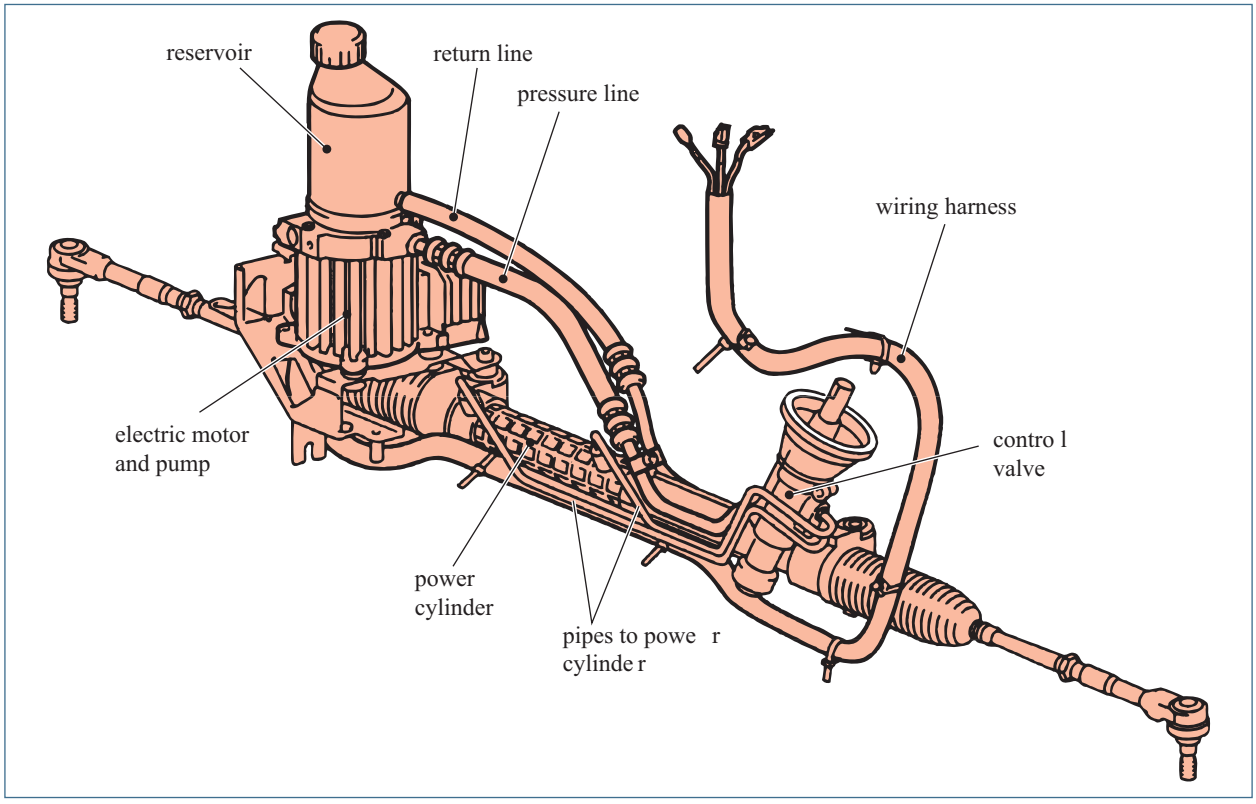


Figure 13.17 Electro-hydraulic power-steering assembly GM HOLDEN LTD

3 Pressure limiting valve . To limit maximum pump pressure
4 Pump assembly . This is a gear-type pump that provides hydraulic pressure
5 Electric motor . To drive the hydraulic pump
6 Motor housing . To enclose the electric motor
7 Electronic control . To control the motor operation.

Operation

The electro-hydraulic unit is connected to the rack-and-pinion assembly by a supply line and a return line. The electric motor operates the hydraulic pump continuously when the ignition is switched on. The system has two modes, standby mode and operational mode, and the electronic control switches between them as required:

1 Standby mode . In the standby mode , where power steering is not required, the motor runs at around 2200 rpm and draws a current of only a few amps. The motor operates the pump , but the flow-control valve in the electro-hydraulic unit is open so there is no pressure and no power assistance .
2 Operational mode . In the operational mode (when the steering wheel is being turned), the control valve on the rack -and-pinion assembly turns. This directs pressure fluid to the power cylinder and provides assisted steering. The motor speed is increased to appro ximately 3200 rpm, and the motor current also increases.

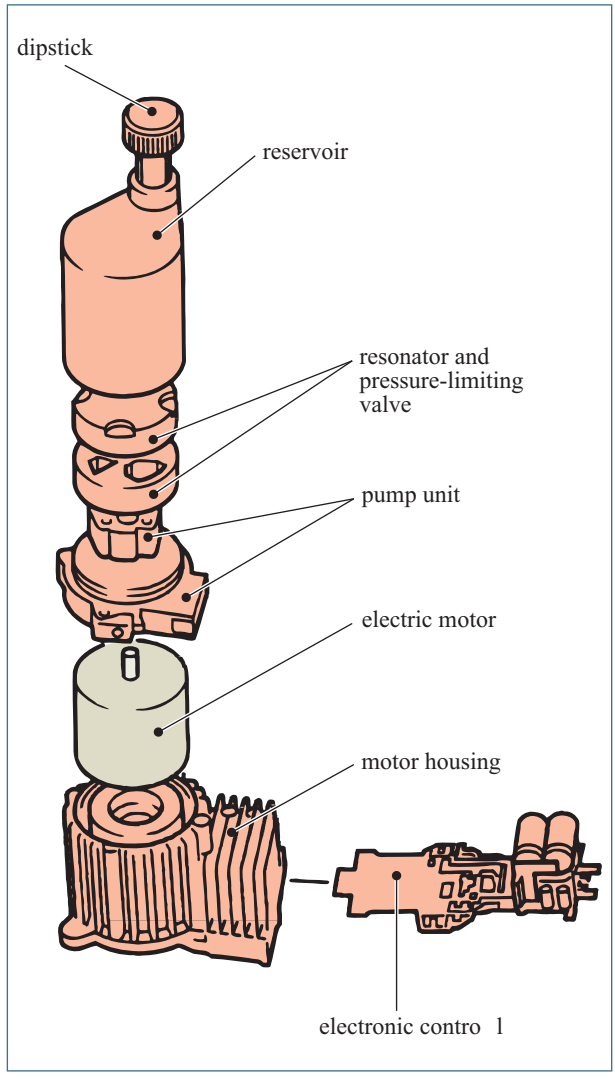


Figure 13.18 Electro-hydraulic power-steering components of the hydraulic supply unit GM HOLDEN LTD

Electronic control

The electronic control has two functions: motor management and control management. *Motor management* regulates the voltage at the motor and controls the motor speed. It also monitors the motor temperature. *Control management* switches between the standby mode and the operational mode.

The electronic control also has a safety function that continually monitors the system and can return it to normal operation if a possible malfunction is detected. If there is a fault with the power system, the steering system of the vehicle will remain operational but there will be no power assistance.

13.10 Electric power steering

Electric power steering uses an electric motor to provide power to assist steering. There is no power-steering pump or other hydraulics, so electric power steering provides a compact assembly and reduces the load on the engine. Figure 13.19 shows an electric power-steering assembly. Forming the upper section of the steering column and carrying the steering wheel, the assembly consists of:

- outer column and steering shaft
- torque sensor
- electric motor and worm gear .

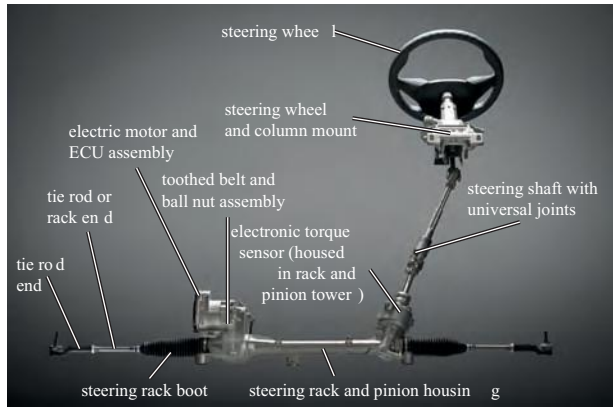


Figure 13.19 Electrical power -steering assembly TRW AUTOMOTIVE

There is also an electronic control unit. Steering assistance is provided by the electric motor, which applies torque to the steering shaft by means of worm gearing and a friction clutch.

When working on electric/electronic control power-steering systems, a scan tool can be used to view live data and check for possible faults, (Figure 13.20). Resistance, voltage drop and open or short circuits can cause a number of problems, so always refer to manufacturers' information for relevant information, specifications and testing procedures. Detailed information about live data, freeze-frame data and diagnostic trouble codes is provided in Chapter 8, Electrical systems.

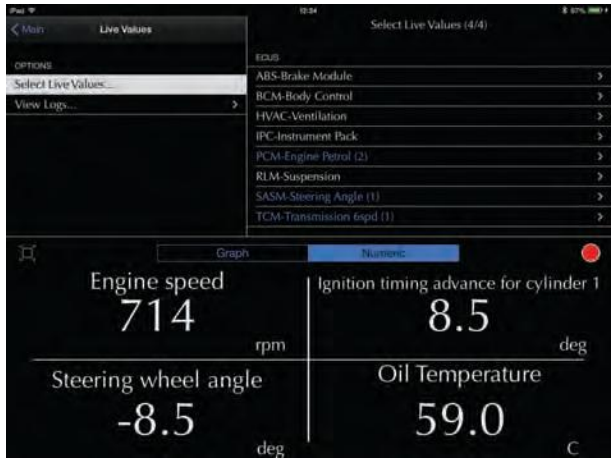


Figure 13.20 A scan tool showing steering information
GAP DIAGNOSTIC

13.10.1 Steer-by-wire

Some high-end vehicles have steer-by-wire technology, which means there is no physical connection between the steering wheel and the tyres. In fact, steer-by-wire systems do not technically require the use of a steering wheel. When a steering wheel is used, a type of steering-feel simulator gives the driver feedback.

13.10.2 Power operation

Power steering is monitored by the electronic control unit. This receives road-speed signals from the speedometer and engine-speed signals from the ECU. When the steering wheel is turned, the ECU also receives signals from the torque sensor which indicate the direction and degree of turn. It uses these signals to determine the torque needed to assist the driver to turn the steering wheel.

The torque will vary according to the road and engine speed, as well as the angle through which the wheels are being turned. The system is speed sensitive; during parking, the engine rpm is low, the road speed is almost zero and the turning angle is great. Under these conditions, the control unit will provide maximum steering assistance.

When driving at lower road speeds, there will be less assistance required than during parking, and this is adjusted by the control unit. At higher road speeds, very little assistance is needed and so the torque is reduced.

13.10.3 Fail-safe provision

An electric steering indicator light on the instrument panel lights up when the ignition is switched on and goes off once the engine starts. If there is a fault in the system, the indicator light will remain on as a warning. The ECU will be isolated and there will be no power assistance. The steering then acts as a manual system. The ECU has a self-diagnosis function and provides fault codes which can be accessed with suitable test equipment.

Safety: With fail-safe , the steering functions normally but the vehicle is heavier to steer .

13.10.4 Self-parking

Self-parking makes parallel parking easier. The driver still regulates the movement of the vehicle, using the automatic transmission selector lever and the brake. But once the parking process begins, the on-board computer system controls the steering.

The vehicle is driven into a position beside the car that is parked in front of the empty parking space; a signal tells the driver when to stop. The driver then selects reverse and releases the brake slightly to begin moving backwards. The computer turns the front wheels and steers the car into the parking space. When it has moved back far enough, another signal tells the driver to stop and shift into drive. The car moves forward and the front wheels adjust to manoeuvre it into the correct parking position.

13.11 Steering boxes with worm gearing

Figure 13.21 shows a worm-and-sector steering box. It has a housing that encloses the worm and a gear sector. The mainshaft, which carries the worm, is supported by bearings in the housing.

The sector is a portion of a gear with a number of teeth. It has its own shaft mounted in bearings or bushes in the housing at right angles to the worm. The outer end of the sector shaft (also referred to as a *pitman shaft* or a *cross-shaft*) is splined to take the pitman arm, which forms part of the steering linkage. Its operation is simple: the mainshaft and worm are turned by the steering wheel, and the worm turns the sector and its shaft.

Worm-and-nut is another basic type of worm steering box. The worm works in a large nut which is wound up and down in the steering box as the steering wheel is turned.

Handy hint: There are other types of steering boxes, but the principles of worm and sector and worm and nut have current applications.

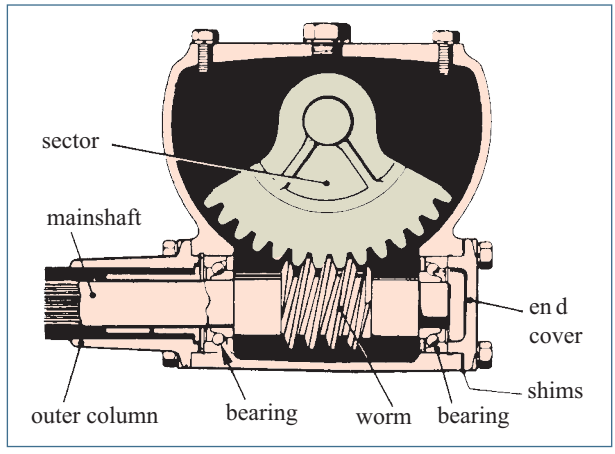


Figure 13.21 Basic arrangement of a worm-and-sector steering box

13.11.1 Recirculating-ball steering box

Figure 13.22 shows a recirculating-ball steering box that combines the principles of worm and nut and worm and sector. The mainshaft has a worm that carries a large square nut and the nut has teeth which are engaged with the teeth of a sector gear.

Friction is kept low by the use of steel balls between the worm and the nut. These run in the grooves in the worm and grooves in the nut. With this arrangement, the nut is virtually mounted on ball bearings on the worm.

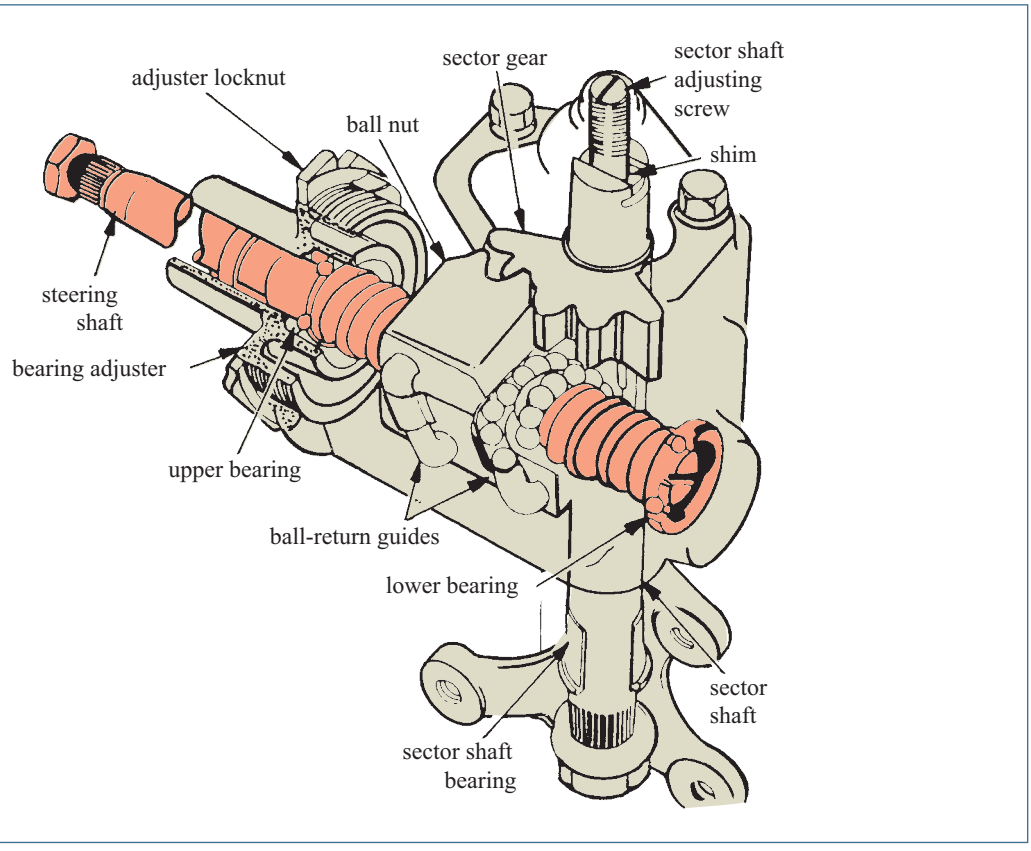


Figure 13.22 Components of a recirculating-ball steering box FORD

As the worm rotates, the steel balls are rolled along the grooves and the nut is moved up or down on the worm. The nut, being meshed with the sector gear, turns the sector shaft and so moves the pitman arm and steering linkage.

The steering box is known as a recirculating-ball type because the balls can pass out of the nut at each end, but are directed back into the nut by tubes called *ball-return guides*. In this way, the balls are recirculated. In the steering box shown (Figure 13.22), the steering shaft bearings are adjustable by a large threaded adjuster at the top of the box. The sector is adjustable for mesh by an adjusting screw at the end of the sector shaft.

13.12 Power steering for worm-type boxes

The main parts of a worm-type power-steering system are shown in Figure 13.23:

- pump and reservoir
- steering bo x
- control-valve assembly .

The pump is belt-driven from the engine. Taking oil from the reservoir, it delivers it through a pressure line to the control-valve assembly in the steering box. A second line returns oil to the reservoir, establishing continuous oil circulation between the pump and the control valve, whether pressure is needed for steering or not.

Under normal driving conditions, the oil is circulated with very little increase in pressure, absorbing little engine power. When the vehicle is on a turn or being parked, the pressure builds up, placing a greater demand on the engine.

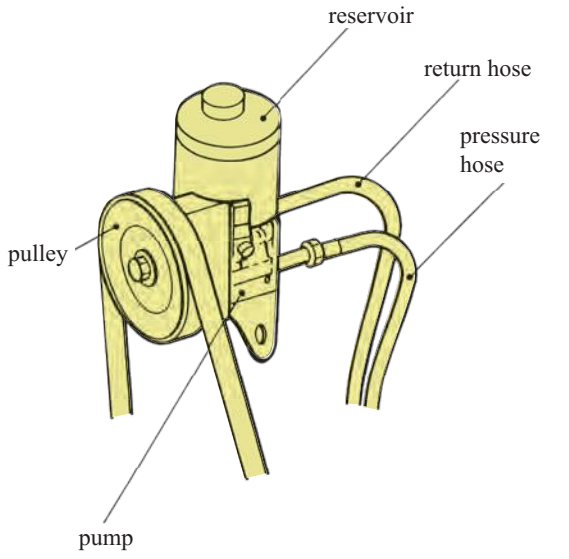


Figure 13.23 Power-steering pump and a worm steering bo x—basic components

Power-steering boxes have mechanical components that work like those in a manual steering box, but they have additional parts to provide the hydraulics for power steering. These are a control valve to direct the fluid and a power cylinder and piston to convert oil pressure into movement.

The basic principle of power steering is that, whenever the steering wheel is turned, a control valve is moved to direct oil under pressure to one side of a piston in a cylinder. This provides hydraulic assistance for steering. The amount of valve movement is limited so that even small movements of the steering wheel will move the valve.

13.12.1 Schematic power-steering system

Figure 13.24 shows the basic arrangement of a power-steering system for a worm-type steering box. The diagram shows:

- oil pump and reservoir
- rotary control valve
- power cylinder and piston.

A vane-type oil pump provides oil pressure. It takes oil from the reservoir and delivers it to the rotary control valve.

The rotary control valve and the power cylinder are both part of the steering box assembly, but the valve is shown separately in the diagram. The power cylinder is an internal part of the steering box and the piston is attached to a toothed rack which is meshed with the teeth of the sector shaft. Oil pressure against the piston helps turn the sector shaft.

The diagram shows the steering on a turn. The inner member of the rotary valve has been turned in relation to the valve sleeve so that pressure oil flows through the valve to the cylinder. The valve also allows oil from the non-pressure side of the cylinder to return to the reservoir. When the vehicle is steered in the opposite direction, the inner member of the valve will be turned to direct pressure oil to the opposite end of the cylinder.

For straight-ahead driving, when no power assistance is needed, the valve will centralise. Oil will continue to flow, but there will be no pressure at either side of the cylinder.

Handy hint: The sector shaft of this particular steering box has a follower for the worm and separate sector teeth for the piston rack.

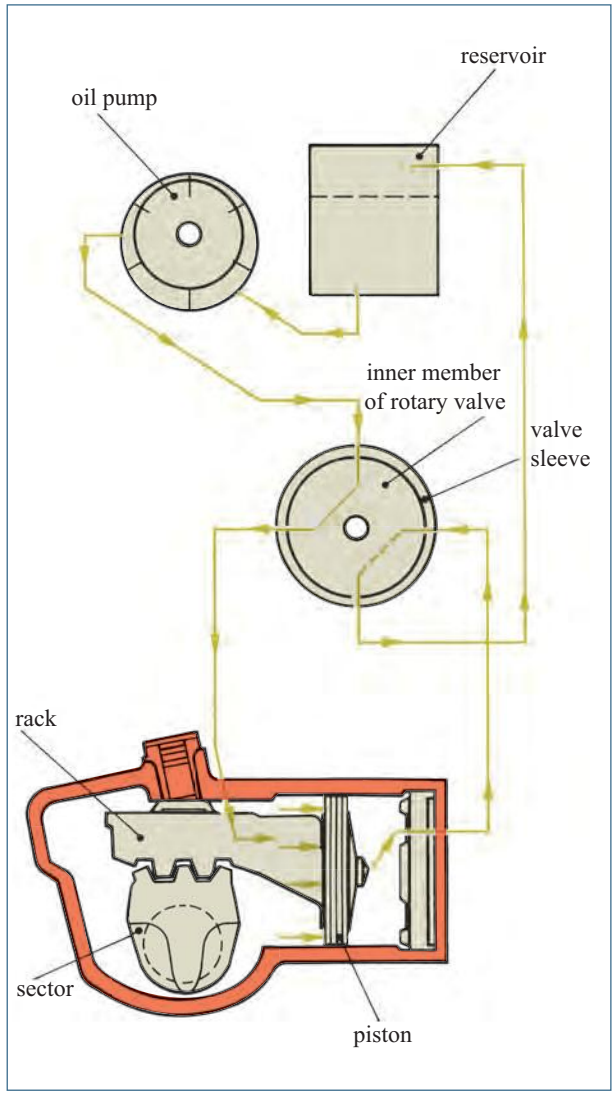


Figure 13.24 Basic principle of power steering for a worm-type steering box

13.12.2 System with recirculating-ball steering box

The diagram in Figure 13.25 shows the operating parts of a power-steering system with a recirculating-ball steering box and a spool-type valve. The operation on a left turn is shown. The spool valve is operated by the action of a torsion rod, which functions in a similar way to rotary valves for rack-and-pinion steering, as discussed previously.

For the left turn, as shown, the spool valve has been moved upwards to allow pressure oil from the pump to pass through the valve to the cylinder and piston. At the same time, oil from the other side of the cylinder is allowed to return to the reservoir.

When the steering wheel is turned, the worm is turned inside the piston to wind it up and down, and this turns the sector shaft. This acts in the same way as a normal recirculating steering box. In addition, oil pressure in the power cylinder assists piston movement.

13.12.3 Power-steering box with recirculating balls and rotary valve

In this kind of steering box, the recirculating balls are between the worm shaft and the piston, which is actually the nut. The piston has teeth that mesh with the teeth of the sector shaft. These parts are similar to those in a manual steering box, except that the piston, which operates in the power cylinder, is also the nut for the worm.

The rotary valve assembly is at the top of the box. It has a torsion bar between the input shaft and the worm. This is similar to the torsion bar in a rack-and-pinion steering box, but the valving is different.

When the input shaft is turned, it will turn the worm and also the valve. Lag between the parts of the valve achieved by the torsion bar between the steering-box input shaft and the worm will cause valve action. Oil pressure will be directed to the piston to provide power assistance.

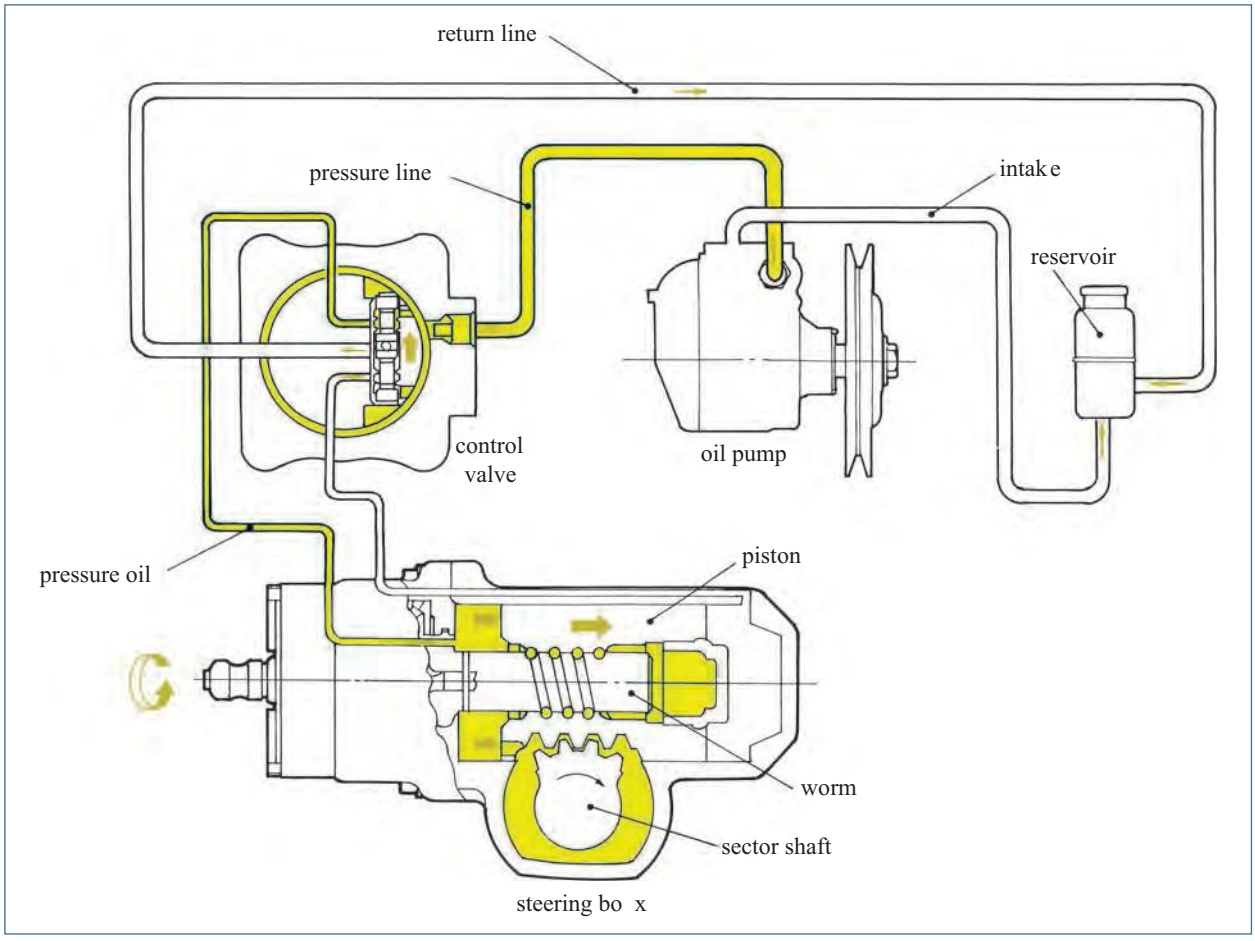


Figure 13.25 Operation of recirculating-ball power steering on a left turn MITSUBISHI

13.13 Power-steering maintenance

Maintenance of power-steering systems includes the following items:

1 Check the oil level in the reservoir.
2 Check the drive belt for condition and correct adjustment.
3 Check the system for leaks.
4 Bleed the system.
5 Change the oil in the system.

Checking the oil level, the drive belt and leaks are routine maintenance items. Bleeding and changing the oil are only carried out if necessary.

Safety: When working with power-steering systems, always wear correct PPE such as safety glasses and gloves, and beware of high pressure and hot oil.

13.13.1 Checking the oil level

The oil level is checked by means of a dipstick attached to the reservoir filler cap. If the level is low, the reservoir should be topped up with automatic-transmission fluid and the various parts of the system checked to determine where the oil has been lost.

13.13.2 Bleeding the system

If the oil has been drained from the system, or the oil in the reservoir has been lost due to leaks, air will enter the system. After filling the reservoir to the correct level, the system must then be bled to remove trapped air.

A general procedure for bleeding a power-steering system is as follows:

1 Top up the reservoir to the correct level.
2 Raise the front wheels of the vehicle.

3 Turn the steering from lock to lock several times.
4 Check the oil level and top up .
5 Start the engine and again turn the steering from lock to lock several times.
6 Stop the engine , and check and top up the oil to the correct level. The oil level will drop as air is removed.
7 Repeat steps 5 and 6 until the oil level no longer drops. This indicates that all the air has been removed from the system.

Constant checks of the oil level should be made to ensure that it does not drop to the extent that air is drawn into the system.

Safety: During the bleeding operations, the steering should not be held on full lock for more than a few seconds at a time .

13.13.3 Checking for oil leaks

When checking for leaks, proceed as follows:

1 Clean away any oil from the area of the suspected leak. This could be at the pump , the pipe connections or the steering bo x.
2 Start the engine and move the steering from lock to lock several times.
3 Stop the engine and check the various parts of the system for oil that has leak ed out. L eaks may be easier to locate when the oil is hot.

Leaks at external connections can be corrected with the steering box in the vehicle, but for more serious problems it will have to be removed and dismantled.

13.13.4 Changing the power-steering oil

It is not usual to change the oil in the power-steering system, but this could be necessary if it becomes contaminated. The system can be drained by disconnecting the return hose and proceeding as shown in Figure 13.26.

The oil is changed and the system flushed by running the engine and directing the oil from the return hose into a container instead of returning it to the reservoir. The steering is moved from lock to lock so that oil circulates on both sides of the power cylinder.

Handy hint: Flushing is recommended whenever components are replaced.

Before starting the engine, the return pipe at the reservoir must be plugged so that the reservoir can be filled with clean oil. This must be kept at a reasonable level so that air is not drawn into the system.

The operation is continued until only clean oil is being discharged from the return hose.

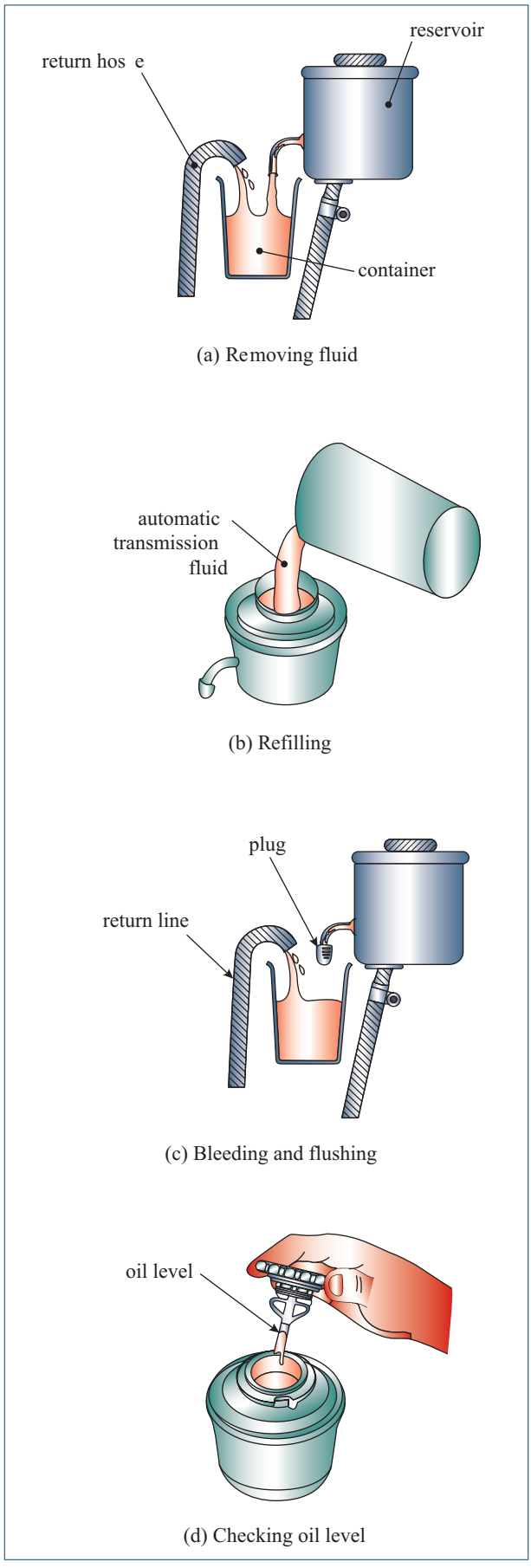


Figure 13.26 Changing the power-steering oil and bleeding the system

Sustainability: Ensure that all oils captured when carrying out service and maintenance on power-steering systems are disposed of in the correct manner .

13.14 Rack-and-pinion steering service

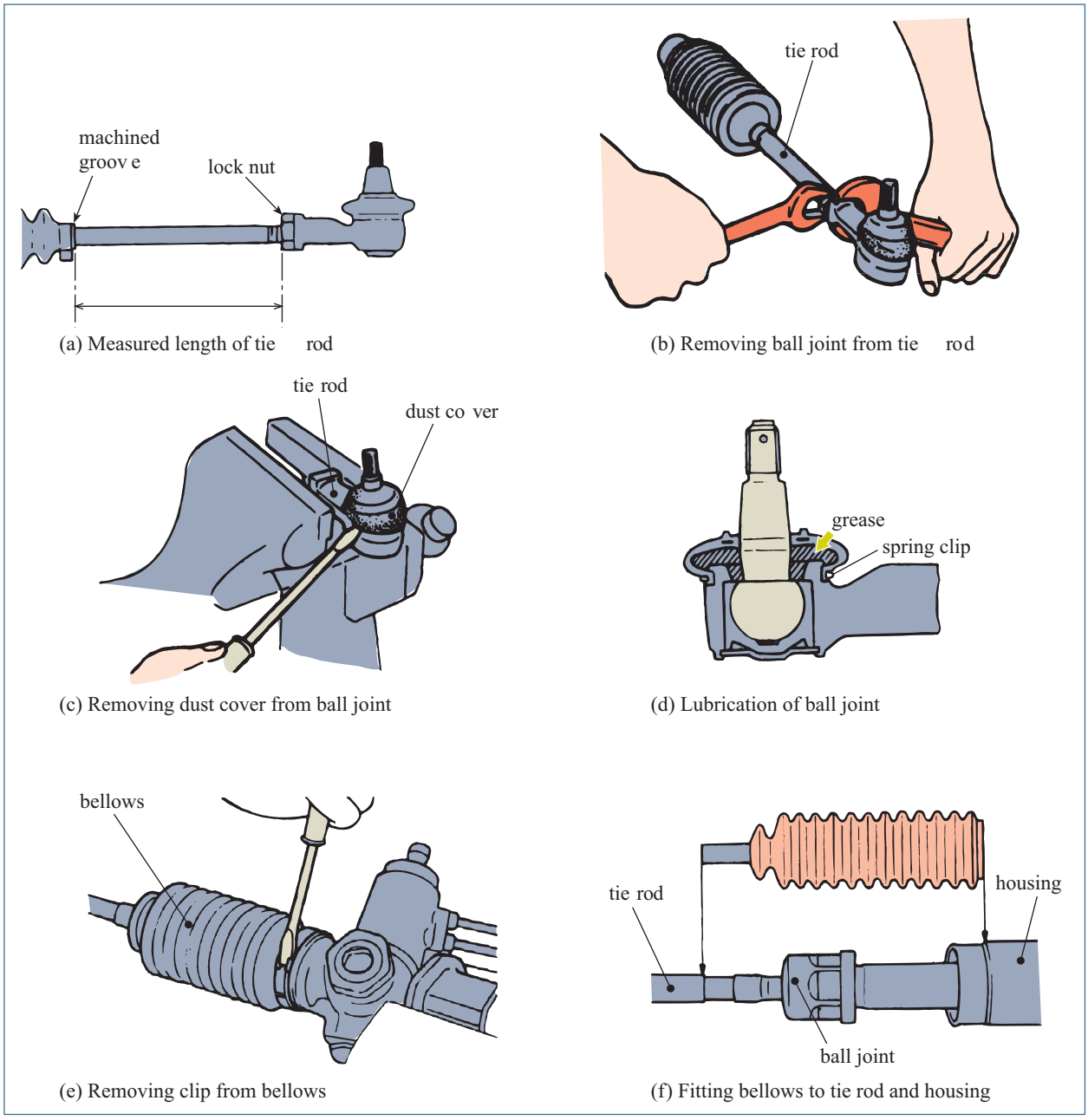
Figure 13.27 shows some service operations on the external parts of a rack-and-pinion steering box. Applicable to both manual and power-steering boxes, they can be carried out with the steering box in the vehicle, or as part of steering-box dismantling.

1 Keeping tie rods the same length. If a ball joint is to be removed, parts should be marked so that it can be replaced correctly (Figure 13.27 (a)).

Both tie rods must be the same length so that the pinion is meshed with the centre of the rack when it is in the straight-ahead steering position.

2 Removing ball joints. The ball joint should be held while the locknut is loosened so that load is not applied to the rack (Figure 13.27 (b)).

After loosening, leave the locknut in its original position and count the number of turns required to unscrew the ball joint from the tie rod. This enables a reinstalled or replacement ball joint to go into the correct position.



(a) Measured length of tie rod

(b) Removing ball joint from tie rod

(c) Removing dust cover from ball joint

(d) Lubrication of ball joint

(e) Removing clip from bellows

(f) Fitting bellows to tie rod and housing

Figure 13.27 Servicing the external parts of a rack-and-pinion steering box

3 Servicing ball joints. The dust cover can be removed from many ball joints by prising it free with a screwdriver (Figure 13.27 (c)).
4 Lubricating ball joints. With the dust cover removed, old grease can be removed and new grease applied in the recess and inside the dust cover (Figure 13.27 (d)).
5 Removing or replacing a bellows. The bellows are retained by clips at each end (Figure 13.27 (e)). The tab end of the clip shown can be raised with a screwdriver to loosen the clip . Other types of clips and clamps are also used.
6 Fitting the bellows. When being replaced, the bellows should be correctly aligned so that the folds are straight (Figure 13.27(f)). One end of the bellows fits into a groove machined in the tie rod, and the other end fits over the end of the housing.

Handy hint: The steering angles will need to be check ed if the tie rod length has been altered by changing the position of its outer ball joint.

13.14.1 Rack-and-pinion dismantling

Figures 13.28 and 13.29 show dismantled rack-and-pinion steering boxes. These are typical manual boxes. Power-steering boxes have similar mechanical components and similar dismantling procedures.

The dismantling procedure for a rack-and-pinion steering is:

1 Support the steering bo x in a vice with suitable soft jaws, or in a holding fixture .
2 Mark the position of the ball joints on the tie rods. Unscrew the ball joints from the tie rods and remove the locknuts.
3 Remove both bellows after loosening the clips that secure them to the tie rods and the housing.
4 Remove the tie rods from the rack by disconnecting the inner ball joints. The rack must be supported when the ball joints are being unscrewed.
5 Loosen the locknut on the yok e plug, unscrew the plug from the housing and remove the yok e.
6 Pry the pinion shaft oil seal from the top of the pinion housing.
7 Remove the snap ring from the pinion housing and withdraw the pinion and bearings.
8 Remove the rack from the steering-bo x housing.

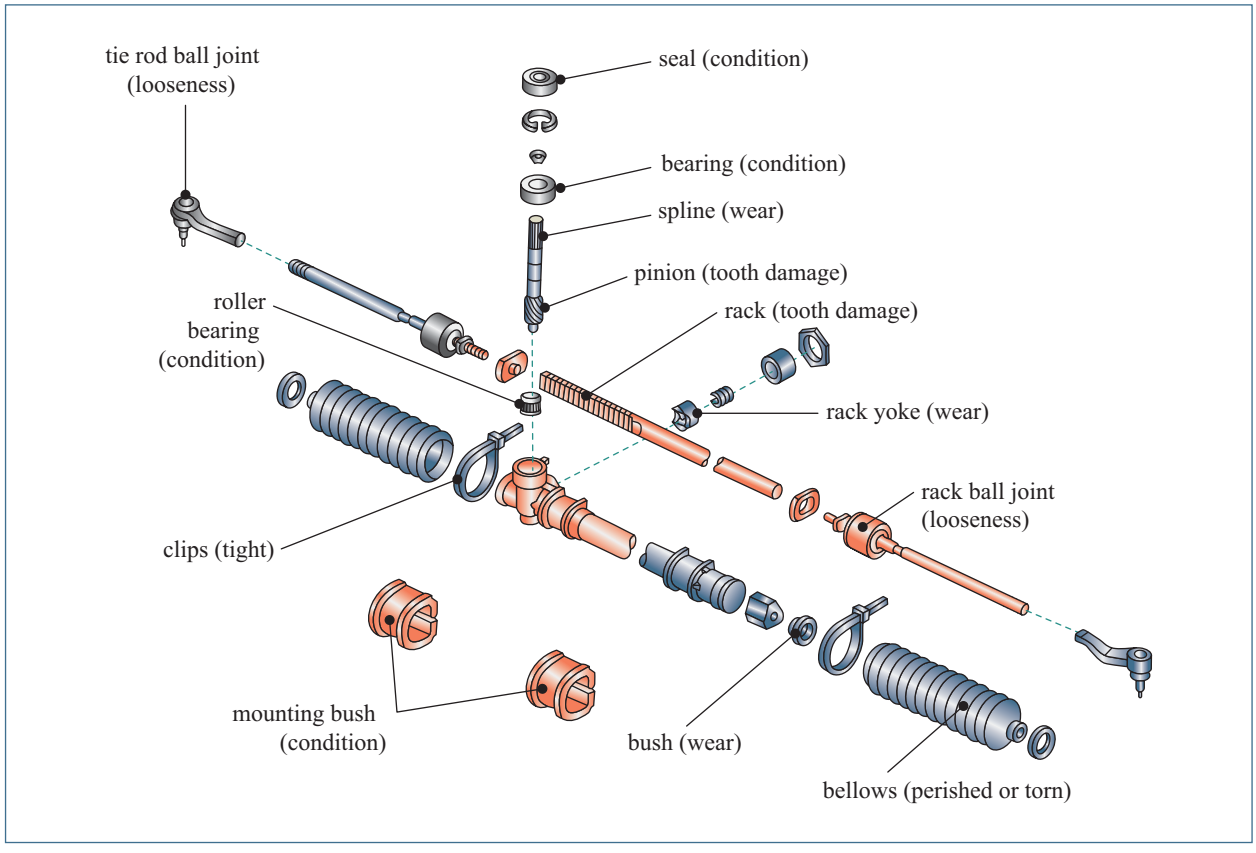


Figure 13.28 Rack-and-pinion steering-bo x assembly—inspection of parts

The above points relate generally to all manual rack-and-pinion steering boxes (but there are a number of design variations).

13.14.2 Inspection of parts

When dismantled, the parts should be inspected as shown in Figure 13.29. The general procedure is:

1 Check all parts for wear and damage .
2 Check the condition of the bearings.
3 Ensure that the bellows do not have tears or deterioration.
4 Inspect the rack and teeth for wear .
5 Check for ex cessive wear between the rack and the bush in the housing.

13.14.3 Reassembly

Reassembly is generally the reverse of dismantling. During reassembly, the rack and other moving parts are coated with specified lubricant (Figure 13.29). Lithium-based grease is used for the mechanical parts.

Handy hint: For power steering, automatic transmission fluid is used to coat all seals and related parts.

Pinion adjustment

In some steering boxes, the pinion shaft bearings are fitted with a light preload, a screw adjustment being provided for this. The preload can be checked by a pull scale and a lever attached to the pinion shaft.

Rack-support yoke adjustment

The rack-support yoke supports the rack and holds its teeth in mesh with the pinion. The yoke has a screw adjustment which enables it to be set with minimum clearance against the back of the rack. The adjusting

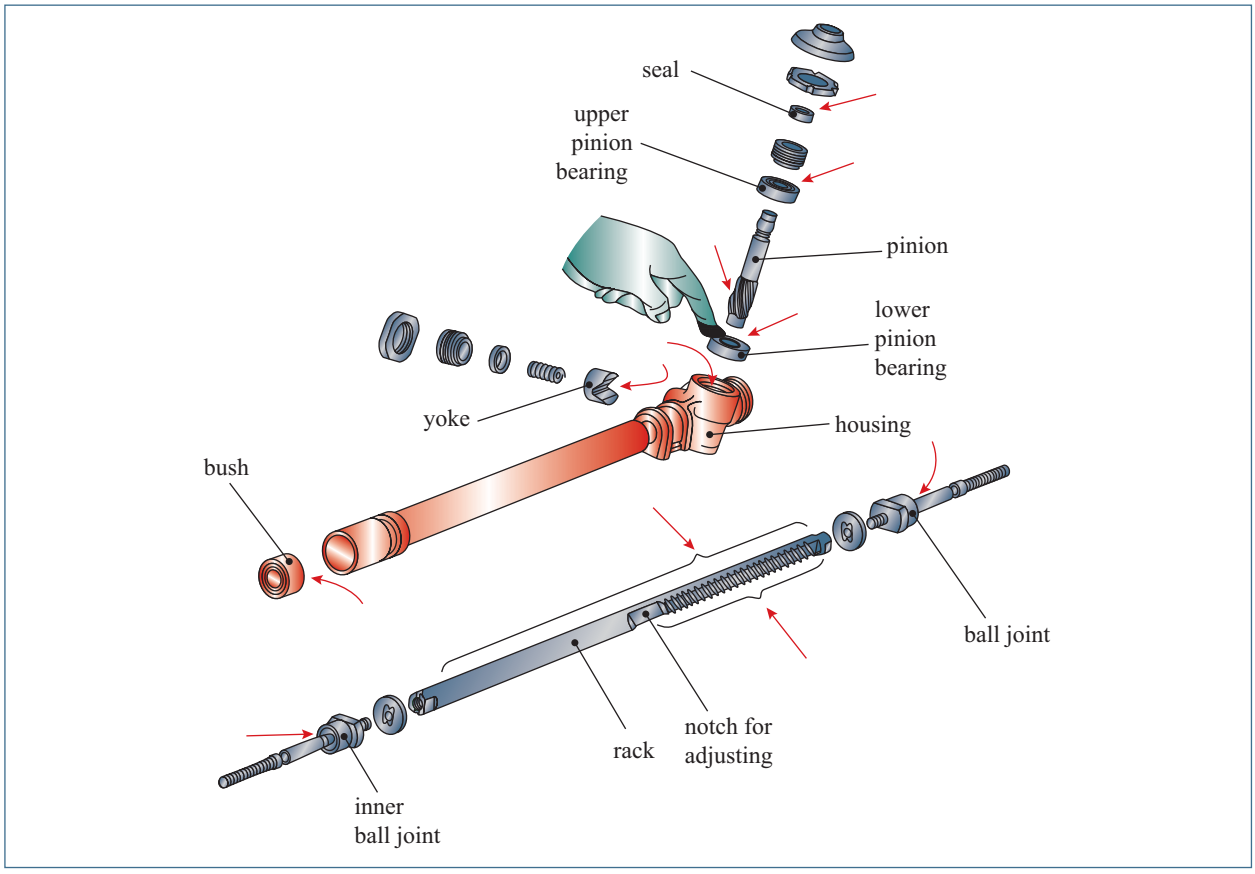


Figure 13.29 Lubrication of steering-bo x parts during reassembly—arrows show parts that are pack ed with grease

screw is tightened to a light torque and then backed off a few degrees to provide a small clearance. The compressed spring provides a thrust against the yoke.

13.15 Rack-and-pinion power-steering service

Figure 13.30 shows a dismantled rack-and-pinion power-steering box. Mechanical and hydraulic parts can be identified. The main hydraulic parts are the rotary control valve assembly and the power cylinder. Apart from these, the construction and servicing procedures are similar to those for a manual-steering box. General points relating to dismantling the power components follow.

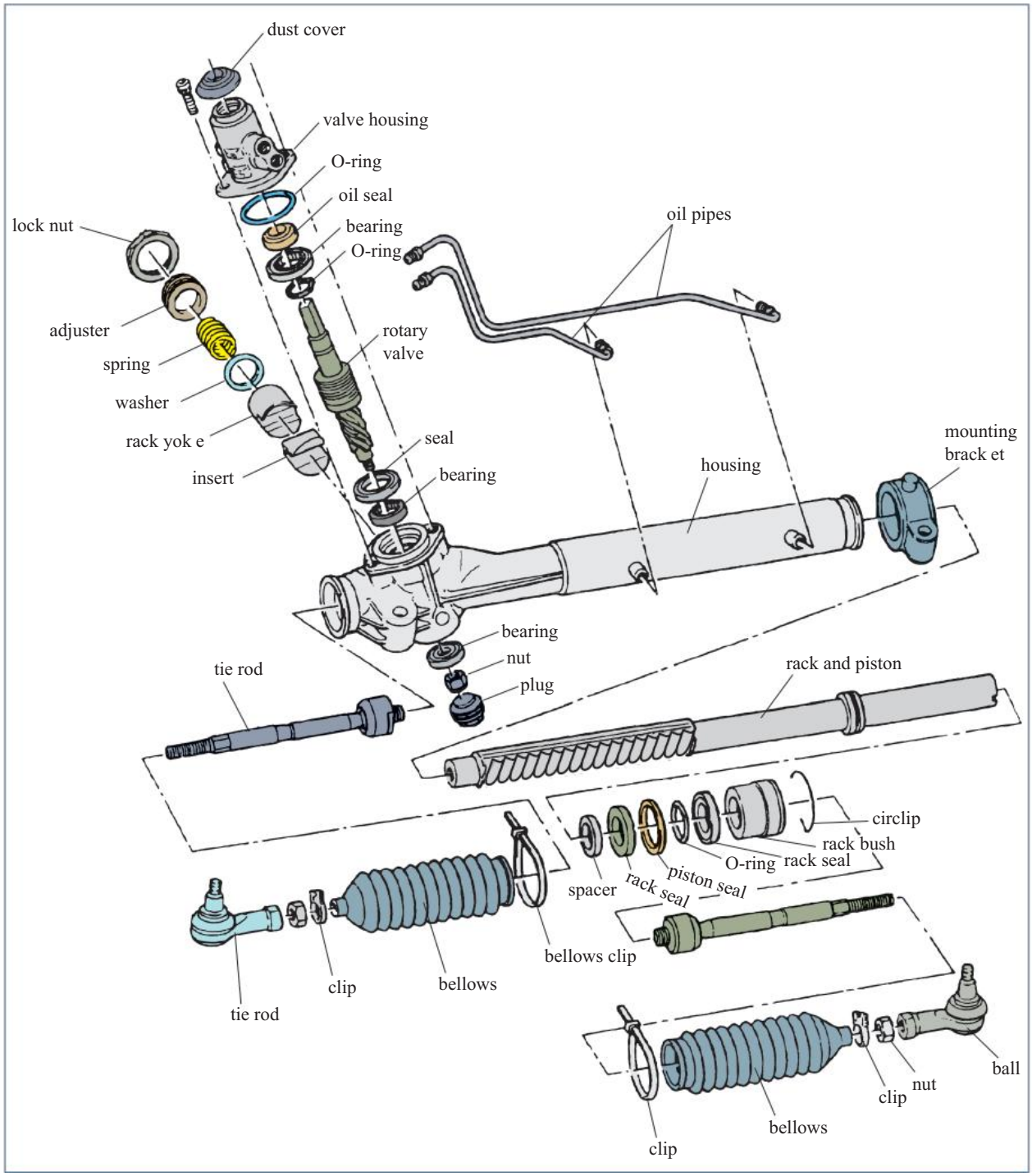


Figure 13.30 Parts of a rack -and-pinion power-steering system GM HOLDEN LTD

13.15.1 Control-valve assembly

1 The hydraulic pipes and hoses, which connect the pump to the control valve , must be disconnected. The pipes between the control valve and the power cylinder must be removed.
2 To remove the rotary control valve , the valve housing is extracted from the top of the bo x, exposing the rotary valve .
3 The rack yok e, which holds the rack against the pinion, has to be removed from the housing, in which it is retained by a threaded plug and locknut. There is also a spring which acts against the yok e.
4 The plug in the bottom of the bo x is removed, g iving access to the nut on the end of the pinion shaft.
5 The pinion, complete with the rotary valve assembly , is withdrawn from the top of the bo x.
6 The rotary valve has T elfer sealing rings that can be replaced, but it is not dismantled any further .

13.15.2 Power-cylinder components

1 Before the rack -and-piston assembly can be removed from the housing, the rack bush in the outer end of the housing has to be removed.
2 In the steering bo x shown in Figure 13.30, the bush is retained by a spring wire circlip . Other bo xes might have a snap ring or a threaded bush.
3 With the bush removed, the rack and piston assembly can be withdrawn from the end of the housing.
4 The piston is fix ed to the rack, but there is a seal on the piston as well as seals at each end of the rack to seal off the cylinder .
5 The power cylinder is part of the housing and so does not dismantle further .

Handy hint: Before any major servicing is attempted, the detailed procedures in the appropriate workshop manual should be consulted.

13.16 Servicing steering linkage

The linkage on all steering systems can be checked for looseness, wear, loss of oil from the steering box or power steering, and for general condition. Where tyre wear is excessive or irregular, or steering difficulties are encountered, a wheel and steering alignment check and adjustment should be carried out.

13.16.1 Checking steering for looseness

With the wheels of the vehicle on the ground, and the steering wheel in the straight-ahead position, rock the steering wheel lightly to the left and right to check the free play. The rim of the steering wheel should have a maximum free movement of 30 mm.

If there is excessive free play, it could be in the steering box or in the linkage. It can normally be corrected by adjustment, unless the internal parts are excessively worn or damaged.

Handy hint: Free play must be check ed in the straight-ahead position. If check ed in any other position, normal clearance between the gears will allow more steering wheel movement.

Checking ball joints

Check the ball joints for looseness by rocking the steering wheel with quick movements so that it moves further than the normal free play. One person rocks the steering wheel while another checks each ball joint in turn for unwanted movement. The idler arm should also be checked for wear and looseness (Figure 13.31).

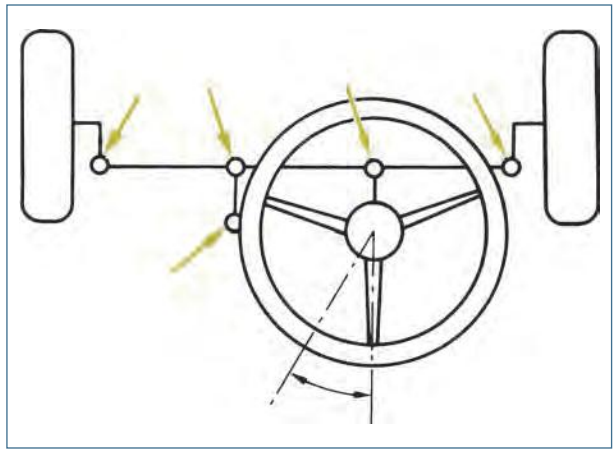


Figure 13.31 Steering-wheel free play and linkage checks—check points are indicated by arrows

13.16.2 Rack-and-pinion linkage

As well as the ball joints on the outer ends of the tie rods, rack-and-pinion steering boxes have a ball joint at each end of the rack, referred to as the *rack balls* or *inner ball joints* (Figure 13.32). These connect the tie rods to the rack and are covered by the bellows.

The outer ball joints can be checked visually by rocking the steering wheel as indicated above. If looseness of the inner ball joints is suspected, the bellows will have to be removed from the end of the housing. Torn or damaged bellows will allow the steering box lubricant to escape so they should be checked at the same time as the ball joints.

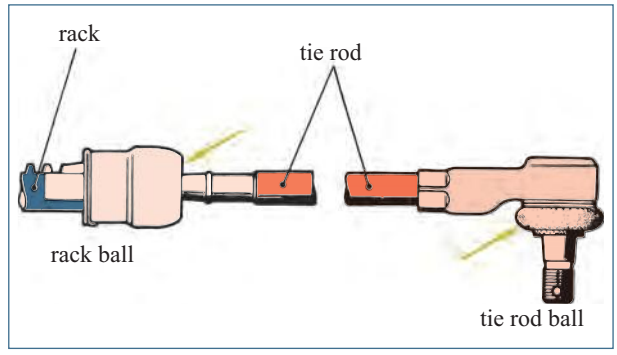


Figure 13.32 Rack-and-pinion ball joints—inspection for looseness and wear

13.16.3 Removing ball joints

A ball joint has a tapered stud that fits into a tapered hole in the steering arm or in some other part of the steering linkage. Special tools are used for removal, one type of which is shown in Figure 13.33. This has a forked end which fits between the ball joint and the steering arm. A forcing screw is tightened with a spanner to spread the tool and apply force to the end of the ball stud. Tapping the steering arm can assist with removal.

Although sealed ball joints cannot be dismantled, damaged boots can be renewed once the ball joint has been removed. Figure 13.34 shows a ball joint of this type. After cleaning, grease can be applied to the exposed part of the joint and to the interior of the new boot before it is fitted. An application of sealer could be required on the edge of the boot, or it might have a spring retaining clip.

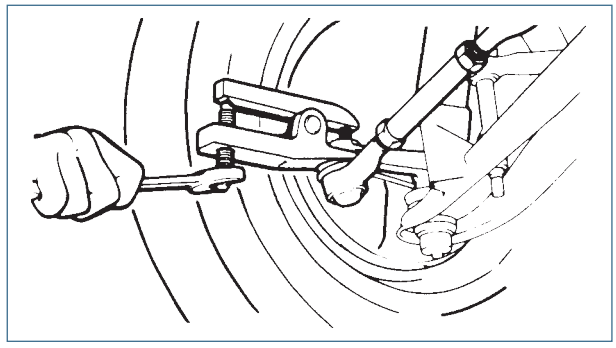


Figure 13.33 Tool for removing steering-linkage ball joints MITSUBISHI

13.16.4 Worm-type steering linkage

Figure 13.35 shows the dismantled parts of a steering linkage for a recirculating-ball steering box. Ball joints have to be removed so that the parts can be separated as shown.

The steering box is bolted to the subframe on the right side, and the idler arm is bolted to the subframe on the left side. Movement of the pitman arm is transferred through the track rod and tie rods to the steering arms.

The sleeves join the parts of the tie rods with a left-hand thread at one end and a right-hand thread at the other. This enables the tie rods to be adjusted for length. Turning the sleeve one way lengthens the rod, and turning it the other way shortens the tie rod.

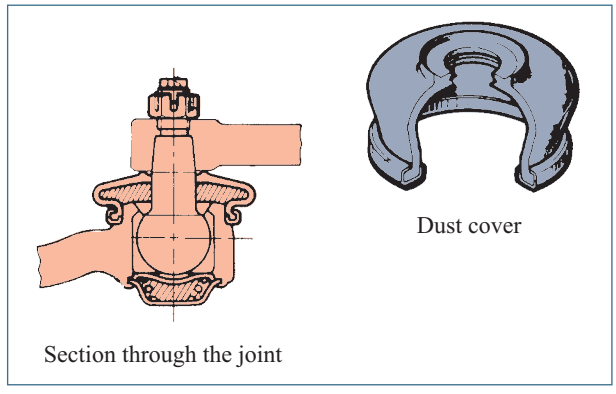


Figure 13.34 Steering-linkage ball joint MITSUBISHI

Handy hint: Both tie rods must be adjusted to the same length.

13.16.5 Removal of pitman arms

The pitman arm on a worm-type steering box is fitted to the sector shaft on tapered splines and retained by a large nut. It usually requires a puller for removal.

The end of the sector shaft, and the pitman arm, are often marked to identify their relative positions (Figure 13.36). A check for marks should be made before the pitman arm is removed. If none are evident, the parts should be marked, although some pitman arms have master splines which allow them to be fitted only in one position.

Handy hint: The pitman arm must be reinstalled in its original position, otherwise the spokes of the steering wheel will be misaligned and the steering box will be off-centre.

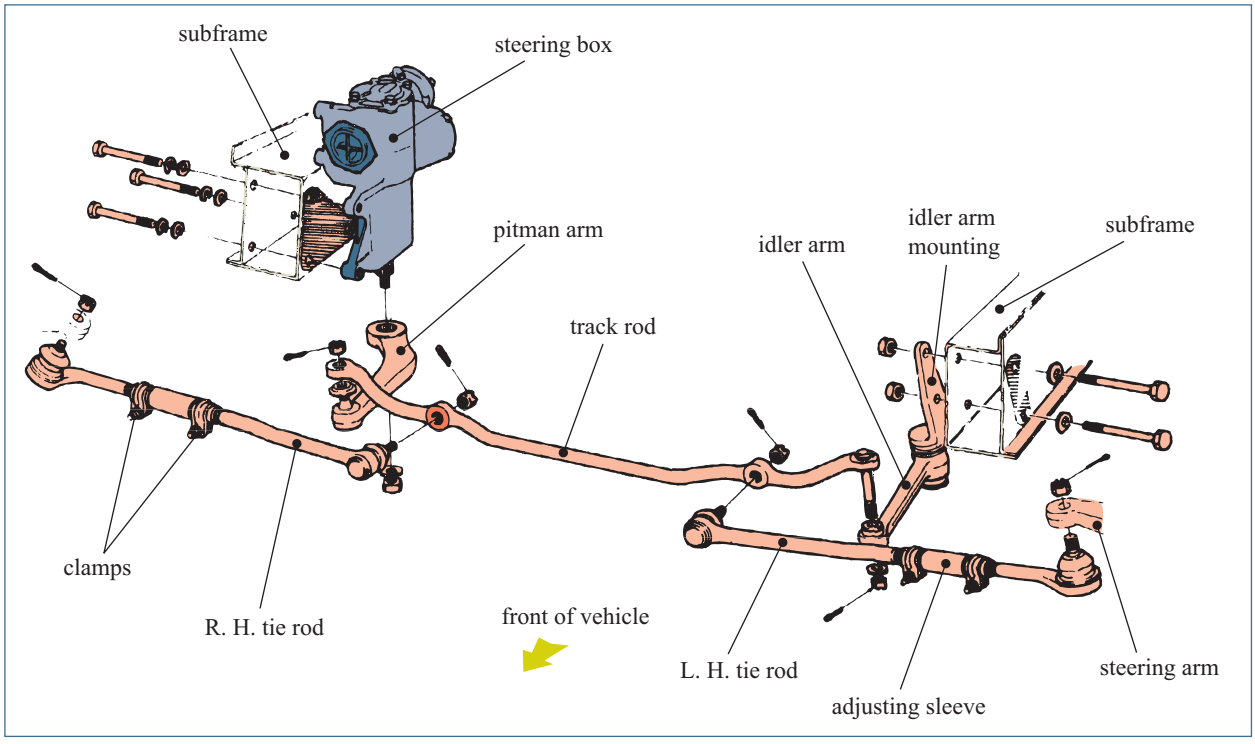


Figure 13.35 Parts of a steering linkage for a recirculating-ball steeri ng bo x FORD

13.16.6 Removal of idler arms

The idler arm mounting is bolted to the subframe. It can be removed after disconnecting the track rod. The idler arm in this system is mounted on rubber bushes. It can be separated from its mounting by removing a retaining nut. This enables worn bushes to be replaced.

13.16.7 Steering-wheel removal

In most systems, the steering wheel is fitted to the mainshaft on tapered splines and requires a puller for removal. Threaded holes are often provided in the hub of the wheel so that puller bolts can be attached. Where there are no threaded holes, a puller with legs that fit under the steering wheel is used. Avoid using undue force on the shaft when removing a steering wheel: it can damage bearings. Also avoid damage to electrical switches and controls while the steering wheel is removed.

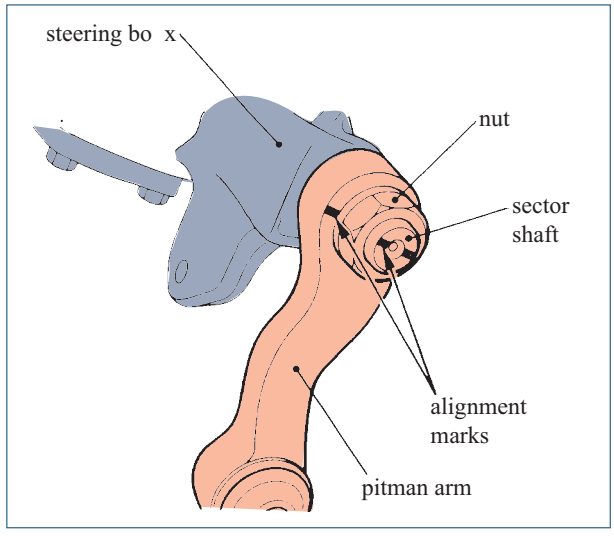


Figure 13.36 Alignment marks on the pitman arm and the end of the sector shaft MITSUBISHI

Handy hint: While many steering wheels and shafts have tapered splines that require some form of puller for removal, steering wheels with parallel splines are easier to remove .

13.16.8 Steering-wheel position

Before removal, the steering wheel should be checked for marks so that it can be replaced correctly. If there are none, the wheel and shaft should be carefully marked so that the steering wheel, when reinstalled, has its spokes correctly positioned.

The steering wheel should be centred when the vehicle is being driven straight ahead. The position of the spokes will show if it is in the correct position. Possible causes for it not being so include incorrectly adjusted tie rods, a poorly installed steering wheel, a bent steering arm or an incorrectly fitted pitman arm.

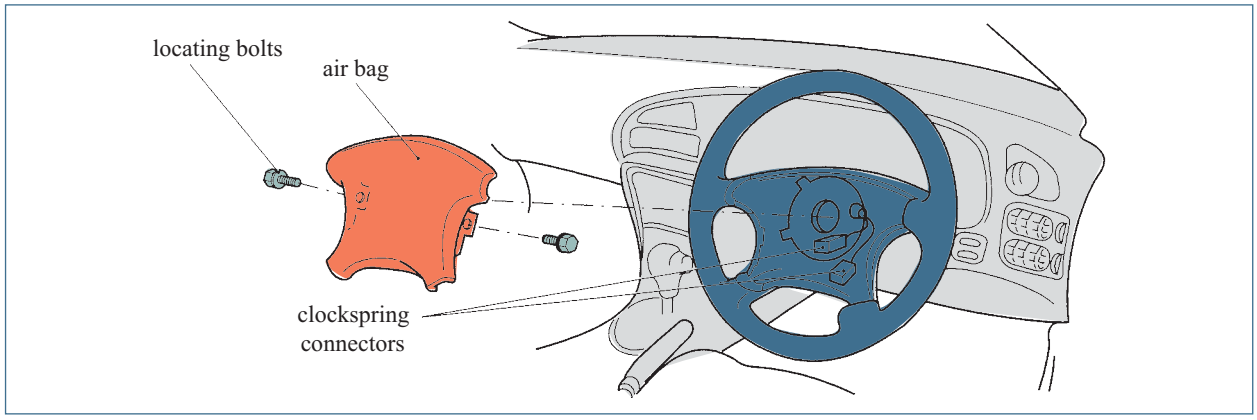


Figure 13.37 Steering wheel with airbag removed FORD

If no marks are available, the steering box should be centred, the steering wheel fitted temporarily and the number of turns from centre to lock on each side checked. The steering wheel can be repositioned, if necessary, before being secured.

13.16.9 Steering wheel with airbag

Where an airbag is fitted, it must be removed and its clockspring electrical connections disconnected before the steering wheel nut is accessible (Figure 13.37). A steering wheel airbag requires special safety precautions to prevent it from being accidentally deployed.

Safety: Knowledge of airbags is essential before working on the parts of a vehicle that have airbag equipment.

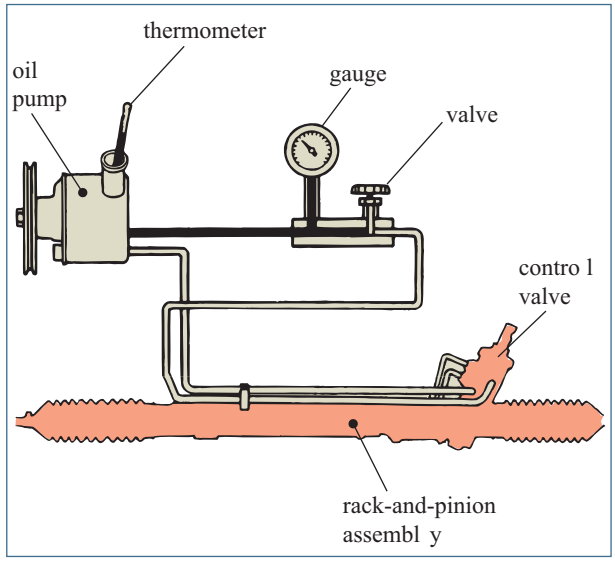


Figure 13.38 Arrangement for checking the pressure of a power-steering system FORD

13.17 Analysing power-steering problems

Heavy steering is the most likely general problem with power steering. There are three possible sources, and these are:

1 The pump . If the pump is not producing pressure , or only low pressure , the steering will be heavy when turned both left and right.
2 The control valve . If the valve is at fault due to leaks across the seals, there could be a difference in power assistance between a left and a right turn. The steering would be heavy when turned in one direction and normal when turned in the other direction.
If the control valve was to fail completely , there would be no power assistance; but this is less lik ely.
3 The power cylinder . If the piston seal is worn, it would allow pressure oil to leak past the piston to the non-pressure side of the power cylinder . There would be reduced power assistance and the steering would be heavier than normal. It would feel the same on both left and right turns.

Handy hint: If the steering is heavy , do not overlook type of tyres, tyre pressures and other steering components as possible contributing causes.

Further information on electronically controlled steering systems (ESP) systems can be found in Chapter 48.

13.17.1 Pressure testing

The system can be pressure tested by connecting a pressure gauge into the system between the pump and the valve, as shown in Figure 13.38. This checks the pump pressure under different conditions. The pressure gauge has a valve which enables the pressure line to be closed off. A thermometer in the reservoir checks the oil temperature, and a tachometer is used for engine rpm.

After connecting the gauge, the system has to be bled to remove air that has entered. Gauge readings are made after cycling the steering wheel from lock to lock and with the engine running at fast idle.

The general methods of checking the pressure are:

1 Pump pressure . With the gauge valve closed, the pressure line is block ed off at the pump and pressure should build up to specifications. The valve should only be closed for a few seconds. If the gauge reading is low, suspect the pump.
2 Power cylinder pressure . With the gauge valve open, the pump is connected to the control valve and the power cylinder . The pressure should also be at pump pressure . If the gauge reading is low , suspect the piston seals.
3 Flow meter . Many power system analysers include a flow meter . Sufficient oil flow is just as important as pressure. Reduced flow will cause slow operation and can be a result of damaged hoses or pipes.

13.18 Steering faults

Table 13.1 lists some general steering faults and their possible causes.

Table 13.1 Diagnosis of steering faults

Symptom	Possible causes
Loose steering	Incorrect front-wheel bearing adjustment Loose linkage ball joints Loose steering-bo x mounting Wear or maladjustment of steering bo x Worn or loose idler arm
Heavy steering	Power steering inoperative Incorrect tyre pressure Incorrect front-wheel alignment Lack of lubrication Tight steering-bo x adjustment
Steering and suspension rattles	Loose linkage connections Loose mountings Loose suspension joints Broken spring
Steering shimmy	Out-of-balance wheels Incorrect front-end alignment Loose linkage connections
Vehicle pulls to one side	Tyre pressures uneven Front-wheel alignment incorrect Sagging or brok en spring Mismatched tyres
Tyre squeals on turns	Low tyre pressure Incorrect wheel alignment Bent steering arm
Wander from side to side of road	Incorrect wheel alignment Loose steering connections Loose steering-bo x adjustments Sagging spring Incorrect tyre pressure Uneven tyres

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe how the steering system is a line of communication between vehicle and driver
- explain modern steering systems' use of assistance systems to provide better feedback and vehicle agility
- describe rack-and-pinion, electro-hydraulic and electric power-steering systems
- apply basic maintenance requirements for steering systems and their components
- identify worn steering components
- test and diagnose steering system faults.

REVIEW QUESTIONS

1 What is the Ackermann principle of steering?
2 Name the main parts of a steering system.
3 What are the two general designs of steering systems?
4 What are the main steering-system angles?
5 What is variable-ratio gearing?
6 Name the main parts of a rack-and-pinion power-steering system.
7 Where is the control valve located in a rack-and-pinion power-steering system?
8 What is a speed-sensitive steering system?
9 How does electro-hydraulic power steering differ from other systems?
10 How would a steering system be checked for looseness?
11 What precautions should be taken when removing a steering wheel?
12 What particular precautions would be taken if the steering wheel has an airbag?
13 What external parts can be checked on a rack-and-pinion steering box?
14 What type of maintenance is power steering likely to need?
15 How is the oil checked in a power-steering system?
16 How can the oil be changed in a power-steering system?
17 What adjustments are provided on a rack-and-pinion steering box?
18 Where are the adjustments located on a worm-type steering box?
19 How is a pressure gauge connected to a power-steering system?
20 What are the possible causes of looseness in a steering system?
21 What are likely causes of hard steering?
22 What does EPS/EPAS stand for?

CHAPTER 14

Wheel alignment

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 prepare to carry out a wheel alignment
2 describe safety procedures and requirements to safely carry out a wheel alignment
3 carry out wheel alignments in accordance with workplace and OEM manufacturers ' requirements and specifications.

Wheel alignment is the correct relationship of all four wheels of the vehicle. When a wheel-alignment service is carried out, checks are made of the suspension as well as the steering. With any steering system of the Ackermann principle type, incorrect wheel alignment will cause tyre wear and also affect steering. Alignment of the front end of the vehicle is more complex than alignment of the rear but rear-wheel alignment, particularly with independent rear suspension, must also be considered.

14.1 Steering and suspension angles

A number of features (angles) are designed into the front suspension to allow a vehicle to be steered and be stable. Some are built into the components and some are adjustable; all are interrelated. They are:

- caster
- camber
- steering-axis inclination (S AI)
- toe (toe-in and toe-out)
- toe-out-on-turns .

Following is an explanation of each of these terms. The basic illustrations are of a ball joint suspension, but the information applies to all suspensions. (Figure 14.8 shows a strut suspension.)

14.1.1 Caster

Caster is the angle at which the steering axis is tilted when viewed from the side of the vehicle (Figure 14.1). The steering axis is a line through the ball joints that the steering knuckle (or the equivalent suspension parts) turns on for steering. Tilting the top of the steering knuckle backwards gives *positive caster*; tilting it forwards gives *negative caster.*

Positive caster is usually used and helps to keep the front wheels pointing in a straight-ahead direction. The centreline of the steering axis, when extended, will reach the road surface at a point ahead of the vertical centreline of the wheel. This is the point about which the wheel pivots for steering (the pivot point). This arrangement gives the wheel a trailing action because most of its mass is behind the pivot point.

This is similar to the action of a common caster wheel which is fitted to mobile workshop equipment (Figure 14.2). The spindle of the caster wheel is ahead of the centreline of the wheel, so that the wheel always trails behind the spindle. The front wheels of a motor vehicle have this trailing action.

Handy hint: Any wheel with caster will trail, and the greater the caster angle , the greater the tendency to maintain a straight-ahead position.

14.1.2 Camber

Camber is the tilt of the front wheels, inwards or outwards, when viewed from the front of the vehicle (Figure 14.3). The top of the wheel is usually tilted outwards to give *positive camber*. If the wheel is vertical, it has *zero camber*. If tilted inwards, it has *negative camber*.

Positive camber brings the point of contact between the tyre and the road more directly under the ball joints or steering axis, so that the load is distributed more evenly on the bearing and suspension parts. Large camber angles were used at one time, but the trend is for camber to be reduced and steering-axis inclination to be increased.

Camber also compensates for any deflection of the suspension under load. Wheels given initial camber will tend to be deflected towards the vertical when under load. Because of the design of their control arms, some suspensions have a natural tendency for camber to be reduced under operating conditions.

14.1.3 Steering-axis inclination

The top of the steering axis is inclined towards the centre of the vehicle (Figure 14.4). This gives a better loading of the ball joints, as the thrust is taken along their axis. Steering-axis inclination (SAI) also tends to keep the wheels pointing straight ahead, giving directional stability to the vehicle.

With the steering axis inclined, a line through the steering axis will intersect the centreline of the tyres at a point near the road surface, as shown in Figure 14.5(a), and the thrust will be taken along the line of the steering axis. Without inclination, a side thrust would be imparted to the ball joints, increasing their loading and make steering difficult (see Figure 14.5(b)).

14.1.4 Toe-in and toe-out

With toe-in (Figure 14.6), the distance between the front wheels is less at the front B than at the rear A. This is normally only about 2 to 3 mm. Toe-out gives the wheels the opposite effect.

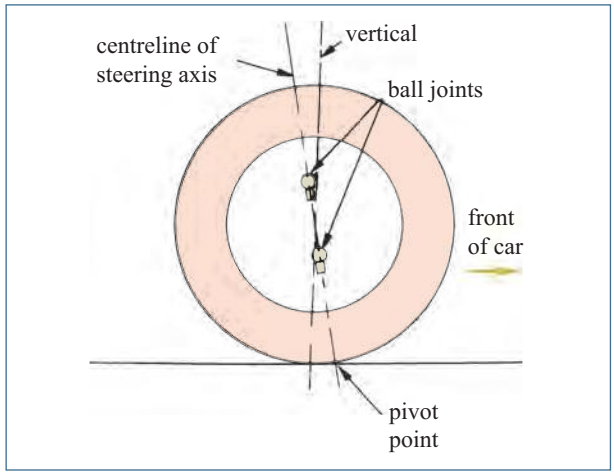


Figure 14.1 Caster of right front wheel—backward tilt of the steering axis gives positive caster

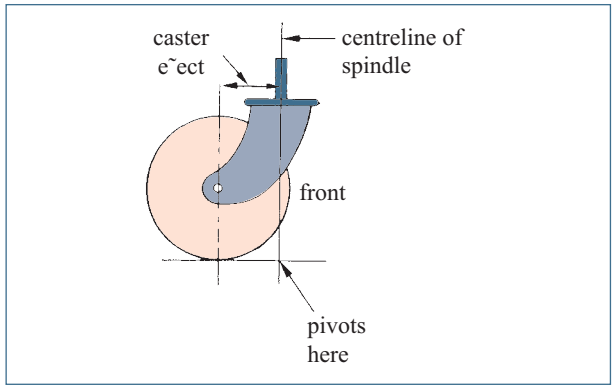


Figure 14.2 Trailing action of a caster wheel

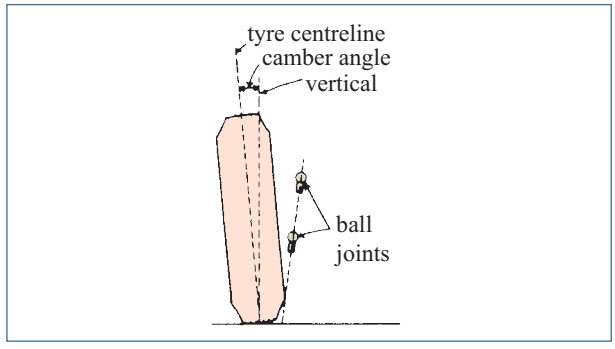


Figure 14.3 Camber angle of front wheel—positive camber is shown

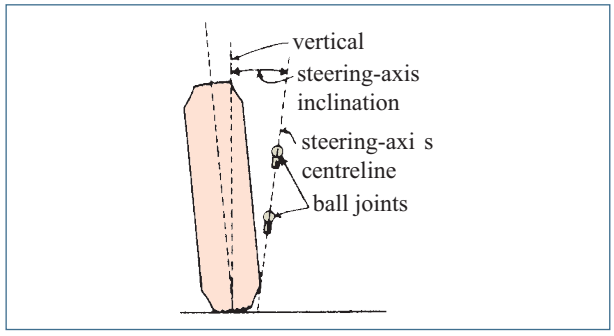


Figure 14.4 Steering-axis inclination

Rear-wheel drive

The toe-in given to the front wheels of rear-wheel-drive vehicles offsets the small deflections in the steering and suspension systems that occur when the vehicle is moving forwards. The deflections are due to the rolling resistance of the tyres on the road. The front wheels are being pushed along the road, and this tends to cause toe-out. Braking has the same effect. The wheels are set to toe-in slightly when the vehicle is stationary, but they will tend to be parallel when the vehicle is on the road and moving straight ahead.

Front-wheel drive

With front-wheel-drive vehicles, the front wheels are pulling the vehicle along the road and so the deflections in the suspension and steering parts are opposite to those of the front wheels of a rear-wheel-drive vehicle. For this reason, the front wheels of most front-wheel-drive vehicles have very little toe-in and some can have toe-out. The rear wheels, on the other hand, can have a small degree of toe-in because they are being pulled along the road and the fronts of the wheels will tend to deflect outwards.

14.1.5 Toe-out-on-turns

The toe-out-on-turns is the number of degrees by which the inner wheel exceeds that of the outer wheel for any particular turn. It is usually measured with the outer wheel on a turn of 20°, but other angles may be specified. Toe-out-on-turns is also referred to as *steering geometry*. If the angles are incorrect, then scuffing of tyres will occur on turns.

The diagram in Figure 14.7 shows how toe-out-on-turns is achieved. The offset steering arms are joined by a track rod and, in the straight-ahead position, this is centred and the wheels are held parallel.

1 Right turn. During a right turn, steering wheel action moves the track rod towards the left as shown by the dotted lines. The end of the track rod pushes the left steering arm and moves in an almost straight line (A in the diagram).

The opposite end of the track rod pulls the right steering arm towards the left and also towards the front of the vehicle (B in the diagram). The movement at B is greater than A, so the right wheel is turned through a greater angle than the left.

2 Left turn. When a left turn is made the opposite occurs—the left wheel is turned through a greater angle than the right. Again, this is because of the offset steering arms.

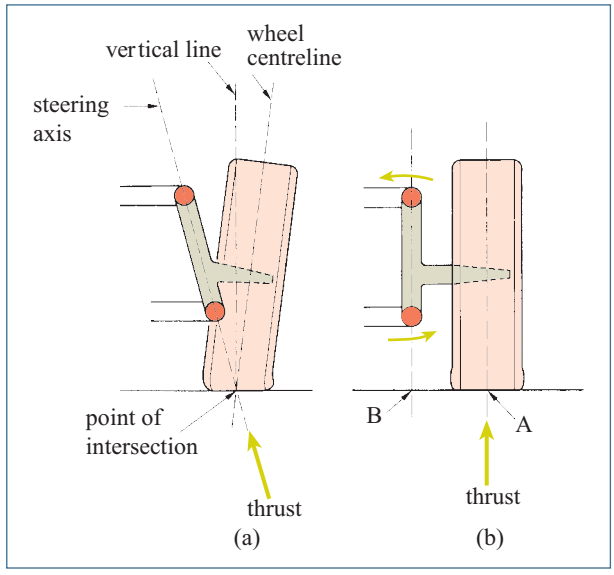


Figure 14.5 Effects of steering-axis inclination (a) with steering-axis inclination, the thrust is upwards through the steering axis (b) without steering-axis inclination, side thrusts are imposed on the ball joints

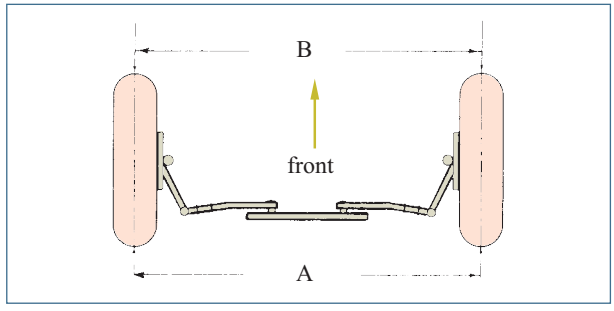


Figure 14.6 Toe-in—dimension B is a shorter dimension than A GM HOLDEN LTD

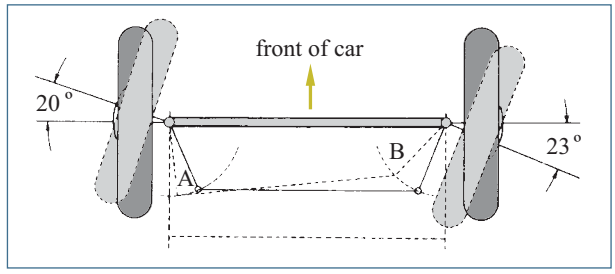


Figure 14.7 Toe-out-on-turns is obtained by offset steering arms that produce unequal angular movement when the wheels are turned—A and B show movement of steering arms

14.2 Front-suspension and steering adjustments

Some vehicles have adjustments for caster, camber and toe-in, while others have the caster and camber angles built into the suspension during manufacture so that only the toe-in can be adjusted. If errors exist in the suspension angles and there are no adjustments, suspension parts are either worn or bent, and should be replaced or straightened. In certain instances, suspension parts can be set (bent slightly) to correct the caster

or camber. This must be done cold, with minor bending only being attempted.

Where alteration to suspension angles is needed, and the suspension has no built-in adjustments, special replacement parts are sometimes fitted. Adjustable pins or bushes in the suspension mounting enable the suspension angles to be altered.

Safety: Heat should never be used to straighten steering or suspension parts.

14.3 Caster and camber adjustments

The location of adjustments, as well as the method of adjustment, varies with different vehicles. Some typical adjustment methods follow.

14.3.1 Strut suspension adjustments

Some strut suspensions have adjustments for caster and camber; others have none. Where errors in the steering angles are found, and there are no adjustments, the ball joints and control arm mounting should be checked for wear and looseness. The suspension parts should also be checked for damage.

The locations of possible adjustments for a strut type of front suspension are shown in Figure 14.8. The ways in which the suspension angles can be adjusted are:

1 Caster adjustment. An adjustment, such as a strut rod which can be lengthened or shortened, will move the wheel forwards or backwards to alter caster (Figure 14.8(a)).

Some suspensions have provision for limited adjustment at the mounting at their top. The mounting is offset on the strut and it can be repositioned in the spring tower. This moves the top of the strut, providing a small alteration to the caster.

2 Camber adjustment. Altering the position of the steering knuckle in the brack et at the bottom of the strut will cause the wheel to lean in or out and so alter camber (Figure 14.8(b)).

3 Steering-axis inclination adjustment. Changing the length of a lower control arm or altering the position of the mounting point with an adjuster will move the ball joint to alter the steering axis angle (Figure 14.8(c)).

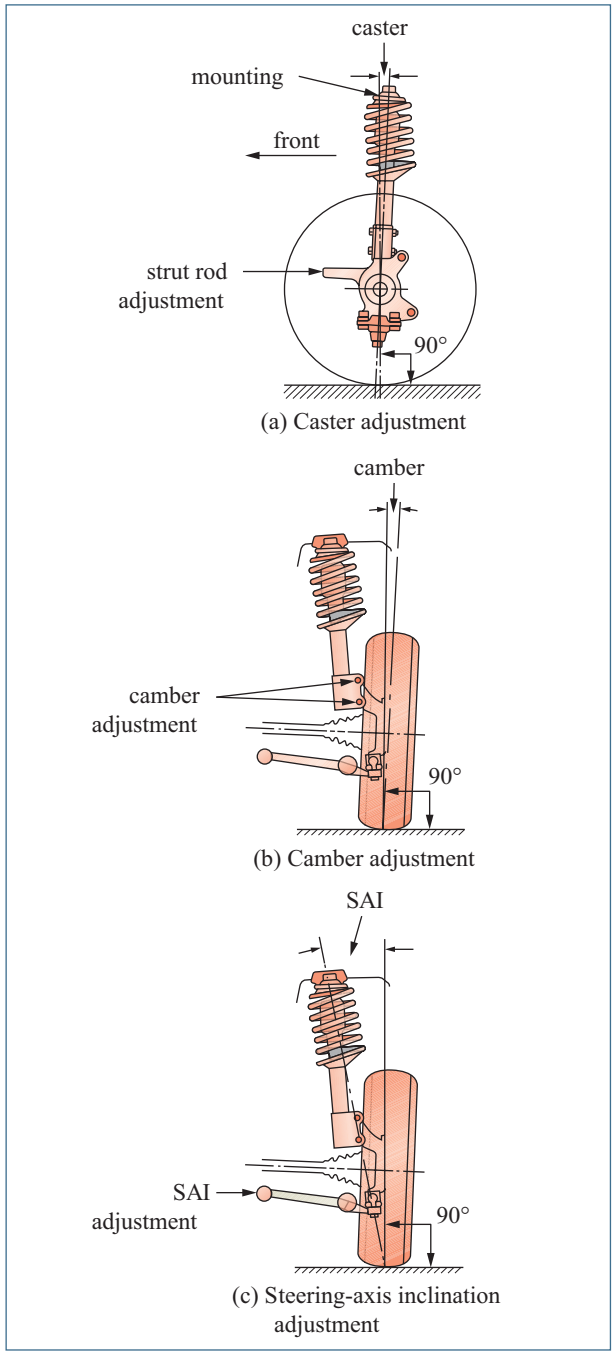


Figure 14.8 Locations of adjustments for caster , camber and steering-axis inclination on a strut suspension

Strut rod adjustment

Figure 14.9 shows an adjustable strut rod. This is located between the lower control arm and the subframe and has a large rubber mounting. The end of the strut is threaded so that its length can be increased or reduced. The caster can be changed by altering the length of the rod to move the lower end of the strut towards the front or rear.

Steering knuckle adjustment

Strut-type suspensions that have the steering knuckle bolted to the lower end of the strut sometimes have a camber adjustment. In other suspensions of this design, a small clearance exists between the bolts and the holes, allowing some camber variation. If a steering knuckle is to be removed from a strut, alignment marks should be placed on both the knuckle and the strut bracket, whether or not an adjustment is provided (Figure 14.10).

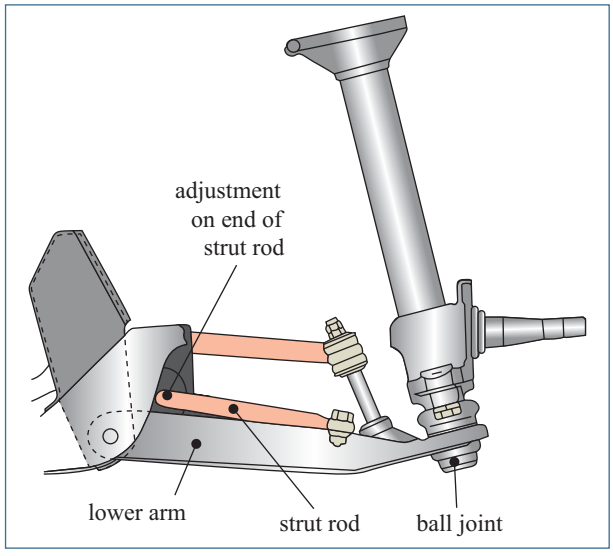


Figure 14.9 Strut suspension—caster adjustment is provided at the threaded end of the strut rod

Figure 14.10 Alignment marks are placed on the knuckle and brack et before dismantling

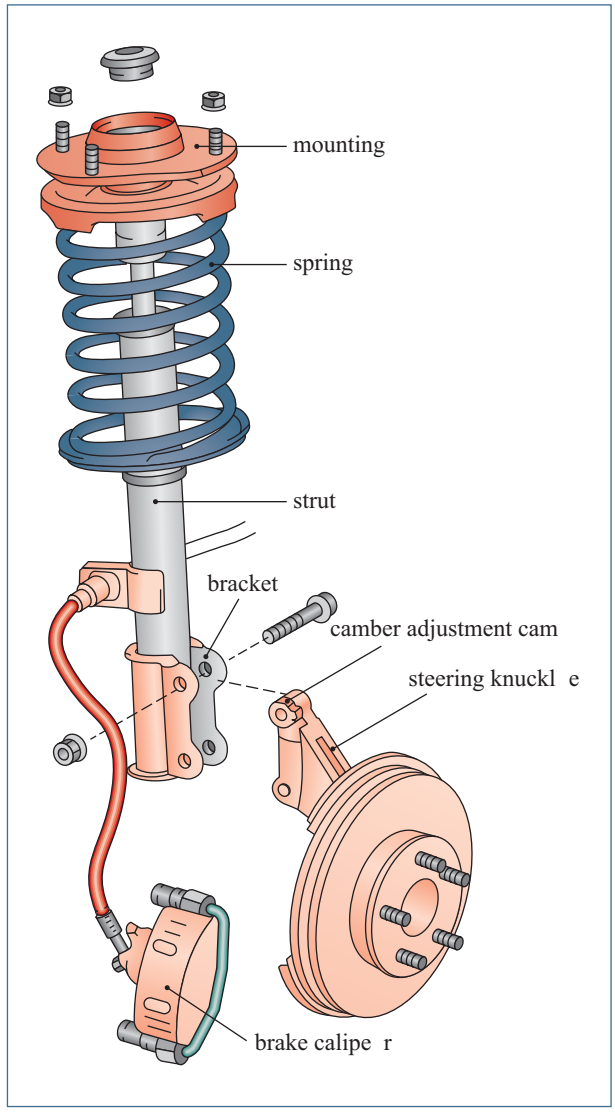


Figure 14.11 Front strut with camber adjustment

Figure 14.11 shows a strut suspension with a camber adjustment. This consists of a cam (eccentric bush) fitted to the upper bolt hole of the knuckle. The camber is adjusted by loosening the bolt, then turning the cam to move the top of the knuckle in or out.

Handy hint: Marking the parts will enable them to be reassembled correctly .

14.3.2 Ball joint suspension adjustments

Some ball joint suspensions have adjusting shims between the upper control arm mountings and the subframe. With wishbone-type control arms, the shims can be fitted at both the front and rear mountings. Caster and camber can be adjusted by removing and installing shims.

If shims of equal thickness are added to (or removed from) both mountings, the upper ball joint will be moved sideways to alter camber. If shims are removed or replaced unevenly at the mountings, the ball joint will be moved backwards or forwards to alter caster.

Caster adjusters

Figure 14.12(a) shows one method of adjusting caster. This alters the length of the strut that is fitted between the lower control arm and the subframe. The end of the strut is threaded and mounted to the subframe with rubber bushes secured by nuts. If the strut rod is lengthened, caster is increased and vice versa.

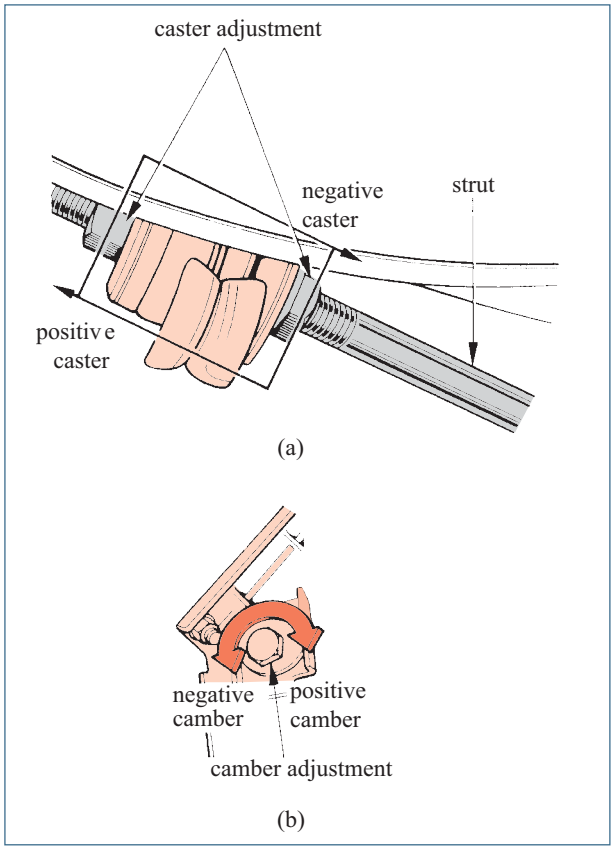


Figure 14.12 Caster and camber adjustments (a) caster adjustment by altering the length of the strut rod (b) camber adjustment by a cam at the inner end of the lower control arm

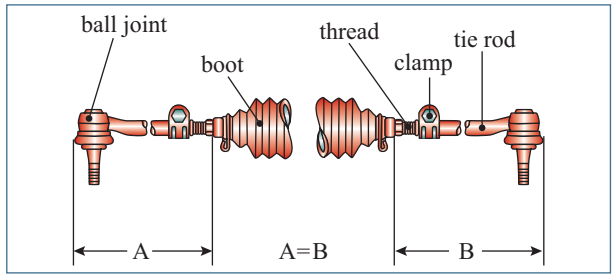


Figure 14.13 The tie rods should be equal in length

Figure 14.14 Adjusting tie rod length

Camber adjusters

An example of a cam-type camber adjuster is shown in Figure 14.12(b). This is used on the inner mounting of either the upper or the lower control arms. The cam enables the control arm to be moved inwards or outwards to alter the camber angle of the wheel. The cam is fitted to the bolt, so when the bolt is turned, the camber is changed.

Handy hint: There are other types of eccentric adjusters that are used in the ends of control arms.

14.4 Toe adjustments

Toe adjustment of the front wheels is provided on all vehicles. This is in the form of threaded adjustments on the tie rods or, in some cases, a single adjustment on the track rod. The location of the adjustment is dependent on the type of steering linkage.

14.4.1 Toe adjustment for rack-and-pinion steering

For rack-and-pinion steering, the tie rods should be adjusted to be of equal length (Figure 14.13), otherwise both the steering wheel and the rack in the steering box will be off-centre. In some cases, the tooth clearance between the rack and the pinion could also be affected.

To adjust the toe of the wheels:

1. Hold the tie rod with one spanner and loosen the locknut with another (Figure 14.14).
2. Loosen the clamp on the outer end of the boot, or bellows, so that it does not twist when the tie rod is being turned.
3. Turn the tie rods to increase or decrease their length as required. Both tie rods have right-hand threads. (The inner ball joint allows the tie rod to be turned.)
4. Adjust both tie rods by an equal amount.
5. After completing the adjustment, tighten the locknut.
6. Straighten the boot and tighten the clamp .

Handy hint: The tie rods must be adjusted evenly so that they are the same length when the adjustment is completed.

14.4.2 Toe adjustment of linkage steering

Figure 14.15 shows the linkage for a steering system with a worm-type steering box. This has a centre track rod and two tie rods that connect it to the steering arms at the wheels.

The track rod is not adjustable, but adjustments are provided on the tie rods to enable their length to be altered. The tie rods have a left-hand thread on one end and a right-hand thread on the other.

The tie rods should be set so that both are of equal length, as unequal lengths will cause the steering box to be off-centre, and the steering-wheel spokes to be out of position. In some steering-linkage arrangements, unequal tie rods will affect toe-out-on-turns. To adjust toe on this type of linkage, proceed as follows:

1 If the steering-wheel spokes are in their normal position with the wheels straight ahead, lengthen or shorten both tie rods equally to obtain correct toe-in.
2 If the steering-wheel spokes are not in their normal straight-ahead position, make the necessary tie-rod adjustments to obtain correct toe-in and steering-wheel spoke position.

Handy hint: The steering wheel should also be correctly positioned on the mainshaft, with the steering box centred.

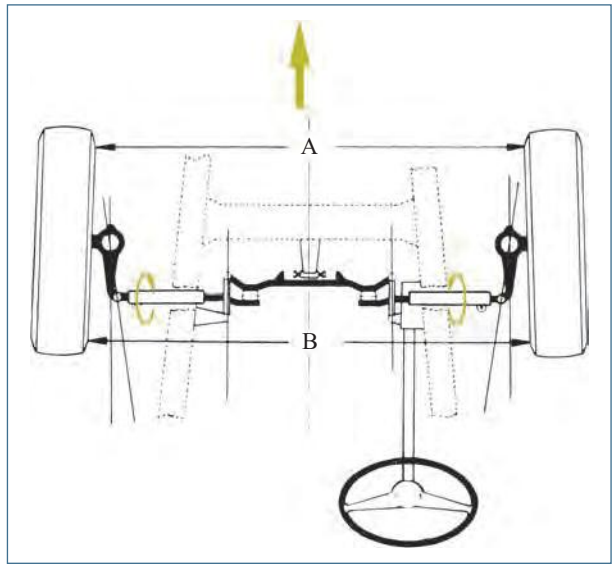


Figure 14.15 Toe-in adjustment by altering tie rod lengths—toe-in is equal to dimension B minus dimension A FORD

14.4.3 Effects of incorrect toe

Any change that occurs in the front-end alignment will nearly always alter toe. This will produce a cross-wear pattern on the tyres (Figure 14.16). For normal straight-ahead driving, the tyres must present themselves to the road surface parallel to each other and parallel to the centreline of the vehicle. If, due to incorrect toe-in or toe-out, this does not occur, the tyre will wear with a round edge on one side of the tread and a sharp edge on the other. This wear can be felt by passing the hand across the tread from side to side. If toe-out is excessive, the sharp edges will be on the outer edges of the tread. If toe-in is excessive, the sharp edges will be on the inner edges of the tread. These two conditions are shown in the illustration.

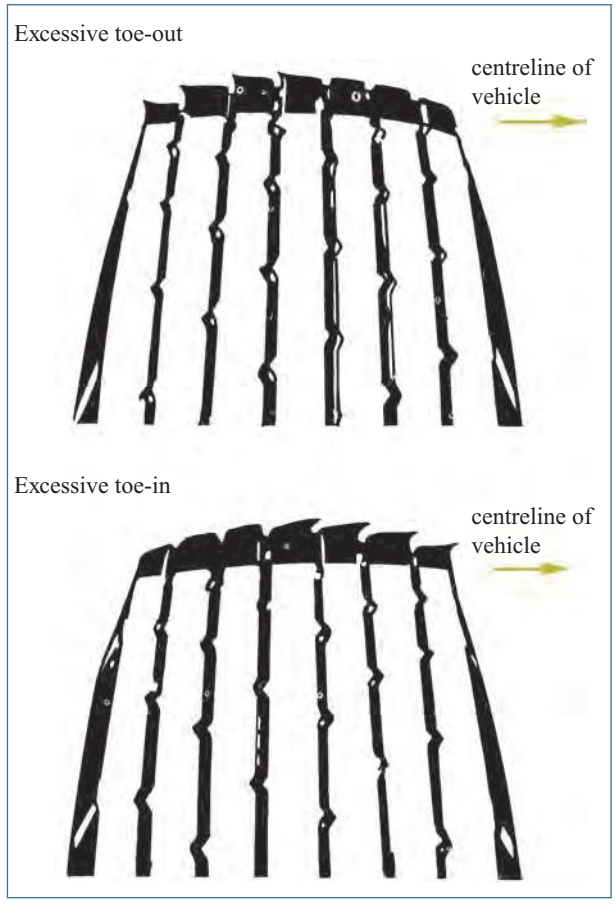


Figure 14.16 Left-hand front tyre showing wear and feathered edges due to incorrect toe

These conditions exist because with either excessive toe-in or toe-out, the face of the tread is not 'square' with the road surface, but one edge is ahead of the other. Wear will cause the leading edge to become round and the trailing edge to become sharp. With excessive toe-out, the tyre is turned so that the inside edge of its tread is leading. Consequently, this edge will wear 'round' while the outside edge will become sharp. The opposite condition applies for excessive toe-in.

14.5 Adjustments for toe-out-on-turns

When the wheel on the outside of a turn is turned 20°, the inside wheel should turn through a greater angle as specified for the particular vehicle (for example, 23°). If this angle is incorrect, there are two possible reasons: a steering arm is bent or the tie rods are of different lengths.

14.5.1 Bent steering arm

The steering arms for most passenger and light commercial vehicles are part of the steering knuckle. If the steering arm is bent, the angular movement of the wheel will be affected and the steering knuckle will have to be replaced. If the parts are accessible, a quick check of the steering arm can be made by measuring between the centre of the tie-rod ball joint and the brake dust shield. This can be compared with a similar measurement taken of the other side. If both measurements are not the same, then one steering arm is bent.

Handy hint: The linear movement of the ball-joint end of the steering arm and the angular movement of the wheel that it produces have to be considered when dealing with toe-out-on-turns.

14.5.2 Uneven tie rods

This applies to worm steering-box linkages. Their tie rods have to be of equal lengths so that the pitman arm and the idler arm will be in their correct positions. Both these arms should be parallel with each other and with the centreline of the vehicle. If the check of the tie rods reveals that they are of equal length, then the cause is probably a bent steering arm. The steering arm, or the steering knuckle, should be replaced.

Handy hint: The maximum difference allowed between the lengths of the tie rods is about 3 mm.

14.6 Rear-suspension adjustments

Independent rear suspensions are subject to variations in toe and camber. Generally, these angles are built into the vehicle and do not alter unless parts are bent or bushes worn, but adjustments are provided on some vehicles. With rigid rear axles, the axle housing holds the wheels in their correct position and there are no adjustments.

14.6.1 Strut-type rear suspension

Figure 14.17 illustrates a toe-in adjuster for a strut-type rear suspension. This is for a front-wheel-drive vehicle, so the rear wheels are non-driving wheels. The suspension has two lateral control links and the adjuster is located at the inner end of the rear link. The toe can be adjusted by turning the adjuster, which has a cam action. This will move the rear control link in or out, so altering the toe of the wheel.

For rear wheels, zero toe-in is required when the vehicle is on the road. A typical specification for toe-in is zero, plus or minus 3 mm.

14.6.2 Independent rear suspension (RWD)

The control arms and hub assembly for an independent rear suspension for a rear-wheel-drive vehicle are shown in Figure 14.18. This has adjustments for both camber and toe. A cam adjuster is fitted between the end of the upper control arm and the top of the knuckle. This enables the top of the knuckle to be moved in or out to alter the camber of the wheel.

The *toe link* is a rod that is connected between an arm at the side of the knuckle and the subframe. There is a toe link for each side of the suspension. The toe of

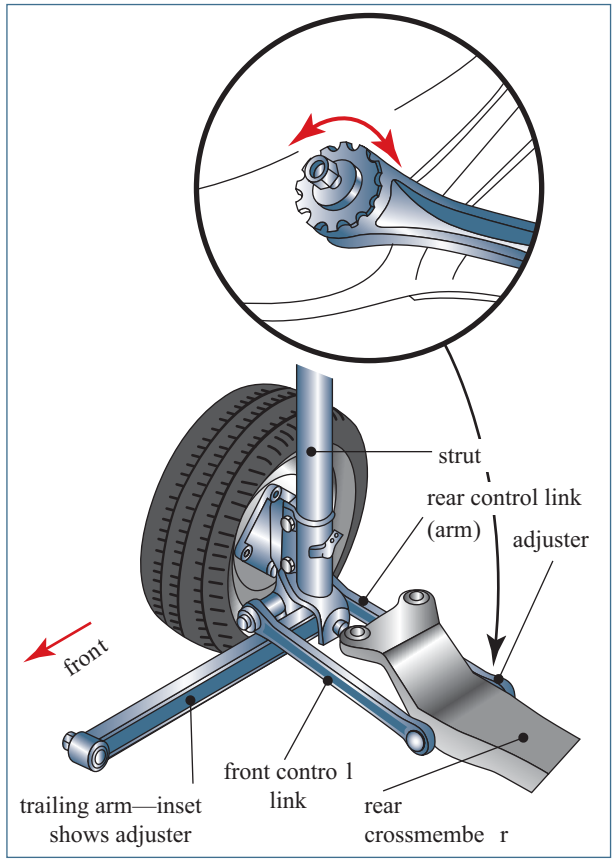


Figure 14.17 Independent rear suspension

the rear wheels can be adjusted by altering the length of the toe link. Shortening the rod toes the wheels in and lengthening the rod toes the wheels out.

Handy hint: The rods on both sides are adjusted so that each wheel has the s ame toe.

14.7 Wheel-alignment equipment

Wheel-alignment equipment can be divided into portable equipment and installed equipment (or wheel-alignment machines). All types consist of turntables, on which the front wheels are supported so they can be turned from lock to lock, and gauges (a form of protractor, for measuring angles). The variety of equipment means there will be different types in different workshops. Portable equipment is used in many general workshops; installed equipment is used where there is a large volume of wheel alignment and front-suspension work.

Safety: Follow procedures for safe manual handling of wheels and wheel-alignment equipment, and use PPE such as safety glasses when working under vehicles.

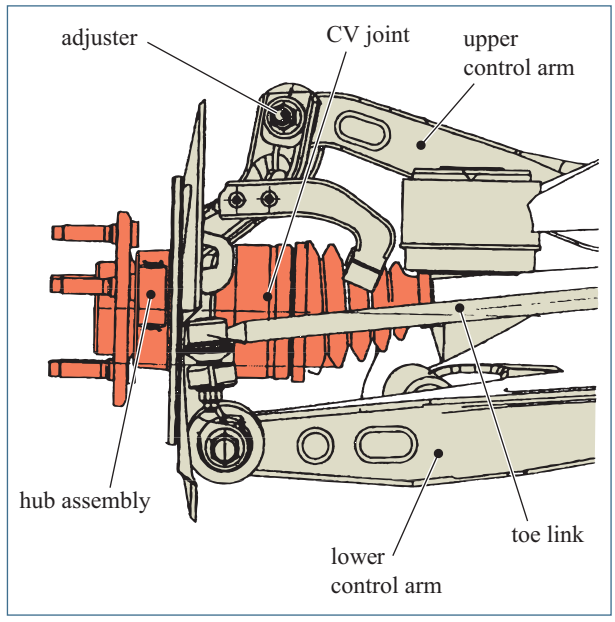


Figure 14.18 Control arms and hub for an independent rear suspension with adjuster for camber and toe (rear-wheel-drive vehicle) FORD

14.7.1 Portable aligners

Portable aligning equipment must be set up with the vehicle on a level floor. Turntables are placed under the front wheels, and packing pieces of the same height as the turntables are placed under the rear wheels (Figure 14.19). (Without the packing pieces, the vehicle will be a little higher at the front, affecting caster readings.) With the wheels facing straight ahead, the zero mark on the turntable is aligned with a mark on the base plate. The turntables allow the wheels to be turned from lock to lock, with measurements read in degrees.

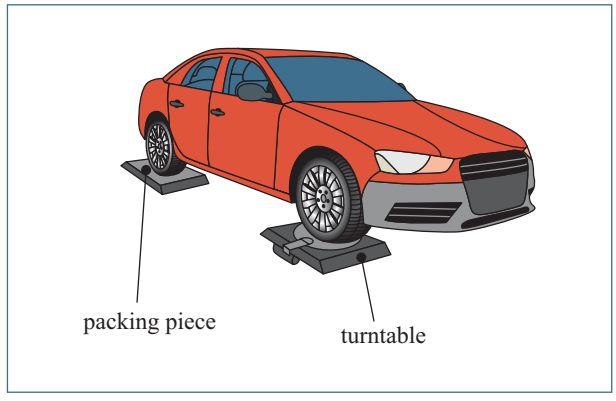


Figure 14.19 Vehicle on turntables that are used with portable aligning equipment

14.7.2 Turntables

Turntables have a degree scale to show the angle through which the wheel is turned. Also used when checking caster and toe-out-on-turns, they can additionally check the maximum angle that the wheels can turn.

Toe-out-on-turns can be read directly from the protractor scale on the turntables by turning the outside wheel through an angle of 20° and reading the angle shown on the protractor for the inside wheel. This should agree with the manufacturer's specifications, usually 23°, but may vary for different models of vehicles.

Handy hint: Turntables are used with both portable and installed equipment.

14.7.3 Wheel-aligners

Wheel-alignment equipment that is permanently in position is referred to as a 'wheel aligner'. Aligners can have a low ramp, with all the equipment mounted above the floor level. The vehicle is driven onto the ramp to raise it above the floor, so that the suspension is accessible. Other aligners have a hoist, which allows the vehicle to be adjusted to the required working height (see Figure 14.22).

Wheel-alignment equipment can also be installed with the gauges at floor level, with access to the suspension from a pit in the floor under the vehicle. All these aligners have equipment for measuring the various steering and suspension angles. The ramp, hoist or pit allow work to be carried out while the front wheels of the vehicle rest on turntables.

14.8 Types of wheel aligners

In general, wheel aligners are of the following types:

1 Laser aligners. These use laser beams, which project onto degree scales.
2 Visual aligners. These have a video display unit, which displays readings from the gauge heads. They also use computer control.
3 Camera aligners. High-resolution cameras produce 3D modelling of all four wheels for display on a computer screen.

14.8.1 Laser wheel aligner

A laser wheel aligner is a type of optical aligner that is used on the floor or on a hoist. It has mini-lasers which project a small spot onto a target scale. The principle of this type of aligner is shown in Figure 14.20. Laser beams are projected from the front of the vehicle to targets with a degree scale at the rear wheels. The track of the vehicle can be checked by comparing the readings of each side.

At the front of the vehicle, laser beams are projected from side to side to check toe. Similar equipment is installed at both wheels. The laser beams are directed to target scales on their opposite sides. The scale shows the toe reading of the wheel from which the beam is being projected. Added together, the readings of both scales give the total toe. Rear-wheel alignment can be checked with the equipment mounted to the rear wheels in a similar way to the front.

14.8.2 Visual aligners

Aligners with a video display unit have this mounted in a console. These are computerised units that display option menus from which alignment procedures can be selected (Figure 14.21(a)). Readings from sensors in the wheel head are displayed on the video screen (Figure 14.21(b)). A printer can be used with the computer in the console to provide a printed copy of the various angles and settings.

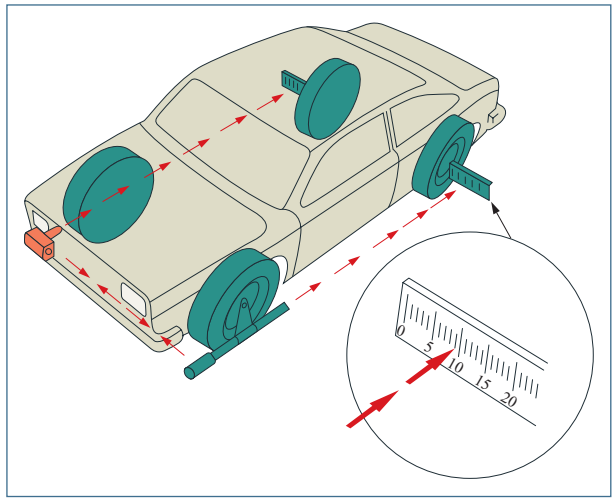


Figure 14.20 Target scales mounted on the rear wheels are used to check track

14.8.3 Camera aligners

The vehicle is driven onto a hoist, which has turntables for the front wheels. The hoist can placed at the desired height when carrying out checks and adjustments (Figure 14.22). Cameras mounted on

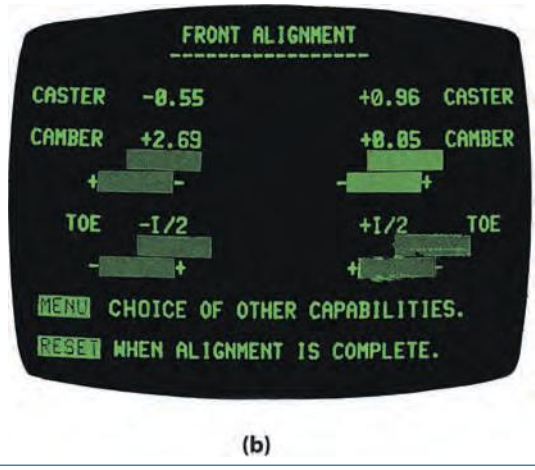


Figure 14.21 Display screen of a wheel aligner (a) menu is displayed to enable options to be selected (b) readings displayed on screen

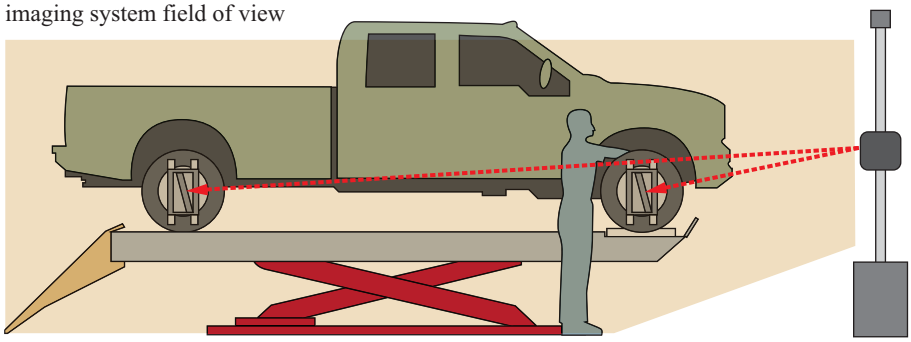


Figure 14.22 Camera aligner tracking the vehicle as it is raised or lowered

vertical tracks at the front of the vehicle are aimed at targets clamped to the vehicle's wheels. The cameras track up and down as the vehicle is raised or lowered, so that they are always correctly aimed. All of the wheel-alignment information from the cameras is displayed on a computer monitor, as shown in Figure 14.23.

14.8.4 Other wheel-alignment methods

There are many aligners other than the ones shown. Some are mechanical, some optical and some electronic; others are combinations.

Handy hint: The wheels must be in the straight-ahead position when checking toe .

Figure 14.23 Visual display of wheel alignment of caster , toe-out-on-turns and maximum steering angle SNAP-ON

14.9 Using wheel aligners

There are three different sets of operations when carrying out a wheel alignment:

1 Pre-alignment checks of the vehicle .
2 Setting up the vehicle and/or setting up the equipment on the vehicle .
3 Checking the various angles and making the necessary adjustments.

There are some common practices for use of wheel-alignment equipment, but there are also many variations so it is necessary to refer to the relevant manufacturer's operation manual.

14.9.1 Pre-alignment checks

Before carrying out wheel alignment or making any front-end or rear-end corrections, all steering and suspension parts should be in serviceable condition. A visual check of frame alignment should be carried out, with checks made as shown in Figure 14.24.

Vehicle kerb/ri de height

The vehicle kerb/ride height or ground clearance is an important measurement that should be checked before carrying out a wheel alignment. It can affect the toe, caster and camber angles. It can be carried out by taking a measurement from the floor to the front guard well, bumper or control arm. It is caused by sagged springs, worn suspension components or twisted body. Always check the manufacturer's specifications for vehicle height measurement.

Tyres

The tyres should be checked for wear and, if necessary, replaced. They should be inflated to the correct pressure.

Wheel runout

With some types of wheel-alignment equipment, wheel runout is checked as part of the setting up of the vehicle on the machine. It can also be checked with a piece of chalk held against the side of the tyre while the wheel is rotated. The true plane of the wheel should then be identified. This is at 90° to the maximum runout position as shown by the chalk mark.

When checking caster and camber, the wheel should be turned so that the mark on the tyre is at either the top or the bottom. When checking toe, the mark on the tyre should be at the front or back.

Handy hint: Using the true plane of the wheel will reduce the effects of runout and provide more accurate readings.

Wheel bearings

The wheel bearings should be checked for looseness and, where necessary, adjusted. Non-adjustable bearings will have to be replaced if there is looseness.

Steering

The steering and suspension should be checked for looseness. The condition of the ball joints and steering connections can be checked by having an assistant move the steering wheel with a rapid side-to-side movement of about half a turn. While this is being done, each steering ball joint should be checked for looseness.

Suspension parts

The vehicle should be raised on a jack, and the ball joints, control arm bushes and other suspension parts checked for looseness and wear. The shock absorbers should also be checked and their bushes and the stabiliser bar bushes should be replaced if necessary.

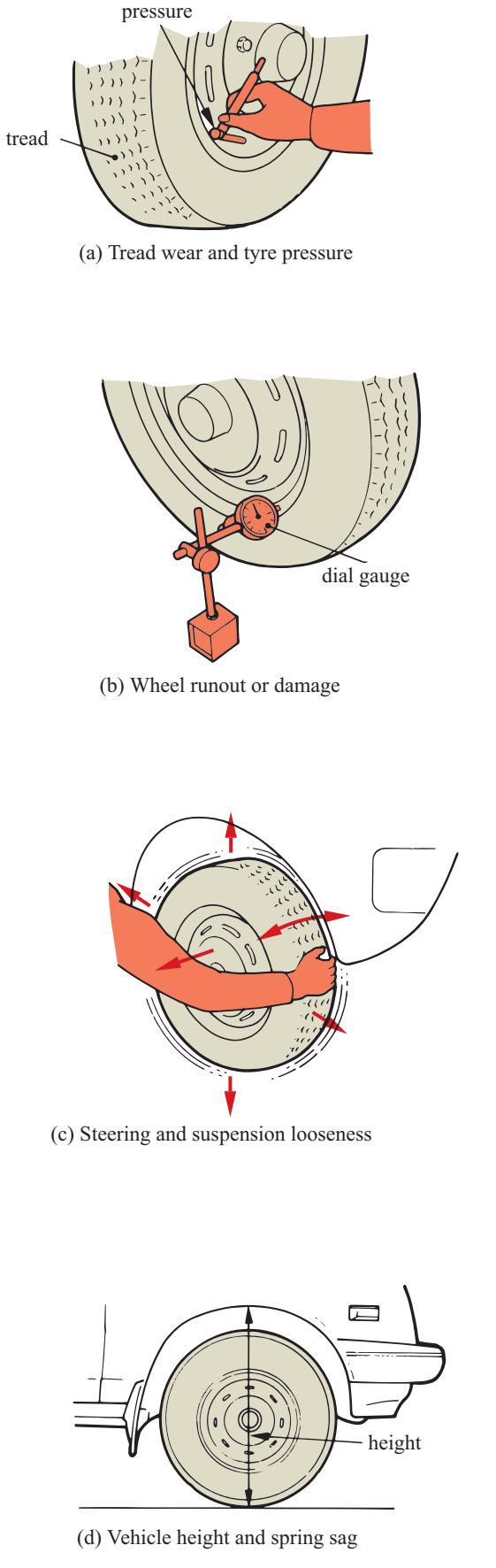
Check of vehicle height

Weak springs will cause a change in the height of the vehicle. A sagging spring will not only lower its own part of the vehicle but can affect the other springs. For example, if a rear spring has sagged, it will lower that part of the body and also tend to raise the front of the vehicle on the opposite side.

Handy hint: Uneven vehicle height will affect the suspension angles.

14.9.2 Setting up the vehicle or equipment

The vehicle should be correctly set up on the machine or turntables and clamps or other attachments fitted



(a) Tread wear and tyre pressure

(b) Wheel runout or damage

(c) Steering and suspension looseness

(d) Vehicle height and spring sag

Figure 14.24 Checks before a wheel alignment

to the wheels. Figure 14.25 shows one design of wheel aligner set up on a vehicle. The following are considerations when setting up equipment.

1 The turntables are positioned to suit the track of the vehicle so that their centres are in line with the centres of the tyres of the front wheels.
2 To prevent damage , the gauge heads and other equipment should be well clear of the vehicle until ready for use.
3 The turntables should be set with their scales on zero , with the wheels straight ahead.
4 The gauge heads should be correctly installed as any errors or looseness will result in inaccurate readings.
5 With portable aligners, the level of the vehicle is important.

Figure 14.25 Vehicle on turntables set up for a wheel alignment

14.10 Front-wheel alignment

The most efficient procedural sequence to follow for a front-wheel alignment check is:

1 Check caster .
2 Check camber .
3 Check toe .
4 Check toe-out-on-turns.

The sequence starts with caster because any adjustment of this can affect both camber and toe. For an independent rear suspension, the alignment of the rear wheels can be checked after alignment of the front wheels. Before commencing the checks, the front and rear of the vehicle should be bounced up and down to stabilise its height (Figure 14.26). This should also be done after making an adjustment.

14.10.1 Checking caster

The caster of each wheel is checked by:

1 Turning the wheel in one direction a specified number of degrees.
2 Adjusting the gauge .
3 Turning the wheel the same number of degrees in the opposite direction.
4 Reading the caster angle from the gauge .

This applies generally to all aligners, although there are many variations. On some aligners, the angle that the wheel is turned is set from the degree scale on the turntables. On others, degree markings on a screen or meter are used.

Handy hint: What is actually being measured is the change in camber angle at the two positions, but **this is read from a scale calibrated to show the change in camber as degrees of caster.**

14.10.2 Checking camber

The camber measurement is carried out as a separate operation at each front wheel. The wheels are placed in the straight-ahead position and the camber reading taken directly from the camber scale.

14.10.3 Checking toe

Checking toe involves measurement at both wheels as one operation. Set the wheels in the straight-ahead position and read the toe from the gauge. This will show a reading of toe-in or toe-out.

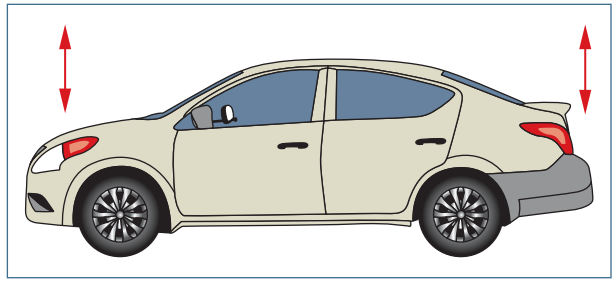


Figure 14.26 The front and rear of the vehicle should be bounced up and down before checking the wheel alignment, and also after adjustment

14.10.4 Checking toe-out-on-turns

The measurement is carried out as a separate operation for each wheel. In each case, the gauge sets the outer wheel before taking the reading at the inner wheel.

1 Turn one wheel inwards at the front through 20 °. This angle is set by turning the wheel until the pointer shows exactly 20° on the scale . Read the angle that the other wheel has turned from the scale of its gauge .
2 The second reading should be greater than 20 °, for example , 23 ° (refer to manufacturer' s specifications).
3 Measure the angle of the other wheel in a similar way . Both wheels should have the same toe-out angle.

Handy hint: A bent steering arm could be the cause of incorrect toe-out-on-turns.

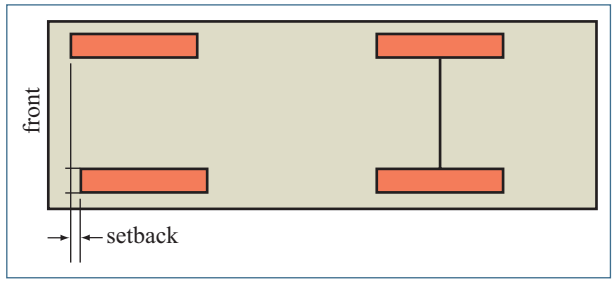


Figure 14.27 Misalignment of one front wheel to the opposite wheel

14.10.5 Setback

Setback is when one front wheel is set back further than the other front wheel. Figure 14.27 shows wheel setback that is often caused by bent suspension components or bent body. Up to 5 mm tolerance is normal. A good four-wheel-drive aligner will reference the front to rear when setting toe to compensate for any misalignment.

14.11 Rear-wheel alignment

The rear wheels can be checked for alignment. With independent rear suspension, toe, camber and track of the wheels could be subject to variation. With rear-wheel-drive vehicles, misalignment of the rear-axle assembly could be possible. Rear-wheel camber and toe can be checked by using similar procedures to those used for the front wheels.

14.11.1 Thrust line

The thrust line of a rear-wheel drive should be in line with the centre of the vehicle. Any variation is called the *thrust angle* and will cause steering problems if excessive (Figure 14.28). The rear toe must be adjusted first to compensate for variations. If the rear is not adjustable, the front toe must be set to allow the steering to be centred.

14.11.2 Track

The track (width) of the front wheels can be wider than the track of the rear wheels; but regardless of any difference in track, all four wheels should be parallel when the front wheels are in the straight-ahead position. The wheels should also be evenly spaced on each side of the vehicle centreline. Wheel aligners enable appropriate checks to be made of all four wheels.

Figure 14.29 shows one type of error where the wheels are parallel but the rear wheels are not spaced evenly in relation to the vehicle centreline. The dimensions shown as A and B should be equal, but with a tolerance of about 5 mm maximum. Other possible problems with track are where one side of a rear axle has swung to the rear, or where one independent rear suspension has moved out of position for some reason, such as worn or damaged suspension parts.

14.12 Function and effects of the various angles

The following section considers the function of the various steering and suspension angles. It also considers their relationship. Understanding these can help with diagnosis and explains why certain things are done when using wheel-alignment equipment.

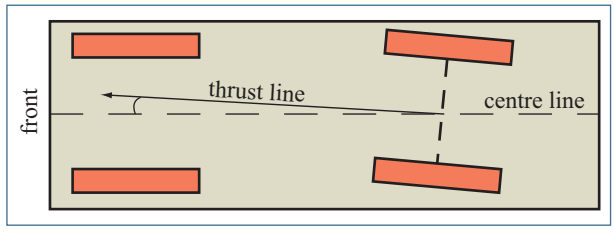


Figure 14.28 Misalignment of the rear axle to centre line of the vehicle

Handy hint: The following sections relate to a wheel spindle , but also apply to suspensions with steering knuckles and hubs.

14.12.1 Function of steering-axis inclination (SAI)

If there is no steering-axis inclination (SAI), the end of the wheel spindle would move parallel to the road surface as it was moved from lock to lock. The wheel would always be vertical, as is the case with the wheel in Figure 14.5(b). However, with the steering axis inclined inwards (as in Figure 14.5(a)), the end of the wheel spindle will move downwards as it is moved from the straight-ahead direction towards each lock. This is shown in simplified form in Figure 14.30. The camber of the wheel will also alter, being close to zero when the wheel is straight ahead but increasing as the spindle is turned towards each lock.

Effects of incorrect SAI

Without steering-axis inclination, the tendency for a wheel to toe-out would be increased. As a vehicle with rear-wheel drive moves along the road, the resistance caused by contact with the road surface tends to push the wheel towards the rear, causing toe-out.

Relating this to Figure 14.5(b), a force is applied at point A, which tends to turn the wheel about the steering axis (line B) and so force the wheels to toe-out. If one wheel had no steering-axis inclination, it would have more toe-out than the other wheel and the vehicle would tend to steer in the direction of least toe-in. This applies to a rear-wheel-drive vehicle. In the case of a front-wheel-drive vehicle, the opposite will occur: the front wheels will be pulling and the tendency would be for the front wheels to toe-in.

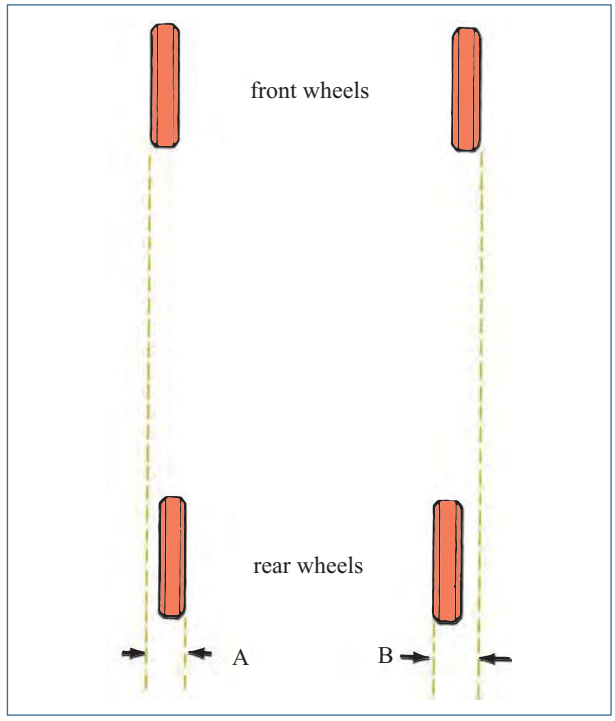


Figure 14.29 Misalignment of the front and rear wheels

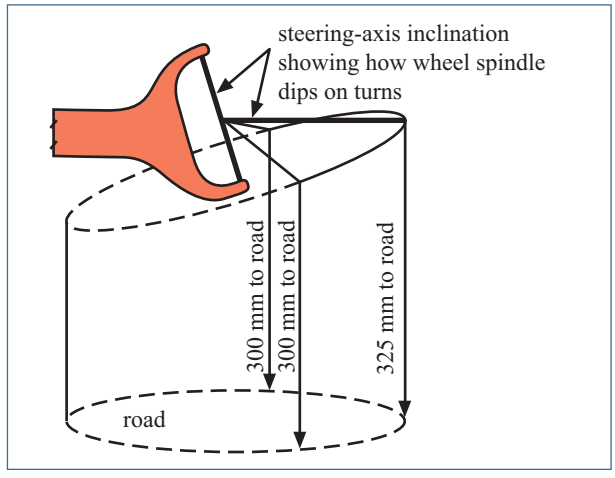


Figure 14.30 Steering-axis inclination causes the end of the wheel spindle to rise and fall when turned from lock to lock

Directional stability of SAI

Steering-axis inclination also helps to keep the wheels pointing straight ahead and gives directional stability. SAI causes the end of the wheel spindle to dip when pivoted in either direction, and this tries to force the wheel harder against the ground. It cannot do this, but instead tends to lift the front of the vehicle. This occurs whenever a turn is made. The mass of the vehicle resists this and so provides a downward force, which tries to bring the wheel spindle back to its original position. This helps with directional stability.

14.12.2 Function of caster

The top of the steering axis is inclined towards the rear to provide caster and, as a result, the end of the spindle will drop further when turned to the rear than when turned to the front; there will be more caster when the spindle is turned to the rear than when it is turned to the front.

As previously indicated, caster tries to move the end of the wheel spindle closer to the ground when the wheel is turned to the rear, and this tends to lift the front of the vehicle. The mass of the vehicle opposes this and, in doing so, tries to make the wheel turn forwards, or toe-in—so caster tends to cause toe-in.

With equal caster at both wheels, the tendency to toe-in is equal. However, if the wheels had unequal caster, the one with the most caster would try to steer the vehicle away from that side. Excessive caster can make a wheel shimmy at low speeds. If the wheel strikes a bump and is deflected, the excess caster will cause over-correction and the wheel will shimmy from side to side.

Handy hint: Insufficient caster has the opposite effect: the wheel will not remain in the straight-ahead position, and this can cause the vehicle to wander .

14.12.3 Function of camber

A wheel with excessive positive camber will wear on the outside of the tyre, while a wheel with excessive negative camber will wear on the inside of the tyre. Uneven camber angles tend to cause the vehicle to steer towards the side with more camber. Where one wheel is heavily cambered, the tyre accepts greatest load on the outside of the tread and so becomes cone-shaped. The tyre then tends to roll outwards, steering the vehicle in that direction. It is therefore necessary to have camber equal on both wheels.

Camber variation and caster

Camber angle changes when the wheel is turned. This is due to the caster angle, which causes the end of the wheel spindle to drop when turned to the rear and rise when turned to the front. Because the end of the spindle drops when turned to the rear, the top of the wheel moves outwards to increase camber. Also, because the end of the spindle lifts when turned towards the front, the top of the wheel moves inwards to reduce camber. There are a number of other points that relate to suspensions and their angles.

Handy hint: It helps to be aware that such changes occur . When caster is being check ed, the angles are not measured directly; caster is found by measuring the change in camber as the wheel is turned from rear to front.

14.12.4 Included angle

The included angle is a combination of steering-axis inclination and camber. For example, if the steering-axis inclination is 7° from vertical and the camber angle 2°, then the included angle will be 9°. In some types of suspensions, camber is not adjustable, but the steering-axis inclination angle is adjustable. When camber is checked and has to be adjusted, it is the steering-axis inclination that is actually altered. The included angle remains the same.

Handy hint: Some strut suspensions that **have the steering knuckle bolted to the lower** end of the strut have an adjustment that actually alters camber (see Figures 14.10 **and 14.11).**

14.12.5 Point of intersection

The point of intersection is the point at which a line through the steering axis and the wheel centreline intersect. This is the point about which the wheel actually pivots. The point of intersection can be at the road surface, but it is usually designed to be above or below it. Figure 14.31 shows a ball joint suspension with the point of intersection below the road surface.

Two other points can be identified in the illustration: the point where the line of the steering axis passes through the road surface and the contact point of the centre of the tyre on the road. The distance

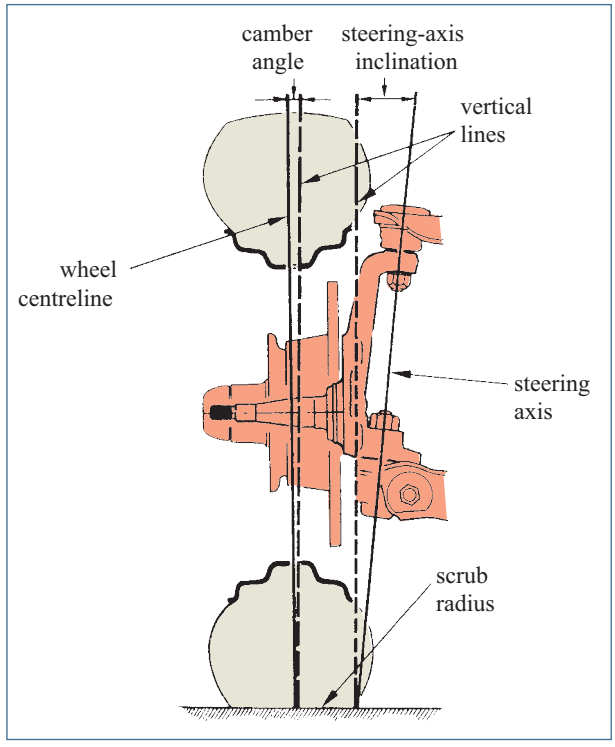


Figure 14.31 Ball joint suspension showing camber angle , steering-axis inclination and positive scrub radius (exaggerated)—the point of intersection is below the road surface

between these two points is known as the *scrub radius.* This is exaggerated in the illustration.

14.12.6 Scrub radius

If the point of intersection is below the road surface, then there will be *positive scrub radius.* If the point of intersection is at the road surface there will be *zero scrub radius,* and if the point of intersection is above the road surface there will be *negative scrub radius.* With zero scrub radius, the tyre will pivot on the road at the point of intersection. This will offer little resistance to turning, but there will be some resistance where either positive or negative scrub radius exist.

Handy hint: Scrub radius is also called camber offset.

Positive scrub radius

The front suspension shown in Figure 14.32 is for a rear-wheel-drive vehicle, and this has positive scrub radius. In operation, the wheel will tend to toe-out. Being a rear-wheel-drive vehicle, the wheel is being pushed in a forward direction by the vehicle, but the reaction force from the road tends to push the wheel back. Since it is positive scrub radius, a turning effect is produced which tends to cause the wheel to toe-out. If the suspension had negative scrub radius, this would have the opposite effect.

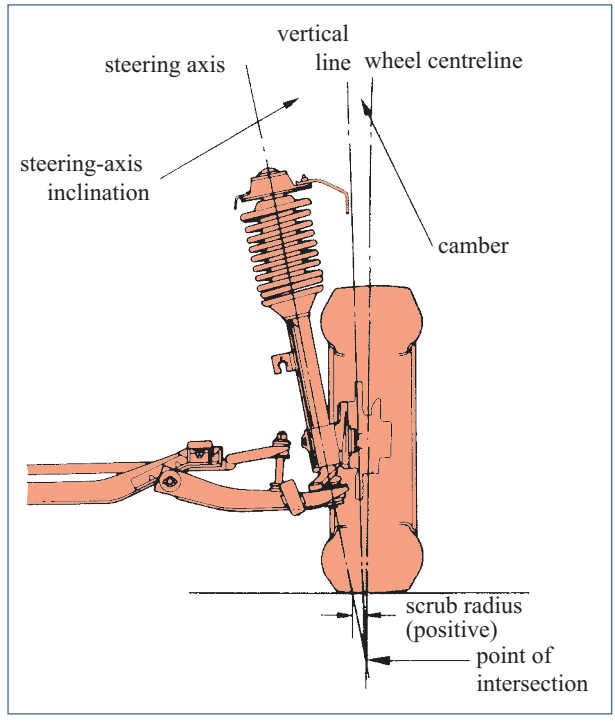


Figure 14.32 Front suspension with positive scrub radius FORD

Negative scrub radius

Figure 14.33 shows a front suspension for a front-wheel-drive vehicle. This has the point of intersection above the road surface and so has negative scrub radius. Being a front-wheel drive, the wheel is pulling and not being pushed, so the effects are the reverse of those that occur with a rear-wheel-drive vehicle. The negative scrub radius tends to produce toe-out because, at the road surface, the pulling force at the centre of the tyre is on the inside of the steering–axis line.

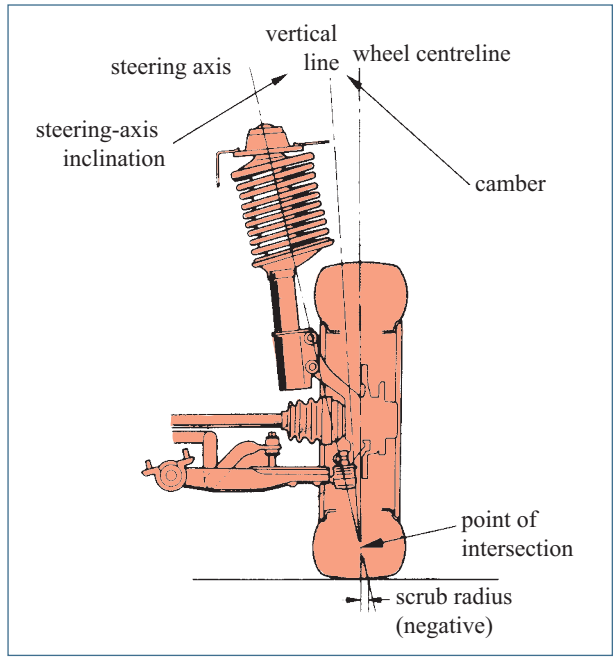


Figure 14.33 Front suspension with negative scrub radius FORD

Scrub radius and braking

Negative scrub radius also improves the directional stability of the vehicle when braking, particularly if one circuit of a diagonally split braking system should fail. If this occurs, only one front wheel will provide braking and the vehicle will pull to that side. However, with negative scrub radius (where the tyre centre is inside the steering-axis line) the braking force of the tyre on the road would tend to turn the wheel towards the centre of the vehicle and so help to counter some of the effects of having only one front brake in operation.

Handy hint: Scrub radius cannot be adjusted, but it will be affected if non-standard wheels or tyres are fitted as this can alter the location of the point of intersection.

Steering angle sensors (SAS) resetting

Various late-model vehicles may require the steering angle sensors (SAS) to be reset or recalibrated after an alignment has been performed or if steering system components have been replaced. There are three main types of reset procedures:

- self-calibration
- pressing specific wires or buttons
- recalibration with a scan tool.

If the steering angle sensors (SAS) calibration is out, most vehicles are able to self-diagnose this when travelling in a straight-ahead positon.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe ways in which wheel alignment can be put out of adjustment
- explain the critical role played by vehicle alignment in vehicle performance
- apply pre-alignment checks
- explain the three main wheel alignment systems
- describe the correct sequence for a front-wheel alignment check
- apply procedures for steering angle sensors resetting.

REVIEW QUESTIONS

1 Name the various steering and front-suspension angles.
2 What is toe-in?
3 What is a likely effect of excessive toe-in?
4 What is toe-out-on-turns?
5 In general terms, how can caster and camber be adjusted?
6 How could toe-out-on-turns be checked?
7 How can a steering arm be checked to determine if it is bent?
8 How can a wheel be checked for runout?
9 Name three different types of wheel aligners.
10 Consider how camber is checked on a wheel aligner.
11 Why would caster be checked before checking camber?
12 Outline the important pre-alignment checks.
13 Why is the alignment of some rear wheels checked?
14 Demonstrate the effects of steering-axis inclination by means of a piece of folded card.
15 What is meant by point of intersection?
16 What is scrub radius?
17 How does steering-axis inclination assist vehicle stability?

PART 3

Engines and engine systems

CHAPTER 15

Engine fundamentals

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 state the operating cycle of automotive engines using the correct terminology
2 apply industry safety requirements
3 inspect and service a range of engines in accordance with workplace and manufacturer/component supplier requirements and specifications
4 document and accurately interpret the results of tests and inspections.

The basic parts of an engine are the cylinder, piston, connecting rod and crankshaft. The piston, of aluminium alloy, is a sliding fit in the cylinder. It has piston rings that provide a gas-tight seal against the cylinder walls.

The engine or internal combustion engine (ICE) converts chemical energy into mechanical energy. The energy is released in the form of heat when the fuel is mixed with air and burnt in the engine cylinders. This is referred to as combustion. The combustion process produces high pressure and high-temperature gases in the cylinder. It is this high pressure that forces the piston down the cylinder to operate the engine.

Most automotive engines have a number of cylinders. A small car engine might have as few as two, while a large engine might have as many as twelve. Similar actions take place in all cylinders.

15.1 Actions within a cylinder

15.1.1 Chemical energy to mechanical energy

The way in which chemical energy is converted to mechanical energy is shown by the movement of the piston in the cylinder in Figure 15.1. The cylinder contains air mixed with a small amount of fuel. The following actions occur within the cylinder of a petrol engine. They are repeated over and over to enable the engine to operate.

1 Compression. The piston is pushed up the cylinder to compress the air–fuel mixture. The mixture consists of tiny particles of fuel (petrol), each surrounded by air. This forms a combustible mixture.
2 Combustion. The piston has been pushed almost to the top of the cylinder to compress the air–fuel mixture into a small space above the piston. This is known as the combustion chamber as this is where burning of the mixture takes place. The air–fuel mixture is ignited by a spark from the spark plug.
3 Power. The pressure created by the burning gases forces the piston down the cylinder, and this action provides the power to operate the engine.

Figure 15.1 Actions in a cylinder that convert chemical energy to mechanical energy

15.1.2 Reciprocating to rotary motion

The up-and-down movement of the piston in its cylinder is called *reciprocating* motion. For this reason, piston engines are sometimes called *reciprocating engines*.

The piston has straight-line motion, but this must be changed to rotary motion. A connecting rod and crankshaft are used for this purpose (Figure 15.2). The connecting rod connects the piston to the crankshaft. The connecting rod has a removable cap, which is bolted to the end of the connecting rod. This is needed so that the connecting rod can be installed on the crankpin. The crankshaft is a 'cranked' (bent) shaft, with a crank for each cylinder. Each crank has a *crankpin* that provides a surface for the bearing in the lower end of the connecting rod.

The piston is held to the upper end of the connecting rod by the *piston pin*. This passes through an eye in the connecting rod and allows a wrist-like action to take place as the crankshaft rotates and the piston moves up and down.

The parts of a piston, connecting rod and crankshaft are shown assembled in Figure 15.2. In Figure 15.3, they are shown dismantled.

15.1.3 Piston strokes

The actions of a piston in a cylinder are divided into strokes. A stroke occurs when the piston moves either from the top to the bottom of the cylinder or from the bottom to the top of the cylinder.

The top of the piston stroke is known as *top dead-centre* (TDC), and the bottom of the stroke as *bottom dead-centre* (BDC) (see Figure 15.4). At each of these positions, the piston virtually stops and changes its direction of travel.

15.1.4 Cycles of engine operation

A cycle is a series of events that repeats itself over and over. The operating cycle of an engine consists of a number of piston strokes. There are two-stroke engines and four-stroke engines. In a two-stroke engine, only two piston strokes are needed for a cycle, and this requires only one revolution of the crankshaft. In a four-stroke engine, the cycle has four piston strokes, thus requiring two revolutions of the crankshaft.

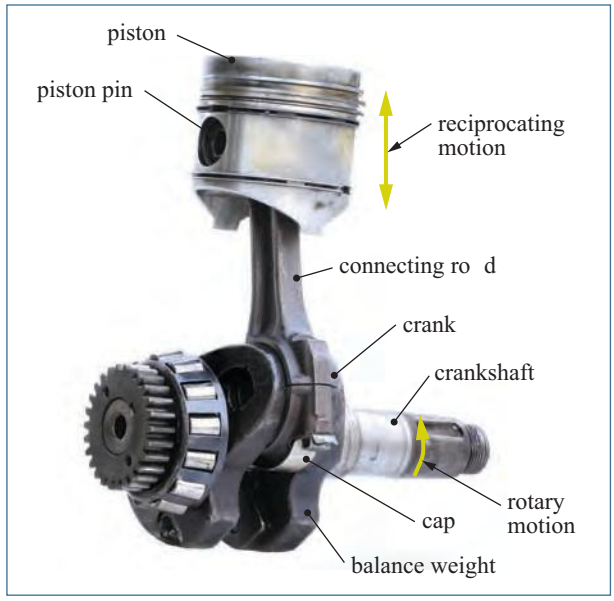


Figure 15.2 Arrangement of a piston, connecting rod and crankshaft showing reciprocating motion SHUTTERSTOCK

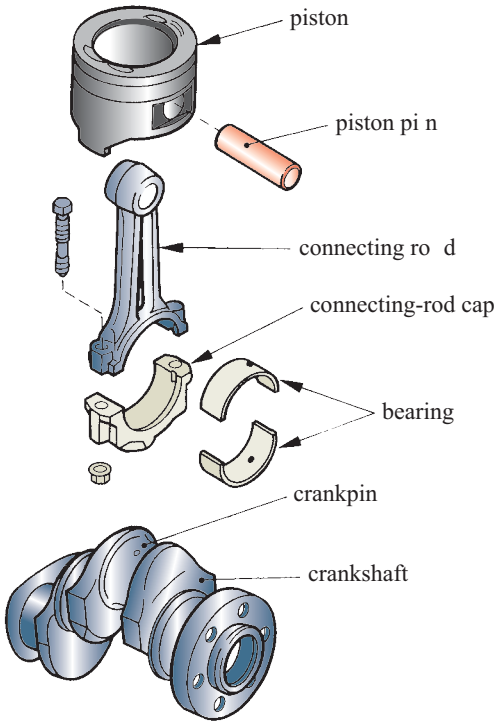


Figure 15.3 Part of a crankshaft, and a piston and connecting-rod assembly

Figure 15.4 Piston stroke positions. Left piston is at BDC, centre piston is at TDC SHUTTERSTOCK

Most automotive engines are four-stroke engines, although some large diesel engines operate on the two-stroke principle. Some small engines, such as those fitted to motor mowers, are two-strokes. Most motor bikes have four-stroke engines, although some have two-strokes. Many marine outboard engines are two-strokes, but some are four-stroke.

The complete cycle for a petrol engine, whether it is a two-stroke or a four-stroke, requires: an air–petrol mixture to be taken into the cylinder; combustion to take place; burning gases to expand and apply force to the piston; the remains of the burnt gases to be exhausted from the cylinder.

15.2 Four-stroke cycle (petrol engine)

For a four-stroke cycle (also known as the *Otto cycle,* after its inventor) there are valves in the cylinder head. These are opened and closed at the correct times by the actions of the camshaft. The intake valve admits the fuel mixture into the cylinder and the exhaust valve releases the burnt gases from the cylinder. Figure 15.5 shows the sequence of the four strokes of a petrol engine during one cycle.

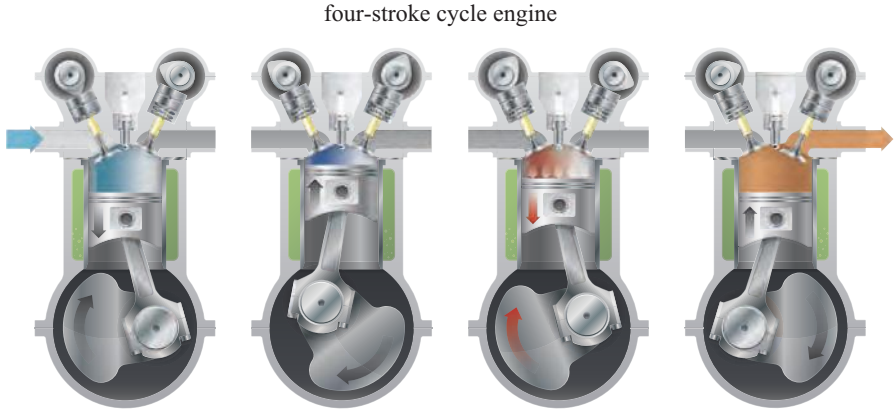


Figure 15.5 The four-stroke cycle of a petrol engine SHUTTERSTOCK

1 Intake. The piston is moving down and air–fuel mixture is drawn into the cylinder through the open intake valve.
2 Compression. The piston is moving up and the air–fuel mixture is being compressed in the cylinder. Both valves are closed.
3 Power. Combustion of the air–fuel mixture has taken place and the piston is being forced down the cylinder by the pressure of the gases.
4 Exhaust. The piston is moving up and forcing the burnt gases out through the open exhaust valve.

These strokes constitute a four-stroke cycle. When the piston reaches TDC on the exhaust stroke, the intake valve will again open to start the cycle over again. This continues as long as the engine is running.

15.2.1 Intake stroke

The intake stroke commences at TDC with the intake valve open and the exhaust valve closed. The piston moves downwards to draw a charge of air–fuel mixture into the cylinder through the open intake port. The mixture of air and vaporised fuel is provided by the engine's fuel system.

Handy hint: The air–fuel mixture is not actually drawn into the cylinder. As the piston moves downwards, it creates a partial vacuum (or negative pressure) and atmospheric pressure forces the mixture into the cylinder.

15.2.2 Compression stroke

When the piston reaches BDC and begins to move upwards on the compression stroke, the intake valve closes. The exhaust valve is already closed, so the air–fuel charge is compressed as the piston moves up the cylinder. By the time the piston reaches TDC, the mixture will be compressed to about one-eighth of its original volume. The pressure in the cylinder will also have increased.

15.2.3 Power stroke

Both valves remain closed during the power stroke. As the piston reaches TDC at the end of the compression stroke, the ignition system produces a spark at the spark plug. The spark ignites the air–fuel mixture, which burns very rapidly to produce gases at high pressure in the cylinder.

The expanding gases force the piston down the cylinder. The force is transferred through the connecting rod to the crankpin, causing the crankshaft to rotate.

15.2.4 Exhaust stroke

As the piston again reaches BDC, the exhaust valve opens but the intake valve remains closed. The piston moves upwards on the exhaust stroke to force the burnt gases out of the cylinder through the exhaust port. When the piston reaches TDC, the exhaust stroke is completed and so is the cycle.

15.2.5 Valve operation

A section through a cylinder head and valves is shown in Figure 15.6. There is an intake valve, an exhaust valve and a mechanism to operate them. The valves are normally held closed by the valve springs, but are opened for certain periods during the operating cycle of the engine. The valve-operating mechanism is called the *valve train.*

The cylinder head shown carries a camshaft, which has a cam for each valve. As it rotates, the cams operate the rocker arms to open and close the valves at the appropriate times.

Cam action lifts one end of the rocker arm, and the rocker arm pivots on its shaft. The other end of the rocker arm moves down against the tip of the valve stem and opens the valve. As the cam continues to rotate, the valve end of the rocker arm rises, and the spring closes the valve.

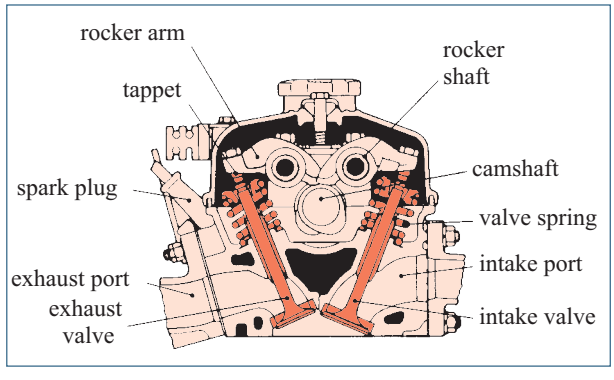


Figure 15.6 Cylinder head and valves for an overhead-camshaft engine MITSUBISHI

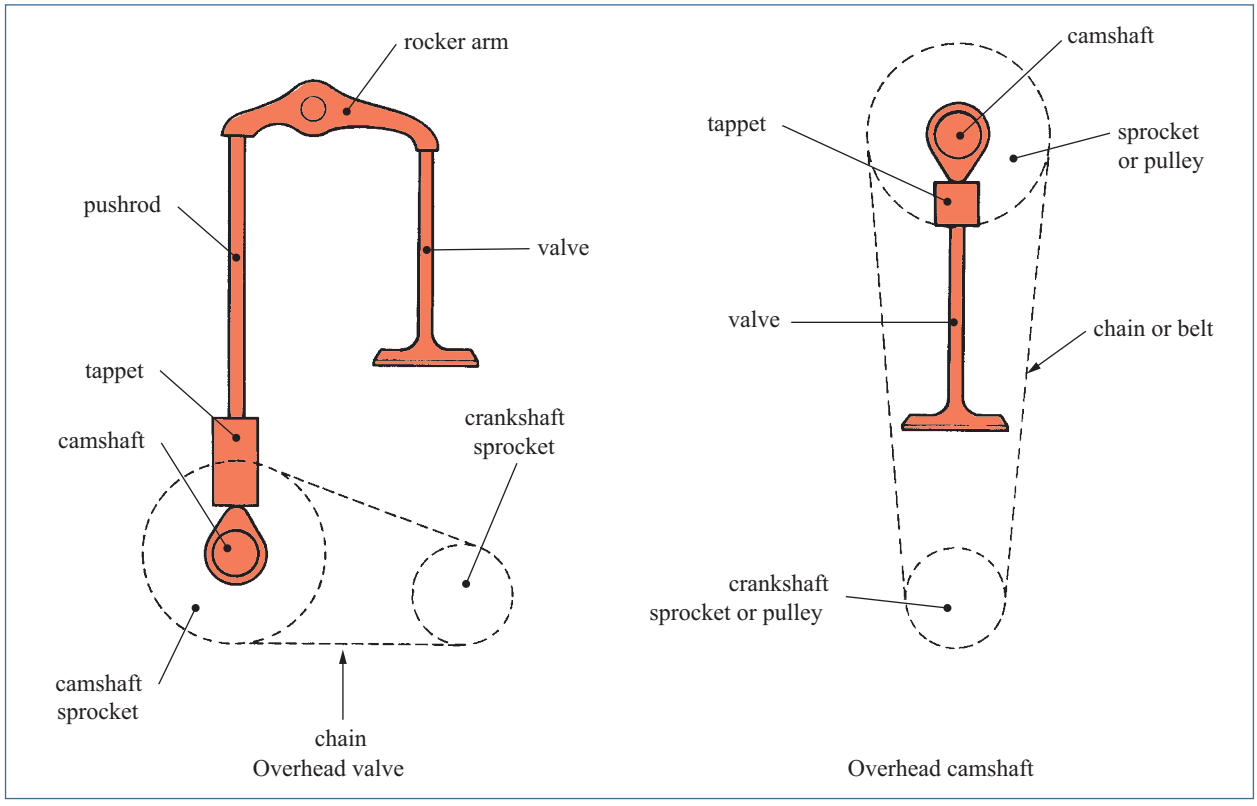


Figure 15.7 Basic valve operation

Valve trains

There are two different types of valve train, those for overhead valves and those for overhead camshafts (Figure 15.7). Overhead camshafts are the most common. In both arrangements, there are either sprockets or pulleys on the camshaft and crankshaft. The sprockets are connected by a chain and the pulleys by a special type of drive belt.

Overhead valves

With overhead-valve engines, the camshaft is located low in the engine block and is driven by a chain from the crankshaft. Tappets (or cam followers) and pushrods transfer the cam action to rocker arms on top of the cylinder head.

As the complete four-stroke cycle takes two revolutions of the crankshaft, the camshaft must rotate at half the speed of the crankshaft. This is accomplished by having the camshaft sprocket twice the size of the crankshaft sprocket. Some overhead-valve engines do not have a chain and use gears directly in mesh instead.

Handy hint: Engines with pushrods in their valve train are sometimes referred to as pushrod engines to distinguish them from overhead camshaft engines.

Overhead camshafts

With overhead camshaft engines, the camshaft is on the top of the cylinder head and is driven by either a timing chain or a timing belt from the crankshaft. Some engines operate with tappets directly between the camshaft and the valves, as shown in the diagram on the right of Figure 15.7. Other engines have rocker arms to operate the valves as shown in Figure 15.6.

15.2.6 Valve timing

In the basic four-stroke engine as described, the valves are opened and closed at TDC and BDC as required, to allow air–fuel mixture into the cylinder and the exhaust gases out of the cylinder. However, in an actual engine, this does not occur right at TDC and BDC. Valves operate before or after these particular points.

Figure 15.8 shows the four separate strokes that make up the two engine revolutions of a four-stroke cycle. These are part of a circle and represent the degrees of rotation of the engine's crankshaft.

1 Intake. The intake valve opens (Figure 15.8(a)) before TDC and closes after BDC. This increases the length of the intake stroke and allows more air–fuel mixture to enter the cylinder.
2 Compression. Both valves are closed (Figure 15.8(b)). While the intake valve closes after BDC and shortens the compression stroke, it does not affect compression.
3 Power. Both valves are still closed (Figure 15.8(c)) and ignition occurs ahead of TDC. The exhaust valve opens before BDC but, by this time, most of the force of combustion is lost.
4 Exhaust. The exhaust stroke is lengthened (Figure 15.8(d)) by opening the exhaust valve before BDC and closing it after TDC.

15.2.7 Valve timing diagram

A valve timing diagram is shown in Figure 15.9. To read it, start with the intake stroke and follow the normal cycle through intake, compression, power and exhaust.

Lead, lag and valve overlap

Lead, lag and *valve overlap* relate to valve opening and closing.

1 Lead. This means that a valve opens before TDC or BDC. The intake valve has lead because it opens before TDC. The exhaust valve has lead because it opens before BDC.
2 Lag. This means that a valve closes after TDC or BDC. The intake valve has lag because it closes after BDC. The exhaust valve has lag because it closes after TDC.
3 Overlap. The intake and exhaust valves are both open for a few degrees around TDC on the exhaust stroke. This is called an overlap.

Interpreting a valve timing diagram

In the valve timing diagram (Figure 15.9), the exhaust valve starts to open at 47° before BDC (lead) at the end of the power stroke, staying open until 21° after TDC (lag) on the intake stroke. Leaving the exhaust valve open longer gives the exhaust gases more time to leave the cylinder.

By the time the piston reaches 47° before BDC on the power stroke, the combustion pressures have dropped considerably. Little power is lost by opening the exhaust valve early and giving the exhaust gases extra time to exhaust from the cylinder. Similarly, leaving the intake valve open for 40° degrees past BDC on the intake stroke (lag) gives additional time for air–fuel mixture to flow into the cylinder.

Giving the intake valve lead and the exhaust valve lag to create 33° of overlap helps with scavenging. That is, the incoming air–fuel mixture helps clear out the exhaust gases.

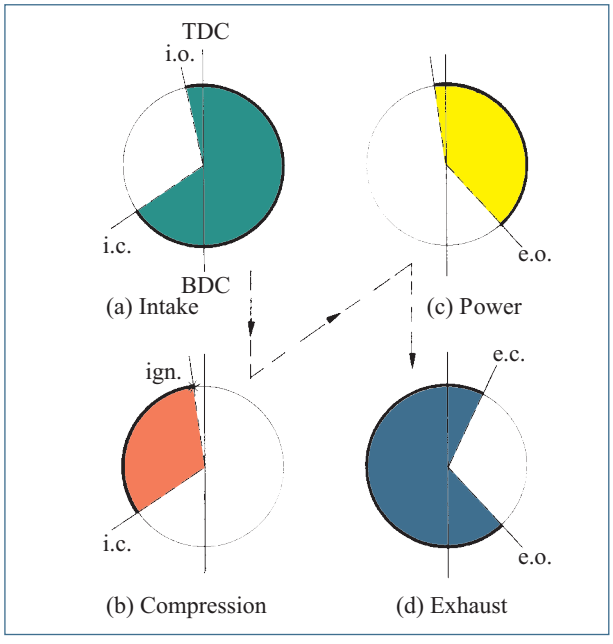


Figure 15.8 A valve timing diagram for a four-stroke engine, drawn as four separate strokes: i.o. (intake valve opens), i.c. (intake valve closes), e.o. (exhaust valve opens), e.c. (exhaust valve closes)

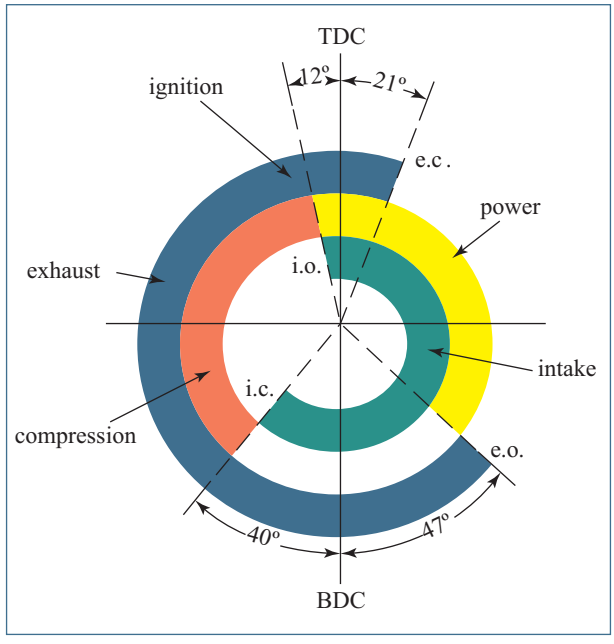


Figure 15.9 Valve timing diagram drawn as a spiral

Handy hint: Variable valve timing (VVT) is now used in most four-stroke engines. It allows the opening and closing of the valve to change depending on the needs of the engine. VVT improves engine performance and reduces exhaust emissions. See Chapter 18 for more information.

Piston movement and crankshaft rotation

Figure 15.10 shows the relationship between piston travel and crankshaft rotation (the former is a linear measurement, while the latter is measured in degrees). Towards TDC and BDC, piston travel is relatively short in relation to the number of degrees of crankshaft rotation.

15.2.8 Alternative valve timing diagram

Figure 15.11 shows a valve timing diagram of the type provided in some service manuals. It also shows the opening and closing times of the exhaust and intake valves, as well as the number of degrees that the valves remain open. All of this is in relation to degrees of crankshaft rotation.

The information on the diagram can be used to check the valve timing of an engine. A circular plate with degrees marked (degree plate) is used. This is attached to the crankshaft. The piston is set on TDC, and the zero mark on the degree plate is set against a pointer which can be attached to the crankcase. The crankshaft can be rotated and the opening and closing of the valves checked. The valve timing of an engine is determined by the design of the camshaft.

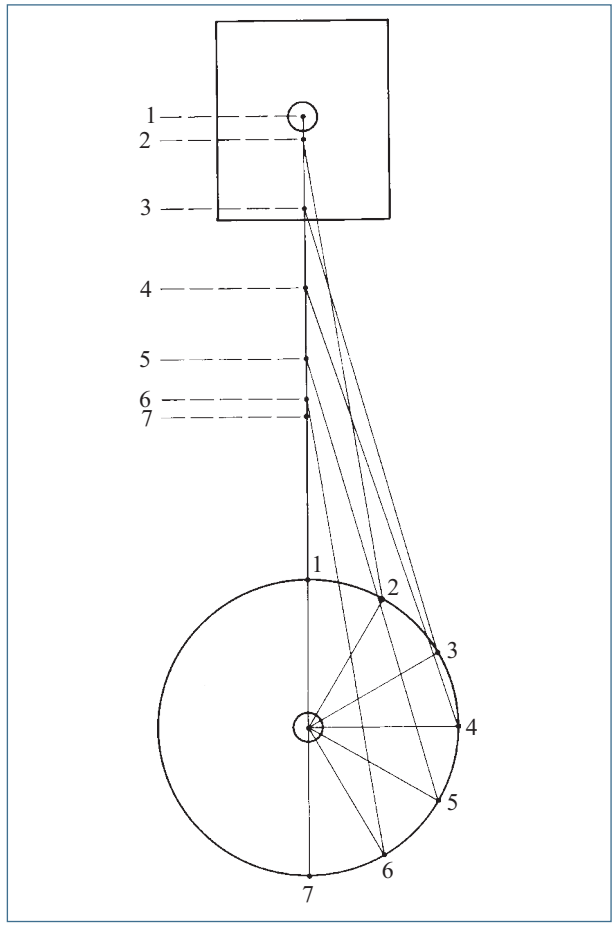


Figure 15.10 Relationship of piston movement to crankshaft rotation

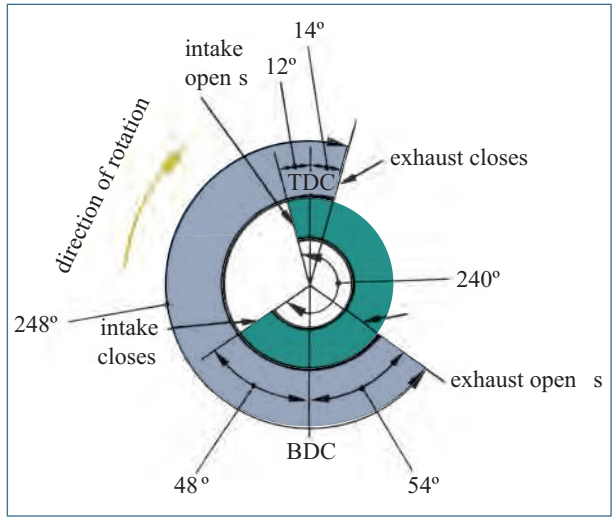


Figure 15.11 Valve timing diagram showing the opening and closing of the intake and exhaust valves

15.3 Two-stroke cycle (petrol engine)

The common small, two-stroke petrol engine has the three-port design shown in Figure 15.12.

1. The intake port. Admits the air–fuel mixture from the carburettor into the crankcase below the piston.
2. The transfer port. Transfers the air–fuel mixture from the crankcase to the cylinder above the piston.
3. The exhaust port. Exhausts burnt gases from the cylinder above the piston.

The ports are opened and closed by the piston moving up and down the cylinder. In this design there are no separate valves.

The four parts of the operating cycle of an engine (intake, compression, power and exhaust) still occur. Some take place in the cylinder above the piston, while others take place simultaneously in the crankcase below the piston. Thus the complete operating cycle can be completed during two piston strokes—one upstroke and one downstroke.

The crankcase is sealed and forms part of the fuel intake system. A petrol-and-oil mixture is used—as well as providing the air–fuel mixture for combustion, the oil also lubricates the piston, cylinder and the bearings. Compression of the air–fuel mixture, combustion, the power stroke and the exhaust stroke occur in the cylinder above the piston.

15.3.1 Two-stroke operation

The events occur as follows (Figure 15.13).

1. Piston upstroke. The upward movement of the piston compresses the fuel mixture in the cylinder above the piston. At the same time it creates a low pressure in the crankcase below the piston, ready for the intake port to be opened. When this happens, fuel mixture from the carburettor can enter the crankcase.
2. Top of the stroke. A spark from the spark plug ignites the fuel mixture near the top of the stroke and combustion occurs. Meanwhile, the piston has uncovered the intake port on its way up the cylinder, allowing fuel from the carburettor into the crankcase.
3. Piston downstroke. The piston is forced down the cylinder during the power stroke. Near the end of the stroke, the top of the piston uncovers the exhaust port to allow the burnt gases in the top of the cylinder to escape. At the same time, piston downward movement compresses the air–fuel mixture in the crankcase, ready for transfer.
4. Bottom of the stroke. Near the bottom of the stroke, the piston uncovers the transfer port. This allows the compressed fuel charge in the crankcase to transfer from the crankcase below the piston to the cylinder above the piston. As the exhaust port is uncovered before the transfer port, most of the exhaust gases will have escaped before the transfer port is uncovered to admit a fresh charge of fuel mixture from the crankcase.

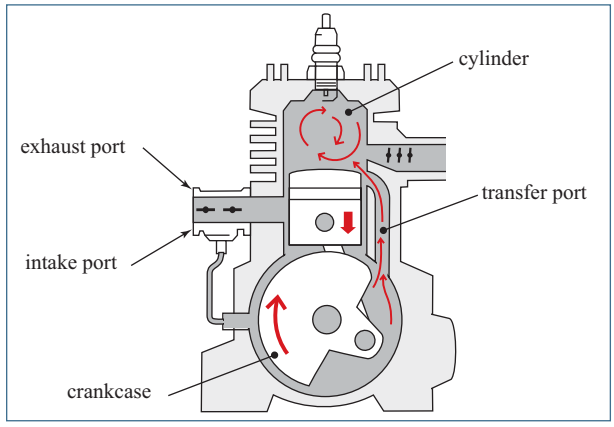


Figure 15.12 Arrangement of a basic two-stroke engine SHUTTERSTOCK

The piston of a two-stroke engine often has a deflector on its head. This directs the intake mixture upwards and the exhaust gases downwards towards the exhaust port. This prevents the incoming mixture from escaping through the exhaust port and also assists in blowing out the exhaust gases. This is known as *scavenging*.

15.3.2 Two-stroke engine with reed valve

Some two-stroke engines, such as outboard marine engines, are designed with a reed valve. This is a small flexible metal plate which covers the intake port; it opens and closes the port automatically as pressure in the crankcase changes (Figure 15.14).

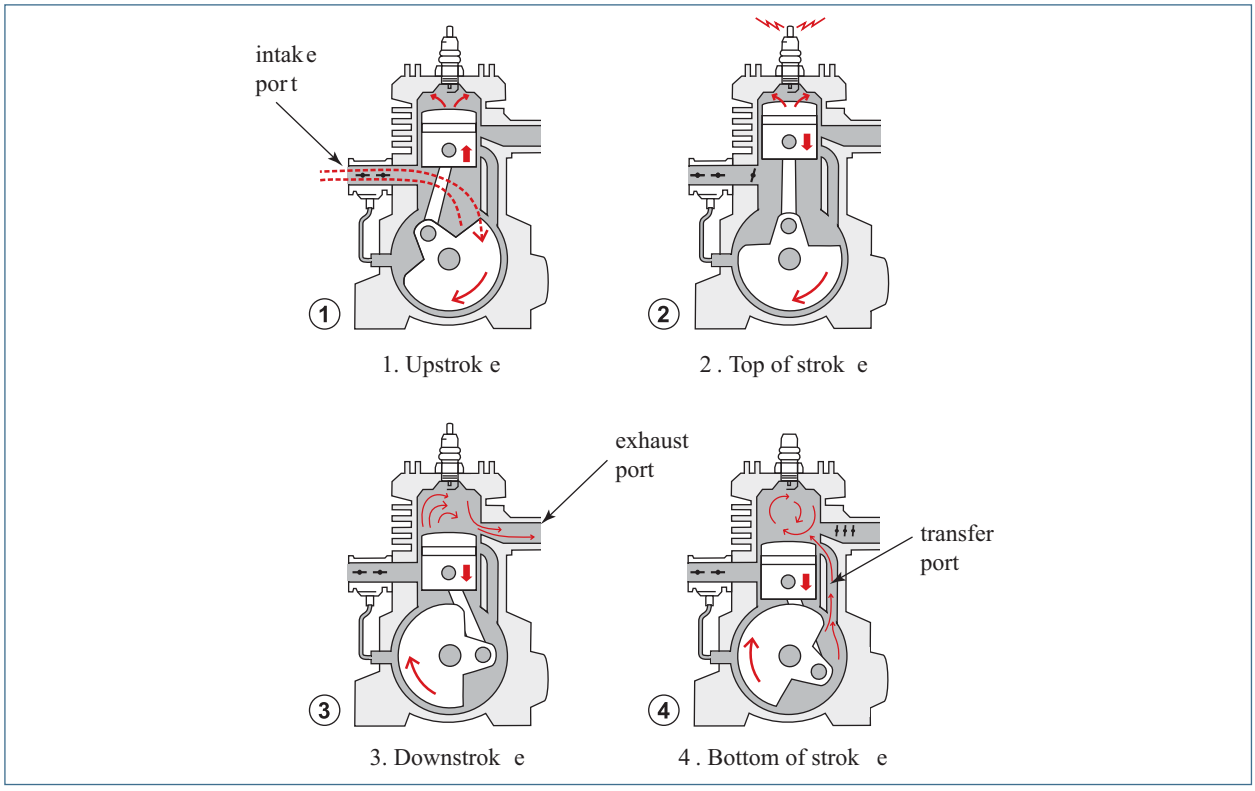


Figure 15.13 Operation of a two-stroke engine SHUTTERSTOCK

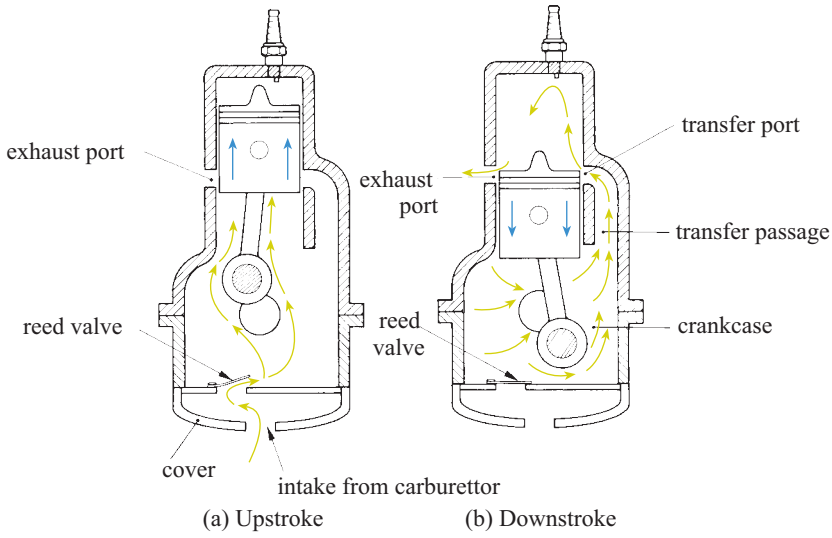


Figure 15.14 Two-stroke engine with a reed valve. Green arrows show the movement of gases. Blue arrows show piston movement

When the piston is moving upwards, a negative pressure (below atmospheric) is produced in the crankcase and the air–fuel mixture from the carburettor, which is at a pressure close to atmospheric, lifts the reed valve off its port to enter the crankcase as shown in Figure 15.14(a).

After the piston reaches TDC and starts moving downwards on the power stroke, pressure develops in the crankcase and forces the reed valve closed. Further downward movement compresses the trapped air–fuel mixture in the crankcase. When the piston nears the bottom of its stroke, it uncovers the transfer port. The pressure which has built up in the crankcase then forces the mixture through the transfer passage into the cylinder above the piston as shown in Figure 15.14(b).

The type of cylinder shown operates in a horizontal position. The crankcase is fitted with a cover, which forms a chamber. The carburettor is attached to the cover and the air–fuel mixture passes from the carburettor into this chamber.

The reed valve is located between the chamber and the crankcase. In engines with more than one cylinder, the section of the crankcase for each cylinder is sealed separately and fitted with a reed valve.

15.4 Diesel engine operation

Although most diesel engines are four-stroke engines, some of the larger ones are two-stroke. These operate differently from small two-stroke petrol engines. Diesel engines run on distillate that, in most engines, is injected directly into the cylinder.

In a diesel engine, air only is taken into the engine during the intake stroke. During the compression stroke, it is compressed to about 600°C. This is hot enough to ignite the distillate as it is sprayed into the combustion chamber. There is no need for a spark plug spark to fire the charge.

15.4.1 Four-stroke diesel cycle

The four strokes of a diesel engine are shown in Figure 15.15.

1. Air intake (downstroke). The intake valve is open and air is drawn into the cylinder as the piston moves downwards. At BDC, it will be full of air.
2. Compression (upstroke). Both valves are closed and air is being compressed in the cylinder. By the time the piston reaches TDC, the air will be compressed to about one-sixteenth of its original volume, and will be hot enough to ignite the diesel fuel that will be injected into it.
3. Power (downstroke). Just before the piston reaches TDC, a small quantity of fuel is sprayed through the injector at the top of the cylinder, into the combustion chamber. The hot air in the chamber forms a combustible mixture with the fuel and ignites it. The pressure resulting from combustion forces the piston down the cylinder on the power stroke.
4. Exhaust (upstroke). The exhaust valve is opened towards BDC of the previous stroke. As the piston moves upwards on the exhaust stroke, it forces the exhaust gases from the cylinder through the open exhaust port.

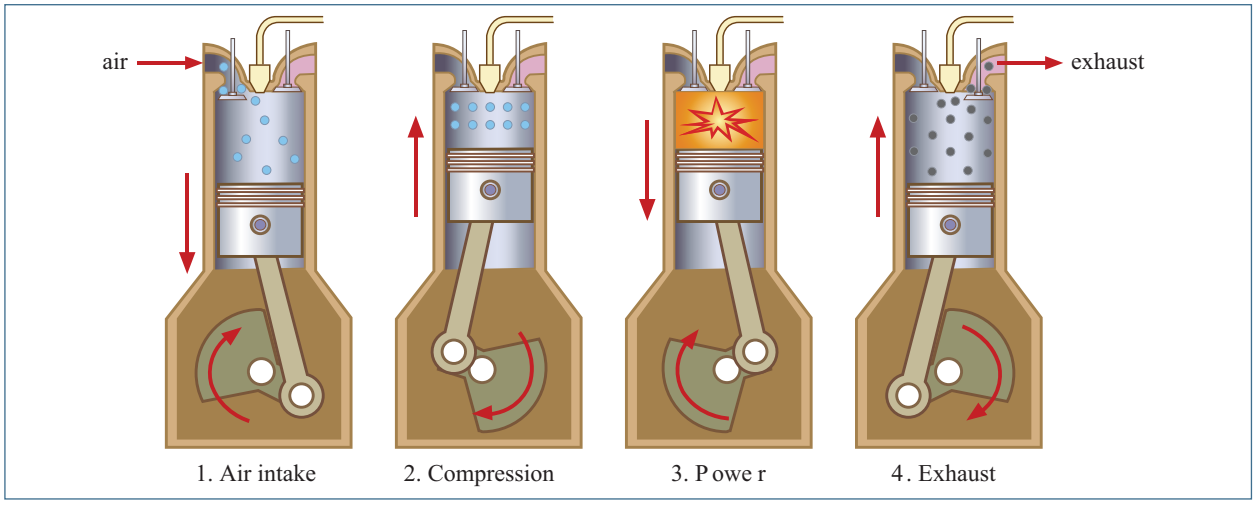


Figure 15.15 Four-stroke diesel cycle—fuel is injected at the top of the compression stroke SHUTTERSTOCK

Diesel engines have a fuel-injection pump that delivers fuel at high pressure to the injectors in the cylinder head. The amount of fuel can be varied and the speed of the engine controlled in this way.

Handy hint: Diesel engines are often classed as compression-ignition engines because the fuel is ignited by the heat of compression.

15.4.2 Two-stroke diesel

Some two-stroke diesel engines have ports for both intake and exhaust. One design has intake ports and exhaust valves, as shown in Figure 15.16. The piston here is almost at TDC on the compression stroke. Fuel is being injected into the combustion chamber and combustion would have commenced.

The engine uses a blower to force air into the cylinder through an intake port. The exhaust gases leave the cylinder through an exhaust valve.

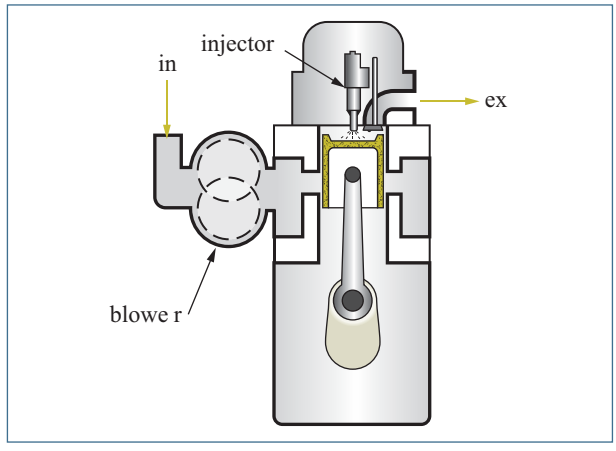


Figure 15.16 Basic two-stroke diesel engine

15.5 Rotary engines

A rotary engine has a rotor in a housing rather than a piston in a cylinder. The motion of the rotor is transferred by a unique gear system to an eccentric shaft which performs the same function as the crankshaft of a piston engine.

Figure 15.17 shows the action of the rotor in its housing and demonstrates the four cycles which occur in the working cylinder. These are similar to the strokes of a four-stroke piston engine, but are performed in a working chamber formed between the rotor and its housing.

The inside of the housing is shaped to accommodate the action of the rotor. There are two ports in the side of the housing—an intake port and an exhaust port. The rotor covers and uncovers them

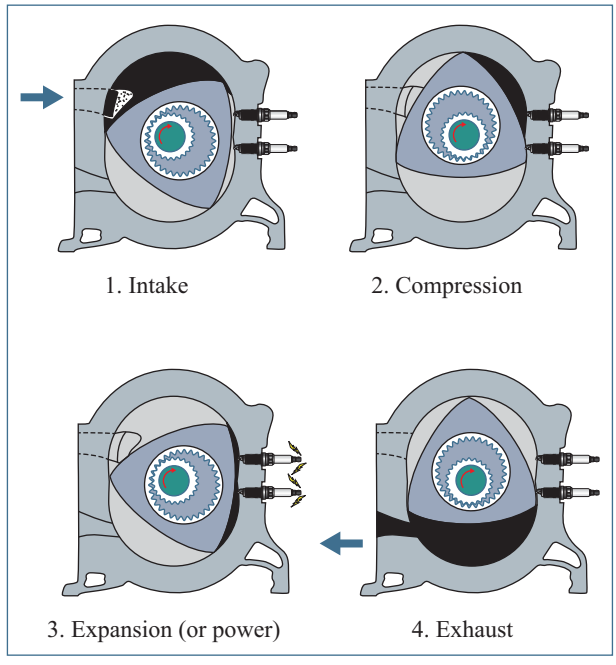


Figure 15.17 The four cycles in the working chamber of a rotary engine MAZDA

so that air–fuel mixture enters through the intake port and the exhaust gases discharge through the exhaust port. There are no valves in the engine. The four cycles are shown in sequence in Figure 15.17.

As the rotor turns in the housing, air–fuel mixture is taken in through the intake port. It is compressed between the rotor and the housing and ignited by the spark plug. Combustion occurs, and the expanding gases turn the rotor. As the rotor uncovers the exhaust port, the exhaust gases are discharged.

The shape of the rotor provides three working chambers. The sequence shown in Figure 15.17 occurs three times during each rotation of the rotor—once in each of the three working chambers.

Safety: When working with running engines, always be aware of the risk of carbon mono xide poisoning in a confined workplace and the dangers posed by moving engine components.

15.6 Multicylinder engines

A single-cylinder engine operating on the four-stroke cycle provides only one power stroke for every two crankshaft revolutions. Power, which is not uniform throughout, is delivered as an impulse, the greatest amount being delivered at the start of the stroke and decreasing towards the end. For a more uniform power flow and smoother operation, most engines have more than one cylinder (commonly, four, six, eight and twelve.

With multicylinder engines, the power strokes are evenly spaced. A four-cylinder engine (four-stroke) has two power strokes for each crankshaft revolution; a six-cylinder engine has three; an eight-cylinder engine has four. In six- and eight-cylinder engines, the power strokes overlap to provide a smoother flow.

With two-stroke engines, each cylinder provides a power impulse for each crankshaft revolution—a two-stroke multicylinder engine will deliver twice as many power impulses as a similar four-stroke engine running at the same speed.

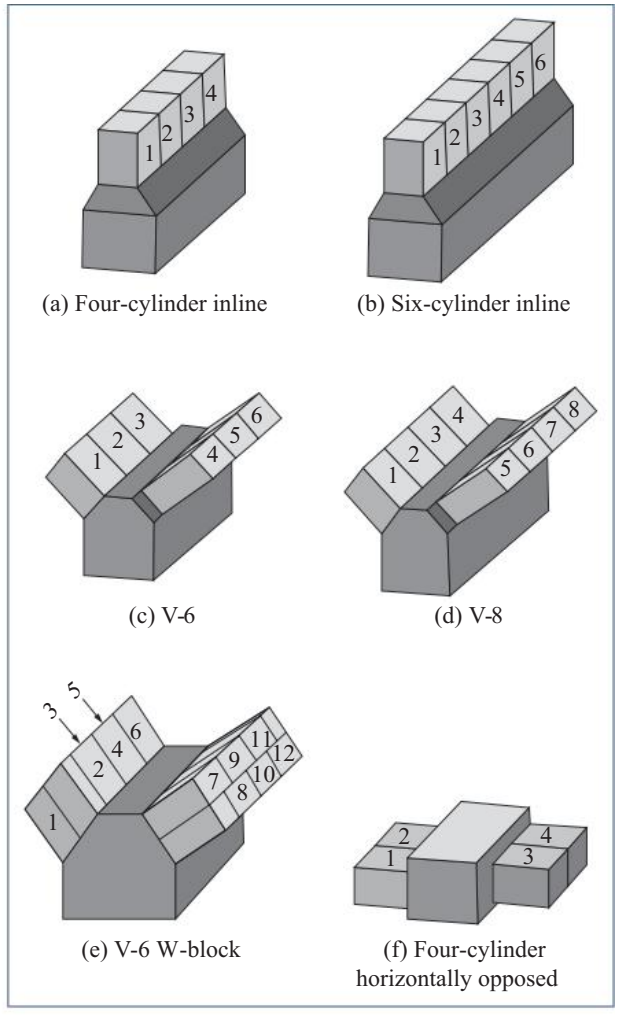


Figure 15.18 Engine configurations

15.6.1 Arrangement of the cylinders

The arrangement of the cylinders is called the *engine configuration.* They can be arranged inline, as a 'V', or horizontally opposed (as shown in Figure 15.18). Whatever the arrangement, the engines operate in the same way.

The usual method of identifying engine cylinders is to number them from front to back, as in the illustration. V-type engine cylinders are usually numbered consecutively on one bank and then the other.

Inline engines

These have their cylinders arranged one behind the other in a straight line. The cylinder block for a four-cylinder engine is shown in Figure 15.19.

The cylinders are usually vertical but, in some inline engines, are tilted at an angle (these are called

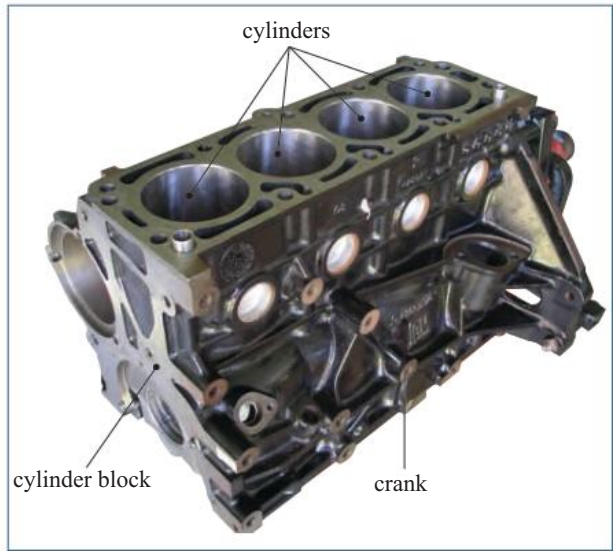


Figure 15.19 Cylinder block for a four-cylinder inline engine

slant engines). Tilting the engine reduces its overall height, enabling it to be used in a passenger car with a lower bonnet line or installed in a truck (where the engine is mounted beneath the cab).

Inline engines can also be designed as flat engines, with the cylinders horizontal, but these are mainly used for heavy vehicles. These engines can be mounted under the cabs of trucks or the floors of buses.

V-type engines

The cylinders of V-type engines are arranged in two banks, with half the cylinders in each. The cylinders are in line, the banks at an angle to each other. In many engines the angle is 90°, but other angles are used. Figure 15.20 shows the cylinder block for a V-8 engine.

Compared with an equivalent inline engine, a V-type engine will be wider and shorter and, generally, be more rigid. It will have a shorter and more rigid crankshaft.

W-type engines

The main components of a W-type engine are shown in Figures 15.21 and 15.22. Its construction is like two V-type cylinder blocks combined to form one block, with double the number of cylinders on each side. The cylinders are offset to each other in a zigzag pattern and share a crankshaft.

Figure 15.20 An aluminium-alloy cylinder block for a V-8 engine

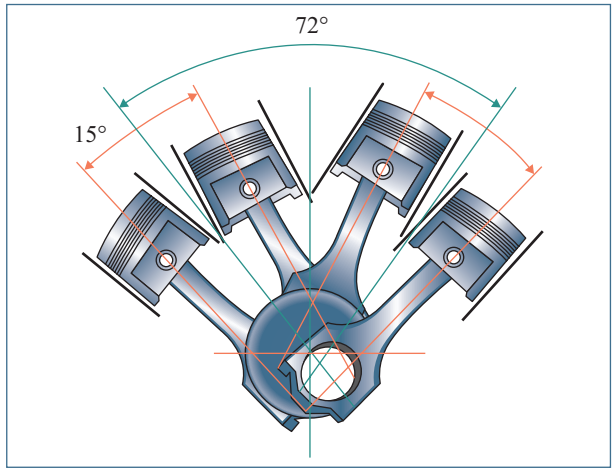


Figure 15.21 Piston position for a W -type engine; offset 15 ° angle between banks 72 °

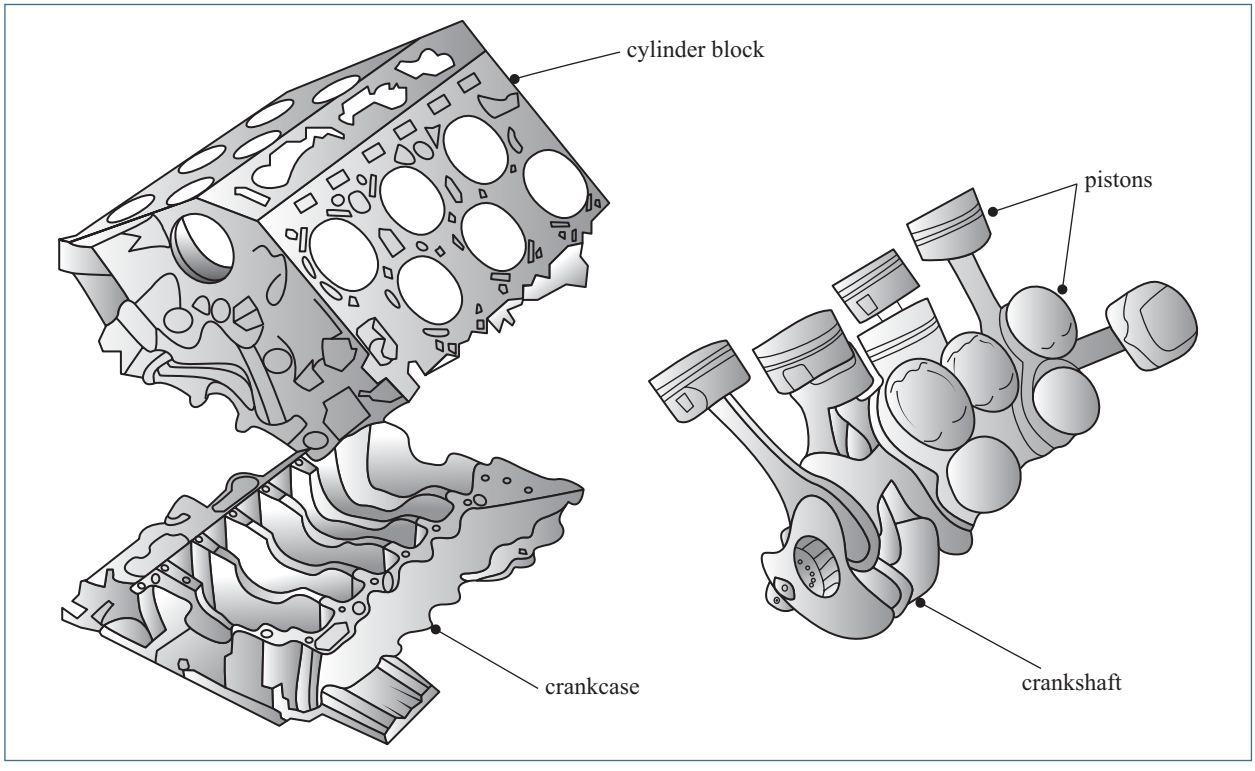


Figure 15.22 Cylinder block, crank case , pistons and crankshaft for a W -type engine

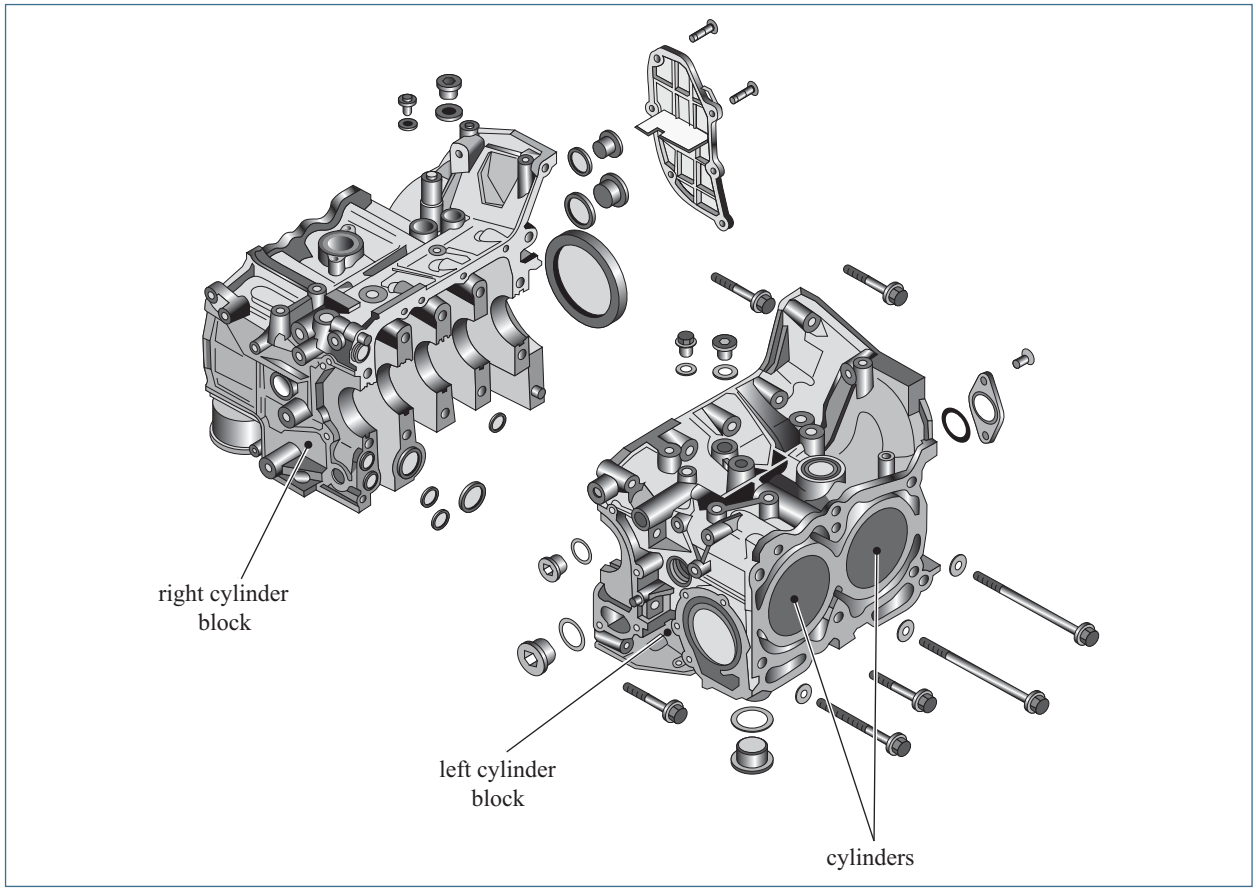


Figure 15.23 Cylinder block for a horizontally opposed engine

The main advantage of the W-type engine is that it fits more cylinders into a smaller space, which is assisted by a 15°-angle offset between pistons on the same bank. That gives an effective 72° angle between the banks instead of the 90° of the V-type engine (see Figure 15.21).

Horizontally opposed engines

These have their cylinders arranged in two horizontal banks with the crankshaft mounted between them. There are two cylinder blocks—a left and a right. The blocks for a four-cylinder engine are shown in Figure 15.23. These are made of aluminium alloy with cast-iron cylinder liners.

Horizontally opposed engines are often called *flat engines*. They are wider and lower than an equivalent inline engine and have better natural balance as the movement of a piston in one direction is balanced by the movement of a piston in the opposite direction.

15.7 Engine terms and definitions

The following are terms and definitions used in relation to engines.

15.7.1 Bore and stroke

The size of an engine cylinder is referred to in terms of its bore and stroke (Figure 15.24). The bore is the diameter of the cylinder. The stroke is the distance the piston travels from TDC (top dead-centre) to BDC (bottom dead-centre). The bore is usually stated first; for example, the cylinder could have a diameter, or bore, of 80 mm and a stroke of 100 mm. These measurements determine the piston displacement.

Engines can have small bores and long strokes, or vice versa. An engine with a bore the same dimension as its stroke is referred to as a *square engine*. If the diameter of the bore is larger than the stroke, it is called an *over square engine*.

15.7.2 Piston displacement

Piston displacement is the volume that the piston displaces as it moves from BDC to TDC. Piston displacement of the cylinder in Figure 15.24 (as an example) would be the volume of a cylinder that has a 4 cm radius and is 10 cm high.

The volume is calculated as:

$$\pi r^2 \times H = 3.142 \times 4 \times 4 \times 10$$
$$= 503 \text{ cm}^3 \text{(approx.)}$$

If the engine has four cylinders, the total displacement would be 2012 cm^3.

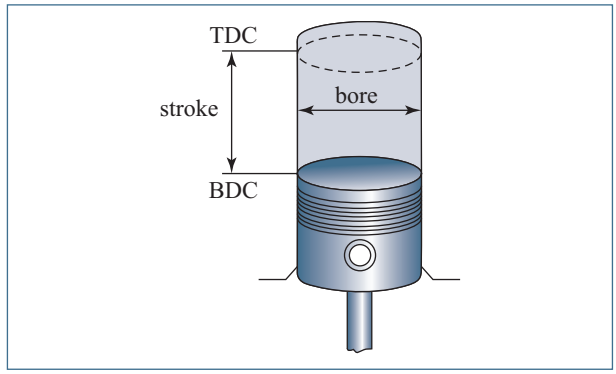


Figure 15.24 The bore and stroke of a cylinder

15.7.3 Engine capacity

The total piston displacement is also called the *capacity* of the engine. The capacity is stated in litres, so an engine with 2012 cm^3 displacement has a capacity of 2.012 litres. This would be rounded off and the engine would be classed as a 2-litre engine.

The litre is used for engine capacity in the International System of Units (SI) as it is the unit for fluids (fluids are liquids and gases). It is the gas capacity of the engine cylinders that is measured.

Handy hint: Older engines that have their bore and stroke are measured in inches have their capacity stated in cubic inches.

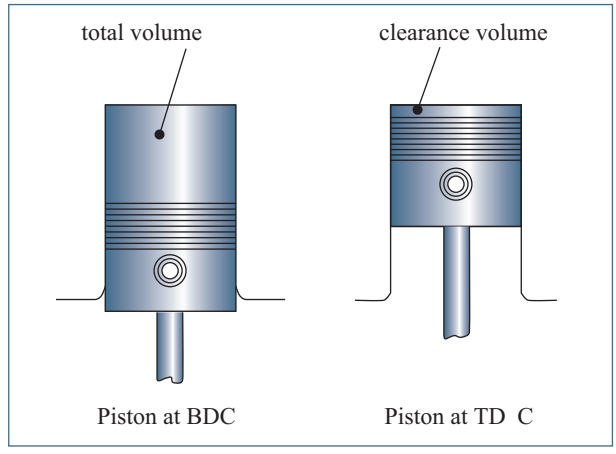


Figure 15.25 The compression ratio is the volume in a cylinder with the piston at BDC divided by its volume with the piston at TDC

15.7.4 Compression ratio

The compression ratio of an engine is a measurement of how much the air–fuel charge is compressed in the cylinder. It is calculated by dividing the volume of the cylinder (and its combustion chamber) with the piston at BDC by the volume with the piston at TDC. This is shown for a simple cylinder in Figure 15.25.

Handy hint: The volume with the piston at TDC is called the clearance volume, since it is the clearance that remains above the piston when it is at TDC.

Example

A cylinder has a total volume of 600 cm^3 and a clearance volume of 75 cm^3. The compression ratio is 600 divided by 75—that is, 8:1. During the compression stroke, the air–fuel mixture is compressed from a volume of 600 cm^3 to 75 cm^3, or to one-eighth of its original volume.

The volume of the actual piston displacement is often called the *swept volume,* since this is the volume of air swept into the cylinder by the action of the piston as it moves down its stroke. The total cylinder volume is then equal to the swept volume plus the clearance volume. The compression ratio can then be stated as:

$$\frac{\text{swept volume} + \text{clearance volume}}{\text{clearance volume}}$$

This is the same as the total volume divided by the clearance volume.

A compression ratio of around 8:1 would be used for a petrol engine. High compression ratios provide high pressure of the air–fuel mixture. As a result, higher combustion pressures are obtained and more force is exerted on the piston during the power stroke. However, there is a limit to the compression ratio of petrol engines. If the air–fuel mixture is compressed too much, detonation and rough running will occur.

Diesel engines have high compression ratios, ranging from about 15:1 to 21:1. These ratios are needed to obtain the high air temperatures for compression ignition.

15.8 Engine systems

In addition to its components, an engine requires the following systems so it can operate.

1. Fuel system. Includes a fuel tank and a fuel pump to supply the fuel to the engine.
2. Lubrication system. Uses a pump and passages to supply oil to all the moving parts of the engine.
3. Cooling system. Includes the radiator, hoses, water pump, water-jackets in the cylinder block and head, plus the coolant that is circulated through the system to prevent the engine from overheating.
4. Starting system. Consists of the battery and starter motor, which rotates the engine for starting via the ring gear on the engine's flywheel.
5. Charging system. An engine-driven alternator provides electrical power and charges the battery.
6. Ignition system. In petrol and gas engines, this provides the spark at the spark plug to ignite the mixture in the combustion chamber.
7. Intake system. Includes the air cleaner, ducting and the intake manifold, which provide clean air–fuel mixture to the engine.
8. Exhaust system. Includes the exhaust manifold, connecting pipes, catalytic converter, muffler and the pipes that carry the exhaust to the rear of the vehicle.

These systems are required for all automotive engines (except the ignition system, which is not required for diesel engines). Other auxiliaries are fitted, such as power-steering pumps or air-conditioning compressors.

Sustainability: When working with engine subsystems, trap any spills and dispose of the fluid correctly.

15.9 Engine classifications

Although there are many variations in engine design, piston engines can be classified according to their main design features. The classifications are:

1. Number of cylinders. Four, six and eight cylinders are the most common, but there are also automotive engines with two, three, five and twelve cylinders.
2. Arrangement of the cylinders. Engines are designed with cylinders that are inline, at an angle to each other (V-type and W-type) or horizontal.
3. Engine capacity. The total volume of all the cylinders of the engine. This provides a common basis for comparing the size of engines.
4. Arrangement of the valve mechanism. The common arrangements are overhead valves (OHV) and overhead camshaft (OHC). Both have overhead valves, their different names coming from the fact that the camshafts are located in different parts of the engine. Some engines have two overhead camshafts, and this arrangement is referred to as double-overhead camshaft (DOHC).

   Some engines have two valves per cylinder, some have three and some have four. This feature is sometimes used to describe the engine, for example, a four-cylinder engine with four valves for each cylinder might be referred to as a sixteen-valve engine.
5. Type of cooling. Engines can be liquid cooled or air cooled. Liquid-cooled engines have water-jackets and a radiator. Air-cooled engines depend on a flow of cooling air.
6. Operating cycle. Engines are classed by their operating cycle, as either four-stroke engines or two-stroke engines.
7. Type of fuel used. There are three automotive fuels: petrol, distillate (for diesel engines) and gas. Most passenger cars have petrol engines, but many four-wheel drives and light commercial vehicles are fitted with diesel engines. Heavy trucks and earthmoving equipment have diesel engines. Gas fuel comes in two forms: liquefied petroleum gas (LPG) and natural gas for vehicles (NGV). NGV also comes in two forms: liquefied natural gas (LNG) and compressed natural gas (CNG). CNG is the more common of the two.

   Car engines and light truck engines can be designed or converted to run on LPG. They are usually arranged as dual-fuel engines, capable of running on either gas or petrol. Gas is also used for special applications. The exhaust gases are much cleaner than those from a petrol engine and so the engines of forklifts and other handling equipment used inside buildings are fitted with fuel systems that use LPG.

   A hybrid car is still considered to be an engine-powered vehicles and its engine is subject to the above classifications. The electric motor generator would be rated according to electrical specifications.

Handy hint: Not all engines of the same capacity will produce exactly the same power output, as some are designed for higher performance than others.

Safety: Check with local government authorities for licensing requirements to work on vehicles fitted with LPG, CNG and LNG.

Safety: Hybrid/electric vehicles contain high voltage systems and present a high-voltage electric shock risk. Shocks of 60 volts and less than 0.5 of an amp can be fatal.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe the fundamental ways of working with engines
- describe the events that occur in an internal combustion engine (ICE) cylinder
- explain how engine components change rotary motion into a reciprocating action
- identify the events that occur in a two- and four-stroke cycle engine
- describe how a diesel engine works
- list the design characteristics of a rotary engine
- identify engine cylinder configurations
- state the bore and stroke, piston displacement, engine capacity and compression ratios
- list the eight engine subsystems
- list the seven engine classifications
- apply procedures to inspect and service a range of engines in accordance with workplace and manufacturer/component supplier requirements and specifications within workplace timeframes.

REVIEW QUESTIONS

1 What is a piston stroke?
2 How is reciprocating motion changed to rotary motion in an engine?
3 Name the parts of a basic engine.
4 What is a cycle?
5 Name the strokes of a four-stroke engine.
6 At what stage are both the valves of an engine closed?
7 What is the speed of the camshaft in relation to the crankshaft?
8 Name two different types of valve-operating mechanisms.
9 State the purpose of the ports in a two-stroke engine.
10 What part does the crankcase play in the operation of a small two-stroke engine?
11 What is a reed valve?
12 Indicate how the cylinders are arranged in different types of engines.
13 State the main differences between a petrol and a diesel engine.
14 What are the different types of fuels that are used in automotive engines?
15 Name the main engine systems.
16 Why is it important to follow OEM recommendations when replacing the oil filter and oil?
17 What is the main function of the cooling system in an engine?

CHAPTER 16

Engine construction

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify the general construction of an engine and its main components
2 observe relevant safety procedures and requirements
3 state how to accurately inspect engines, and document and analyse results
4 carry out work on engines according to workplace and manufacturer requirements and specifications.

16.1 Engine construction

While multi-cylinder engines contain components which perform the same functions as those of a single-cylinder engine, they are more complex and there are many more parts. It is easier to understand how an engine is constructed if it is first broken down into sections before being considered as a whole.

This is best done by looking at the internal parts at the top of the engine, at the front of the engine, at the rear of the engine, the main internal parts and finally, the components of an engine assembly.

16.1.1 Components at the top of the engine

Figure 16.1 shows the top section of one cylinder of an engine. These parts (except the piston) are serviced during what is known as a *top overhaul*. The illustration shows:

- timing belt
- camshaft timing pulley
- camshaft
- rocker arms and shafts
- two intake valves and springs
- two exhaust valves and springs
- piston.

16.1.2 Components at the front of the engine

Figures 16.2 and 16.3 show parts that are located at the front of the engine. These include:

- piston
- connecting rod
- crankshaft
- crankshaft timing pulley
- timing belt
- crankshaft pulley and balancer .

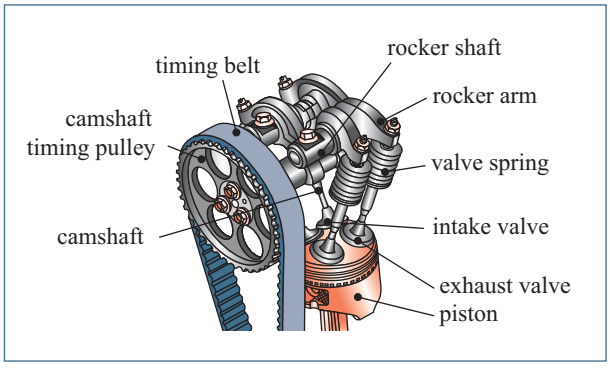


Figure 16.1 Components at the top of an engine

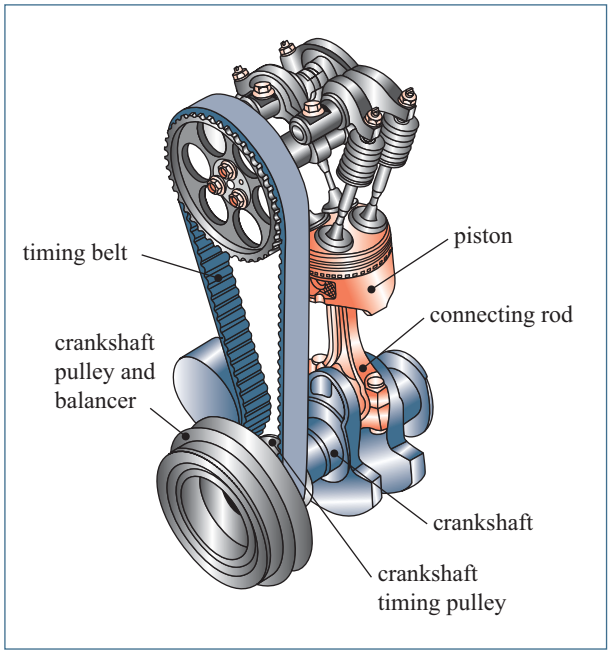


Figure 16.2 Components at the front of an engine DAIHATSU

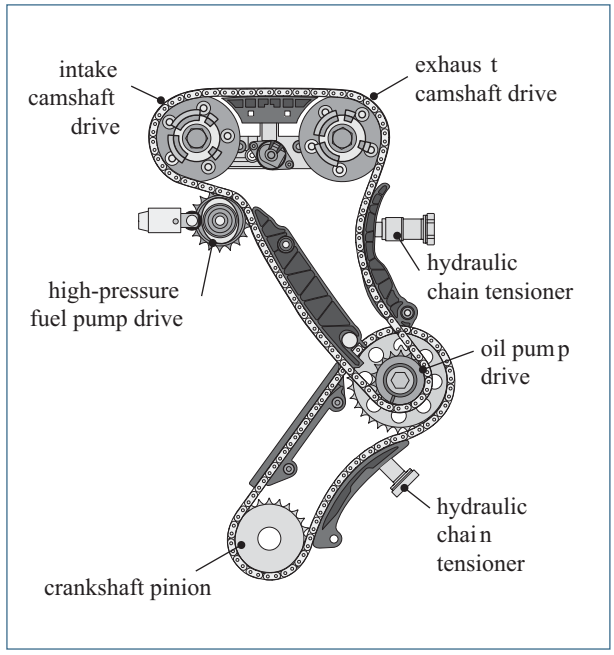


Figure 16.3 Timing chain arrangement for a twin overhead cam (OHC) engine

16.1.3 Components at the rear of the engine

A section at the rear of the engine is shown in Figures 16.4 and 16.5. The parts shown include:

- flywheel
- starter ring gear
- piston and connecting rod
- part of the crankshaft and the crankshaft flange .

16.1.4 Components at the bottom of the engine

Figure 16.6 illustrates the lower section of the engine. The parts identified are:

- four pistons
- connecting rods
- crankshaft
- crankshaft balance weights
- crankshaft main-bearing journals
- pulley and balancer .

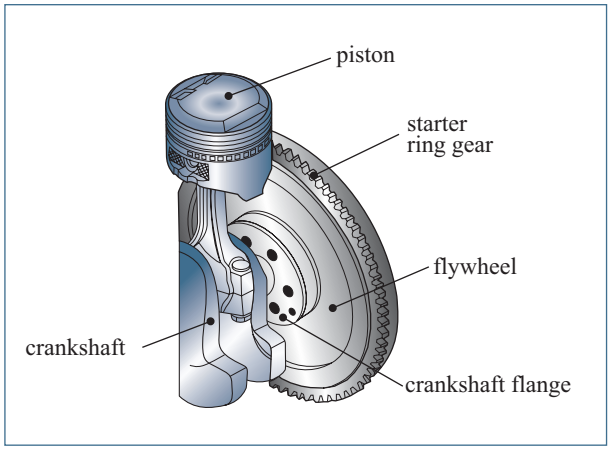


Figure 16.4 Components at the rear of an engine

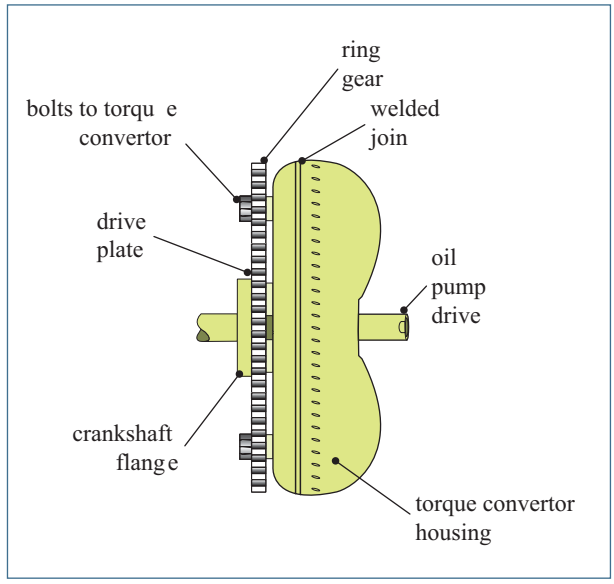


Figure 16.5 Drive plate and torque converter bolted to the crankshaft

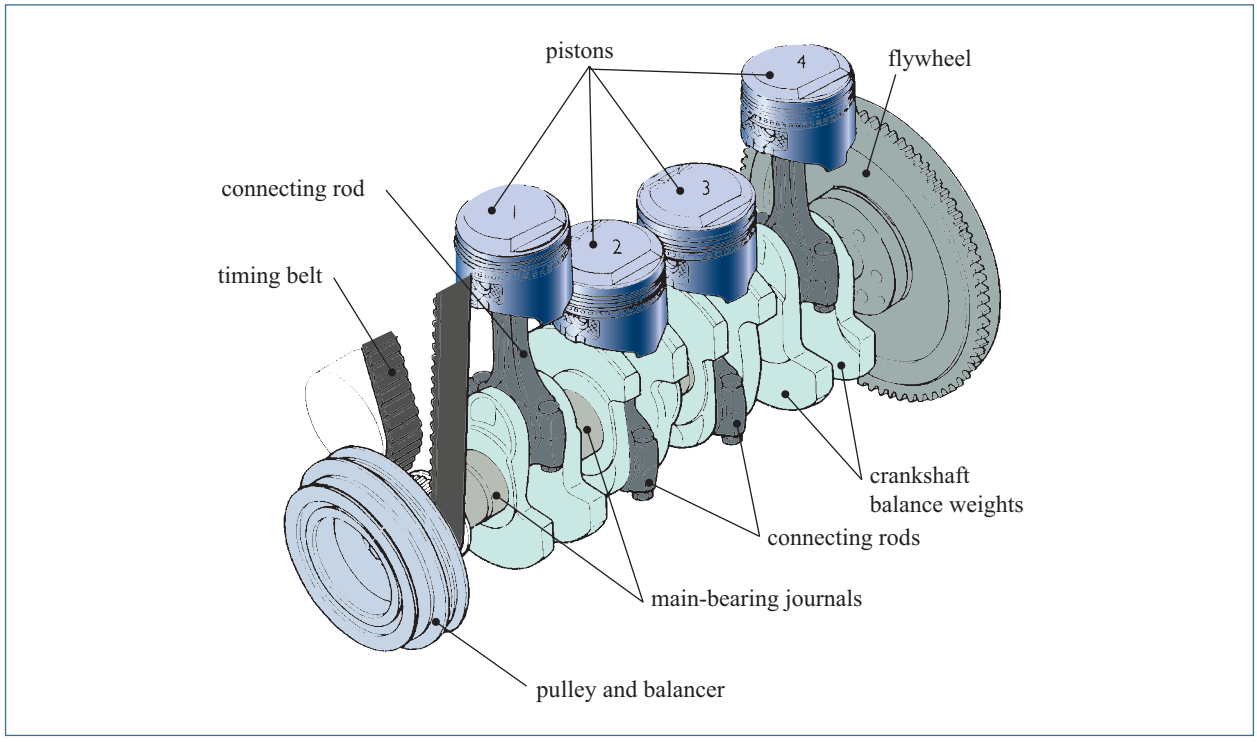


Figure 16.6 Internal components at the bottom of an engine

16.1.5 Components inside the engine

Figure 16.7 combines the parts already shown to present the main operating engine parts. They include the valve mechanism, timing belt (or chain), crankshaft, pistons, connecting rods and flywheel.

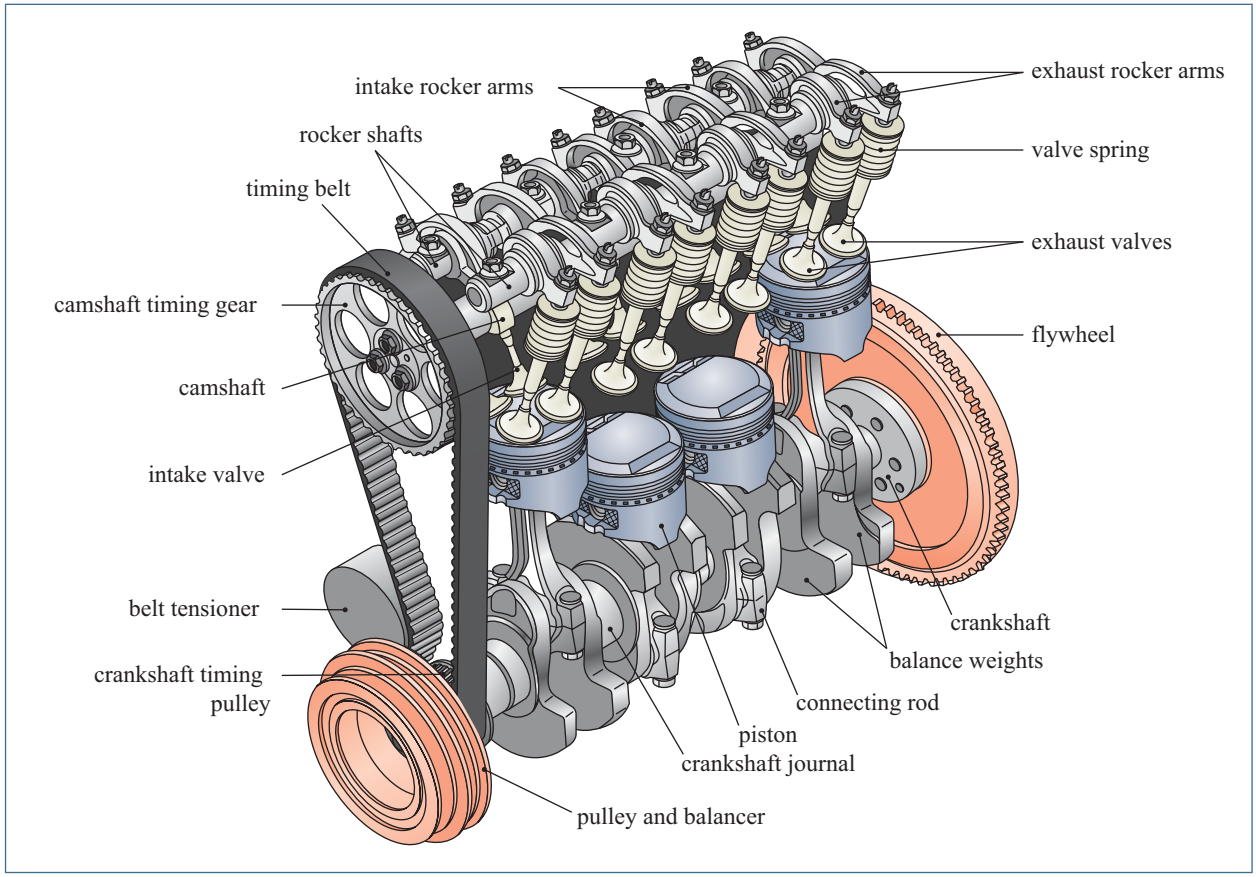


Figure 16.7 Internal parts of an engine identified

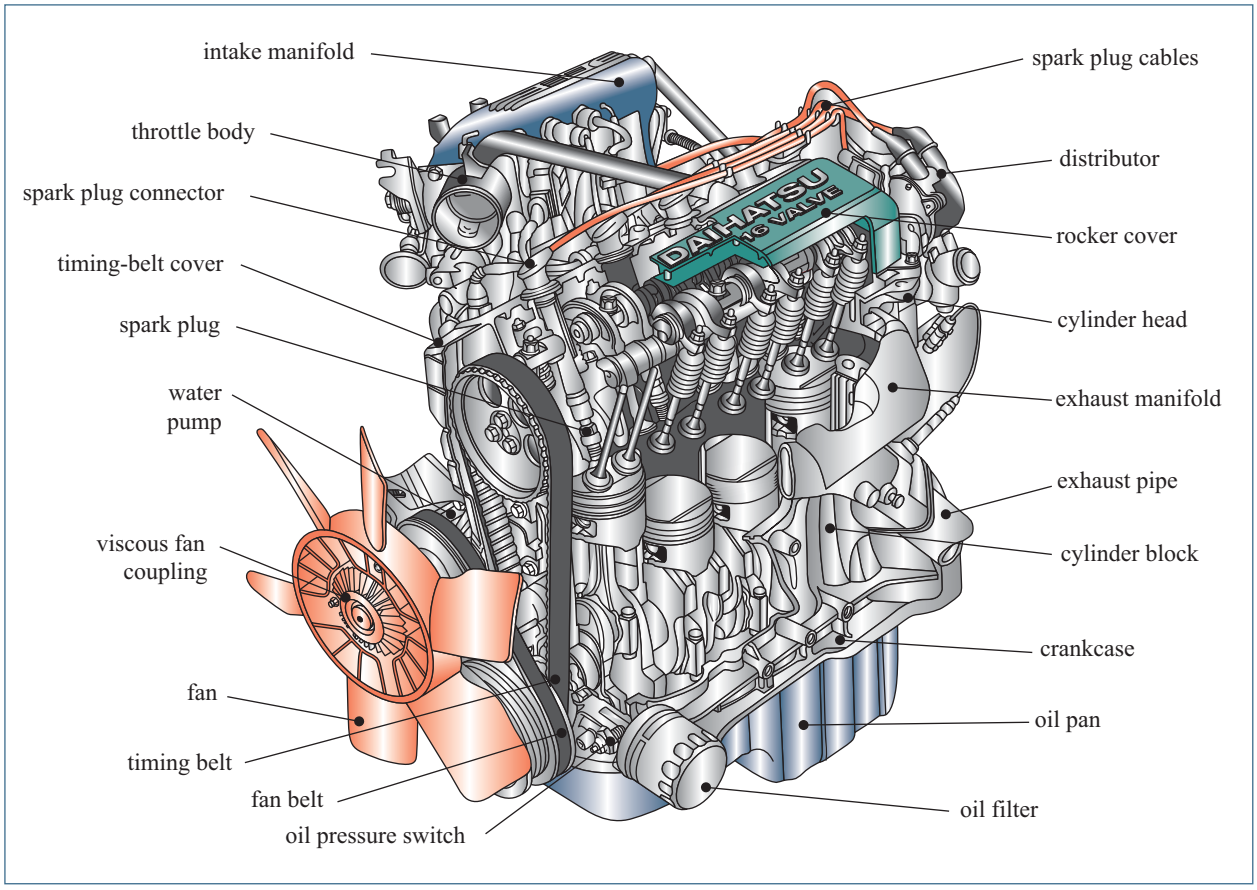


Figure 16.8 External components of an engine identified

16.2 Components of an engine assembly

Figure 16.8 shows the complete engine. The internal parts are now installed in the cylinder block and in the cylinder head, with ancillaries on the outside of the engine. The cylinder block and cylinder head have been cut away to show the internal parts of the engine. The following are identified: cylinder block, cylinder head, valve cover, oil pan, exhaust manifold, intake manifold, throttle body, fan, water pump, distributor with cables, spark plugs, oil filter and the oil pump.

16.2.1 Cylinder block

Figure 16.9 shows a bare engine block. The cylinder block is the largest part of the engine. It has cylinders in which the pistons operate and bearings that carry the crankshaft. In some engines, the cylinder block also carries the camshaft.

The cylinders and pistons are in the upper part of the cylinder block, the crankshaft in the lower. This lower part is called the crankcase. It has webs which carry the crankshaft main bearings.

16.2.2 Crankshaft and bearings

The crankshaft is fitted to the engine block and is supported by the main bearings to take the radial loads from the connecting rods. One set of main bearings also has a thrust bearing fitted to it to take loads along the crankshaft. Figure 16.10 shows a crankshaft and its related bearings.

16.2.3 Piston and connecting rod assembly

The large end of the connecting rod connects to the crankshaft and the small end connects to the piston. The piston pin or gudgeon pin connects the piston to the connecting rod.

The piston is fitted with three piston rings. The top two rings seal the piston to the cylinder wall and prevent combustion gases from entering the crankcase. The bottom ring prevents excessive oil from entering the combustion chamber from the crankcase.

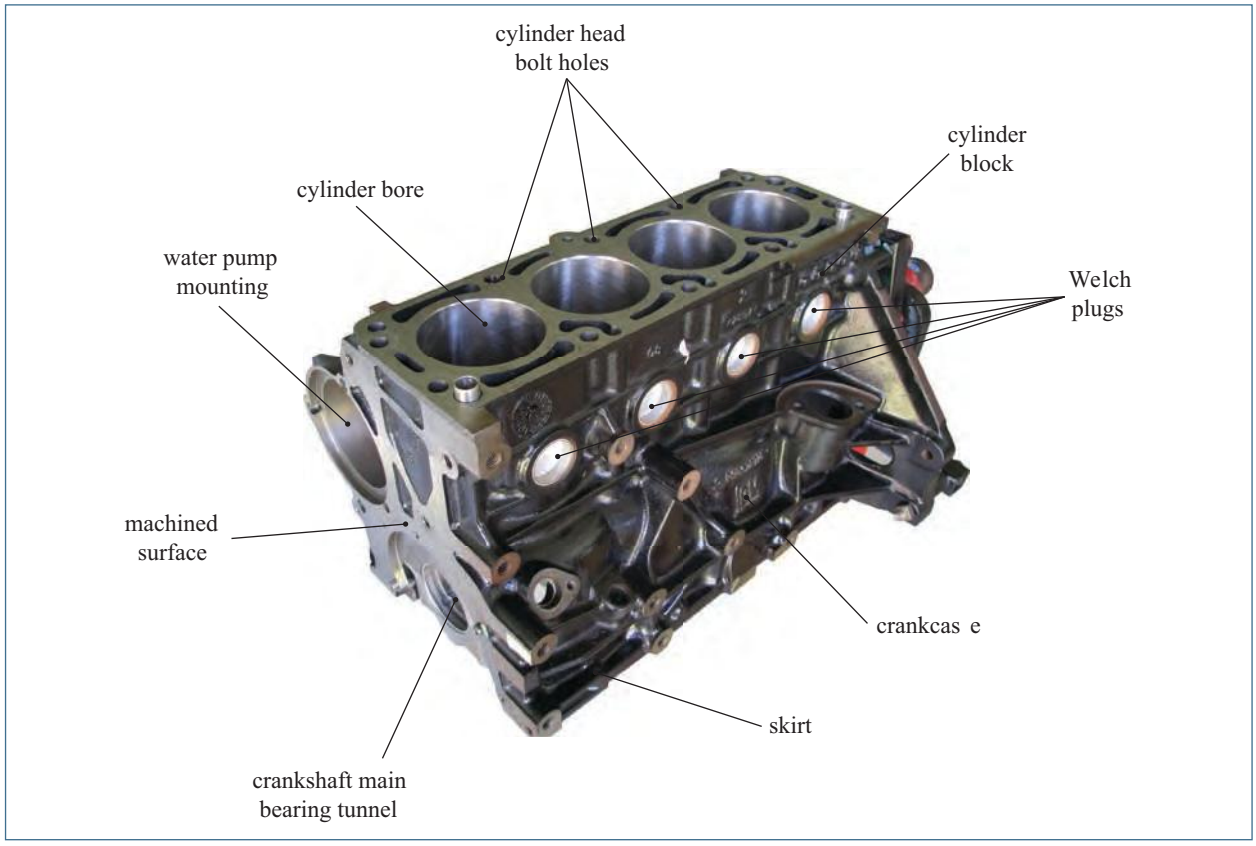


Figure 16.9 Bare engine block for a four-cylinder engine

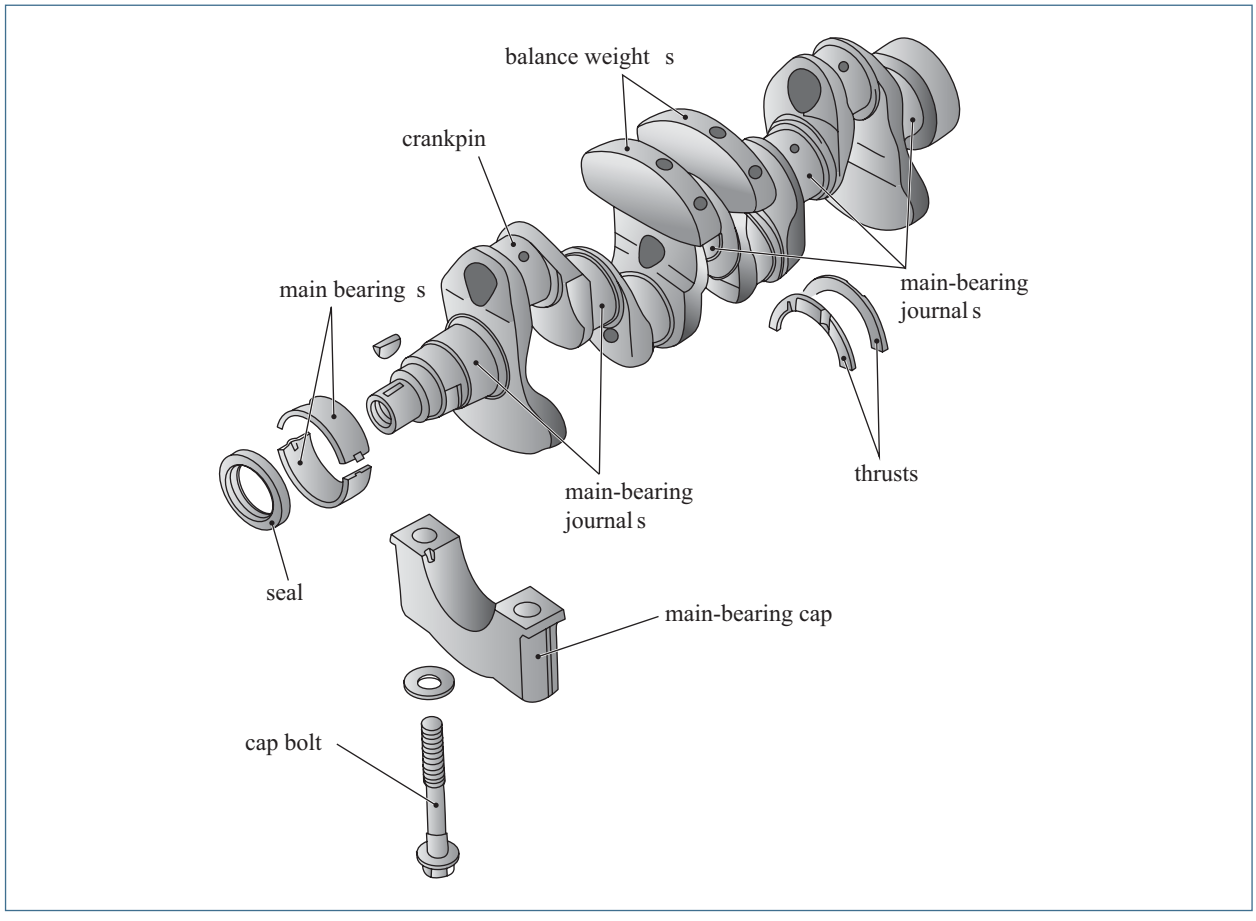


Figure 16.10 Crankshaft and bearings for a four-cylinder engine—i t has four crankpins and five main bearings

16.2.4 Cylinder head

The cylinder head is bolted to the top of the cylinder block. The *cylinder-head gasket* is fitted between the parts to provide a seal.

The cylinder head can be made of aluminium alloy or cast iron. It is shaped above each cylinder to form the combustion chambers in which the air–fuel mixture is burnt. The cylinder head carries the camshaft, the valves and the valve-operating mechanism. Intake and exhaust ports in the cylinder head are opened and closed by the action of valves.

16.2.5 Single overhead camshaft (OHC)

A single camshaft is located on the top of the cylinder head and driven by a toothed belt and toothed pulley, or by a chain and sprocket. For an example, refer to Figure 16.13. The camshaft in Figure 16.11 is driven by a toothed belt. It has five journals that support it on top of the cylinder head and eight cams to operate the valves.

Handy hint: Toothed pulleys are also referred to as sprockets, although this term is usually reserved for gears that are used with chains.

16.2.6 Double overhead camshafts (DOHC)

Many engines use two camshafts (DOHC). Each cylinder of a DOHC engine has four valves – two intake and two exhaust valves. One camshaft is used for the intake valves and the other for the exhaust valves. Figure 16.12 shows a cylinder head with two camshafts. These have toothed pulleys that are driven by a toothed belt.

With V-type engines, two camshafts are used for each bank of cylinders, so the engine has four camshafts. This arrangement is sometimes referred to as *quad-cam.*

16.2.7 Valve cover

The aluminium alloy valve cover fits on top of the cylinder head and covers the valve mechanism. A gasket is fitted between the valve cover and the top of the cylinder head to provide an oil seal.

16.2.8 Oil pan

The oil pan, or sump, is attached to the bottom of the crankcase, closing off the internal parts and acting as a reservoir for the engine oil. The oil is circulated throughout the engine by the oil pump before returning to the oil pan.

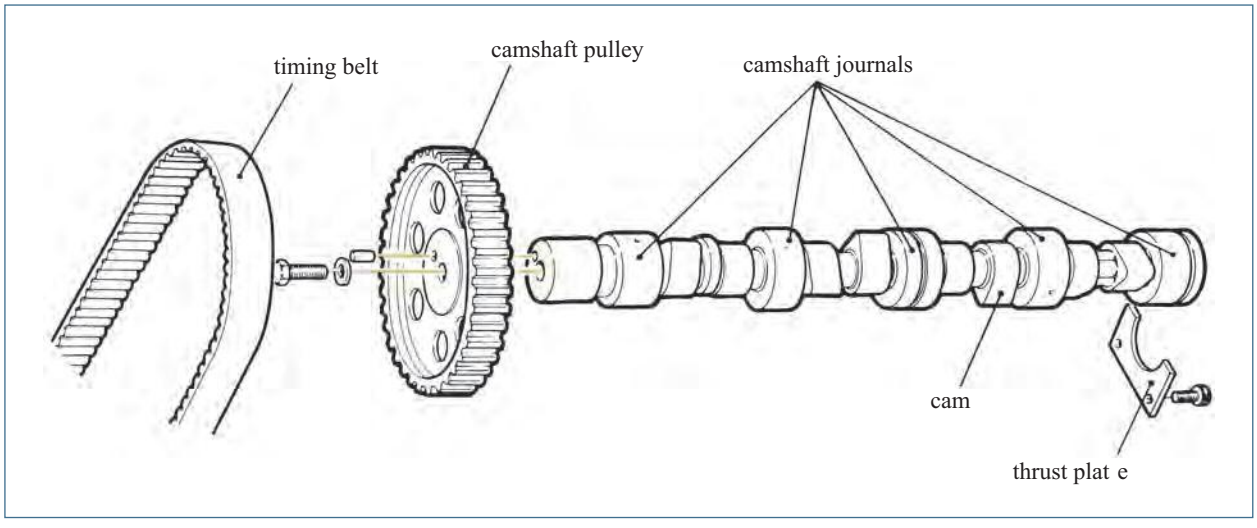


Figure 16.11 Camshaft for a four-cylinder OHC engine GM HOLDEN LTD

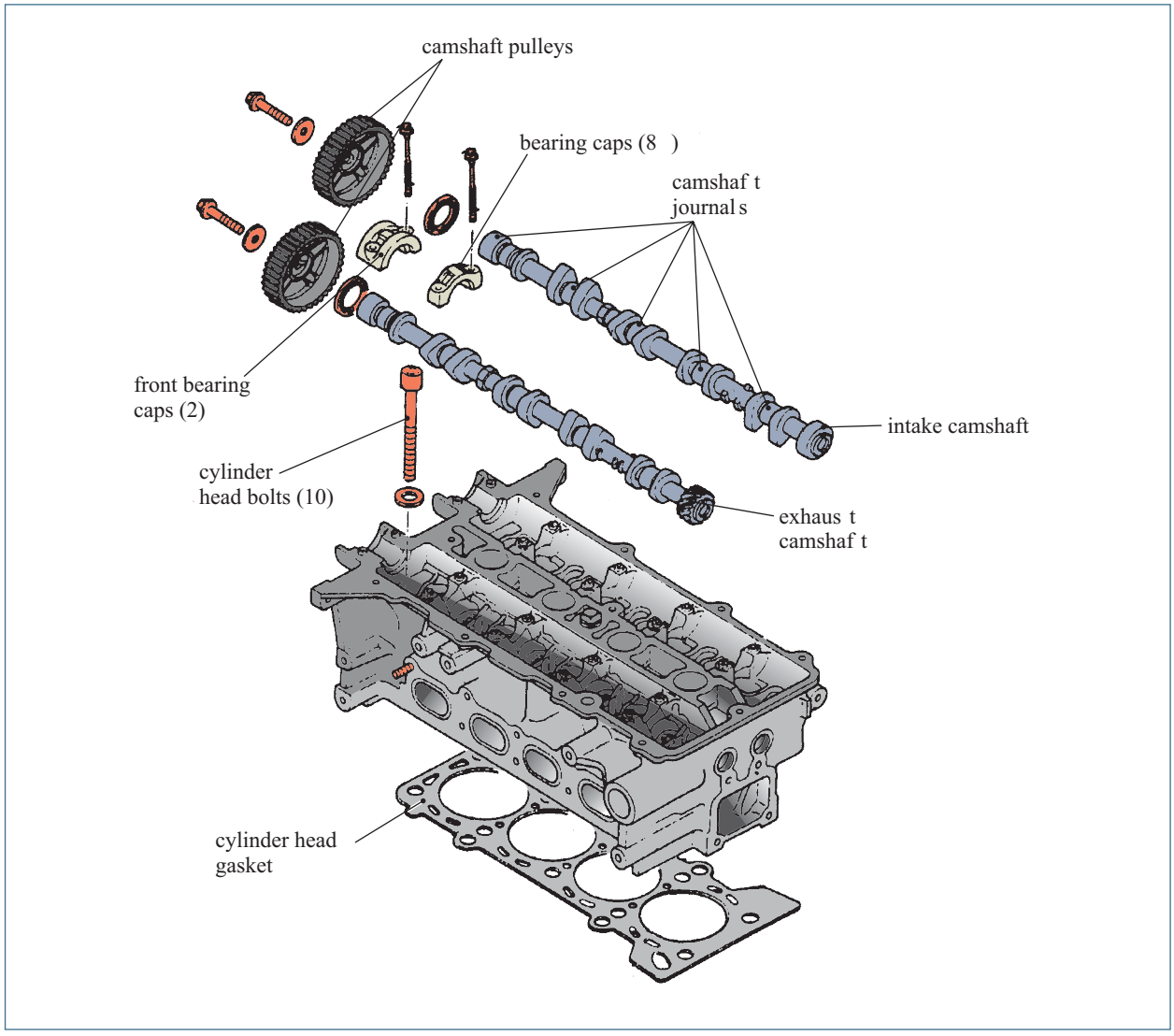


Figure 16.12 Cylinder head assembly with double overhead camshafts FORD

16.2.9 Oil pump and oil filter

The oil leaving the oil pump passes through the oil filter before it is circulated through the engine. The filter removes particles of carbon or other foreign material from the oil.

16.2.10 Intake manifold and exhaust manifold

The intake manifold carries the air–fuel mixture into the engine. The engine illustrated in Figure 16.8 has electronic fuel injection (EFI), and has a throttle body attached to the intake manifold.

The exhaust manifold is on the opposite side of the engine to the intake manifold. Flange-mounted to the cylinder head over the exhaust ports, it has pipes or branches that carry the burnt gases away when the exhaust valves open. The exhaust manifold is made of cast iron to resist heat.

16.2.11 Fan

The fan at the front of the engine provides a flow of air through the radiator as part of the engine's cooling system. The engine in Figure 16.8 has a variable-speed fan that is belt-driven, but electric fans are also used.

16.2.12 Water pump

The water pump is driven by the fan belt from the crankshaft pulley. It circulates coolant throughout the engine and radiator assembly.

16.2.13 Distributor, cables and spark plugs

The distributor is at the rear of the cylinder head and is driven by the camshaft. It distributes high voltage to each spark plug, triggering the spark that ignites the air–fuel mixture. The cables from the distributor are connected to the spark plugs which, on the engine in Figure 16.8, are located in the centre of the cylinder head. The firing order (the sequence in which the pistons deliver the power strokes) for a four-cylinder engine is 1-3-4-2 or 1-2-4-3.

16.3 Engine features

The following illustrations show different engine design features. All engines work in basically the same way, but there are many variations in actual engine design. These are variations in type of fuel used, number of valves per cylinder, number of camshafts, and so on.

16.3.1 Sectional view of an engine

Figure 16.13 shows a cross-sectional view of a basic engine, illustrating its construction. Items that can be identified are: water-jackets in the cylinder head and cylinder block, intake and exhaust valves and their ports, the camshaft and rocker arms, the cylinder-head gasket, piston, crankshaft and connecting rod.

16.3.2 Sectional view of a V-type engine

Figure 16.14 shows a V-6 engine. It has two banks of cylinders at an angle of 60°, with each bank having three cylinders and two camshafts—one for the intake valves and one for the exhausts. The intake camshaft is driven by a toothed belt, and the exhaust camshaft is driven from the intake camshaft by a pair of gears.

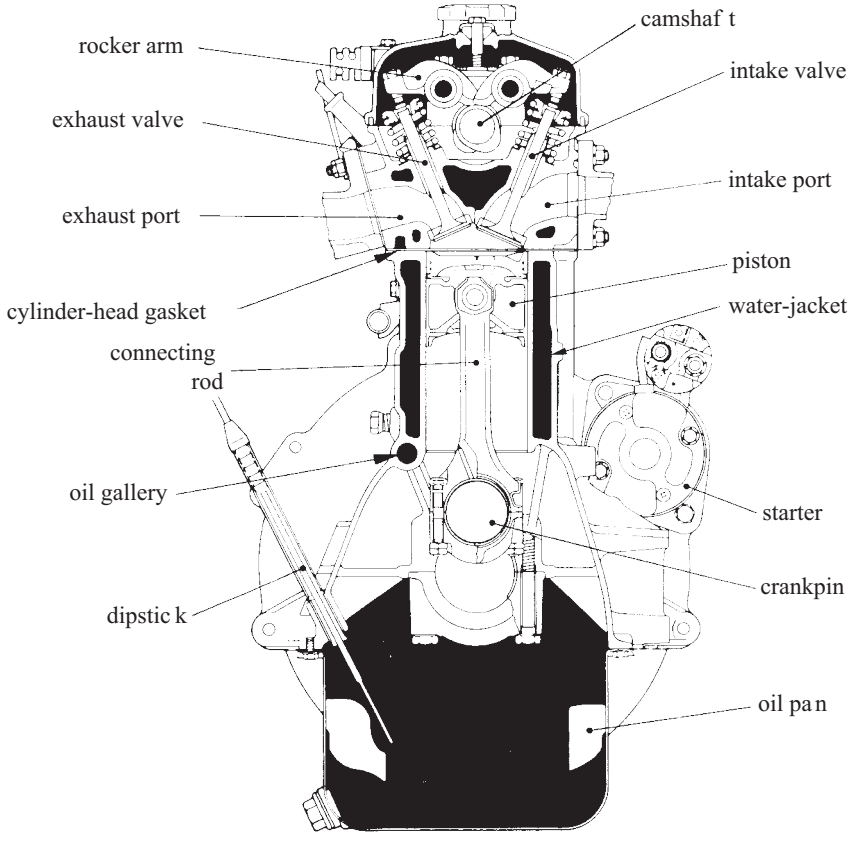


Figure 16.13 Cross-sectional view of a basic single OHC engine, showing the internal parts MITSUBISHI

16.3.3 Horizontal engine

The arrangement of the various features of a horizontal engine, often referred to as a flat engine because of its construction, is shown in Figure 16.15. This is a four-cylinder engine with its cylinders horizontally opposed.

This has a different dismantling sequence to an inline engine. There are two cylinder heads to be removed, and two cylinder blocks that are separated at the crankcase.

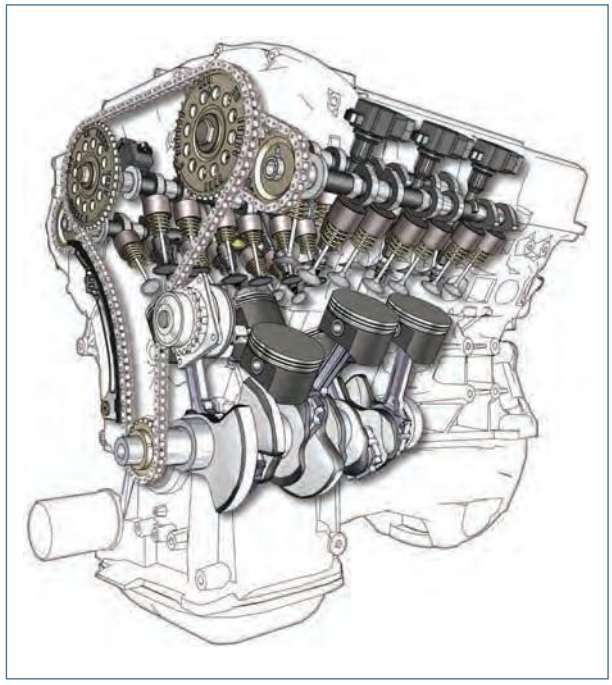


Figure 16.14 Sectional view of a V -6 engine with a double overhead camshaft

16.3.4 Diesel engine

Figure 16.16 shows the basic construction of a diesel engine. This is an overhead-valve engine with the camshaft mounted in the cylinder block. Cam followers operate on the cams of the camshaft, and pushrods transfer movement to the rocker arms on top of the cylinder head.

The camshaft is driven by timing gears which also drive an auxiliary shaft. This, in turn, drives the injection pump and a vacuum pump.

As this is a diesel engine, injectors are fitted to the cylinder head. It also has long pistons, which have a combustion chamber in the piston head. Diesel engines have the same mechanical parts as petrol engines, except that diesel engine components are generally stronger and heavier. Diesel engines' design produces a unique diesel knocking, making them noisier than petrol engines.

16.3.5 Working on engines

Much ancillary equipment is attached to engines, and some of this has to be removed to gain access to engine components. Items that might need to be removed are: engine covers, the air cleaner and air ducts, coolant hoses, drive belts, power-steering pump, air-conditioning compressor, alternator, starter, parts of the fuel system or emission controls.

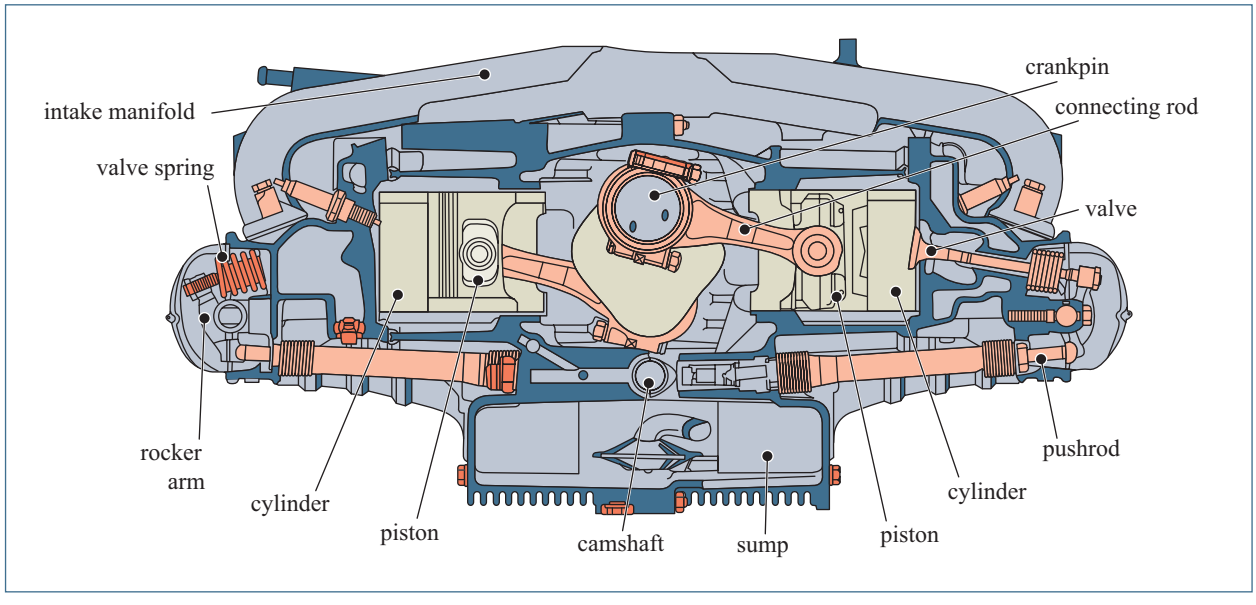


Figure 16.15 Arrangement of a horizontally-opposed engine

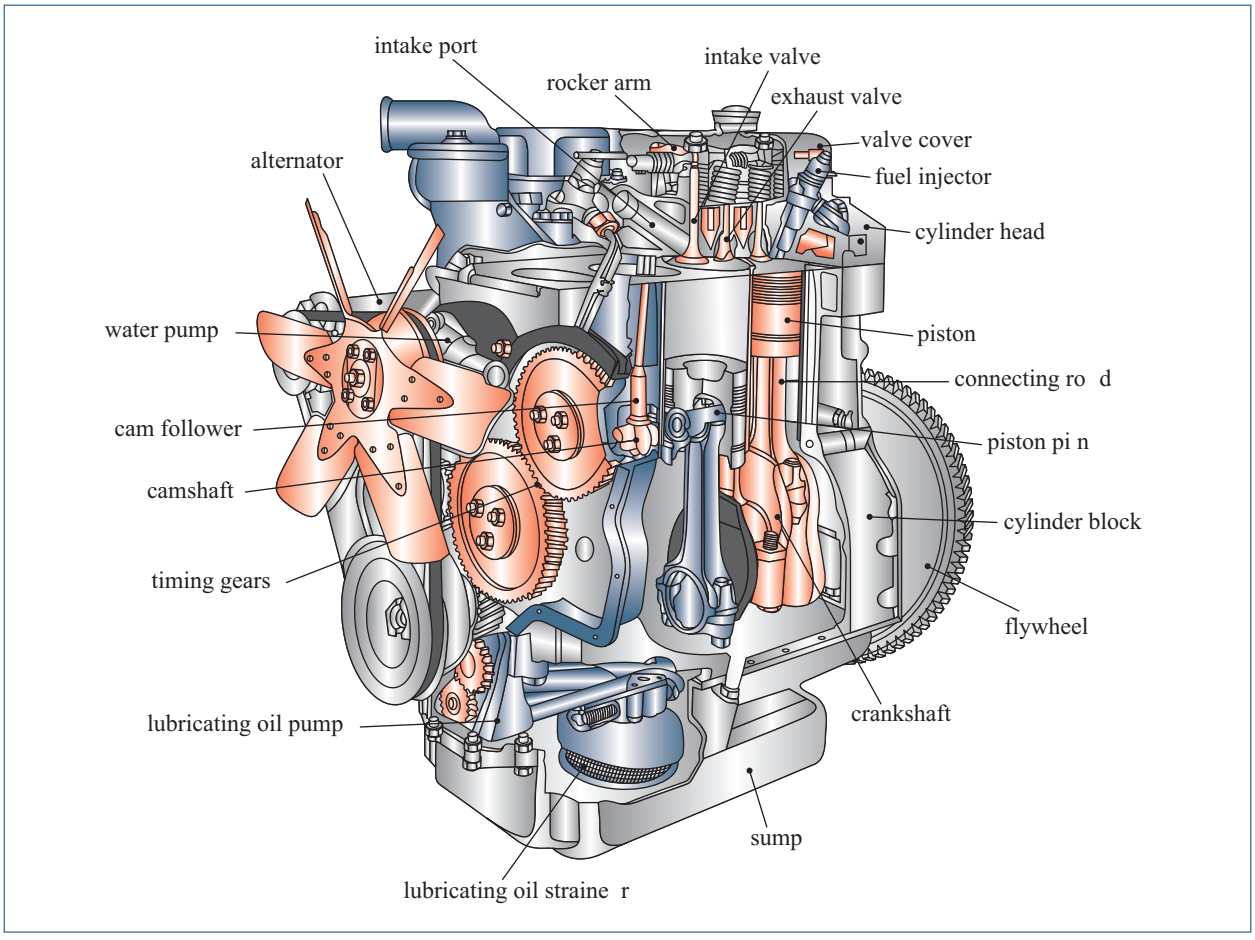


Figure 16.16 Basic diesel-engine construction

There is also equipment mounted in the engine compartment. Figure 16.17 shows the general arrangement of an engine compartment of a transverse engine. Some engine parts are accessible only from underneath, so the vehicle is raised on a jack or hoist. With transverse engines, some parts are accessible from under the mudguards and the wheels have to be removed to provide working space.

When working under the bonnet, use covers on the mudguards to protect the paintwork. Clean up liquid spills immediately, particularly hydraulic brake fluid and coolant additives, as these can remove paint.

Handy hint: Before dismantling an engine, make sure you are familiar with its construction details and features; these can be obtained from the appropriate workshop manual.

16.3.6 Engine repairs

During an engine repair, pay attention to the following:

1. Small parts. Tag parts such as fuel lines and emission hoses to enable correct replacement.
2. Fuel lines. Remove these carefully so they are not damaged. The fuel lines for electronic fuel injection systems hold pressure, even with the engine stopped. Release this slowly, to prevent oil spraying everywhere.
3. Holes and pipes. Cover or plug these to keep out dirt and foreign objects.
4. Air-conditioning parts. Use refrigerant-recovery equipment if you need to disconnect air-conditioning pipes. Refrigerant cannot be released into the atmosphere as it causes pollution, and any work involving its use must be carried out by a licensed person.
5. Dismantled parts. After parts have been removed or dismantled, lay them out in an order that helps identify them. When you have cleaned them, arrange them for reassembly.

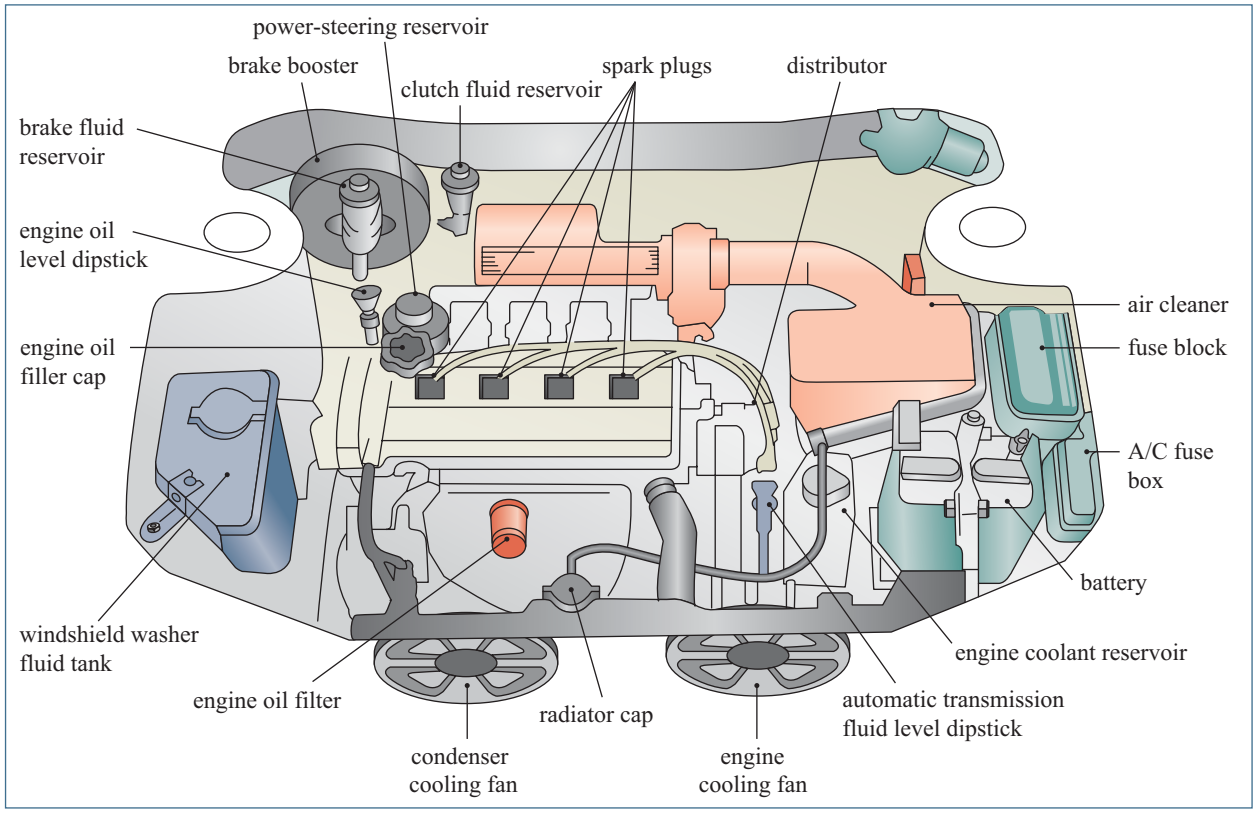


Figure 16.17 General arrangement of the components in the engine compartment of a vehicle with a transverse engine

Cleaning and inspecting

1 Cleaning. Clean parts by washing them in solvent, using a scraper on flat surfaces, brushing or immersing them in a cleaning tank. After cleaning, coat parts that could rust with oil. Wrap small parts, such as bearings, to keep them clean.
2 Inspecting. Some parts have to be measured for wear; others are checked visually for cracks, damage, corrosion or distortion.

Installing

1 Installing parts. Before installing a new part, check it against the old part to make sure that both are identical. Replace parts in their original positions, without forcing them. If any part does not fit into place easily, look for the reason.
2 Gaskets and seals. These must be correctly positioned when being installed. Sealant is recommended for some parts, and seals should be lubricated.
3 Tightening. Tighten bolts and nuts in the correct sequence and to the correct torque. Overtightening could damage the bolt or strip a thread. Undertightening could cause leaks or allow a part to come loose.

Adjusting and checking

1 Adjusting. Some parts have to be adjusted to specifications. These include drive belts, some valve clearances and throttle cables.
2 Checking. After reassembly, make a final check that all necessary work has been done. The engine has to be started and run for some checks, and the vehicle road-tested for others.

Safety: Always ensure you use the correct size of hand tools so that you can hold them securely.

16.4 Working on the underside of the engine

16.4.1 Oil pan

The oil pan, or sump, is secured to the bottom of the cylinder block by a number of bolts. Figure 16.18 shows the general procedure for removing and replacing an oil pan.

Removing the oil pan

1 Raise the front of the vehicle , or raise the complete vehicle on a hoist.
2 Drain the engine oil.
3 Remove the oil pan retaining bolts.
4 Carefully insert a screwdriver or special tool between the oil pan and the crank case to separate the oil pan (Figure 16. 18(a)).
5 Remove the oil pan completely (Figure 16. 18(b)).
6 After removing the oil pan, inspect it for damage and check the condition of the thread in the drain plug hole . Check the oil pump screen and clean it if necessary (Figure 16. 18(c)).
7 Clean the oil pan and remove all the old gask et or sealing material from the mating surfaces of the oil pan and the crank case . Fit the drain plug, using a new washer if necessary .

Sustainability: All waste oils must be stored and disposed of according to environmental and industry requirements.

Installing the oil pan

1 Fit a new gask et to the flange of the oil pan and retain it with grease; or apply a 3 mm bead of liquid silicone gask et material to the flange of the oil pan, as shown in Figure 16. 18(d). The silicone must form a continuous bead around the flange and must be inside the bolt holes to prevent leaks.
2 Install the oil pan to the crank case , fit the bolts and tighten them to the correct torque .
3 Refill the oil pan with oil, run the engine and check for oil leaks.

Handy hint: Where silicone is used, the oil pan has to be reinstalled and the bolts tightened within about 15 minutes. The material cures when exposed to air and parts must be assembled within a limited time .

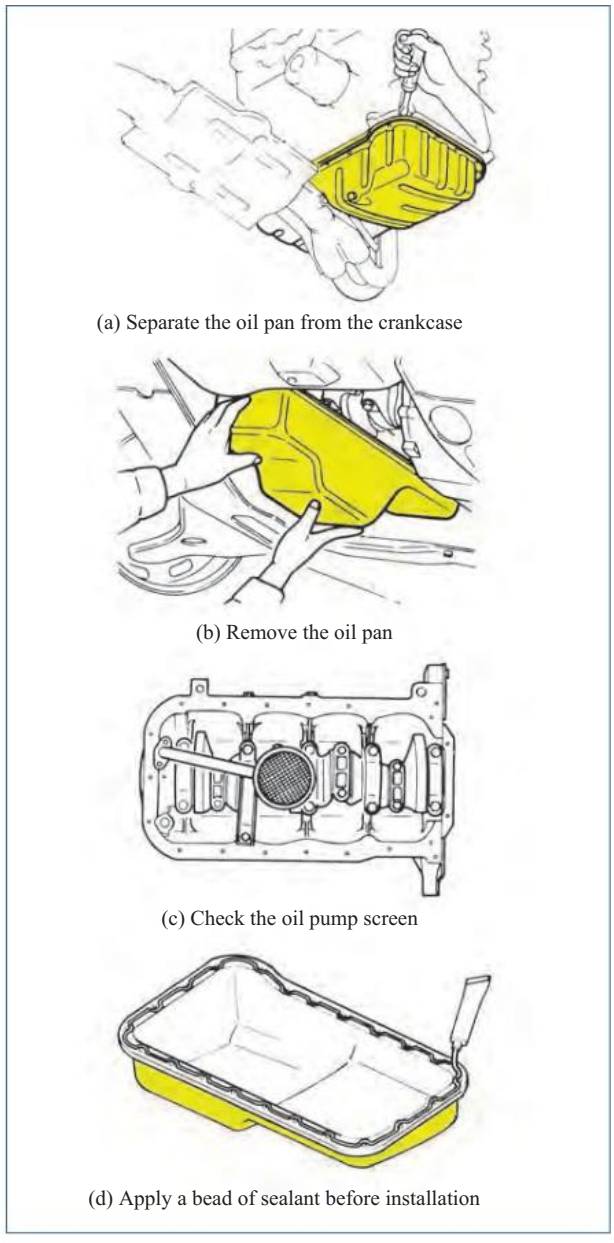
16.4.2 Oil pump

Some oil pumps are chain-driven, some are shaft-driven and some are driven directly by the crankshaft. Figure 16.19 shows the location of a chain-driven oil pump that is secured to the crankcase by two bolts and is accessible with the oil pan removed.

Where the oil pump is driven by the crankshaft, the timing cover and housing will have to be dismantled from the front of the engine before the oil pump can be removed.

16.5 Working on the front of the engine

Parts located at the front of the engine include the water pump (on most engines), the crankcase pulley and vibration damper, the timing cover and the timing chain or timing belt.



(a) Separate the oil pan from the crankcase

(b) Remove the oil pan

(c) Check the oil pump screen

(d) Apply a bead of sealant before installation

Figure 16.18 General procedures when removing and installing an oil pan FORD

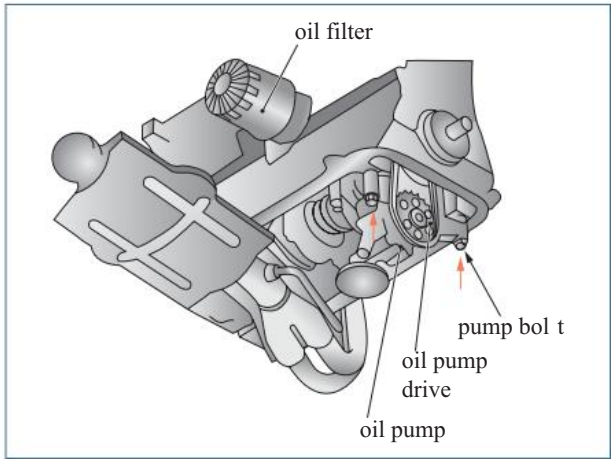


Figure 16.19 Location of an oil pump at the front of the crank case—the pump is held by two bolts

Engines with a timing chain have a cast-metal or pressed-metal cover. The timing chain is lubricated by engine oil and the timing cover has to be oil-tight to retain oil within the engine.

Engines with a timing belt have a plastic timing cover. This keeps out dirt but does not have to retain oil, because the timing belt runs dry.

16.5.1 Removing a crankcase pulley

The pulley assembly fits on the end of the crankshaft, to which it is keyed and retained by a bolt or nut. A puller is needed to remove some pulleys. After removing the bolt or nut securing the pulley, a puller is fitted to the pulley as shown in Figure 16.20.

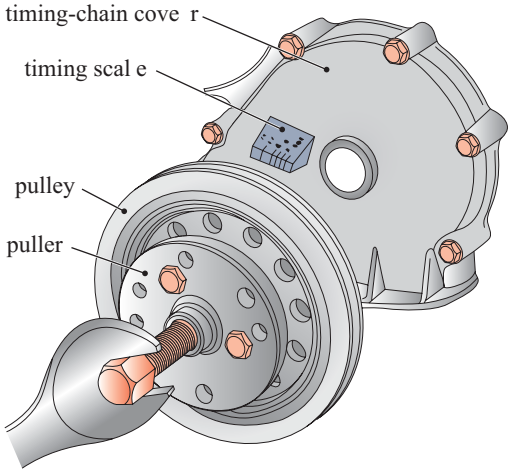


Figure 16.20 Using a screw-type puller to remove a crankshaft pulley

16.5.2 Removing the timing cover

Metal timing covers are retained by a number of bolts and can be removed after the crankcase pulley has been removed. There will be a gasket or sealing material between the timing cover and the cylinder block.

The timing cover is removed and treated in a similar way to the oil pan. Timing-belt covers are made of plastic material and are retained by fewer bolts than metal covers. They have no gaskets or sealer, and so are easier to remove.

16.6 Working on engine ancillaries

There are various components attached to the engine which have to be removed for servicing, or to obtain access to other parts. These include: the water pump, power-steering pump and air-conditioning compressor. These are all belt-driven from a pulley on the front of the crankshaft.

The drive belt (or belts) must be removed before the components can be removed from the engine. When the parts are replaced, the tension of the drive belts will have to be adjusted. The engine in Figure 16.21 has a single belt that drives a number of pulleys.

16.7 Working on engine electrical systems

The main engine electrical components are:

- the ignition system components
- the battery
- the starter
- the alternator
- the electrical wiring system that is used to connect these various parts.

(Items 1, 3 and 4 are identified on the engine in Figure 16.21.) These components form the basic starting, charging and ignition systems that are needed to start the engine and keep it running. However, there are many other electrical and electronic components. Some are attached to the engine, while others are located in the engine compartment.

Many vehicles have engine management systems that use electronic control units to operate and monitor a range of engine functions.

16.7.1 Ignition system

Ignition system service includes removing and replacing spark plugs and checking the ignition timing. Distributors with electronic ignition and other electronic ignition systems which do not have a distributor do not require routine servicing. Older vehicles have distributors with breaker points and these need regular service.

⚠ Safety: Hands should be kept clear of the ignition system when the engine is running as very high voltages are produced.

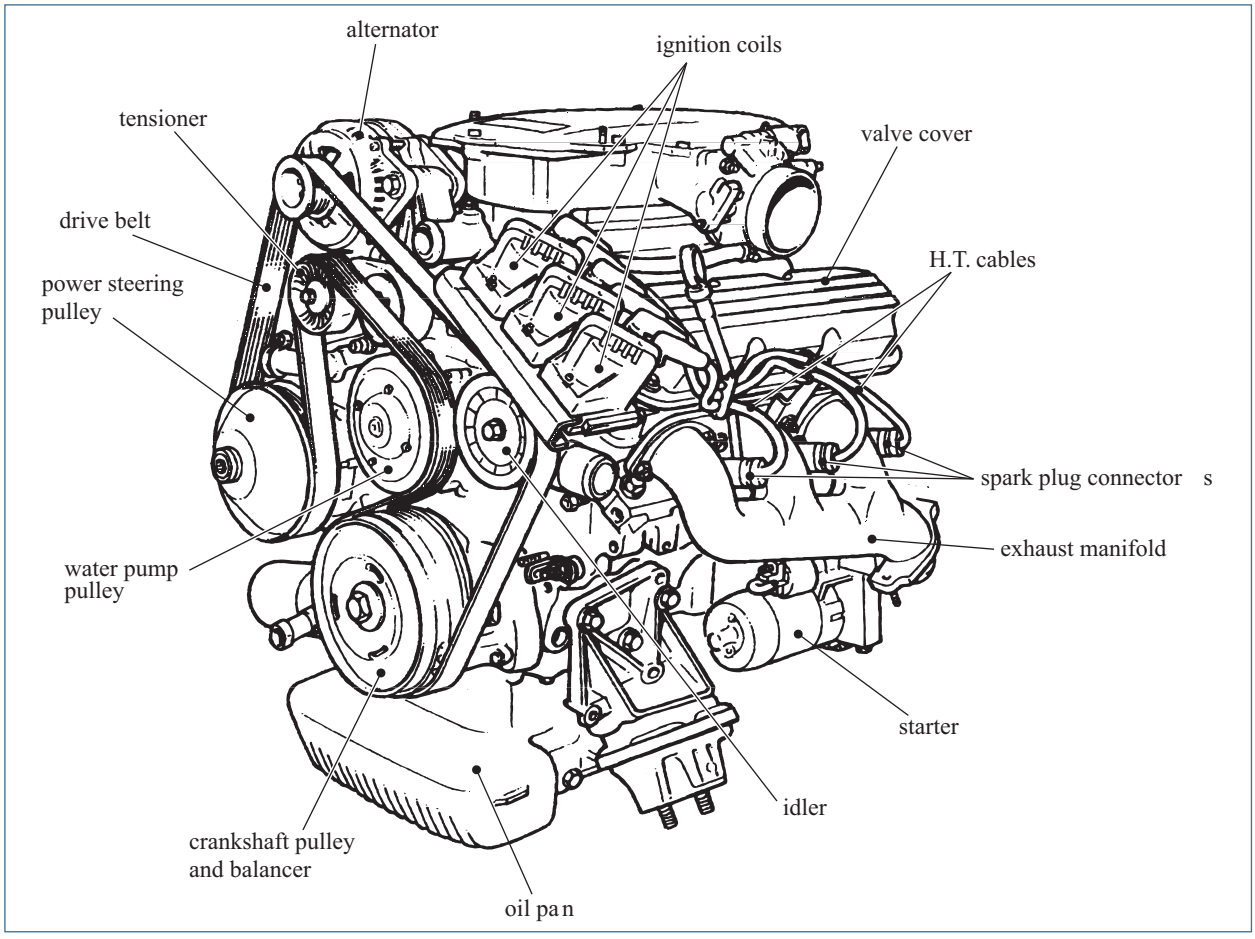


Figure 16.21 External components of a V-6 engine—the single belt drives a number of pulleys GM HOLDEN LTD

Spark plugs

Removing and inspecting spark plugs is a routine service item for ignition systems. Spark plugs are screwed into threaded holes in the cylinder head. They are removed and replaced as follows:

Figure 16.22 Remove spark plug connectors by pulling and twisting

1. Remove the cables from spark plugs by holding and pulling the connector and not the cable (Figure 16.22). Pulling the cable will permanently damage it.
2. Use compressed air to clean around the plug before removal to prevent dirt from entering the engine.
3. A special spanner is used to remove spark plugs. It should be used carefully to avoid breaking the ceramic insulator, which is very brittle.
4. Check the condition of the spark plug after it has been removed. The deposits on the spark plug can indicate its condition, how well it has been firing and possibly the condition of the engine (Figure 16.23).
5. Replace defective spark plugs.
6. Before installing a spark plug, the gap should be set (Figure 16.24).
7. The gap between the electrodes is checked with a feeler gauge and the earth electrode carefully bent if the gap has to be adjusted. Any force applied to the centre electrode will crack the nose of the insulator and the plug will be worthless.
8. When replacing a spark plug, start the first few threads by hand and make sure that the plug is not cross-threaded. Tighten the plug until it seats firmly, but do not overtighten. The tightening torque is about 15 to 20 Nm.

Spark-plug conditions: A brown, tan or grey firing end is indicative of correct engine running conditions and the selection of th e appropriate heat rating plug.

White deposits have accumulated from excessive amounts of oil in the combustion chamber or through the use of low-quality oil. Remove deposits or a hot spot may form.

Black sooty deposits indicate an over-rich fuel–air mixture, or a malfunctioning ignition system. If no improvement is obtained, try one grade hotter plug.

Wet, oily carbon deposits form an electrical leakage path along the insulator nose, resulting in a misfire. The cause may be a badly worn engine or a malfunctioning ignition system.

A blistered white insulator or melted electrode indicates over-advanced ignition timing or a malfunctioning cooling system. If correction does not prove effective, try a colder grade plug.

A worn spark plug not only wastes fuel but also overloads the whole ignition system because the increased gap requires higher voltage to initiate the spark. This condition can also affect air pollution.

Figure 16.23 After removal, the spark plugs should be examined—they can provide useful information

16.7.2 Battery

Batteries require regular checks of the electrolyte level, even though some are classed as being *maintenance free* or *low maintenance*. The top of the battery should be kept clean and the terminals should be clean and free of corrosion.

Handy hint: Dirty battery terminals can prevent the starter from operating.

16.7.3 Starter

The starter draws a high current when turning the engine for starting. Starter operation depends on good battery maintenance—it needs a good, well-charged battery with clean terminals.

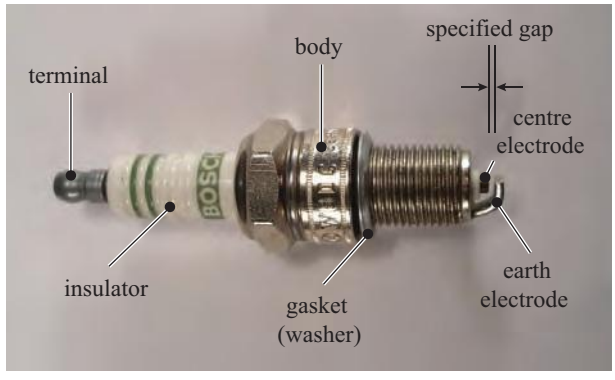


Figure 16.24 The spark plug electrodes have a specified gap

16.7.4 Alternator

The alternator drive belt must be correctly adjusted to prevent slip. A loose belt could allow the battery to run down. A quick check of the alternator can be made using a voltmeter as follows:

1. With the engine stopped, connect a voltmeter across the battery terminals.
2. The voltmeter should read approximately 12 volts.
3. Start the engine and run it at a speed above idle.
4. The reading on the voltmeter should be higher than before, and around 14 volts.

Safety: When the alternator is being checked, the voltmeter must be connected with correct polarity.

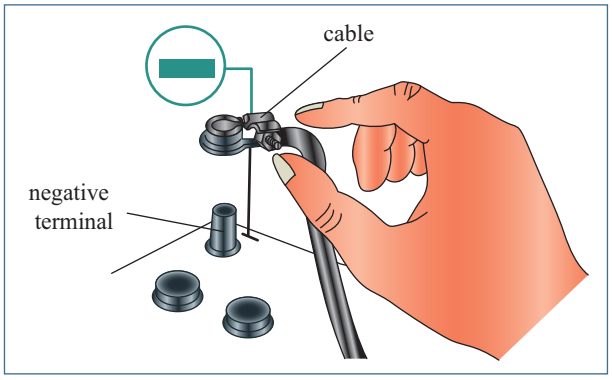


Figure 16.25 The negative terminal should be removed first and replaced last when working on electrical systems

Electrical wiring and connectors

When servicing electrical parts, take the following precautions:

1. Disconnect the battery as a safety precaution where 'live' wires or components could cause a problem (Figure 16.25). This is a general safety rule but, in some vehicles, disconnecting the battery might cause loss of data or diagnosis information. A low-voltage ECU protection device can be fitted when disconnecting a battery.
2. Disconnect electrical connectors carefully to avoid damage. Pull the connector, not the wires. Some connectors have a small catch that must be released before the parts can be separated.
3. Keep wiring away from hot manifolds and exhausts.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe engine construction
- identify the internal and external components of an engine
- identify engine design configurations
- identify engine ancillaries and electrical systems.

REVIEW QUESTIONS

1. Name the main components that are located at the top of an engine.
2. Name the main components that are located at the front of an engine.
3. What is a flywheel and what is its purpose?
4. What is the function of the connecting rods and crankshaft?
5. What is the purpose of the timing belt?
6. Why is an engine timed?
7. How are the valves operated?
8. In the illustrations, locate and identify the following parts: camshaft, camshaft pulley or sprocket, timing belt, intake valves, exhaust valves, rocker shafts, crankshaft, balance weights.
9. How does a diesel engine differ from a petrol engine?
10. What is meant when an engine is referred to as an EFI engine?
11. How would sealant be applied to a part, such as an oil pan?
12. How is a crankshaft pulley removed?
13. In what sequence would components be dismantled from the top of an engine? (Refer to the illustrations.)
14. Why are cylinder-head bolts loosened and tightened in a specified sequence?
15. What is meant by ignition timing?

CHAPTER 17

General engine service

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 apply general engine service techniques
2 apply relevant safety procedures and requirements
3 state the method of engine service using correct terminology
4 demonstrate how to inspect and clean an engine
5 measure , analyse and document inspection results
6 apply service techniques to a range of engines in accordance with workplace and manufacturer/component supplier requirements and specifications.

17.1 Reasons for dismantling an engine

An engine is usually only dismantled after it has operated for many thousands of kilometres and its internal parts have become worn. Wear could be indicated by excessive oil consumption, smoke from the exhaust, noise or loss of power (Figure 17.1); if engine performance has fallen off gradually, it may not have been obvious.

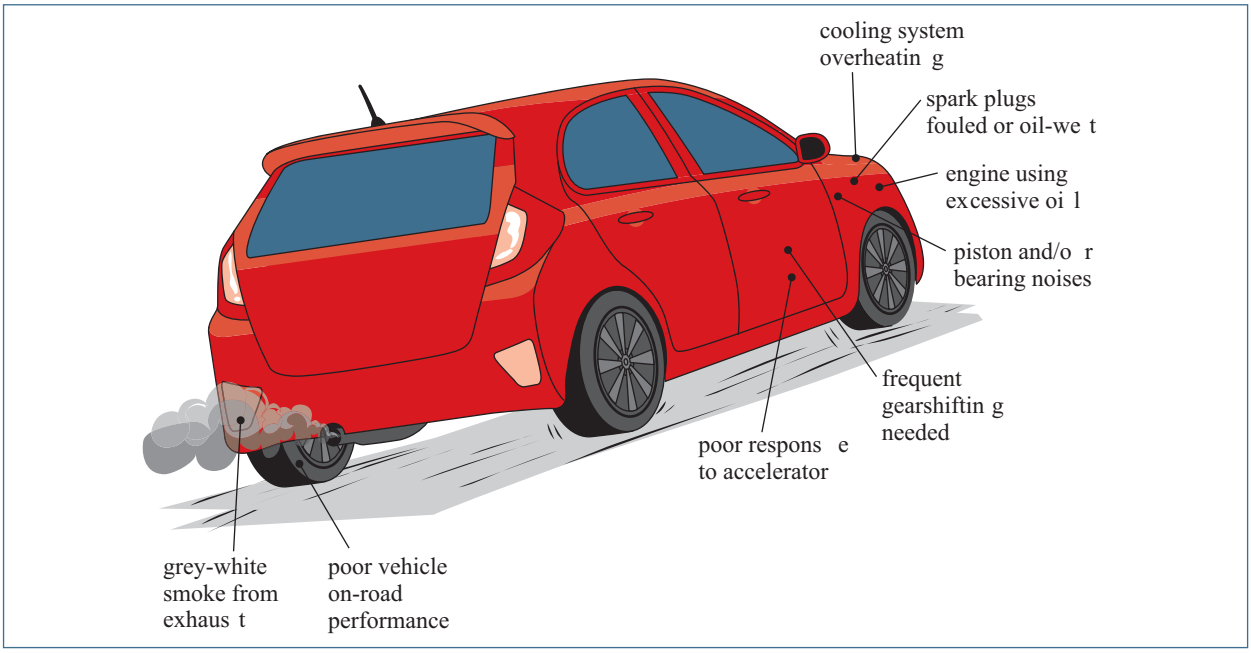


Figure 17.1 Conditions which show that an engine needs attentio n

Other reasons for dismantling an engine are to correct particular problems such as a burnt-out valve, a blown cylinder-head gasket or an engine knock. There could be damage to bearings and other parts due to a shortage of oil or loss of coolant.

Failure of an internal part could cause damage to other parts of the engine. This is noticed quickly because of unusual engine noises or a sudden drop in performance.

17.2 Types of engine work

17.2.1 Engine maintenance

This includes the usual maintenance services, such as changing the oil and oil filter, changing the coolant in the cooling system, servicing the air cleaner, checking the fuel system and checking the ignition system.

Safety: When conducting service procedures, always wear safety glasses and beware of hot liquids.

Sustainability: Services maintain engine performance , prevent unnecessary exhaust emissions and prolong the life of the engine .

17.2.2 Mechanical repairs

Mechanical repair is work that is necessary because of a particular problem such as oil leaks or loss of power. The extent of the work depends on the extent of the problem.

17.2.3 Top overhaul

This is where the cylinder head and associated parts are removed to decarbonise the combustion chambers and carry out work on the valves. This could be part of a maintenance program, but is more likely to be performed because of a burnt valve, a leaky cylinder-head gasket or worn valve-guide oil seals.

17.2.4 Partial overhaul

This could include a top overhaul as well as renewal of piston rings and connecting-rod bearings. If the engine has cylinder sleeves that are worn, they could be replaced. A partial overhaul might be carried out to correct a loss of engine power, excessive oil usage or engine noise.

17.2.5 Complete overhaul

This is where an engine is dismantled and all worn parts either renewed or reconditioned, restoring it to 'as new' condition. Once the engine is dismantled, the condition of the pistons, cylinder walls, crankshaft journals and bearings are checked. This determines the extent to which the parts need reconditioning, a process that could include cylinder reboring, cylinder resleeving or crankshaft grinding.

This work is done in engine reconditioning workshops rather than in service workshops. Exchange engines are made available for some models, usually as a *short motor* (which is the cylinder block, complete with pistons, connecting rods, crankshaft and associated parts). Removal and replacement of the engine is carried out in service workshops.

17.2.6 Engine removal

While many repairs can be done with the engine in the vehicle, it will have to be removed if it needs to be completely dismantled. Some front-wheel-drive vehicles have restricted room in the engine compartment, and the engine is removed complete with the transmission. Removal may also be necessary for transmission overhaul.

The engine is lifted from the vehicle with a workshop crane or overhead tackle, a chain sling being attached to lifting eyes on the engine (Figure 17.2).

With some vehicles, the engine is removed from below. The vehicle is raised on a hoist and the engine is lowered onto a floor jack or other support, (Figure 17.3). Here a wooden block has been placed between the engine and the jack to distribute the weight and prevent damage.

Safety: Use appropriate handling equipment, and never use rope or homemade slings. No chains or lifting equipment should ex ceed the safe working load (SWL) that is mark ed on them.

Figure 17.2 Engine lifted with a sling attached to lifting eyes on the engine

A special lifting device is used for some vehicles. This consists of a crossbar supported on the reinforced panels at the top of the suspension (Figure 17.4). This supports the engine when the transaxle or components such as engine mounts are being removed.

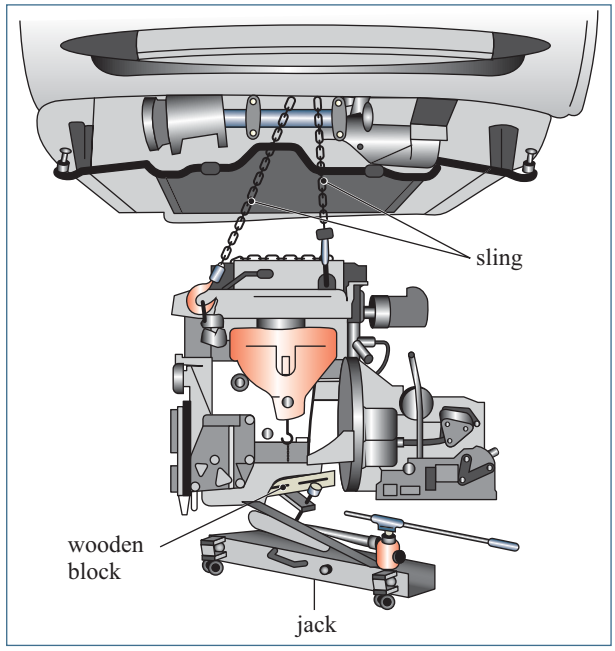


Figure 17.3 Removing an engine from below

17.3 Sequence of engine work

The general sequence for engine repair or overhaul is:

1 Diagnosing and checking
2 Dismantling
3 Cleaning and inspecting
4 Taking measurements
5 Reconditioning or renewing parts (Refer to chapters 18 and 19)
6 Reassembling and adjusting
7 Finalising and checking.

Figure 17.4 Engine supporting fixture

17.4 Diagnosing and checking

Before dismantling or removing an engine, any known problems should be diagnosed or isolated. Some problems are difficult to diagnose unless the engine is running, so as many checks as possible should be made while it is operational.

17.4.1 Checking engine noise

When trying to locate the source of an engine noise, consider the type of noise and its frequency. Noises can vary considerably, and they include the following:

1 Valve noise . A light tap at camshaft speed could be caused by incorrect valve-clearance adjustment, a worn cam follower or cam, a worn rock er arm or a faulty hydraulic valve lifter .
2 Chain noise . Timing chains and sprock ets will produce noise at idle speed if the chain is worn or loose , or if the tensioner is not operating properly .
3 Timing-belt noise . A timing belt can flap and produce noise if it is damaged or stretched and does not have the right tension.
4 Gear whine . Timing gears can produce this if they are worn or not lubricated.
5 Piston noise . Pistons and cylinders that have ex cess clearance through wear can cause piston slap when the engine is cold. A damaged or collapsed piston could also be noisy , whether hot or cold.
6 Bearing knock. A connecting-rod bearing will knock if it is damaged or worn. The noise will be regular and more pronounced under load. If all bearings are in bad condition, there could be some general noise . Crankshaft main bearings could become noisy , but will not knock lik e a connecting-rod bearing.
7 Dull knock. A loose flywheel could produce a dull knock at crankshaft speed, but this is less lik ely than other noises.

Some noises come from sources outside the engine, such as the exhaust system, the water pump, the power-steering pump, the air-conditioning compressor, the alternator or the transmission. These possibilities should not be overlooked when diagnosing noises.

Safety: If running an engine for any period of time , ensure that the exhaust system is connected to an extraction system.

17.4.2 Checking oil consumption

When investigating excessive oil use, do not automatically assume the cause to be worn piston rings carrying the oil into the combustion chambers. This could be the case, but oil can also pass down the valve stems if there are worn seals or guides, or there could simply be a leak.

Oil burning in the combustion chamber shows as smoke from the exhaust. If there are no external oil leaks, but engine performance is poor and smoke is coming from the exhaust, the problem could be faulty piston rings. A cylinder compression check should be carried out (see 'Checking cylinder compression'); if that proves to be satisfactory and the exhaust puts out smoke after downhill engine braking, the valve seals or guides are likely to be worn.

Sustainability: When servicing an engine , mak e sure that all oils, coolants and fuel are captured and stored and then recycled to meet state authority standards.

17.4.3 Checking oil leaks

Examine all the places that oil could leak from, such as the valve cover, timing cover, oil pan, oil filter, oil cooler and front and rear crankshaft seals. Next, clean suspect areas and then run the engine until it reaches operating temperature, or until the leak is found.

Handy hint: An oil leak can cause a considerable loss of oil; even a small leak can produce a large oil-wet area.

17.4.4 Checking oil pressure

Oil pressure can be checked by connecting a pressure gauge to the main oil gallery of the lubrication system (Figure 17.5). The pressure could be low at engine idle speed, but it should rise to regulated pressure when speed increases.

Consistent low oil pressure could be the result of worn crankshaft bearings, or a restricted oil pump intake screen. High oil pressure could be caused by a sticking relief valve, or a restricted oil filter.

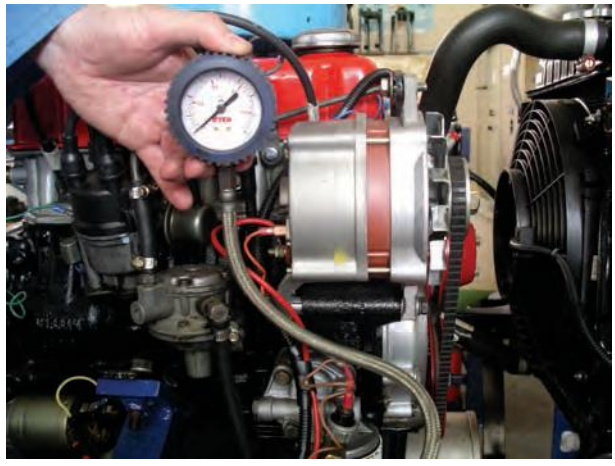


Figure 17.5 Pressure gauge connected to the oil gallery of an engine to check oil pressure

17.4.5 Checking cylinder compression

The cylinders should be given a compression test in cases of rough running or power loss. This will check the sealing ability of the piston rings and valves. A cylinder compression gauge is used. It has an adaptor to suit the spark plug hole of petrol engines (Figure 17.6).

To use a compression gauge with a petrol engine, remove the spark plugs from the engine and isolate the ignition. Fit the compression gauge to the spark plug hole of one cylinder. Spin the engine with the starter over two or three compression strokes and note the reading. Do the same with the other cylinders. Possible pressure results are:

1 All cylinders appro ximately the same —cylinder conditions satisfactory .
2 Low reading on one cylinder —suspect the valves.

Figure 17.6 Compression gauge adapted to fit a spark plug hole

3 Low reading on adjacent cylinders —suspect a cylinder-head gasket.
4 Low reading on all cylinders —suspect the piston rings.

Safety: Before conducting a compression test, disable the ignition and fuel systems.

To check cylinders with low pressure where faulty piston rings are suspected, squirt a small quantity of oil into the cylinders. This will act as a seal on the rings and should increase the pressure readings. If there is no increase in pressure, assume that the valves (and not the piston rings) are the problem.

Diesel engines require a special compression gauge as their compression pressure is much higher than that of a petrol engine.

Remove the injectors from the engine and attach the compression gauge to each cylinder in turn. Isolate the injection pump to prevent fuel delivery while the starter is turning the engine.

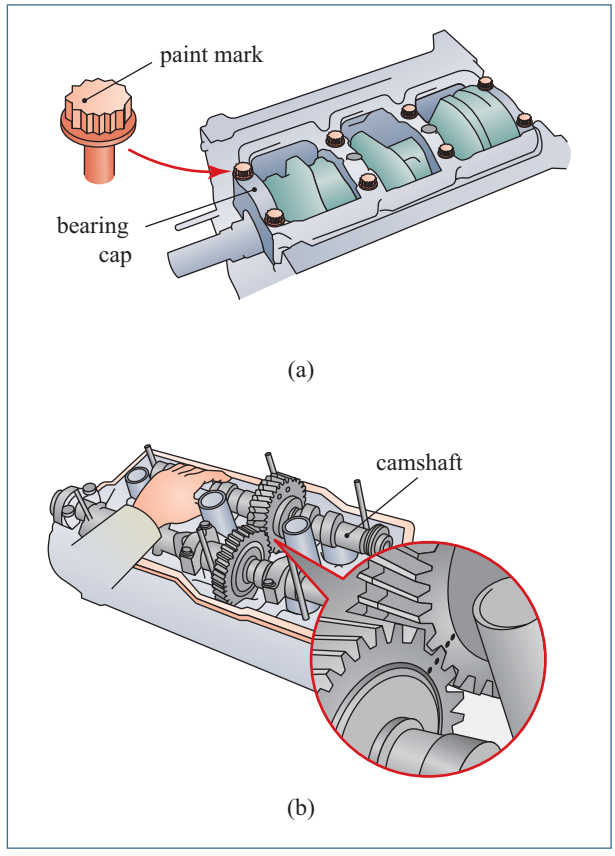


Figure 17.7 Parts provided with identification marks (a) bolt with paint mark (b) camshaft gears with punched timing marks

17.5 Dismantling

Engine dismantling requires knowledge of the construction of the engine and an understanding of good workshop practices. Correct tools are needed, as is a source of ready reference, such as a service or workshop manual. The following practices are particularly important.

1 Observation. Note the location of engine accessories for correct reassembly, and carefully mark the component and its mounting for correct reinstallation. Taking photos of the engine bay will assist in reassembly, in conjunction with the workshop manual.
2 Identification. Identify parts' features as they are being removed or replaced. Be aware of their functions, and any necessary adjustments or special precautions. Check for identification marks (Figure 17.7).
3 Witness marks. These are wear marks that occur between moving parts; they can also be impressions from mating parts, or marks from gaskets or seals. They can be used to show how one part was originally fitted to another.

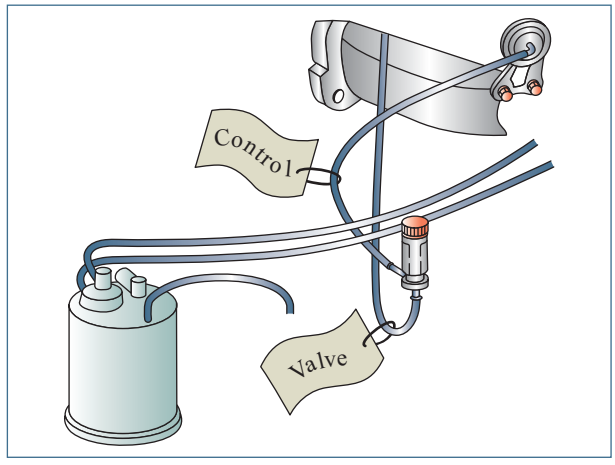


Figure 17.8 Tag vacuum lines, cables and other small parts for easy identification

4 Visual checks. These are checks made during dismantling. They include checking the condition of parts for wear or damage.
5 Procedures. Dismantling and subsequent reassembly should be treated as procedures that include observation, identification and using a logical sequence.
6 Storing parts. Parts should be labelled, especially external connections (Figure 17.8). Smaller parts should be stored in trays. Bolts, nuts and related small fittings should be kept together, but in separate containers for easier reassembly.

Handy hint: Parts that work together should be kept together so that they can be reassembled in their original locations.

17.6 Cleaning and inspecting

Useful information can be obtained from engine parts both before and after cleaning. Whenever an engine or component is dismantled, it is good practice to look for the causes of any damage or wear.

Every part of an engine gradually wears out, and the rate at which this occurs often depends on how the engine is operated and how well it has been serviced. Overloading, overspeeding, overheating, poor air filtration, poor lubrication and lack of maintenance will all affect engine life.

The following are some of the checks that can be made when investigating problems.

17.6.1 Oil and coolant

Check coolant to see if it is clean or if there are signs of engine oil (Figure 17.9). Oil should be checked for signs of coolant, which will cause it to become emulsified.

Check the bottom of the oil pan for sludge and deposits that could indicate the general engine condition. If impurities are present, try to establish why.

Handy hint: Oil that is emulsified will become thick and be milky in appearance .

17.6.2 Cylinder head

When the cylinder head is removed, examine the surface for warping. If the head and the surface of the cylinder block are flat, the pattern of the gasket will be clearly defined on the metal surfaces. If there is evidence of carbon or burning gases on the gasket around the combustion chamber, or if there are corrosion trails from the bores to the water-jacket, either the cylinder head or the surface of the block are likely to be warped.

Corrosion of the cylinder head around coolant passages could indicate poor cooling system maintenance.

Safety: Use safe handling procedures when removing and lifting heavy parts such as cylinder heads.

17.6.3 Valves and guides

Valves can be checked for carbon build-up under their heads, on their stems and in their ports. The amount of carbon will indicate whether excessive oil has been passing through the valve guide.

Valve stem-to-guide clearance should be checked to see if new guides are needed. The condition of the valves and valve springs should also be checked.

17.6.4 Cylinder block

Check the cylinder bores for scores or other damage and measure them for wear. If new piston rings are to be fitted, remove the unworn ridge at the top of the cylinder bore.

A ridge-removing tool is used for this operation (Figure 17.10). Take care not to remove too much metal and not to cut into the ring-travel area. The ridge reamer will produce metal chips, which must be cleaned out of the cylinder.

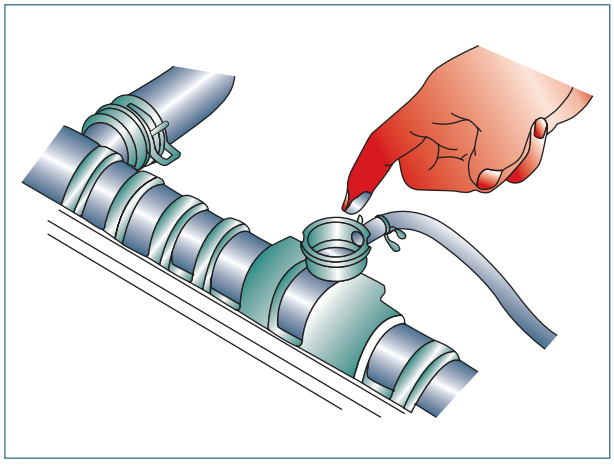


Figure 17.9 Check the radiator filler neck and the coolant for signs of oil

Figure 17.10 Using a ridge reamer to remove the ridge from the top of a cylinder bore

17.6.5 Connecting rods

Examine the connecting rods for marks or numbers (Figure 17.11). If none exist, they should be made so that the cap and connecting rod will be kept together and replaced in their original location.

Note whether the numbers on the connecting rods face to the left or right side of the engine so that they can be installed correctly.

Figure 17.11 Identification of connecting rod and cap . One dot means it is from the No .1 cylinder

17.6.6 Pistons and rings

When pistons are removed, check their heads for identifying marks or numbers. Pistons must be assembled to the connecting rod and installed in the engine in the same way as they were originally fitted. Figure 17.12 shows methods of marking the head of the piston to identify the front.

Pistons and rings should be examined as soon as they are removed from their bores. Look for damage to the lands. Check for broken rings and excessive side clearance in the top ring groove. Check the wear pattern on the thrust sides of the piston for signs of misalignment or excessive clearance (Figure 17.13). Check the piston-pin fit to see if wear is excessive.

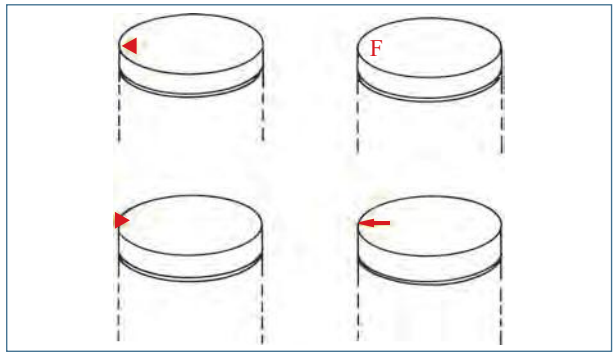


Figure 17.12 There are various ways of identifying the front of the piston

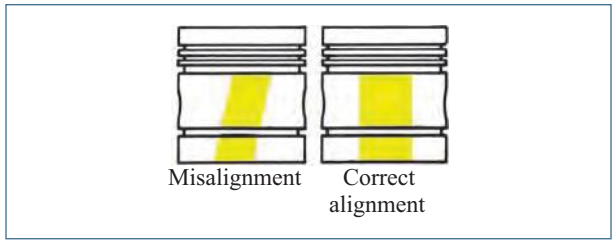


Figure 17.13 Wear pattern on a piston skirt

17.6.7 Crankshaft bearings

The condition of the bearings can show how an engine has been operated. With connecting-rod bearings, badly worn or fatigued upper inserts (Figure 17.14) could indicate that it has been subjected to prolonged lugging (which is heavy operation at very low engine speed).

Similar conditions in the lower inserts could indicate very high engine speeds, or overuse of the engine in low gear for braking. An uneven wear pattern could indicate misalignment of the connecting rod. Fine dust or abrasive particles in the bearing could indicate that the engine has been operating under dusty conditions, or with a faulty crankcase-ventilation system.

Figure 17.14 Fatigue failure of a crankshaft bearing

17.6.8 Crankshaft

Examine the crankshaft for scored or worn journals. If there is excessive wear, they will have to be ground undersize, and undersize bearings fitted. The crankpin journals are likely to have more wear than the main journals.

17.6.9 Flywheel

Check the condition of the flywheel face that the clutch operates against. Also examine the ring-gear teeth and, if necessary, replace the ring gear.

17.6.10 Camshaft and timing

Before removing the timing chain, timing belt, gears or pulleys, check the timing marks. It is far better to check the timing during dismantling than deal with confusion during reassembly. One example of timing marks is shown in Figure 17.15.

A typical belt removal and replacement procedure is:

1 Mark the belt direction of rotation with chalk before removal if it is to be reused.
2 Rotate the engine in the correct direction of rotation and align timing marks, as shown in Figure 17.15.
3 Lock the timing gears so they cannot move .
4 Release the belt tensioner and remove the belt.
5 To replace the belt, reverse the order , noting there should be no belt looseness on the drive side during installation.
6 Rotate the engine two complete turns and recheck the timing marks.

Handy hint: When a new belt has been fitted, a decal showing the date and kilometres travelled should be fix ed inside the engine bay , and the service indicator reset on the instrument panel.

Check the gears, sprockets and chain (or pulleys and belt) for wear. Also check the operation of the chain damper or the belt tensioner and examine the camshaft for worn lobes, journals and bearings.

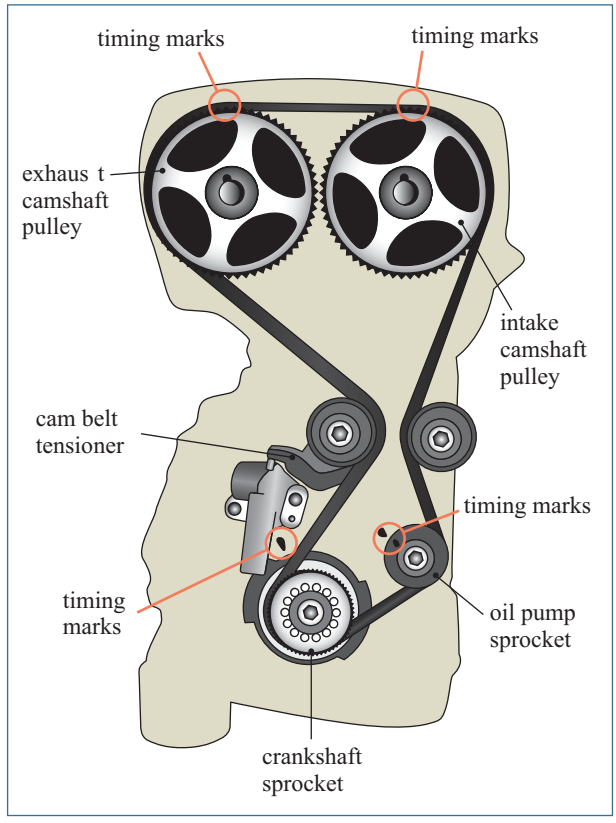


Figure 17.15 Timing marks for double-overhead camshafts

17.7 Taking measurements

While a visual inspection is satisfactory for some engine parts, many other parts must be measured accurately. This enables the amount of wear to be determined, and whether the part can be reused or renewed.

Measurements are also taken when making adjustments. Specifications of the size of the component or the clearance will be listed in service manuals or obtained from other service information.

Handy hint: Check the accuracy of measuring instruments before using them

17.7.1 Micrometers

Micrometers are used for accurate measurement of shafts and bearings, pistons, cylinder bores, bearing bores and many other components. Figure 17.16 shows measurements being taken with an outside micrometer. The diameter of the valve stem is measured and compared with specifications (Figure 17.16(a)). With the cam of the camshaft (Figure 17.16(b)), a measurement is being taken from base to lobe. Comparison with the other cams will determine cam wear. The measurement should also be compared with the engine specifications.

17.7.2 Vernier calipers

Vernier calipers can be used in a similar way to micrometers. They have the advantage that they can be opened and closed easily to read a range of dimensions. Figure 17.17 shows them being used to check the free length of a valve spring.

17.7.3 Dial gauge

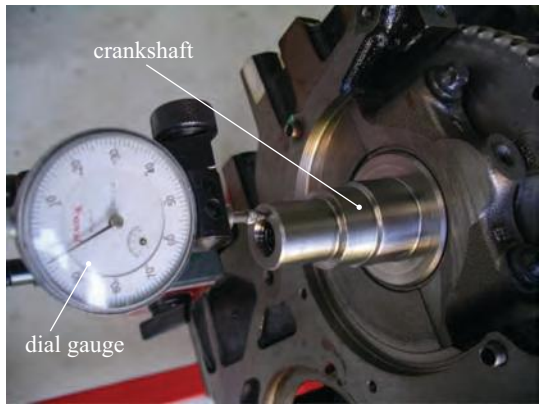
A dial gauge enables accurate readings to be taken and changes in dimensions to be easily seen. One application of a dial gauge is checking the end-float of a shaft, such as the crankshaft (Figure 17.18(a)). This is shown on the gauge when the crankshaft is moved backwards and forwards.

A dial gauge can also be set up to check the runout of a rotating part. Figure 17.18(b) shows this in application to a flywheel. With the dial gauge mounted as shown, the gauge is set to zero, the flywheel rotated and the changes in gauge reading noted.

(a)

(b)

Figure 17.16 Measuring with micrometers (a) valve stem (b) cam lobe



(a)

(b)

Figure 17.18 Measuring with a dial gauge (a) end -float of a crankshaft (b) flywheel runout

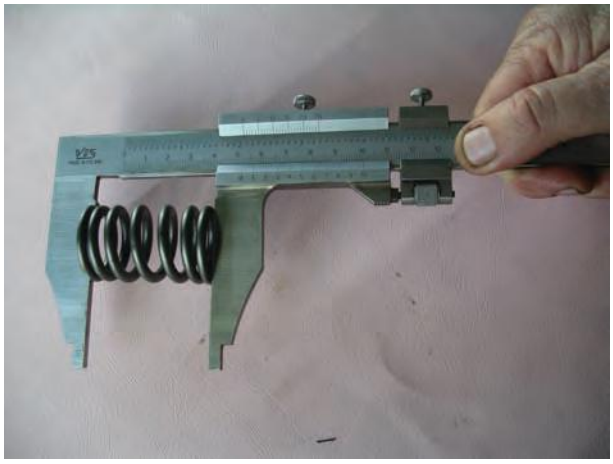


Figure 17.17 Measuring spring free length with calipers

Figure 17.19 Measuring cylinder wear with a cylinder-bore gauge

A dial gauge can also be used to check a shaft for alignment. The shaft is set up between two V-blocks with the gauge against its centre. The shaft is then carefully rotated and the gauge reading noted.

A cylinder-bore gauge is a special arrangement of a dial gauge for a cylinder bore (Figure 17.19). The gauge checks ovality and taper of the cylinder to determine its amount of wear.

17.7.4 Feeler gauges

Feeler gauges are used to check small clearances between parts. Figure 17.20(a) shows a feeler gauge being used to check a piston ring in its bore. The ring has been placed in the unworn portion at the bottom of

the bore, and the feeler gauge is being used to measure the ring gap. In Figure 17.20(b) a feeler gauge is being used with a straightedge to measure the flatness of the surface of a cylinder head. A feeler gauge and straightedge can be used to check the flatness of any surface.

Feeler gauges can also be used to check small clearances, such as that between the crankshaft thrust and the thrust of the main bearing. This is an alternative to using a dial gauge to check crankshaft end-float.

17.7.5 Plastigage

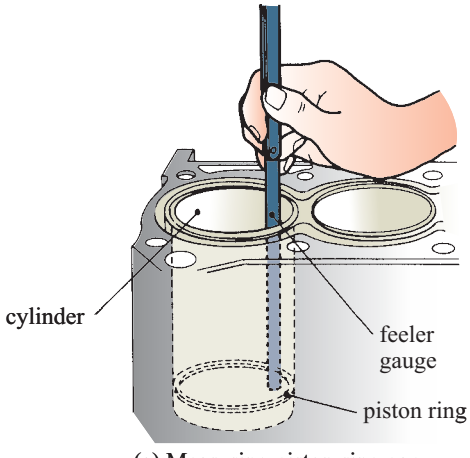
Plastigage can be used wherever the clearance between a shaft and a bearing needs to be checked. A check of the clearance of a camshaft bearing is shown in Figure 17.21. Similar checks can be made of connecting-rod bearings and main bearings. Plastigage enables bearing clearance to be checked without removing the shaft.

17.8 Working with bolts and fasteners

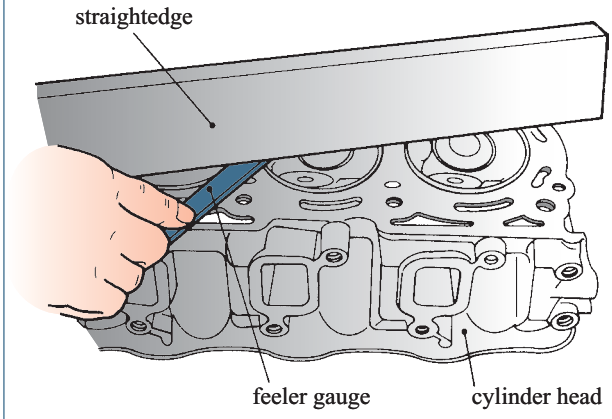
Bolts and nuts hold parts together and it is vital that they are tightened correctly.

17.8.1 Torque-wrench tightening

Torque settings are specified for almost all engine bolts and nuts, so a torque wrench is essential during engine reassembly. It is typically used for bearing cap

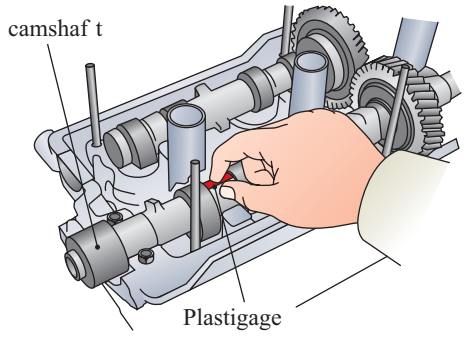


(a) Measuring piston-ring gap

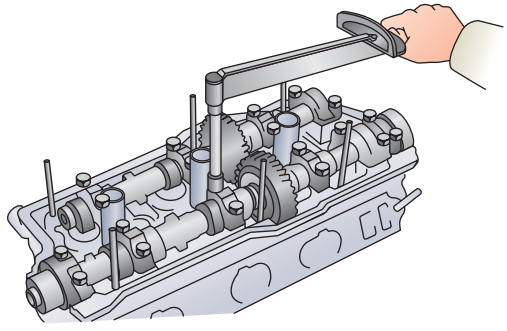


(b) Measuring surface flatness

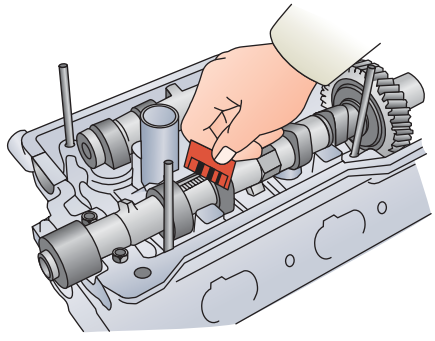
Figure 17.20 Measuring with feeler gauges GM HOLDEN LTD



Placing Plastigage on journal



Installing bearing cap



Checking flattened Plastigage

Figure 17.21 Using Plastigage to check camshaft bearing clearance

bolts, flywheel bolts, cylinder-head bolts and bolts securing the valve mechanism as in Figure 17.21.

A torque wrench measures the torque being applied to a bolt, and so is a measure of its tightness. As well as preventing bolts from being over-tightened, it also enables them to be tightened uniformly to a specified torque. This ensures that the bolts are sufficiently tight and that the part secured by them is not distorted by uneven tightening.

Handy hint: A torque (tension) wrench must be regularly check ed for correct calibration.

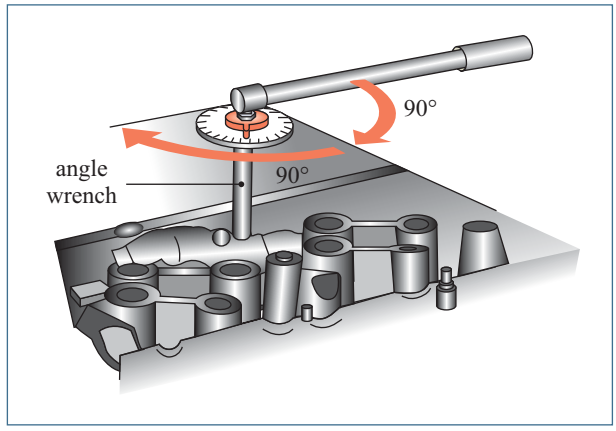


Figure 17.22 Tightening with an angle wrench

17.8.2 Angle tightening

With angle tightening, bolts are first tightened in a sequence to a specified torque. They are then turned through a specified angle to provide additional tightening. This is sometimes done in two steps (Figure 17.22).

When a bolt is being tightened, torque is applied to the bolt to place it under tension. This stretches it slightly, and it is this tension within the bolt that provides the clamping load that is needed to hold parts firmly together.

Why angle tightening is used

Angle tightening is more accurate than using a torque wrench. A torque wrench can tighten a number of bolts (such as cylinder-head bolts) to the same torque, but they may not all have the same tension. Angle tightening places all the bolts under the same tension.

When a bolt is being tightened, there is friction between the threads and the area under the head of the bolt. When it is tightened to a specified torque, some of the torque is applied to overcome the friction and some is applied to place the bolt in tension. However, the friction will not be the same for all the bolts, so tightening a number of bolts to the same torque does not mean that they will all have the same tension (and clamping force).

Using an angular tightening method overcomes the variations in friction that occur between different bolts. It therefore provides uniform tension in the bolts and a uniform clamping force.

Handy hint: This method of tightening is also called the torque angle method. It is used where tightness of bolts is critical.

17.8.3 Torque-to-yield tightening

This is an angular tightening method that places tension on the bolt that is close to its yield point. Bolts tightened to these specifications generally cannot be reused.

When a bolt is tightened, it is placed in tension and slightly stretched. When it is loosened, it usually returns to its original length. The material the bolt is made of has a certain *elasticity* that allows this to occur.

However, if a bolt is tightened until it is stretched beyond its *elastic limit,* it will reach its *yield point.* This is the point where the bolt will no longer return to its original length and will remain stretched.

When bolts are tightened with a torque-to-yield method, they are stretched close to their yield point and, once removed, are unsuitable for further use.

17.8.4 Checking critical bolts

Bolts subjected to high tightening torque and high loading can reach their yield point and become permanently stretched. As a means of checking the suitability of bolts for reuse, some manufacturers provide specifications of bolt lengths.

Figure 17.23 shows two bearing cap bolts for which the length would be specified. Both have their shanks reduced to a smaller diameter than the root diameter of the thread. This confines stretching to the shank of the bolt; otherwise, it would occur at the root of the threads.

The diameter of a bolt can also be checked to see whether it has suffered permanent deformation from stretching.

Handy hint: Bolt length measurement is from under the head to the end of the thread.

17.8.5 Bolts in aluminium castings

Engines with aluminium cylinder blocks and heads should be allowed to cool before bolts are removed from threaded holes. Aluminium expands at a greater rate than cast iron when heated so there is greater distortion of the threads in aluminium castings.

Figure 17.24 shows how thermal expansion can alter the thread form. If bolts are removed while the parts are still hot, the threads in an aluminium casting could be damaged. Further damage could occur when the bolt is being reinstalled.

While aluminium does not have the strength of cast iron, this is usually compensated for by having deeper holes and longer threads.

Handy hint: Impact tools should not be used on aluminium castings, but they can generally be used on cast-iron components.

17.8.6 Thread repair methods

Threads can be repaired by drilling out worn threads, tapping an oversize thread with a special tap and then installing a wire-type insert to bring the hole back to its original size. The method used for cast-iron components is shown in Figure 17.25.

The threads in aluminium castings, such as cylinder blocks, can be repaired in a similar way, but a flanged insert is used. The thread-repair process involves drilling out the thread to produce an oversize hole, counterboring the hole for the flange of the insert, tapping a thread in the hole to take the insert and installing the threaded insert in the hole.

17.8.7 Sealants and locking compounds

Sealants and locking compounds are available in a range of grades to suit different applications. Locking compounds are used on threads to prevent loosening, on splines to prevent backlash and on bushes and sleeves to hold them in place. Sealing compounds are used between bare metal surfaces instead of gaskets, on the threads of bolts and nuts and for other sealing applications.

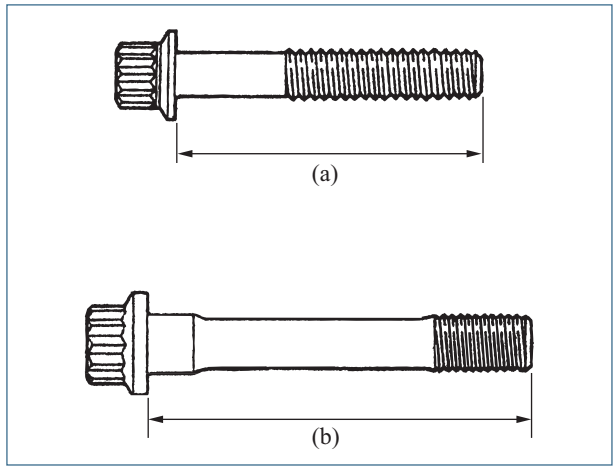


Figure 17.23 Check of the length of used bolts, (a) the connecting-rod cap bolt (b) the main-bearing cap bolt

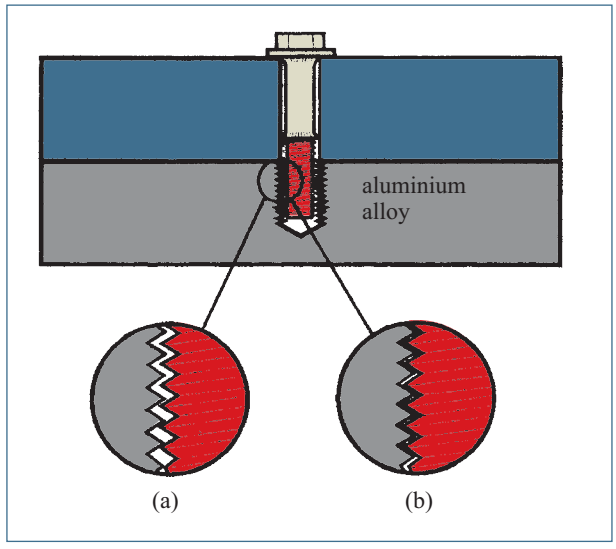


Figure 17.24 Thermal expansion of aluminium alloy (a) thread form when hot (b) thread when cool
GM HOLDEN LTD

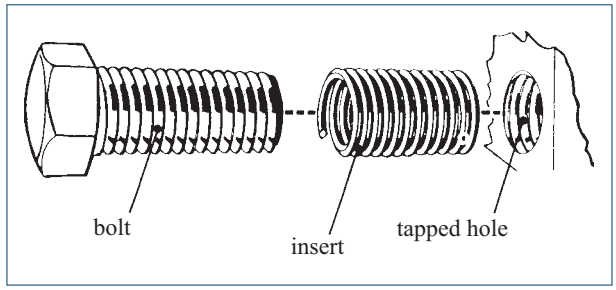


Figure 17.25 Method of using an insert to repair a thread

Safety: Wear gloves and safety glasses when applying sealants and locking compounds.

These compounds are supplied in liquid form. They have an *anaerobic action* that commences when they are excluded from air. When used between two surfaces, the compound cures by chemical action. This commences when air is excluded by clamping two parts together.

17.8.8 Bolt identification

Bolts are manufactured from materials with different strength ratings, which determine the torque to which they can be tightened.

Metric bolts are marked as shown in Figure 17.26. The number on the head identifies the bolt strength–the higher the number, the stronger the bolt. The most commonly used metric fasteners are class 4T or 7T.

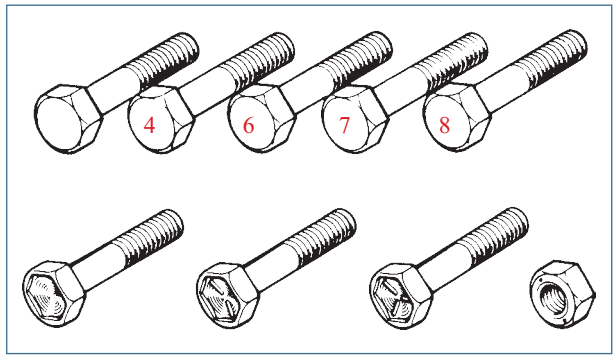


Figure 17.26 Identification of classes of bolts
GM HOLDEN LTD

The class of hexagon-head bolts with a flat head is marked by a number. Bolts with recessed heads have embossed lines, with two lines representing class 5T and three lines representing class 7T. Unmarked bolts are usually class 4T. Nuts may have a punch mark identification on the nut face.

Replacement bolts should be of the same length and thread as the originals. The strength classification of a replacement bolt should be the same as the original, or higher.

The torque that can be applied to tighten various sizes of bolts is shown in Table 17.1. The torque is given in newton metres (Nm) for different classes of standard bolts. The table is a guide only, so consult the vehicle manufacturer's service information for actual bolt specifications. As well as the bolts shown, there are special bolts that are identified by manufacturers in other ways.

17.9 Reassembling and adjusting

An engine is reassembled in the reverse sequence to dismantling. Cleanliness is vital, as any dirt or abrasive particles left behind after grinding valves or honing cylinders could accelerate engine wear or cause damage. Points to be observed during reassembly include:

1 Moving parts. All moving parts should be well oiled as they are being reassembled. This prevents corrosion and provides initial lubrication.
2 Gaskets and seals. New gaskets and seals should be fitted carefully so that they are correctly located and not damaged. Sealant should be applied to gaskets and surfaces where specified (Figure 17.27(a)).
3 Bolts and nuts. These should be tightened to the specified torque. Threads should be clean, and thread sealer or locking compound should be applied where recommended (Figure 17.27(b)).
4 Bearing bores. These should be perfectly clean before installing the bearings. The bearing inserts should have sufficient spread to snap into position when being fitted. They should stand slightly above the bore, indicating that they have crush. Tightening of the bearing cap should be completed with a torque wrench.
5 Rear main-bearing oil seal. This is not readily accessible once the engine is assembled, so extra care should be taken to avoid leaks.
6 Connecting rods. The pistons must be correctly installed. Both the pistons and the connecting rods are identified so that they can be reinstalled in their original locations.

Table 17.1 Guide to the tightening torque of bolts

Bolt diameter (mm)	Pitch (mm)	Tightening torque (Nm)			
		Class 4T	Class 5T	Class 6T	Class 7T
6	1.00	5.5	6.5	8	10
8	1.25	13	15	20	25
10	1.25	25	30	40	50
12	1.50	45	60	75	95
14	1.50	75	90	110	140
16	1.50	100	120	140	220

7 Piston rings. These should be installed on the piston with their gaps staggered and away from the thrust sides of the engine .
8 Piston, rings and cylinder bores. These should be liberally coated with oil to facilitate installation when using the ring compressor . The oil also provides initial lubrication.
9 Cylinder-head bolts. These should be tightened to the specified torque or angle , working to the recommended tightening sequence .

Handy hint: Overtightening or under - tightening can lead to thread damage and cylinder-head or cylinder-bore distortion.

10 Camshaft. When the camshaft is installed, the timing marks on the gears or sprock ets must be correctly aligned for correct valve timing. The timing should be double-check ed to mak e sure that the marks line up exactly as they did prior to dismantling.
11 Manifolds. The intak e and exhaust manifold bolts should be uniformly tightened to the cylinder head so that neither air nor exhaust gas leaks occur .

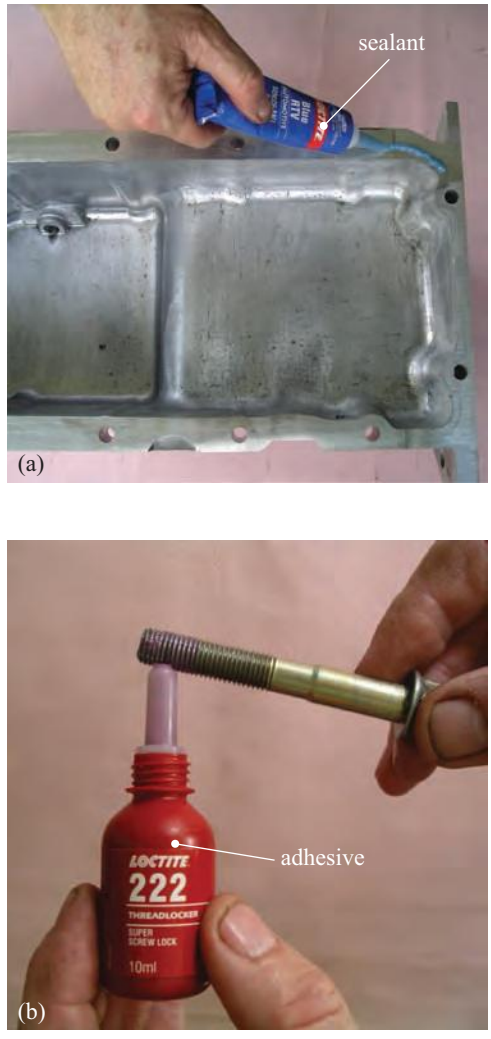


Figure 17.27 Sealant and adhesive compounds are used on specified bolts and surfaces of joints

17.10 Finalising and checking

In addition to the actual mechanical parts of the engine, the components of the engine systems will need to be checked and serviced. Much of the finalising will relate to external work on the engine, including tune-up and possibly road testing of the vehicle. Items to be considered include the following:

1 Pipes and cables. These should be k ept in their original locations, with clips and fasteners correctly installed to hold them in position.
2 Air cleaner . This should be serviced and a new filter element fitted. The air cleaner must be securely mounted, with the air-duct connections free of air leaks.
3 Thermostat. The thermostat must always be fitted and operating to specified temperatures.
4 Radiator . The radiator must be clean and in good condition. Doubtful radiator hoses should be renewed. The radiator cap should be in a serviceable condition and operating at the correct pressure .
5 Driving belts. The belts that drive the fan, water pump , alternator , air-conditioning compressor or power-steering pump should be check ed for condition. Belts showing any signs of deterioration should be renewed.
6 Fuel system. The injectors should be check ed and cleaned. The fuel pump should be check ed for operation and fuel filters cleaned or renewed. If the system has a carburettor , it should be dismantled and cleaned.
7 Ignition system. Spark plugs should be serviced and the high-tension cables check ed. The ignition timing should be adjusted (as applicable). If there is a distributor , this should be check ed.
8 Injection system. With diesel engines, the injectors should be serviced and the injection timing check ed. Fuel filters should be cleaned and the fuel system bled of air .
9 Ventilation system. The hoses and connections of the crank case-ventilation system should fit correctly , and the PC V valve check ed to mak e sure that it is operating.
10 Emission controls. The various parts of the emission controls should be check ed to ensure that all the connections are correct and that the controls are operating.
11 General. Before starting, the engine must be filled with the correct running-in oil and a new oil filter fitted. Running-in oils are a single -grade S AE 30 oil to assist bedding in of engine components. The engine should be crank ed with spark plugs or injectors removed until the correct oil pressure has been achieved. A fter the engine has been started and is running normally , a check should be made to mak e sure that there are no oil leaks, coolant leaks or fuel leaks. Never let the engine idle during warm-up .

With some engines, the valve clearances should be rechecked after running.

17.10.1 Road testing and running in

After completing the necessary checks and adjustments in the workshop, the performance of the engine can be checked on the road. During the road test, the engine is checked for normal operation, with performance in the various gears and during acceleration being noted.

Depending on the type of repair, it could be helpful to operate the engine at reasonable speeds and loads for the first 500 kilometres, to run new parts in. After the first 1000 kilometres, replace the running-in oil with the recommended engine oil and recheck.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- demonstrate the basic process of dismantling an engine
- list the categories of engine work tasks
- list the correct order of carrying out engine work tasks
- apply engine testing procedures
- describe systematic engine dismantling and reassembly procedures
- explain the correct way to clean, inspect and measure an engine and its associated parts
- demonstrate the correct use and application of bolts and fasteners when working with engines
- demonstrate how to finalise work and check that it has been carried out to industry standards.

REVIEW QUESTIONS

1 What could be the reasons for dismantling an engine?
2 What types of pre-dismantling checks could be made when diagnosing engine problems?
3 How is an engine compression check carried out?
4 What could cause an engine to use excess oil?
5 Name the places that would be checked for oil leaks.
6 Why is it important to check for marks on engine parts while dismantling and reassembling?
7 What type of inspection would be given to pistons after they are removed from the engine?
8 Name the instruments that would be used for measuring wear of engine parts.
9 What engine parts can be checked with a dial gauge?
10 Explain how a straightedge is used to check a surface.
11 Explain how to measure the clearance between a shaft and bearing.
12 What precautions should be taken when installing new connecting-rod bearings?
13 What points should be observed when a piston is being installed in a cylinder?
14 What precautions should be taken in relation to valve timing?
15 What items should be kept under observation when an overhauled engine is started for the first time?

CHAPTER 18

Cylinder head repair and overhaul procedures

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify cylinder head components
2 carry out cylinder head and valve servicing, repair and overhaul tasks, related terminology and procedures to meet automotive industry standards
3 accurately inspect cylinder heads and document and analyse inspection results
4 repair and overhaul a range of cylinder heads and components in accordance with workplace and manufacturer requirements and specifications.

Two different designs of cylinder heads and valves are used in the engines of passenger cars and light commercial vehicles. In the first type , overhead-valve (OHV) engines have camshafts mounted in the cylinder block and use pushrods to transfer movement from the camshaft to the valve mechanism on top of the cylinder head. The second type is where overhead-camshaft (OHC) engines have the camshaft mounted directly on top o f the cylinder head.

18.1 Cylinder head construction and designs

Inline engines of passenger cars and light commercial vehicles have a single cylinder head that covers all the cylinders. Larger inline engines can have two or more cylinder heads, each enclosing some of the cylinders. V-type engines and horizontally opposed engines have a separate cylinder head for each bank of cylinders.

18.1.1 Cylinder-head casting

Figure 18.1 shows the top and bottom views of a cylinder head for a V-8 overhead-valve engine. This type of cylinder head is produced as a casting of aluminium alloy or cast iron.

The casting is finished by machining operations that produce a cylinder head with: a flat surface on the underside where it fits onto the top of the cylinder block: machined surfaces on the top for the camshaft and valve mechanism; holes for the valve guides; threaded holes for the spark plugs and for securing other parts; mounting surfaces for the manifolds; a machined surface on top for the valve cover.

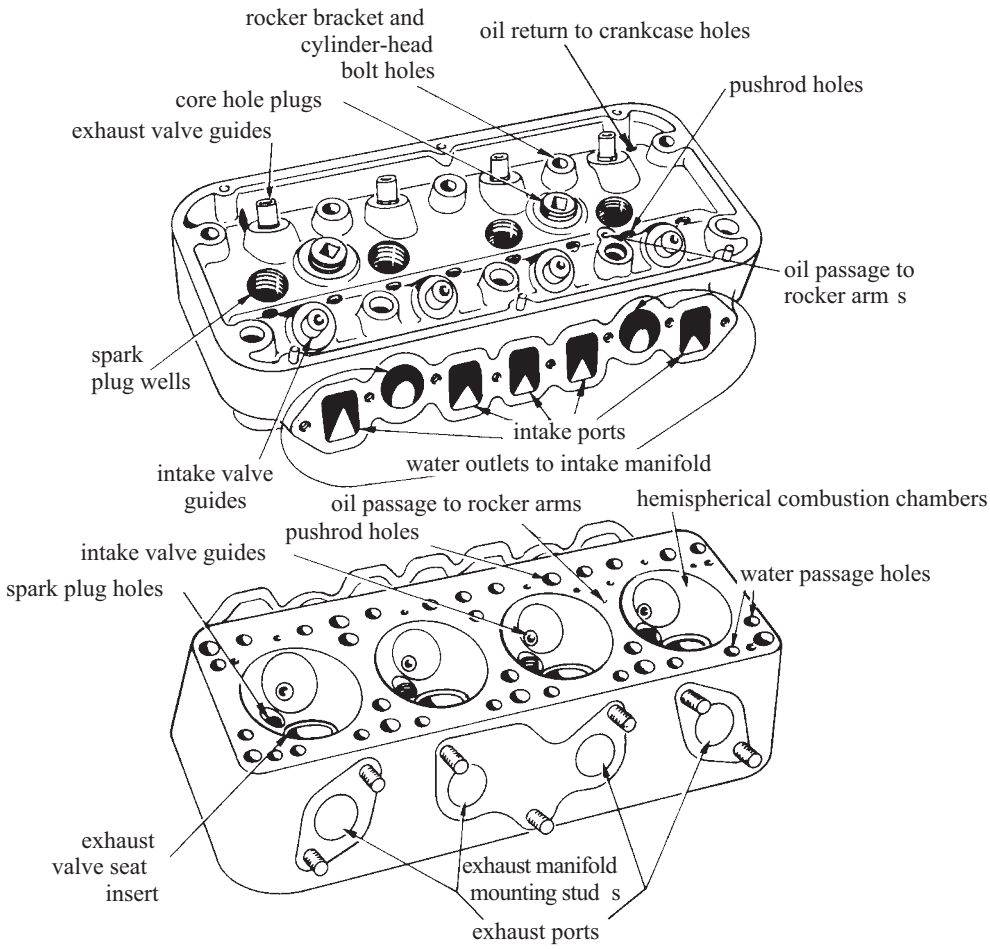


Figure 18.1 A cylinder head for a V-8 engine: the upper illustration shows the top of the cylinder head, and the lower illustration shows the underside with its hemispherical combustion chambers

18.1.2 Cylinder-head designs

While most cylinder heads perform the same function, there are different designs, depending on whether it is for an overhead-valve, an overhead-camshaft, a V-type or a horizontally-opposed engine.

The parts of a cylinder head for a V-type overhead-valve engine are identified in Figure 18.1, and the parts of a cylinder head for a four-cylinder petrol engine are shown in Figure 18.2. This is the basic arrangement for an overhead-camshaft cylinder head assembly, which includes the camshaft, rocker assembly and the valves and associated parts.

The cylinder head and valve assembly in Figure 18.3 are quite different as they are for a horizontally opposed engine with four cylinders. The cylinder head shown is for two cylinders on one side of the engine. There is another cylinder head of the same design for the two on the opposite side of the engine.

The camshaft is supported in the cylinder-head casting. The rocker arms are of cast aluminium alloy and are fitted with hydraulic lash adjusters. The various parts are shown in the illustration.

18.1.3 Cylinder-head cooling

Cylinder heads for liquid-cooled engines have water-jackets through which the coolant is circulated. Heat from the combustion process is absorbed and transferred to the radiator.

Handy hint: Air-cooled engines have cooling fins cast into the cylinder head. Working in conjunction with a fan, they dissipate heat to the atmosphere.

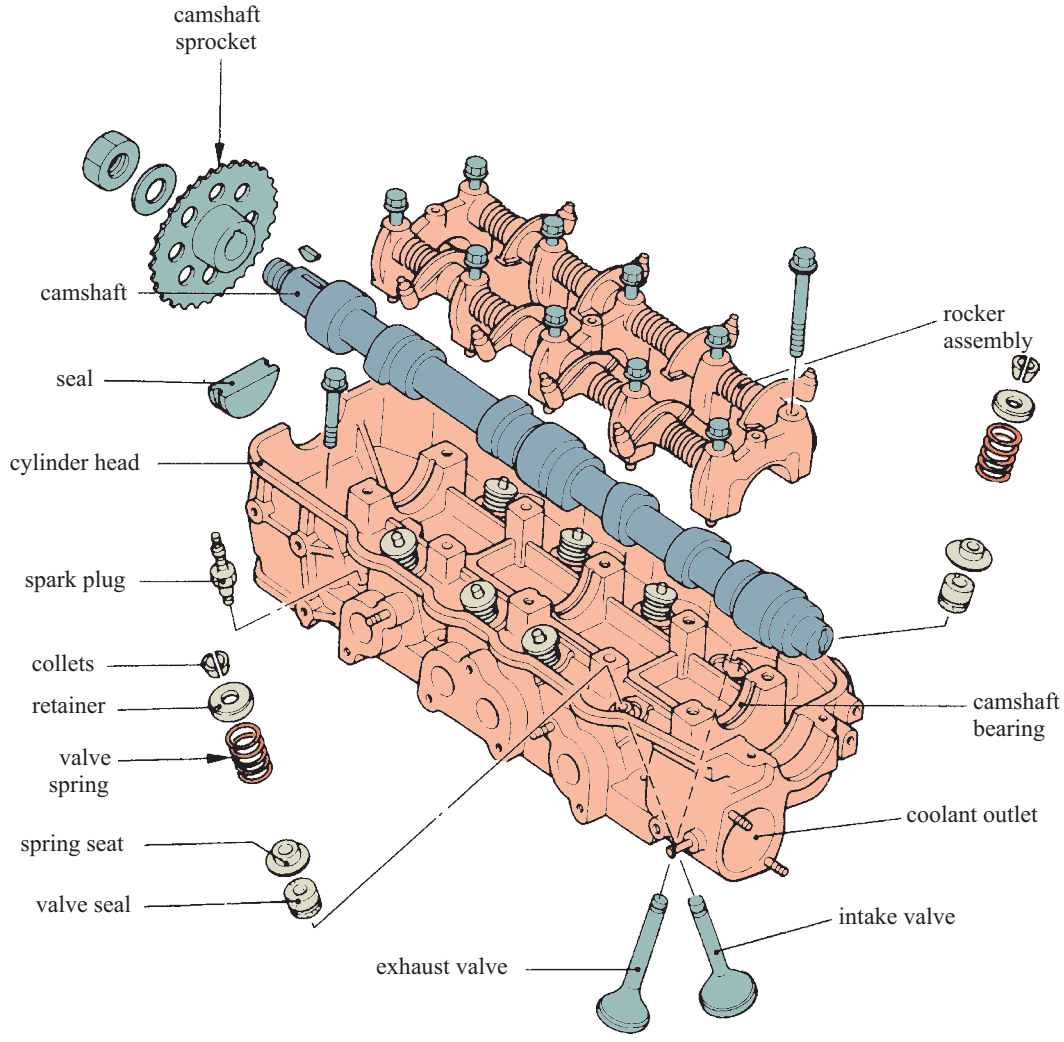


Figure 18.2 Basic arrangement of a cylinder-head assembly for an OHC engine FORD

18.2 Combustion chambers

The combustion chamber is the space between the top of the piston and the cylinder head when the piston is on top dead centre (TDC). This is where the air–fuel mixture is compressed and burnt. In petrol engines, most of the combustion chamber is formed in the cylinder head. In diesel engines, it is formed in the piston head, although some diesels have a precombustion chamber in the cylinder head.

Handy hint: TDC is when the piston is at the top of its stroke, and BDC is when it is at the bottom.

18.2.1 Turbulence

The cylinder head, valve ports and combustion chambers of petrol engines are designed so that the air–fuel mixture will be subjected to swirl, or turbulence. This occurs while the mixture is being taken into the cylinder (Figure 18.4), and also when it is being compressed in the combustion chamber.

Turbulence mixes the air and fuel, preventing fuel droplets from settling on the combustion chamber and cylinder wall surfaces. It also helps to prevent local high-pressure and high-temperature areas during combustion, which could cause detonation.

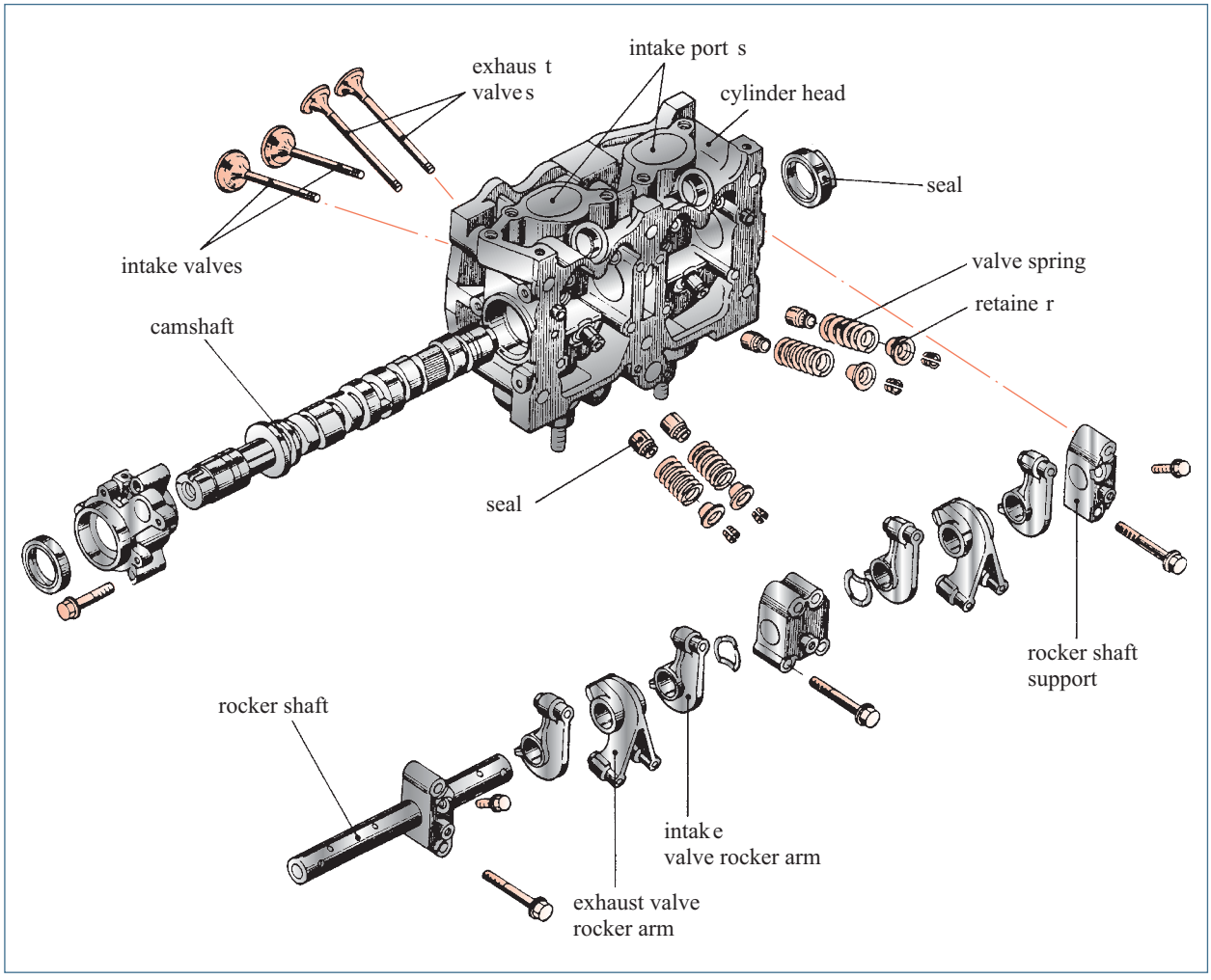


Figure 18.3 Cylinder head for two cylinders of a horizontally opposed engine SUBARU

18.2.2 Combustion chamber designs

There are three basic petrol engine combustion chamber designs. Their names relate to their shapes, and are hemispherical, bathtub and wedge.

As well as the combustion chamber formed in the cylinder head, the top of the piston can be crowned or hollowed. In some cases, the pistons have depressions for the valves.

Handy hint: These designs do not apply to diesel engines, which have different cylinder heads and different pistons.

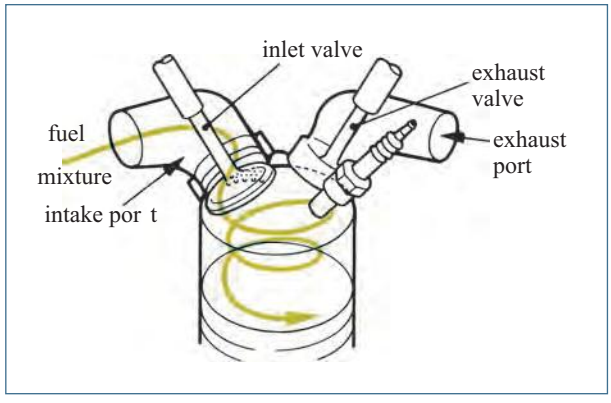


Figure 18.4 Combustion chambers are designed to create turbulence FORD

18.2.3 Diesel cylinder heads

With diesel engines, the face of the cylinder head is usually flat. The combustion chamber is formed in the top of the piston instead of the cylinder head (Figure 18.5). In some designs, the rim of the piston provides 'squish', which forces the air towards the centre of the piston and into the combustion chamber. This causes turbulence as the fuel is being injected into the cylinder.

Combustion chambers of diesel engines are designed to promote turbulence, so the compressed air and injected fuel are properly mixed.

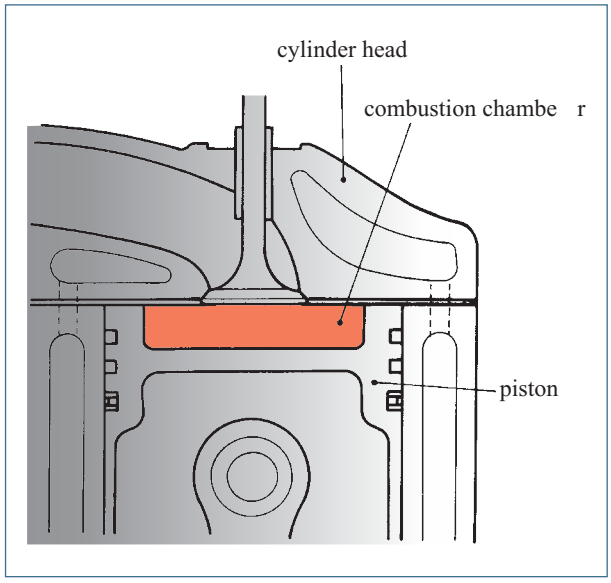


Figure 18.5 A section of a diesel cylinder showing a combustion chamber in the piston head

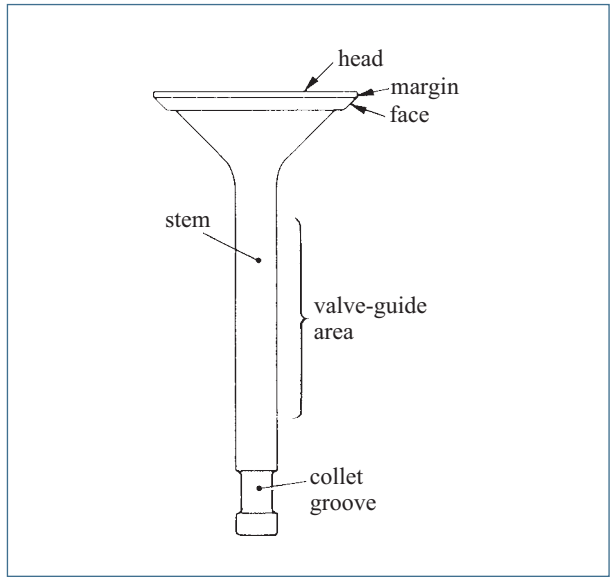


Figure 18.6 An engine valve with the parts named

18.3 Engine valves

A valve with its parts identified is shown in Figure 18.6. The two main parts are the *stem* and the *head.* The valve is fitted to a port in the head, its face providing a gas-tight seal against the seat in the port. This type of valve is known as a *poppet* or *mushroom* valve.

A portion of a cylinder head with an intake and an exhaust valve is shown in Figure 18.7. Associated parts such as the valves, springs, seals, guides and valve-seat inserts are also shown.

The intake valves are larger than the exhaust valves. This is because the intake air that is being taken into the cylinder through the intake port is at a low pressure, while the gases being forced from the cylinder through the exhaust port are at a much higher pressure. The larger intake port and valve opening are designed to assist intake air flow.

18.3.1 Number of valves per cylinder

Some engines have two valves for each cylinder—one intake and one exhaust. Others have three valves for each cylinder—two intake and one exhaust. Still others have four valves for each cylinder—two intake and two exhaust.

Two intake valves provide better *breathing* by allowing larger intake passages and a freer flow into the cylinder, so that the cylinder receives a better charge. This increases the engine's volumetric efficiency. Having two exhaust valves enables the engine to have larger exhaust passages. These provide a freer flow of exhaust gases from the cylinder, resulting in less gas residue.

Handy hint: The term breathing refers to the engine 's taking in air or air–fuel mixture .

18.3.2 Valve seats and guides

The valve ports in the cylinder head have seats on which the valves rest when they are closed, and this forms a gas-tight seal. The seats are metal rings

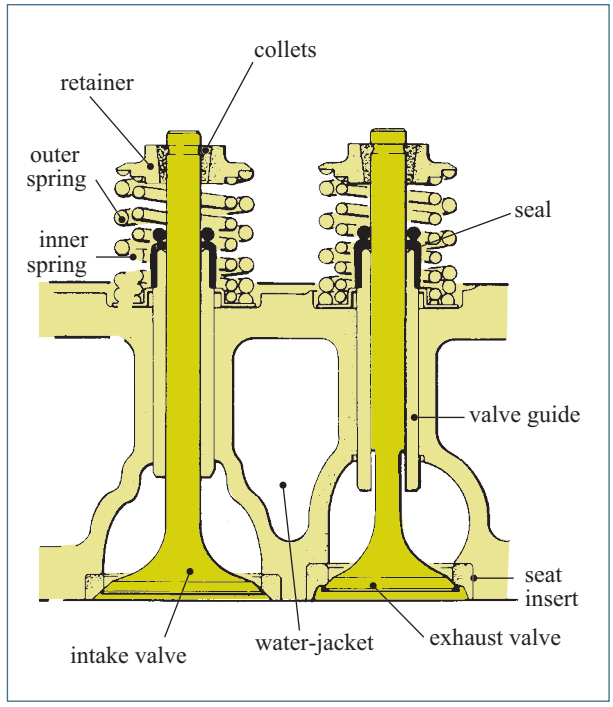


Figure 18.7 Arrangement of an intak e valve and an exhaust valve with their associated parts

(inserts) pressed into recesses in the head. They are made of a special iron alloy designed to withstand the high temperatures of the gases that pass through the exhaust ports.

The valves operate in *valve guides* that are a form of cast-iron bush. The guides are pressed into holes bored through the cylinder head into the valve ports. Guides can be replaced if they become worn.

18.3.3 Valve springs

The valves are normally held on their seats by one or two coil springs which are compressed between the top of the cylinder and a retainer on the valve stem. The retainer is held on the end of the valve stem by conical-shaped *collets* (Figure 18.8), which are also known as *cotters, keepers* or *keys.*

The pitch of the coils of valve springs is often closer at the bottom of the spring than at the top. This is to keep the valve on its seat when it closes and prevent *valve bounce.* A simple spring could have *resonance* that would allow the valve to bounce on its seat under certain operating conditions. For this reason, two springs, an inner and an outer (as in Figure 18.7), are sometimes used.

Safety: When compressing value springs and removing valve collets, ex ercise caution and wear safety glasses.

Springs can also be tapered, with the top coils having a smaller diameter than the lower coils. This reduces the mass of the spring that moves when the valve is opened and closed.

18.3.4 Valve-stem seals

Oil seals are fitted to the valve stems or valve guides. These prevent excessive oil from passing down between the stem and guide into the combustion chamber. Oil seals fitted to the tops of the valve guides can be seen in Figure 18.7.

The action of a valve stem seal is shown in Figure 18.9. The coil spring on the outside holds the sealing edge against the valve stem, while the angle at the top of the seal forms a small reservoir of oil to lubricate the stem and guide.

Some oil is needed for valve stem lubrication, but too much passing through the guides will be problematic.

Sustainability: Worn valve guides will also cause ex cessive oil consumption and smok e from the exhaust which will impact on air quality .

Reason for valve stem seals

The intake valve is more likely to pass oil through its guide than the exhaust valve. This is because the intake port has low pressure that tends to suck the oil in; the exhaust port has a higher pressure that tends to keep the oil out.

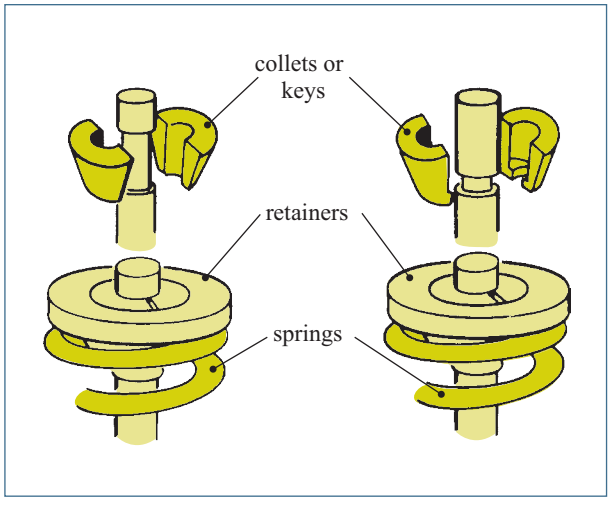


Figure 18.8 Valve-spring retainers

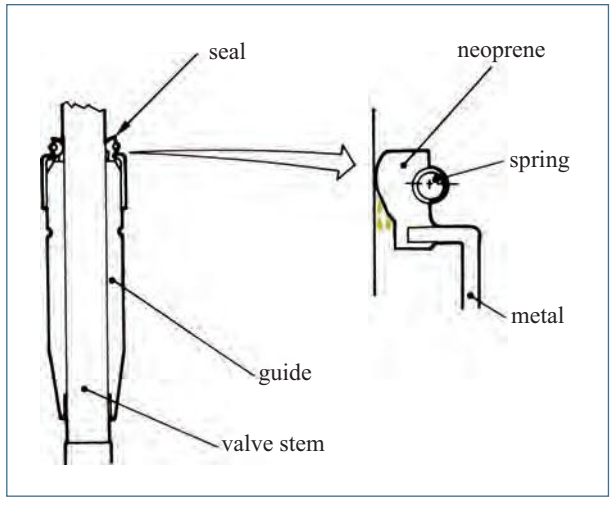


Figure 18.9 Valve stem seal installed on top of a valve guide FORD

Oil will pass the intake valves if the seals are worn, or if the valve guides are worn and there is excessive valve-to-guide clearance. More oil will tend to pass through the guides in light or no-load operating conditions, such as when travelling downhill; the intake manifold pressure will be much lower than atmospheric pressure, causing more oil to pass down through the valve guides.

18.3.5 Valve temperatures

Intake valves pass air or air–fuel mixture and so run at a cooler temperature than exhaust valves. As the latter are in the path of the hot gases that pass through the exhaust ports, their heads become very hot.

Figure 18.10 shows the typical temperature pattern of an exhaust valve. During operation, the stem transfers heat to the guide, so the stem is the coolest part of the valve. The head near the face of the valve transfers heat to the valve seat, so that is the coolest part of the head. The valve seat and guide are in turn cooled by the coolant in the water-jackets that surround the valve ports.

The valve temperatures show the importance of correct valve seating. If a valve does not seat properly, there will be a smaller contact area through which heat transfer can occur, and the face will overheat. Local hot spots will reach very high temperatures, and the edge of the valve will burn.

The exhaust-valve seat is also subjected to extremely high temperatures, which is why exhaust-valve seats in engines are fitted with heat-resistant alloy inserts.

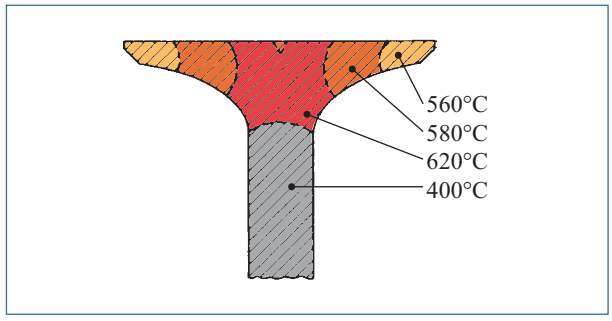


Figure 18.10 The temperature in different parts of an exhaust valve

18.3.6 Sodium-cooled valves

Some engines have sodium-cooled valves. These have hollow stems that are partly filled with metallic sodium. This melts at about 90°C and so becomes liquid at engine operating temperatures.

As the valve moves up and down in its guide, the liquid sodium is thrown around inside the valve stem, absorbing heat from the hotter part of the valve near the head and transferring it to the cooler part of the valve at the stem.

The cylinder head in Figure 18.11 shows valves with hollow stems. The intake valve stem is hollow to reduce its mass. The exhaust valve stem is also hollow, but contains sodium for cooling. Sodium valves can often be recognised by their stems, which are larger in diameter than normal valve stems.

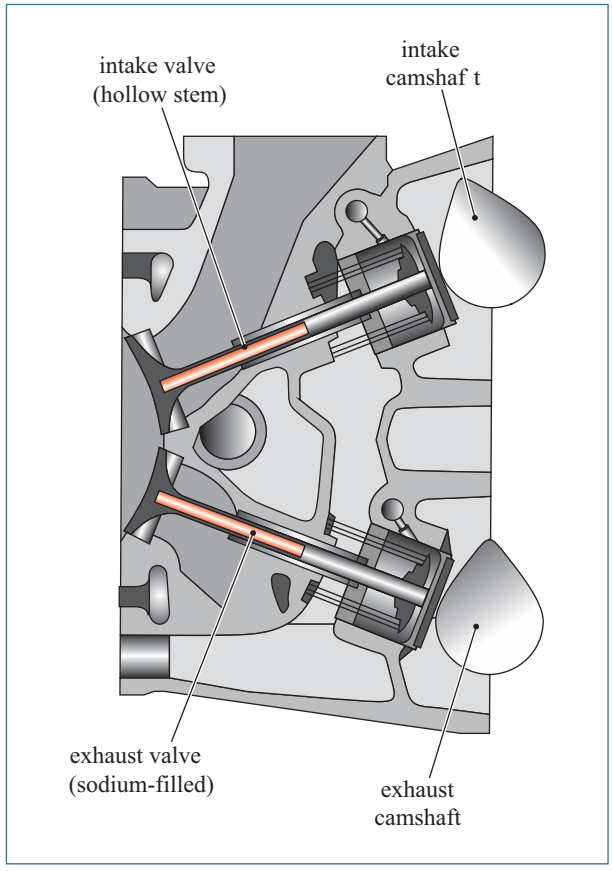


Figure 18.11 Cylinder head of a horizontally opposed engine with a hollow-stem intak e valve and a sodium-filled exhaust valve

Safety: Old sodium-filled valves should not be tampered with and should be disposed of safely .

18.3.7 Valve-face angles

Valve faces are usually ground at an angle of 45° to the valve stems.

The valve seats are often ground to the same angle as the valve face, but some manufacturers use an *interference angle,* as shown in Figure 18.12. With this, the valve face and seat are ground to slightly different angles. These vary with different engines, and the interference angle may be as little as 0.5°, or as much as 2°. A typical specification is 45° for the valve face and 44° for the valve seat.

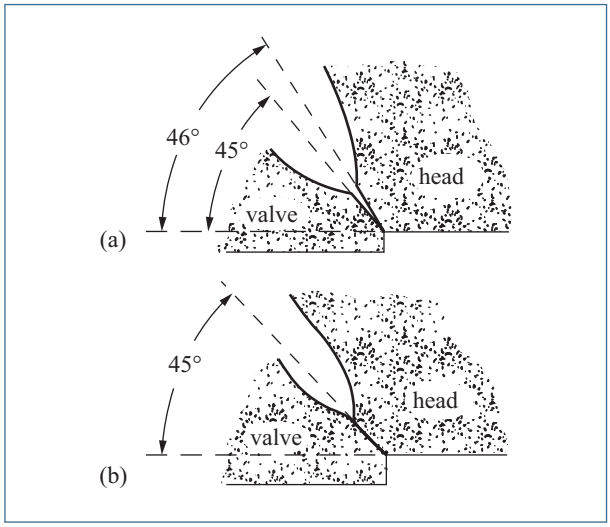


Figure 18.12 Valve angles (a) interference angle between the valve face and seat (b) identical angle

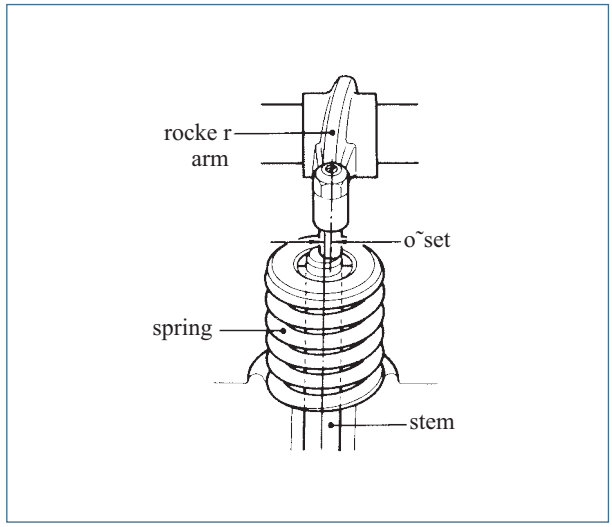


Figure 18.13 Rock er-arm offset helps with valve rotation
FORD

Handy hint: An interference angle gives a quick bedding in of the valve face to the seat on new engines. It is not always used when reconditioning valves and seats.

18.3.8 Valve rotation

Valve rotation refers to the action of a valve turning a little as it opens and closes, so that it gradually rotates and does not always seat in the same place. It produces a slight wiping action, which tends to keep the face and seat free of carbon; it helps to prevent sticking in the valve guide and distributes the heat around the valve seat. These help to prolong valve service life.

Valves naturally rotate, and this is aided in different ways such as having the rocker arm slightly offset to the valve stem, as shown in Figure 18.13. This causes the valve to turn slightly each time it is opened.

18.4 Valve trains for OHV engines

The various components used to operate the valves are referred to as the valve train. Generally, an overhead-valve (OHV) engine with its camshaft in the crankcase has a greater number of moving parts than an overhead-camshaft (OHC) engine.

A basic arrangement of an inline OHV engine is shown in Figure 18.14. The valve train consists of:

- camshaft
- valve lifter
- pushrod
- rock er arm.

18.4.1 Camshaft

In OHV engines, the camshaft is located in bearings in the cylinder block or crankcase. It is driven from the crankshaft at half the engine speed and has a cam for each valve. As the cams rotate, they move the valve lifters up and down, and this movement is transferred through the other parts of the valve train to the valves in the cylinder head.

18.4.2 Valve lifters

The cams and valve lifters change the rotary motion of the camshaft into linear (straight-line) motion of the pushrods. Rotation of the camshaft moves the valve lifters up and down, and this movement is transferred by the pushrods to the rocker arms on top of the cylinder head. The two main types of valve lifters are solid lifters and hydraulic lifters.

18.4.3 Pushrods and rocker arms

Some rocker arms are made of cast steel, while others are a steel pressing or made from aluminium alloy. Figure 18.14 shows pressed-steel rocker arms supported by ball pivots mounted on studs in the cylinder

head. The ball is lubricated from an oil gallery in the cylinder head through a drilling in the stud. The pushrod is also hollow, and this carries oil to lubricate the end of the rocker arm.

Valve trains with solid valve lifters have a small clearance, referred to as *valve clearance, valve lash* or *tappet clearance.*

Cast rocker arms have a screw adjustment at the pushrod end to adjust the clearance. Pressed-steel rocker arms (Figure 18.14) have hydraulic valve lifters and do not have clearance at the valve tip. However, they can be adjusted for certain conditions by turning the nut on the ball stud to raise or lower the rocker arm.

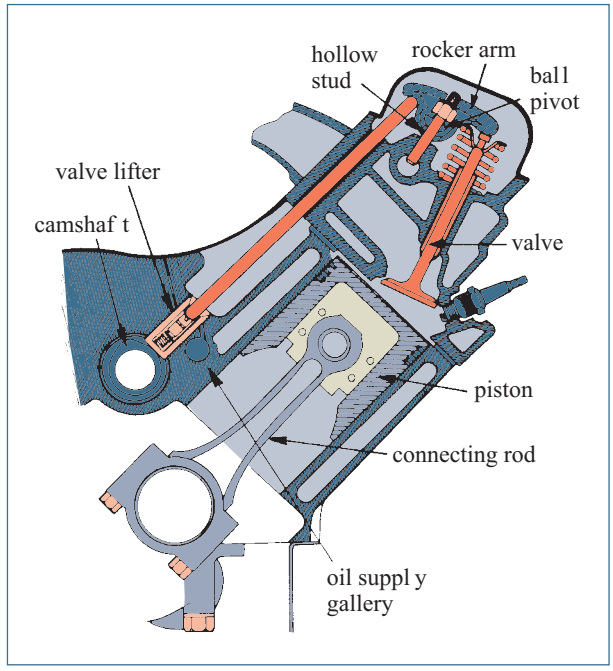


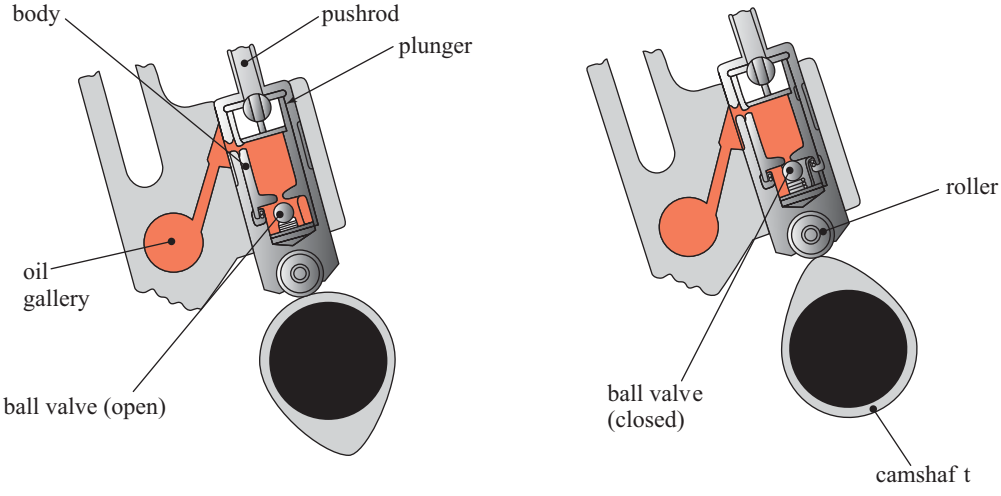
Figure 18.14 One bank of a V-type engine with a hydraulic valve lifter and a ball-pivoted rocker arm

18.5 Hydraulic valve lifters for OHV engines

Figure 18.15 shows the construction and operation of a hydraulic lifter for an OHV engine. There are two main parts, a hollow body and a plunger in the body. The lifter gets pressure oil from the engine's lubricating system. A ball valve under the bottom of the plunger allows oil into the chamber beneath the plunger, holding the plunger against the pushrod.

18.5.1 Operation of a hydraulic valve lifter

1. With the engine valve closed there is no load on the lifter and the plunger is held up by the plunger spring.
2. Oil from the oil gallery enters the lifter through holes in the lifter body and plunger.
3. Oil pressure forces the check valve open to keep the chamber below the plunger full (Figure 18.15(a)), removing lash from the valve train.
4. As the cam rotates and raises the lifter, the check valve closes to trap the oil in the chamber below the plunger.
5. The lifter moves upwards as an assembly (as shown in Figure 18.15(b)) to open the engine valve in the usual way.
6. As the cam continues to rotate, the lifter moves downwards to close the engine valve, and the force on the plunger is relieved; any oil lost from the chamber is replaced by oil through the check valve.
7. The lifter is designed to have a slight leak past the plunger. This acts as a lubricant between the plunger and body, and enables air to be bled from the lifter.



(a) Engine valve closed (b) Engine valve open

Figure 18.15 Hydraulic valve lifters for an OHV engine

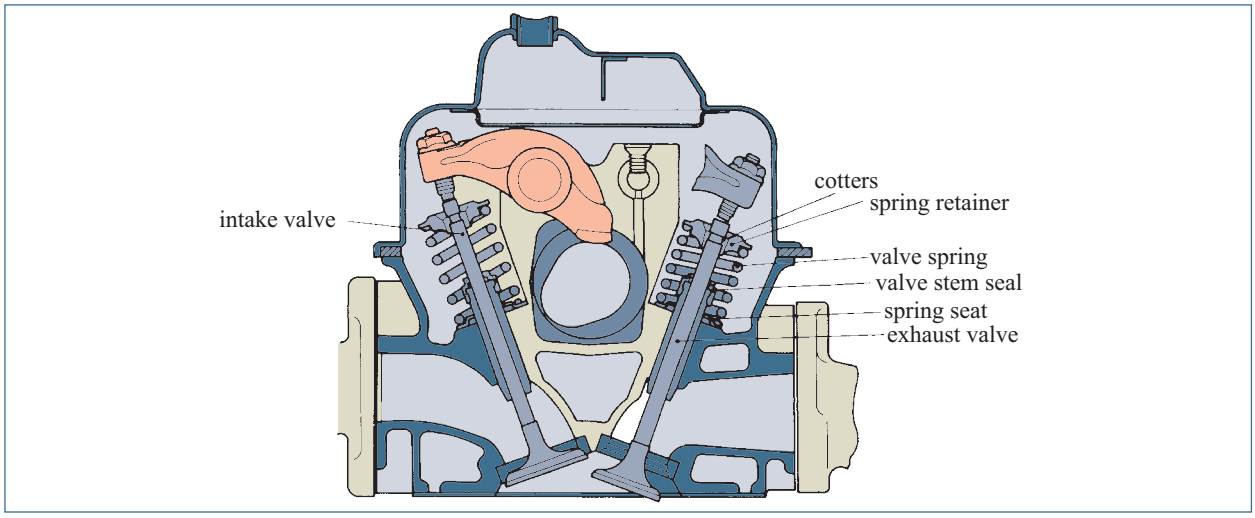


Figure 18.16 Valve components GM HOLDEN LTD

18.6 Valve trains for OHC engines

Overhead camshaft engines have the camshaft mounted on top of the cylinder head. This provides a short valve train, although a long timing chain or belt is needed between the crankshaft and the camshaft or camshafts. Having the camshaft overhead eliminates the reciprocating parts that are used in the valve trains of overhead-valve engines. This is an advantage with smaller high-speed engines where reciprocating parts could produce vibration.

The valves in overhead camshafts are operated by rocker arms or, more directly, by bucket-type tappets. There are a number of different arrangements.

18.6.1 Rocker arms

Figure 18.16 shows a section through a cylinder head with a single overhead camshaft and rocker arms to operate the valves. This is the basic arrangement for OHC engines.

Rocker arms are a form of lever, with one end against a cam of the camshaft and the other end against the stem of a valve. As the camshaft rotates, cam movement is transferred by the rocker arm to open and close the valve.

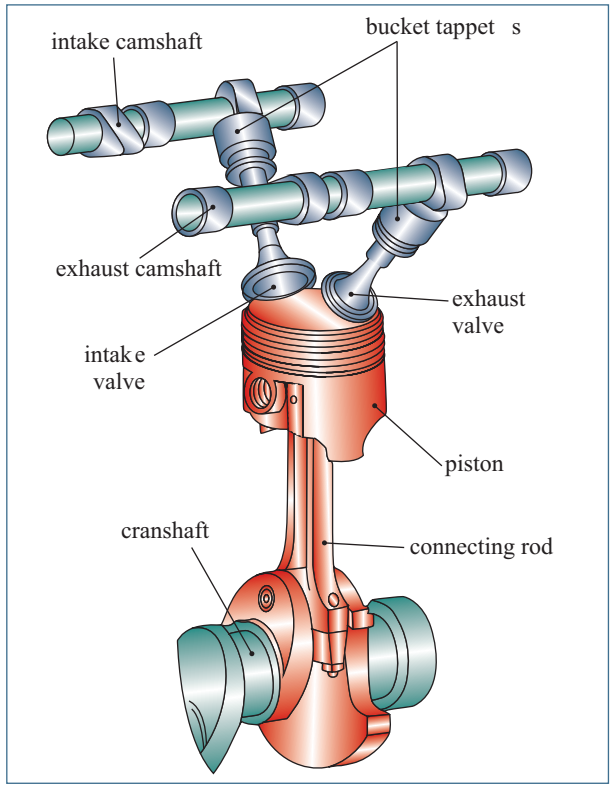


Figure 18.17 Twin overhead-camshaft arrangement with bucket tappets

They must have some clearance in the valve train to allow for changes in temperature, otherwise the valve could be prevented from seating properly. The illustration shows rocker arms with screws to adjust the valve clearance.

18.6.2 Bucket tappets

Figure 18.17 shows the arrangement for bucket tappets and a double overhead camshaft. The camshafts are mounted directly above the valves. Although two valves are shown, the cylinder actually has four – two intake and two exhaust.

The bucket tappets are located between the cams of the camshaft and the ends of the valve stems. Cam movement is transferred directly through the tappet to the valve.

The bucket tappet is cup-shaped so that it fits over the end of the valve and spring. It operates in a guide which protects the valve against the side thrusts it would receive if the cam operated directly against the valve. There is a small clearance between the cam and the tappet. This is adjusted by altering the thickness of shims or spacers in the tappet.

Handy hint: Buck et tappets can be identified in Figures 18.21 and 18.37, which also have two camshafts.

18.7 Hydraulic lash adjusters for OHC engines

Some overhead-camshaft engines are fitted with hydraulic *lash adjusters* that are used to remove the lash from the valve train. These operate in a similar way to hydraulic valve lifters for OHV engines. With hydraulic lash adjusters, there is no clearance at the valve stem and this eliminates the need for adjustment.

OHC engines have three general locations for hydraulic lash adjusters:

1 In the valve end of the rock er arm
2 In the cylinder head at the end of the rock er arm
3 In buck et-type tappets.

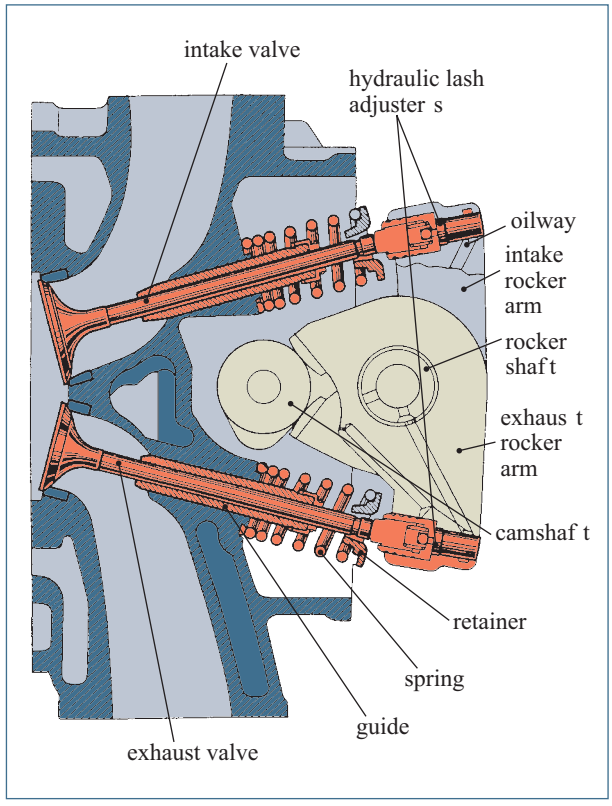


Figure 18.18 Section through a cylinder-head assembly for a horizontally opposed engine; the hydraulic lash adjusters are in the ends of the rock er arms SUBARU

18.7.1 Adjuster in the rocker arm

Figure 18.18 shows hydraulic lash adjusters fitted in the ends of the rocker arms which operate against the valve stems. They have a body with a plunger which is held against the valve stem by a spring. Oil supplied to the adjuster keeps the plunger in contact with the valve and eliminates lash from the valve train.

Figure 18.19 shows the detail of a hydraulic lash adjuster. When the lash adjuster is under load, the plunger is held outwards against the valve tip by the plunger spring. Oil is trapped in the high-pressure chamber by the check ball, eliminating any lash in the valve train; the lash adjuster acts like a solid lifter.

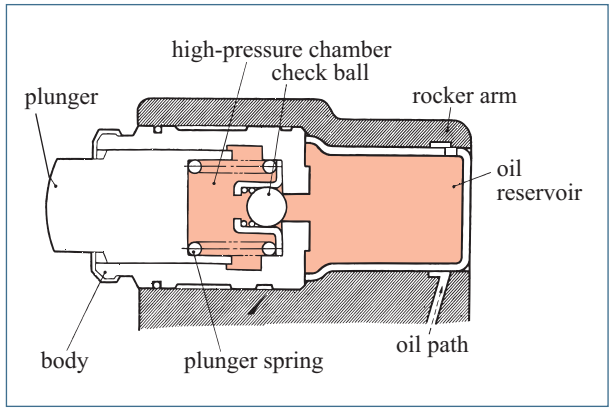


Figure 18.19 Hydraulic lash adjuster for a rock er arm SUBARU

There is a reservoir of oil in the adjuster that is supplied by the engine's lubricating system. Any loss of oil from the high-pressure chamber will allow the plunger to move back into the body. But, when the load is released, the spring will move the plunger outward, allowing oil from the reservoir to enter the high-pressure chamber. Thus it is always full and the plunger is always in contact with the valve tip.

18.7.2 Lash adjuster in cylinder head

The cylinder-head assembly in Figure 18.20 has a double camshaft and pivot-type hydraulic lash adjusters mounted in the cylinder head. The rocker arms are a roller type, with a roller bearing operating against the cam to reduce friction and wear.

The lash adjusters operate in the same way as those in a rocker arm, except that they are stationary and provide a ball pivot for one end of the rocker arm. The ball is on the end of the lash-adjuster plunger, and this holds the roller up against the cam.

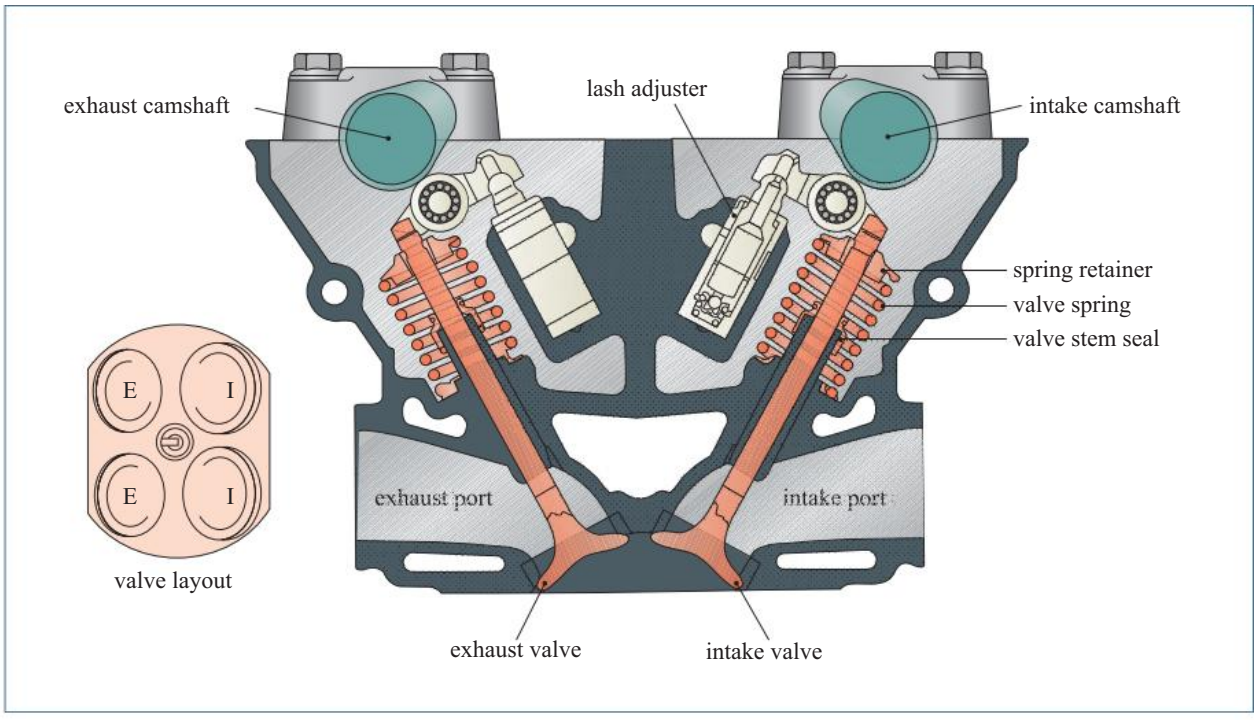


Figure 18.20 Cylinder head with double overhead camshafts and pivot-type hydraulic lash adjusters

18.7.3 Lash adjuster in bucket tappet

The arrangement for a bucket tappet is shown in Figure 18.21, where the lash adjuster is inside it. In this design, the hydraulic action of the plunger tends to spread the tappet. This holds the bucket body against the cam on the camshaft and the plunger against the tip of the valve stem, giving zero clearance.

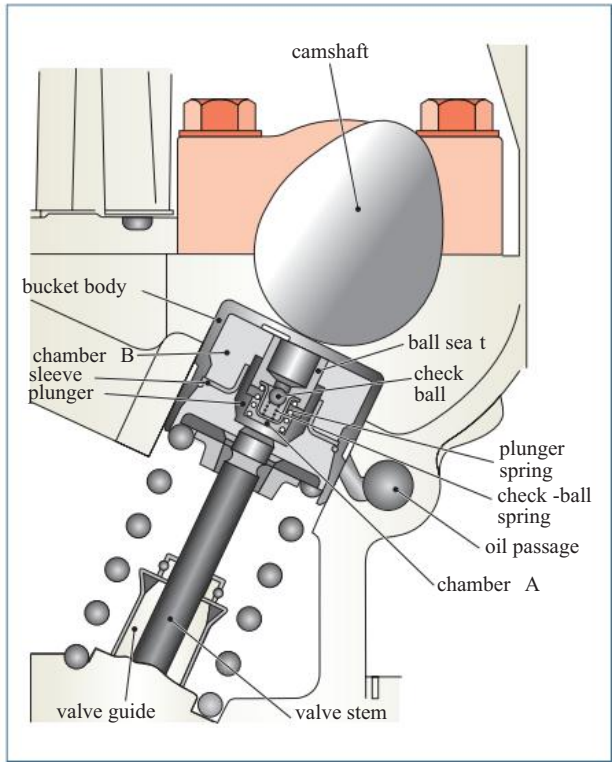


Figure 18.21 Bucket tappet with a hydraulic lash adjuster

18.8 Camshaft classifications

The basic purpose of the camshaft is to control the opening and closing of the valves. The entire action of the valve depends on the shape of the cam (referred to as the *cam profile* or *cam contour*). This determines when the valve starts to open, its maximum opening, how long it remains open and when it closes.

The three basic camshaft arrangements are: *single overhead camshaft* (SOHC); *double overhead camshaft* (DOHC); *overhead-valve (OHV) camshaft.*

18.8.1 Single overhead camshaft (SOHC)

A single overhead camshaft is located on the top of the cylinder head. It is driven by a toothed belt and toothed pulley, or by a chain and sprocket. The camshaft in Figure 18.22 is driven by a toothed belt. It has five journals that support it on top of the cylinder head and eight cams to operate the valves.

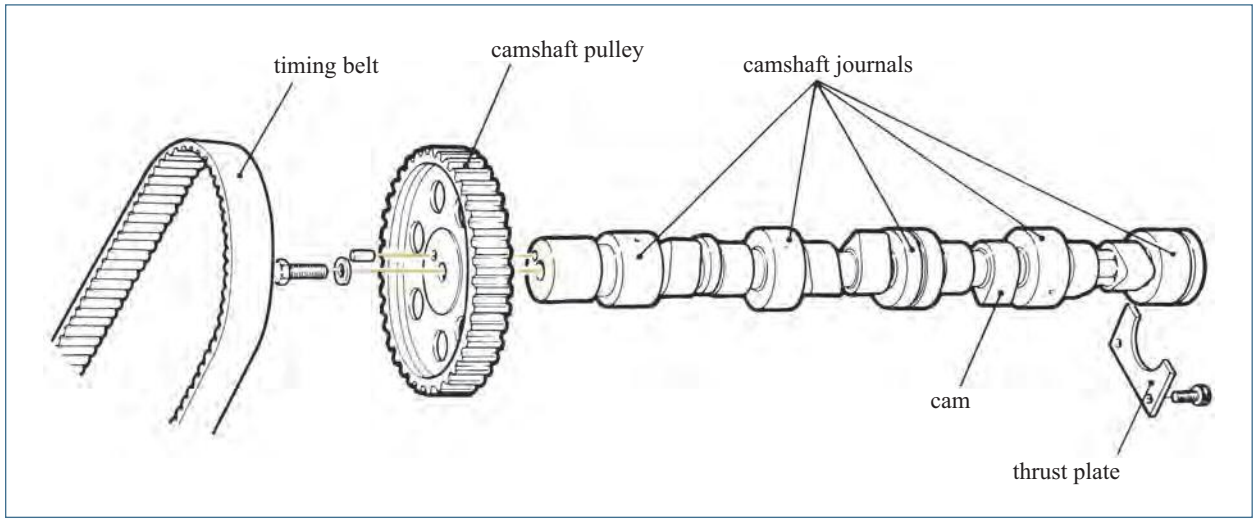


Figure 18.22 Camshaft for a four-cylinder OHC engine GM HOLDEN LTD

Handy hint: Toothed pulleys are also referred to as sprockets, although this term is usually reserved for gears that are used with chains.

18.8.2 Double overhead camshafts (DOHC)

Many engines use two camshafts (DOHC). Each cylinder of a DOHC engine has four valves—two intake and two exhaust. One camshaft is used for the former, and the other for the latter. These have toothed pulleys driven by a toothed belt.

With V-type engines, two camshafts are used for each bank of cylinders, so the engine has four camshafts. This arrangement is sometimes referred to as *quad-cam.*

18.8.3 Camshafts for overhead valves (OHV)

In overhead-valve (OHV) engines, a single camshaft is mounted in the cylinder block and valve lifters and pushrods transfer the cam action to push rods on top of the cylinder head. With a V-type engine, the camshaft is in the cylinder block directly above the crankshaft, as in Figure 18.23. The camshaft is fitted with a sprocket driven by a short timing chain from a sprocket on the end of the crankshaft. Here, the oil pump is driven directly by the crankshaft.

18.8.4 Camshaft drives and timing

Camshafts are driven at half the crankshaft speed by timing gears, timing chains or timing belts that are connected between the camshaft and the crankshaft. The camshaft is designed so that the valves open and close correctly in relation to each other and in the correct firing order for the engine. The camshaft should be timed to the crankshaft so that the valves open and close at the correct times in relation to piston movement. This is a function of the camshaft drive.

Handy hint: The drive should be correctly timed; timing marks are provided for this purpose.

18.8.5 Timing gears

Where timing gears are used, the camshaft gear is twice the size of the crankshaft gear (Figure 18.24). The latter has marks on two adjacent teeth, while the former only has marks on one tooth. For correct valve timing, the single marked tooth on the camshaft gear is meshed between the two marked teeth on the camshaft gear, as shown.

18.8.6 Timing chains

Figure 18.25 illustrates the chain arrangement for a V-type OHV engine. This is a double-roller chain, with a sprocket on the camshaft and another on the crankshaft. The sprockets carry timing marks. For correct

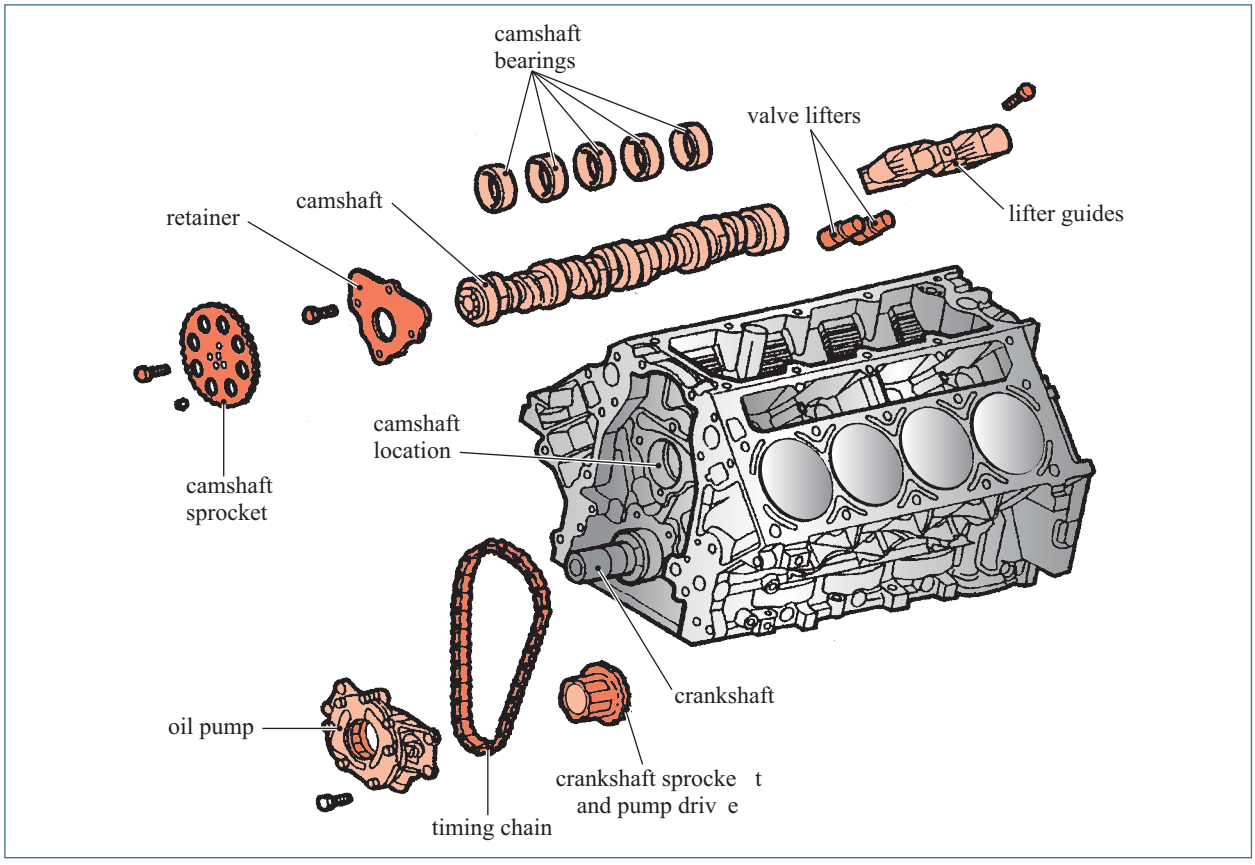


Figure 18.23 Cylinder block, crankshaft assembly and drive for a V-type OHV engine GM HOLDEN LTD

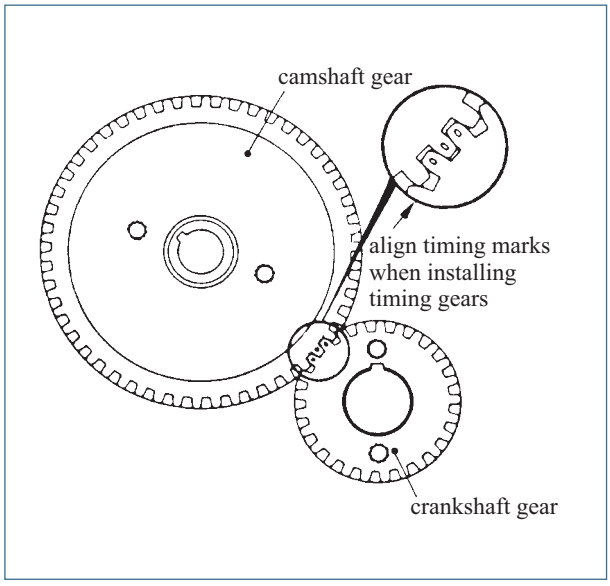


Figure 18.24 Camshaft and crankshaft gears with timing marks

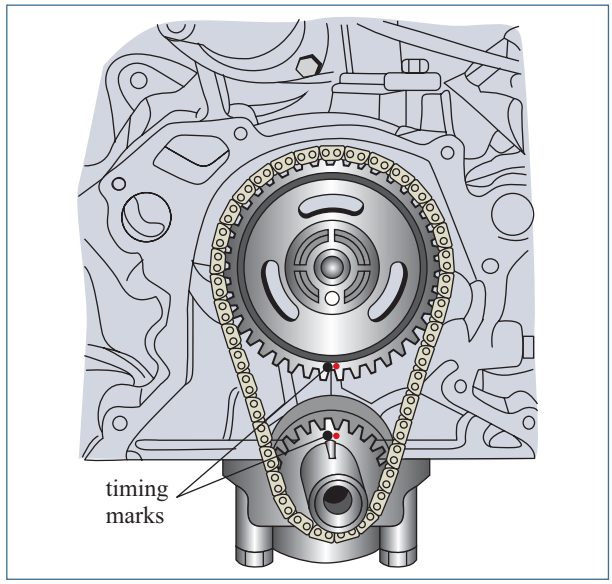


Figure 18.25 Timing chain and timing marks for a V-type OHV engine—the marks on the sprockets are in line with the centrelines of the shafts

timing of the arrangement shown, the timing mark on each sprocket and the centre of each shaft should be in line when No. 1 piston is on top-dead centre (TDC).

Overhead camshaft chains

Overhead camshafts can be driven by chains in different ways. In Figure 18.26, a single chain drives the camshaft sprocket and an auxiliary shaft sprocket. The auxiliary shaft drives the oil pump. The chain has

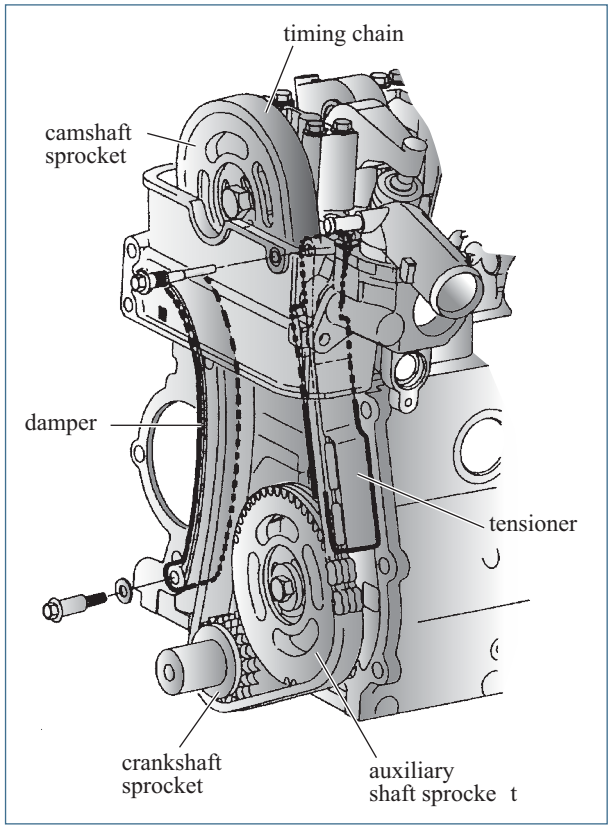


Figure 18.26 Timing chain for an inline engine with an overhead camshaft—the sprockets carry timing marks (not shown) FORD

a damper, or guide, on one side and a hydraulic tensioner on the other.

There are two timing chains in Figure 18.27. One drives an auxiliary shaft for the oil pump, and the other drives the two sprockets for the two overhead camshafts shown. This avoids what would otherwise have to be a long chain drive.

18.8.7 Timing belts

Toothed timing belts are used with many overhead camshafts. Quieter in operation than chains, they do not require lubrication and can be wrapped further around the pulleys or sprockets than chains. Belt tensioning pulleys and idler pulleys are relatively simple as they can run on the smooth back of the belt to guide it and keep it tight.

Figure 18.28 shows the construction of a timing belt. It consists of a core of glass fibre that has a high tensile strength to resist stretching, a canvas-reinforced tooth section to resist wear and a rubber backing with good heat- and wear-resistant properties.

Timing belt arrangements

Figure 18.29 shows a timing belt for a single overhead camshaft. This has timing marks that are identified by arrowheads. The crankshaft pulley is

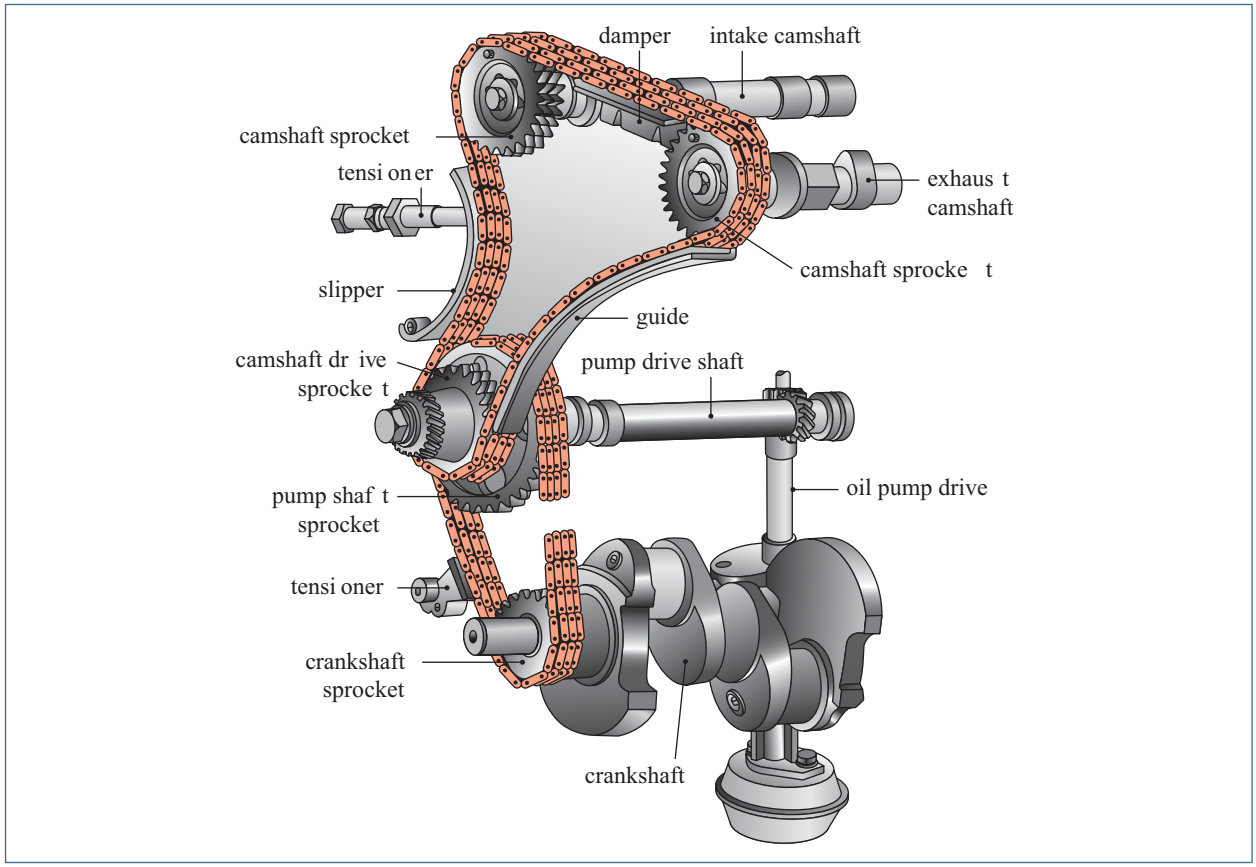


Figure 18.27 Timing-chain arrangement for double overhead-camshaft engine

positioned with the key to the top, and the camshaft pulley is positioned in line with its timing mark as shown.

Figure 18.30 shows the timing belt for a horizontally opposed engine. This is a long belt that drives a water pump as well as the two camshafts. There are two idler pulleys on the back of the belt that guide the belt and keep it wrapped around the pulleys. An automatic tensioner pulley keeps the belt tight.

The arrangement of the timing belt and timing marks for an overhead camshaft V-type engine is shown in Figure 18.31. This is a long timing belt that drives the camshaft pulleys on each bank and

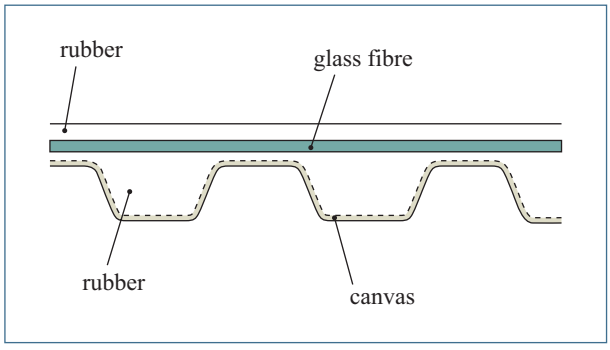


Figure 18.28 Construction of toothed timing belt

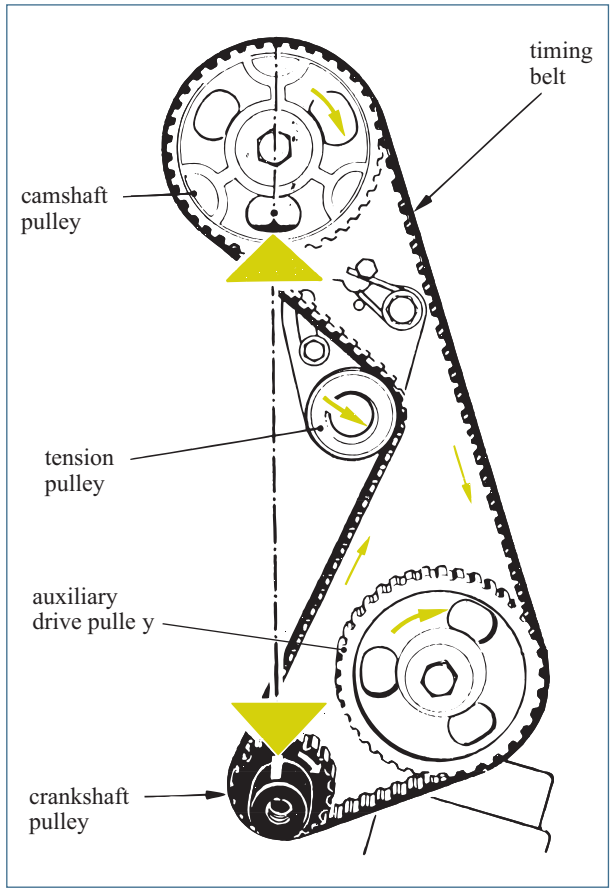


Figure 18.29 Toothed-belt drive and timing marks for a single overhead-camshaft engine FORD

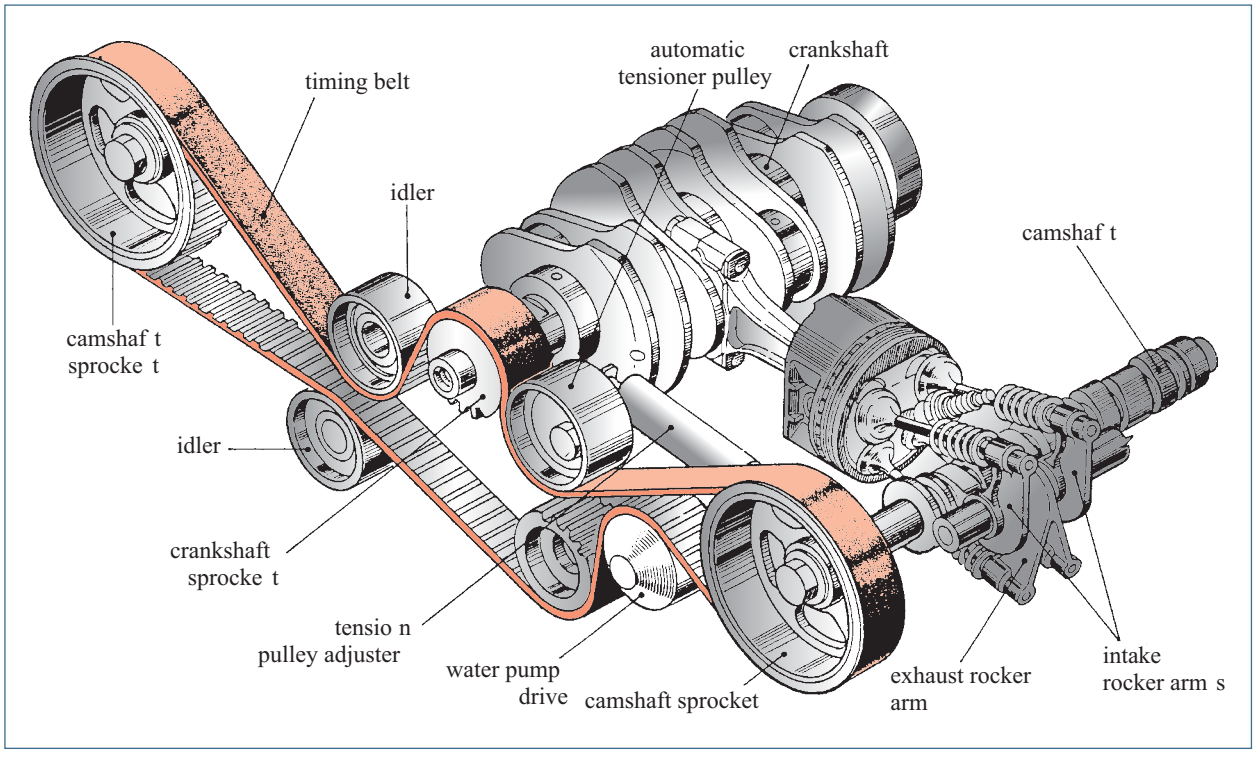


Figure 18.30 Timing belt, sprock ets and pulleys for a horizontally opposed engine SUBARU

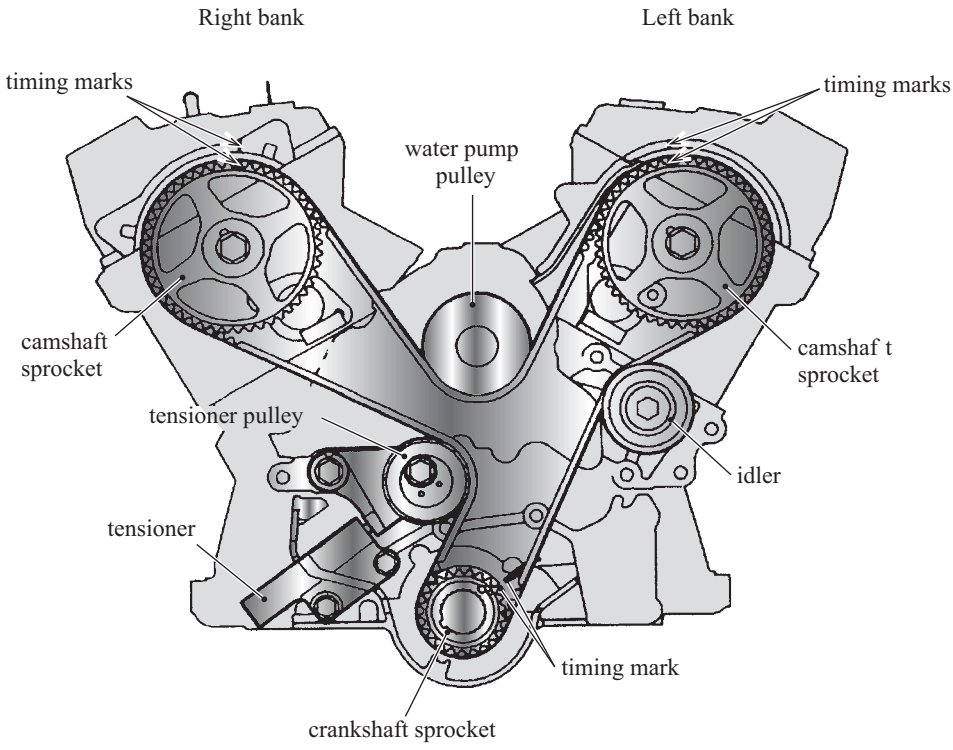


Figure 18.31 Timing belt and timing marks for a V -type OHC engine MITSUBISHI

also the coolant pump. An idler pulley on the back of the belt acts as a guide and a hydraulic tensioner keeps the belt tight.

18.9 Drives for double OHC

The drive for double overhead camshafts (DOHC) can be arranged in several different ways. For example, the upper chain in Figure 18.29 drives both camshafts. In other engines, a chain or belt is used between the crankshaft and the exhaust camshaft. A drive chain is then used between a sprocket on the exhaust camshaft and a sprocket on the intake camshaft (Figure 18.32).

The exhaust camshaft is timed to the crankshaft, but the intake camshaft must be timed to the exhaust camshaft. There are timing marks on both the chain and on the sprockets for this.

Another method of driving double camshafts is by gears. The gears between the camshafts (Figure 18.33) are sometimes called *scissor* gears and these also have timing marks. To reduce lash between the gears, the intake camshaft has a thin sub gear that is held against its drive gear. This generates side friction between them.

Both gears are in mesh with the exhaust camshaft gear, but the teeth of the sub gear mesh differently as its profile is different from that of the drive gear; this results in an arrangement of lash between the two drive gears being dampened out.

18.10 Tensioners and dampers

Various methods are used to dampen out the lash and provide tension on timing belts and chains. When operating under a constant load, a chain or belt will have one slack side and one tight side. At engine idle, the slack will vary due to the power pulses of the engine and the chain or belt will tend to vibrate. Each time the engine speeds up or slows down, the tension will alter and the slack will move from one side to the other. To prevent this and reduce noise, a damper or tensioner is used.

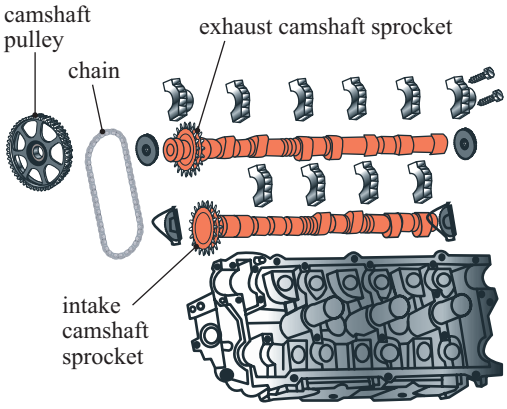


Figure 18.32 Double overhead camshafts with a chain drive between camshafts

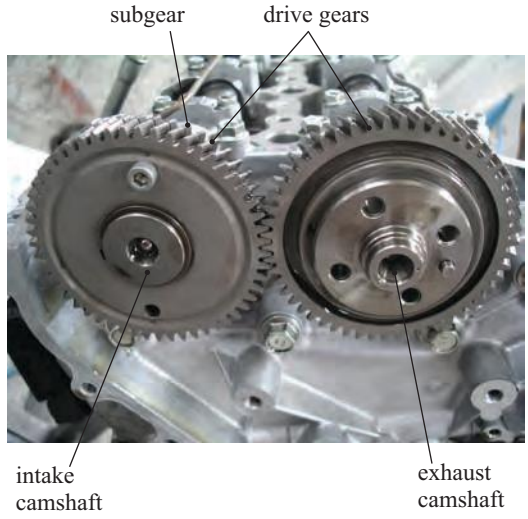


Figure 18.33 Double overhead camshafts with a gear drive between the camshafts

18.10.1 Chain devices

The three devices that are used with chains are:

1 Dampers. Act on the back of a chain to prevent it from vibrating
2 Guides. Direct the chain in relation to the sprock ets
3 Tensioners. Provide a load against the chain to k eep it tight.

These devices can be seen in Figures 18.26 and 18.29.

18.10.2 Belt devices

Timing belts use idlers and tensioners in the form of rollers that run on the back of the belt. The idlers guide the belt so that it wraps around the crankshaft and the camshaft pulleys. This increases the length of belt that is in contact with the pulleys.

There are many arrangements of idlers and tensioners. The belt shown earlier in this chapter in Figure 18.29 has a simple spring-loaded tensioner that is manually adjustable. Figure 18.30 has idlers and a hydraulic tensioner. Figure 18.31 also has an idler pulley and a hydraulic tensioner.

18.11 Variable valve timing

Variable valve timing, also called *variable camshaft timing,* is fitted to some engines. It enables the camshaft to be advanced or retarded to suit the engine's speed and operating conditions. This improves both low- and high-speed performance. The range of advance will depend on the design of the particular unit, but can be as much as 40° of crankshaft rotation.

Handy hint: There are different methods of providing variable valve timing, but they are all used to improve engine performance .

18.11.1 Variable valve timing with SOHC

A variable camshaft timing unit for a single overhead camshaft is shown in Figure 18.34. This is bolted to the camshaft sprocket, which is driven in the normal way by the timing chain; this rotates the camshaft timing unit as well as the camshaft. While the camshaft is rotating, the timing unit moves it in relation to the sprocket to advance or retard the valve timing.

As well as the unit shown, there is a housing bolted to the front of the engine that contains oil passages and an oil-control valve operated by a solenoid. The timing unit is operated hydraulically by engine oil pressure and the oil-control valve controls the supply of engine oil to and from the timing unit.

The main parts of the camshaft timing unit are:

1 Camshaft sprocket. Driven by the timing chain and has the timing unit attached.
2 Inner sleeve. Bolted to the front of the camshaft, it has helical gear teeth which mesh with the ring gear.
3 Ring gear. A ring-shaped gear with both external and internal teeth. The latter mesh with the teeth on the sleeve, the former with the teeth inside the housing. The ring gear is attached to the ring piston, which is operated by engine oil pressure.
4 Housing. Enclosing the parts, its internal teeth mesh with the external teeth of the ring gear. It also provides a cylinder in which the ring piston operates.
5 Ring piston and return spring. The ring piston is operated by engine oil pressure to advance the camshaft. The spring is used to return the ring piston to retard the camshaft.

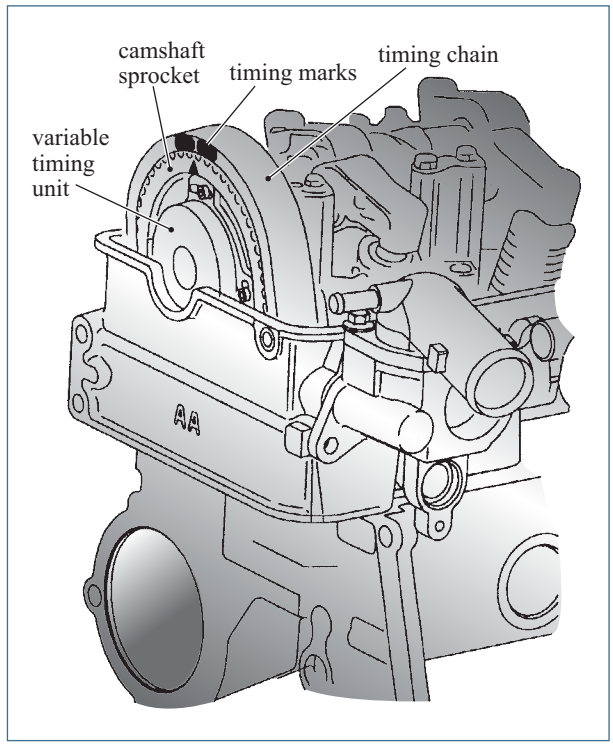


Figure 18.34 Variable camshaft timing unit for an SOHC engine FORD

18.11.2 Variable valve timing with DOHC

With double overhead camshafts (DOHC), an advance device is fitted to the *intake camshaft* but not to the exhaust camshaft. This is because altering the intake valve timing is far more beneficial than altering the exhaust timing.

The components of the system include:

- variable valve-timing unit
- oil control valve
- electronic sensors
- engine electronic control module (ECM).

18.11.3 Hydraulic system

Figure 18.35 shows the arrangement of the hydraulic system. The variable valve-timing unit has a rotor in its housing. The housing carries the timing pulley and the rotor is mounted to the end of the camshaft. Movement of the rotor in relation to the housing will advance or retard the camshaft timing.

The rotor is shaped to fit into the housing and fitted with seals to form hydraulic chambers (Figure 18.35(a)). The spool valve and a section through the timing unit are shown in Figure 18.35(b); the spool valve has been moved by the solenoid to direct oil to the advance side of the rotor. This has turned the rotor in the housing to fully advance the camshaft.

To retard the camshaft, the spool valve is moved in the opposite direction. Pressure oil is directed to the retard side of the rotor and drained away from the advance side.

The camshaft does not have to be fully advanced or retarded. It can be held in any intermediate position by the spool valve directing pressure oil to both sides of the rotor. The ECM determines the camshaft timing for the particular operating conditions.

When the engine is stopped, the rotor is held in the retarded position by a spring-loaded pin. When it is started, engine oil pressure disengages the pin so that the rotor can be turned in the housing.

18.11.4 Variable valve opening

With variable valve opening, the intake valve is arranged to open further at higher engine speeds. This increases the intake air flow and improves volumetric efficiency. There are different ways of achieving this. One is where each cylinder has an extra intake rocker arm operated by a high-lift cam on the camshaft. At lower engine rpm the cam moves the rocker arm up and down, but the rocker has no effect on the intake valves. At higher rpm, a plunger is moved hydraulically to connect the high-lift rocker arm to the normal intake rocker arm. Both rocker arms then operate together, but the intake valve will now be opened further because of the high-lift cam.

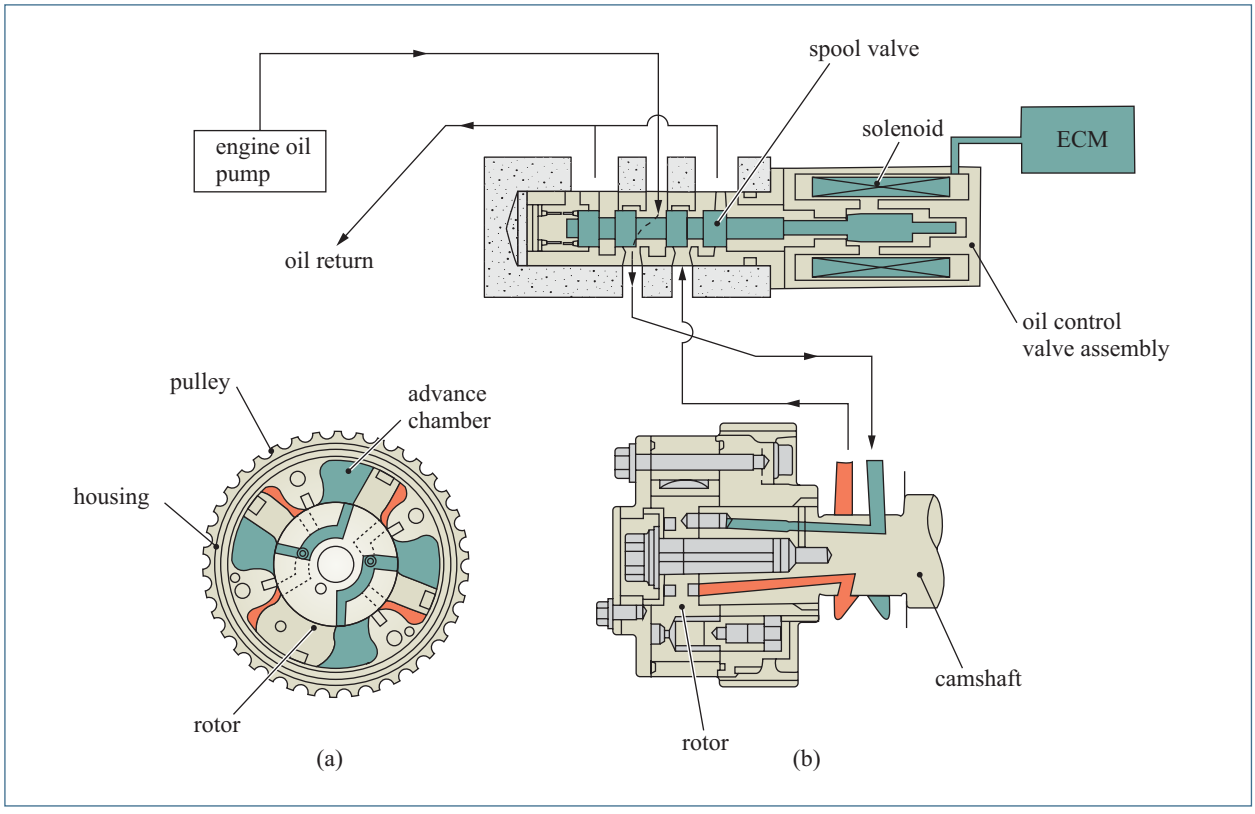


Figure 18.35 Variable valve timing in maximum advance mode (a) variable timing unit (b) hydraulic arrangement

Another method involves a bucket-type tappet with a spring-loaded plunger that provides lost motion at low engine rpm. This has the effect of reducing the intake valve opening as the full movement of the tappet is not used.

At higher engine rpm, a wedge is hydraulically inserted between the plunger and the body of the tappet. This eliminates the lost motion so the intake valve is opened further than at lower engine speeds. Again, the increased valve opening improves air flow and engine efficiency.

18.12 Valve-timing chart

Valve-timing diagrams show how the valves are timed during the four strokes of an engine (intake, compression, power and exhaust). They illustrate show how the valves are timed to open and close in relation to top dead-centre (TDC) and bottom dead-centre (BDC) of the piston strokes.

To illustrate variable valve timing and intake camshaft advance, the diagram in Figure 18.36 shows two intake strokes, and how advancing and retarding the intake camshaft affects the valve timing:

1 Intake valve timing, both opening and closing, can be varied 40 °.
2 Exhaust valve timing does not change .
3 Valve overlap will vary from 5 ° to 45 °.

The valve timing is adjusted to suit driving conditions. In general, at idle speed and light loads there are slower piston speeds and slower air intake movement, so opening the intake valve can be delayed. The opposite conditions apply at higher engine speeds.

Varying the valve overlap for different conditions is beneficial for the following reasons.

1 At low speeds and light loads, less overlap allows more exhaust gas to be expelled from the cylinder before the intak e valve opens—idling is improved.
2 At medium speeds, increasing overlap recirculates more exhaust gas within the engine (internal EGR). This lowers combustion temperatures and reduces the nitrous o xide emissions from the exhaust.
3 At higher speeds and heavier loads, the timing of the intak e valve closing is varied, and this helps with volumetric efficiency .

18.12.1 Valve-timing terminology

Lead, lag and overlap are terms associated with valve timing. The intake valve opens before TDC and the exhaust valve opens before BDC. This is called *lead*.

The intake valve closes after BDC and the exhaust valve closes after TDC. This is referred to as *lag*.

The intake and the exhaust valves are both open for a few degrees around TDC of the exhaust stroke, and this is called *overlap*.

Handy hint: Advancing or retarding the intake camshaft alters the intake valve's lead and lag. It also alters valve overlap.

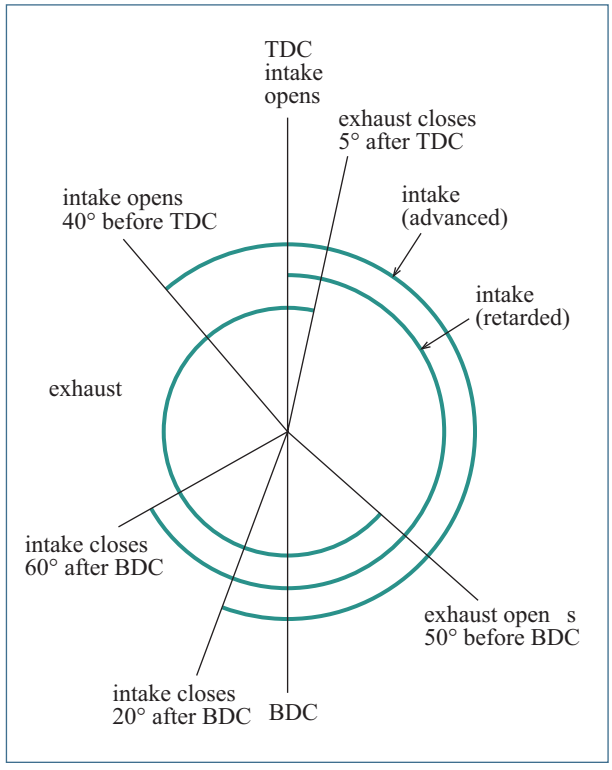


Figure 18.36 Timing diagram for variable valve timing, showing the advance and retard for the intake valves

18.13 Cylinder-head service

During servicing, the cylinder head is removed from the cylinder block, the valves are removed from the cylinder head and all parts are cleaned of carbon. The valves are refaced and the seats ground so that the valves seat correctly in the cylinder head.

Reasons for removing cylinder head include:

1. Burnt-out valve
2. Blown cylinder-head gasket, or a coolant leak
3. Faulty valve seating causing loss of compression in the cylinders.

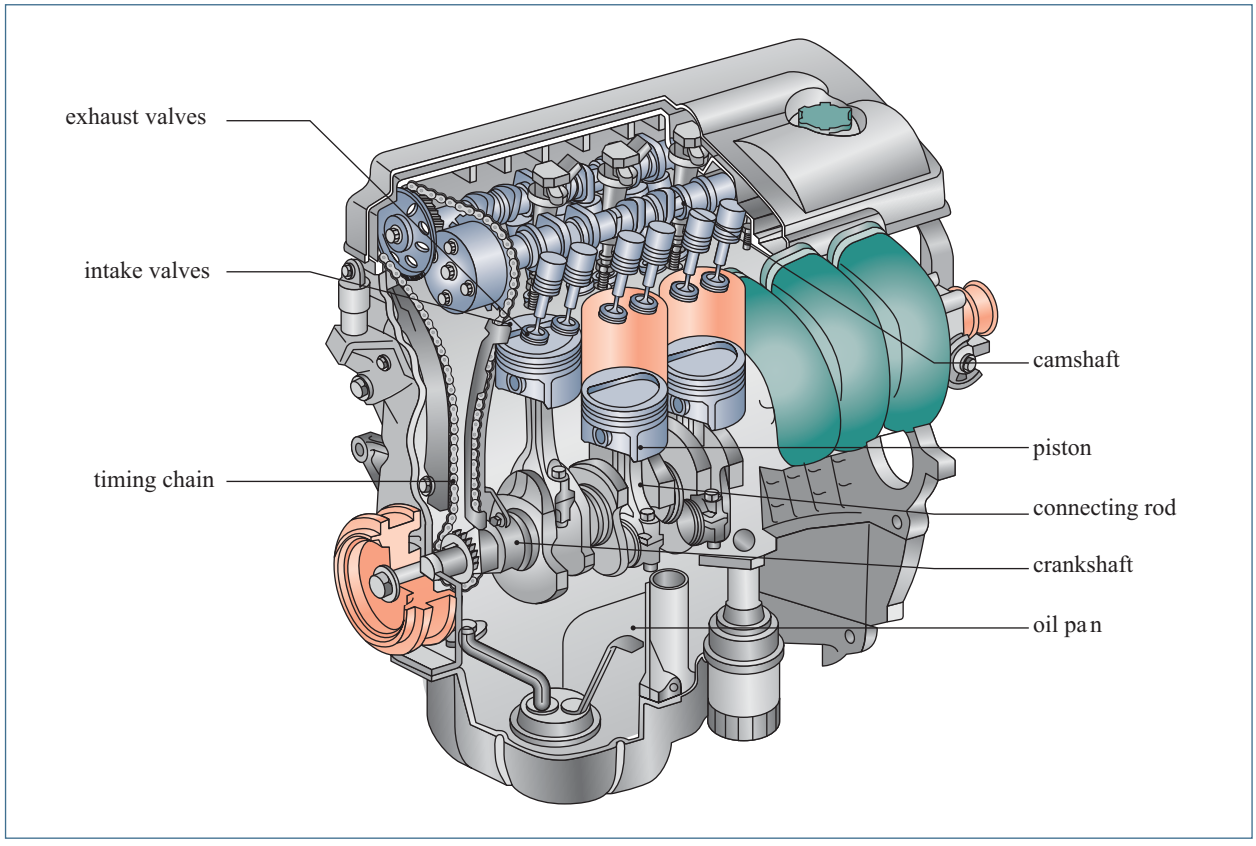


Figure 18.37 Twin overhead-camshaft engine: features are bucket tappets on the valves, crossflow cylinder head, spark plug in centre of combustion chamber

The service that involves removing, reconditioning and replacing a cylinder head is often called a *top overhaul*. Procedures for removing and replacing cylinder heads will vary, depending on whether they are being carried out for an overhead-valve or an overhead-camshaft engine. Procedures for removing auxiliary equipment such as air cleaners, air-intake systems, fuel systems, exhaust systems and emission controls will also vary for different engines.

When dismantling an engine while it is in the vehicle, there are two groups of parts to consider: auxiliary equipment and attachments that are on, or associated with, the engine; actual mechanical parts of the engine.

With most motor vehicles, there are a number of parts that must be removed before the mechanical parts of the engine are accessible, as in Figure 18.38. This shows a cylinder head for a four-cylinder, double overhead-camshaft engine with a number of dismantled components. Some of these are parts that must be removed to gain access to the cylinder head. Others are parts that are dismantled from the cylinder head itself.

18.13.1 Auxiliaries and attachments

The following points relate to auxiliary parts and accessories:

1. Engine cover. Must be removed to make other parts accessible.
2. Coolant. Must be drained from the radiator and engine block; any left in the engine will find its way into the cylinders when the cylinder head is removed.
3. Coolant system. Coolant hoses, thermostat and heater hoses must be removed.
4. Air-intake system. The air cleaner or ducting is usually removed early in the procedure to give access to other parts.

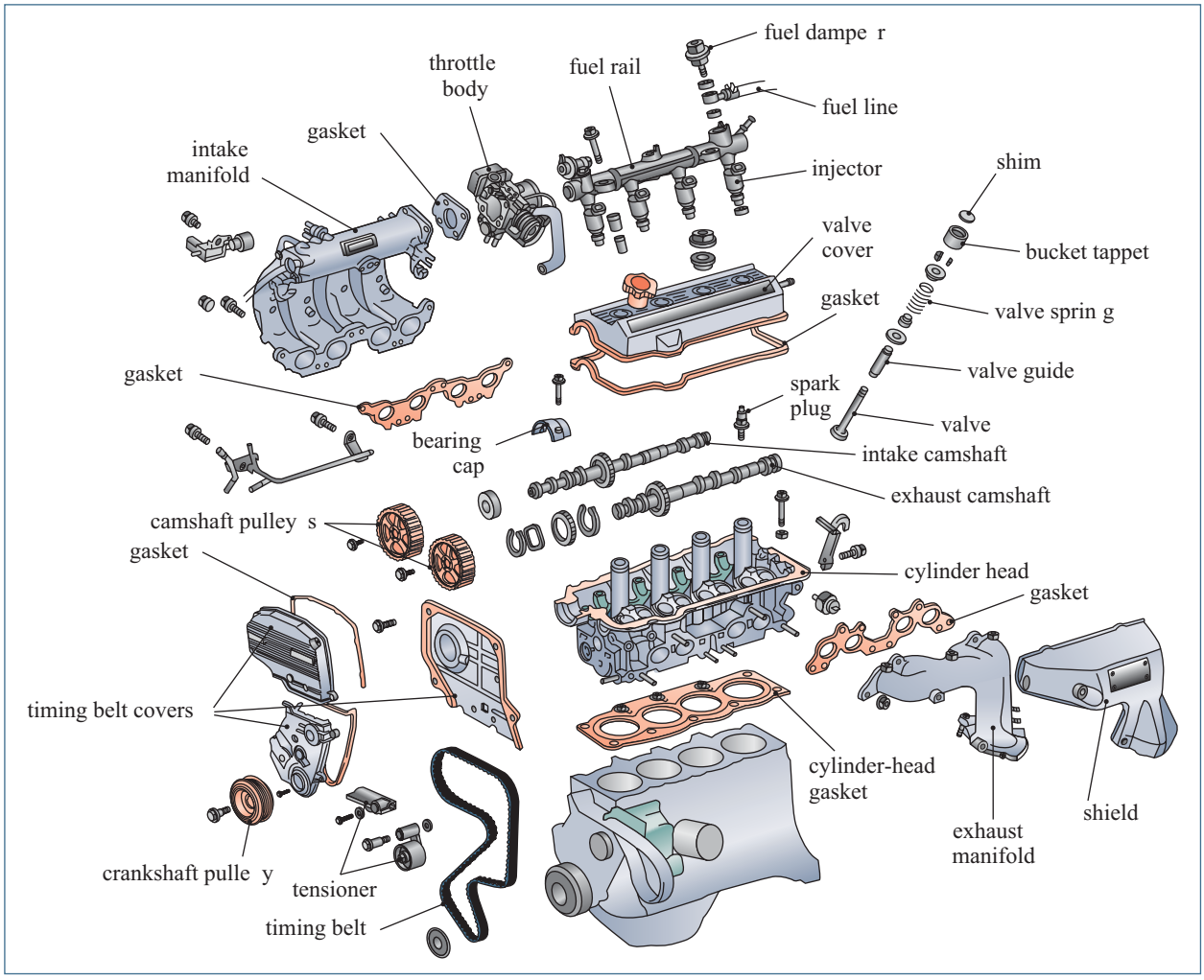


Figure 18.38 Components associated with cylinder-head removal and dismantling

5 Accelerator cable . This and the electrical connections at the electronic fuel injection (EFI) throttle body should be removed.
6 Emission pipes and hoses. Their position and connections should be noted and labels attached before removal for correct reinstallation.
7 Ignition system. The spark plug cables and ignition coil packs should be removed. If there is a distributor , it should also be removed.
8 Spark plugs. These are removed so that the crankshaft is easy to rotate .
9 Electrical connections. The various connections in the engine compartment must be disconnected. Multipin connectors can only be connected one way; other connections that are not obvious should be labelled.
10 Drive belts for the alternator . These and other auxiliaries are removed; tensioners may have to be released.
11 Fuel system parts. Many of these must be removed so that other parts are accessible .

Safety: Always disconnect 12 volt batteries when carrying out head repairs.

18.13.2 External mechanical parts

These external parts must be removed:

1 Intake manifold. Often in two parts, these can be separated for removal.
2 Exhaust manifold. Inline engines have one manifold, while V -type and horizontally opposed engines have two.
3 Valve cover . Removing this gives access to the valve-operating mechanism and, on overhead-camshaft engines, to the camshaft.
4 Engine timing cover . Removing one or more of these gives access to the timing chain or belt and to the sprockets or pulleys.
5 Engine timing. Check the timing marks and set them with No . 1 cylinder at TDC.
6 Supercharger . If one has been fitted, it must be removed (and its parts possibly disconnected).

Handy hint: Always arrange disassembled components sequentially to aid correct reassembly .

18.14 Dismantling the valve mechanism

The valve operating mechanism must be removed from the top of the cylinder head before it can be removed from the cylinder block. How this is done depends largely on whether the engine is an overhead-camshaft (OHC) or an overhead-valve (OHV).

18.14.1 Overhead-camshaft (OHC) engines

With OHC engines, camshafts are removed from the top of the cylinder head. Variations in the dismantling procedures will depend on whether:

1 The engine has rocker arms or bucket tappets
2 There are hydraulic lash adjusters
3 There are one or two camshafts
4 The camshaft has a belt drive or a chain drive .

The camshafts are carried in bearings in the cylinder head and retained by bearing caps. With bucket-type tappets, the camshaft can be removed from the cylinder head and the tappets then removed. With rocker arms, the camshaft cannot be removed until they or their assembly has been removed.

Some rocker arms are mounted individually, but many are mounted on bearings or bushes on a shaft. These, which are removed from the cylinder head as an assembly, are shown in Figure 18.39.

The camshaft bearing caps are secured to the cylinder head with four bolts. When removing this type of assembly, release the bearing cap bolts a little at a time and sequentially. This is necessary because some parts of the camshaft are under load from the compressed valve springs. Progressive loosening of the bearing cap bolts will prevent distortion.

18.14.2 Overhead-valve engines

Procedures for dismantling the valve mechanism of a V-type engine with overhead valves include removing the valve cover from the top of the cylinder head and the intake manifold from between the banks of cylinders.

In the illustration, the valve covers have been removed and the valve train parts are visible. A single camshaft is mounted in the crankcase. This operates hydraulic valve lifters which have rollers that bear against the cams of the camshaft to reduce friction and wear.

Pushrods are located between the valve lifters and the rocker arms (Figure 18.40). The rocker arms are independently mounted and they pivot about a fulcrum retained by a stud which is threaded into the cylinder head.

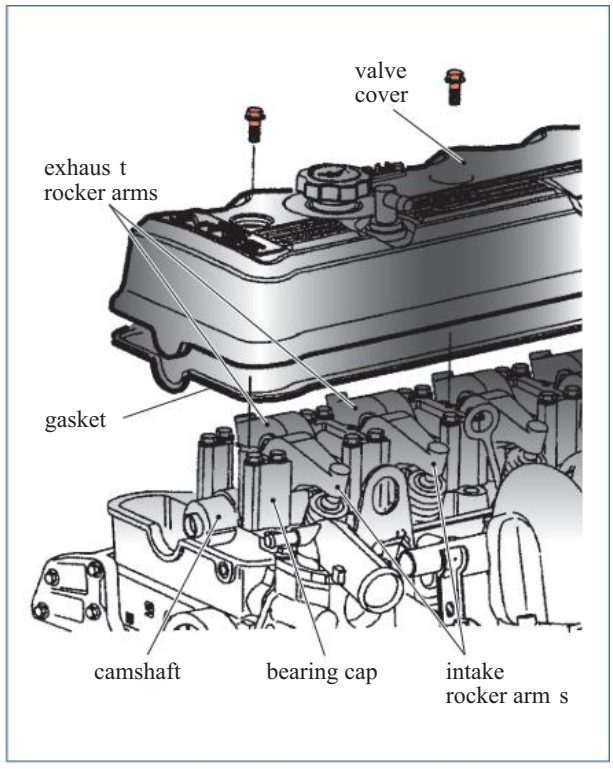


Figure 18.39 Valve arrangement for an inline OHC engine FORD

18.15 Removing and dismantling cylinder heads

With the valve gear removed from the cylinder head, the head itself can be removed from the cylinder block. Cylinder-head bolts should be released gradually, in the correct sequence (Figure 18.41). If they are not all the same length, the location of the different types should be noted. When they have been removed, the head can be lifted from the block. Do not lever between the mating surfaces as that causes burrs on the surfaces, making sealing on reassembly difficult.

Handy hint: Most automotive repairers send heads away to engine reconditioning specialists for dismantling, cleaning and checking.

18.15.1 Dismantling, cleaning and checking

To remove the valves from the cylinder head, the valve springs are compressed so that the collets or keepers can be removed from the groove in the end of the stem.

A cylinder-head work station, shown in Figure 18.42, can reduce work times if a lot of cylinder head work is carried out in the workshop.

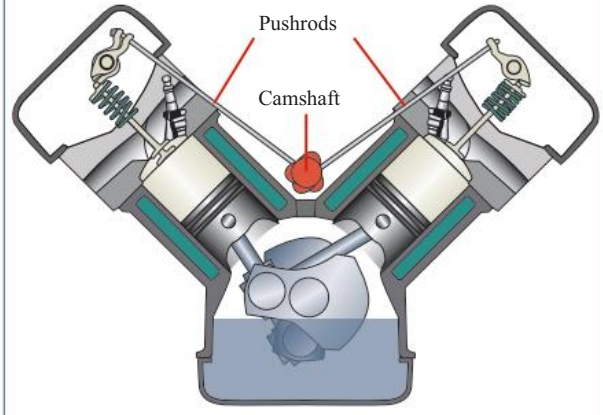


Figure 18.40 Pushrods

A valve-spring compressor is often used (Figure 18.43). Once the valve spring has been released, the retainer, spring, seal and spring seat can be removed.

The valves and associated parts should be kept in the correct order for reinstallation. They are usually identified from front to rear for inline engines. V-type engine parts are identified as right hand (RH) or left hand (LH), and also as either intake (IN) or exhaust (EX), as shown in Figure 18.44.

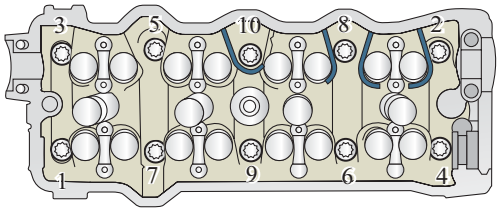


Figure 18.41 Cylinder-head bolts—sequence for loosening and removing

Figure 18.43 Using a valve-spring compressor on a cylinder head

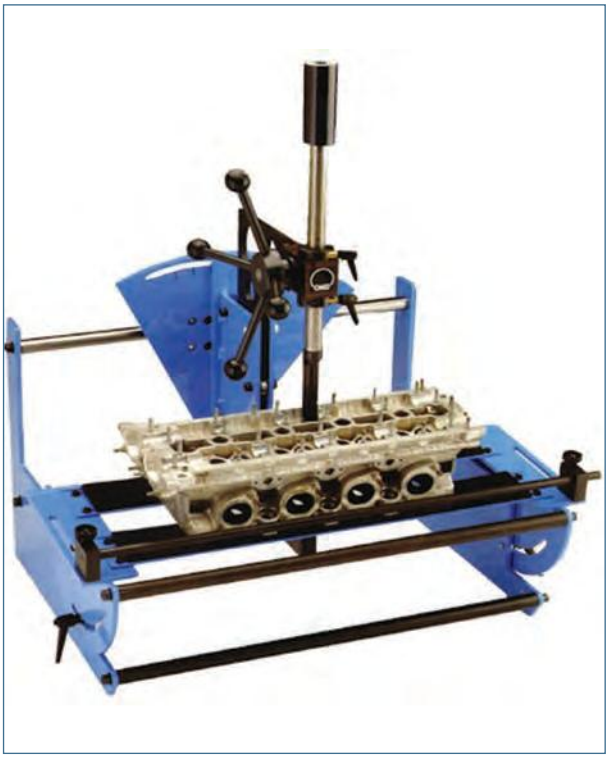


Figure 18.42 Cylinder-head work station S.A.E. SPECIALISED AUTO EQUIPMENT

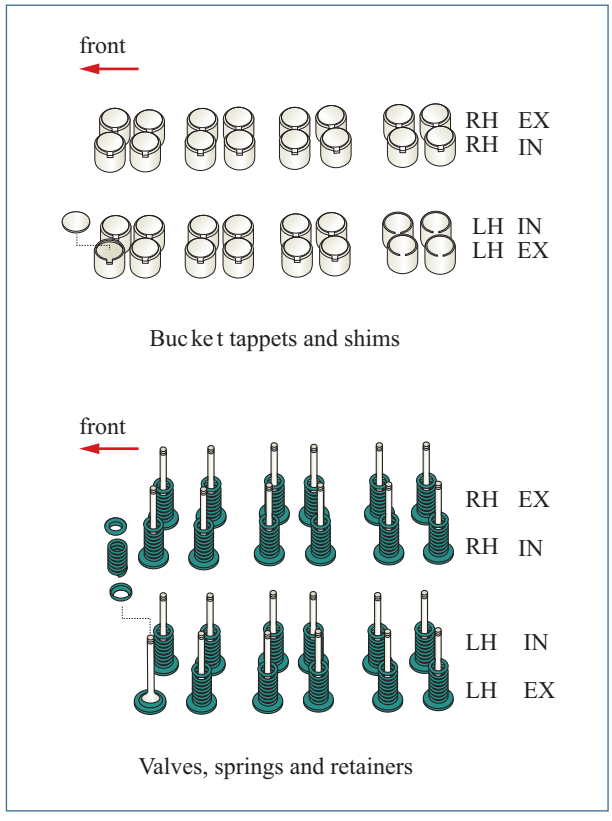


Figure 18.44 Dismantled parts should be kept in order and reinstalled correctly

Safety: When using a valve-spring compressor tool, wear safety glasses and exercise caution.

Cleaning

As well as removing oil and grease with solvent, a scraper can be used to remove the carbon from the combustion chambers and valve ports. Parts of the cylinder-head gasket that adhere to the face of the head should be removed with a flat scraper to avoid scratching the surface (Figure 18.45).

A shaped wire brush fitted to a small electric drill can be used to finish off the combustion chambers and valve ports (Figure 18.46). Carbon and dust should be blown away with compressed air.

Valves can be cleaned with a wire wheel on the bench grinder. The surface of the cylinder block must also be cleaned. Carbon can be removed from the piston heads with a scraper. Turn the crankshaft until the

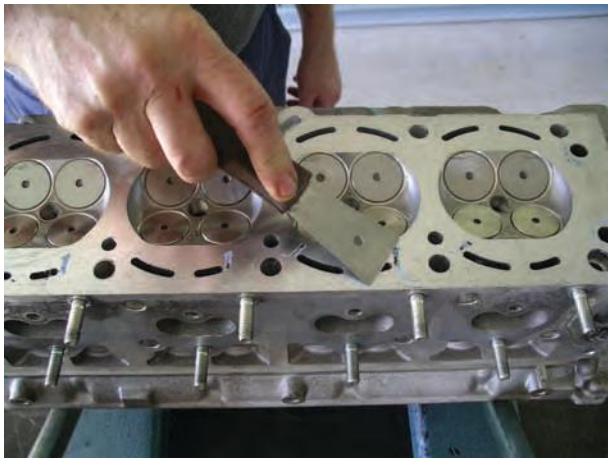


Figure 18.45 Use a scraper to remove the old cylinder-head gasket

Figure 18.46 Removing carbon from a combustion chamber with a wire brush

piston is on TDC and place rags in the other cylinders to keep carbon particles out. The bolt holes in the cylinder block should be flushed out with air to expel carbon particles.

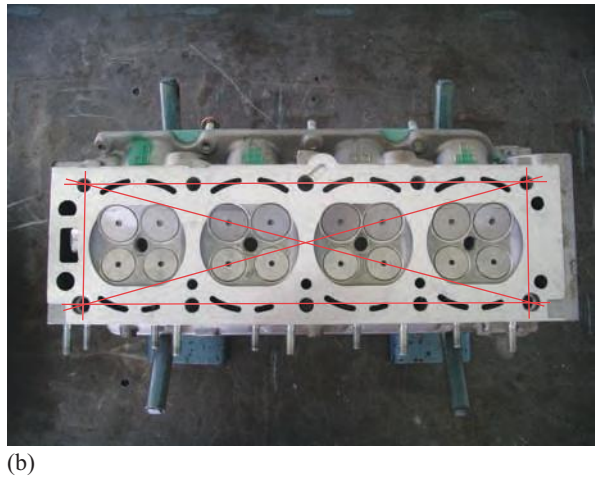
Handy hint: Carbon left in the bottom of bolt holes will affect bolt tightening.

18.15.2 Inspecting cylinder heads

After cleaning, a cylinder head should be checked for cracks, warping or rough surfaces. Flatness can be checked with a straightedge against the cylinder head face. Feeler gauges are used between the straightedge and the surface of the head as shown in Figure 18.47(a) and (b). Rough spots and burrs can be removed by careful use of a fine file.

Specifications generally allow 0.2 mm maximum warping in the overall length of a head, or approximately 0.1 mm in any 150 mm in any direction. The face of the cylinder head can be restored using a surface grinder, but generally not more than 0.05 mm of metal should be removed. OHC cylinder heads should also have the camshaft bearing tunnels checked with a straightedge if the head surface is warped. Grinding the head surface without correcting tunnel alignment will result in camshaft failure.

(a)



(b)

Figure 18.47 Checking the face of a cylinder head for flatness; the straightedge is used in the positions shown (a) checking flatness (b) checking locations

Handy hint: If an aluminium head has been overheated, it should have its hardness checked by the engine reconditioner.

18.15.3 Checking cylinder heads for cracks

Cracks in cylinder heads often occur in or around the combustion chamber and the valve port areas. Hard to spot with the human eye, they can usually only be located by special methods such as the use of magnetism or dye. Engine reconditioners use pressure testing: the cooling jackets of the head are sealed and air pressure and water applied. The head is then visually inspected for leaks.

18.16 Installing cylinder heads

Installing a cylinder head is the reverse procedure to removal. Points to consider are:

1. Before installing the cylinder head, the surfaces of both the cylinder head and cylinder block should be clean, as should the bolts and threads in the cylinder block.
2. A new cylinder-head gasket should be used. Gaskets are ready for use and sealer is generally not used. Aligning studs can be installed in two diagonally opposite holes to keep the gasket in place.
3. Cylinder-head bolts should be tightened in the correct sequence and to the correct torque. Incorrect tightening can cause head or block distortion, gasket leakage or bolt failure.

Handy hint: Most gaskets will only fit one way, but some have the top identified, as shown in Figure 18.48.

18.16.1 Tightening cylinder-head bolts

A spiral tightening sequence is often used. This starts with the bolts at the centre of the head and proceeds in a spiral so that bolts are tightened progressively outwards. Another sequence starts at the centre and follows a diagonal pattern towards the ends (Figure 18.49). The cylinder-head bolts can be tightened to a specified torque using a torque wrench. They are tightened in three steps, with the torque being increased each time.

Handy hint: Torque wrenches should be checked regularly for correct calibration.

Torque-angle tightening

Many cylinder head bolts are tightened using a torque-angle method. A torque-angle wrench can be used, or the bolt head can be marked to identify its position. The relevant service manual should be consulted for the recommendations for a particular vehicle.

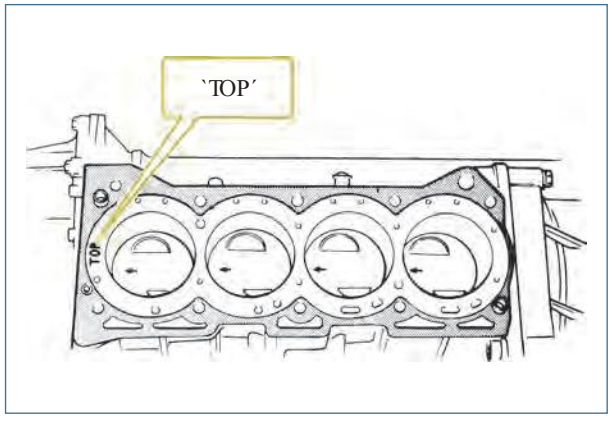


Figure 18.48 A cylinder-head gasket that has the top marked GM HOLDEN LTD

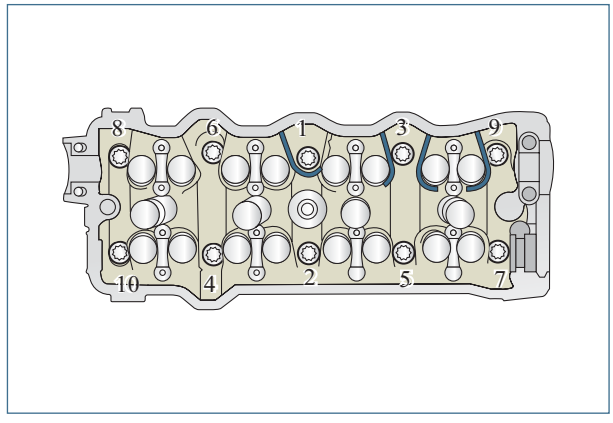


Figure 18.49 Cylinder-head bolt-tightening sequence

Figure 18.50 shows torque-angle tightening (there are variations to both method and specifications):

1 Figure 18.50(a): a torque wrench tightens the bolts to a torque of 30 newton metres (Nm). This is done gradually and sequentially .
2 Figure 18.50(b): when tightened, the front of each bolt head is mark ed. A normal wrench handle is then used to turn the bolts through an angle of 90 °.
3 Figure 18.50(c): the bolts are tightened further by turning them an additional angle of 90 °.

Handy hint: The mark on the bolt head in the illustration would have turned 180 °, and should now face the rear of the cylinder head. New torque-to-yield head bolts should be used.

18.16.2 Installing manifolds

Manifold bolts should be tightened gradually, sequentially and to the correct torque. This applies to any casting. An example of an exhaust manifold is shown in Figure 18.51, where the bolts are tightened from the centre towards the ends. Intake manifolds will have a similar type of sequence.

18.16.3 Installing valve mechanisms

When installing valve mechanisms, consider:

1 Camshaft. With OHC engines, the camshaft is installed on top of the head. The valve timing is set to the timing marks with No . 1 piston on TDC. The chain or belt is installed and the tensioner adjusted to provide the correct chain or belt tension.
2 Rock er assembly . When rock er gear is being installed, the bolts are screwed down gradually and then tightened to the correct torque . Screw adjustments on rock er arms can be back ed off to relieve the load of the valve springs.
3 Pushrods. On OHV engines, pushrods must be installed before the rock er mechanism.
4 Valve clearances. These are adjusted with the engine cold (in some cases, the clearances can be recheck ed when it is hot). With hydraulic valve lifters or hydraulic lash adjusters, clearances do not have to be adjusted.

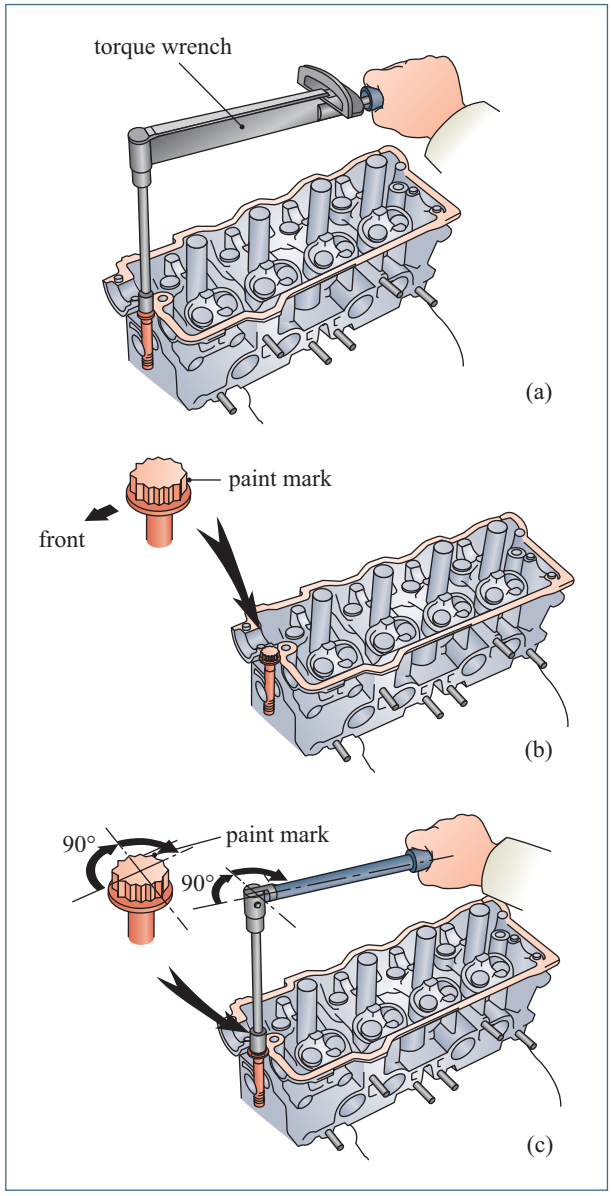


Figure 18.50 Torque-angle method of tightening cylinder-head bolts (a) torque sequence (b) identify front of bolt (c) turn through specified angle

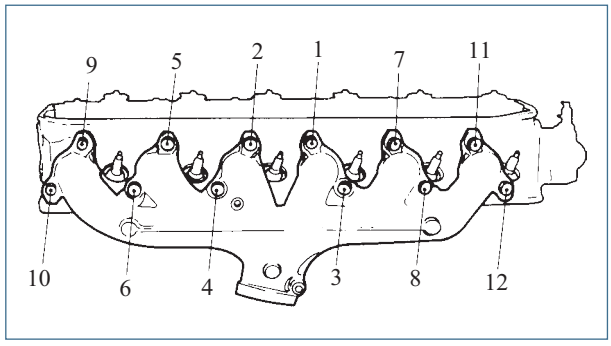


Figure 18.51 Tightening sequence for an exhaust manifold FORD

18.17 Valve-clearance adjustments

The valve clearance (also referred to as tappet clearance) is checked and adjusted in different ways for different engines. Clearances of engines with hydraulic valve lifters or hydraulic lash adjusters do not need adjusting.

Before checking the valve clearance, the valve should be in the fully closed position. The clearance is checked using a feeler gauge (Figure 18.52).

If the clearance is correct, the feeler gauge will be firm (but not tight) when moved between the two parts being checked. Using two feeler gauges (one a little thicker, the other a little thinner than the specified clearance) gives greater accuracy.

Handy hint: Two gauges used in this way are referred to as go and no-go gauges.

18.17.1 Screw adjustments

Some rocker arms have an adjusting screw and locknut in their valve end. Clearance is checked between the adjusting screw and the tip of the valve stem. Most clearances are adjusted *cold,* but some are specified *hot.*

In the latter case, the engine is run until it reaches operating temperature and the valve cover is then removed. However, if an engine is being reassembled, the clearances are set cold and, if specified, rechecked hot after the it has been assembled and run.

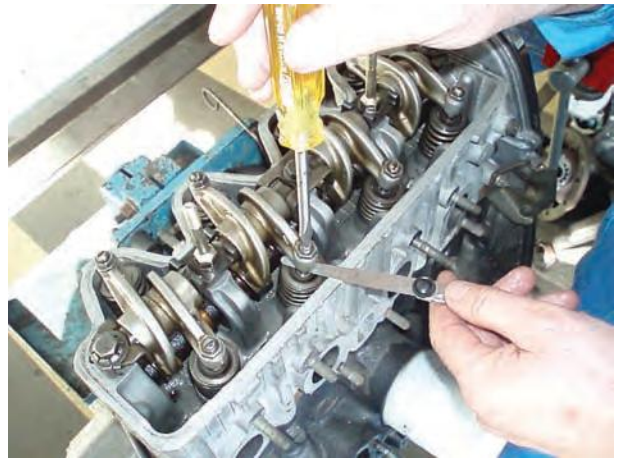


Figure 18.52 Adjusting valve clearance using a feeler gauge

18.17.2 Bucket-type tappet adjustments

Bucket tappets have a spacer or shim between the top of the tappet and the cam on the camshaft (Figure 18.53). The clearance is checked by inserting a feeler gauge between them. Shims are available in a range of sizes, thicker or thinner ones being fitted to adjust the clearance.

To change a shim, a tool is used to depress the tappet and valve spring. This gives space between the top of the tappet and the cam so that one shim can be removed and another fitted.

In some engines, the spacers are fitted inside the tappet against the tip of the valve stem and can only be adjusted with the camshaft removed. This is usually only done when the cylinder head is dismantled. The clearance is checked prior to dismantling. If incorrect, it is adjusted by fitting a spacer of different thickness during reassembly.

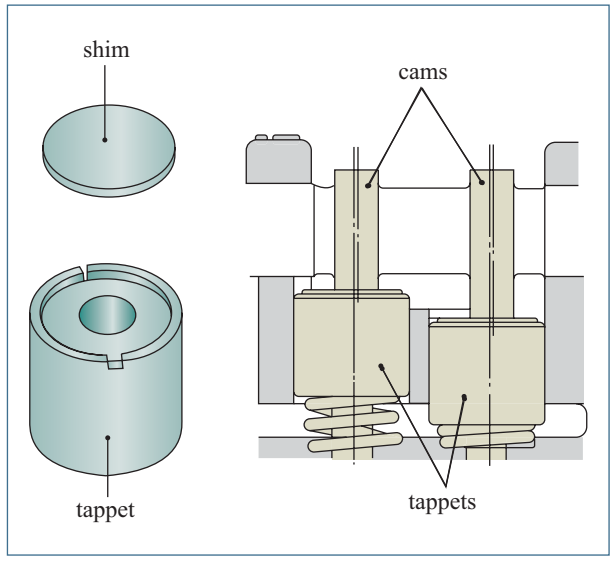


Figure 18.53 Bucket tappets and adjusting shims

Handy hint: When buck et tappets are removed from the cylinder head, each one should be kept in order with its own spacer or shim.

The correct shim can be selected by using the calculation:

$$T = U + (M - S)$$

In this calculation:

T = thickness of the new shim
U = thickness of the used shim
M = measured valve clearance
S = specified valve clearance

18.17.3 Sequence of valve adjustment

The valve being checked or adjusted should be fully closed. Its lifter, rocker arm or tappet should be on the heel of the cam. This position can be obtained by rotating the crankshaft until the cylinder piston of the valves being checked is on TDC of the compression stroke. The clearance of both the intake valve and the exhaust valve for the particular cylinder can be adjusted.

The clearance of the valves of each of the other cylinders can then be adjusted by rotating the crankshaft to bring each piston to TDC in turn. Following the firing order of the engine will require the least rotation of the crankshaft.

The above sequence requires the crankshaft to be rotated a number of times before all the valve clearances can be adjusted. However, sequences which enable the clearance to be adjusted with fewer rotations on the crankshaft can be obtained from service manuals.

The sequence of adjusting the valves for a four-cylinder engine is shown in Figure 18.54. This requires minimum rotation of the crankshaft.

The valves labelled A in the illustration are adjusted with the piston of No. 1 cylinder on TDC at the end of its compression stroke. The crankshaft is then turned once completely so that No. 4 cylinder is on TDC at the end of its compression stroke. The valves labelled B are adjusted.

18.17.4 Locating TDC

Top dead centre for No. 1 cylinder can be located by setting the zero mark on the crankshaft pulley in line with the pointer on the timing cover (Figure 18.55). At the top of the compression stroke, the intake and exhaust valves for the cylinder will be fully closed.

Usually, the engine can be turned with a spanner on the bolt at the end of the crankshaft. Watch the movement of the valves as the engine is being turned; when the intake valve closes, the piston will be at BDC; a half-turn of the crankshaft will bring the piston to TDC.

For a four-cylinder engine, use the timing marks to locate TDC at the end of the compression stroke. If this is done for No. 1 cylinder, the TDC of the other cylinders will occur, in firing order, at each half-turn of the crankshaft.

Handy hint: The timing marks will align when both No. 1 and No. 4 cylinders are on TDC, but only one will be on the top of its compression stroke.

For a six-cylinder engine, a piston will be on TDC at each 120° of crankshaft rotation; for an eight-cylinder engine, a piston will be on TDC at each 90° of engine rotation.

18.18 Servicing valves and springs

The parts of the valve to be checked are shown in Figure 18.56. The valve face should be inspected for wear, pits, grooves and burn marks to determine if it is suitable for further use. Minor defects can be removed by refacing the valve. Valves that are badly burnt, warped or cracked should be discarded.

The margin or thickness of the edge of the valve face should be about 1 mm minimum. A smaller margin will cause the valve head to overheat and the edge will burn.

The valve stem should be inspected to see if it is bent. The end of the stem should be inspected for grooves or scores, and its clearance in the valve guide should also be checked.

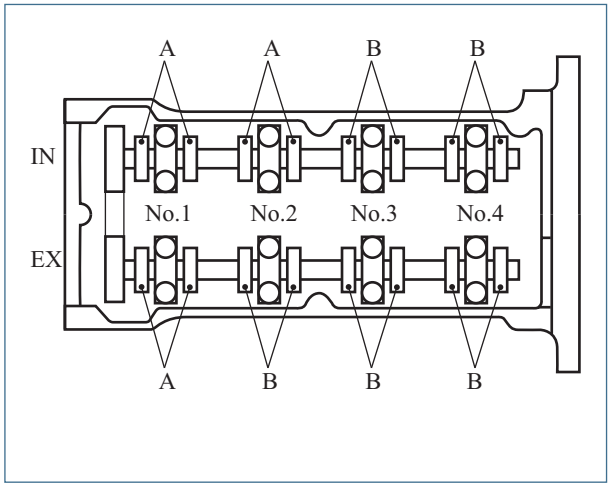


Figure 18.54 Tappet adjustment sequence A with No. 1 piston on TDC, B with No. 4 piston on TDC

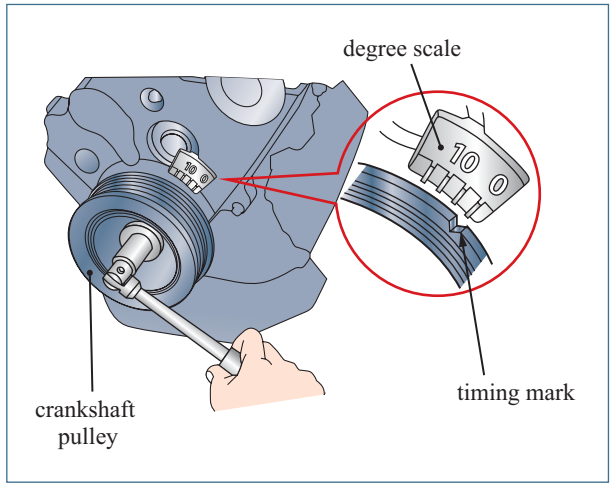


Figure 18.55 Turning the crankshaft to set No. 1 cylinder on TDC

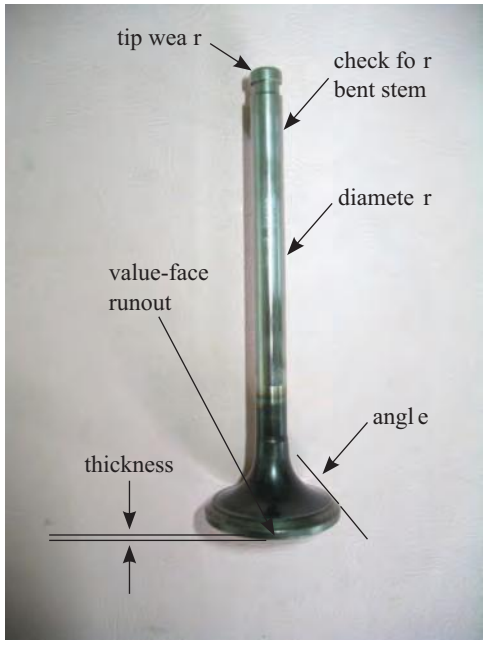


Figure 18.56 Points to be checked on a valve

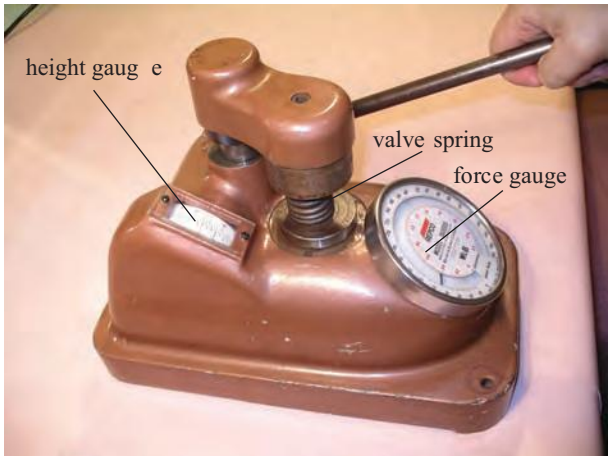


Figure 18.57 Valve-spring tester being used to test a valve spring

Figure 18.58 Checking the squareness of an engine valve spring

18.18.1 Testing valve springs

Valve springs should be tested for compression and squareness. Special testers measure the force required to compress the spring to a specified length (Figure 18.57).

To check for squareness, stand the spring on end on a flat surface against a square (Figure 18.58). Rotate the spring slowly to see if the top coil moves away from the blade of the square. Turn the spring upside down and check again. If the spring is more than 2 mm out of square, or if it does not have correct compression at the specified length, discard it.

Weak springs that do not close the valve quickly enough will allow gas leaks and cause excessive valve-head temperatures. They could also cause excessive wear to the lifters or cams.

Handy hint: Springs that are not square impart a sideways thrust to the valve stem, causing excessive wear to stems and guides.

18.18.2 Replacing valve seals or springs

On some engines, the valve stem seals and springs can be removed and installed without removing the cylinder head from the engine.

An adaptor is fitted to the spark plug hole and an airline connected. Compressed air is then applied to the cylinder to hold the valve against its seat, and a special tool is used to depress the valve spring (Figure 18.59).

The method can be used with different types of valve mechanisms, providing a suitable tool is available and the top of the valve spring is accessible. With some OHC engines, the camshaft has to be removed.

To remove a valve spring, the piston of the particular cylinder is brought to TDC on the compression stroke and air pressure is applied to

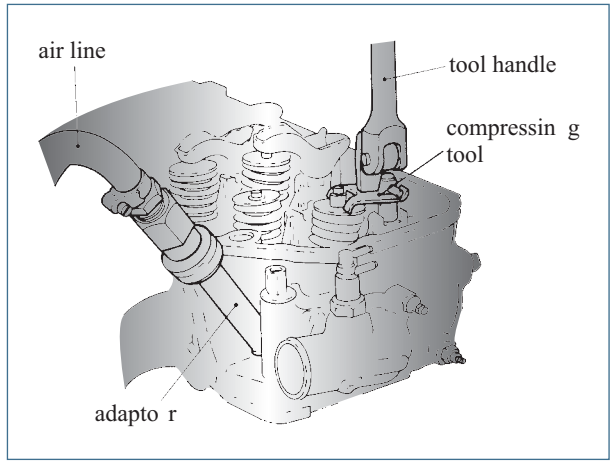


Figure 18.59 Compressing a valve spring with the cylinder head installed

the adaptor in the spark plug hole. The engine should be prevented from turning so that the valve will rest on the top of the piston if air pressure is lost.

Handy hint: If air pressure will not hold the valve on its seat, a faulty valve or seat is indicated.

18.19 Servicing rocker-arm assemblies

Where the rocker arms are mounted on a shaft, remove them as an assembly. Observe the arrangement of arms, springs and washers and lay them out in order. Not all rocker arms are the same shape.

On engines with independently mounted rocker arms, the rocker arms are dismantled separately by removing the mounting stud threaded into the cylinder head.

After the rocker arms are removed, they should be examined for wear or damage. Those with bushings can be rebushed if they are worn. On some rocker arms, the end that operates against the cam has a roller, while others can be ground on a valve refacer. However, excessively worn rocker arms must be replaced.

18.20 Servicing hydraulic lifters and lash adjusters

The valve-train length can be checked on OHV engines that have hydraulic valve lifters. This is done to make sure that the hydraulic lifter can operate properly. With a good lifter, the plunger of the hydraulic lifter normally operates around the centre position of the body. The check runs as follows:

1. Turn the crankshaft so that the lifter is on the low part of the cam.
2. Use a special tool on the rocker arm to force the oil from the lifter so that the plunger bottoms in the body (Figure 18.60).
3. Use feeler gauges to check the clearance between the tip of the valve stem and the rocker arm.
4. If the clearance is too small, the valve might not close properly; if it is too large, the lifter could be noisy in operation.

Handy hint: If the valve train has no adjustment and a valve is noisy, the hydraulic valve lifter must be dismantled and cleaned, or replaced.

18.20.1 Dismantling hydraulic lifters

Figure 18.61 shows a dismantled lifter. Dismantling is carried out by depressing the pushrod cup and plunger and removing the circlip. This allows the removal of the pushrod cup, the plunger and the valve.

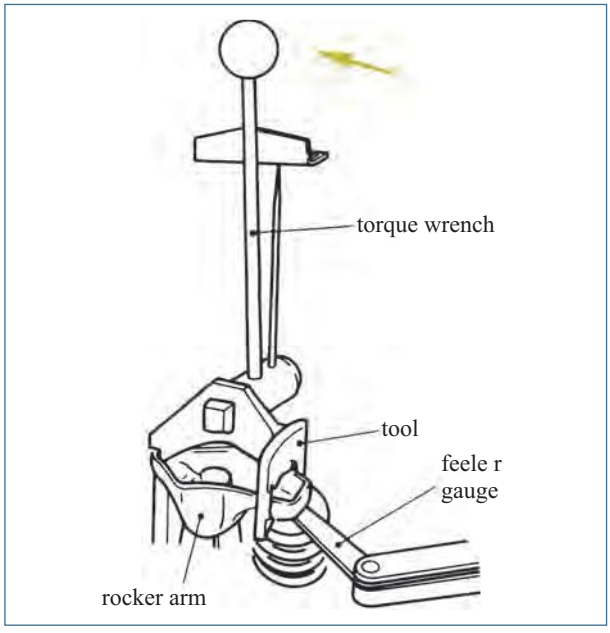


Figure 18.60 Bleeding down a hydraulic valve lifter and checking the valve clearance FORD

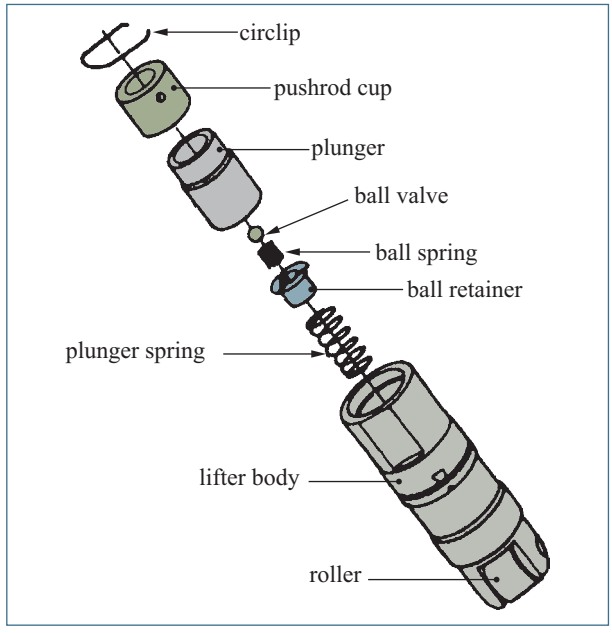


Figure 18.61 Roller-type hydraulic valve lifter FORD

Observe the sequence of dismantling for correct reassembly and work on one lifter at a time. Parts should not be mixed with other lifters.

Check the condition of the parts, including the roller (if there is no roller, check the bottom of the lifter for wear).

If all the parts are serviceable, they can be cleaned in distillate, reassembled and the lifter can be tested. If they are scored or defective in any way, the complete lifter should be renewed.

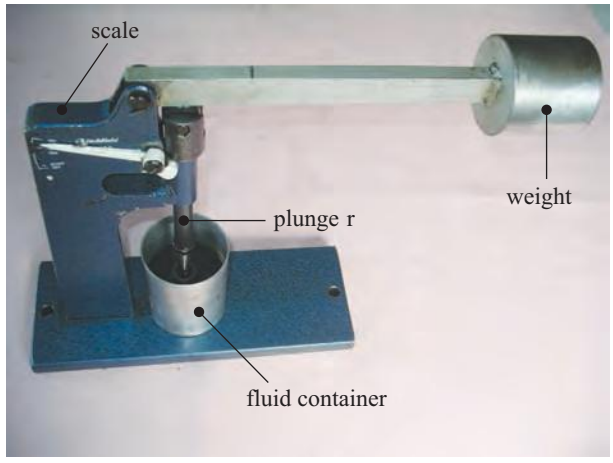


Figure 18.62 Tester for hydraulic valve lifters

18.20.2 Testing hydraulic lifters

Hydraulic valve lifters are tested for their leak-down rate. A good one will leak down slowly, but if its plunger is sticking the leak-down will be too slow. If its plunger is worn, or the check valve is leaking, it will be too fast.

The tester (Figure 18.62) consists of a base with a vertical standard carrying a ram. It has a cup that holds test fluid. The ram is operated by a weight on the end of an arm. A scale and pointer indicate movement of the plunger.

Test method

1. Place the lifter in the tester cup and cover with fluid (either a special light oil or distillate).
2. Place the steel ball in the pushrod cup under the end of the ram.
3. Work the plunger up and down with the weight until air is bled from the lifter and it is full of fluid.
4. Adjust the length of the ram so that the pointer is in line with the top mark of the scale when the ram is just touching the ball in the pushrod cup.
5. Raise the lever and let the weight and ram force the plunger down.
6. Measure how long it takes the pointer to move across the scale. This is the leak-down rate.

For example, a used lifter should take at least 5 seconds, but not more than 60, to leak down; a new lifter should take at least 10 seconds, but not more than 60. A suspect lifter should be tested three or four times. Lifters that do not test within specifications should be replaced.

18.20.3 Hydraulic lash adjusters

Some hydraulic lash adjusters for OHC engines can be tested in a similar manner to that described for hydraulic valve lifters. Generally, hydraulic lash adjusters cannot be dismantled, but they can be bled to remove air. This also provides limited cleaning.

A faulty lash adjuster will produce noise with the engine idling at normal operating temperature. Some noise is not unusual when the engine is cold and has been standing as the plunger of the adjuster could have leaked down.

Hydraulic lash adjusters can be bled of air by working them in a container of clean distillate. To prevent contamination, the outside of the adjuster should be cleaned before it is immersed for bleeding.

Handy hint: If a lash adjuster is still noisy after bleeding, it should be replaced.

18.21 Valve refacers and refacing

Valve refacers are used to restore valves by producing a finely ground valve face. This should be at the correct angle and concentric to the valve stem. Valve refacers consist of two grinding wheels and a workhead which holds and rotates the valve (Figure 18.63).

Safety: When operating any machinery or equipment, make sure that it is cleaned to an industry standard and that you follow the manufacturer's procedures.

Figure 18.63 Valve refacer

Figure 18.64 Using a grinding stone to restore a valve seat

18.22 Valve-seat reconditioning

Worn or burnt valve seats in the cylinder head can be restored by either grinding or cutting. This removes pit marks and burns and produces a seat that is concentric with the valve guide. Seats can also be *narrowed* to give the correct width.

18.22.1 Valve-seat grinding

Small grinding stones are used to restore the valve seats. The stones are available in various diameters and are dressed to suit the valve-seat angle. Narrowing stones are dressed to other angles.

The stones are mounted on the threaded end of the stone carrier (Figure 18.64). To grind the valve seat, the carrier is mounted with a pilot in the valve guide and driven by an electric drill.

The carrier has a clutch as part of its drive. The clutch is designed to have some slip, and this can be adjusted by the knurled sleeve at the top of the carrier. Clutch slip causes the stone to chatter on the seat that is being ground, and this assists the grinding action. The clutch can be adjusted for roughing or finishing.

Pilots

There are two types of pilot that the carrier is mounted on: *expanding pilots* and *solid pilots*. They are used in the valve guide to support the stone carrier as it rotates. This keeps the stone grinding the seat true with the valve guide.

An expanding pilot is held stationary in the valve guide and the carrier spins on it. A solid pilot is fitted to the stone carrier and rotates in the valve guide.

The valve guides should be clean and not excessively worn, and the pilot should be correctly fitted. Any errors or looseness will cause the seat to be ground eccentric with the guide so that the valve will not be able to seat properly.

18.22.2 Grinding valve seats

The procedure for grinding a valve seat is as follows:

1 Clean the valve guides thoroughly so that the pilot will centre correctly in the guide . This ensures that the valve seat is ground concentric with its guide .
2 Select a stone to suit the diameter and the angle of the valve seat. Fit it to the carrier and dress if necessary .
3 Select a pilot to suit the valve guide . Fit this to the carrier or into the valve guide , depending on the type of equipment you are using.
4 Place the carrier on the pilot and spin it with the electric drill, applying a light pressure to grind the valve seat. The clutch in the carrier can be adjusted to produce chatter , which assists with grinding.
5 Make a light grind to check that the stone is grinding correctly , then continue cleaning up the seat.

Handy hint: Make sure that the valve seat is ground concentric with the valve guide . Guides should be in good condition.

Figure 18.65 Lapping a valve to the valve seat

Figure 18.66 Blue test of valve and seat

18.22.3 Lapping valves

After the valves have been refaced and seats ground, the valve and seat can be lapped to each other as follows.

1 Place a small amount of fine valve-grinding paste evenly around the valve face , keeping it away from the stem.
2 Place the valve in its guide and, by means of a suction cup and handle , rotate it back and forth a few degrees on its seat, using light pressure (Figure 18. 65).
3 Raise the valve frequently during lapping and turn it to a new position after a few laps.
4 Lap only until a continuous-but-narrow lapping mark is obtained on both the seat and face .
5 To check for correct seating, give the valve face a light coating of bearing blue and install it in its guide , forcing it against its seat (Figure 18. 66).

Handy hint: After lapping, clean all traces of grinding paste from both the seat and the valve .

18.22.4 Narrowing valve seats

The width of a valve seat is important. A narrow seat gives a good seal, while a wider seat transfers heat from the valve head to the cylinder head. Balance is necessary, with the intake valve seat usually being narrower than the exhaust valve seat.

Specifications vary for different engines but examples of valve-seat widths are: intake valve 1.5 to 2 mm; exhaust valve 1.8 to 2.5 mm. If a seat is too wide, it can be narrowed by grinding its top and/or bottom (Figure 18.67).

Safety: Using the correct tools for valve adjustment helps prevent hand injuries.

The position of the valve on the seat can also be altered. Narrowing by removing metal from the top of the seat will lower the seat in relation to the valve face. Narrowing by removing metal from its bottom will raise it.

Handy hint: During reconditioning, it is often necessary to grind angles at the top and bottom of the seat to obtain the correct seat.

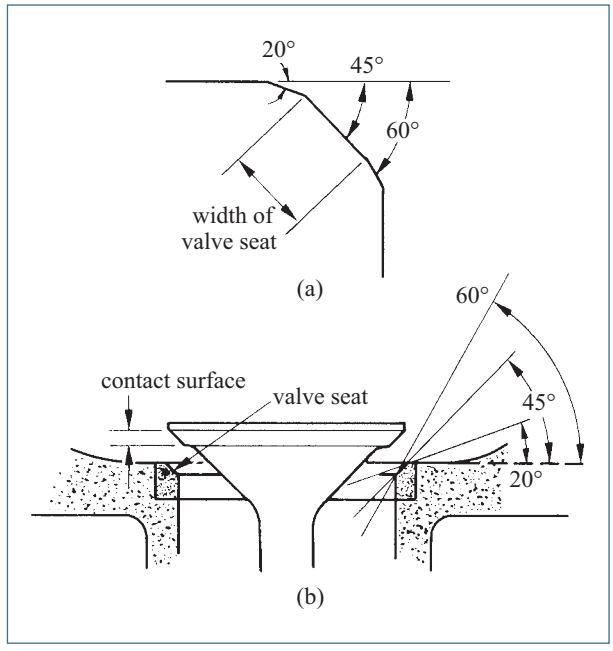


Figure 18.67 Angles used when grinding valve seats
(a) angles (b) sectional view

Figure 18.68 Dressing the valve-seat stone on the valve refacer to the exact angle of the valves

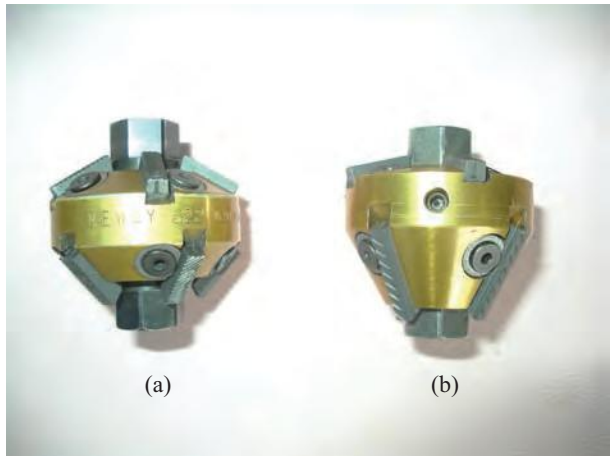


Figure 18.69 Valve-seat cutters (a) seat cutter (b) narrowing cutter

18.22.5 Synchro-seating valves

A process called synchro-seating can be used to produce valve seats with a fine finish and at exactly the same angle as the valve face. This refaces valves as per usual, and the seats in the cylinder head are rough-finished to the correct angle with a stone.

After rough-finishing the seats, the carrier with its stone and pilot is mounted in the valve refacer in the same way as a valve (Figure 18.68). The grinding wheel is then used with a very light feed to dress the stone. The stone will have a fine finish at exactly the same angle as the valves.

The seats are then given a finish grind with the finely dressed stone. This method matches the seat angle with the valve angle. The valves can be checked for correct sealing with bearing blue, but lapping is not usually required.

18.22.6 Valve-seat cutters

Figure 18.69 shows valve-seat cutters that are used to restore valve seats. These have a number of tungsten steel cutting blades. They can be used with a T-handle, or they can be power-driven. Figure 18.69(a) shows a seat cutter with blades at 30° and 45°. Figure 18.69(b) is a narrowing cutter with its blades at angles for top-narrowing and bottom-narrowing of seats.

The cutting head is fitted with two sets of blades, so either side can be used. The blades are mounted in slots in the cutting heads and retained by screws. They can be adjusted by altering their position in the slots and they are replaceable.

18.22.7 Using the cutting equipment

Select a cutter of the correct size for the valve seat and adjust the blades to suit the seat diameter.

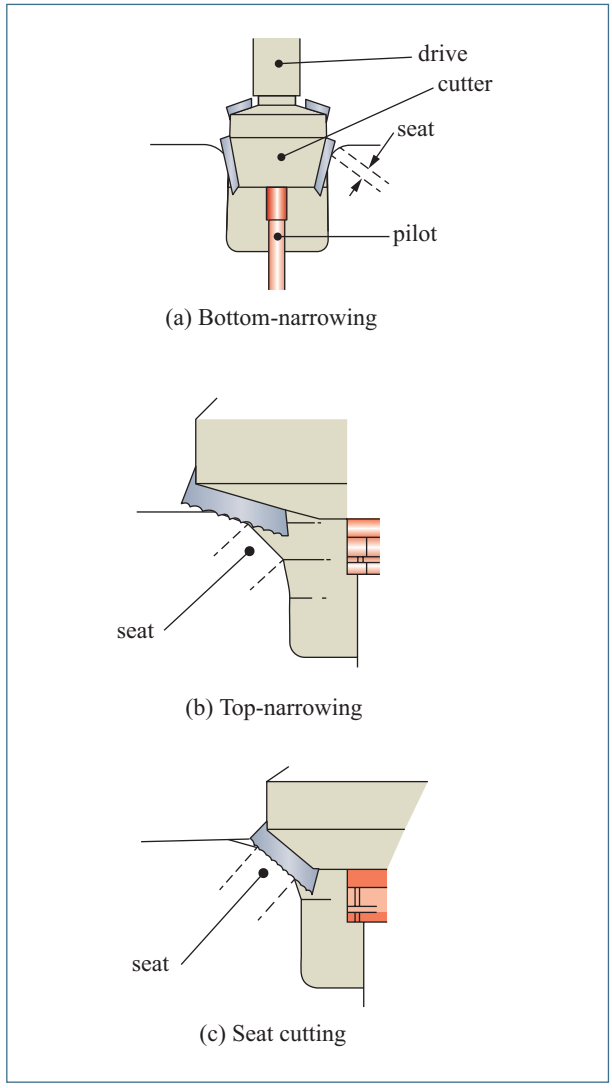


Figure 18.70 Method of using a cutter to recondition a valve seat

Fit the cutter to a carrier with a handle. Install a pilot of the same diameter as the valve stem in the valve guide and the carrier with its cutter is installed on the pilot.

To make a cut, turn the cutter clockwise while maintaining a light downward pressure. Make a finish cut of one or two turns without pressure.

Cutting a seat

The procedure for cutting a valve seat is shown in Figure 18.70 and is as follows:

1 Clean the seat with one or two turns of a seat cutter . Inspect it for pits and burns that will have a bearing on the amount of metal to be removed.
2 Take a bottom cut with a narrowing cutter—this raises the seat.
3 Take a top cut with a narrowing cutter until the seat width is slightly narrower than required—this lowers the seat.
4 Finish cut with the seat cutter , cutting lightly until the seat is the correct width.

18.23 Servicing valve guides

Valve guides can be checked for wear in a general way by using a new valve as a gauge. The valve stem should be a free-sliding fit in the guide without excessive free play. The stem-to-guide clearance is about 0.05 mm to 0.1 mm, with the exhaust valve usually having a slightly greater clearance than the intake valve.

To measure guide wear, the valve is held slightly clear of its seat by a spacing sleeve. A dial gauge is mounted on the cylinder head, with its plunger against the head of the valve (Figure 18.71). The valve can then be moved from side to side of the guide, to indicate the clearance on the dial gauge.

Alternatively, mount the dial gauge against the end of the valve stem, with the valve resting lightly on its seat.

Handy hint: In the methods described, the dial gauge indicates wear , but does not accurately measure clearance .

Valve guides wear eccentric, and also *bellmouth* (this is wear at the end of a hole that causes it to become bell shaped). A telescopic gauge and micrometer can be used to detect these types of wear.

18.23.1 Replacing valve guides

Most valve guides are replaceable, but they can also be cast integral with the cylinder head. Methods of service differ with each type.

With replaceable guides, the old guides are either pressed or driven out of the cylinder head (Figure 18.72). This is often done from the spring end of the guide because the valve-port end can become brittle and coated with carbon, making the guide hard to remove.

New guides should have an interference fit in the cylinder head of about 0.1 mm. They are driven or pressed into the head with a stepped punch. When installed, they should project from the top of the head the same distance as the original guides.

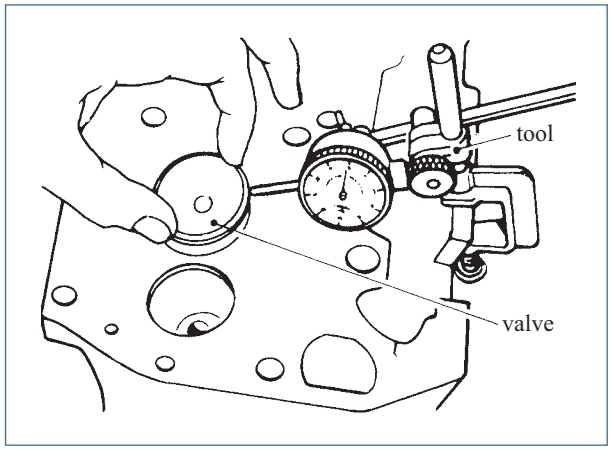


Figure 18.71 Dial indicator set up to measure valve-guide wear

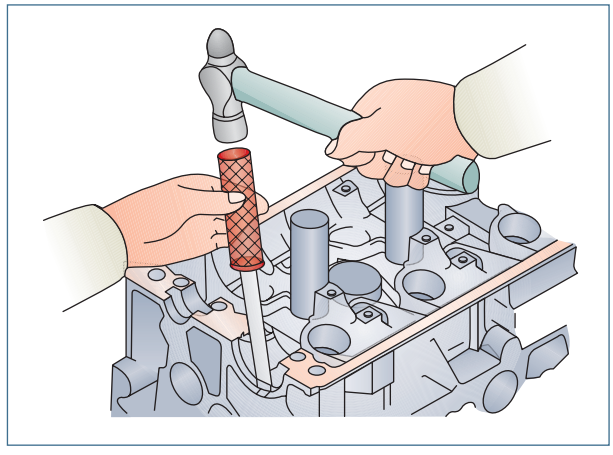


Figure 18.72 Using a punch to remove a valve guide

When fitting new guides, a guide can be installed in the correct position at each end of the cylinder head. A straightedge is then used between these two guides as a height gauge for the other guides. After fitting, a guide may have to be lightly reamed to provide a fit for the valve stem (Figure 18.73).

Integral valve guides are part of a cast-iron cylinder head and cannot be removed. However, worn guides of this type can be reamed oversize and new valves with oversize stems fitted.

Another method is to ream the guide oversize and fit thin wall guides. This has the advantage of using the existing valves.

Handy hint: Cast-iron cylinder heads can be worked on cold, but aluminium cylinder heads should be heated.

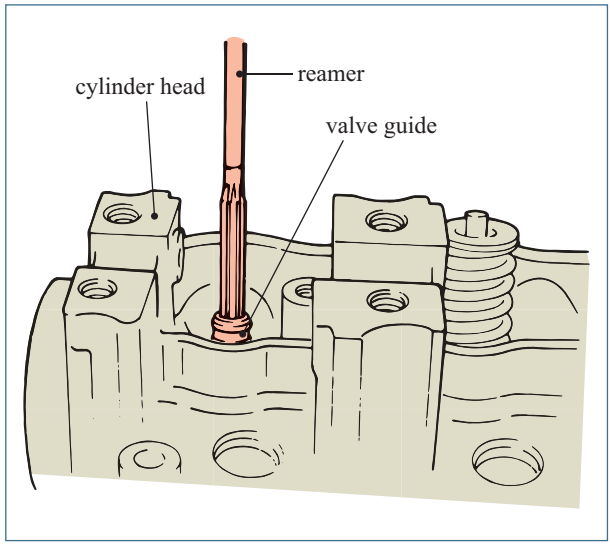


Figure 18.73 Reaming a valve guide to size GM HOLDEN LTD

Valve guides in aluminium heads

Valve guides are removed from an aluminium cylinder head after it has been heated. This can be done in an oven or in water, as shown in Figure 18.74. The head is heated to about 90°C. The guides can be removed once the cylinder head has reached a uniform temperature.

New valve guides must have the correct interference fit in their bores in the cylinder head. Before the new guides are fitted, the cylinder head should be reheated. A stepped punch or press tool is used to replace the guides.

Restoring valve guides

Valve guides can be restored by *knurling*. In this process, a tool with a small knurling wheel is used to form a spiral groove down the inside of the valve guide. The tool displaces metal on each side of the wheel as it works its way down the guide, reducing the guide's diameter.

After knurling, a reamer is used to ream the guide to fit the valve stem. When restored, the valve guide will have a spiral groove from top to bottom and the valve stem will have minimum clearance in its guide. A valve and reworked guide are shown in Figure 18.75.

18.24 Servicing valve seats

Valve-seat inserts can be used to replace damaged or worn valve seats in the cylinder head. In the case of an aluminium head, the old insert is removed and the insert recess machined to accept the new insert.

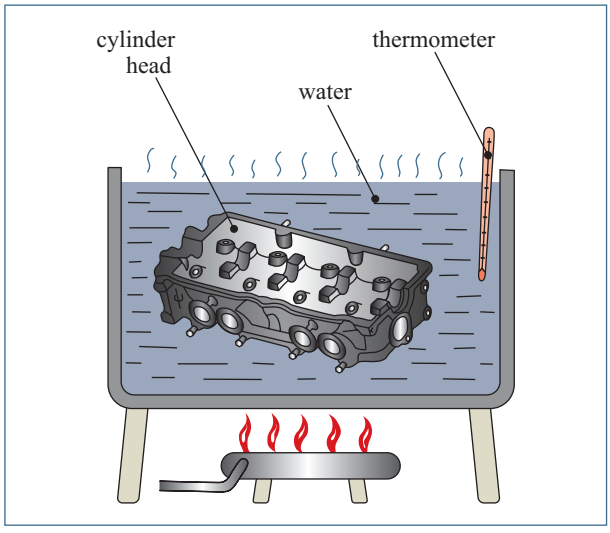


Figure 18.74 Heating an aluminium cylinder head before removing or replacing the valve guides

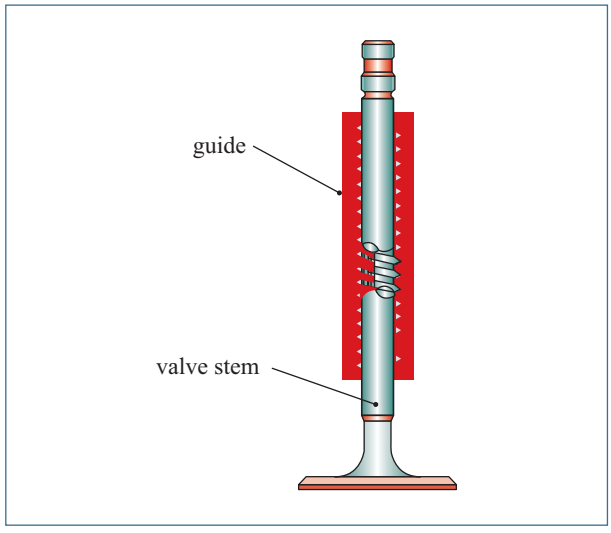


Figure 18.75 Valve guide restored by knurling

Figure 18.76 shows a new insert being fitted. The insert is frozen and the head heated in the same way as it was for the valve guides in Figure 18.74.

Handy hint: The new insert should be machined with a new seat surface with the correct angle and width.

18.24.1 Assembled valve height

When all service operations have been carried out on the valve and seat, the *assembled height* of the valve should be checked before final assembly. The assembled height is the distance the valve stem protrudes above the valve spring seat. Figure 18.77 shows the height being measured.

Handy hint: Shims are available to place under the valve spring to restore the height to within 0.25 mm of original, as shown in Figure 18.78.

18.25 Camshaft service

The procedure for camshaft removal varies considerably with different engines. In OHV engines, the camshaft is mounted in the crankcase and is accessible from the front of the engine after removing the timing cover and timing chain.

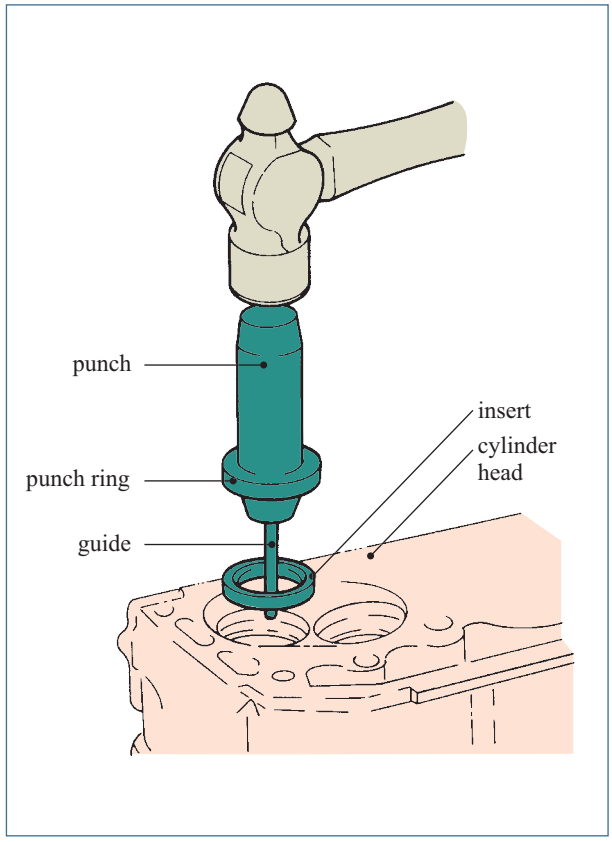


Figure 18.76 Punch being used to install an insert in a cylinder head FORD

The rocker-arm assembly and pushrods should also be removed. Valve lifters should be removed or raised to clear the cams before the camshaft can be withdrawn through the front of the engine.

With OHC engines, the camshaft is more readily accessible on top of the cylinder head. Before the camshaft can be removed, the timing pulley or sprocket and the timing belt or chain are removed from its front. There is also a valve-operating mechanism that might have to be removed from the cylinder head.

The camshaft bearing caps must be removed before the camshaft can be lifted from the lower half of its bearings. The bearing cap bolts should be released gradually and in a recommended sequence.

Figure 18.77 Checking the assembled valve height with a vernier

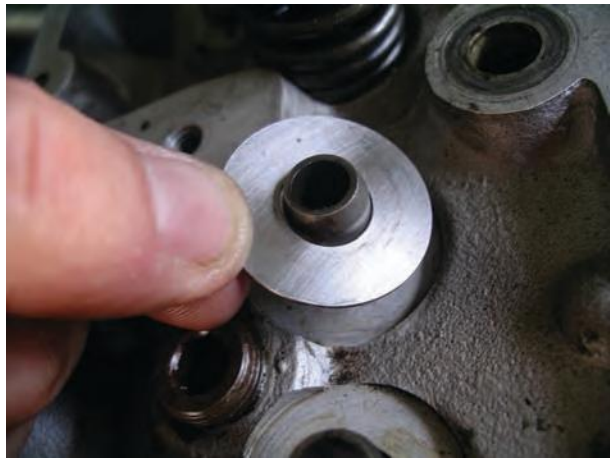


Figure 18.78 Placing a spacer shim on the valve spring seat

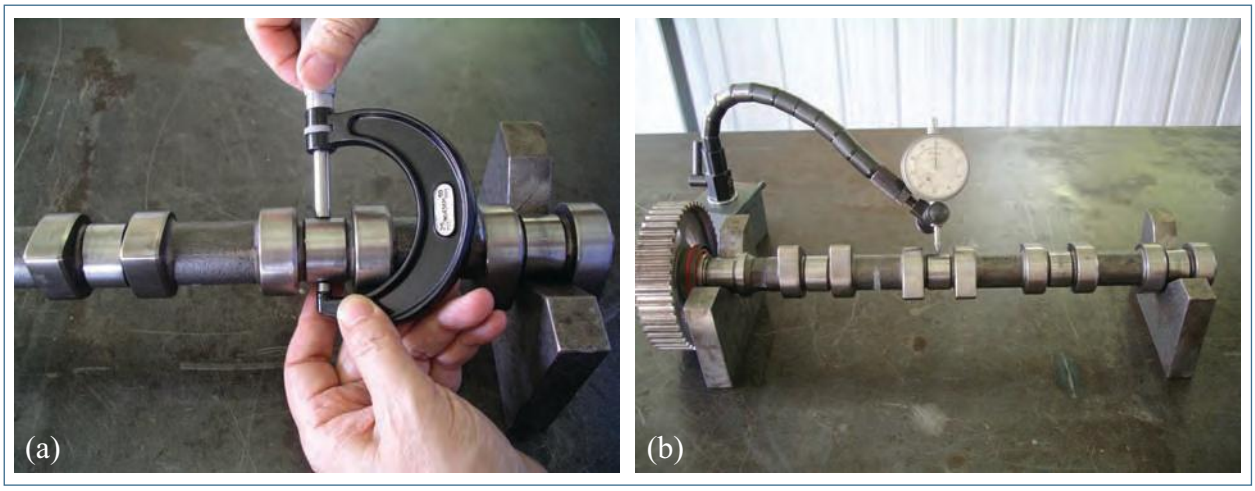


Figure 18.79 Checking a camshaft (a) a micrometer measuring a bearing journal (b) a dial gauge measuring eccentricity or run out

18.25.1 Checking a camshaft

A camshaft is checked for alignment by mounting it in V-blocks and using a dial gauge to check for eccentricity. Journal diameters should be checked with a micrometer, the bearings with a telescopic gauge. The two dimensions can then be compared to determine whether bearings are worn (Figure 18.79).

With the camshaft removed, cam wear can be checked either visually or by measurement with a micrometer. Figure 18.80 shows normal and abnormal wear patterns. If wear shows across the full width of the cam, and excessive wear of the cam lobe has taken place, a new camshaft should be installed. The valve lifter or other mechanism should also be checked.

18.25.2 Checking cam lift

Camshafts can also be checked in the engine. Figure 18.81 shows how this is done on an OHV engine.

With the rocker assembly removed and the dial gauge positioned as shown, the crankshaft is turned slowly until the valve lifter is on the base of its cam. The dial gauge is set to zero and the crankshaft rotated until the lifter is on the top of the lobe. The reading is the cam lift. This can be compared with the other cams and with the engine's specifications.

On OHC engines, the dial gauge can be mounted on the cylinder head so that its plunger is in direct contact with the cam, although rocker arms will have to be removed on some engines.

18.25.3 Camshaft bearings

Camshaft bearings of OHV engines can be removed from the engine block with a special bearing remover. This is a fairly major operation.

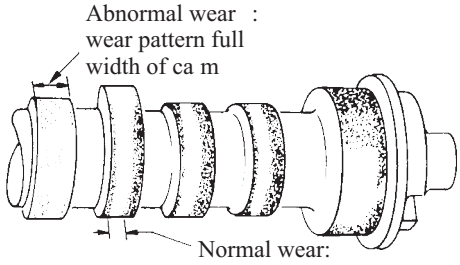


Figure 18.80 Examples of cam wear

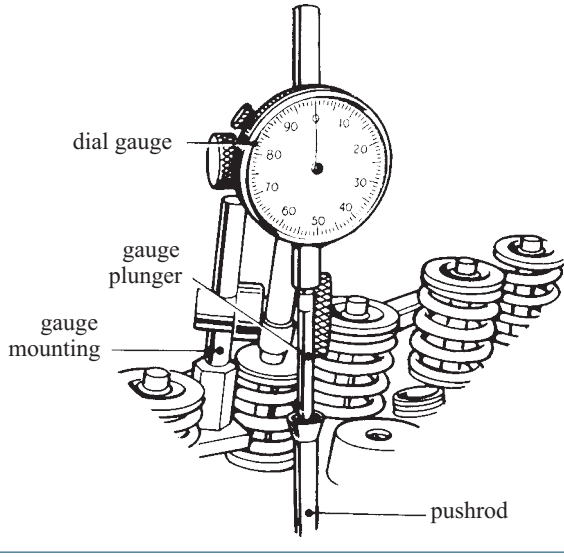


Figure 18.81 Checking a camshaft on an OHV engine by measuring cam lift

The remover is a threaded puller bar that is inserted through the bearings. Puller sleeves slightly smaller than the bearing outside diameter are installed on the bar behind the bearings. When the nut on the end of the puller bar is turned, the bearings are pulled from their bores in the crankcase. New bearings are installed via a similar method.

Camshaft bearings of OHC engines can be checked for clearance with Plastigage, but they are not usually replaceable.

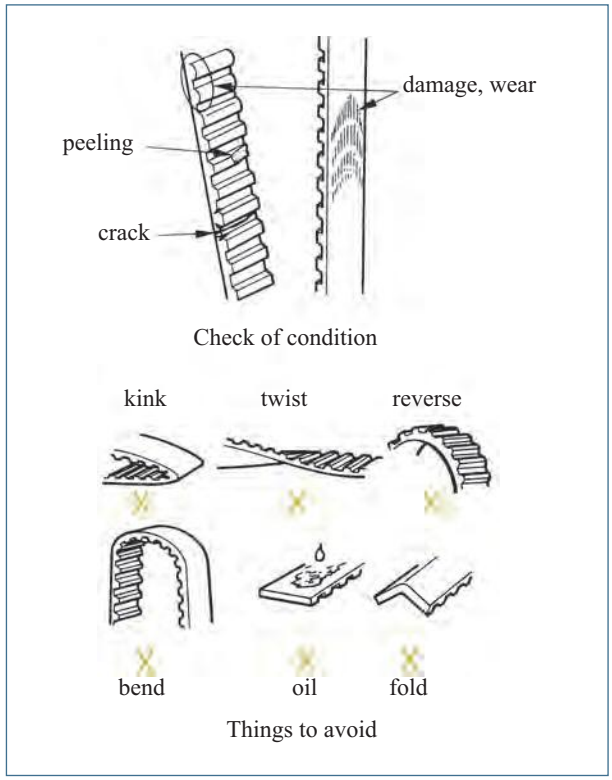


Figure 18.82 Timing belt checks FORD

18.25.4 Timing gears, chains and sprockets

Gear and sprocket runout can be checked by mounting a dial gauge on the cylinder block or head, with the plunger resting on the side of the gear or sprocket.

Backlash between gears is measured by a dial gauge, or by inserting narrow feeler gauges between the meshing teeth. Excessive runout or backlash will require replacement of one or more gears.

Timing chains can be checked for tension and wear. Excessive slack, which cannot be corrected by adjustment, indicates a worn chain and possibly worn sprockets. Worn parts should be renewed.

18.25.5 Timing belt and pulleys

Timing belts should be checked for tension and adjustment. They should also be checked for condition, as shown in Figure 18.82.

Handy hint: If a timing belt is being removed and is to be reused, an arrow should be chalked on the back of the belt to show the direction in which it runs. When reinstalled, the belt must run in the same direction.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe cylinder head construction and design
- identify the three combustion chamber designs: hemispherical, bathtub and wedge
- state diesel cylinder head variances
- state the number of engine valves per cylinder and seats, guides, springs, valve-stem seals and construction
- describe valve trains arrangement and components of OHV engines, including the camshaft, valve lifter, pushrod and rocker arm
- describe the seven hydraulic valve lifters operation for OHV engines
- identify three general locations for hydraulic lash adjusters in OHC engines
- describe the three camshaft arrangements: single overhead camshaft (SOHC), double overhead camshaft (DOHC) and overhead-valve (OHV) camshaft
- the functions of timing gears, timing chains, timing belts, tensioners and dampers
- explain valve timing and its relationship to the four-stroke cycle
- explain valve-timing terms such as lead, lag, TDC and BDC

- demonstrate the correct procedures for removing and reinstalling an engine cylinder head and components.
- demonstrate correct dismantling procedures of the engine cylinder valve mechanism
- demonstrate how to remove, dismantle, clean and check the cylinder head and components
- identify valve-clearance types and describe how to carry out adjustments
- explain valve and spring serviceability checks
- demonstrate the correct procedure for checking and servicing rocker-arm assemblies, hydraulic lifters and lash adjusters
- describe how to carry out valve-seat reconditioning procedures such as valve-seat grinding, lapping valves, synchro-seating valves and replacing valve guides
- demonstrate the correct procedures for checking and servicing camshafts, timing gears, chains, sprockets, timing belts and pulleys.

REVIEW QUESTIONS

1 What are overhead valves?
2 How are overhead camshafts driven?
3 Name the parts of an overhead valve train and an overhead-camshaft valve train.
4 Name the parts of an engine valve.
5 What is likely to be the hottest part of an exhaust valve? Explain why.
6 Why is tappet clearance provided on some engines?
7 What are bucket-type tappets?
8 Why is valve rotation provided on some engines?
9 What are valve inserts and why are they fitted?
10 Indicate some of the ways in which overhead camshafts are driven.
11 What is a hydraulic valve lifter?
12 What are hydraulic lash adjusters?
13 Where are hydraulic lash adjusters likely to be found?
14 Why are timing-belt tensioners used?
15 What is the purpose of idler pulleys?
16 What is variable valve timing and how is this different to normal valve timing?
17 What are valve lead and valve lag?
18 What is valve overlap?
19 After removing a cylinder head, what form of inspection should be carried out?
20 How is a cylinder head checked for flatness?
21 How are valves removed from a cylinder head?
22 How are valve springs checked?
23 How is a valve checked for serviceability?
24 How can valve-guide wear be checked?
25 How can valve guides be restored?
26 How are valve seats reconditioned?
27 What precautions would be taken when installing a cylinder-head gasket?
28 Explain how a cylinder head would be tightened when it is being installed.
29 Explain the sequence that is used to check the valve clearance of a four-cylinder engine.
30 How are hydraulic valve lifters tested?
31 What checks can be made on a camshaft?
32 When would a timing belt be discarded?

CHAPTER 19

Cylinder -block repair and overhaul

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 state the function of cylinder-block components, and their repair and overhaul requirements in the automotive industry
2 observe relevant safety procedures and requirements
3 identify types of cylinder blocks, ways of working with them and the relevant terminology used in the automotive industry
4 inspect cylinder blocks, and accurately document and analyse inspection results
5 repair and overhaul a range of cylinder blocks and their components in accordance with workplace and manufacturer requirements and specifications.

The cylinder block is the largest part of the engine , and is the base upon which many other parts are assembled or attached. Its upper part carries the cylinders and pistons, its lower part forming the crank case which supports the crankshaft. The cylinder block must be rigid to withstand stresses and vibration, and must be unaffected by temperatures reached when the engine is in operation.

19.1 Cylinder blocks

Cylinder blocks are made of cast iron or aluminium alloyed with other materials. Cast-iron cylinder blocks are cast from grey iron alloyed with metals such as nickel or chromium.

During manufacture, patterns in the shape of the cylinder block are used to form a sand mould. Molten cast iron is poured into the mould, where it cools to become a rough casting of a cylinder block. Before casting, the shapes of water-jackets, cylinders and some other parts are made up as *sand cores*. These are fitted into the moulds so that they do not become solid cast iron during the casting process.

After casting, the sand is removed through holes in the sides and ends of the block. This leaves internal spaces for the water-jackets and other parts. During manufacture, the casting undergoes machining operations that include boring and finishing the cylinders, machining surfaces, drilling holes and cutting threads to produce the finished cylinder block, as shown in Figure 19.1.

⚠ Safety: When carrying out machining operations, wear appropriate personal protective equipment such as safety glasses and a hair net. Ensure that engine machinery is operated correctly .

19.1.1 Cylinder-block assembly

Figure 19.2 shows the components of a basic cylinder-block assembly, which, with the crankshaft, connecting rods and pistons, is sometimes called a *short motor*. A short motor does not include the cylinder head, the oil pan, the timing pulleys, the timing belt or the flywheel.

The lower section of the engine block forms the *crankcase,* and the part of the crankcase that extends below the main bearings is called the *skirt.* In some engines, the skirt goes well below the centreline of the crankshaft and is called a *full skirt.* A full skirt gives the engine rigidity. Other engines have a very short skirt (or none at all), and rigidity is obtained in other ways.

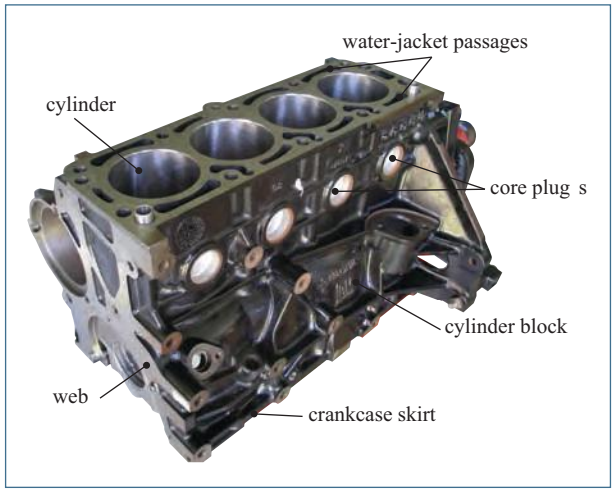


Figure 19.1 Bare cylinder block with its parts identified

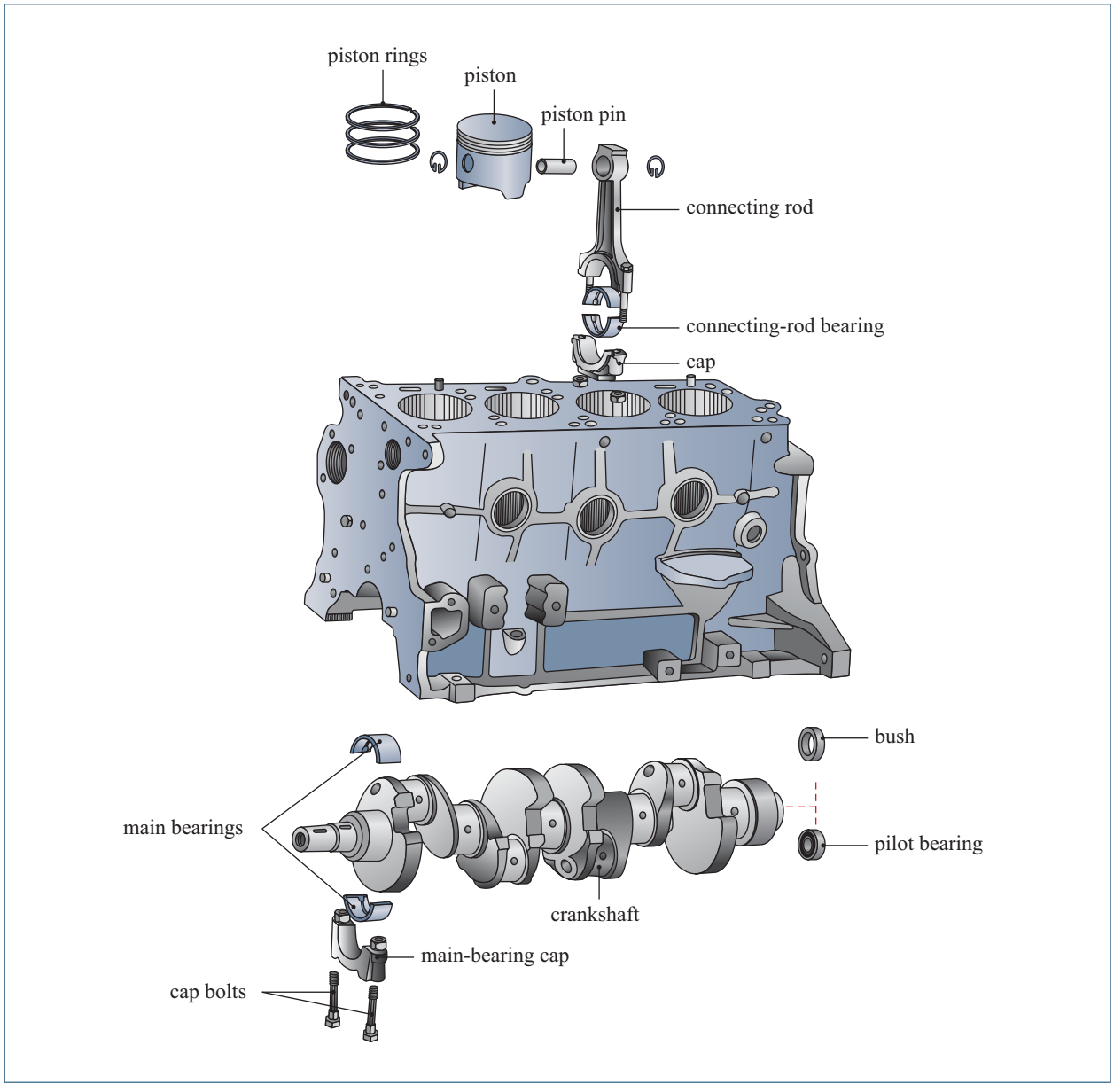


Figure 19.2 Basic cylinder-block assembly for a four-cylinder engine

19.1.2 Cylinder-block construction

In most engines, the cylinders, cylinder block and crankcase are cast together. This is known as *monoblock* construction, as distinct from engines that have their cylinders as separate parts, as in air-cooled engines.

Monoblock engines with cast-iron blocks have the cylinders bored directly in the cast-iron casting. Cast iron is suitable for cylinders as it wears well and resists the effects of heat. Cylinder walls can be plated with chromium, which is very resistant to wear, although this is not common for passenger-car engines.

Aluminium cylinder blocks

Casting cylinder blocks in aluminium alloy is preferable to doing so in cast iron, as it is lighter. However, aluminium alloy is not suitable for cylinders on its own, as it wears rapidly under the action of the pistons and piston rings. For this reason, liners of cast-iron sleeves that are either cast or pressed into the block are used. These have grooves on the outside that form a key between the liner and the block, preventing any possible movement. (The cylinder block in Figure 19.5 is of cast aluminium alloy with cast-iron liners.)

Handy hint: The terms cylinder liner and cylinder sleeve are generally interchangeable.

Aluminium cylinder blocks without liners

Aluminium cylinder blocks can be designed without liners, but special alloys are needed. Figure 19.3 shows a V-8 cylinder block that has no cylinder liners. The cylinders' aluminium alloy has been specially treated to expose hard silicon crystals, providing a low-wearing surface for the pistons and piston rings.

Aluminium alloy reduces the weight of the engine, and has the advantage of being better at transferring heat than cast iron. The aluminium of the block has a similar expansion rate to the pistons.

Cylinder blocks for horizontally opposed engines

The arrangement of the cylinders for a horizontally opposed engine (also called a boxer engine) is shown in Figure 19.4. This has a split crankcase—two cylinder blocks are joined by the crankcase flanges. The cylinder blocks are of aluminium alloy, with cylinder liners of cast iron cast into the aluminium block during manufacture.

Handy hint: As with all cylinder blocks, the aluminium-alloy castings are made with ribs, webs and fillets for rigidity.

Two-part cylinder blocks

The cylinder block for the four-cylinder inline engine in Figure 19.5 is in two aluminium parts—the cylinder block and the base plate. The cylinders have dry liners pressed into the block. They are not replaceable.

The main-bearing caps are combined with the base plate which has webs carrying the lower halves of the crankshaft main bearings. The cylinder block and the base plate are matched during manufacture and cannot be replaced separately.

Handy hint: With this design, there are no individual caps for the main bearings.

The methods used to make aluminium castings enable the production of detailed components. For example, in the cylinder block shown, the oil filter housing is cast as part of the cylinder block and the base plate has the mounting for the starter.

As well as the two parts of the cylinder block, there is a cast aluminium oil pan bolted to the underside of the base plate, further increasing the assembly's rigidity.

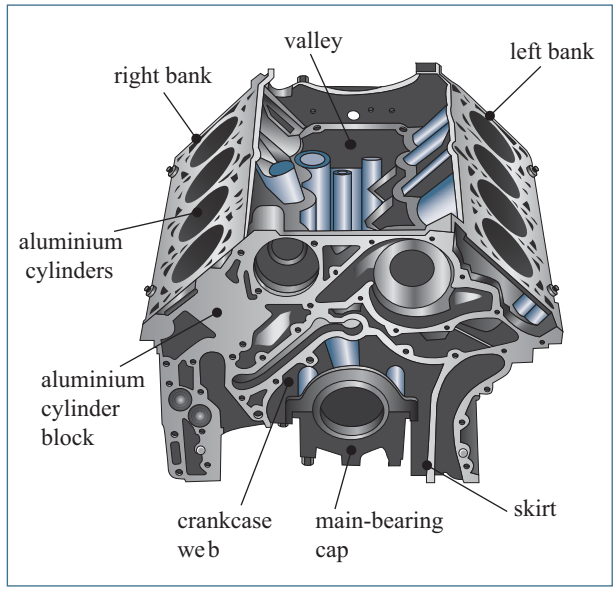


Figure 19.3 An aluminium-alloy cylinder block for a V-8 engine—it has specially treated aluminium bores

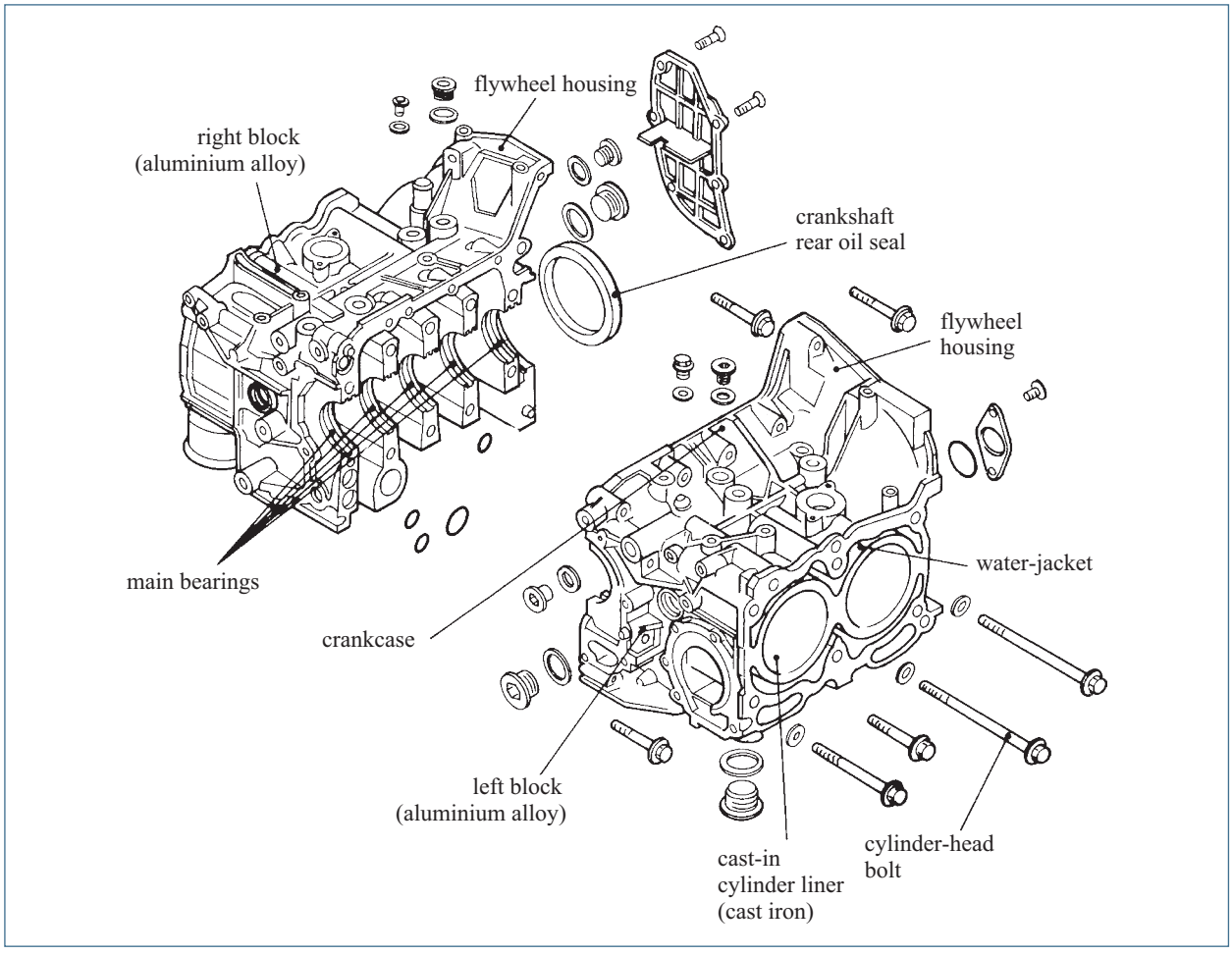


Figure 19.4 Cylinder-block arrangement for a horizontally opposed engine—the cylinder blocks are of aluminium alloy with cast-iron cylinder liners SUBARU

19.2 Cylinder sleeves

Cylinder blocks can be designed with cylinder sleeves (or liners) which are fitted to cast-iron blocks. They are different to the liners that are cast into aluminium-alloy cylinder blocks.

With cast-iron blocks, the sleeves are cast separately and then fitted into place when the engine is being assembled. Separate sleeves allow more control over the manufacturing process and a grade of iron that is different from the block can be used. The cast iron for the block can be of a grade which is easy to cast, while the sleeve is made more resistant to wear.

There are three types of cylinder sleeves: *dry sleeves, flanged dry sleeves* and *wet sleeves* (Figure 19.6).

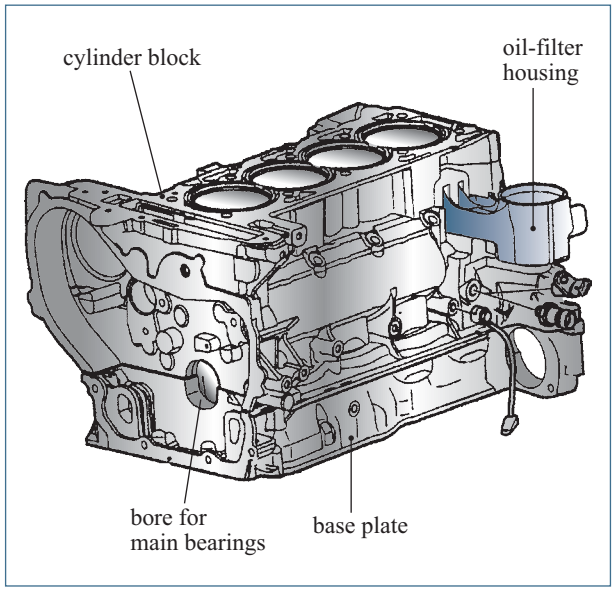


Figure 19.5 Two-part aluminium cylinder block with pressed-in cylinder liners GM HOLDEN LTD

19.2.1 Dry sleeves

A thin dry sleeve is of uniform diameter throughout its length and is a press fit in its bore in the cylinder block. The wall of the sleeve is about 2 mm thick, and its outer surface is in contact with the block for its full

length. The top of the sleeve is finished flush with the top of the cylinder block and is hardly visible. This type of sleeve is sometimes fitted to new engines, and is used to recondition badly worn or damaged cylinders that cannot be rebored without removing excess metal.

19.2.2 Flanged dry sleeves

Flanged dry sleeves are sometimes used on larger engines. These are similar to a normal dry sleeve, except for having a flange at the top which fits into a recess in the surface of the cylinder block. The sleeve is not a tight fit and can be replaced when worn. The cylinder head holds the flange down and prevents the sleeve from moving.

The bore in the block must be true because the accuracy of the sleeve depends on its contact with the block. This also has a bearing on heat transfer from the cylinder.

Handy hint: This type of sleeve is not generally used for passenger or light commercial vehicles.

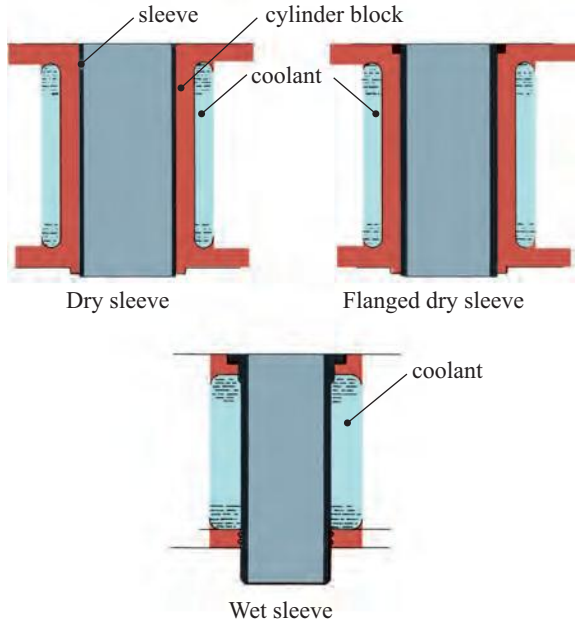


Figure 19.6 Arrangement of sleeves in cylinder blocks

19.2.3 Wet sleeves

The outer surface of a wet sleeve forms part of the water-jacket around the cylinder. It is called a *wet sleeve* because it has coolant against its outer surface. This eliminates problems of heat transfer between the sleeve and the coolant in the water-jackets. However, the sleeve must be sealed to prevent coolant leaks. Seals are used at the top to prevent coolant from entering the combustion chamber and at the bottom to prevent coolant from entering the crankcase.

Figure 19.7 shows a cylinder block and wet sleeve. The block does not have full-length bores, but has mounting holes at the top and bottom. Wet sleeves have thicker walls than dry sleeves. They do not have the same support in the block and they depend on their wall thickness to prevent distortion.

The top of the sleeve has a flange which fits into a recess in the block. Some sleeves have a sealing ring under the flange as well as the cylinder-head gasket. The lower end has one or two neoprene sealing rings.

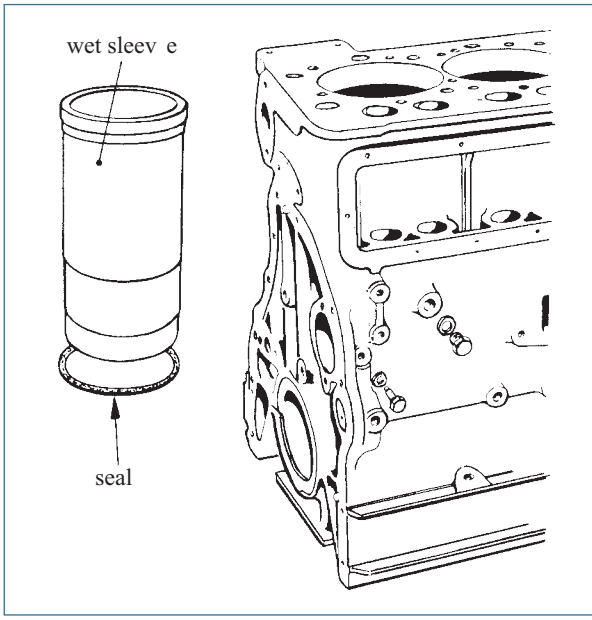


Figure 19.7 Cylinder block for wet sleeves with one sleeve shown

Engines with wet sleeves can be reconditioned by fitting new sleeves and pistons which are supplied ready to install.

Handy hint: Wet sleeves are commonly used in larger diesel engines.

19.3 Cylinder-surface finish

The surface of the cylinder consists of fine scratches in a crosshatch pattern (Figure 19.8). Cylinder walls must be smooth enough to enable the piston rings to seal and for the pistons to operate without friction. At the same time, they must have a surface that can retain a film of oil.

If the surface of the cylinder (the cylinder wall) is too smooth, oil will be wiped from the cylinder by the piston rings. Oil can also be 'pumped' upwards by the pistons and rings into the combustion chamber, where it will burn. This will produce smoke and carbon.

The ideal finish for a cylinder is a series of plateaus, or very small flat surfaces between the fine grooves that are left after honing. These grooves retain oil.

A surface with sharp peaks and grooves will also retain oil, but the peaks will have to wear away to allow the piston rings to 'bed in' before a satisfactory working surface is obtained. During this time, there could be some blow-by and the engine could use oil.

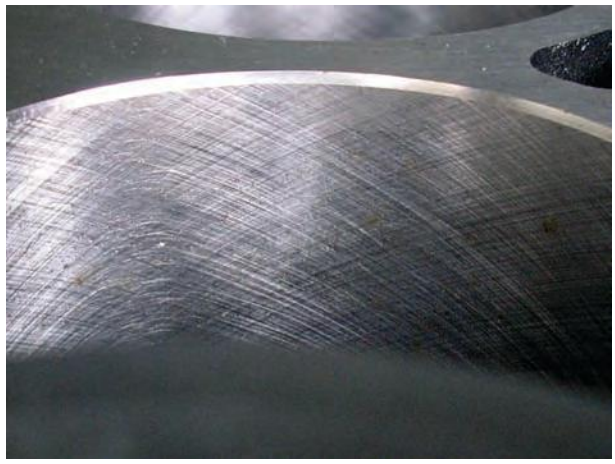


Figure 19.8 Cylinder walls are finished with a crosshatch pattern

Handy hint: The term blow-by refers to combustion gases that escape past the piston rings.

19.4 Cylinder wear

Figure 19.9 gives an exaggerated illustration of how an engine cylinder wears. Most wear occurs at the top of the cylinder, making it tapered. The maximum wear is at the top, just below the ring ridge. This is where combustion pressure and temperature are greatest. As the piston moves down the cylinder on the power stroke, the pressure and temperature both decrease so that less wear takes place.

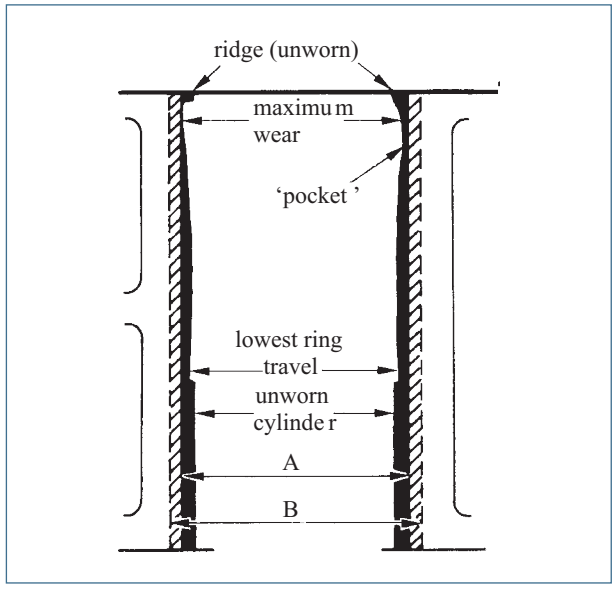


Figure 19.9 Wear of engine cylinder (exaggerated) A rebored cylinder diameter, B cylinder bored to fit a dry sleeve

The cylinder also tends to wear oval-shaped, due to piston side-thrust as it moves down the cylinder on the power stroke. The side thrust is caused by the angle of the connecting rod (see Figure 19.32).

Worn cylinders can be reconditioned to a certain extent by honing, but badly worn cylinders have to be *rebored*. The worn cylinder shown could be bored oversize to the diameter A, or bored out to diameter B and a dry sleeve fitted.

Handy hint: The ring ridges at the top and bottom of the cylinder are caused by the limits of the piston-ring travel.

19.5 Crankshafts

Figure 19.10 shows a basic crankshaft with its parts named. It is for a four-cylinder engine, and has four cranks. Each crank, also called a throw, consists of a crank web and a journal (crankpin) with a finely finished surface for the connecting-rod bearing. This crankshaft is supported in the crankcase by three main bearings and so is referred to as a *three-bearing* crankshaft.

Figure 19.11 shows the type of crankshaft normally used. This is a five-bearing crankshaft, with a main bearing located between each crank. It also has balance weights. The extra main bearings reduce shaft distortion, and the balance weights reduce vibration.

Crankshafts are a one-piece casting or forging of heat-treated alloy steel with high mechanical strength. The crankshaft must be strong enough to take the downward thrusts of the pistons during the power strokes without distortion, as well as being well balanced to offset the effects of the cranks.

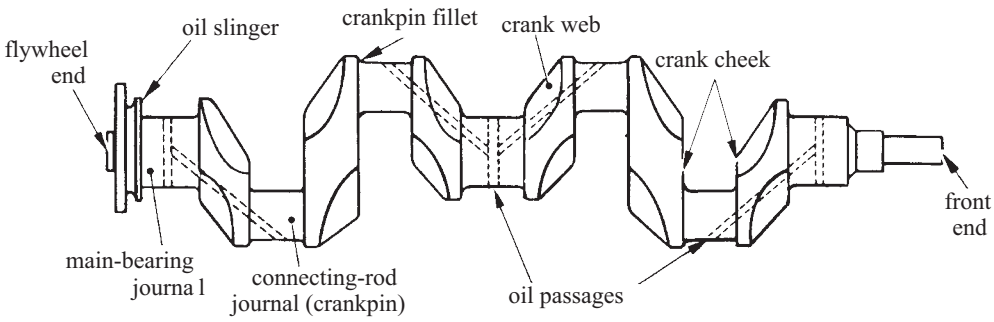


Figure 19.10 Basic crankshaft with various parts named

19.5.1 Balance weights

In automotive engines, which operate at high speeds, centrifugal force is produced by the rotating crankpins. In a four-cylinder crankshaft, balance weights are placed on the crankshaft opposite the crankpins. Centrifugal force also acts on the balance weights, but in an opposite direction to that on the crankpins. The forces tend to cancel out, reducing vibration.

A four-cylinder inline engine operating at low speeds would need very little balance, because No. 1 cylinder is balanced by No. 2 cylinder, and No. 3 is balanced by No. 4. However, for a shaft operating at high speeds, separate balance weights are used for each crankpin. This contains the forces within the parts of the crankshaft in which they are produced.

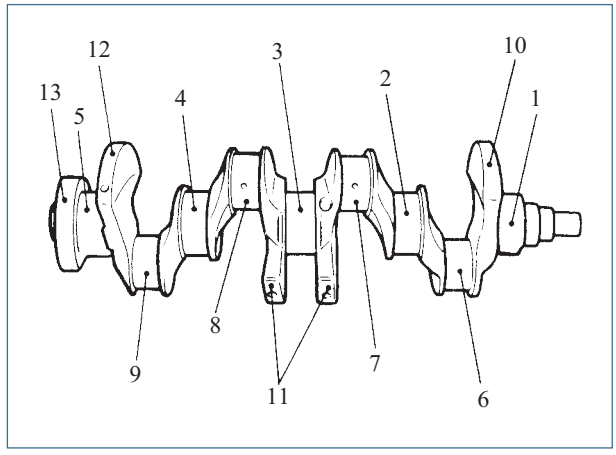


Figure 19.11 Crankshaft for a four-cylinder engine
1–5 main-bearing journals, 6–9 crankpin journals, 10–12 balance weights, 13 mounting flange for flywheel or drive plate

19.5.2 Crankshaft designs

The crankshafts of six-cylinder engines require more complex balance weights (V-type engines have these arranged differently again). Figure 19.12(a) shows a crankshaft for a V-6 engine, with its cylinders arranged at an angle of 90°. Also shown are its camshaft and balance shaft.

Many V-type engines have the connecting rods of opposite cylinders connected side-by-side to a common journal but, in this engine, each connecting rod has its own journal. The crankpin journals for opposite cylinders are on the same throw of the crankshaft, but are offset at an angle of 30° to each other (Figure 19.12(b)) so that the firing order of the cylinders can be evenly spaced at each 120° of crankshaft rotation.

Some crankshafts are solid, but others have hollow crankpins. This reduces their mass and thus the effects of centrifugal force, aiding shaft balance.

Handy hint: Hollow crankpins do not affect the strength of the shaft because , mass for mass, a hollow shaft has greater strength than a solid one .

As well as balancing for the rotating crankpin, design must also consider the portion of the connecting rod that is connected to the crankpin. While the connecting rod has a complex movement, about two-thirds of its mass can be considered to be rotating with the crankpin.

Journal overlap

A rigid crankshaft that will resist twisting and bending needs large journal diameters and thick webs, two requirements combined in a design feature called *journal overlap*. With this, the crankpins overlap the main

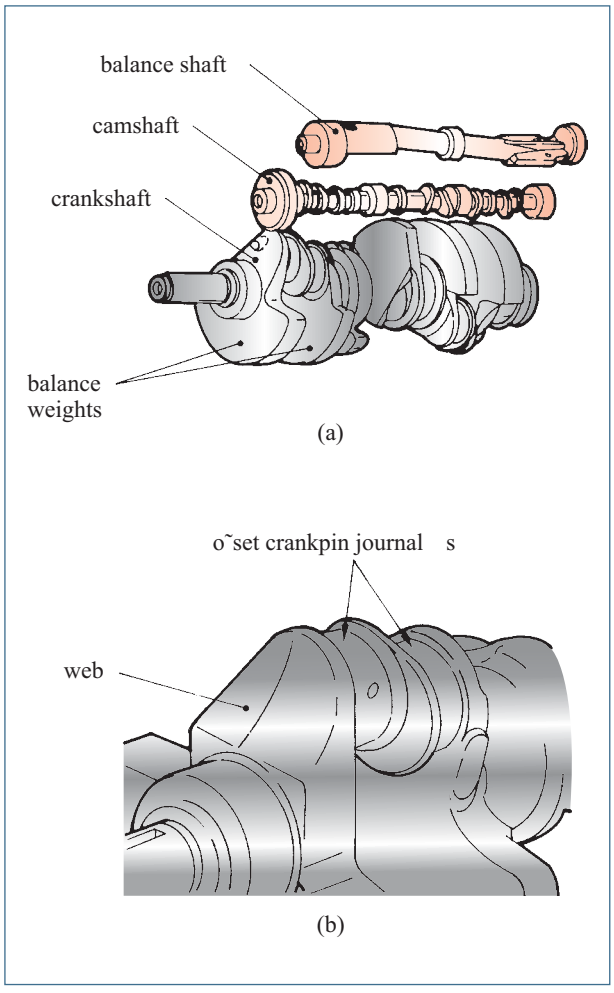


Figure 19.12 Shafts of a V-6 engine (a) crankshaft, camshaft and balance shaft (b) crankshaft has offset crankpin journals GM HOLDEN LTD

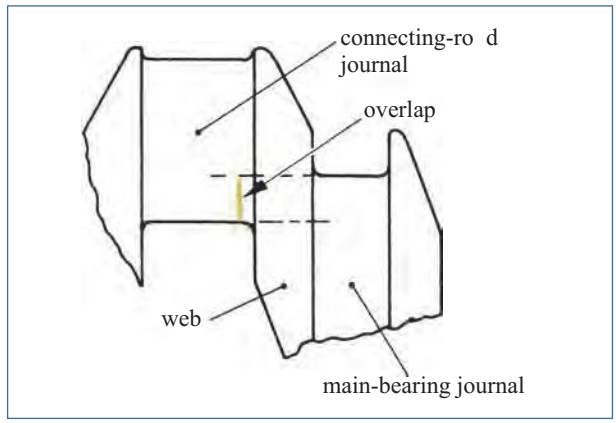


Figure 19.13 Crankshaft journal overlap

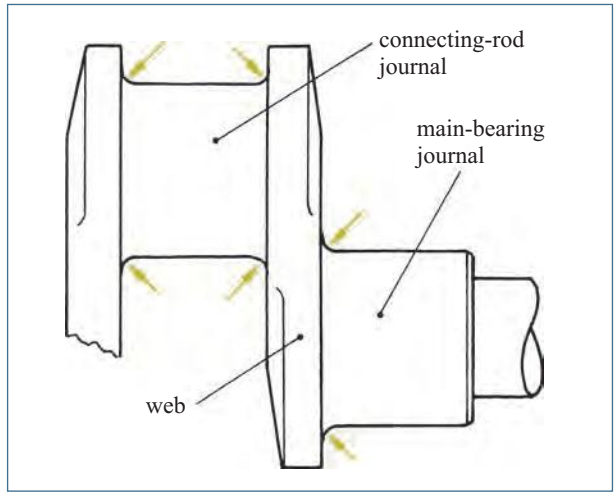


Figure 19.14 A radius or fillet is formed between the crankshaft journals and webs, as shown by the arrows

journals as shown in Figure 19.13. This makes the crankshaft more rigid. If necessary, the web thickness can be decreased to reduce the overall length of the shaft while maintaining rigidity. Compare Figure 19.13 with Figure 19.14, which has no overlap.

Crankshaft fillets

A radius, or fillet, is formed between the edges of the journal and the webs of the crankshaft. Fillets are important: they provide a gradual change in the section's thickness (Figure 19.14).

With no fillet, this section of the crankshaft will be subjected to a *stress rise,* meaning that it will carry a greater load (and greater stress) than the section next to it. Stress could cause fatigue and a crack could occur.

Handy hint: A crankshaft that is badly ground during reconditioning could fail because of badly shaped fillets.

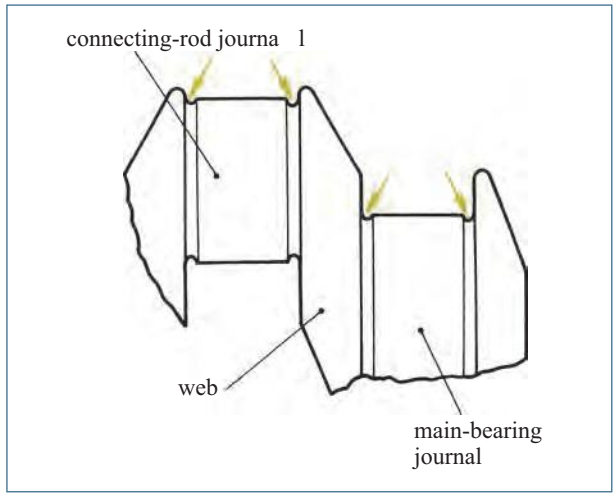


Figure 19.15 Crankshaft with rolled fillets as shown by arrows

Figure 19.15 shows a journal with rolled fillets. These reduce local stress points between the journals and the webs. The crankshaft also has journal overlap, so it is not subjected to the stress rise of a crankshaft without overlap.

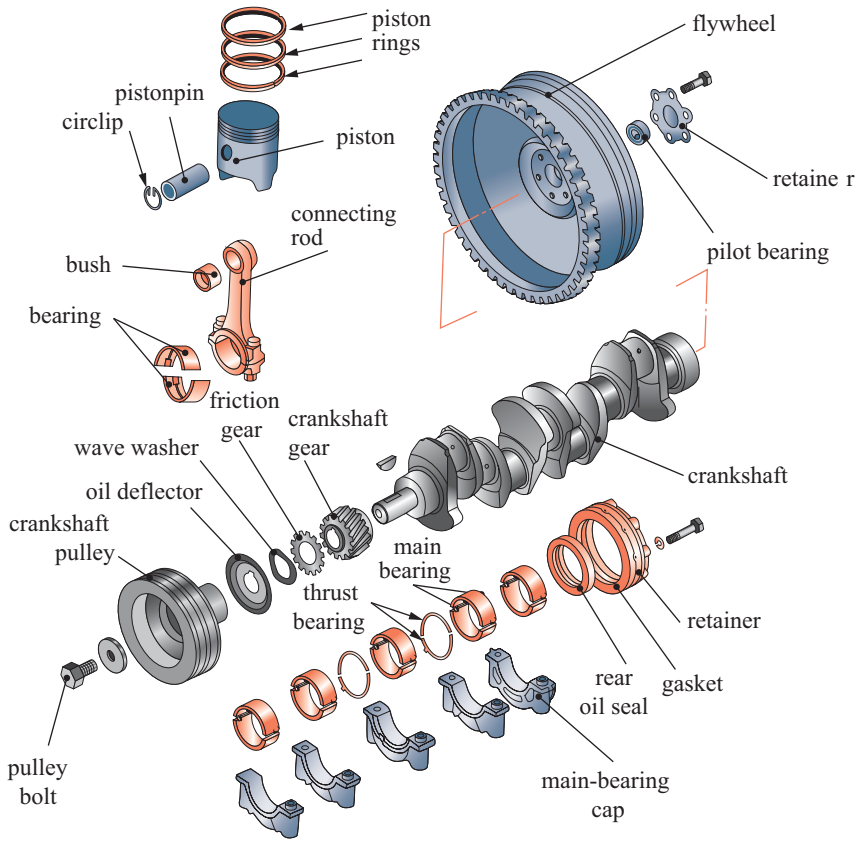


Figure 19.16 Crankshaft for a four-cylinder diesel engine and its associated parts

19.6 Crankshaft bearings

Figure 19.16 shows a crankshaft and its related parts, including the crankshaft bearings. There are two sets of these: the *main bearings,* which support the crankshaft in the crankcase, and the *connecting-rod bearings,* located between the connecting rod and the crankpin journal.

The crankshaft main bearings and the connecting-rod bearings are of the split-sleeve type, which means that they are in two halves. They cannot be used on their own and must be inserted into a housing of some kind that has been accurately machined to suit them.

With main bearings, the upper half of the bearing fits into a machined section of a crankcase web, and the lower half is carried in the bearing cap, which bolts onto the crankcase web (Figure 19.17).

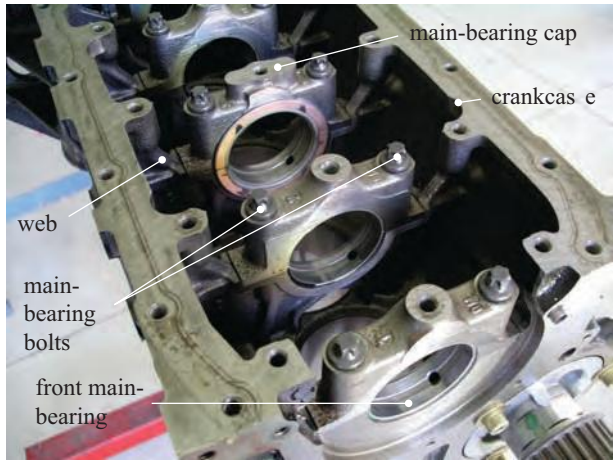


Figure 19.17 Crank case (underside) and crankshaft main bearings

The upper half of connecting-rod bearings is carried in the big end of the connecting rod, and their lower half in the connecting-rod cap.

One of the main bearings has thrust faces to accept end movement of the crankshaft. These are either built into the bearings or provided as separate segments. They are faced with bearing material and located at each side of one of the main bearings.

19.6.1 Precision-insert bearings

The precision inserts used for crankshaft bearings consist of a steel back to which a thin layer of bearing material is bonded. In some bearings, more than one layer of bearing material is used. Replacement bearings are accurately finished to size and are installed directly into their housings without any fitting or adjustment.

Figure 19.18 shows a bearing insert with parts identified. An oil hole is located in the centre of the bearing. For a main bearing, the oil hole lines up with an oil drilling in the crankcase web, and for a connecting-rod bearing, the oil hole lines up with a hole in the crankpin journal.

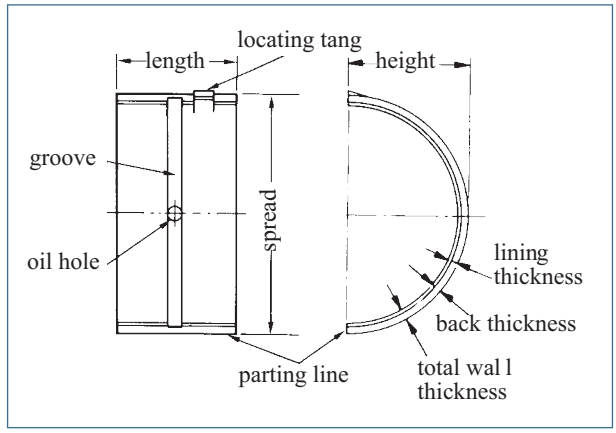


Figure 19.18 Bearing insert with parts identified

Some main bearings have an annular oil groove as shown, while others are plain. The bearing insert is correctly positioned by a locating tang that fits into a slot in the bearing housing or cap.

Handy hint: Crankshaft and connecting rod bearings are usually referred to as inserts, but they are also called slippers or shells.

19.6.2 Bearing requirements

Apart from reducing friction and wear, crankshaft bearings have a number of different requirements:

1. Load-carrying capacity. The bearing must be large enough to carry the loads imposed on it. It must also be made of a suitable material to sustain the loads under various conditions of engine operation. The bearing material must be hard enough to resist wear but soft enough to avoid damaging or wearing the shaft on which it operates. A very hard bearing could seize on its shaft if heavily loaded.
2. Fatigue resistance. Crankshaft bearings are subjected to varying loads and are repeatedly stressed. The bearing material must be able to resist this without fatigue failure, which occurs when a piece of metal is repeatedly stressed, causing it to flex or bend. This hardens the metal, which ultimately breaks.
3. Embeddability. This refers to a bearing's ability to permit small foreign particles to become embedded in it as a form of self-protection. Precision-insert bearings, with their thin layers of alloy material, have very little embeddability and depend on good filtration and a flow of oil to flush away any dust particles that might reach them.
4. Conformability. This refers to a bearing's ability to conform to small variations in shaft alignment and journal shape. If a bearing material has high conformability, it will cold-flow slightly to relieve heavy loads on local areas. Conformability is very limited for precision-insert bearings.
5. Corrosion resistance. Bearing materials must be resistant to corrosion as some of the by-products of combustion can form corrosive substances. These could affect the bearing material. This is one of the reasons crank cases have positive ventilation, where air circulation removes corrosive gases.

19.6.3 Bearing materials

Insert bearings have a steel back and are lined with alloys that include copper, lead, tin, aluminium, antimony and cadmium in many combinations. These alloys generally have limited *conformability* and *embeddability,* and depend on finely ground journals and a good flow of oil to wash away any foreign particles that might reach the bearing.

Engine bearings are overlay-type bearings. A typical bearing of this type has a thin, flexible steel back, with a 0.05 mm layer of alloy and another layer of 0.02 mm of softer material. Some bearings have an extra overlay of thin plating.

19.6.4 Bearing clearances

A working clearance is provided between the bearing and the crankshaft journal (Figure 19.19). This varies with the type of bearing material, but 0.02 mm to 0.08 mm is typical.

Too little clearance will not allow adequate lubrication and will cause rapid wear, bearing failure and shaft damage. Too much can cause loss of oil and low oil pressure. Also, there will be a lot of oil thrown from the

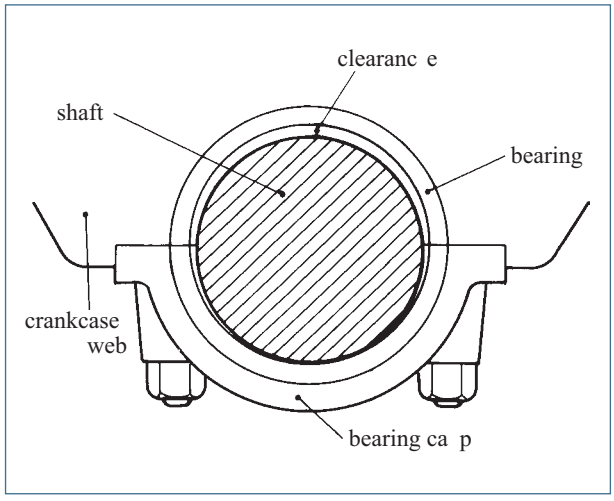


Figure 19.19 Crankshaft main-bearing arrangement showing clearance (exaggerated); this is normally around 0.02 to 0.08 mm

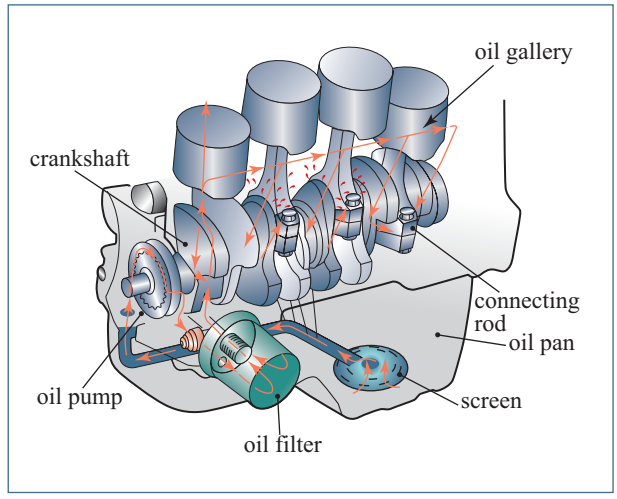


Figure 19.20 Oil supply to the crankshaft main bearings and to the connecting-rod bearings

bearings and onto the cylinder walls. The piston rings will find this hard to control, and oil will find its way up past the piston into the combustion chamber, where it will burn to form carbon and cause other problems.

19.6.5 Bearing lubrication

Engine bearings must have adequate lubrication to remove heat and reduce friction and noise.

Figure 19.20 shows the flow of lubricant to the crankshaft and bearings. Oil from the oil pan is circulated by the oil pump at the front of the crankcase. It passes through the oil filter, along the main oil gallery and then down through drillings in the crankcase webs to the main bearings.

The connecting-rod bearings are lubricated from the main bearings through holes drilled in the crankshaft webs. Oil thrown from the connecting-rod bearings helps to lubricate the pistons, the cylinder walls and other engine parts.

19.7 Cylinder block and crankcase design

There are a number of variations in crankcase design. As previously indicated, some cylinder blocks have a skirt below the crankshaft's centreline, while others do not. The skirt also influences the design of the oil pan and the main-bearing caps.

Crankcase design variations produce a stiffer engine structure and also allow the use of lighter materials or thinner sections. Having a more rigid cylinder-block assembly also helps to reduce engine vibrations.

The two-part engine block assembly in Figure 19.5 is made of aluminium alloy, its two parts being split along the crankshaft centreline. There are no main-bearing caps. The cylinder block carries the upper halves of the bearings in the normal way and the *block base* carries the lower halves of the bearings.

This arrangement provides a stiff crankcase and well-supported bearings. There is also a cast aluminium-alloy oil pan fitted to the underside of the block base, which adds to the engine's rigidity.

19.7.1 Main-bearing caps

The main-bearing caps of many engines are secured by two bolts, as shown in Figure 19.17. However, they can also be secured by four or more bolts, as shown in Figure 19.21.

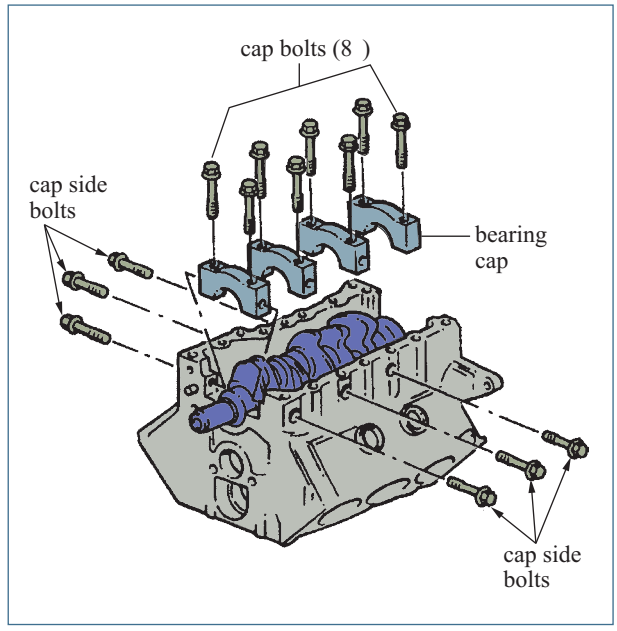


Figure 19.21 Cylinder block with a full skirt and side-bolted main-bearing caps GM HOLDEN LTD

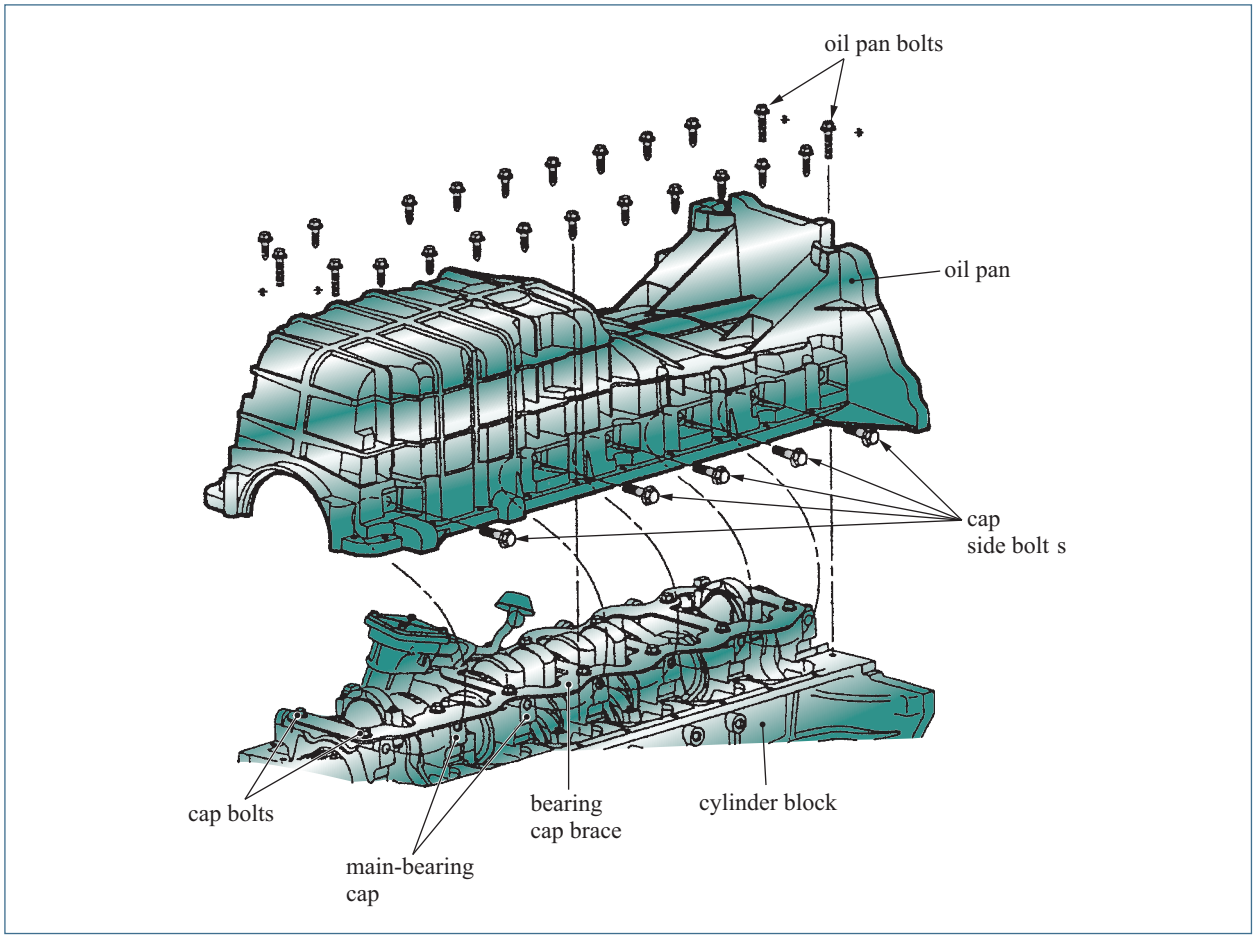


Figure 19.22 Oil pan and part of an engine block —the main-bearing caps have a brace and side bolts FORD

This cylinder block for a V-6 engine has a skirt that extends below the crankshaft. The main bearings have the usual two bolts at the top of each cap, but they also have side bolts. The side bolts pass through the skirt of the crankcase from the outside and are threaded into the main-bearing caps. This increases the rigidity of the bearing caps.

Inline engine

Figure 19.22 shows part of a cylinder block and crankshaft assembly for an inline engine. This cylinder block does not have a skirt. Each of the main-bearing caps is secured by four bolts—two through the top of the cap and one on each side. There is also a support brace on top of the bearing caps held down by the cap bolts.

The oil pan bolted to the underside of the cylinder block is made of cast aluminium alloy. The side bolts pass through its sides and are threaded into the sides of the bearing caps. The engine block, main-bearing caps, support brace and oil pan are bolted together to form a rigid assembly.

19.8 Pistons

Pistons are designed to resist high combustion temperatures, and their rings have to seal against high combustion pressures. Connecting rods must withstand high stresses as they transfer the reciprocating motion of the pistons to the cranks of the crankshaft.

The piston, piston rings, piston pin, connecting rod and the bearing form the piston and connecting-rod assembly. Figure 19.23 shows a piston with its parts identified. This is a short-skirt piston with grooves for three piston rings. Variations in piston design include those of shape, mass, provision for expansion and type of material.

Pistons are made of cast iron or aluminium alloy. Aluminium-alloy pistons are used in petrol and smaller diesel engines because they are much lighter than cast-iron pistons. However, aluminium has a greater rate of expansion than the cast-iron cylinders in which most pistons operate, so aluminium-alloy pistons

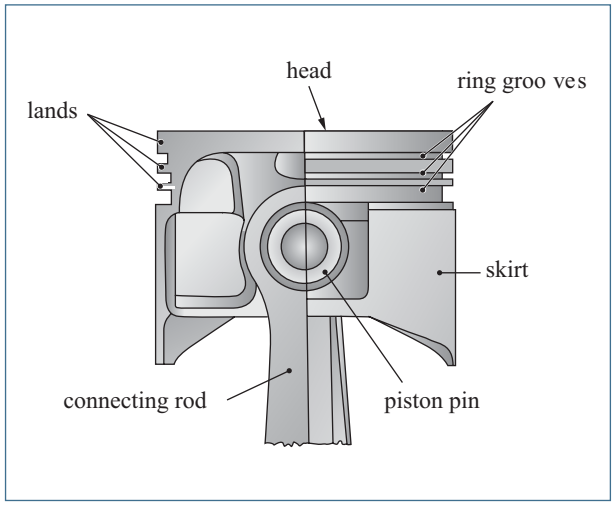


Figure 19.23 Piston in half-section with its parts identified

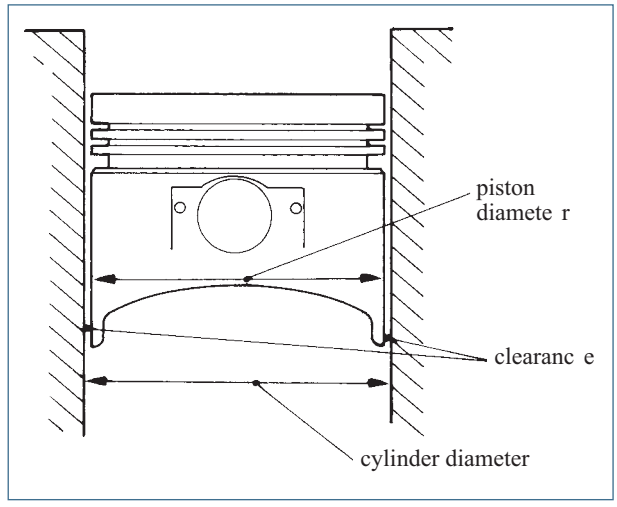


Figure 19.24 Clearance of a piston in a cylinder

are specially designed to control expansion. Some larger diesel engines, which operate at lower rpm than petrol engines, have cast-iron pistons.

19.8.1 Piston clearance

A piston is slightly smaller in diameter than the cylinder in which it operates. This gives it a working clearance of about 0.02 mm to 0.05 mm. Figure 19.24 illustrates the clearance of a piston in its bore, but there are particular ways in which it is measured.

If a piston has insufficient clearance, it will not have enough room to expand when it is hot and it will tend to seize on the cylinder wall, scoring both itself and the cylinder.

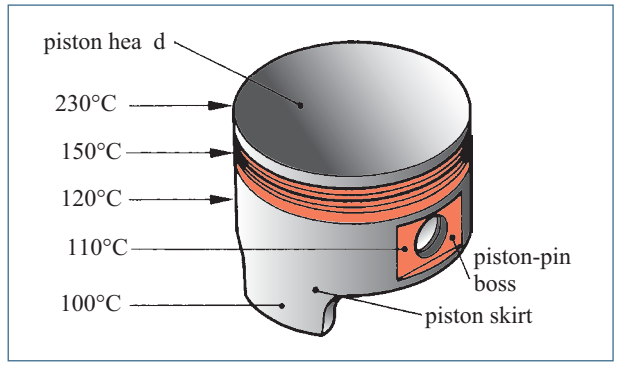


Figure 19.25 Typical operating temperatures of various parts of a piston

If there is too much clearance, piston slap will occur, particularly when the engine is cold. *Piston slap* is caused by the sudden tilting of the piston in the cylinder as it starts down its power stroke that occurs with such force that it produces a noise.

Handy hint: Piston slap can occur in older engines that have ex cessive piston clearance due to worn cylinders or worn or collapsed piston skirts.

19.8.2 Piston temperature

As the piston is subjected to the full effects of combustion, it has to be resistant to heat. Typical operating temperatures are shown in Figure 19.25. Under heavy operating conditions, temperatures can rise even higher.

There is a big difference between the temperature of the head of the piston and its skirt. The heat causes expansion, which is greatest at the top of the piston. For this reason, the lands there are given extra clearance. They could be as much as 0.75 mm smaller in diameter than the skirt.

19.9 Control of piston temperature

There are several methods used to prevent pistons from excessive expansion. These include cam grinding, using steel struts, controlling the heat path and oil cooling.

19.9.1 Cam-ground pistons

A cam-ground piston is slightly oval. The shape is obtained by relieving some metal in the area of the piston-pin bosses (Figure 19.26). This makes the diameter of the piston slightly smaller at the piston-pin bosses

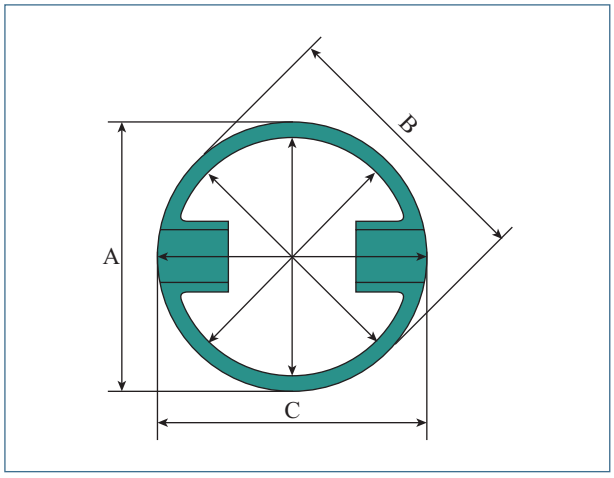


Figure 19.26 Cam-ground piston A largest diameter , C smallest diameter , B extra relief at lik ely scuffing areas

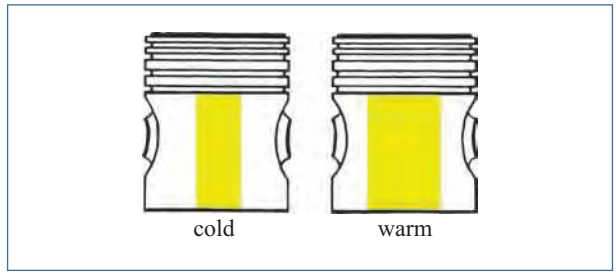


Figure 19.27 As a cam-ground piston warms up , skirt expansion increases the area of contact

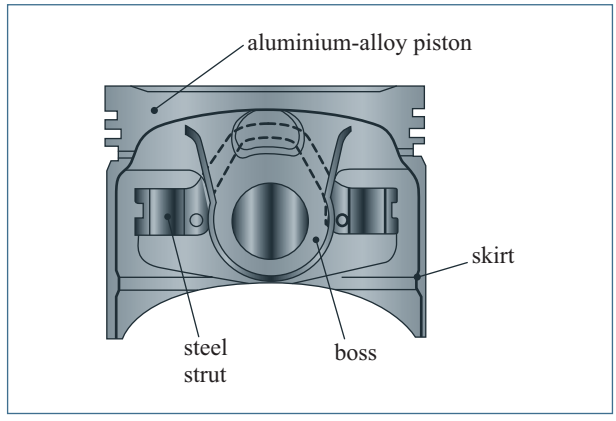


Figure 19.28 An aluminium-alloy piston that has steel struts to reduce expansion

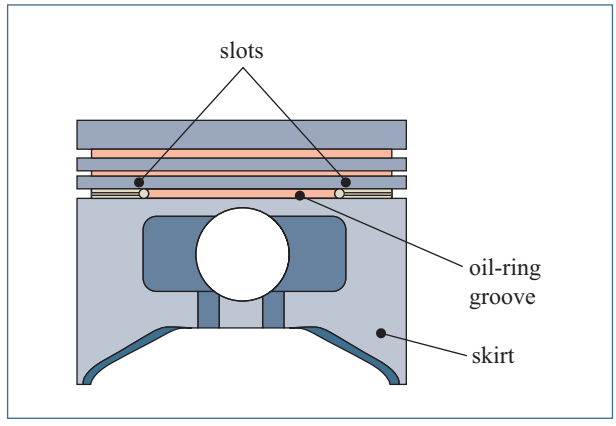


Figure 19.29 Piston with slots behind the oil ring, used for heat control and oil drainage

than at the thrust faces, allowing it to be fitted to the cylinder with minimum clearance at the thrust sides. The extra clearance provided at the bosses by cam grinding allows for piston expansion.

Cam-ground pistons get their name from the process by which the pistons are finished to size. The machine uses a cam to move the piston backwards and forwards as it is being ground. When cam-ground pistons warm up, they become more round in shape, increasing the area of contact with the cylinder wall (Figure 19.27). Grinding generally refers to cast-iron pistons; aluminium pistons can be turned, rather than ground.

19.9.2 Steel-strut pistons

A special alloy steel strut is fitted to each side of the piston (Figure 19.28). The steel from which these are made has a very low rate of expansion when heated; contrastingly, aluminium alloy has a fairly high rate of expansion. As the piston temperature increases, the aluminium alloy tries to expand but is restrained by the steel struts. This holds the piston at the thrust face to its specified size.

19.9.3 Heat path in pistons

As well as controlling piston expansion by struts, heat is kept away from the thrust faces of the piston as much as possible, reducing expansion. One way of doing this is with horizontal slots in the thrust sides of the piston, either in or below the oil-ring groove (Figure 19.29). The slots break the heat path between the head of the piston and the skirt at the thrust faces, directing it to other parts of the piston, such as the piston-pin bosses, where there is more clearance and more metal to absorb the heat. This reduces expansion at the thrust faces.

19.9.4 Piston coatings

A variety of permanent treatments or coatings can be used to improve piston performance. The piston crown can be coated with a ceramic material to withstand the higher operating temperatures in modern engines. Less heat is lost through the piston and cylinder wall, thereby improving the thermal efficiency of the engine.

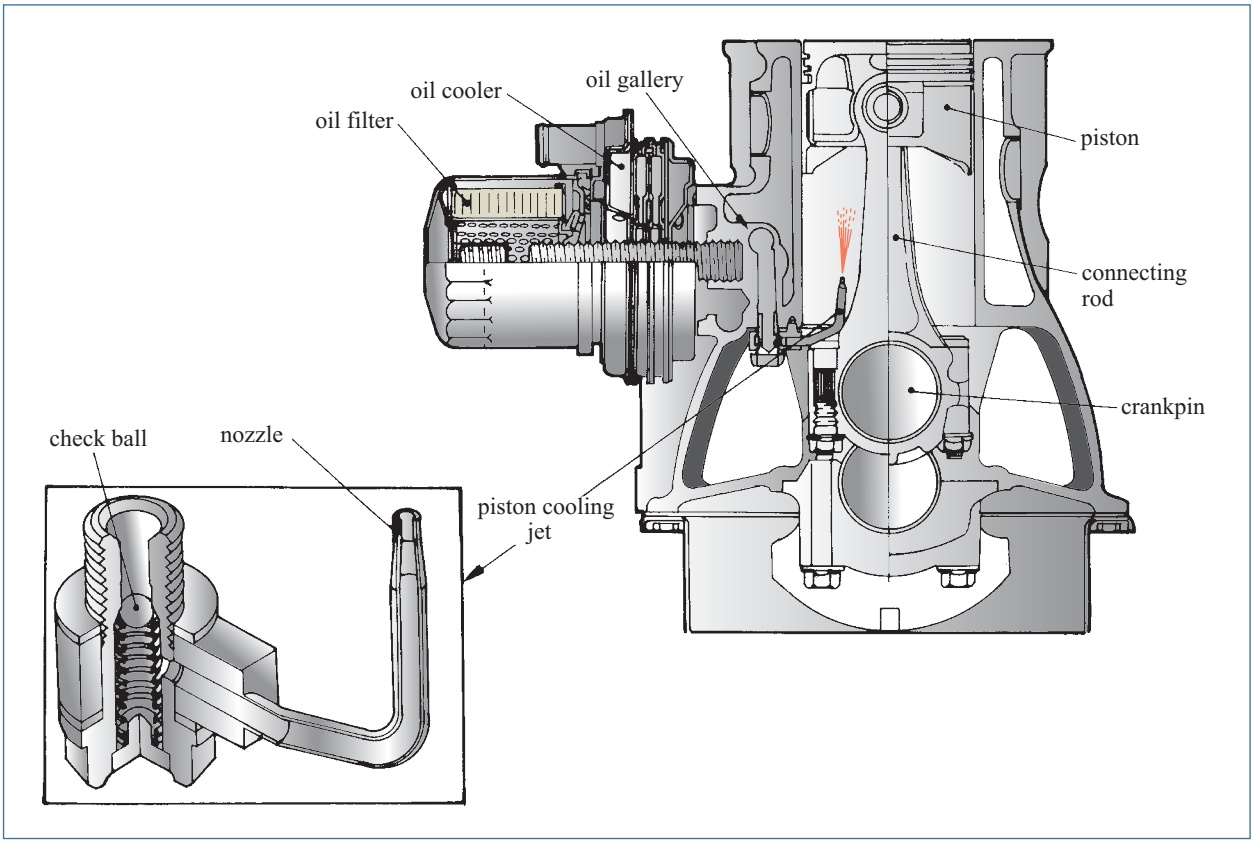


Figure 19.30 Piston cooling jet that sprays oil into the piston FORD

The piston skirt can be coated with materials such as molybdenum and graphite, which reduce friction between the piston and cylinder wall. The main advantages of piston coatings are improved mechanical efficiency, fuel economy and extended engine life.

19.9.5 Piston cooling jets

Normal lubrication helps cool the pistons and cylinder walls, and some engines also have cooling jets—small nozzles which spray a jet of oil up into the piston. The oil strikes the piston head, absorbs heat and then drops back into the oil pan. It also lubricates the piston pin and cylinder walls.

Figure 19.30 shows a cooling jet and its action. The jet is supplied with oil from the main oil gallery of the engine. It has a ball check valve that closes when the oil pressure in the gallery is low, or when the engine is stopped. At normal operating pressure, the ball valve is forced off its seat, so that the jet sprays oil into the piston.

19.10 Piston designs

Pistons are designed with various shapes. Their heads can be flat, domed or hollow, and they can have a short skirt, a full skirt or the skirt can be cut away.

The shape of the piston head is designed to suit the type of combustion chamber of the engine and improve turbulence of the air as it is being compressed. The head of the piston can also be designed with recesses or depressions to provide clearance for the heads of the valves.

Petrol engines use a *slipper-type* piston (Figure 19.31). Cutting away the piston's skirt not only reduces its mass but also provides clearance for the crankshaft balance weights when the piston is

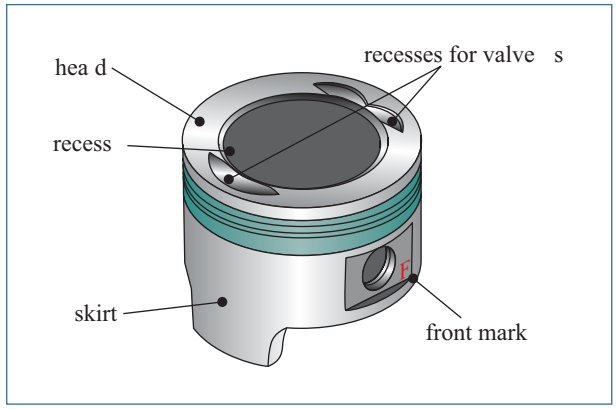


Figure 19.31 Slipper-type piston with a recessed head and recesses for the valves—the front of the piston is identified with an 'F'

at BDC. This enables shorter connecting rods to be used, giving a more compact engine design. On some engines, the balance weights are contoured to avoid interference between the weights and the pistons.

Some pistons have a very narrow top land so that the top compression ring is close to the top of the piston. This reduces the size of the crevice between the piston and the cylinder wall, above the top piston ring. The crevice can collect traces of unburned fuel, which finds its way out of the exhaust; reducing the crevice size reduces the hydrocarbon emissions from the engine.

19.10.1 Piston thrusts

During power strokes, combustion pressures force the piston downwards. However, it does not bear evenly against the walls of the cylinder but is thrust against the sides of the cylinder due to the angularity of the connecting rod (Figure 19.32).

The combustion pressures force the piston downwards, and the connecting rod offers resistance, at an angle. The result is a side thrust of the piston against the cylinder wall, as shown.

The piston also has a side thrust during the compression stroke, but this is on the opposite side of the cylinder. Also, this is a lesser thrust because the downward force from compression is much less than the downward force of combustion.

The thrusts are sometimes referred to as the *major* and *minor* thrusts. Because the thrust during the power stroke (major thrust) is most important, this side of the engine is often referred to as the *thrust side.* It is necessary to know about the thrust side of an engine because the pistons in most engines have to be installed in a particular way. Pistons are often provided with a mark to show how they should be fitted in relation to the front of the engine.

Handy hint: Thrusts occur on both the upstrokes and the downstrokes, but the major thrust occurs during the power stroke.

19.10.2 Offset piston-pin bosses

Pistons often have the bosses for the piston pin slightly offset from their centreline, towards the major thrust side (Figure 19.33). The offset, of about 1.50 mm, slightly alters the angle of the connecting rod, transferring some of the force away from the thrust side of the piston. There is less tilt applied to the piston during the power stroke and thus less chance of piston slap.

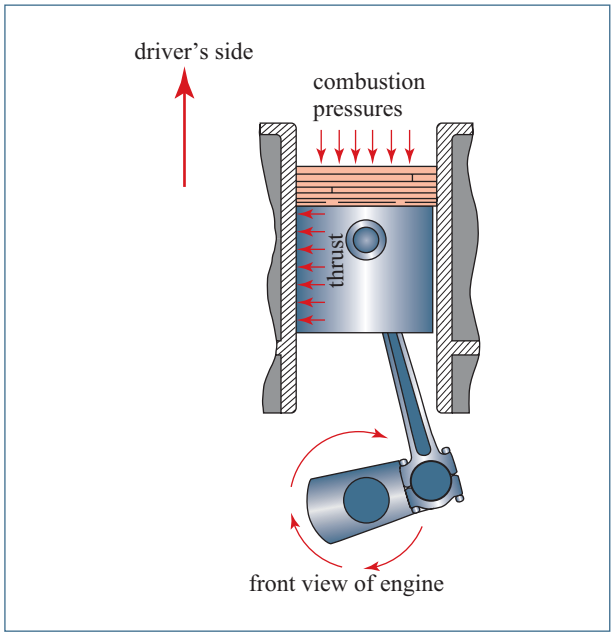


Figure 19.32 Thrust side of the engine when viewed from the front

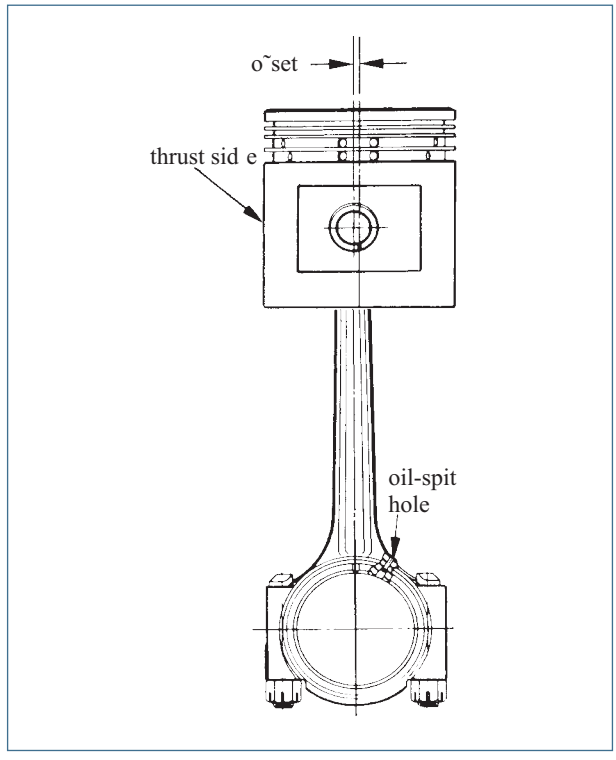


Figure 19.33 Piston with the piston-pin hole offset towards the thrust side—the oil-spit hole sprays oil onto the cylinder wall

Offset pistons must be correctly installed, otherwise the tilting action would be increased, which would cause pronounced piston knock. The front of the pistons are marked to assist installation.

19.11 Piston rings

There are two main types of piston rings—*compression rings* and *oil rings*. Fitting accurately into the grooves in the pistons, compression rings provide a gas seal against the cylinder walls, while oil rings control the oil on the cylinder walls and return excess oil to the oil pan.

Handy hint: Oil rings are also referred to as oil-control rings.

Figure 19.34 shows a basic compression ring and a basic oil ring with their parts named (there are a number of design variations, however). Piston rings are split so that they expand against the cylinder walls. This also enables them to be fitted into the grooves in the piston.

When removed from the engine, piston rings are larger in diameter than the cylinder but, when installed, are compressed so that the gap is almost closed. The tension within the rings keeps them against the cylinder walls.

19.11.1 Compression rings

Compression rings provide a seal that prevents loss of air during the compression stroke and loss of gas pressure during the power stroke. If the rings do not seal properly on the compression stroke, there will be loss of compression and engine power. If they do not seal properly during the power stroke, combustion gases will be forced past the piston into the crankcase. This occurs in worn engines and is known as *blow-by*.

Types of compression rings

Figure 19.35 shows the shapes of the cross-section of a number of compression rings. They all depend on the tension within the ring to hold them outwards against the cylinder walls, but some have features that provide additional pressure in operation. Some have a torsional action.

1 Tapered ring— has a slightly tapered face that helps to scrape oil from the cylinder walls.
2 Chamfered ring—the chamfer on the back of the ring produces an increased pressure against the cylinder walls.
3 Counterbored ring—a back edge of the ring is cut away to give a torsional action.
4 Undercut ring— the face is slightly tapered and its lower part cut away to give a torsional action.
5 Plain ring—has a rectangular section and is held against the cylinder wall by its own tension.
6 Faced ring— the facing resists heat and wear .

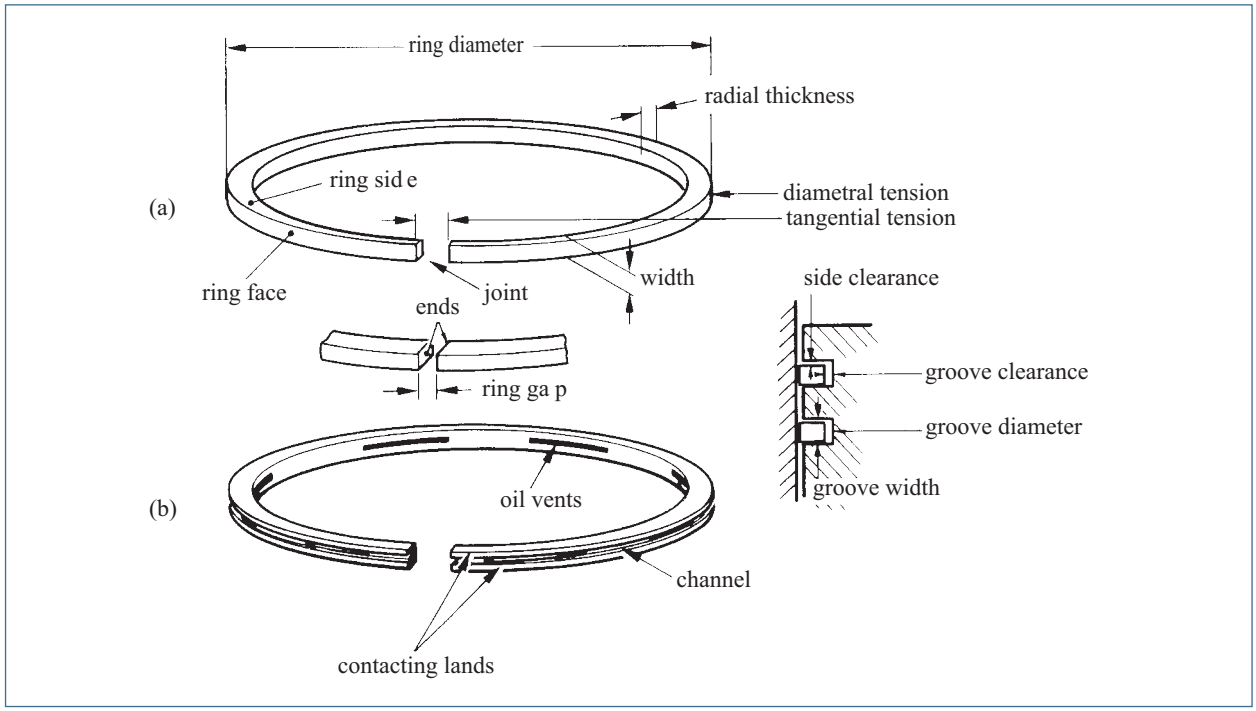


Figure 19.34 Basic piston rings with various parts identified (a) compression ring (b) oil ring

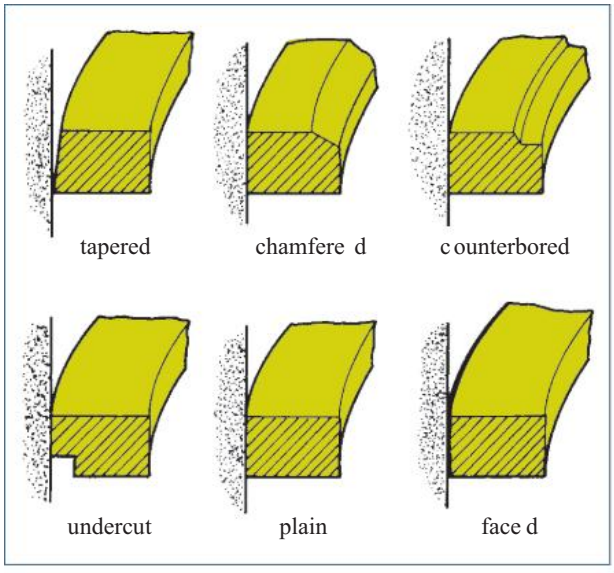


Figure 19.35 Different shapes of compression rings

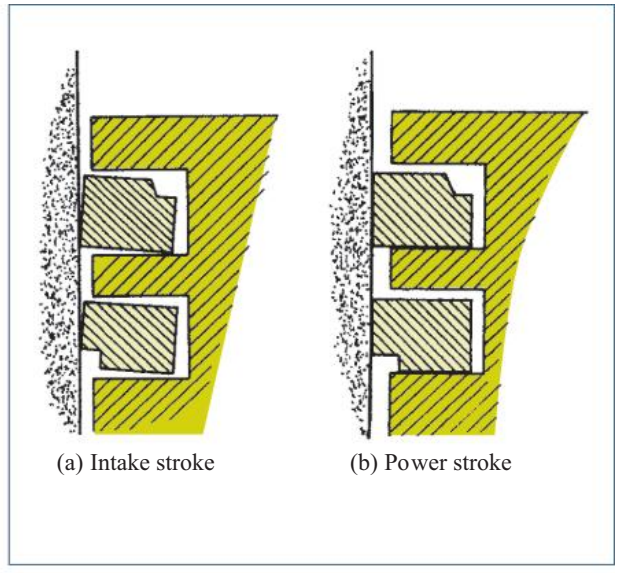


Figure 19.36 Action of torsional rings

Torsional rings

Figure 19.36 shows the torsional action of compression rings with shaped cross-sections. This is shown on both the *intake* stroke and the *power* stroke.

During the *intake stroke,* internal forces in the ring (caused by the removal of a corner of the ring) make it twist slightly (Figure 19.36(a)). As the piston moves down the cylinder, the rings have a scraping action that removes surplus oil from the cylinder walls. On the piston upstrokes, the rings tend to slide over the film of oil and so have less tendency to carry oil up into the combustion chamber.

During the *power stroke* (Figure 19.36(b)) combustion pressure forces down on the top of the ring and also against its back. Figure 19.37 shows this combined action. This straightens the ring so that it has full-face contact with the cylinder walls. This provides effective sealing.

Because of their twisting action, rings with a chamfer or counterbore that act in the way described are known as *torsional rings.*

Where shaped rings are used, their tops are marked to guide correct installation (Figure 19.38).

Handy hint: Incorrectly installed rings would cause loss of compression and increased oil consumption.

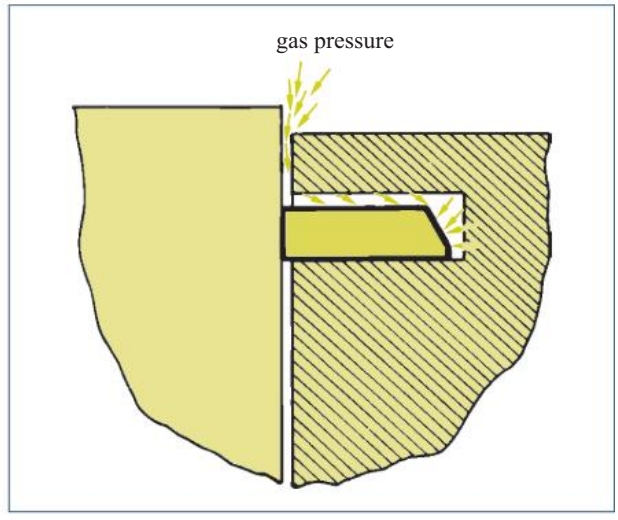


Figure 19.37 Gas pressure forces the piston ring against the piston and the cylinder wall

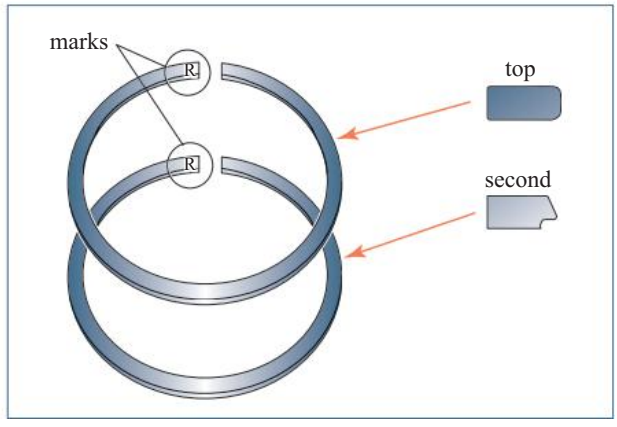


Figure 19.38 Compression rings are marked on the upper side so that they are installed the right way

19.11.2 Oil rings

Oil-control rings prevent excessive oil from working up past the piston into the combustion chambers. The oil that has to be controlled is thrown from the connecting-rod bearings and, in some cases, from an *oil jet* or from an *oil-spit hole* in the connecting rod (see Figure 19.43). Generally, there is more oil than needed on the cylinder wall and the oil rings remove the surplus. They also help to provide a seal.

Types of oil rings

The oil ring in Figure 19.34(b) is a one-piece ring that depends on its own tension to hold it against the cylinder walls. The slots in the ring, and the holes in the piston behind it, allow oil to return to the oil pan. This type of oil ring is usually used only in conjunction with another oil ring.

Most oil rings are *segmental* types with three or four segments (as in Figure 19.39). This ring has two side rails and an expander, which also acts as a spacer for the rails. The side rails are usually made of steel, with very little tension of their own. They depend on the expander to hold them against the cylinder walls. The expander is made of spring steel with a series of crimps which give it an outward spring force.

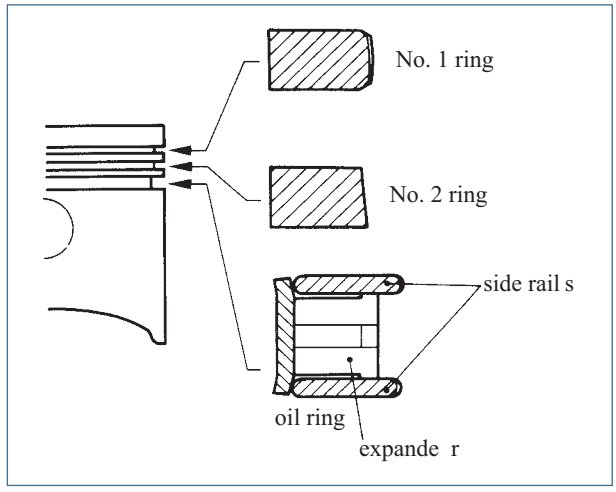


Figure 19.39 Set of piston rings: No . 1 ring has a chrome-plated face; No . 2 ring is a scraper ring; the oil ring is a segmental type MITSUBISHI

Handy hint: Segmental oil rings are very flexible , their open construction allowing oil to pass through readily .

Oil control

There is usually far more oil on the cylinder walls than is needed for lubrication, but it has several roles, including lubricating, cooling, cleaning and sealing. Most of the oil that is not needed for lubrication is scraped off the cylinder walls by the oil rings.

Figure 19.40 shows how oil can be controlled. As well as drain slots behind the oil ring, the piston has grooves which allow oil to pass down the sides. Oil scraped by the oil ring is returned to the oil pan through the spaces at the end of the piston-pin bosses and through the grooves in the sides of the piston.

19.11.3 Piston-ring coatings

The engines of most passenger cars and light commercial vehicles have pistons with a set of three rings. Typical ring sets are shown in Figures 19.39 and 19.41. Although there are various combinations, the standard one is a top compression ring, a scraper ring and a segmental oil ring.

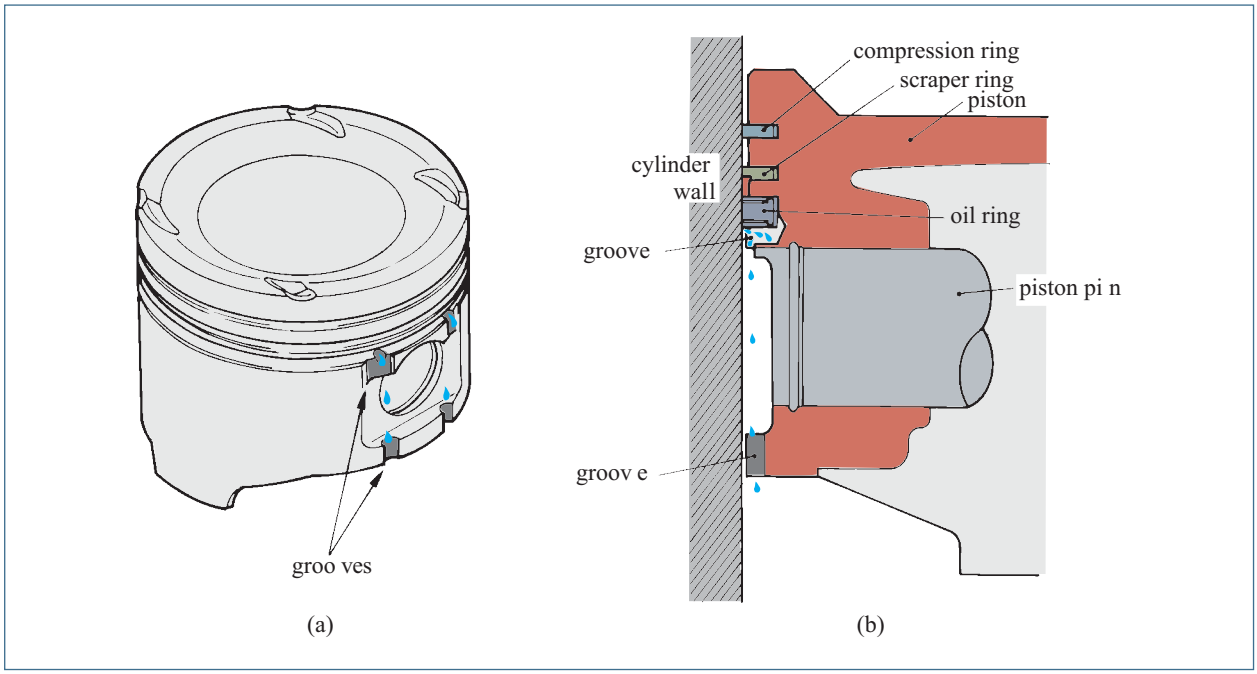


Figure 19.40 Piston (a) design (b) section of the piston showing control of oil on the cylinder wall FORD

Some piston rings are coated with a soft material to help them 'bed in'. New rings and cylinders have very small irregularities, and when these wear off the rings will provide a better seal. To assist this process, the rings can be coated with phosphate, graphite or iron oxide. These are relatively soft substances which wear more quickly than the ring material. The coatings also absorb oil and help with ring lubrication, preventing scuffing of the cylinder walls.

To prevent wear, the face of the piston ring can be coated with chromium. Although relatively hard, it operates well against the cast-iron cylinder walls without scuffing.

Molybdenum is also used as a coating for compression rings, having properties that give quick bedding-in. Rings coated with molybdenum resist abrasive wear much better than uncoated cast-iron rings, but not as well as chromium-plated rings.

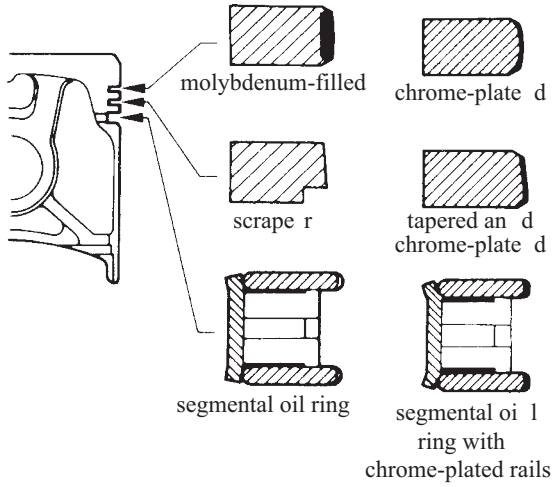


Figure 19.41 Coated piston rings MITSUBISHI

19.12 Piston pins

The piston pin secures the piston to the small end of the connecting rod and also provides the wrist-like action that is needed between the two parts.

There are different methods used to retain the piston pin, but two that are commonly used are shown in Figure 19.42. These are:

1 Press-fit pin. The piston pin is a press fit in the eye of the connecting rod and floats in the piston. The fit in the connecting rod is tight enough to retain the pin and prevent it from moving. This is the most common method for engines in passenger cars and light commercial vehicles.

2 Floating pin. The piston pin is arranged to float in both the eye of the connecting rod and the piston. The connecting rod is fitted with a bronze bush to provide a bearing surface for the piston pin. Circlips in grooves in the piston bosses retain the piston pin and prevent it from coming into contact with the cylinder walls.

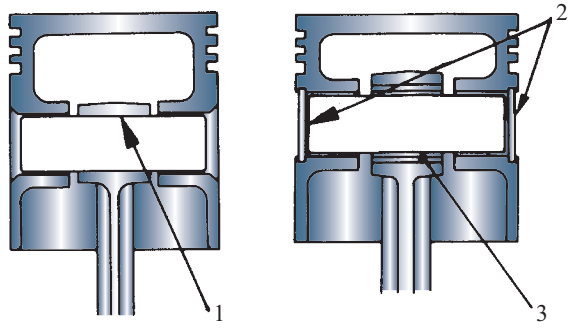


Figure 19.42 Arrangements for piston pins 1 press fit, 2 circlips in piston, 3 bush in rod

There are variations of the designs shown. With some floating piston pins, thrust pads of soft metal are fitted in the pin ends. The pin floats in the piston and in the connecting rod. The thrust pads come into contact with the cylinder wall but, being soft and lightly loaded, do no harm.

The piston pin can also be clamped in the connecting rod. The eye of the rod is split and a bolt is used to form it into a clamp. This design increases the mass at the small end of the connecting rod, which is not desirable as it adds to the mass of the reciprocating parts.

Handy hint: The piston pin is also referred to as a wrist pin, and sometimes as a gudgeon pin.

19.12.1 Piston-pin lubrication

Most piston pins depend on splash and oil mist for lubrication, but some are pressure lubricated, with an oil passage drilled the full length of the connecting rod. Oil from the connecting-rod bearing passes through the passage to the piston pin.

Most engines have a connecting rod with a 'spit hole', or oil jet, in the crankpin end. This hole lines up with the oil hole in the crankpin once on each revolution of the crankshaft. When this occurs, a squirt of oil is directed onto the cylinder walls as shown in Figure 19.43. This also lubricates the piston pin.

In engines with piston cooling jets, the oil directed from the jet cools the piston and also lubricates the piston pin (Figure 19.30).

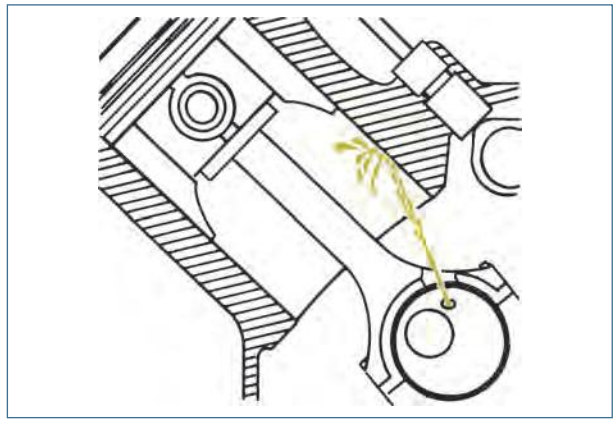


Figure 19.43 Oil sprayed on to the cylinder wall through a spit hole in the connecting rod

19.13 Engine vibration and balance

There are four main causes of vibration in an engine.

1 Rotating parts. Centrifugal force acts on all parts that rotate . Parts such as the crankshaft, flywheel and clutch must be balanced.
2 Power impulses. The pistons deliver power to the crankshaft as impulses, causing a type of rotary vibration in the crankshaft.
3 Reciprocating parts. The pistons produce an inertia force at the top and bottom of their strok es. This causes up-and-down vibrations in an engine .
4 Resonance . Vibrations can be transmitted between parts and amplified, even though the parts may not be directly connected.

19.13.1 Vibration dampers

A vibration damper is fitted to the front of the crankshaft. This is usually part of the crankshaft pulley (Figure 19.44). The damper consists of two main parts: a hub that mounts on the front of the crankshaft, and an inertia ring (a small flywheel) that is attached to the hub by a bonded-rubber insert. The rubber allows the inertia ring to move a little in relation to the hub. Dual-type dampers have two inertia rings.

The inertia ring dampens out crankshaft vibrations in the following way:

1 When the crankshaft tends to speed up , the inertia ring tends to lag behind to oppose the force producing the vibration.
2 When the crankshaft tends to slow down, the inertia ring tries to k eep it moving. In this way , the action of the inertia ring on its rubber mounting helps to dampen out crankshaft vibrations.

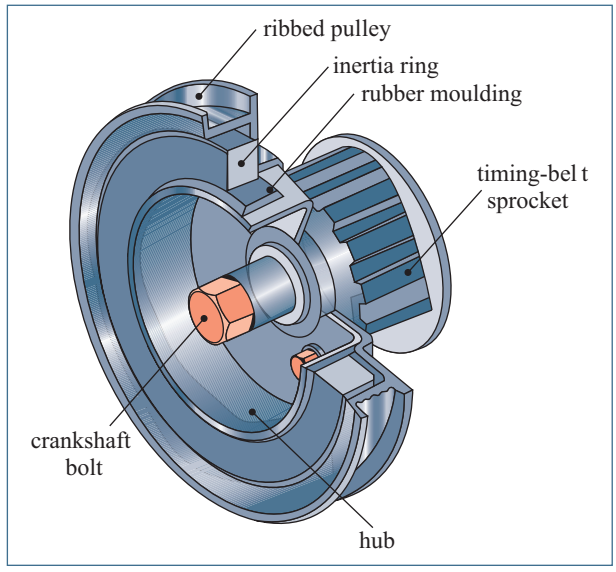


Figure 19.44 Torsional vibration damper fitted to the front of a crankshaft

Inertia is the tendency of a body to resist changes in motion. For example, a flywheel does not suddenly start to rotate if a force is applied, nor does it suddenly stop if the force is removed.

19.14 Balance of reciprocating parts

The reciprocating parts of the engine are the piston assembly and the upper part of the connecting rod. Each time a piston reaches TDC or BDC, it has to stop and change its direction. Each time this occurs an inertia force is produced which tries to keep the piston moving, and this tries to move the engine up or down.

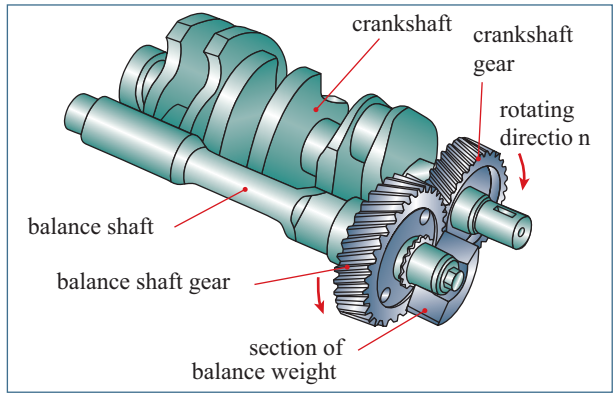


Figure 19.45 Single balance shaft driven by gears from the crankshaft

To reduce the effects of inertia forces, all the pistons and associated parts are of equal weight.

19.14.1 Balance shafts

Balance shafts reduce vibration. Some engines have a single balance shaft (Figure 19.45), while others have two (Figure 19.46). They are mounted in bearings in the crankcase, parallel to the crankshaft, and are driven by a chain or gears.

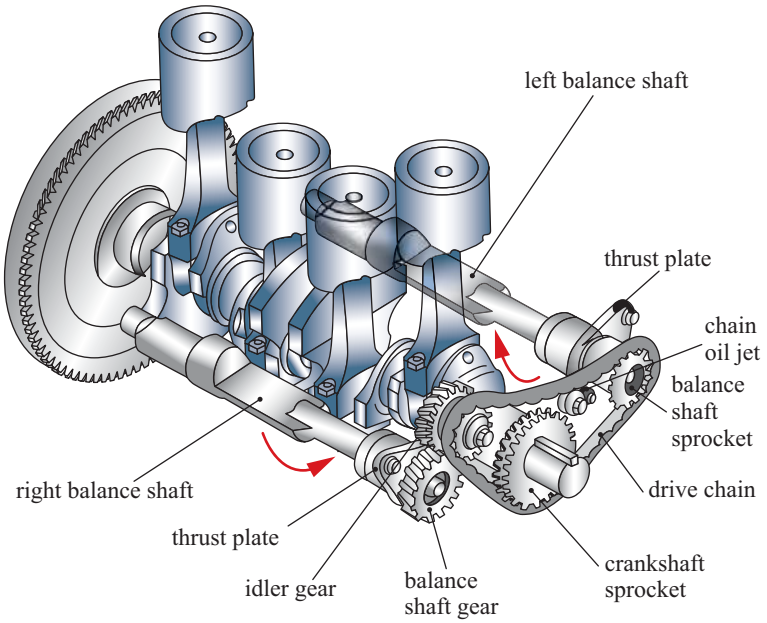


Figure 19.46 Arrangement of two balance shafts driven by a chain and gears

Balance shafts reduce the up-and-down vibrations of the engine by producing their own inertia forces. The shaft is designed to counter the forces at both TDC and BDC. Balance shafts can be driven at engine speed, but are often driven at twice engine speed to increase their effect.

19.15 Diagnostic procedures for cylinder-block repairs

Applying diagnostic procedures during cylinder-block repairs can help determine how and why engine components wear, fatigue and fail during day-to-day operation.

There are two main causes of cylinder-block problems and engine failure.

1 Lubrication problems. The engine requires oil between its moving parts, not only to reduce friction but also to carry away heat. Low oil pressure is often the main contributing factor in engine failures. Possible causes include:
   - insufficient engine oil changes (causing visible sludge deposits)
   - incorrect oil viscosity (low oil pressure or oil being too thick can result in it reaching engine parts too late or in insufficient quantities)
   - worn piston rings causing the engine to burn oil (indicated by oil-fouled spark plugs)
   - oil leaks (from front or rear main seals).
2 Overheating. This can cause problems such as metal expansion and scuffed and seizing pistons. Possible causes of overheating include coolant loss from such sources as the head gasket, water pump and Welch plugs, or head and block corrosion, cracks or warpage. All of these can be checked by eye.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- state the function of cylinder block components
- describe the construction of the cylinder block
- balance reciprocating parts
- apply procedures for cylinder-block and component repair and overhaul to industry standards
- apply diagnostic procedures for cylinder-block repairs.

REVIEW QUESTIONS

1 Briefly describe the construction of a cylinder block.
2 What are the different types of cylinder sleeves ?
3 What is a wet sleeve ?
4 What causes cylinders to wear?
5 Indicate where the greatest wear occurs in a cylinder .
6 Why is the surface finish of a cylinder important?
7 Name the parts of a crankshaft.
8 What are bearing inserts , and where are they used?
9 How are crankshaft bearings lubricated?
10 What are the reciprocating parts of an engine ?
11 What are the main causes of engine vibration ?
12 How is torsional vibration reduced in an engine ?
13 What is a balance shaft ?
14 Why are pistons made from aluminium alloy ?
15 Explain piston clearance .
16 A piston is cam-ground. What does this mean ?
17 What is the thrust side of a piston ?
18 Why does a piston need piston rings ?
19 What are the two main types of piston rings ?
20 Why are the faces of some piston rings coated?
21 Explain how oil-control rings operate .
22 Explain how gas pressure helps compression rings seal.
23 What is the purpose of a connecting rod?
24 How are piston pins lubricated?
25 What is a piston cooling jet ?
26 What type of displacement are most oil pumps ?
27 What is Plastigage and what is its purpose ?
28 What safety precautions must be tak en before taking a compression reading ?
29 What colour smok e from the exhaust would indicate an internal mechanical problem ?

CHAPTER 20

Cooling systems and servicing

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 describe the fundamental points about cooling systems and related basic components–types of cooling systems, ways of working with them and the terminology used in the automotive industry
2 apply industry safety requirements
3 demonstrate how to inspect and service a range of cooling systems in accordance with workplace and manufacturer/component supplier requirements and specifications
4 document and accurately interpret the results of tests and inspections.

Only about a quarter of the heat generated in an engine is actually used; the rest has to be disposed of to prevent damage to the engine . The cooling system keeps the engine at its optimal operating temperature .

There are two general types of cooling system: air cooling, in which the air is blown directly over the engine; and liquid cooling, in which coolant is circulated through the engine and radiator . Most automotive engines are liquid-cooled.

20.1 Basic liquid-cooling system

A basic liquid-cooling system is shown in Figure 20.1. The main parts are:

1 radiator
2 water pump
3 water-jack ets
4 radiator hoses
5 thermostat
6 fan
7 coolant .

The cooling system transfers heat from inside the engine to the outside air by circulating the coolant (water with additives) through the engine and the radiator. The water pump takes coolant from the bottom of the radiator and pumps it through the engine to the top of the radiator.

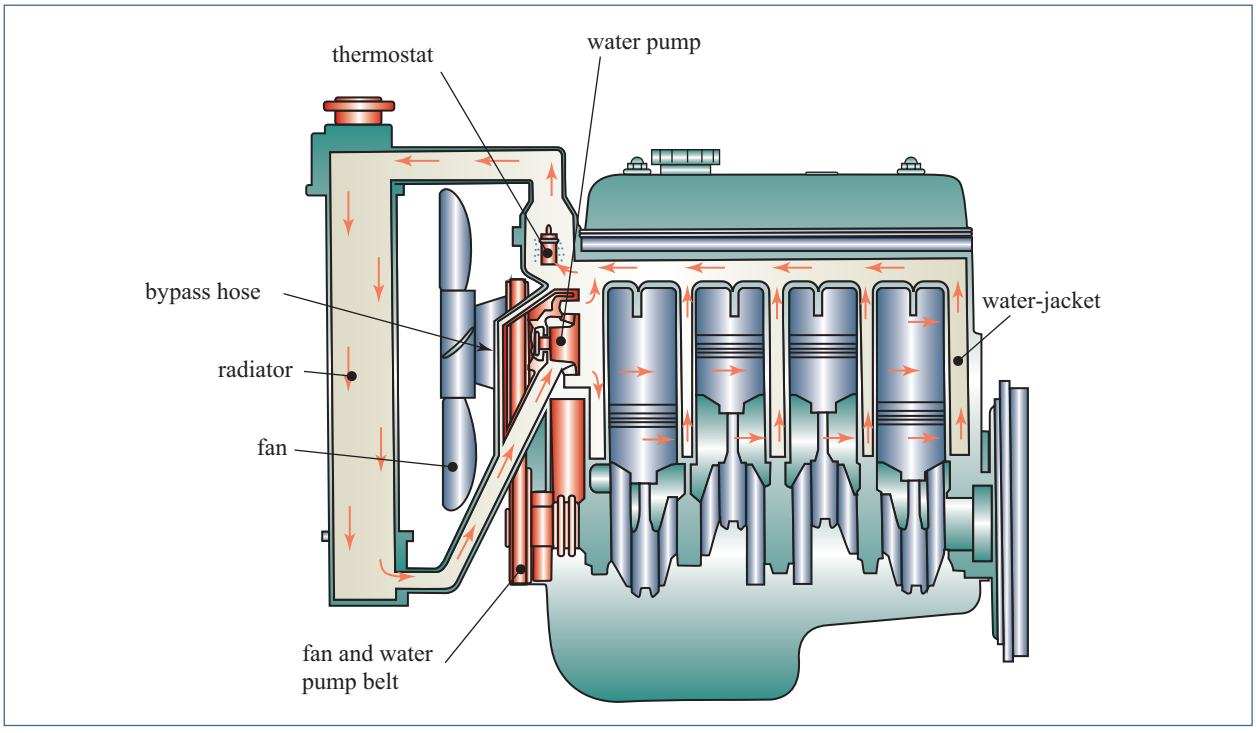


Figure 20.1 The parts of a liquid-cooling system

Heat is generated in the combustion chambers of the engine and is transferred (by conduction) through the cylinder walls and cylinder head to the water-jackets, where it is transferred to the coolant. As it circulates, coolant carries the heat from the engine to the top of the radiator.

Hot coolant passing down through the radiator transfers heat to the radiator. Heat is then dissipated by air that passes over the fins and through the radiator core, with the airflow assisted by the fan. When the coolant reaches the lower radiator tank, it is cool enough to re-enter the engine to remove more heat.

Some heat is also dissipated by radiation. Heat radiates from the outside of the engine and the exhaust into the atmosphere, to other parts of the engine and to the body of the vehicle.

The thermostat is located at the outlet from the cylinder head. This is a heat-operated valve which prevents coolant from flowing through the radiator until the engine warms up.

20.1.1 Need for a cooling system

Combustion of the air–fuel mixture in the cylinders produces a considerable amount of heat. This is absorbed by the cylinder walls, the cylinder head and the pistons, all of which are protected by the cooling system to stop them becoming overheated.

Cooling also prevents the oil on the engine parts from breaking down and losing lubrication properties. While the engine must be cooled, it still needs to operate at a high temperature. Removing too much heat would lower its thermal efficiency, losing useful energy.

20.2 Heat and temperature

Heating and cooling are fundamentally important to the operation of the engine. It is the heat from the burning fuel in the combustion chamber that provides the energy that causes the engine to function. Heat and temperature are not the same. Heat is energy and is measured in Joules, while temperature is the degree of hotness (or coldness) and is measured in degrees Celsius. Something is referred to as being *hot* when it is above normal atmospheric temperature, and *cold* when it is below atmospheric temperature.

20.2.1 Effects of heat

Heat has the following effects on materials:

1 Change of temperature . Heat applied causes the temperature to rise; heat removed causes it to fall.
2 Change of colour . Heat applied to metals, particularly steel, causes a change in colour . If a bright steel surface is heated, it will gradually change colour and, depending on the temperature , different colours will be obtained. An overheated engine part can usually be identified because it will be discoloured.

3 Change of state . Heat can change a solid to a liquid, and a liquid to a gas. For example , ice can change to water and water to steam. Metal heated during welding will change from a solid to a liquid.
4 Change of volume . Heat applied causes expansion; heat removed causes contraction. This is because the molecules of a substance being heated will move further apart and so increase the volume , while molecules of a substance being cooled will move closer together and so decrease the volume .

All substances expand when heated and contract when cooled. Gas expands to many times its size, but liquids and solids expand only a small amount as their molecules are fixed.

20.3 Heat transfer

Heat can be transferred in three ways:

1 By conduction
2 By convection
3 By radiation.

All of these are used to remove heat from the engine. Heat always moves from a hotter place to a colder one. Figure 20.2 shows how heat from the coolant in a radiator is transferred to the cooler air.

20.3.1 Conduction

Conduction is the transfer of heat through solids. Heat is conducted from the combustion chamber through the metal parts of the engine to the coolant in the cooling system.

20.3.2 Convection

This is heat transfer by molecule movement, and it relates to gases and liquids, not to solids. When a liquid or a gas in a container is heated, it expands and its density is reduced.

The heated particles become lighter and they float upwards, allowing the colder, denser particles to sink towards the bottom of the container. This sets up convection currents, as shown in Figure 20.3.

20.3.3 Radiation

With radiation, heat is transferred across space as rays. These are transformed into heat when they strike a colder object, thus increasing its temperature.

20.4 Air-cooling systems

The simplest cooling system is the air-to-air system. Engines with these are cheaper to produce, lightweight and require less maintenance as they have fewer parts and no heavy liquids. They are noisier than liquid systems and can have wide changes in temperature. Air-cooled engines are usually used on outdoor power equipment.

20.5 Liquid-cooling systems

There are a number of variations to liquid-cooling systems. While they all function alike, the location of the components varies with the type of engine.

Figure 20.4 shows the arrangement for a transverse engine that has been sectioned to show the water-jackets around the cylinders. The radiator is at the front of the vehicle and the water pump is at the front of the engine. Arrows show that the coolant flows from the bottom of the radiator to the water pump, then through the cylinder block and cylinder head to the top of the radiator.

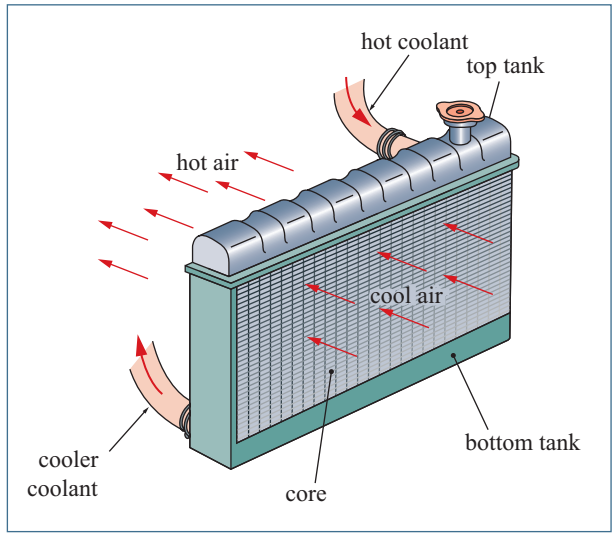


Figure 20.2 Transfer of heat in a radiator

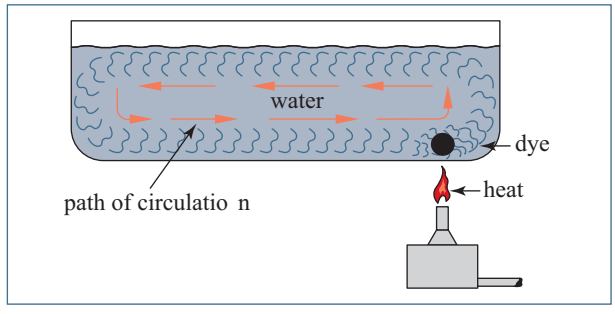


Figure 20.3 Heat applied to the edge of the container produces convection currents in the water—a spot of dye in a transparent container allows this effect to be seen

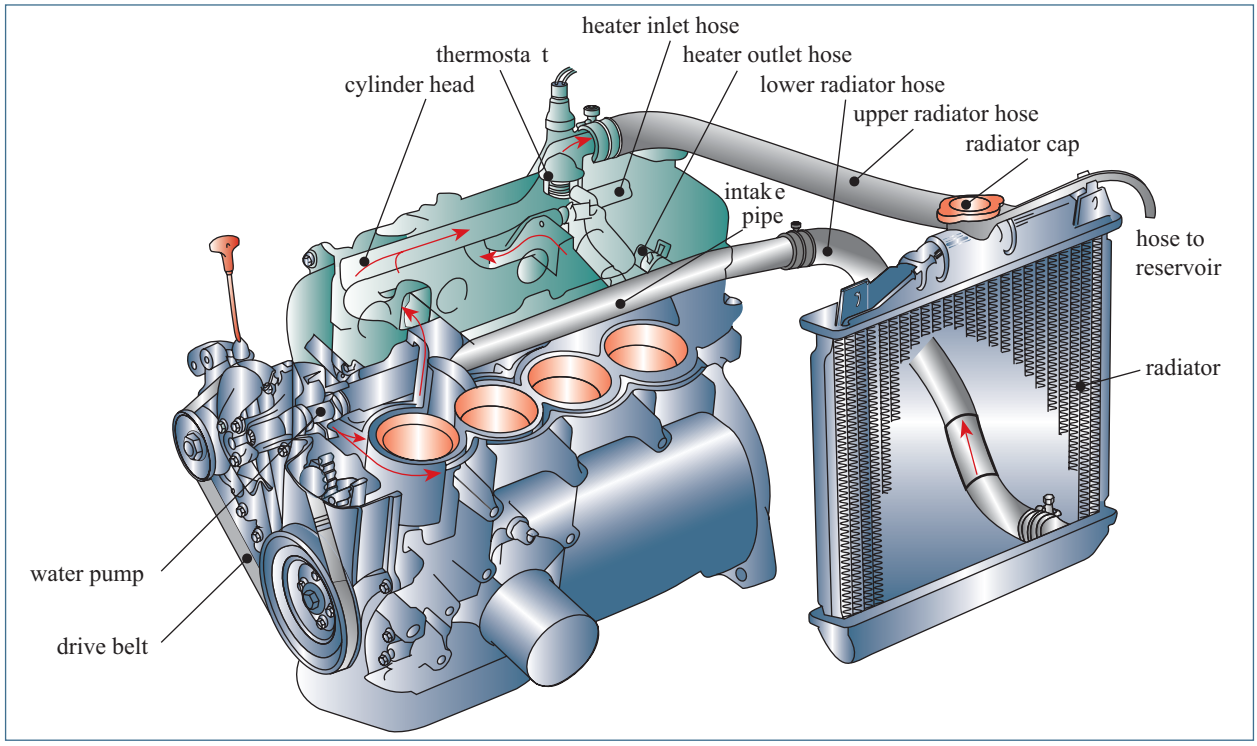


Figure 20.4 Basic cooling system arrangement for a transverse engine

20.5.1 Coolant flow

Figure 20.5 is a simplified arrangement of a cooling system viewed from above the engine. Arrows show the coolant flow. The thermostat, which controls the flow through the radiator, is at the rear of this engine,

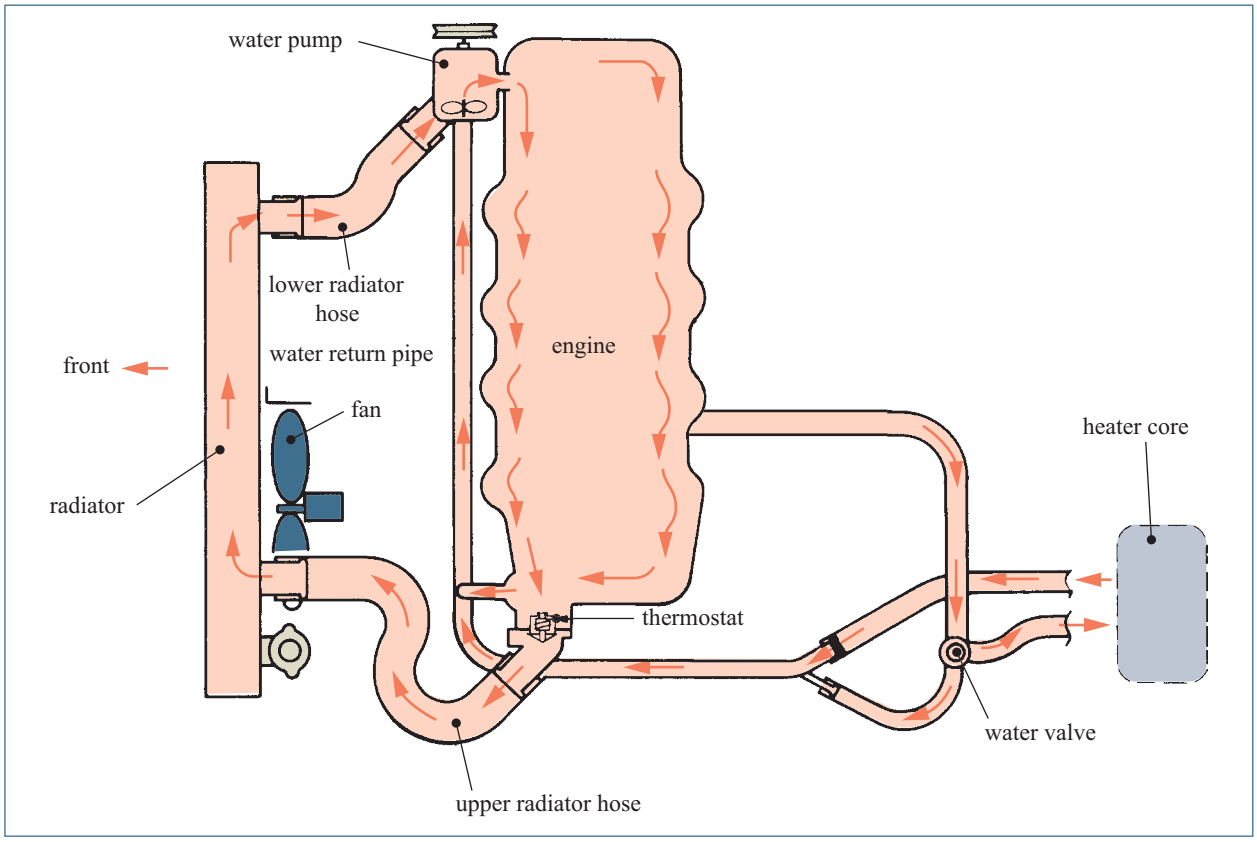


Figure 20.5 Diagram of a cooling system showing the coolant flow in the engine , radiator and heater core of the interior heater FORD

although in many engines it is at the front. When the engine is cold, the thermostat is closed. This blocks off the flow to the top of the radiator, and the pump circulates the coolant within the engine only. When operating temperature is reached, the thermostat opens and coolant circulates through the radiator too.

To provide heating inside the vehicle, small hoses carry coolant to and from the heater core, which is under the dash. The flow of coolant is controlled by the water valve.

20.6 Cooling-system components

20.6.1 Water-jackets

These are the spaces around the cylinders and within the cylinder head that carry the coolant. They are cast into the cylinder head and block during manufacture. Because the valve seats and guides need cooling, the head is designed to allow the coolant to reach them. There are coolant passages between the cylinder block and the cylinder head which direct the coolant flow.

20.6.2 Water pumps

Water pumps are usually mounted at the front end of the cylinder block, between the block and the radiator. Pumps consist of a housing with a coolant inlet and an impeller (Figure 20.6). Coolant enters the pump at the front of the impeller. When the impeller rotates, coolant between the blades is thrown outwards and forced through the pump body and into the cylinder block.

The pump inlet is connected to the bottom of the radiator by a hose, and coolant from the radiator is drawn into the pump to replace the coolant that is pumped through the engine.

The impeller shaft is supported in one or more bearings. A seal between the impeller and the housing prevents coolant from leaking out around the bearing. The pump shaft has a flange for a pulley that is driven by a belt from the crankshaft pulley.

Most water pumps are driven by an external belt, but Figure 20.7 illustrates a water pump driven by the timing belt. The pump is mounted to the front of the engine and fitted with a notched pulley which is engaged with the teeth of the timing belt.

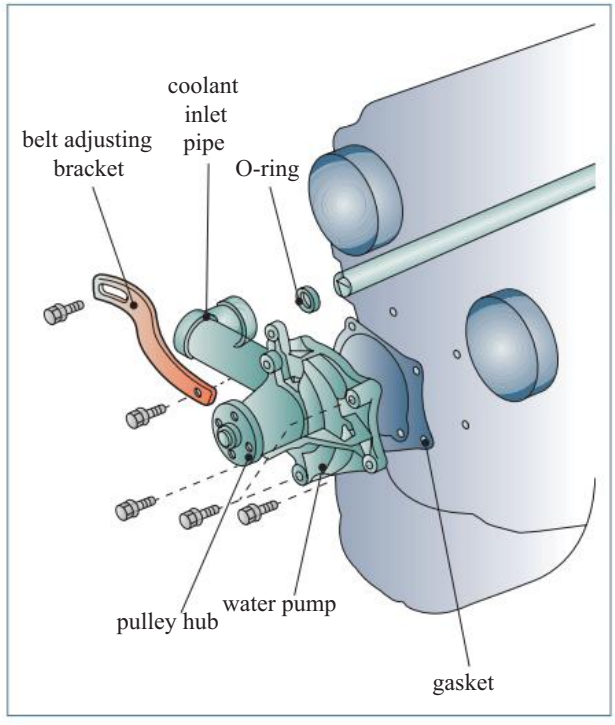


Figure 20.6 A water pump located on the front of the engine

20.6.3 Drive belts

Two types of belts are used for fans and water pumps:

1. V-belts. Friction between the sides of the belt and the sides of the pulley grooves enables drive to be transmitted from one pulley to another. V-belts have a wedging action in the pulley grooves that helps to prevent belt slip.
2. Ribbed belts. These are a combination of a flat belt and a V-belt (Figure 20.8). The pulleys used with the belts have a number of small grooves, and the belt has a number of small ribs to match.

⚠ Safety: When working with drive belts, always use safety glasses and beware of moving components like electric fans and drive belts.

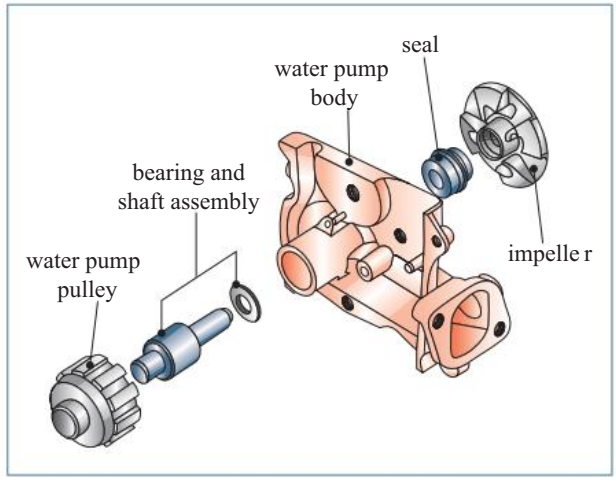


Figure 20.7 Parts of a water pump driven by the timing belt

The drive belt for the cooling system also drives other components such as the alternator, the power-steering pump and the air-conditioning compressor. Figure 20.9 shows a typical drive belt configuration for a serpentine belt, where one long belt is used to drive a number of pulleys. In other arrangements, two separate belts are used.

Handy hint: Long belts are also known as serpentine belts because they wrap around the pulleys like a snake.

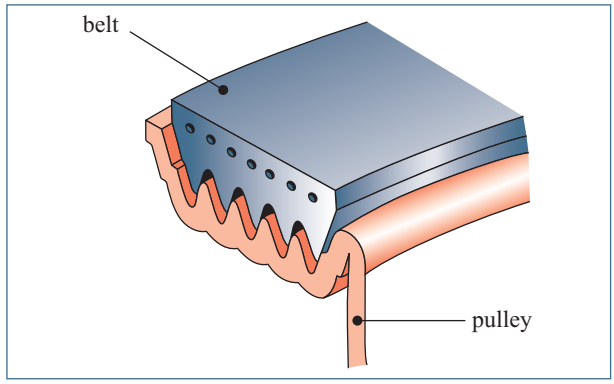


Figure 20.8 Section through a ribbed belt and pulley

20.6.4 Electric fans

Electric fans can be installed either in front of the radiator or behind it.

Figure 20.10 shows the components of an electric fan assembly, including an electric motor with a plastic fan fitted to its shaft, and a plastic shroud. The motor is mounted on the shroud, which is behind the radiator. Two of these fan assemblies can be located side by side.

Electric fans are used extensively on vehicles with transverse engines. This enables the fan (and the radiator) to be fitted to the front of the vehicle, something that would be difficult to achieve with a belt drive.

Fan operation and control

Figure 20.11 shows the basic arrangement of an electric fan and its controls. There are two parts to the electrical circuit:

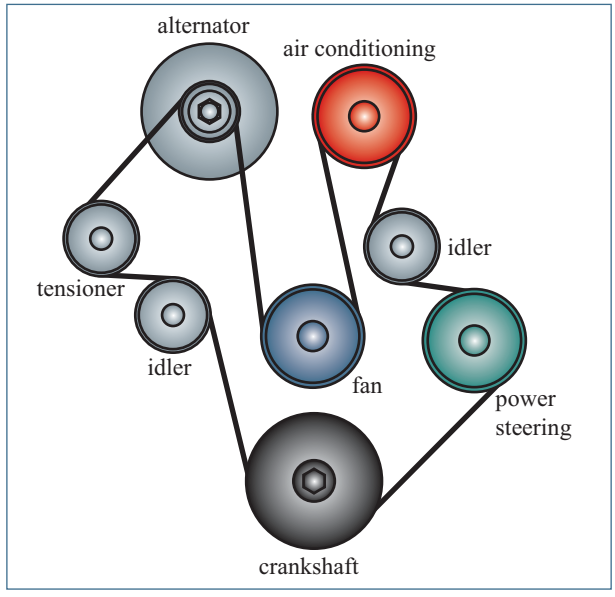


Figure 20.9 Serpentine drive belt for the cooling fan alternator, air conditioning and power steering

1 Fan operating circuit. This includes the fan motor, the fan relay and the fan switch. The circuit can be traced from the top fuse and connector to the fan motor, and then to earth through the fan relay. When the relay points are closed, the fan will operate.
2 Fan switch circuit. The switch circuit is from the bottom fuse through the windings of the relay to the fan switch and then to earth. It is a thermo switch whose end is fitted into the cooling system. The switch is normally closed, but it opens when the coolant temperature reaches a pre-set level such as 100 °C.

The circuit in Figure 20.11 is for a single-speed fan. Dual-speed fans have a two-stage fan switch and operate at a lower speed when less air is needed.

Fan switch operation

When the coolant temperature is less than 100°C, the fan switch is closed. Current flows from the fuse, through the relay windings and the fan switch to earth. This energises the relay windings and holds the relay points open so that the fan does not operate.

When the coolant reaches 100°C, the fan switch opens, the relay windings are de-energised and the relay points close. This completes the fan circuit to earth and the fan operates.

The fan continues to operate until the coolant temperature drops and the fan switch closes again. When this occurs, the relay windings are energised and the relay points open to stop the fan. The fan cuts in and out as the temperature of the coolant varies at the fan switch.

20.6.5 Thermostats

The thermostat brings the engine up to operating temperature as quickly as possible and keeps it there. It is usually located in a small housing attached to the cylinder head (Figure 20.12). The housing also includes the coolant outlet from the cylinder head to the radiator, and the thermo switch for the electric fan.

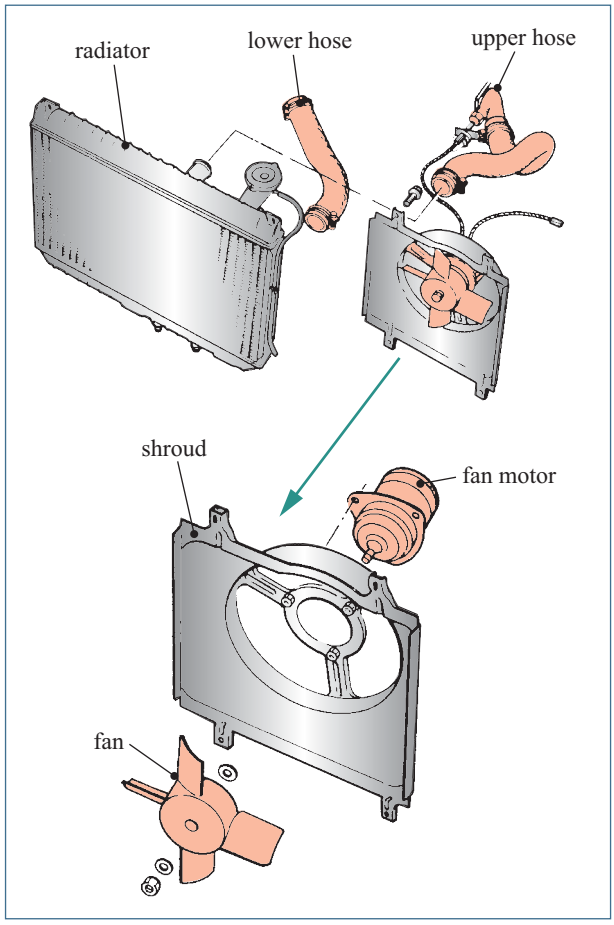


Figure 20.10 Electric fan and radiator assembly FORD

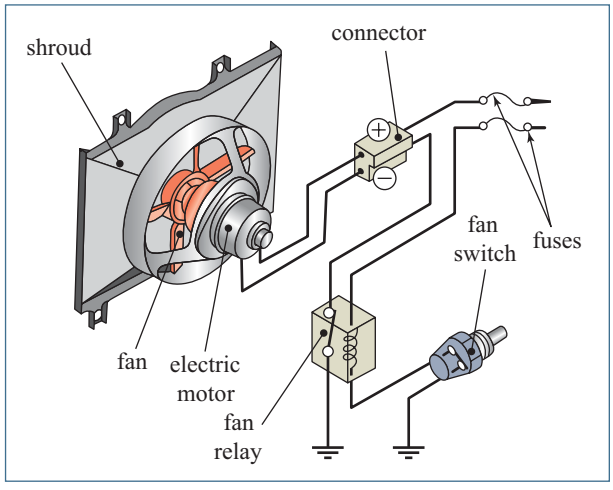


Figure 20.11 Electric fan and associated components FORD

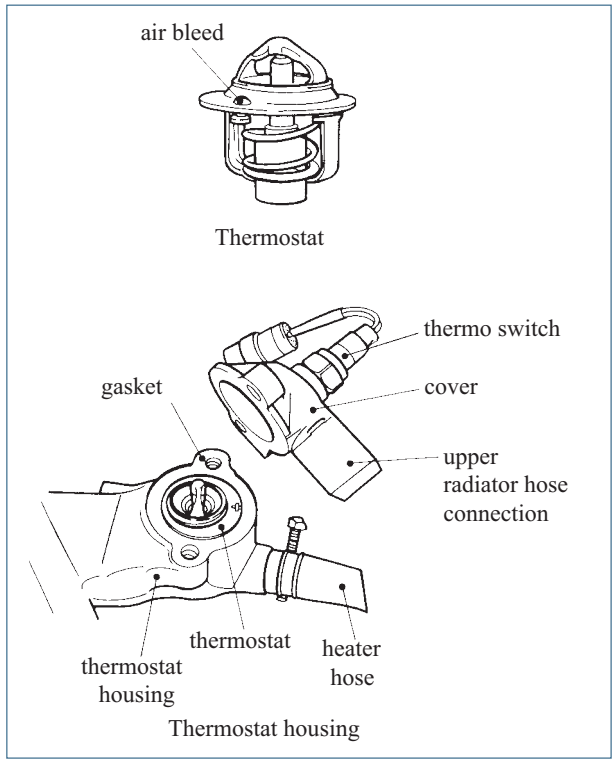


Figure 20.12 Thermostat and housing GM HOLDEN ITD

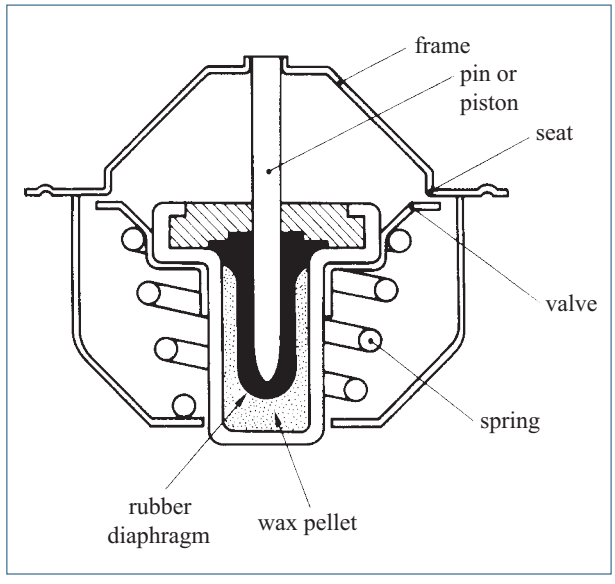


Figure 20.13 Construction of a wax-pellet thermostat

The thermostat consists of a temperature-sensitive device, which controls the opening and closing of a valve in the coolant passage.

The function of the thermostat is to close off the coolant outlet to the radiator when the engine is cold. This bypasses the radiator but allows the coolant to circulate within the engine. When the operating temperature is reached, the thermostat opens to allow the coolant to flow through the radiator.

Single-valve thermostats

Most thermostats are of the wax-pellet type (Figure 20.13). In the closed (cold) position, the valve is held on its seat by the spring so that coolant cannot pass through the thermostat. This blocks off the passage to the radiator, except for a small bleed hole.

As the temperature of the coolant increases, the wax in the pellet expands and applies pressure to the rubber diaphragm. This tries to force the pin out but it is fixed, so the pellet container moves downwards. This moves the valve off its seat, opening it and allowing coolant to flow to the radiator.

When the engine temperature drops, the wax in the pellet contracts and allows the spring to close the valve, blocking the flow of coolant to the radiator.

Bypass thermostats

Bypass thermostats increase cooling system efficiency by ensuring that all coolant passes through the radiator when the engine is at correct operating temperature.

This thermostat has two valves, a primary and a secondary. When the engine is cold, the primary valve is closed and this prevents fluid from reaching the radiator (Figure 20.14(a)). The secondary valve is open, allowing the coolant to bypass the radiator and go back into the engine.

As the engine temperature rises, the primary valve opens and the secondary valve closes (Figure 20.14(b)). This blocks off the bypass and all the coolant is then directed through the radiator.

These two types of thermostat are not interchangeable.

Handy hint: Thermostats are designed to open at specific temperatures. For example a thermostat designated as an 80°C unit will start to open between 78°C and 82°C and be fully open at 95°C.

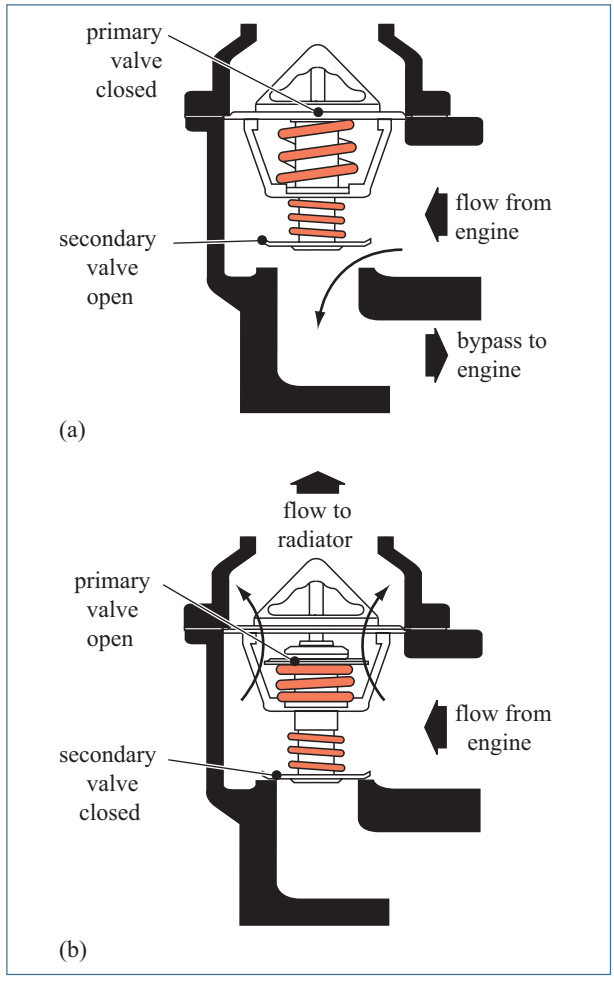


Figure 20.14 Bypass valve operation: (a) cold engine (b) warm engine TRIDON

Heated thermostats

Some systems are fitted with heated thermostats to improve cooling systems and engine efficiency. The thermostat housing shown in Figure 20.15 has a heating element controlled by the vehicle's electronic control unit (ECU).

One wire on the heating element receives battery voltage while the other is grounded through the ECU to control the opening of the thermostat. The thermostat operates normally when the coolant around it is heated. The heater typically operates when the engine is under heavy load and has not reached operating temperature.

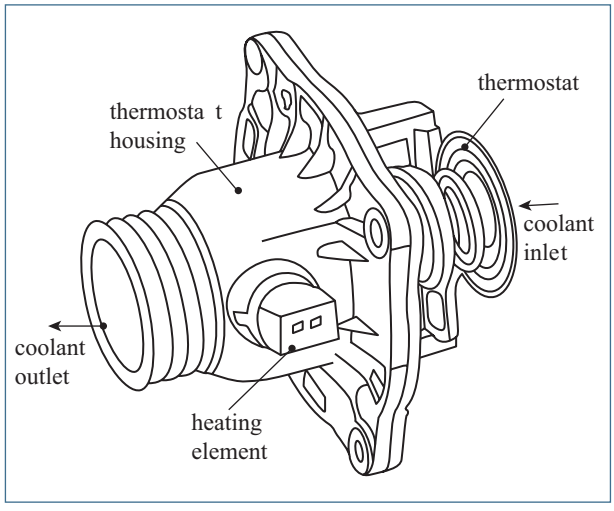


Figure 20.15 Electronically controlled heated thermostat

20.6.6 Temperature indicators

The cooling system has a temperature gauge, and sometimes a warning light. Any unusual rise in temperature should result in the engine being stopped and checked before serious damage occurs. A thermo-sensor in the radiator or cooling system operates the gauge or warning light on the instrument panel.

20.6.7 Interior car heater

Vehicle interior heaters have a small radiator that transfers heat from the cooling system to the passenger compartment of the vehicle. Hot coolant from the engine is circulated inside the radiator and a small electric

fan blows air through the radiator (Figure 20.16). The air absorbs heat so it is warm when it enters the passenger compartment of the vehicle.

The coolant to the heater can be turned off by a shut-off valve which is operated by the heater controls. Air flow volume can be controlled by altering the motor speed. Its direction is controlled by opening and closing shutters in the ducting it flows through.

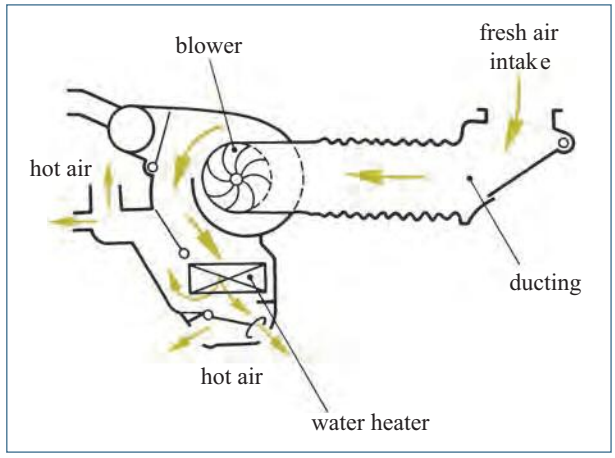


Figure 20.16 Principle of a car interior heater FORD

20.7 Radiator assembly

The radiator consists of two tanks and a core. The core is made up of a number of tubes, which carry the coolant between the tanks. Air from the fan, and also from vehicle movement, passes between the tubes, removing heat from their coolant. The tubes have fins which increase the surface area over which the air flows, enhancing heat transfer.

There are two designs of core: those with centre fins and those with horizontal fins. Each has a slightly different construction. Passenger cars and light commercial vehicles usually have cores of the tube and centre-fin type, as shown in Figure 20.17. Here, the fins are corrugated strips between the tubes. There can be a single row of tubes, or two or more.

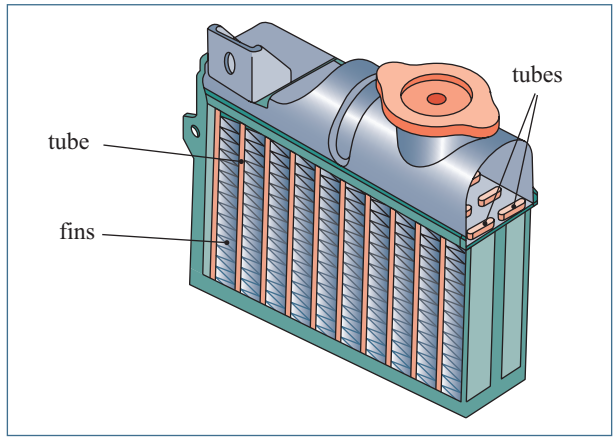


Figure 20.17 Radiator core with a double row of tubes

20.7.1 Crossflow radiators

Many radiators have a top tank and a bottom tank and a vertical core, but crossflow radiators have a tank at each side. The coolant flows horizontally from one side to the other; in other radiators, it flows vertically. A crossflow radiator is illustrated in Figure 20.18. The design enables the use of wider but lower radiators.

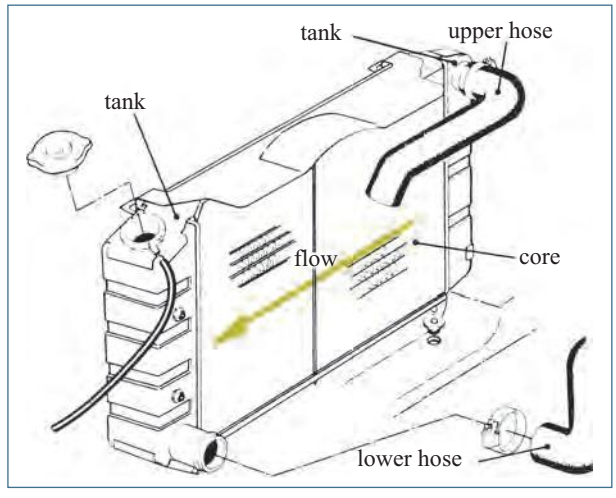


Figure 20.18 Crossflow radiator–coolant flows through the core from one side to the other FORD

20.7.2 Automatic transmission cooler

Some radiators for vehicles with automatic transmissions have a heat exchanger in the lower radiator tank. This removes heat from the automatic transmission fluid. Pipes from the automatic transmission carry fluid to and from the heat exchanger. This is hotter than the coolant, so heat is transferred to the coolant as the fluid passes through the heat exchanger.

The radiator in Figure 20.34 has an automatic transmission oil cooler.

20.8 Radiator pressure cap and reservoir

A pressure cap is used on the radiator to hold pressure in the system and so raise the boiling point of the coolant. This enables the engine to operate at higher temperatures without the coolant boiling. At no pressure, water boils at 100°C. When enclosed in a container such as a radiator at a pressure of 50 kPa, the boiling point is raised to 112°C.

The higher coolant temperature also improves heat transfer from radiator to air. This is because there is a greater difference between the temperature of the coolant and that of the cooling air passing through the radiator.

Handy hint: Increasing the pressure of water in a container naturally increases its boiling point. As coolant consists mostly of water, **its boiling point is increased in a sealed cooling system.**

20.8.1 Radiator cap operation

The operation of a radiator cap is shown in Figure 20.19. It has two valves: a pressure valve and a vacuum valve. The coolant expands and contracts as it is heated and cooled, so coolant is passed to and from the radiator and reservoir.

1. Pressure valve. This is held closed by a calibrated spring, which determines the pressure in the system. When the system pressure is reached, the pressure valve is lifted from its seat. This releases coolant from the radiator to the reservoir and prevents excessive pressure in the system.
2. Vacuum valve. When the engine cools and the pressure drops, the vacuum valve opens to allow coolant back into the radiator. Thus the system remains full and is pressurised when the engine is running.

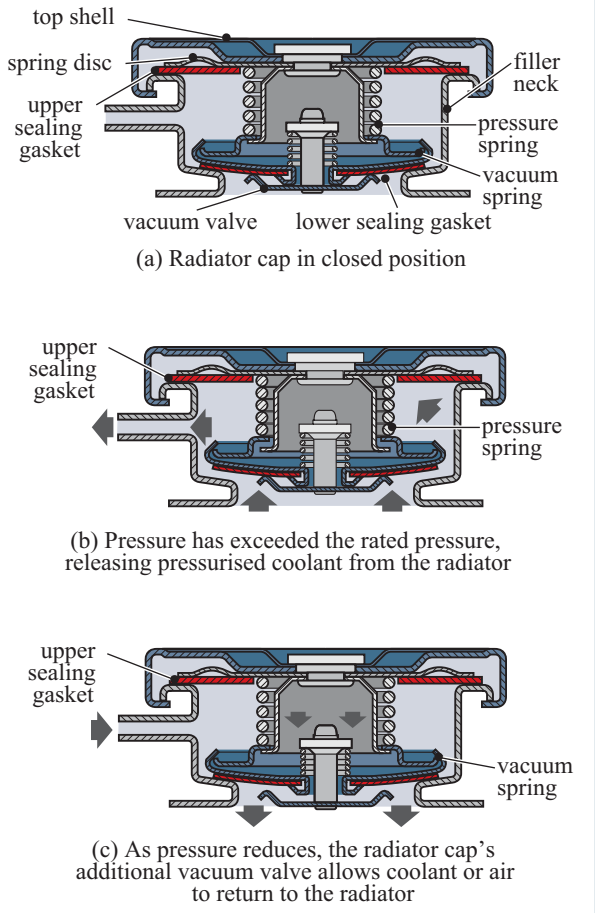


Figure 20.19 Operation of the valves in a radiator cap TRIDON

Pressure and boiling point

Radiator caps are made in various pressure ratings, as shown in Table 20.1. The boiling point of the coolant in the radiator is raised as shown. This can be compared with water in an open container which, at sea level, normally boils at 100°C.

Table 20.1 Radiator cap pressure ratings

Cap pressure rating (kPa)	Approximate boiling point (°C)
30	108
50	112
70	116
90	120

20.8.2 Coolant reservoir

Sealed coolant systems have a reservoir connected to the vent under the pressure cap in the top radiator tank (Figure 20.20). This is usually made of plastic so that the level of coolant can be seen. High and low levels are marked on the outside of the reservoir.

When the vehicle is operating, the coolant is heated and it expands. When the pressure lifts the valve in the pressure cap, some coolant will flow from the radiator into the reservoir, raising the level in the reservoir.

When the vehicle is stopped, the temperature of the coolant in the system drops and coolant is drawn from the reservoir back into the radiator. With this arrangement, the cooling system is constantly completely full. Sealed systems not only keep the system full of coolant to provide more efficient cooling but they also exclude air from the system, and help to reduce the effects of oxidation and corrosion.

20.8.3 Header tanks

Some systems use a pressurised coolant reservoir as the header tank instead of it being part of the radiator. The tank, fitted with a pressure cap, must be the highest part of the cooling system. Any air in this system is removed by self-bleeding.

Handy hint: The radiator cap should not be removed to check the coolant level. This should be done by checking the level at the reservoir.

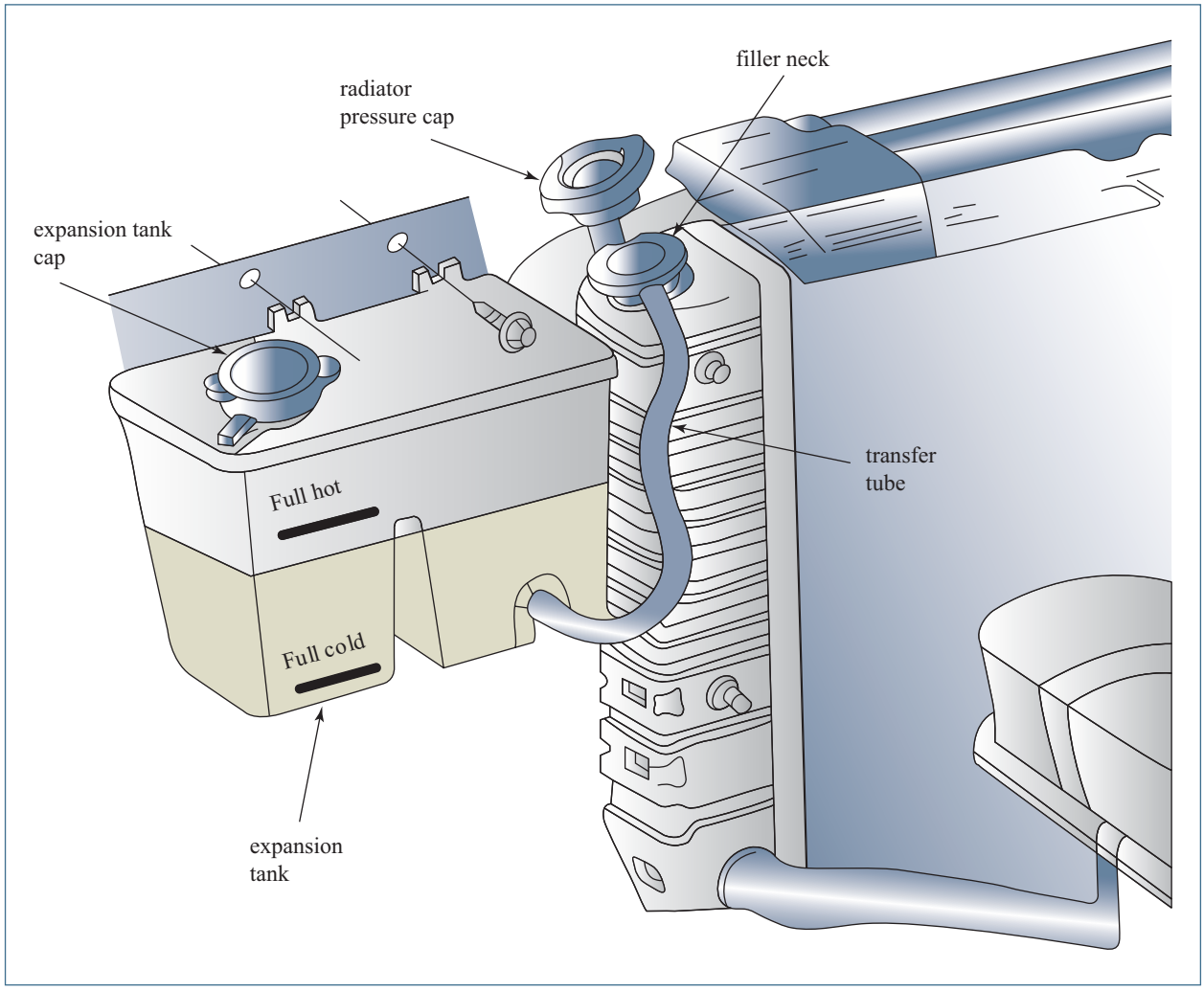


Figure 20.20 Coolant reservoir

20.9 Coolant

Coolant is a mixture of water and chemicals (Figure 20.21). Distilled or deionised water is used as it is free of harmful chemicals. The coolant mixture protects against corrosion and acts as an antifreeze.

The chemical additives, or inhibitors, protect the cooling system from corrosion and keep it clean. They are needed in the coolant because of the different types of metals used in the cooling system. Without protection, different metals can react with each other.

Aluminium cylinder heads and other aluminium parts, such as coolant outlets, would soon corrode if water were used instead of a proper coolant mixture.

Figure 20.21 Coolant is the correct mixture of distilled or deionised water and chemical inhibitor

20.9.1 Antifreeze

The chemicals in the coolant also act as an antifreeze. Antifreeze solutions are required to prevent the water freezing when temperatures drop below 0°C, which could expand and damage the cylinder block or the radiator.

There are three main types of antifreeze:

- ethylene glycol
- organic acid technology (OAT)
- hybrid OAT.

Before the advent of long-life coolant, the most common type was ethylene glycol-based antifreeze. The ethylene glycol materials are permanent because they do not evaporate when heated to the boiling point of water. Silicate and phosphate are added as corrosion inhibitors. These are effective but have to be changed frequently.

Antifreeze materials are mixed with water in various proportions. The lower the temperature, the higher the percentage of antifreeze material needed to prevent the mixture from freezing.

For most products, the coolant mixture is 30% additive and 70% water. For very cold conditions, a mixture of 50% additive and 50% water is used.

Organic acid technology

Organic acid technology (OAT) coolants are longer lasting and are referred to as extended-life coolants. They do not usually contain silicate or phosphates but use organic acids as corrosion inhibitors. These chemicals are slower acting so they extend the service life of the coolant. OAT coolants give good protection for cast iron and aluminium but are not as good for copper, brass and solder, so they might not offer the best protection for older vehicles.

Hybrid OAT coolants use different organic acids from standard OAT coolants, as well as some silicates to improve protection of aluminium surfaces.

Handy hint: Adding corrosion inhibitors and antifreeze chemicals to water also increases its boiling point, although this is not the main reason for using a coolant mixture.

20.10 Cooling-system service

Maintenance checks and servicing of the cooling system include the following:

1. Check the coolant level and condition.
2. Pressure test the system for coolant leaks.
3. Check for combustion gas leakage into the cooling system.
4. Check the radiator and cap.
5. Check the condition of hoses.
6. Check the condition and tension of the fan belt, water pump and belt.
7. Check fan operation.
8. Test the thermostat operation.
9. Drain and flush the cooling system.
10. Check the coolant level.
11. Renew and refill coolant.

In most systems, the coolant level can be viewed via the plastic reservoir. The maximum and minimum levels are marked, and the coolant should be above the minimum when the vehicle is cold. The radiator cap should not usually be removed to check the coolant.

Safety: When carrying out a cooling system service, beware of possible burn injuries from working with pressurised hot cooling systems. Always follow correct work practices for de-pressurising the cooling system.

20.10.1 Checking the coolant condition

Coolant should be replaced if it is discoloured or over the service schedule limit. Most coolants have a limit of two years. If the coolant is not discoloured, the concentration of additive should be checked. This can be done in a number of ways.

Figure 20.22 shows a hydrometer being used to check the percentage of coolant additive. The hydrometer has five coloured discs that float at different concentrations of coolant.

Safety: All coolant must be captured via the use of drip trays. It must be correctly disposed of and/or recycled as per EPA regulations.

Removing the radiator cap

Care should be taken when removing a radiator cap when the engine is hot. It should not normally be removed unless the engine is cool and there is no pressure in the system, but if it does have to be removed, proceed carefully, as follows:

1 Cover the cap with a piece of cloth to prevent burns to the hands and coolant spraying onto the arms and face .
2 Turn the cap only to the first stop and wait so that pressure in the system can be released through the overflow tube .
3 Turn the cap further to remove it.

20.10.2 Pressure testing the cooling system

A pressure tester (Figure 20.23) consists of a small hand pump with a pressure gauge that fits onto the radiator or the header tank, and an adaptor for the radiator cap. It can be used as follows to test the cooling system for both external and internal leaks:

1 Fit the pressure tester instead of the radiator cap and apply a pressure slightly above the normal operating pressure (Figure 20.23(a)). If the pressure holds steady , the system is not leaking.
2 If the pressure drops, check for external leaks at hose connections, core plugs, the water pump and the radiator .
3 If no external leaks are evident, then either a faulty cylinder-head gask et or the more serious problem of a crack ed cylinder head should be suspected.
4 The radiator cap can be pressure tested using the adaptor (Figure 20.23(b)). The cap is tested to see that it holds pressure and that the relief valve opens at the rated pressure . A cap should be discarded if it does not test correctly , if it is damaged or corroded, or if the seals have swollen.

20.10.3 Checking for internal leaks

Where an internal leak is suspected, the engine oil can be checked for coolant. If coolant has found its way into the oil pan, the dipstick could show overfull and the oil will be emulsified.

Run the engine until operating temperature is reached. Accelerate it sharply several times and check for abnormal discharge of water through the exhaust tailpipe, which could indicate a faulty cylinder-head gasket or cylinder head.

Handy hint: Small quantities of water that come from the exhaust pipe when the exhaust is cold are the result of condensation occurring in the exhaust system and should not be confused with a coolant leak.

Figure 20.22 Using a hydrometer to check the percentage of coolant additive

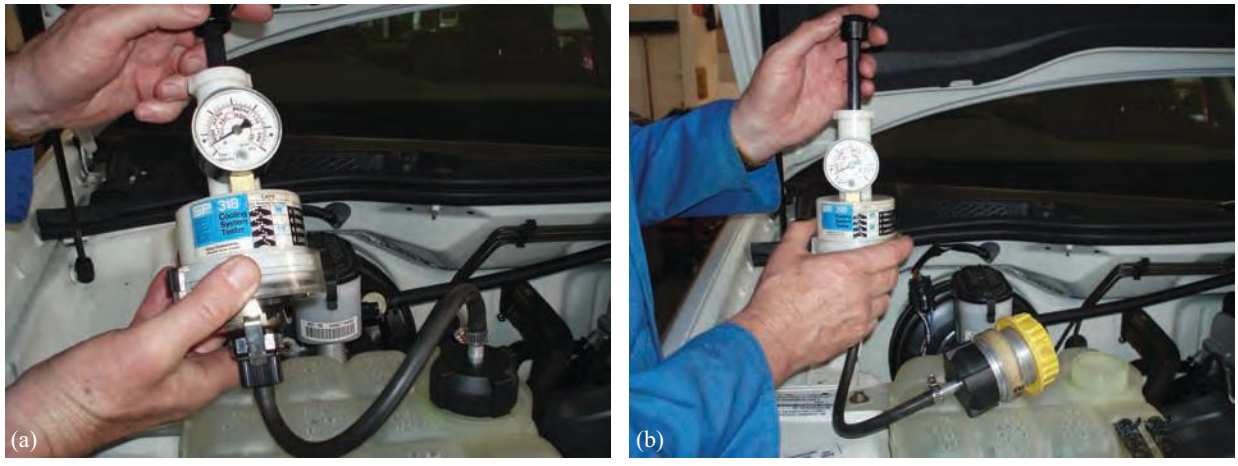


Figure 20.23 Pressure testing: (a) checking the cooling system (b) checking the radiator cap

20.10.4 Checking for combustion gas leakage into the cooling system

A defective cylinder-head gasket can allow combustion gases to leak into the cooling system. Apart from forcing coolant from the system, the gas can form acids, which can cause corrosion.

A general test for gas leakage can be made by running the engine with the radiator cap removed. The coolant in the radiator tank is checked for bubbles or any rise in level that may not be due to normal circulation by the water pump. Another method is to check for hydrocarbons (HC) in the coolant. A leaking head gasket will allow small traces of unburnt fuel (hydrocarbons) into the cooling system. Figure 20.24 shows a combustion leak detector being used on the radiator. The test fluid in the detector will change colour when hydrocarbons are detected.

The pressure tester can also be fitted to the radiator when the engine is cold. Start the engine and observe the pressure gauge. A slow rise in pressure as the engine warms up is normal. A sharp rise in pressure indicates combustion pressure in the cooling system, normally from a faulty head gasket.

Figure 20.24 Combustion leak detector

20.10.5 Checking the radiator

Leaks in the radiator can become noticeable as corrosion or scale on the tubes and fins below the leak. Corrosion can also appear around a leak at the joint of the core and the tank.

A radiator can be tested by removing it from the vehicle and immersing it in water. The openings to the tanks are sealed off and air pressure is applied at about 70 kPa. Air bubbles will identify any leaks.

The radiator core can be cleaned externally by carefully blowing through the core from the rear to the front to dislodge dust, insects or any other matter which could restrict airflow.

Handy hint: Send the radiator to a radiator specialist to inspect and clean it, and report on how blocked the radiator cores are, to help identify any possible overheating problems.

20.10.6 Checking drive belts

The drive belt should be checked to make sure that it is in good condition. Various belt conditions are shown in Figure 20.25. These are for a V-belt, but ribbed belts can suffer from the same conditions. A belt that has deteriorated should be discarded as it could slip and break and cause overheating. Where the belt drives the alternator, pulley slip could lead to a discharged battery.

The drive belt must be correctly adjusted. If it is too tight, excessive loading will be placed on the water pump and alternator bearings. If the belt is too loose, slipping will occur. The basic adjustment is shown in Figure 20.26. The belt should be able to be deflected about 10 mm without applying undue force. When a new belt is first installed, it should be adjusted tighter than a worn belt, to allow for stretching.

A special belt tension gauge (Figure 20.27) can be used to adjust belts. The gauge is placed on the belt and force is applied to deflect the belt. The force

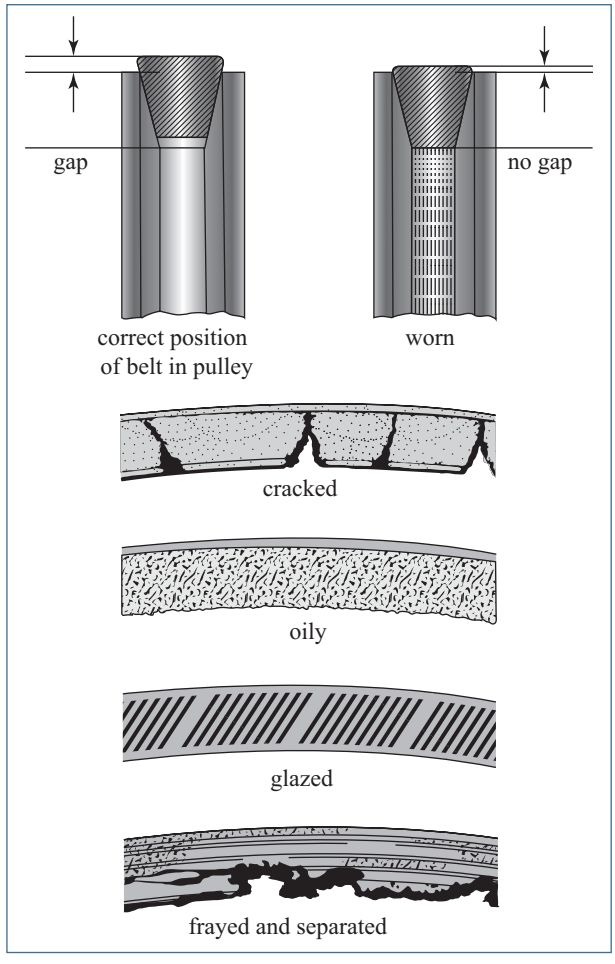


Figure 20.25 Possible conditions of V-belts

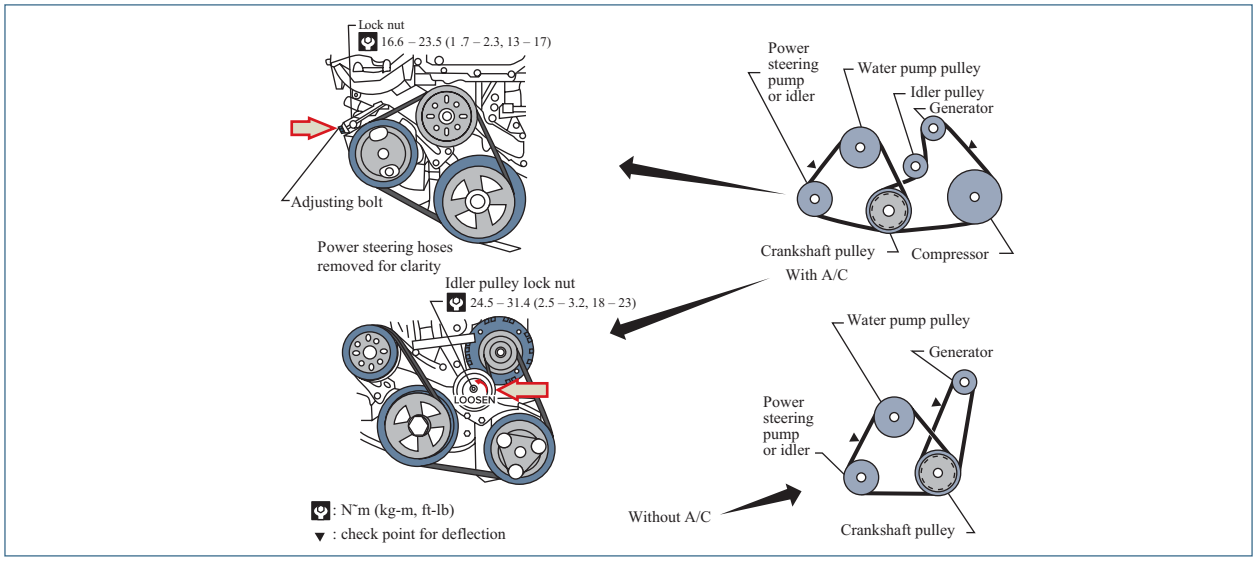


Figure 20.26 How to check, tighten or replace a V -type drive belt

can be read directly from a scale on the gauge. Belt tension gauges are normally used for air-conditioning drive belts that require higher tension than fan belts.

Automatic adjustment

Some ribbed belts use an automatic tensioning device in the form of a pulley running on the back of a belt. This is spring loaded and maintains the correct tension on the belt at all times. A pointer on the engine and a mark on the tensioner will indicate when the belt is due for replacement, as shown in Figure 20.28.

Figure 20.27 Fan belt tension gauge SNAP-ON

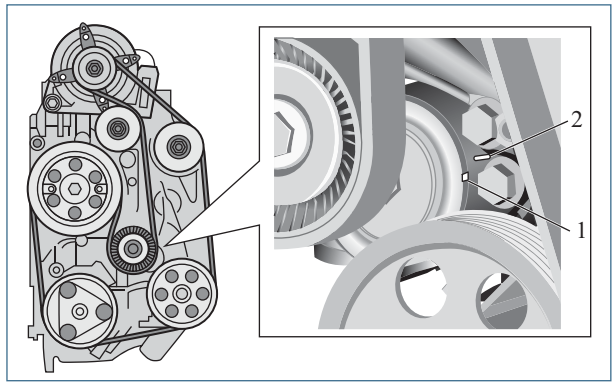


Figure 20.28 Automatic belt tensioner for a ribbed belt. When the tensioner mark (1) aligns with the engine pointer (2) the belt is due for replacement

20.10.7 Belt replacement

Only use the correct replacement belt, which should be the right length to allow for easy fitting and adjustment as it wears. Check the fit of the belt in the V of the pulley (see Figure 20.25). Also check the idler pulley bearings for smooth operation and replace if necessary.

Non-adjustable belts that require different fitting methods are now available. Always check with manufacturers about correct fitment.

20.10.8 Fan operation

Fan blades should be checked, as any damage will cause vibration and water pump failure. Clutch drive fans should also be checked if they work at engine operating temperatures. With the engine switched off, they should be difficult to turn by hand when hot.

Electric fans should be checked for correct rotation in relation to the air flow. Also make sure that the temperature sensor cuts in at the correct temperature.

These temperatures are usually stamped on the flange of the thermostat.

20.10.9 Thermostat operation check

Operation of the thermostat can be checked by suspending it by a wire in a pan of water and heating it as shown in Figure 20.29. A thermometer is used to show the temperature at which the thermostat starts to open, as well as the temperature at which it is fully open. These temperatures are usually stamped on the flange of the thermostat.

20.10.10 Water pump check

The most likely water pump faults are leaks and noise. Leaks are usually more noticeable cold, and the first indication may be loss of coolant after the vehicle has been standing overnight.

Handy hint: Noise from the bearing is a dull rumble . Noise from the seal is more high-pitched.

20.10.11 Draining and flushing the cooling system

A cooling system showing signs of rust or corrosion can be cleaned with special chemical radiator cleaners and then flushed with water using a normal water hose.

Flushing equipment that uses compressed air and water pressure is also used. Air pressure creates surges of water, helping to dislodge scale and corrosion. The radiator and the water-jackets are usually flushed separately.

Figure 20.30 shows the arrangement for a radiator being reverse-flushed. Air and water pressure are being applied to the bottom of the radiator and a hose has been connected to its top to carry the water away.

The water-jackets in the engine can be flushed similarly. During flushing and cleaning, the interior heat control should be turned to the hot position so that water will circulate through the heater.

Handy hint: Changing the coolant at regular intervals, and using deionised water and a suitable antifreeze/inhibitor will keep the internal parts of the cooling system in good condition.

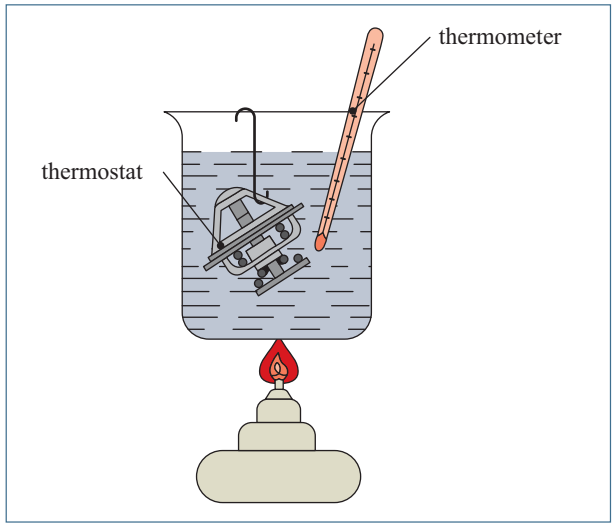


Figure 20.29 Testing a thermostat in hot water

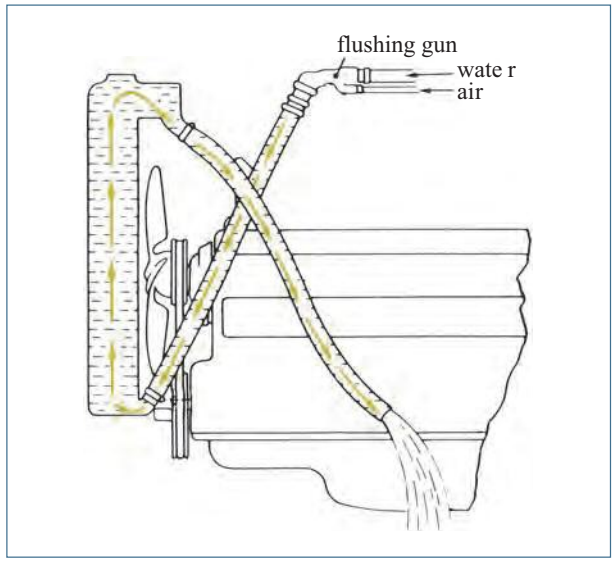


Figure 20.30 Method of reverse-flushing a radiator

20.10.12 Renewing and refilling coolant

Always refill with coolant of the correct concentration of additive to suit the engine and operating conditions. Mix the coolant and follow this procedure:

1 Check all hoses and fittings for security .
2 Open the heater control to 'hot' .
3 Slowly fill the system until the coolant reaches the neck of the radiator or the header tank is on the full mark. A radiator fill kit, as shown in Figure 20.31, may be necessary when the radiator is lower than the engine .
4 Start the engine with the radiator cap removed and top up if necessary .
5 Fit the radiator cap and allow the engine to reach operating temperature . Some systems require air to be bled from the highest point, as shown in Figure 20.32.
6 Check for leaks and top up to the full mark when the engine has cooled.

A pressure tester should be used to check for leaks prior to starting if major repairs have been carried out.

20.11 Cooling-system repairs

20.11.1 Removing and replacing the radiator

Figure 20.33 shows a typical radiator assembly with an electric fan. The radiator is mounted in rubber insulators at the top and bottom. It is not bolted firmly to the body but is allowed a small movement in the insulators. This allows it to become a form of vibration damper, which helps absorb some of the engine vibrations.

Figure 20.31 Filling the cooling system using a fill kit

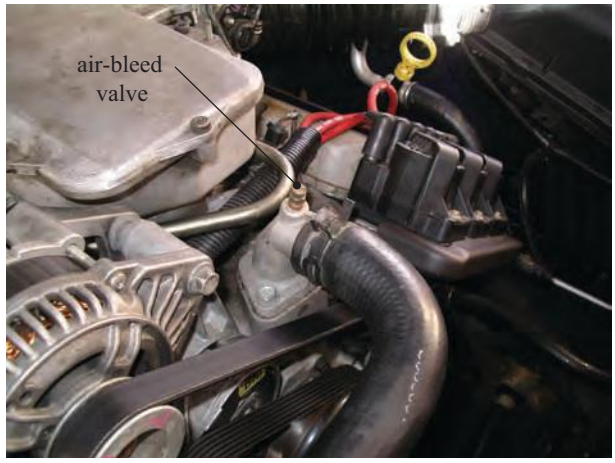


Figure 20.32 Air-bleed valve

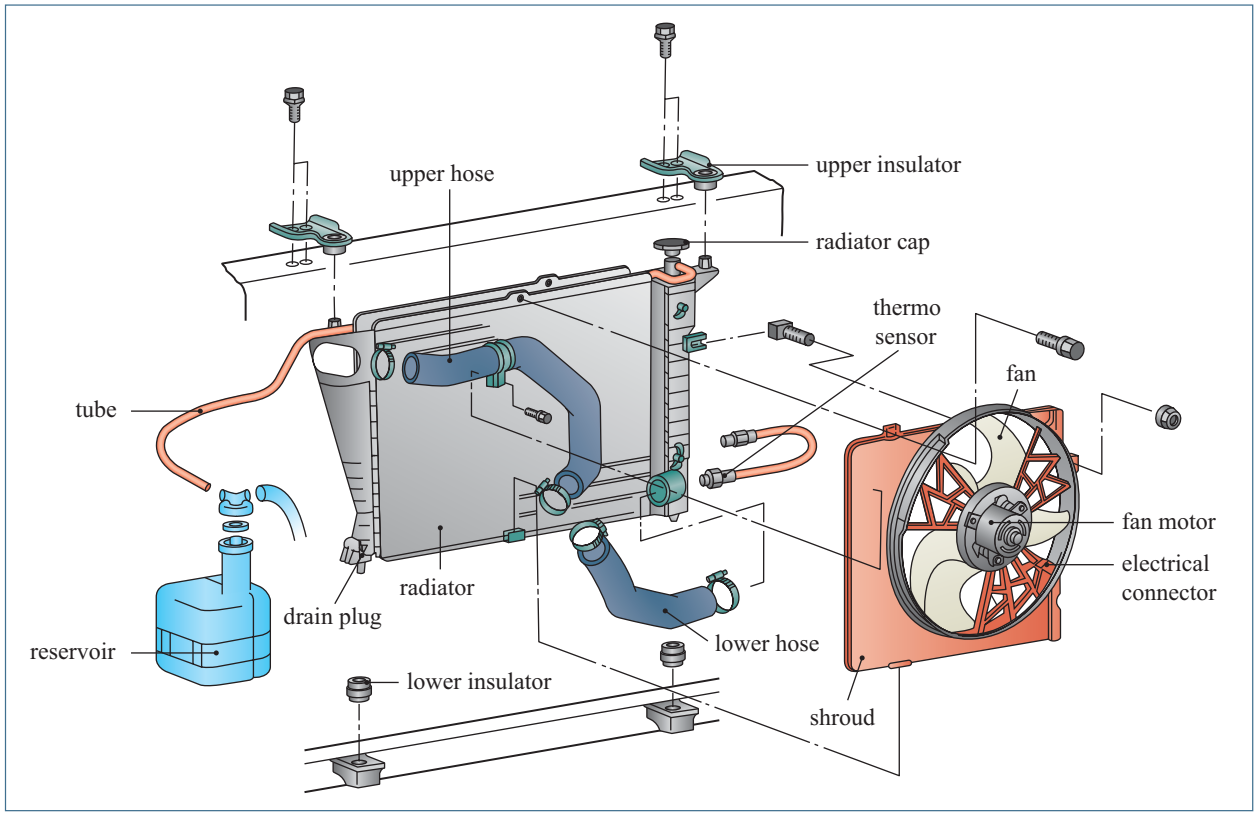


Figure 20.33 Radiator assembly components

The general procedure for removing a radiator is as follows:

1 Drain the coolant.
2 Remove the upper and lower radiator hoses.
3 Remove the automatic transmission cooler hoses (where fitted).
4 Disconnect the overflow tube from the reservoir .
5 Disconnect the electrical connection from the thermo sensor .
6 Remove the electric fan and shroud from the rear of the radiator (and also from the front, if one is fitted).
7 Unbolt the upper insulator brack ets from the body member .
8 Lift the radiator out of the lower insulators.

To replace the radiator, use the reverse procedure, with attention to the correct fitting of hoses and tightness of hose clamps. After filling with coolant, run the engine then recheck to make sure the system is actually full, and that there is no air trapped within it.

20.11.2 Radiator repairs

Radiators with metal cores and metal tanks have the tanks soldered to the core. These can be separated by melting the solder. With the tanks removed, the tubes of the core can be cleaned, or a new core fitted. When the tanks are refitted, they are soldered to the core.

Radiators are also made with aluminium cores and plastic tanks. Figure 20.34 shows a crossflow radiator of this type. It has an oil cooler for the automatic transmission fluid in one of the side tanks.

The plastic tanks are flange-mounted to the aluminium core and secured by clinch tabs that are formed as part of the core. When the radiator is assembled, the tabs are bent over the flanges of the tanks. To make the joints coolant-tight, high-temperature rubber seals are used between the core and the side tanks.

The tanks can be removed by levering the clinch tabs away from the tanks. During assembly the tabs are bent over the edges of the tanks to secure the core to the tanks and compress the seal. Pliers, or a special clamping tool, are used to bend the tabs into place.

20.11.3 Replacing the core plugs (Welch plugs)

Core plugs that show signs of corrosion or leaking need to be replaced. Plugs can be removed by drilling a hole in the centre and levering them out using a pry bar. The recess should then be cleaned and the replacement plugs coated with a water- and heat-resistant sealant before installation. Cup types can be fitted with a socket and hammer. Disc types require expanding in the recess. This can be done by using a large flat punch with a hammer in the centre of the disc.

20.11.4 Metal loss in the cooling system

1. Corrosion. This occurs when a material reacts chemically with its surroundings. Water and oxygen normally combine with a metal to form an oxide of the metal. Corrosion weakens the metal and if it is not treated it will eventually cause failure of the component. Coolant loss and poor coolant condition are major causes of corrosion.
2. Cavitation. This is the implosion of small vapour bubbles against a metal surface causing erosion of the metal particles. Cavitation is caused by changes in pressure of the coolant and usually occurs around the water pump impellor. Correct pressure in the cooling system is the method of solving the problem.
3. Electrolysis. This is the loss of metal particles, especially soft metals such as aluminium and solder, by electrical action in the cooling system. The electrical source can be from inside or outside the cooling system.

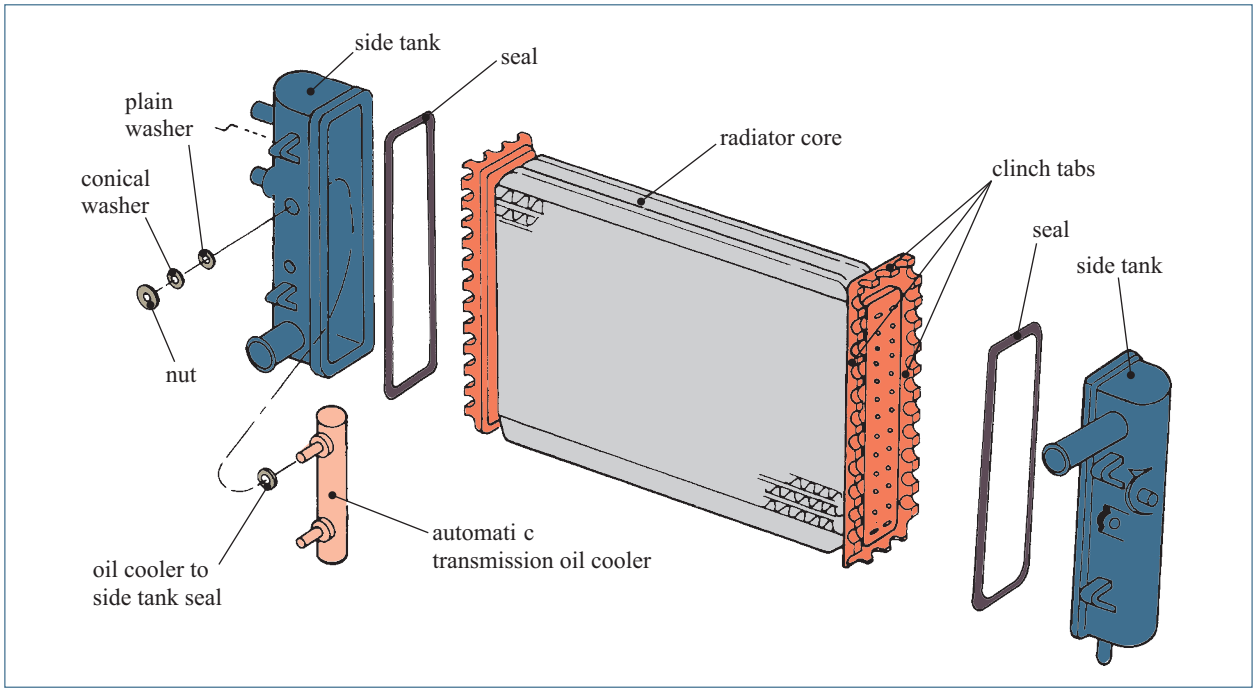


Figure 20.34 Radiator assembly with an aluminium core, plastic side tanks and an automatic transmission cooler
GM HOLDEN LTD

External sources can be cooling fans or lights with an electrical fault seeking an earth path through the coolant and radiator core. Internal electrical sources of metal loss are usually caused by poor coolant condition. Check the coolant condition using a coolant hydrometer. Discoloured coolant should be replaced and the cooling system flushed.

20.12 Cooling-system problems

Figure 20.35 gives an easy to follow diagnostic procedure for the three main cooling system problems: overheating, loss of coolant and slow warm-up.

20.12.1 Overheating

Overheating is indicated by a high temperature-gauge reading, its main causes being loss of coolant and accumulation of rust and scale in the system. These will restrict coolant flow, and particles carried into the radiator tank will clog the tubes.

Overheating can sometimes be caused by a fault in the ignition or fuel systems. Any loss of power could cause a heating problem, but poor engine performance should be more noticeable than overheating.

Safety: An infra-red thermometer can be used to check and diagnose cooling system problems as it eliminates the danger of coming into contact with hot surfaces.

20.12.2 Coolant loss

Coolant loss is indicated by the need to constantly top up the coolant in the reservoir. Bad coolant leaks are easy to find, but leaks which occur only under operating pressure are more difficult to locate, and the system has to be pressure-tested.

External leaks could come from the radiator, water pump, hose connections or core plugs in the cylinder block or head. Internal leaks could be due to a faulty cylinder-head gasket, a cylinder head with a warped surface or enlarged water passages in the cylinder head and water pump due to corrosion. Less well-known causes of metal loss are cavitation or electrolysis. Internal leaks can often be detected by running the engine at fast idle and looking for the formation of bubbles in the radiator.

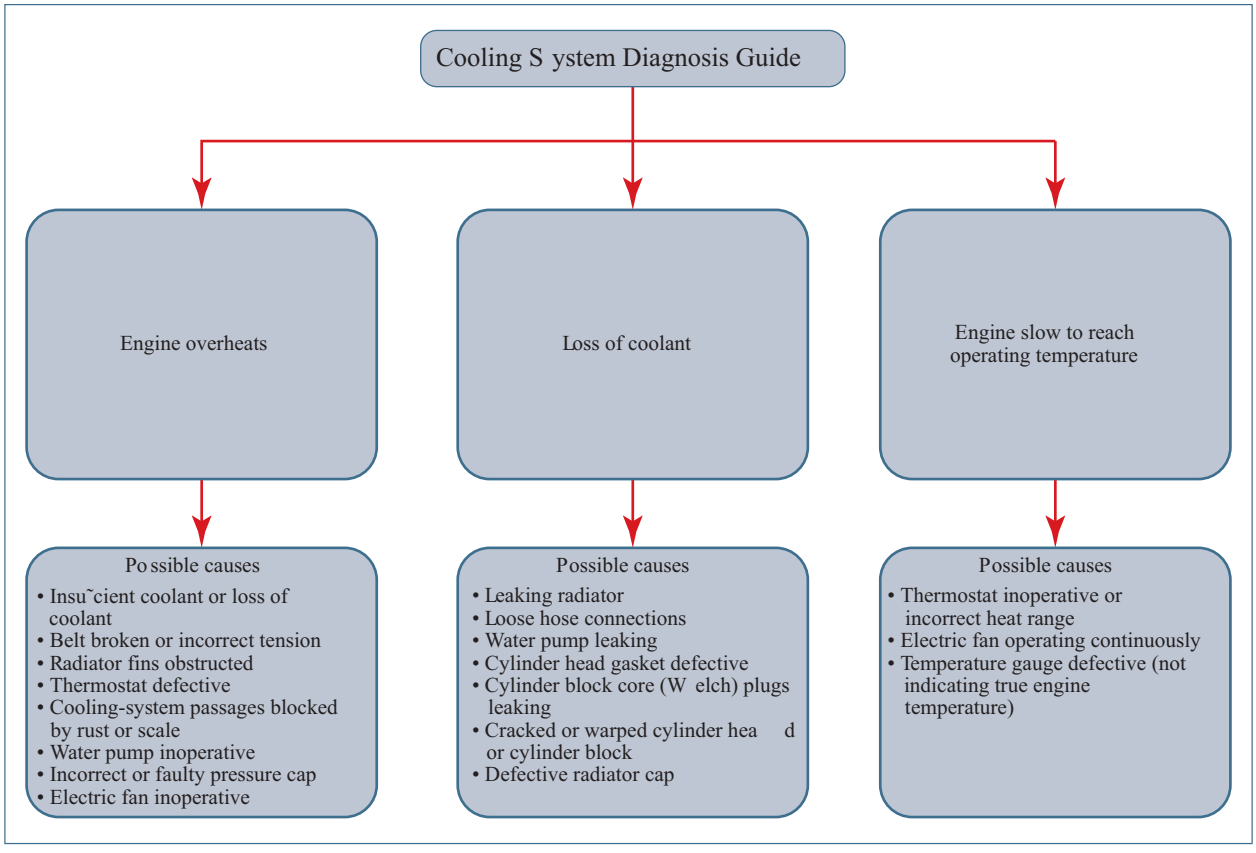


Figure 20.35 Diagnostic guide to cooling system problems

Oil in the radiator can indicate a leaky cylinder-head gasket, or a faulty automatic transmission oil cooler. Where an engine-oil cooler is fitted, a leak in the cooler could allow engine oil to mix with the coolant. Water formation, emulsified oil or an overfull reading on the engine-oil dipstick could be the result of an internal leak.

20.12.3 Slow warm-up

The likely cause of a slow warm-up is that the thermostat is faulty and not closing, or that it has been removed. The silicone clutch on a variable-speed fan could be faulty, or an electric fan may not be cutting out when the engine is cold.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify the seven basic liquid-cooling system components
- explain why cooling systems are necessary
- describe the difference between heat and temperature
- describe the four main effects of heat
- describe heat transfer via conduction, convection and radiation
- demonstrate how to carry out a cooling system service and repairs to industry standards
- diagnose cooling system problems.

REVIEW QUESTIONS

1 Name the basic parts of a liquid-cooling system.
2 What is the difference between heat and temperature?
3 What are the four possible effects of applying heat to a material?
4 What effect occurs when the temperature of water is reduced?
5 Heat can be transferred in three different ways. What are these?
6 What is radiation?
7 Briefly, how does a variable-speed fan operate?
8 Where are electric fans located?
9 How is heat removed from an engine?
10 How does a water pump operate?
11 What is a water-jacket?
12 Where is a thermostat located?
13 How can a thermostat be checked?
14 How does a bypass thermostat increase cooling system efficiency?
15 Why are pressure caps used on radiators?
16 How is a pressure tester used to check a cooling system?
17 What is reverse flushing a cooling system?
18 Why are additives used with water in the cooling system?
19 State two types of core (Welch) plugs.
20 What are the possible causes of engine overheating?
21 What is stray or transient electric current in the cooling system?

CHAPTER 21

Engine-lubricating systems

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 understand fundamental points about engine-lubricating systems—types of systems, ways of working with them and the relevant terminology used in the automotive industry
2 understand industry safety requirements and observe related procedures
3 inspect and service a range of engine-lubricating systems in accordance with workplace and manufacturer/component supplier requirements and specifications
4 accurately document and interpret the results of tests and inspections.

The engine-lubricating system distributes oil to all parts of the engine to reduce friction and prevent wear. Improved engine oils, together with the design of engine-lubricating systems, have extended the periods between services and increased the service life of engines.

21.1 Engine lubrication

Figure 21.1 shows how the main parts of an engine are lubricated by oil pumped to them from the oil pan. The oil reaches the parts through pipes, passages, drillings, holes and grooves. These, together with the oil pump, oil filter and oil pan, make up the lubricating system.

The main parts of the engine are provided with positive lubrication, as shown. As they receive oil directly under pressure, they are referred to as being pressure-fed. Other parts that are not as heavily loaded are lubricated with oil sprayed through a hole or jet.

Some parts of the engine do not require pressure lubrication as they receive lubrication from oil travelling back to the oil pan. Other parts depend on the oil mist that is present in the crankcase when the engine is operating.

21.1.1 Functions of lubricating oil

Engine lubricating oil performs the following functions:

1 minimises wear
2 reduces friction and power loss

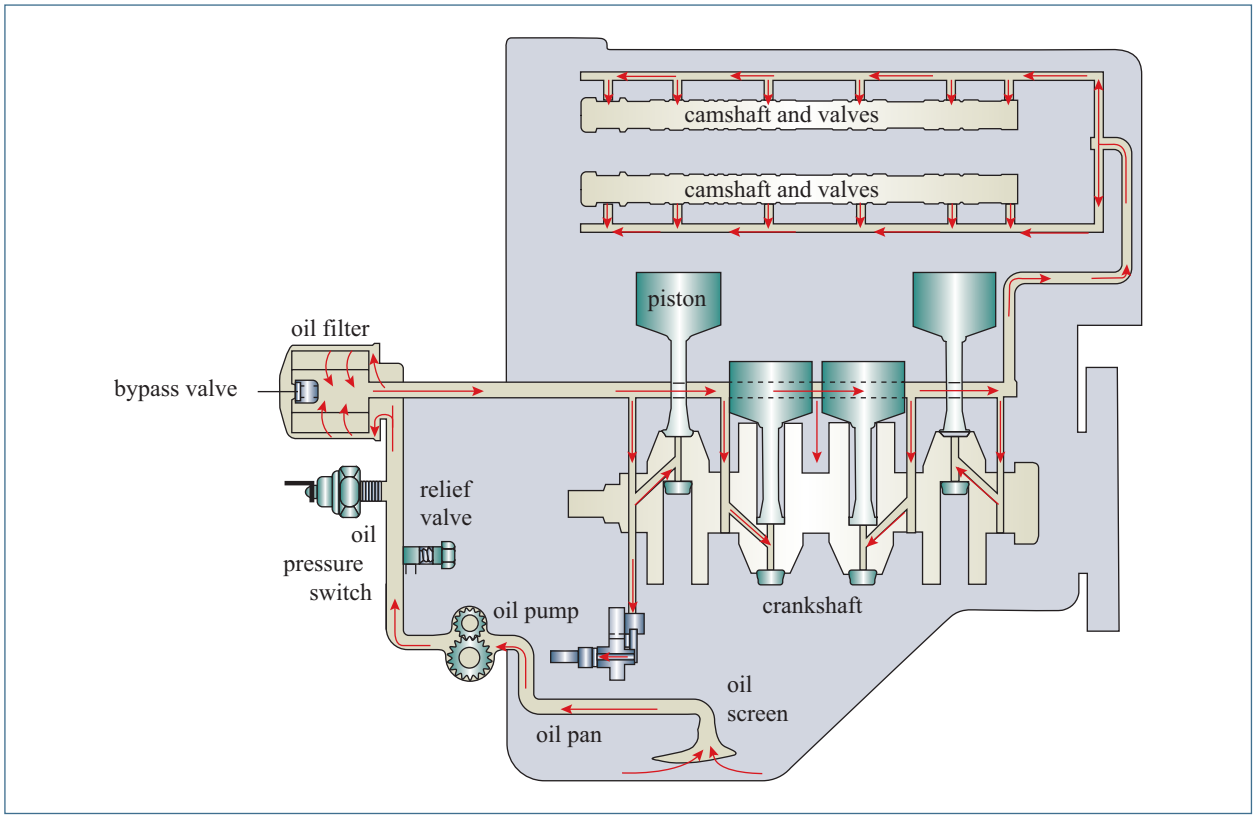


Figure 21.1 Lubricating oil from the oil pan is pumped throughou t the engine

3 removes heat
4 reduces engine noise
5 forms a seal
6 cleans.

Oil minimises wear

With proper lubrication, all the parts that are subject to wear are separated by a thin layer of oil. The oil prevents metal-to-metal contact so that there is minimum wear. This is illustrated in Figure 21.2, which shows how oil is needed between the connecting-rod bearings and the crankshaft journals, and also between the pistons and cylinder walls.

Without proper lubrication, the bearings would wear quickly and eventually fail, causing damage to the crankshaft and other engine parts.

Lack of oil on the cylinder walls would cause excessive wear and scoring of the cylinders, pistons and piston rings.

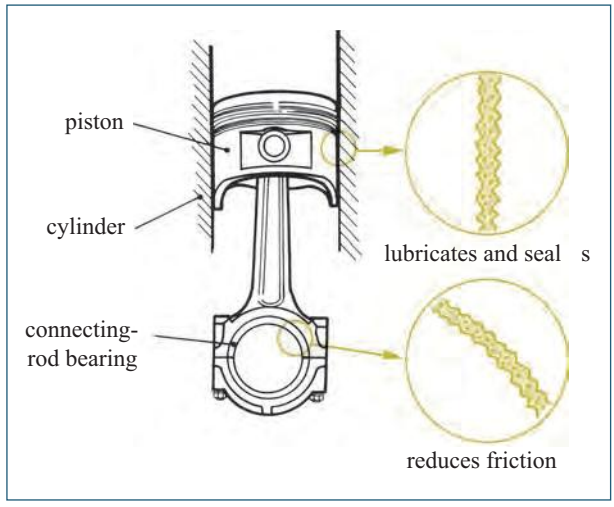


Figure 21.2 Oil fills the very small irregularities in the surfaces—it reduces friction in bearings and helps seal pistons and rings

Oil reduces friction and power loss

All the moving parts of the engine are provided with oil, reducing the friction between surfaces that are in contact. Less friction means less power loss within the engine.

There is still some friction in the engine, but this is fluid friction between the layers of oil, and is much less than dry friction.

Oil removes heat

The oil is being continuously circulated throughout the engine, and while it lubricates the various parts, it also removes heat from them and carries it back to the oil pan. Heat from the oil pan is carried away by the surrounding air.

Some engines are fitted with an oil cooler. This transfers heat from the engine oil to the cooling system, or to the atmosphere, reducing the oil temperature.

Oil reduces engine noise

There is always some clearance between the bearings and journals, and between other working parts. When the load on a part is suddenly increased, the oil between the parts acts as a cushion to absorb the shock and reduce noise.

Oil forms a seal

Piston rings must form a gas-tight seal between the piston and the cylinder wall. The oil on the cylinders helps by filling the very small grooves in the surfaces. At the same time, the oil on the cylinder walls lubricates the pistons and rings.

Oil cleans

As it flows through the engine, the oil tends to carry away any particles of carbon or foreign matter and take them back to the oil pan. Heavier particles drop to the bottom of the oil pan. Lighter particles are removed by the oil filter.

Most of the cleaning is done by chemical *detergents* in the oil which keep engine parts clean, and by *dispersants* which hold particles suspended in the oil so that they are not deposited on the internal parts of the engine. More information on engine oil and lubricants can be found in Chapter 8, Fuels, fluids and lubricants.

21.2 Oil circulation

The lubricating system of an overhead-camshaft engine is shown as a block diagram in Figure 21.3. The arrows show how the oil flows through the system.

Figure 21.4 shows a similar lubricating system, but is an engine diagram illustrating how the oil reaches the actual engine parts. In both diagrams, oil flow starts at the oil pan and, after circulating through the engine, returns to the oil pan.

Oil circulates through the lubricating system, the various parts of which are:

1. Oil pump. Driven by the engine, this takes oil from the oil pan through the strainer and suction pipe and delivers it to the filter. The strainer prevents foreign matter from reaching the pump.
2. Relief valve. The relief valve controls the pressure in the system. When the specified pressure is reached, the valve opens to stop it increasing. Surplus oil is then bypassed to the intake side of the pump.
3. Oil filter. This filters all the oil that leaves the pump before it enters the engine, removing carbon particles and any other matter, thus protecting the engine. The filter has a bypass valve that opens if it becomes blocked. This allows unfiltered oil to pass into the system so that the engine is not starved of oil.
4. Main oil gallery. This is a passage running the full length of the crankcase. A number of drillings and passages from the gallery service other parts of the lubrication system. Figure 21.4 shows a passage from the main oil gallery carrying oil to the overhead camshaft and valve gear; a drilling through each of the crankcase webs supplies oil to the main bearings.

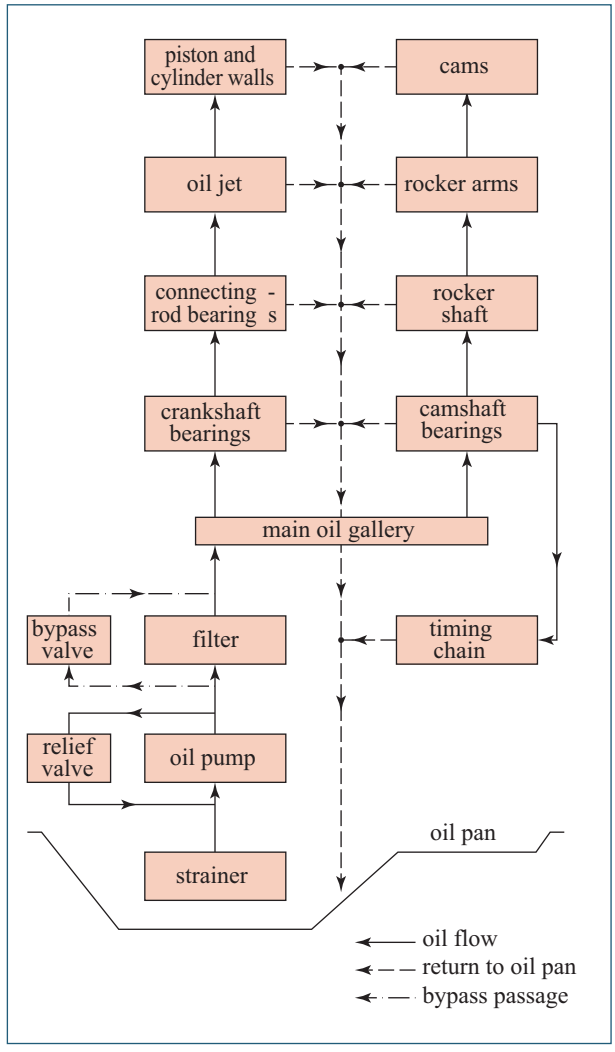


Figure 21.3 Block diagram showing the oil flow in an engine lubricating system

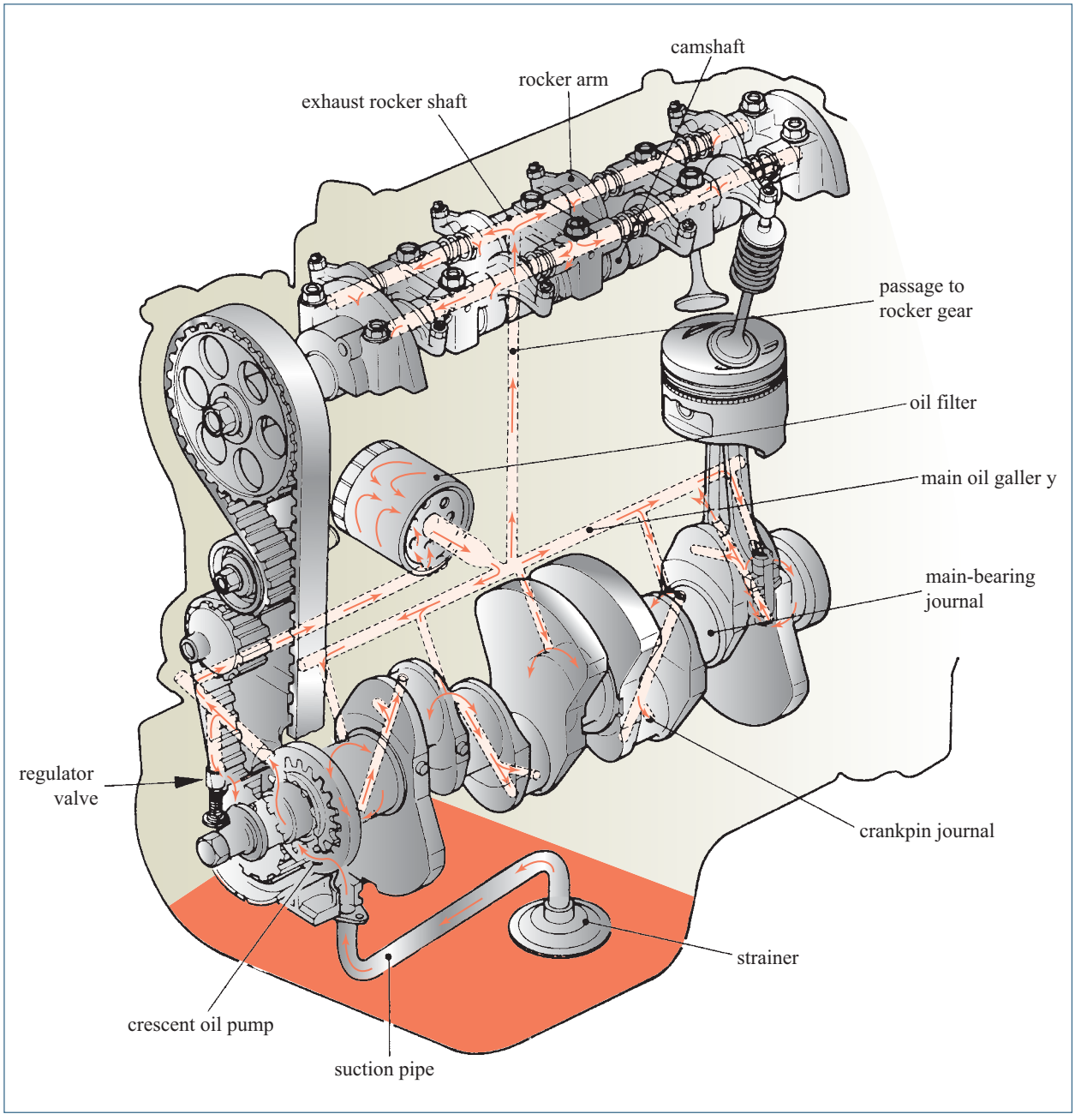


Figure 21.4 Engine-lubricating system for an overhead-camshaft engine

5 Crankshaft main bearings. Each of the five main bearings receives oil through a separate drilling from the main oil gallery.

6 Connecting-rod bearings. Drillings in the crankshaft carry oil from the main bearings to the connecting-rod bearings. Some oil leaves the connecting-rod bearings and is thrown around as a mist, helping to lubricate the internal parts of the engine.

7 Oil jet. This lubricates the cylinder walls and pistons (Figure 21.5). A small hole in the side of the connecting rod is lined up with the oil drilling in the crankpin journal. Simultaneously, a spray of oil is directed onto the cylinder walls. This happens once in each crankshaft revolution.

8 Camshaft bearings. The camshaft receives its oil supply from the main oil gallery. In the arrangement shown in Figure 21.4, there are separate rocker shafts for the intake and exhaust valves. The oil to lubricate the camshaft bearings is carried through the hollow rocker shaft to the camshaft bearing caps, where drillings take it to the camshaft bearings.

9 Rocker shafts. Drillings here provide oil to the rocker arms which, in turn, have a small drilling to provide lubrication to the cams (Figure 21.6).

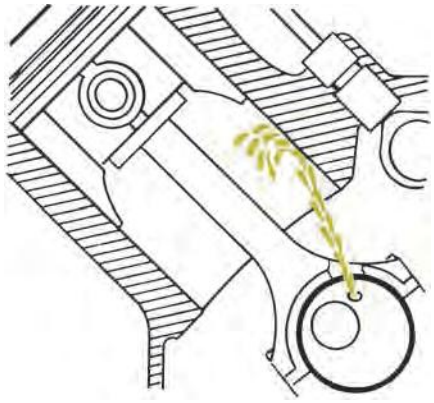


Figure 21.5 When a hole in the connecting rod aligns with a hole in the crankpin, oil is sprayed onto the cylinder wall to lubricate the piston and rings

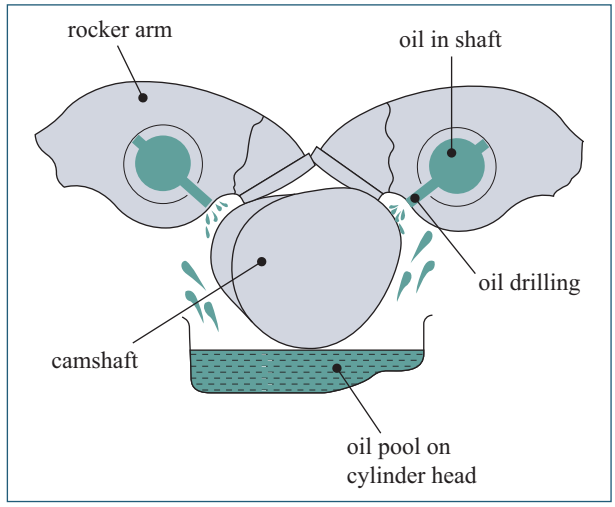


Figure 21.6 Lubrication of rocker arms and cams

10 Cams. As well as receiving oil directly from the rocker arms, the cams are lubricated by splash. The cylinder head under the camshaft is shaped to form an oil reservoir from which oil is splashed by the cams to lubricate the cam surfaces, valve stems and valve springs.
11 Timing chain. Where a timing chain is fitted, oil is provided from the end camshaft bearing or similar source so that the chain and sprockets are lubricated.
12 Return oil. After lubricating the various components, oil from the cylinder head drains back to the oil pan through oil drain holes. Oil from the crankshaft drops directly back to the oil pan.

21.3 Oil pumps

There are three types of oil pump. The basic arrangements are shown in Figure 21.7. They are:

1 gear pumps
2 crescent-type pumps
3 rotor pumps.

Handy hint: Oil pumps can be driven by gears or by a chain, or directly from the crankshaft.

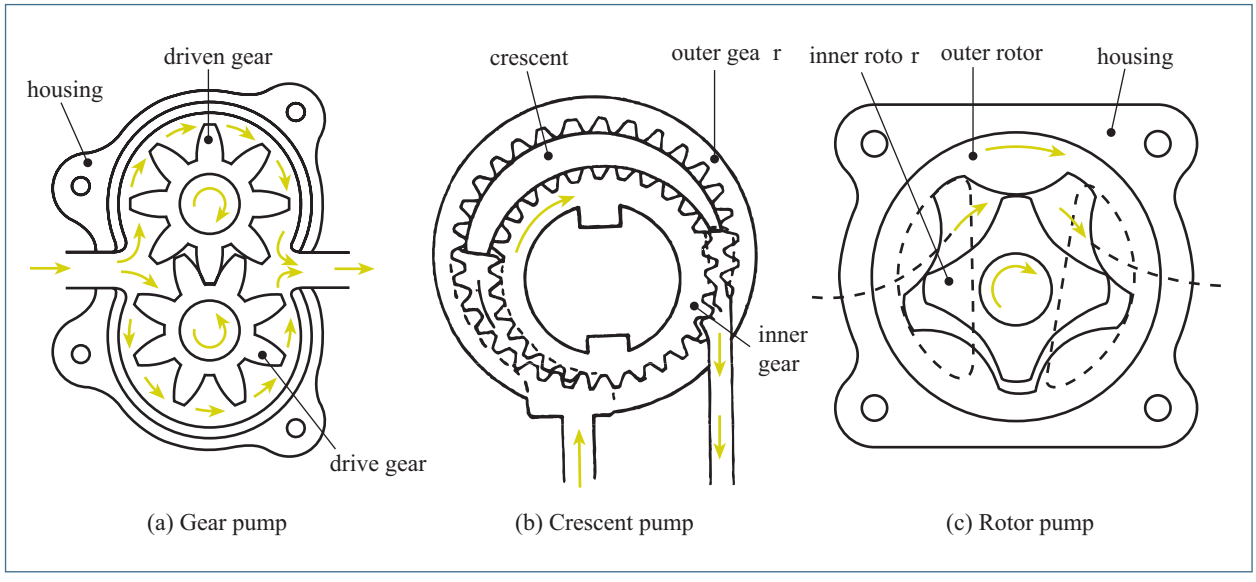


Figure 21.7 Three basic designs of oil pumps

21.3.1 Gear pump

A gear pump, as shown in Figure 21.8, has two gears: a drive gear and a driven gear. The former is fixed to a shaft and driven by gears from the engine's camshaft. The driven gear is mounted on a stationary shaft and is rotated by the drive gear.

The gears are contained within the pump body by the lower cover. The strainer is attached to the pump inlet, which is part of the cover, and immersed in oil in the oil pan.

In operation, oil enters the pump inlet through the strainer and is carried around between the gear teeth and the body of the pump to the outlet, where it is delivered from the top of the pump into the lubricating system.

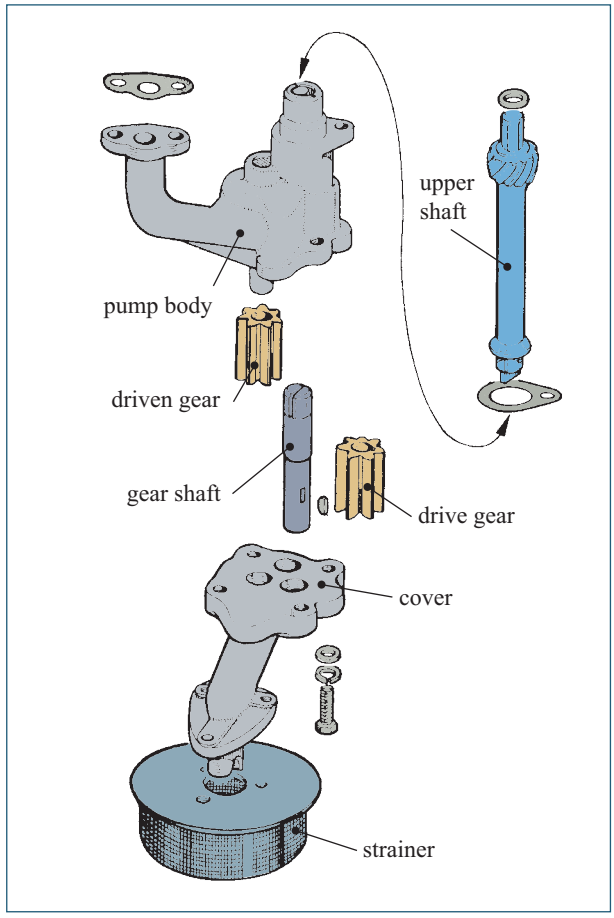


Figure 21.8 Gear-type oil pump driven by a shaft

21.3.2 Crescent pump

The crescent pump in Figure 21.9 has an external-toothed gear meshed with an internal-toothed gear. Some of the gear teeth are in mesh, while others are separated by a crescent-shaped part of the pump housing. The pump is mounted on the front of the crankcase with the inner gear on the end of the crankshaft, so that the pump is driven directly from the crankshaft. When the pump is operating, oil is taken in through the intake port and is carried around between the gears and the crescent to the outlet port.

The oil pump of the engine-lubricating system shown in Figure 21.4 is also a crescent-type pump.

Figure 21.9 Crescent oil pump–clearance can be checked where shown and also between the gears and crescent

21.3.3 Rotor pump

The pump housing is bolted to the front of the crankcase. It has an inner rotor and an outer rotor (Figure 21.10). The inner rotor is mounted on the crankshaft and so rotates whenever the engine is running. The lobes of the inner rotor fit into the outer rotor which is rotated in the housing.

Oil is taken into the pump through an inlet pipe and strainer and carried around between the lobes of the rotors to the outlet port. A relief valve in the pump body controls the pressure in the system.

21.3.4 Oil pump relief valve

The oil pump can supply much more oil than is needed to maintain a pressure in the lubricating system, so a relief valve is fitted to it to limit the maximum pressure of the system.

The relief valve consists of a spring and plunger, which opens and closes a port to regulate the flow of oil. A simplified relief valve is shown in Figure 21.11. A relief valve can also be seen in the housing of the oil pump shown in Figure 21.10. This is how it works:

1 When the engine is started, the pump supplies oil to the system. At engine idle speed, the port is closed by the plunger. All the oil from the pump enters the system and provides a low oil pressure.

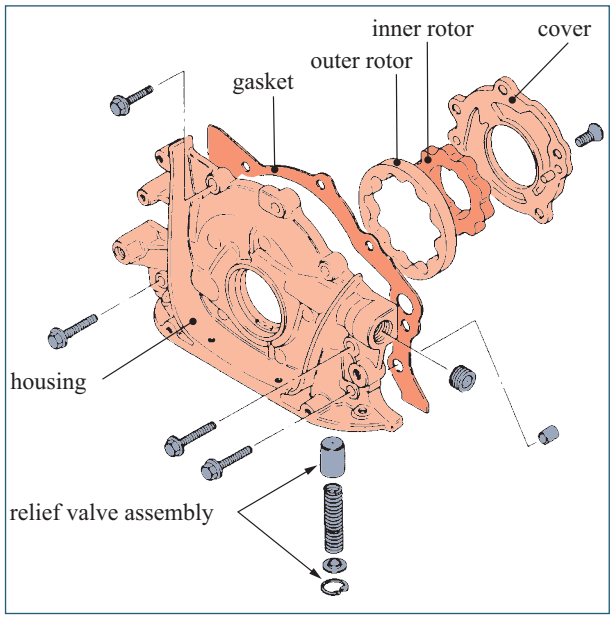


Figure 21.10 Rotor oil pump GM HOLDEN LTD

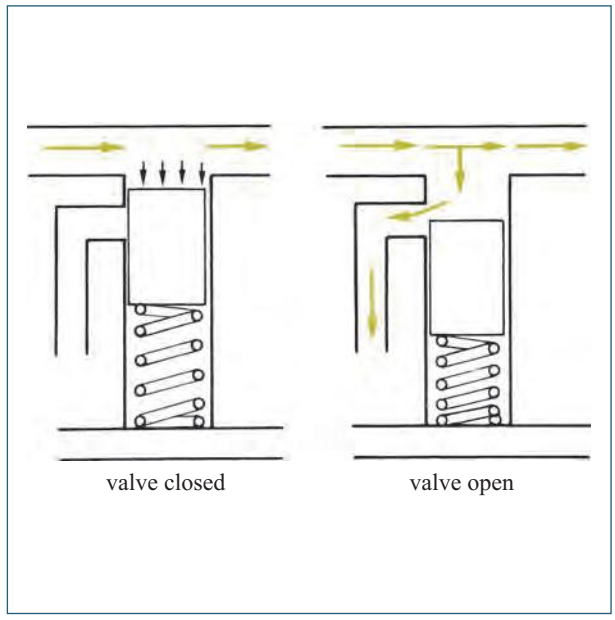


Figure 21.11 Operation of an oil pressure relief valve—pressure on top of the plunger is opposed by the spring

2 As engine speed increases, the pump speed also increases and so more oil is delivered into the system. This increases the pressure in the system. Pressure on the top of the plunger moves it down its bore .

3 When the system reaches a certain pressure , which is determined by the strength of the plunger spring, the plunger will have moved far enough to open the port.

4 Oil which is not needed to maintain pressure in the system will then pass through the port and return to the intak e side of the pump .

5 The plunger will open and close the port as needed, to release surplus oil and limit the pressure in the system. Whether the port is open or closed will depend on the engine speed and the temperature of the oil. It will also depend on the condition of the engine .

21.4 Oil filters

During engine operation, carbon particles, dust and small metal particles become mixed with the lubricating oil. The oil filter keeps the oil clean by removing these impurities, which would otherwise find their way through the oil passages to the bearings and other surfaces.

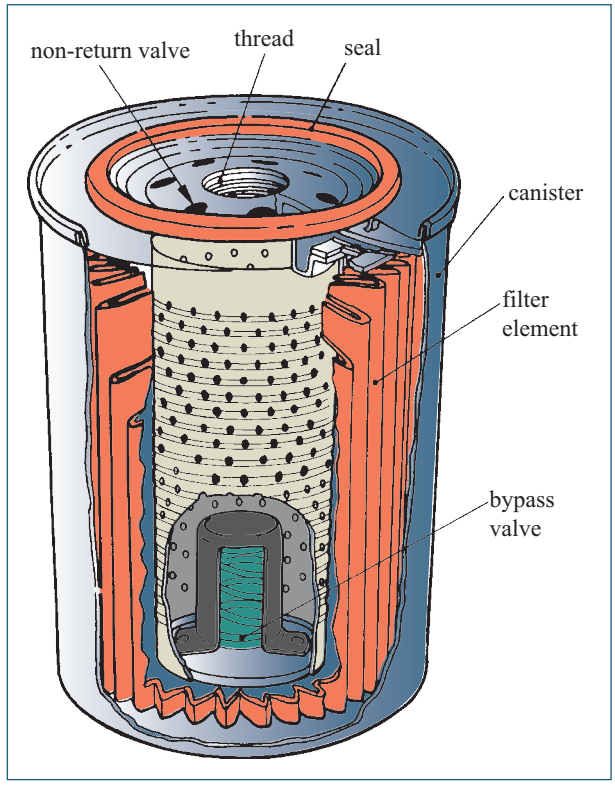


Figure 21.12 Construction of a canister-type oil filter

A sectioned oil filter is shown in Figure 21.12. It consists of a metal canister with a pleated-paper element. This is porous to allow oil to flow without restriction, but its pores are fine enough to filter out impurities. The canister is threaded onto a tubular mounting on the engine block. A rubber ring provides a seal between the filter and its mounting.

The filter has a non-return valve at the open end of the canister which prevents oil from draining from the filter when the engine is stopped. The valve is a rubber disc that covers a ring of holes.

When the engine is running, oil flows into the filter through the non-return valve holes to the outside of the element. It passes through the element to the inside of the canister, then back to the engine through the tubular mounting.

A bypass valve inside the canister is a safety valve, which opens to allow oil to go straight through the filter should the element become blocked.

21.4.1 Replaceable filter element (cartridge) and spin-on

Initial engine oil filters were a cartridge (or replaceable element) construction, in which a permanent housing contained a replaceable filter element or cartridge. The housing is usually mounted directly on the engine block. The spin-on oil filter design was introduced as self-contained housing and element assembly which was screwed or unscrewed from its mount, discarded and replaced with a new one. This makes filter changes more convenient and less messy, which quickly became the dominant type of oil filter in the automotive industry.

Sustainability: Automotive manufacturers have begun to shift back to replaceable-element (cartridge) filter types. These have less impact on the environment and create less waste with each filter change .

The filter assembly in Figure 21.13 has a replaceable filter element.

The oil flow in the filter is similar to that of a canister filter.

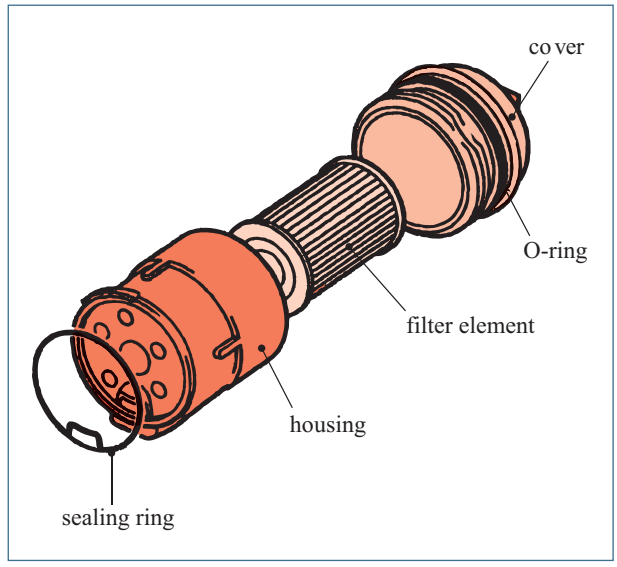


Figure 21.13 Oil filter with a replaceable element
GM HOLDEN LTD

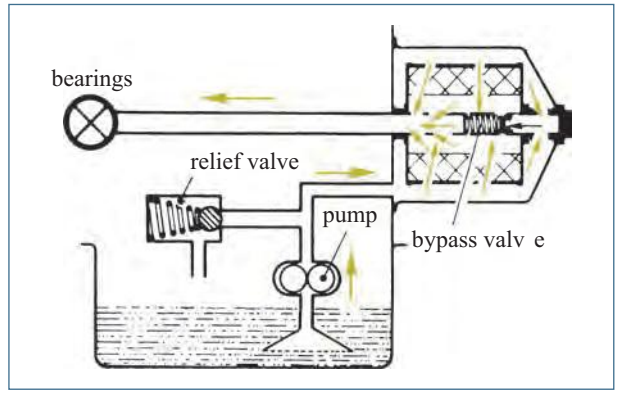


Figure 21.14 Principle of a full-flow oil filter—all the oil entering the system is filtered

21.4.2 Full-flow and bypass filters

There are two filter arrangements: full-flow filters and bypass filters. Full-flow filters are mainly used, but some diesel engines have a full-flow filter as the main oil filter, and a bypass filter as a supplementary filter. Figure 21.14 shows a full-flow oil filter. Oil from the pump passes through it on its way to the bearings and other engine parts, so that only filtered oil is used for lubrication. A bypass valve is located in the filter so that if the filter becomes clogged, the valve will open and oil will still be supplied to the system.

21.5 Oil coolers

Oil coolers are heat exchangers, in which heat in the oil is transferred either to the engine coolant or to the atmosphere.

There are two designs of oil coolers:

1 oil-to-coolant coolers
2 oil-to-air coolers.

21.5.1 Oil-to-coolant oil cooler

Both oil and coolant flow through this type of cooler, the two being separated by tubes or baffles. This enables heat to be transferred from the oil to the coolant as the oil is hotter.

An oil cooler and oil filter assembly for a small diesel engine is shown in Figure 21.15. Both the cooler and the filter are installed on the oil filter mounting on the cylinder block. Oil from the oil gallery passes through the oil cooler before it enters the filter, so that oil leaving the filter has been both cooled and filtered. The cooler has external connections for the coolant hoses that connect it to the cooling system.

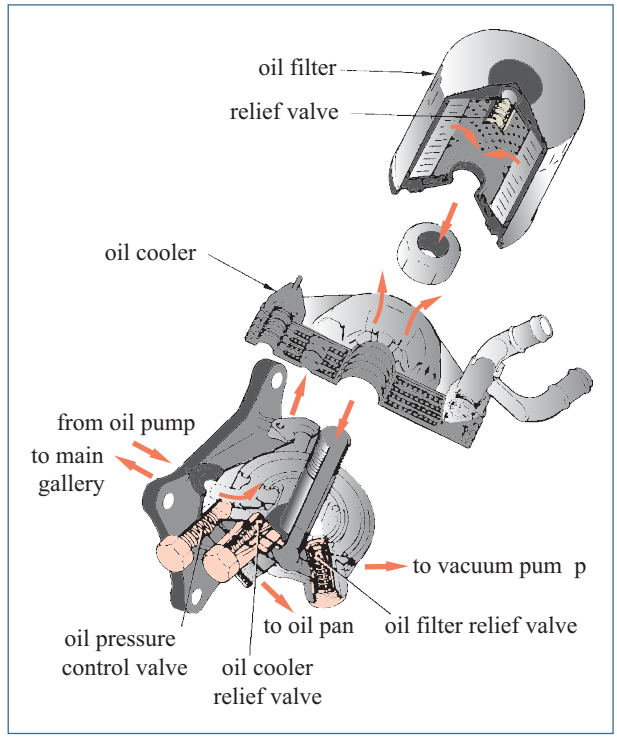


Figure 21.15 Oil-to-coolant-type oil cooler and oil filter assembly FORD

21.5.2 Oil-to-air oil cooler

This type of oil cooler is similar to a radiator in that it has tubes and fins (Figure 21.16). Oil from the lubrication system is circulated through the cooler, and air is directed across them, removing heat from the oil and reducing its temperature. The cooler is located in the engine compartment where it will get an adequate flow of air, usually near the radiator.

21.5.3 V-type engine-lubricating system

Figure 21.17 shows the lubricating system for a V-type petrol engine. This has a lot of overhead gear, including two camshafts on each cylinder head. Oil has to be supplied to four camshafts and also to the camshaft gears.

The lubricating system includes an oil-to-coolant oil cooler.

21.5.4 Turbocharger lubrication

Oil coolers are fitted to engines with turbochargers as they rotate at high speeds and are also subjected to exhaust heat. A constant flow of oil is provided to the turbocharger bearings to cool and lubricate them. An oil line from the oil gallery delivers the oil to the turbocharger and a drain pipe returns the surplus oil to the oil pan.

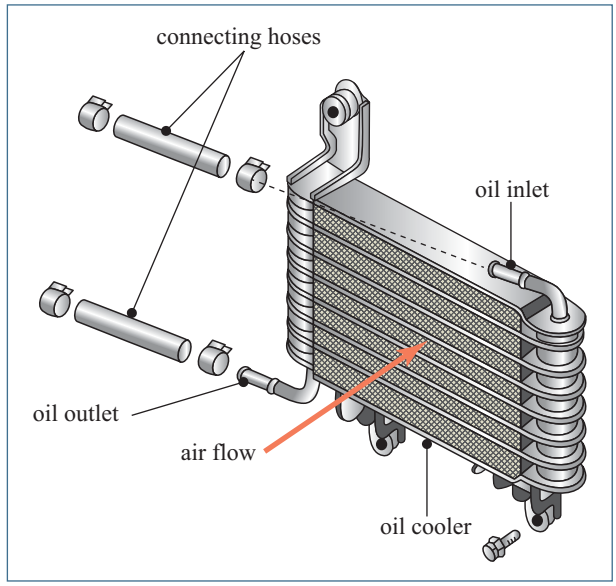


Figure 21.16 Oil-to-air-type oil cooler

21.5.5 Warning devices

The engine should be protected from low oil pressure and a low oil level to avoid serious damage.

Oil pressure warning light

A pressure-operated switch is screwed into the main oil gallery or oil pump. This switch will be 'on' when the engine is stopped and there is no pressure in the system. It is switched off by the pressure in the system once the engine is started. When the switch is 'on', a warning light appears on the instrument cluster indicating no oil pressure, or low pressure.

21.5.6 Low-oil-level sensor

Figure 21.18 shows a low-oil-level sensor. Mounted in the base of the oil pan with the sensor blade facing upwards, it uses ultrasonic wave technology to check the level, temperature and viscosity of the engine oil. It notifies the driver of the oil service requirement.

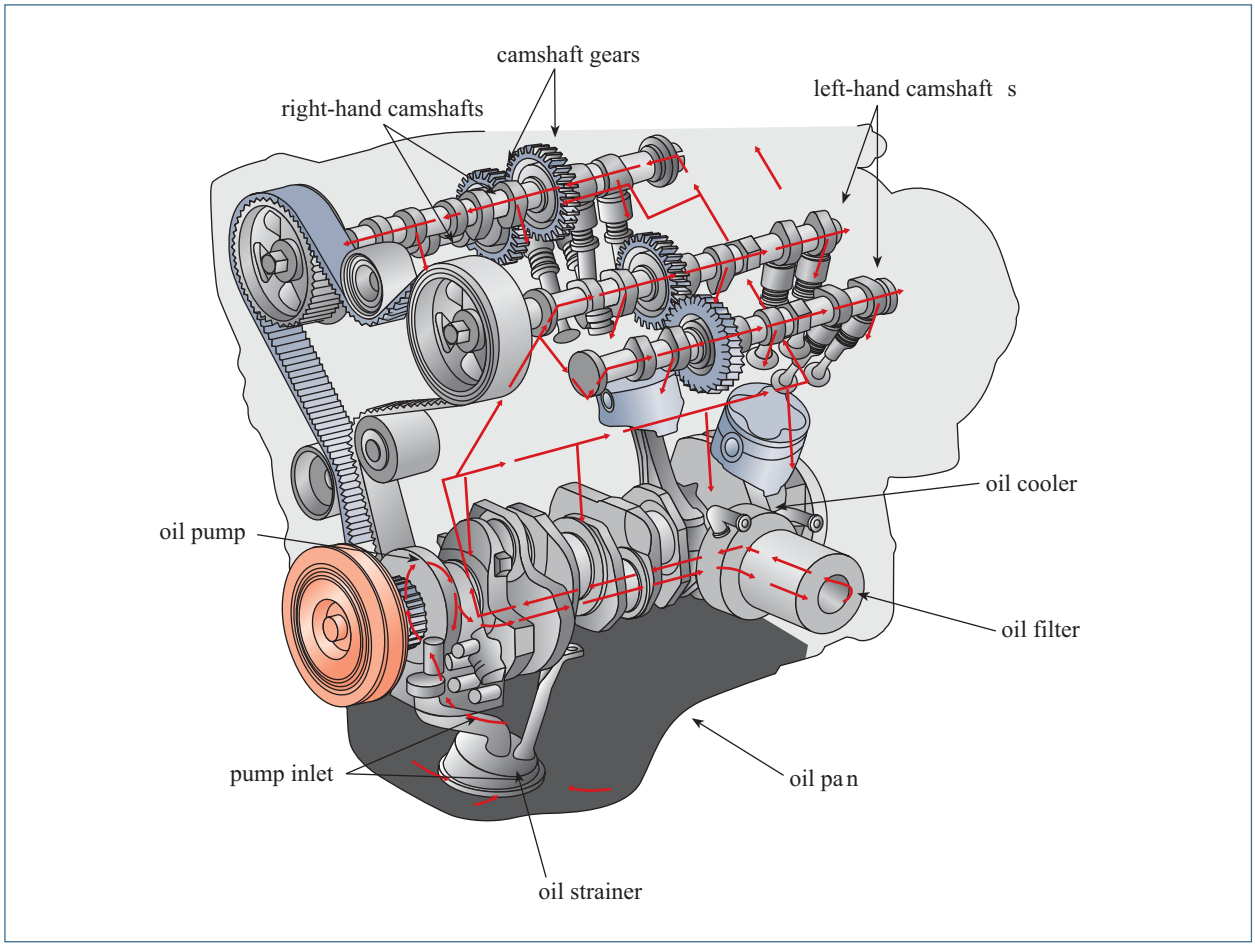


Figure 21.17 Lubricating system for a V-type engine–it has an oil-to-coolant oil cooler

21.6 Lubrication of engine bearings

The main purpose of a lubricant is to convert dry friction to fluid friction.

1. Dry friction. This occurs between dry surfaces.
2. Fluid friction. Lubricated surfaces have some friction, due to the molecules of oil which have to be moved, but this is small compared with dry friction.
3. Boundary friction. A condition between dry friction and fluid friction, where the surfaces are almost unprotected, being coated only by an oily film. The surfaces are actually in contact and are not separated by a layer of oil.
4. Boundary lubrication. The very small amount of lubricant (or oil film) that is on a shaft and bearing under boundary friction conditions.

Figure 21.18 Low-oil-level sensor BOSCH

Handy hint: Engine parts rely on boundary lubrication for a short time when the engine is first started, before all the lubricating passages have had time to fill. This is a critical period in terms of engine wear.

21.6.1 How engine bearings are lubricated

Bearings such as crankshaft bearings are supplied with oil under pressure from an oil pump. The pressure oil does not merely lift the shaft off the bearings and cause it to float on the oil—the rotation of the shaft is responsible

for this. The shaft collects layers of the oil delivered to the bearing and carries them around with it.

The layers of oil are wedged between the shaft and the bearing, so that the shaft is forced to rise (or float) on the oil. So it is shaft rotation that causes floating to occur to prevent metal-to-metal contact, and not the fact that oil is being delivered from the pump under pressure. This is known as *hydrodynamic lubrication.*

Engine lubrication diagrams show the oil to the main crankshaft bearings entering at the top, so it cannot force the shaft upwards off the bearing. The very small clearance between the crankshaft journal and its bearings is sufficient for hydrodynamic lubrication to occur.

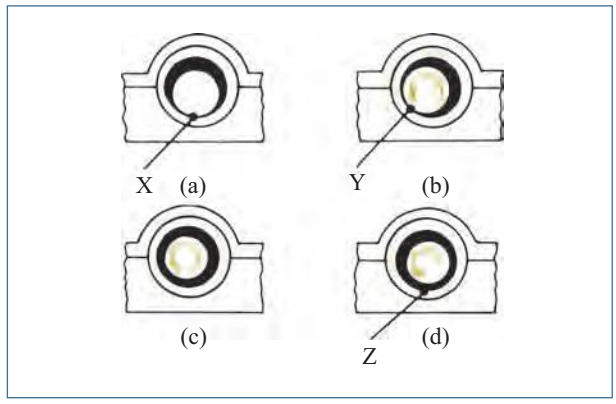


Figure 21.19 Principle of lubrication of a shaft and bearing—the shaft rotates in an anticlockwise direction

Bearing, shaft and oil wedge

Figure 21.19 shows in sequence, from (a) to (d), the action of a shaft as it starts to rotate in a bearing and build up an oil wedge. The clearances between the shaft and the bearing in the illustrations are exaggerated to show this effect.

1 The shaft is stationary (Figure 21.19(a)). X shows where only a thin film of oil covers the shaft and bearing. This is the stage at which boundary lubrication (and boundary friction) are present.
2 When the shaft starts to rotate (Figure 21.19(b)), it rolls to contact the bearing at Y . This is still only boundary lubrication. There is a thick layer of oil at the top , but little oil at the bottom. As the shaft rotates, it acts like an oil pump, causing pressure to build up at Y . This forces the shaft towards the centre of the bearing.
3 The shaft speed has increased and pick ed up layers of oil (Figure 21.19(c)). The shaft has been forced over to the right so that it is now surrounded in oil.
4 The shaft runs floating on oil (Figure 21.19(d)). Pressure from rotation is greatest at Z, and this k eeps the shaft away from the bearing.

21.7 Lubrication system maintenance

Lubrication system maintenance consists of checking the level of oil in the oil pan by means of the dipstick, carrying out regular oil and filter changes and checking for possible oil leaks.

Many vehicles, particularly four-wheel drives, have an indicator on the instrument cluster to show low engine oil in the sump.

21.7.1 Dipstick check

The oil level on the dipstick should be checked with the vehicle in a level position, not on a slope. Remove the dipstick, wipe it clean and also wipe the top of the dipstick tube to remove dust. Reinsert the dipstick and then remove it again to check the level.

The oil level should be between the high and the low marks, but close to the high mark (Figure 21.20). Top up if necessary, but do not overfill.

Handy hint: Using the dipstick to check **the engine oil level is simple but crucial.**

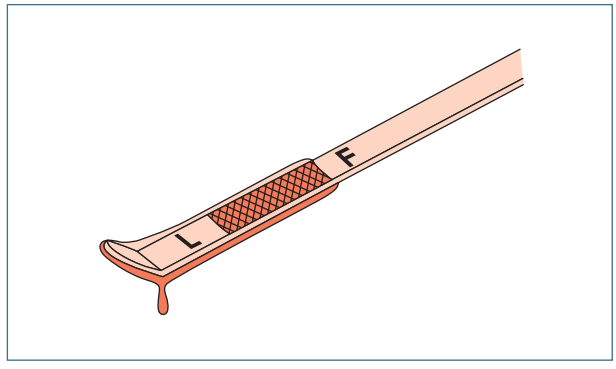


Figure 21.20 The level on the dipstick should be check ed carefully

21.7.2 Changing the engine oil and filter

The general procedure for changing the oil and filter is as follows:

1 Warm up the engine .
2 Remove the oil filler cap from the valve cover .
3 Remove the drain plug from the oil pan and drain the oil into a suitable container .

4 Check the condition of the plug washer . Wipe around the plug hole and replace the plug. Tighten firmly, but not too much.
5 Remove the oil filter and replace it with a new one .
6 Pour sufficient oil into the filler hole in the valve cover to show on the dipstick.
7 Start the engine and run it slowly until the filter fills and the oil pressure warning light goes out, then stop the engine .
8 Check the level of the oil on the dipstick and top up to the 'full' mark. The vehicle should be level.
9 Run the engine and check the filter seal for leaks. Make a final check of the oil level.

Handy hint: Use the correct type and grade of oil recommended by the vehicle manufacturer .

21.7.3 Servicing oil filters

Most filters consist of a metal canister containing a filter element. These are sometimes referred to as 'throw-away' filters because the complete filter is unscrewed from its mounting on the engine and a new one fitted in its place (Figure 21.21.)

An oil filter-removing tool is shown in Figure 21.22. It has a band that fits around the filter canister, tightening onto the canister as it is being used, enabling the filter to be unscrewed from its mounting.

Oil filters should be replaced at specified service periods. Figure 21.23 shows the procedure for installing a canister-type filter.

1 Clean the filter mounting.
2 Coat the rubber seal with oil.
3 If possible , fill the filter with oil before fitting.
4 Screw the filter into place until the seal contacts the mounting surface .
5 Tighten, by hand, an extra one-half to three-quarters of a turn.
6 After running the engine , check for oil leaks.

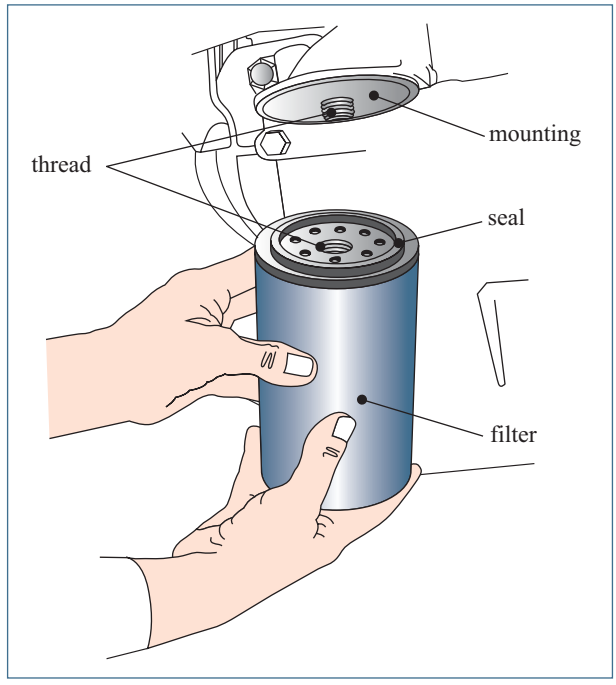


Figure 21.21 Replaceable oil filter that is threaded on to its mounting

Figure 21.22 An oil filter-removing tool

(a) Clean the filter mounting

(b) Coat the seal with oil

Figure 21.23 Installing a canister-type oil filter

(c) Tighten the filter by hand

(d) Check for oil leaks

Figure 21.23 Continued

For a replaceable-element-type filter, its outer cover is removed to gain access to the filter element. The old filter element is discarded and, after making sure that the filter housing is clean, a new one installed.

Safety: When carrying out oil and filter changes, wear safety glasses and gloves to avoid burns from hot oils.

21.7.4 Checking for oil leaks

The most likely places for oil leaks are the oil filter, the valve cover and the oil pan. Where oil has coated the engine and the leak is not easy to find, clean the engine and then run it until the oil is warm. With the parts of the engine clean and the oil thin, leaks should be easier to find.

21.8 Lubrication system problems

Table 21.1 lists general problems that can occur with an engine-lubricating system.

Table 21.1 General engine- lubricating system problems

Problem	Possible cause
Frequent topping up	Oil leaks
	Oil being burnt because of worn engine
Oil leaks	Loose bolts
	Faulty gask et or seal
	Filter not tight
	Leak at the drain plug
Oil pan overfull	Coolant leak into cylinders
	Overfilled when topping up
Emulsified oil	Coolant mix ed with the oil
Sludgy oil	Incorrect oil
	Badly worn piston rings
	Faulty crank case-ventilating system
	Oil not changed
Low oil pressure	Low oil level
	Faulty relief valve
	Worn oil pump
	Worn engine bearings

(continued)

Table 21.1 General engine- lubricating system problems (continued)

Problem	Possible cause
Warning light shows	Loss of pressure
	Faulty switch
	Low oil level
Warning light not working	Blown bulb
	Faulty pressure switch or connector
Engine noises	Insufficient oil
	Low oil pressure
	Worn bearings
	Worn cylinders

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe the six functions of engine-lubricating oil —to minimise wear; reduce friction and power loss; remove heat; reduce engine noise; form a seal; and clean.
- identify the three types of oil pump —as gear, crescent and rotor
- describe the function of oil filters —which is to remove contaminants from the vehicle's engine oil
- identify the two types of oil coolers —as oil-to-coolant coolers and oil-to-air coolers
- describe the procedure for replacing the engine oil and filter —as 1 Clean the filter mounting; 2 Coat the rubber seal with oil; 3 If possible, fill the filter with oil before fitting; 4 Install the filter into place until the seal contacts the mounting surface; 5 Tighten, by hand, an extra one-half to three-quarters of a turn; 6 After running the engine, check for oil leaks
- diagnose lubrication system faults.

REVIEW QUESTIONS

1 What functions does the engine oil perform?
2 How does oil reduce the power loss of an engine?
3 Briefly describe the various types of engine-lubricating systems.
4 How are the cylinder walls lubricated?
5 Name the different types of oil pumps.
6 What is the purpose of the relief valve in the lubricating system?
7 What is the principle of a full-flow oil filter?
8 What is a bypass oil filter?
9 Describe how the connecting-rod bearings are lubricated.
10 Where are oil coolers fitted?
11 How are oil leaks located?
12 Where are the most likely places for an oil leak?
13 Explain how an oil filter is changed.
14 What are the possible causes of low oil pressure?
15 What could cause an overfull reading on the dipstick?

CHAPTER 22

Intake, forced induction and exhaust systems and servicing

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 state the operating principle of intake, forced induction and exhaust systems
2 observe related safety procedures and requirements
3 state the terminology and procedures relevant to carrying out services and repair tasks for intake, forced induction and exhaust systems
4 accurately inspect those systems, and document and analyse inspection results
5 service and diagnose a range of intake, forced induction and exhaust systems in accordance with workplace requirements and manufacturers' specifications.

The intake system includes the air cleaner and the intake manifold and other ducting and passages. Its function is to provide clean air and carry it into the engine cylinders. In some petrol engines, the air from the intake system carries some air–fuel mixture into the cylinders, while in other petrol engines and diesel engines the intake system carries only air.

Engine output is determined by the amount of fuel mixture that is burnt during each combustion stroke. There are many ways to increase output, the most effective of which is to increase its volumetric efficiency—that is, to get more air–fuel mixture into the cylinders. This can be done by improving the flow of the air–fuel mixture into the cylinders, or by forcing more air into the cylinders by turbocharging or supercharging.

The exhaust system carries the exhaust gases away from the engine and reduces the exhaust noise. It consists of the exhaust manifold, exhaust pipes and one or more mufflers. Most petrol engines also have a catalytic converter to reduce the exhaust emissions.

22.1 Air cleaners

An air cleaner has a filter element through which all the air passes before entering the engine. The air-cleaner body also acts as a silencing chamber to muffle the sound of the incoming air.

A considerable amount of air passes through the intake system into the engine—by mass, about fifteen times the amount of fuel. The air must be filtered because, even under good conditions, it will contain dust and grit. If unfiltered air enters the engine, it acts as an abrasive, causing premature wear to the valve guides, piston rings, pistons and cylinder walls.

22.1.1 Types of air cleaners

There are a number of different types of air cleaners, all of which contain some type of filtering element to remove dust from the air. Air cleaners for passenger and light commercial vehicles have a dry filter element, but there are also air cleaners with wet elements that have a filtering element that is wet with oil.

There are different arrangements of the filtering systems for carburettor engines, EFI engines and diesel engines.

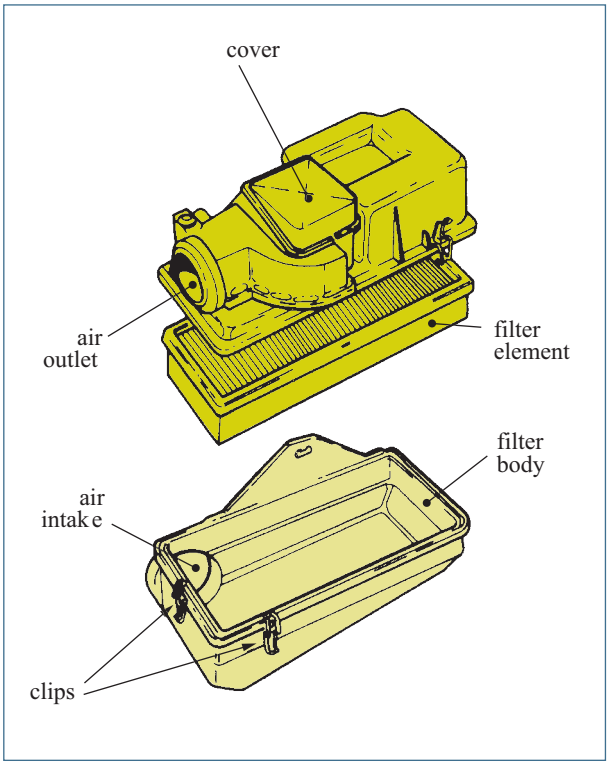


Figure 22.1 Air cleaner for an EFI system

22.1.2 Oil-wetted air filters

An oil-wetted air filter has an element made of metal strands packed closely together. These are wet with oil. The air moving through the air cleaner passes through the element, where particles of dust collect on the oily strands.

Safety: Oil-wetted air filters are found on some motorcycles and small engines. When applying oil or foam to these filters, always wear safety glasses.

22.2 EFI air cleaners

Electric fuel injection (EFI) systems usually have the air cleaner located at the side of the engine and connected into the intake system by large hoses and ducts. Air cleaner elements can be rectangular or round.

The EFI air cleaner in Figure 22.1 has a plastic body. The flat rectangular filter is made of cellulose fibre and this is supported in the air-cleaner body and enclosed by a cover. The air cleaner is mounted beside the engine, in the air intake system, ahead of the airflow sensor and throttle body. Air enters through the air intake at the side of the air-cleaner body and passes upwards through the filter element.

22.2.1 EFI air cleaner and ducts

Figure 22.2 shows the components of an EFI air-cleaner assembly plus hoses and ducting. The air intake is made of moulded plastic material and located at the front of the engine compartment. The intake shown has an air chamber that can hold a volume of air. This acts as a resonator to reduce the noise of the incoming air. The system shown also has a supplementary resonator fitted after the air cleaner. This helps to reduce air pulsation.

Figure 22.3 shows the air cleaner and air ducts for a different EFI system. This carries air from the front of the vehicle to the throttle body on the intake manifold of the engine.

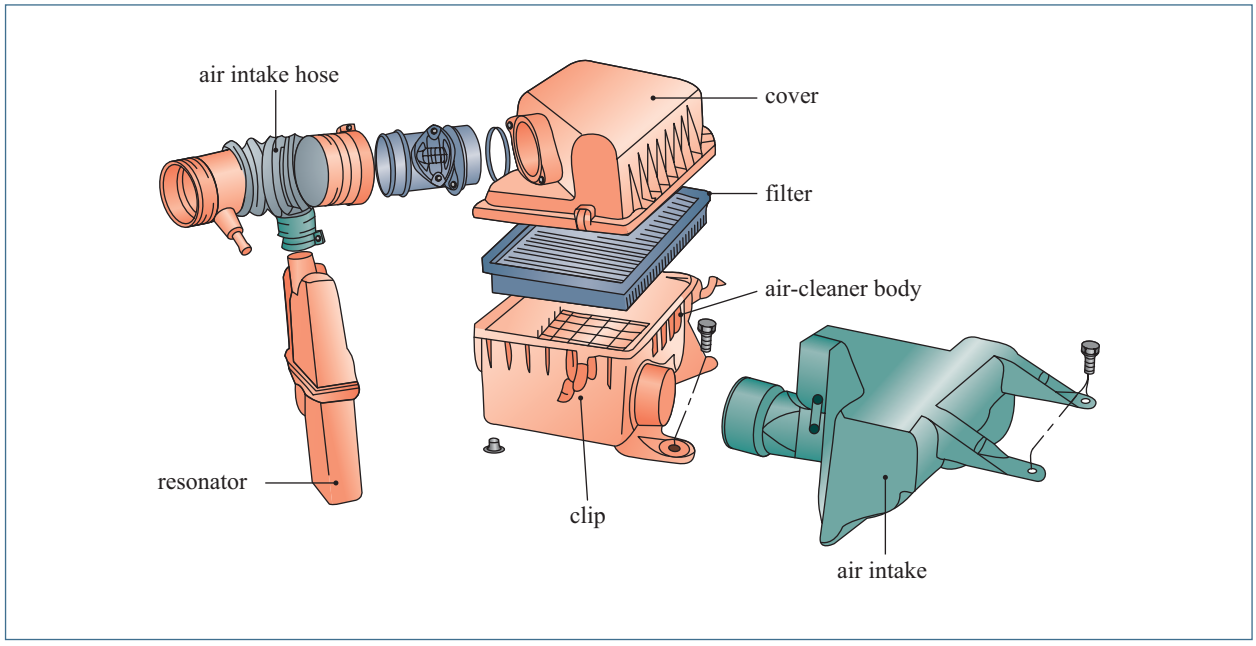


Figure 22.2 Air cleaner and ducting for an EFI engine

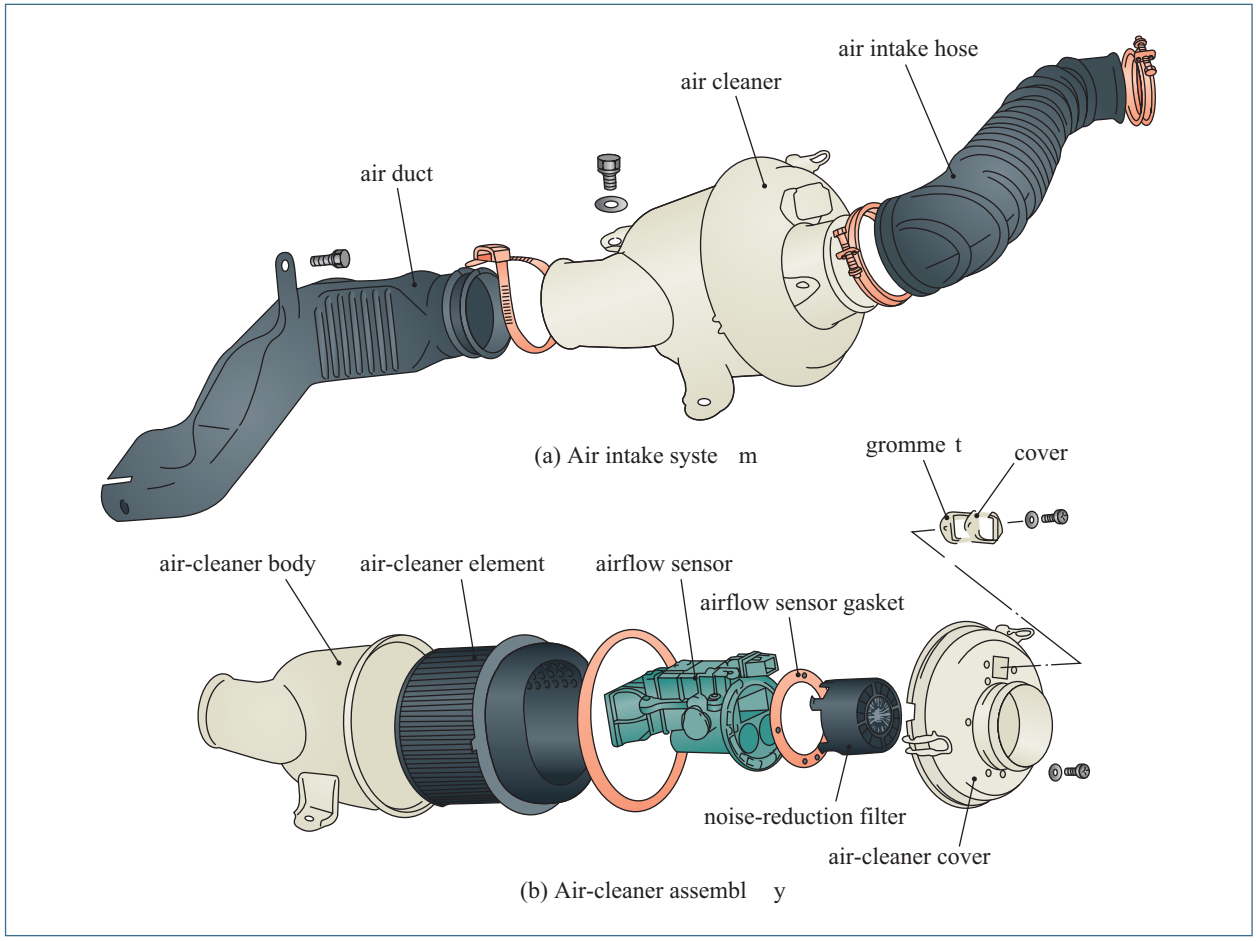


Figure 22.3 Air intake system for an engine with EFI

Figure 22.3(a) shows the parts of the system. The air cleaner is bolted to the body beside the engine. There is a long duct between the air cleaner and the front of the car for air intake, and a flexible hose between the air cleaner and the throttle body.

Figure 22.3(b) shows the dismantled air-cleaner assembly. This has an air filter element and also a noise-reduction filter. The airflow sensor for the EFI system is attached to the air-cleaner cover. When the cover is assembled to the body, the airflow sensor fits inside the filter element. An electrical connector on the sensor connects it to the electronic control unit.

Safety: Take care when removing or disassembling air cleaners and duct work to avoid injury from sharp components.

Handy hint: With EFI systems, it is essential that there are no air leaks as an air leak at a post-sensor connection can upset the air–fuel mixture. All the air entering the engine is measured by the airflow sensor.

EFI intake system

Figure 22.4 shows the intake system for a four-cylinder engine. The air is taken in through the air intake at the front of the engine. It passes through the air cleaner, the airflow sensor and the throttle body to the plenum chamber. This acts as a form of air reservoir. Air is then carried through the intake manifold to the cylinders.

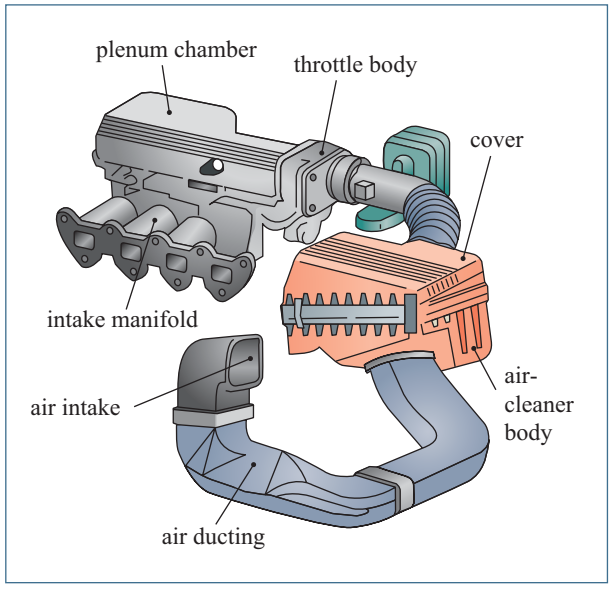


Figure 22.4 Air intake system and intake manifold for a four-cylinder EFI engine

22.3 Diesel air cleaners

Diesel engines often have more than one air cleaner, and these are often mounted away from the intake manifold. They have ducting that connects them to the engine (Figure 22.5). Off-road vehicles are likely to have a precleaner and a main cleaner.

The air intakes on some off-road vehicles are mounted externally and raised to the height of the passenger cabin. This keeps the air intake above the dust and allows for water crossings

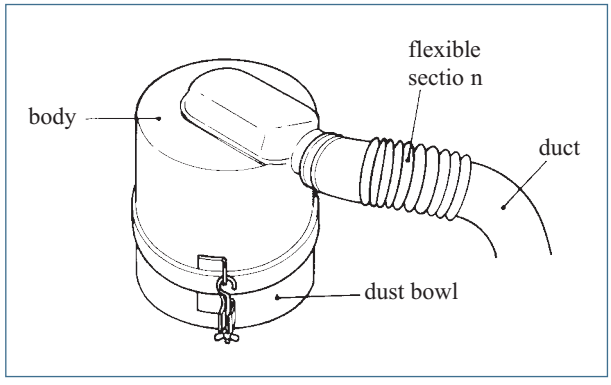


Figure 22.5 Air cleaner of the type used for diesel engines

22.3.1 Cyclone-type air cleaners

Figure 22.6 shows a cyclone-type air cleaner. As the filtering arrangement is not efficient enough on its own, it is used as a precleaner for a dry-type filter. The cyclone filter has a swirling air flow as it passes through the air element, the flow being created by vanes fitted inside the air cleaner body.

The air cleaner operates in the following way:

1. Air entering the air cleaner passes over the angled vanes.
2. The vanes impart a rotary motion to the airflow, spinning out the heavier particles of dust, which are collected in the bowl at the bottom of the cleaner.
3. The air then passes through a dry-filter element for further cleaning before entering the intake manifold.

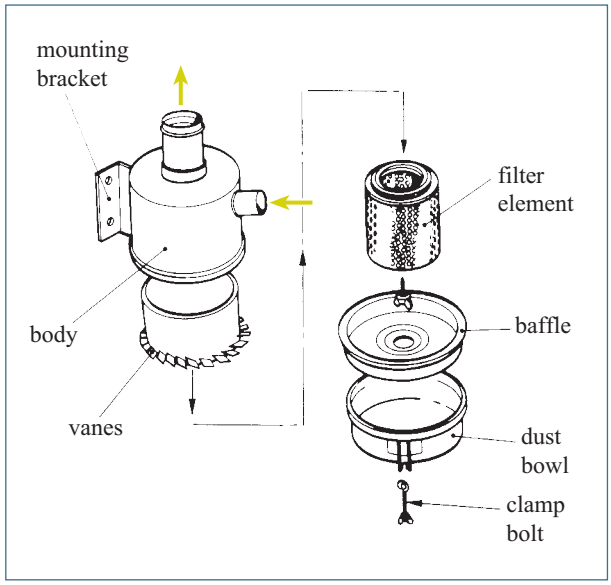


Figure 22.6 Cyclone-type air cleaner. In this image, the cyclone filter and a dry-air filter are combined, but cyclone filters are also made as separate air cleaners

22.4 Air-cleaner service

Filter elements should be serviced at manufacturer-recommended intervals. However, if the vehicle is operating in unusually dusty conditions, the air cleaner must be serviced more frequently. Servicing the element can vary according to its type.

Handy hint: The main purpose of the air cleaner is to keep damaging dust from entering the engine. **If the element becomes clogged or damaged it will impact on engine performance and wear.**

22.4.1 Dry-element cleaners

The element can be removed for cleaning and its condition examined against a light. It should not be washed in any type of cleaning solution as this will destroy the filtering effect. To clean the element, carefully and lightly tap it on a clean flat surface to dislodge the dust particles. Keep the element flat and do not strike its edge or hit it in such a way that it will become distorted or damaged and so fail to seal when reinstalled.

Renewing the filter element

While the filter element can be cleaned, the pores of the filtering material will gradually become blocked, restricting airflow. Manufacturers specify that the filter element should be renewed after, for example, every 30 000 km of operation, or more often if the vehicle is used in dusty conditions.

When reassembling the element to the air cleaner, make sure that it fits and seals correctly. Sealing is important to prevent unfiltered air from entering the system.

22.4.2 Oil-wetted filters

The oil-wetted filter can be serviced by immersing it in cleaning solvent and shaking it to remove oil and dirt. After draining and blowing with air, the element is re-oiled with engine oil (or a foaming spray). Any surplus oil must drain off before it is reinstalled.

22.4.3 Cyclone cleaner service

This type of air cleaner is serviced by removing the dust from the bowl from the bottom of the cyclone cleaner assembly. The inside of the body can be cleaned with a damp cloth. When operating in dusty conditions, it should be cleaned more frequently. If the cyclone air cleaner also has a filter element, this can be removed and cleaned in the same way as other dry-type elements.

22.4.4 EFI air-cleaner service

With some EFI filters, clips secure the cover to the body. Releasing these enables the cover to be separated from the body. The filter element can then be removed.

The element is cleaned in the same way as other dry-type elements. If electrical connections have to be disconnected to access the filter, this should be done carefully. The ducts and hoses should be checked to make sure that the connections are tight and that the joints do not have air leaks.

22.5 Engine manifolds

There are basic differences between the manifolds used on EFI engines and diesel engines. This applies particularly to intake manifolds. The differences are:

1. EFI engines with throttle-body injection have intake manifolds with the throttle body mounted in the centre of the manifold. Fuel is injected at the throttle body so that the manifold carries a mixture of air and fuel.
2. EFI engines with multipoint injection have intake manifolds that carry air. Injectors in the manifold spray fuel into the intake ports of the cylinder head.
3. Diesel engines have manifolds that carry air only. The fuel is injected directly into the cylinder.

22.5.1 EFI engine intake manifolds

Figure 22.7 shows an inlet manifold for an EFI engine. Made from aluminium alloy, it has long branches and a plenum chamber that provides a surge chamber, reducing intake air resistance. The branches of the manifold are of equal length, creating an inertia-charging effect that improves intake efficiency.

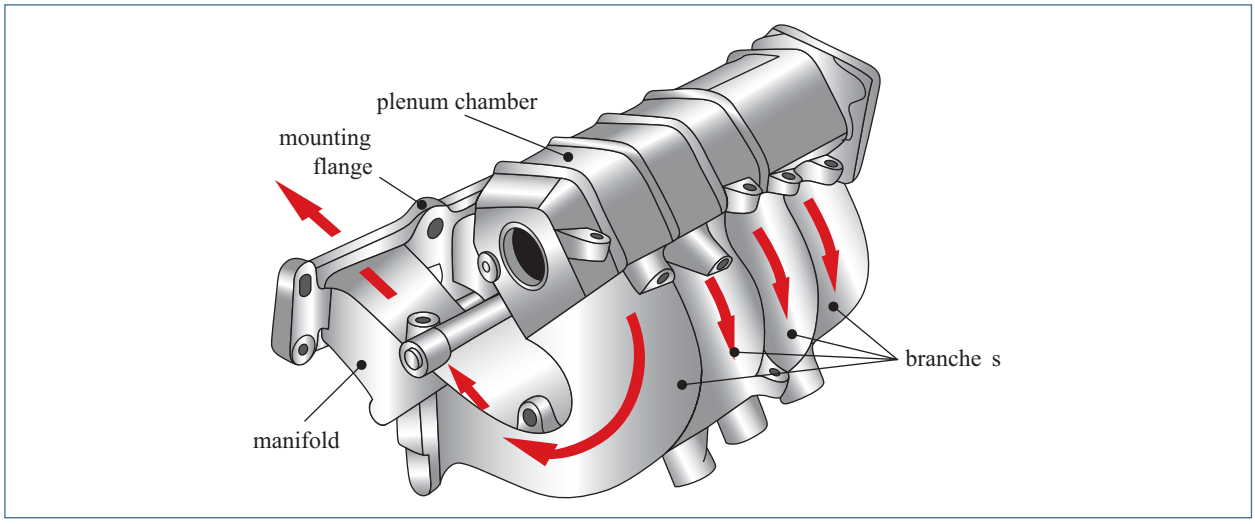


Figure 22.7 Intake manifold for an EFI engine—arrows show the airflow

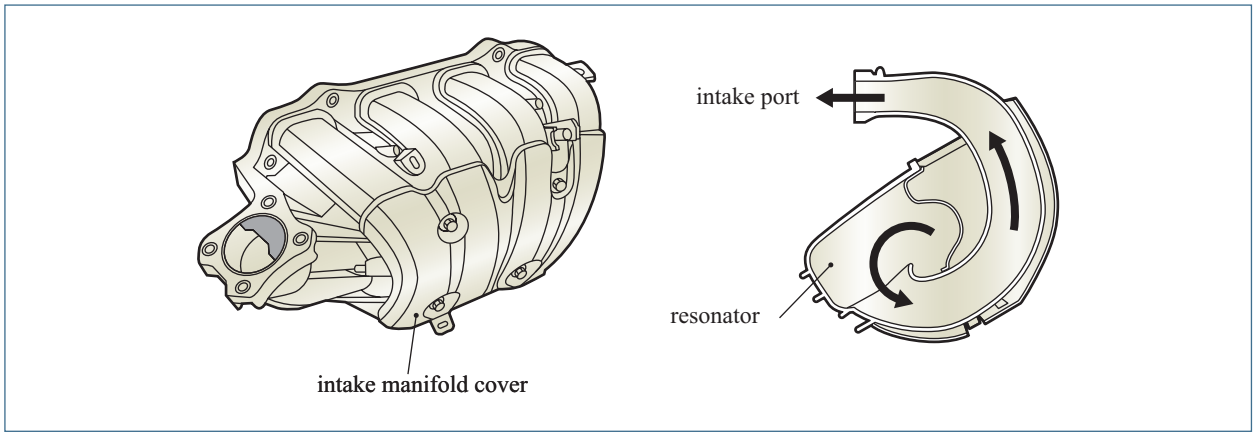


Figure 22.8 Plastic intake manifold showing airflow

Volumetric efficiency can be further improved by having a plastic intake manifold. This reduces the amount of heat transferred from the cylinder head, lowering intake air temperatures. Figure 22.8 shows a plastic manifold with a resonator to improve mid-speed torque and a cover to reduce intake air noise.

V-type engine intake manifolds

V-type engines have the intake manifold located in the valley between the two cylinder heads. Branches of the manifold go to the intake ports at each side. Figure 22.9 shows the parts of an intake manifold assembly for a V-6 engine. The lower intake manifold fits between the cylinder heads and the upper intake manifold and is bolted to it. The cover is then bolted to the upper intake manifold to form the plenum chamber.

Seals are used between the parts so that the assembly is airtight. The injectors fit into holes in the lower intake manifold. They are attached to the fuel rails, which supply them with fuel.

22.5.2 Variable intake manifold

With EFI engines, the branches of an intake manifold (also called runners) have a particular length and diameter to suit the engine. The design is something of a compromise, because the requirements of an intake manifold at high engine speeds are different to those at low speeds.

At low engine speeds, the branches of the intake manifold need to be of small diameter so that the velocity of air is maintained. At high engine speeds, the branches need to be larger in diameter so that the airflow is not restricted.

The pulsation of the air in the manifold must also be considered. A ram air effect can be created in the manifold if it is tuned to the right length. The ram effect originates with piston and valve action, which produces pulsations in the manifold. The pulsations can be accentuated by the design of the manifold and used to produce the ram effect.

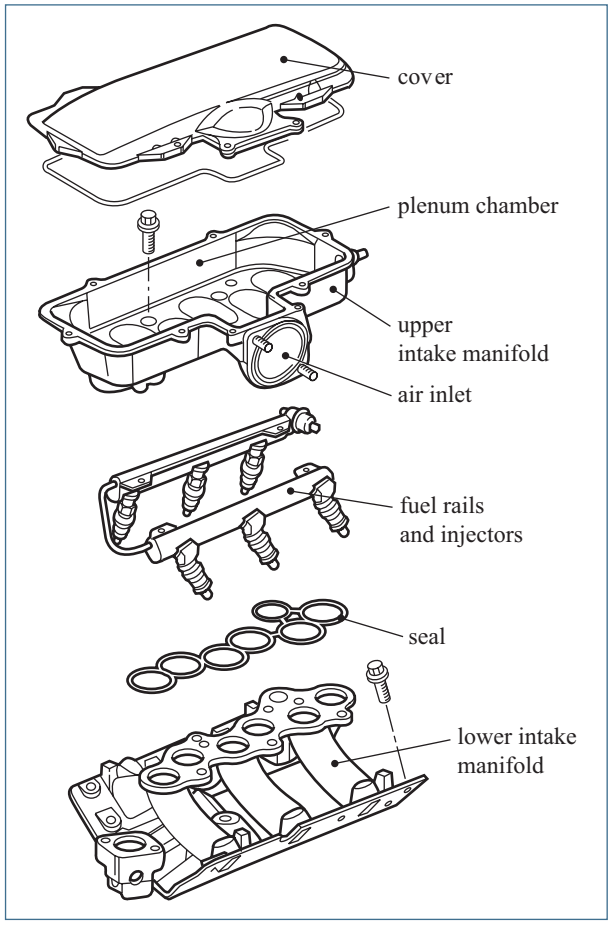


Figure 22.9 Parts of an intake manifold assembly for a V-type engine—the fuel rails and injectors are also shown GM HOLDEN LTD

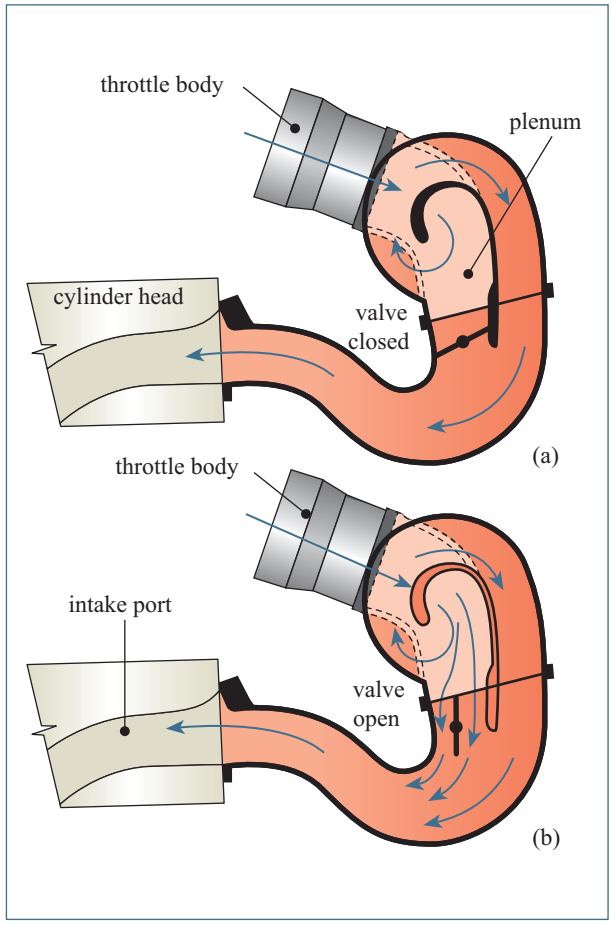


Figure 22.10 Intake manifold with dual branches (runners) (a) airflow at low engine speeds (b) airflow at high engine speeds

22.5.3 Dual branches or runners

To provide for the different requirements at high and low engine speeds, intake manifolds can be designed with dual branches, as shown in Figure 22.10. The diagrams show a cross-section of one branch. There are two paths that the air can take, a long path and a short path. These are controlled by throttle-type valves. At low speeds, the valve plate is closed as shown in Figure 22.10(a) and the air is directed around the longer and narrower path to the engine.

At high speeds, the valve plate is opened, as in Figure 22.10(b). Most of the air then passes through the valve and takes the shorter and wider path to the engine.

The valves are located between the plenum chamber and the manifold branches (Figure 22.7). There is a valve plate for each branch, and these are mounted on a common shaft that is rotated by a vacuum control unit (Figure 22.11). This, in turn, is controlled by the engine's power control module.

22.5.4 Primary and secondary intake manifold

A manifold with primary and secondary sections is the basis of a system referred to as a *variable-inertia charging system.* This system uses the inertia (or pulsing) effect of the flow of intake air in the manifold to increase volumetric efficiency.

To maintain the desired high-speed air flow in the system, the primary section is made long and narrow for the low-rpm range of the engine. The secondary section is shorter and wider for the high-rpm range.

The secondary intake port is fitted with a valve, which enables it to be opened and closed. The valve is controlled by the engine's computer in relation to the engine rpm. This allows the effective length of the manifold pipe to be regulated to suit all engine speeds.

22.6 Intake-system problems

1 Restricted filter . A blocked filter element in the air cleaner could restrict airflow and cause loss of engine power, particularly at higher speeds.
2 Air leaks, EFI system. An air leak after the air filter and ahead of the throttle body will admit unfiltered air into the system.

Any air leak after the throttle body will upset the fuel mixture, because the air will be additional to that measured by the airflow sensor.

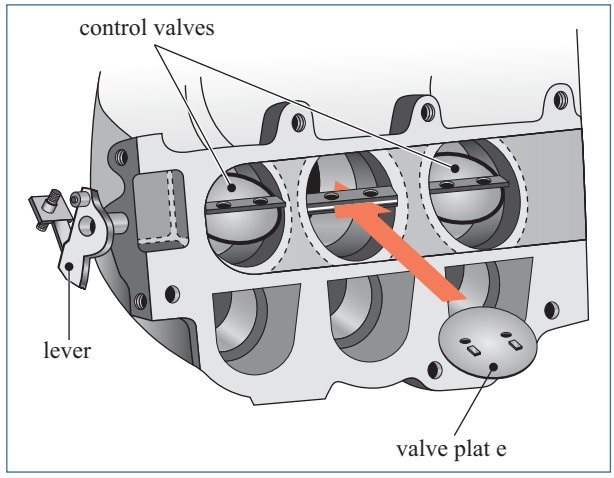


Figure 22.11 Lower part of an intake manifold with dual branches and control valves

22.7 Turbocharging and supercharging

The term *supercharger* describes a device that is driven mechanically, while *turbocharger* describes one that operates via a turbine driven by exhaust gas flow.

Turbocharging and supercharging both increase the volumetric efficiency of the engine. Naturally aspirated engines (those without turbocharging or supercharging) have a volumetric efficiency of about 85%. This is due to resistance of flow in the intake system and the effects of residual gases in the cylinders. Turbocharged and supercharged engines can have a volumetric efficiency of more than 100%.

22.8 Turbocharger construction and operation

A turbocharger is an exhaust-driven device that uses the waste energy in exhaust gases. About 30% of the total heat produced in an engine is usually lost through the exhaust, but some of this can be utilised when a turbocharger is fitted. This energy is used to drive the turbocharger, which then forces additional air or air–fuel mixture into the engine cylinders.

Turbochargers are used on large and small engines. They are suitable for smaller engines because they do not directly use engine power.

Figure 22.12 shows a simplified turbocharger arrangement. Exhaust gases are carried from the exhaust manifold into the turbine, which is rotated at high speed by the force of the hot exhaust gas.

The compressor is also driven at high speed through a common shaft. Air entering the compressor is then forced through ducting to the intake manifold.

In some instances, an intercooler is fitted. This removes heat from the compressed air before it enters the engine.

Engines without turbochargers (or superchargers) are known as *naturally aspirated engines*—that is, they take air or air–fuel mixture into the cylinders by the normal pumping action of the pistons. Turbochargers and superchargers force air or air–fuel mixture into the cylinder, increasing engine output. Turbochargers are used with both petrol and diesel engines. (Refer to Chapter 35 for information about turbochargers on diesel engines.)

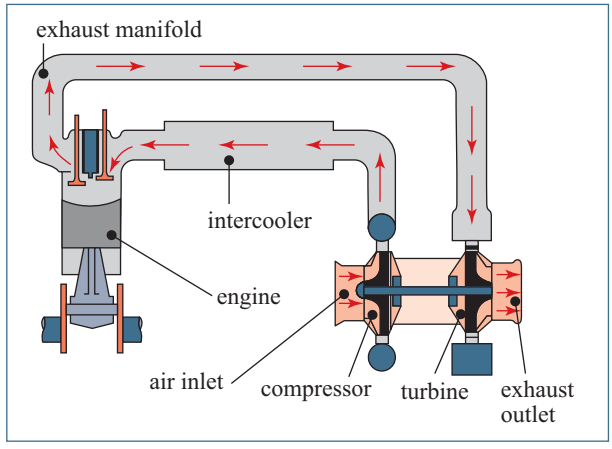


Figure 22.12 Basic arrangement of a turbocharger system

22.8.1 Boost

Naturally aspirated engines operate with negative intake manifold pressures (that is, below atmospheric). Turbocharged engines operate with intake manifold pressures above atmospheric, for example at around 40 to 60 kPa for a passenger car engine. However, for special engines, the pressure could be much higher. This pressure is referred to as *boost* or *boost pressure*.

22.8.2 Lag

The time taken for the engine to bring the turbine up to speed and produce boost is called *turbo lag*. When the throttle is opened at low engine speeds, the turbine shaft is not spinning fast enough to produce a positive pressure in the intake manifold. The exhaust gas must overcome the inertia of the impeller, compressor and shaft, and this takes time.

22.8.3 Turbocharger construction

Figure 22.13 shows a partly cut-away view of a turbocharger. This has two distinct sections:

1 Turbine section. This is the driving section.
2 Compressor section. This provides compressed air .

These two sections are referred to as being coaxial—that is, they have a common axis. The two outer sections are joined at the bearing housing. Also, the turbine wheel and the compressor wheel are mounted on a common shaft. The turbocharger has a wastegate which is operated by an actuator. This controls the flow of exhaust gases to the turbine, thus controlling the turbocharger speed.

22.8.4 Turbocharger operation

The two sections of the turbocharger (turbine and compressor) operate together at the same speed, but they will be considered separately here. One is the driving section and the other is the driven section.

Turbine operation

The turbine housing forms a volute, or spiral-shaped passage, which surrounds the turbine wheel. The exhaust gases from the engine are directed into this. It has a slot around its inner edge through which gases flow to the turbine wheel. This provides a force against the turbine blades, making the turbine wheel rotate (Figure 22.14).

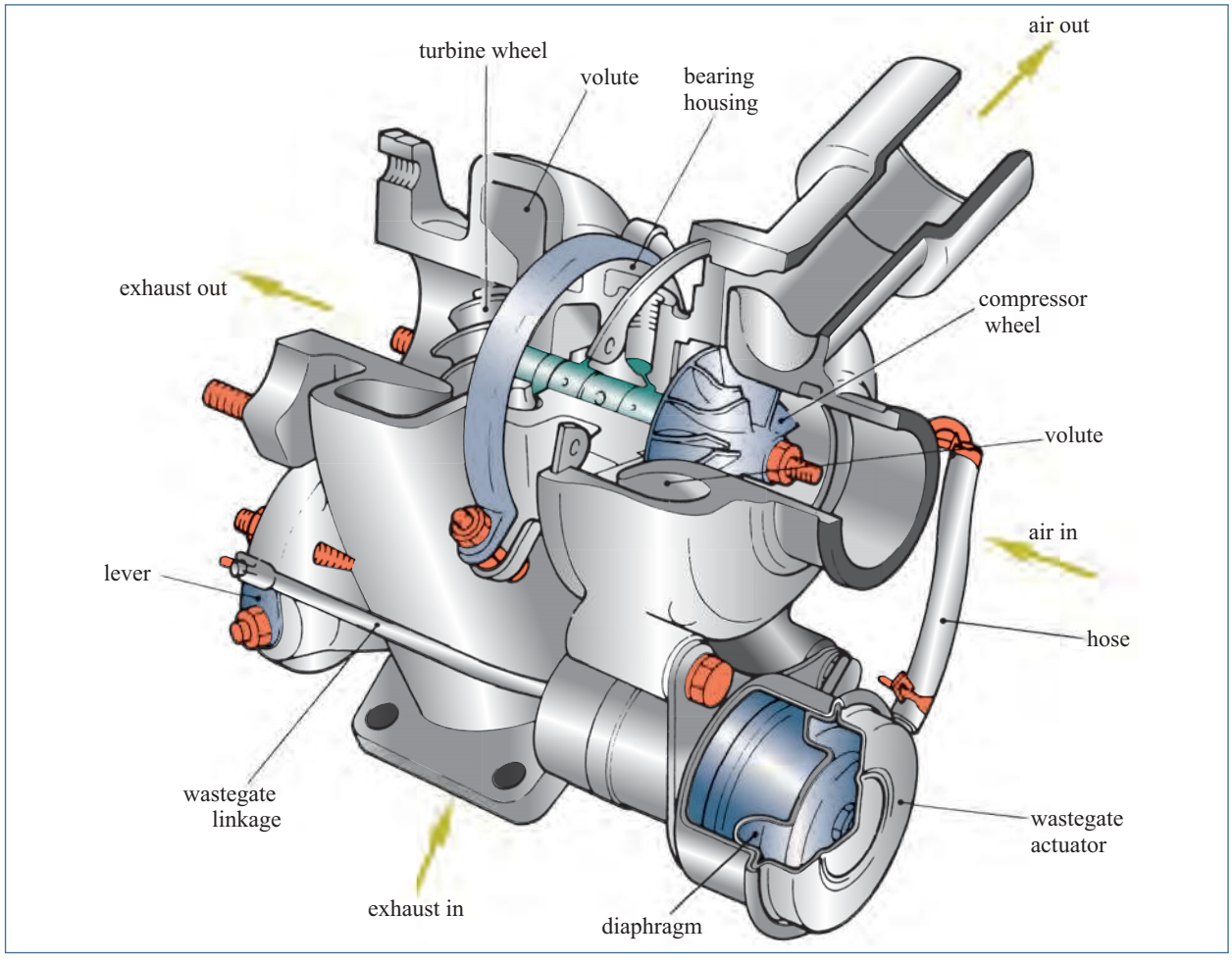


Figure 22.13 Sectional view of a turbocharger for a petrol engine MITSUBISHI

The gas flow is from the slot in the volute to the outer edge of the turbine wheel, through the turbine blades towards the centre. The gas then flows from the outlet in the centre of the turbine to the exhaust system.

The volute passage becomes smaller as it scrolls around the turbine housing, maintaining the velocity of the exhaust gas as it flows through the volute. The turbine blades are curved and are closer and smaller towards the centre. This also maintains the exhaust gas velocity so that as much energy as possible is obtained from the exhaust gas before it leaves the turbine.

The continuous flow of gas through the turbine rotates the turbocharger at high speed.

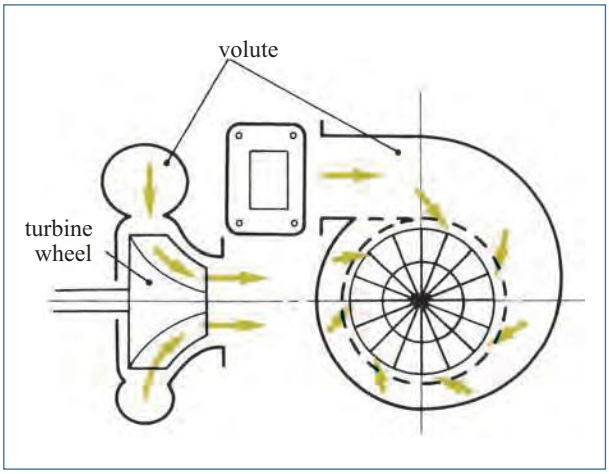


Figure 22.14 Flow of exhaust gases through the turbine of a turbocharger

Compressor operation

The compressor acts in an opposite manner to the turbine. The compressor wheel has curved blades which pick up air from the inlet in the centre of the compressor housing. The air is then thrown outwards by centrifugal force, leaving the outer tips of the blades and passing into the volute in the compressor housing. The volute increases in size towards its outlet, reducing the velocity of the air before it is delivered to the engine.

22.8.5 Lubrication and cooling

The turbocharger gets a flow of oil from the engine's lubrication system. The oil lubricates and cools the bearings before returning to the oil pan. It does not drain away from the turbocharger when the engine is stopped, and there is always a small reservoir of oil in the bearing housing.

Due to the high speeds reached by the turbine wheels and the heat absorbed from the exhaust gases, a turbocharger must have an adequate supply of oil. This is needed for both lubrication and cooling.

To prevent high oil temperatures, which could cause the oil to deteriorate, an oil cooler is fitted to the engine's lubricating system. (Some turbochargers are also fitted with a water-jacket.) This allows coolant from the engine's cooling system to be circulated through the turbocharger to remove heat (Figure 22.15).

22.9 Turbocharger control

To control the boost pressure, the turbocharger is fitted with a wastegate or bypass valve which controls its speed by controlling the flow of exhaust gas to the turbine wheel and thus the turbine speed. By allowing some gas to go to the turbine and some to go directly to the exhaust outlet, the turbine speed can be controlled.

Figure 22.16 shows the control system of a turbocharger. It operates in the following way:

1 The wastegate actuator has its diaphragm connected by linkage to the wastegate . Normally, the wastegate is held closed by a spring under the diaphragm.
2 The actuator is connected by a hose to a port on the pressure side of the compressor , so that the diaphragm is sensitive to any change in turbocharger pressure .
3 When the turbocharger pressure is below the specified pressure , the wastegate will remain closed and all the exhaust gas will pass through the turbine to drive the turbine wheel.
4 As the turbine speed increases, turbocharger pressure increases. When it becomes high enough, pressure on top of the actuator diaphragm will overcome the spring under the diaphragm.
5 The diaphragm will move downwards to open the wastegate and allow part of the exhaust gas to bypass the turbine wheel and go directly into the exhaust system.
6 The reduced gas flow reduces the turbine speed so that the turbocharger speed is k ept within the specified range.

The illustration also shows the arrangement of the pressure switch that provides a signal to the electronic control unit. This sends signals to the warning buzzer and warning light if the system pressure is too high.

Handy hint: Some systems also include a safety valve , referred to as a blow-off valve , in the intak e manifold to protect against over-boost.

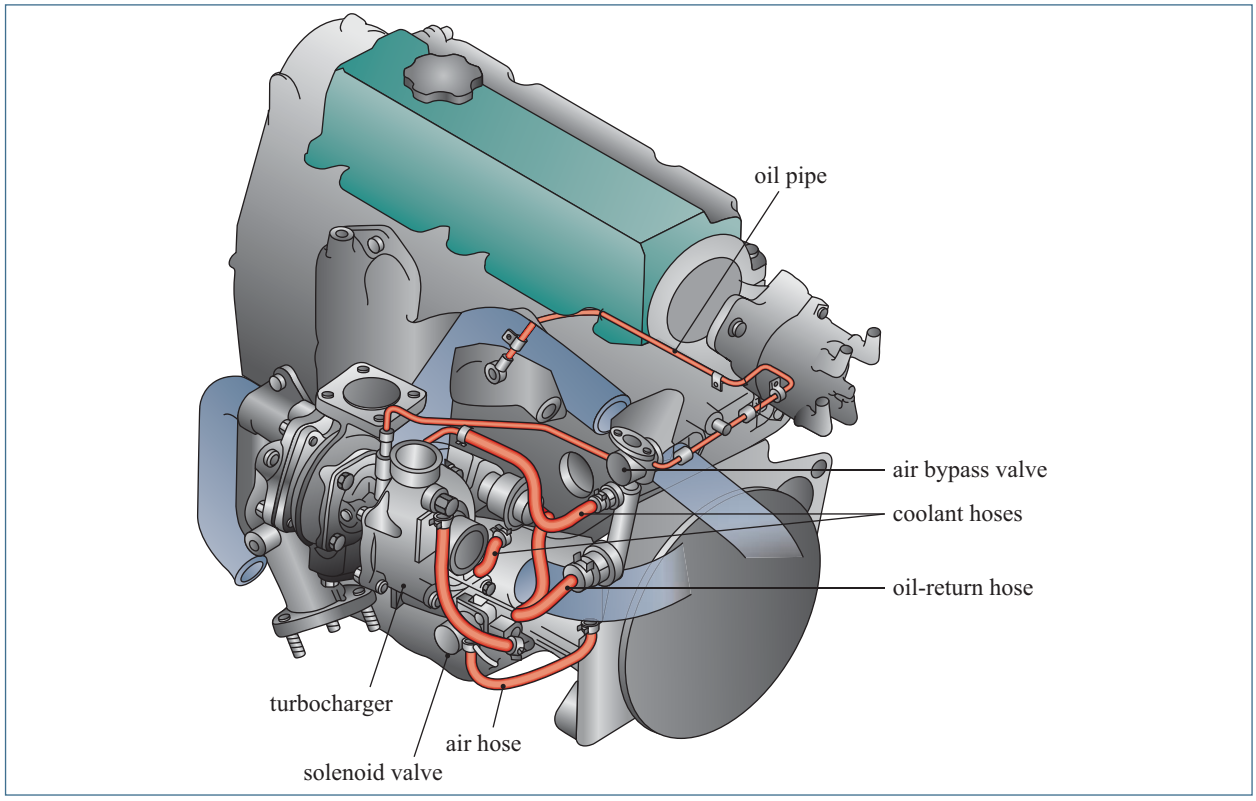


Figure 22.15 Turbocharger installation showing coolant connecti ons and oil supply pipe

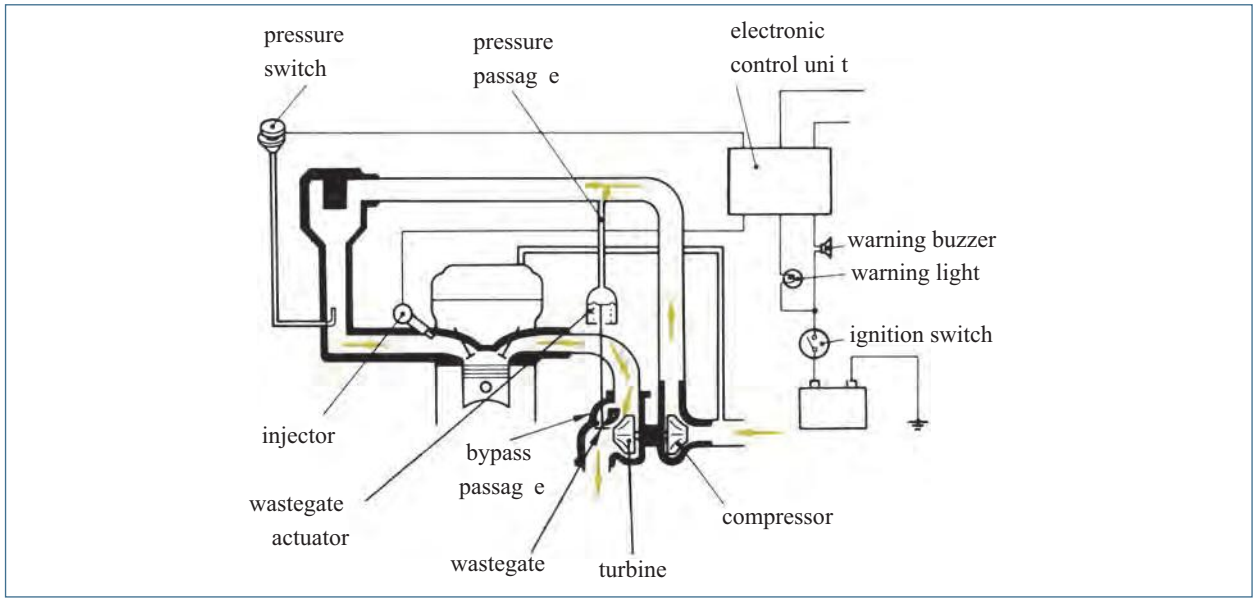


Figure 22.16 Turbocharger control system—includes a warning light and buzzer FORD

22.9.1 Electronic control

Figure 22.17 is a diagram of the intake and exhaust systems of a diesel engine. It includes a turbocharger and the controls and sensors associated with its operation. The actual controls are in the form of vacuum actuators, which are controlled by vacuum switching valves (VSVs). An engine-driven vacuum pump provides the source of vacuum.

The engine's electronic control unit (ECU) operates the VSVs. It receives input signals from a number of sources, processes that information and then sends output signals to the VSVs. The VSVs are operated by electric solenoids that they open when the solenoid is energised and close when it is de-energised.

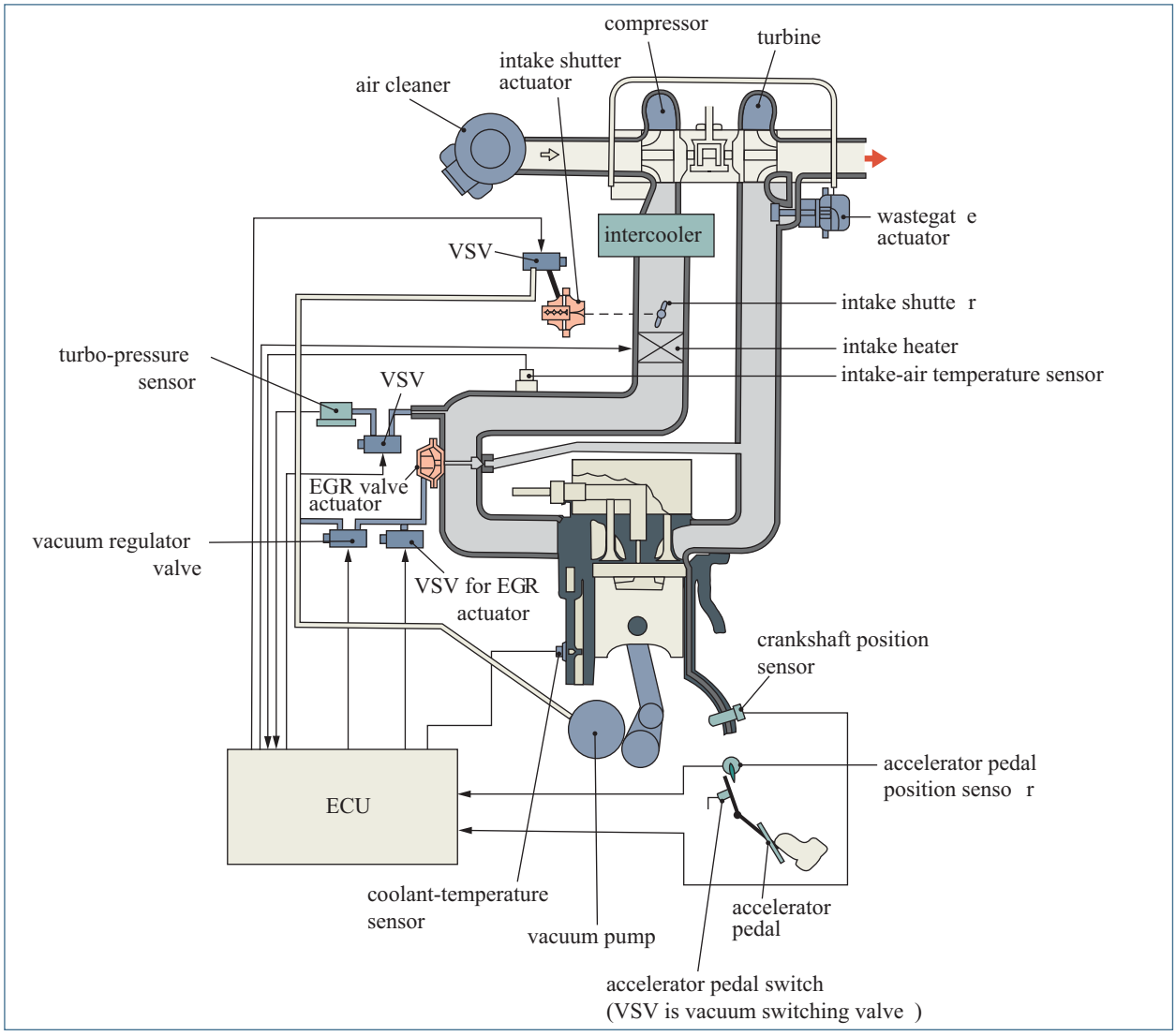


Figure 22.17 Controls and sensors associated with the turbocharger and the intake and exhaust systems of a diesel engine

The functions of the various controls are as follows:

1 VSV. Controls vacuum to the intake shutter actuator
2 Intake shutter actuator. Operates the intake shutter in the air-intake system.
3 Intake shutter. Closes off the airflow to the engine.
4 Intake heater. Provides heated air in extreme cold conditions.
5 Intake air temperature sensor. Senses the temperature of the air entering the engine.
6 Turbo-pressure sensor. Provides turbo sensor information to the ECU. Overheating will operate a warning light or sound a warning signal.
7 VSV. Controls vacuum to the turbo-pressure sensor.
8 EGR valve actuator. Opens a valve to recirculate some of the exhaust gas.
9 Vacuum regulator valve. Regulates vacuum to the EGR valve.
10 VSV. Controls vacuum to the EGR actuator.
11 Coolant-temperature sensor. Checks temperature of the coolant in the water-jackets.
12 Crankshaft position sensor. Used for engine rpm and timing.
13 Accelerator pedal sensor. Indicates position of the accelerator (there is no cable control).
14 Accelerator pedal switch. Indicates when the throttle is closed for idle.

22.9.2 Intake shutter valve

Compression vibrations are sometimes evident when turbocharged diesel engines are being shut down. The air-shutter valve blocks off air from the turbocharger during shutdown, reducing the compression pressure and thus helping to eliminate compression vibrations as the engine comes to a stop.

An air-intake shutter and its vacuum actuator are shown in Figure 22.18.

22.9.3 Warning indicators

The turbocharger system has a warning light and a buzzer to prevent the engine from being operated with excessive boost pressure. These are connected to the electronic control unit of the engine's management system.

A pressure switch is fitted to the intake manifold. If the pressure becomes too high, the switch signals this to the electronic control unit, which causes the warning light to flash and the buzzer to operate. It also cuts off fuel to the injectors, reducing the engine speed.

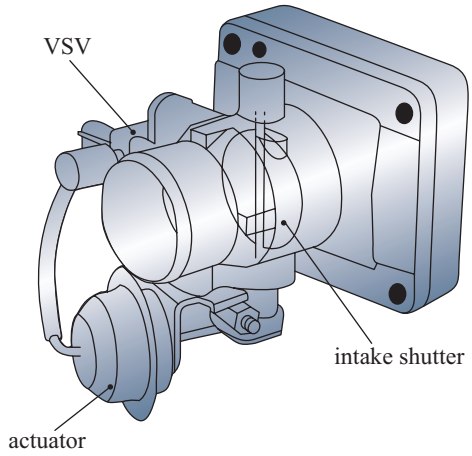


Figure 22.18 Air-intake shutter valve for a turbocharged diesel engine

22.10 Twin-scroll turbocharger

The operation of a turbocharger with a twin scroll or volute is shown in Figure 22.19. There are two entry ports—a primary and a secondary.

At low engine rpm, gases to the secondary port are blocked off and the exhaust gas passes through the primary port into the turbine. This concentrates the gases at high speed. Also, the design of the scroll directs the gas onto the blades of the turbine wheel at a sharp angle for maximum impact.

At higher rpm, both the primary port and the secondary port are open and both scrolls are delivering exhaust gas to the turbine. This changes the angle at which the gas is directed across the blades.

Figure 22.20 shows the arrangement of a complete twin-scroll turbocharging system for a rotary engine. This has a wastegate and actuator to control turbocharger speed. It also has a switching actuator and scroll-switching valve to control the flow of exhaust gas through the secondary port.

The switching actuator is a diaphragm unit which is operated by low pressure from the intake manifold. A solenoid valve in the low-pressure line is, in turn, operated by a signal from the electronic control unit.

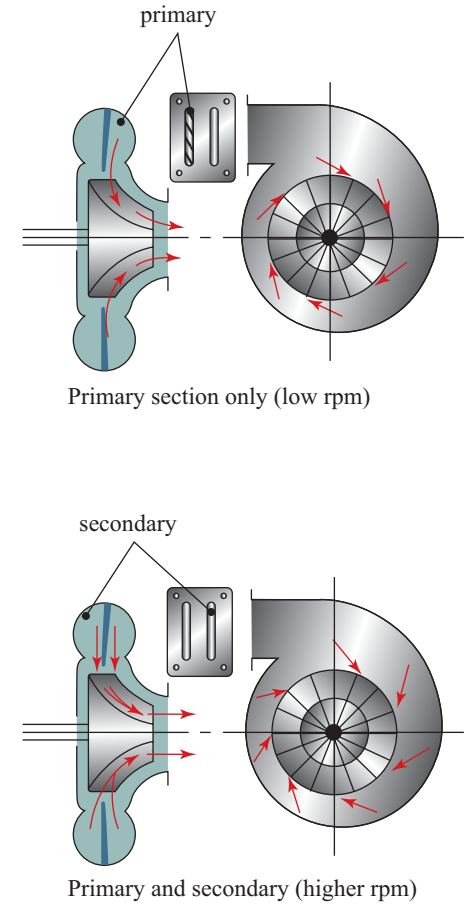


Figure 22.19 Operation of a twin-scroll turbine

22.10.1 Variable geometry turbochargers

Another method to improve turbocharger efficiency is to vary the area of the nozzle or volute. The flow of exhaust gas onto the turbine can be varied by varying the angle of a set of vanes.

Operation

At low rpm, the vanes are closed, forcing the exhaust gas through a narrow opening (see Figure 22.21(a)). This accelerates the gas onto the turbine blades, making them spin faster. As speed increases, the actuator opens the vanes fully, as shown in Figure 22.21(b). The high exhaust gas is then directed onto the turbine blades.

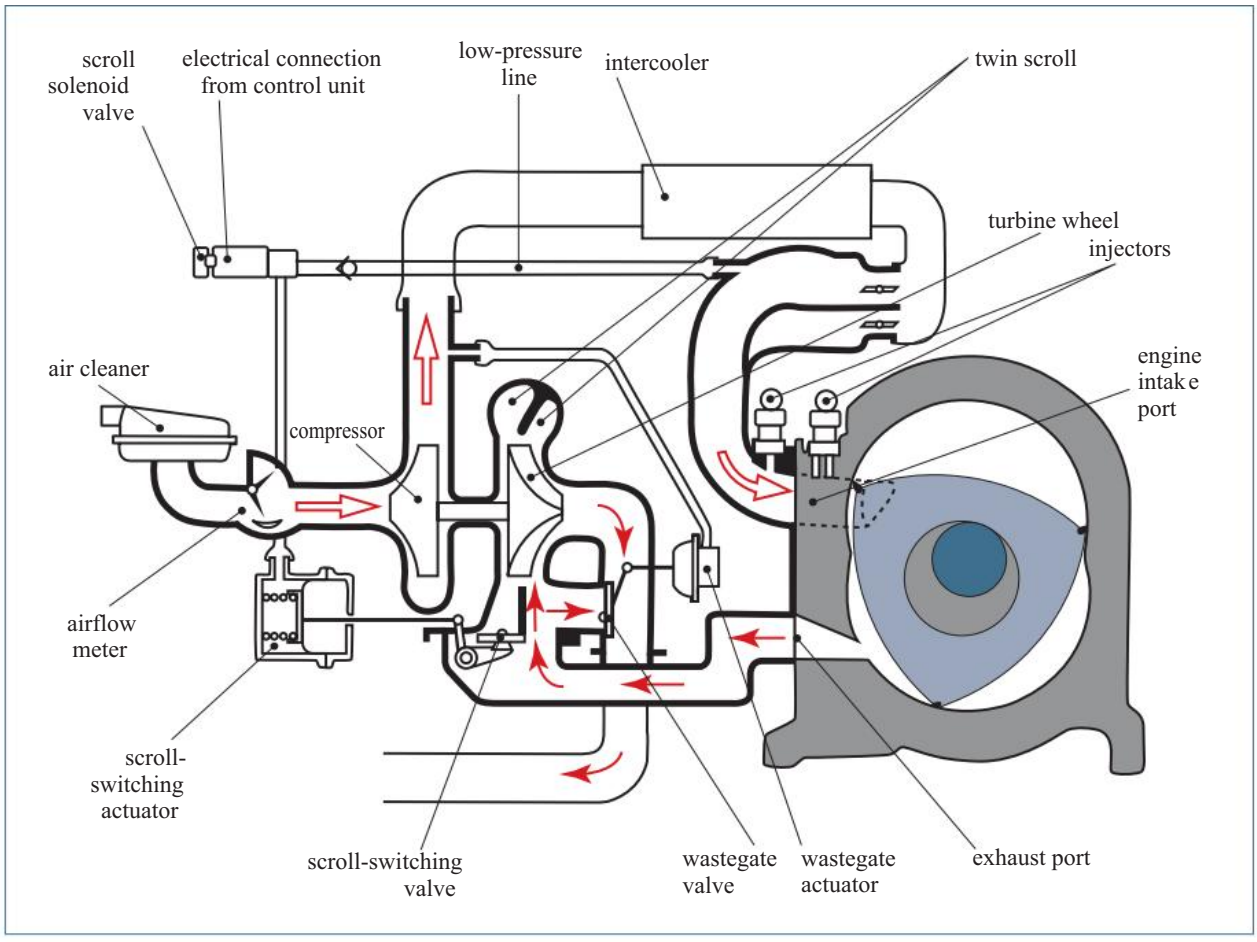


Figure 22.20 Arrangement of a twin-scroll turbocharger and electronic fuel injection for a rotary engine

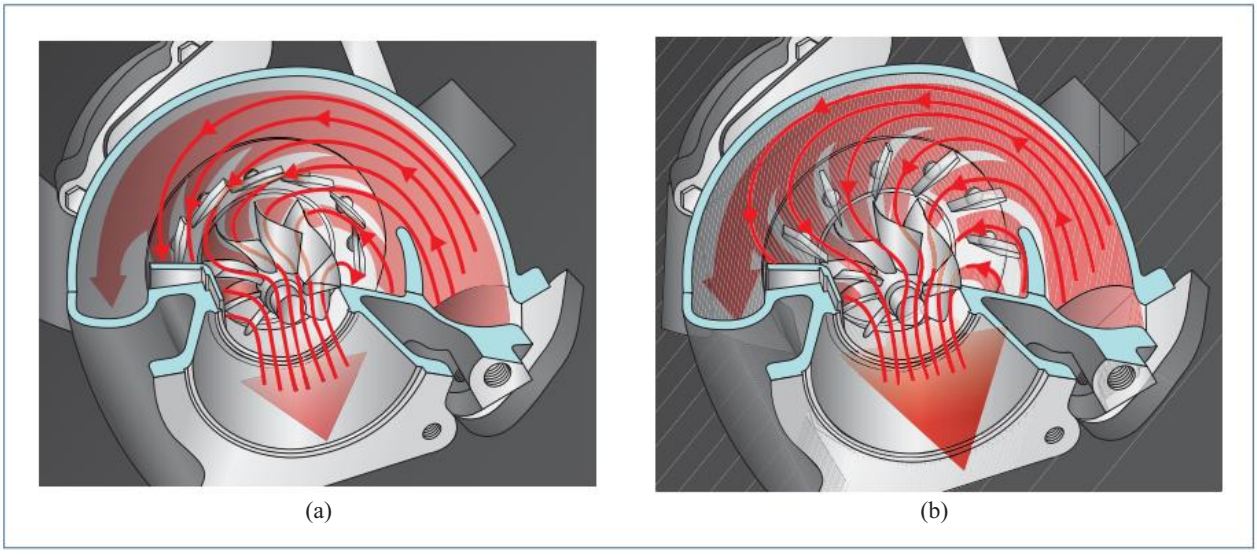


Figure 22.21 Operation of a variable geometry turbocharger: (a) low rpm with vanes closed (b) high rpm with vanes fully open

22.11 Intercooler

Figure 22.22 shows a turbocharger with an air-to-air intercooler. Mounted at the front of the vehicle, it uses fresh airflow through the outside of the core to reduce the temperature of the intake air ins the intercooler.

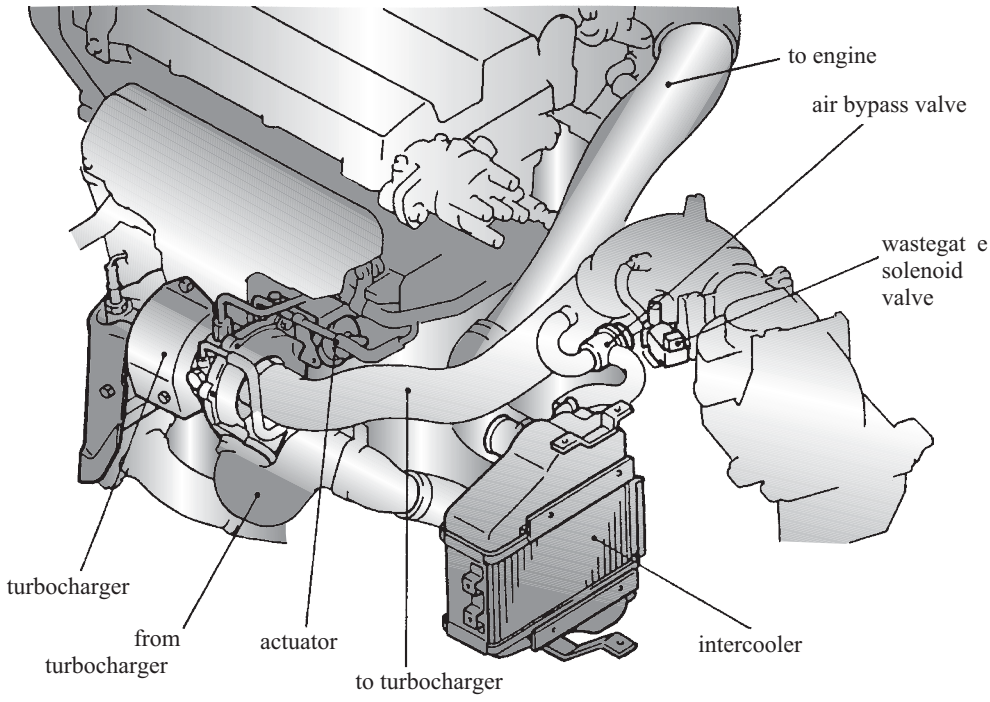


Figure 22.22 Turbocharger system with an air-to-air intercooler

All the intake air that leaves the compressor passes through the intercooler on its way to the engine. The air has been heated by being compressed, reducing its density. The intercooler reduces its temperature and increases its density. This improves the charging efficiency and increases engine output.

The illustration shows an air bypass valve. During deceleration, it carries air that bypasses the turbocharger, preventing air vibration noise from the pulsing effect of air in the ducting.

22.12 Operating a turbocharged engine

The following points apply to operating a vehicle with a turbocharged engine.

1 Do not race the engine under no-load conditions when the engine is cold.
2 Do not accelerate or decelerate sharply until the engine has reached normal operating temperature .
3 After heavy-load or high-speed operation, run the engine at idle for about one minute before stopping it.
4 For abnormal operating conditions, extend the idle time to about two minutes (if this is not controlled by the ECU).
5 If there is a sudden loss of power while driving, immediately reduce speed and drive at the lowest possible speed before shutting off the engine .
6 Use the correct type of engine oil and change the engine oil and the oil filter within the specified periods.

22.13 Service requirements for turbochargers

The following are general service requirements for turbochargers:

1 With the engine cold and the hose removed from the compressor intak e, check the blades of the compressor wheel to mak e sure that they are clean and undamaged.
2 Rotate the compressor wheel to check for roughness or radial play of the bearings.
3 With the outlet from the turbine removed, check the blades of the turbine wheel for damage .
4 Check the wastegate actuator linkage for free movement.
5 Check the actuator operation with a vacuum pump .
6 Check the tightness of all hoses and connections.
7 Keep the engine oil in good condition by regular oil and filter changes. The oil is usually changed more often than for a naturally aspirated engine because it is subjected to more severe operating conditions.
8 Generally , small turbochargers fitted to passenger cars are not repaired when faulty but are replaced.
9 If a turbocharger is removed, the reservoir between the bearings must be filled with oil before it is reinstalled. This also applies to installing a new turbocharger (Figure 22.23).

Safety: Exercise extreme caution when working or servicing a turbocharger. Be aware of the dangers of sharp moving parts.

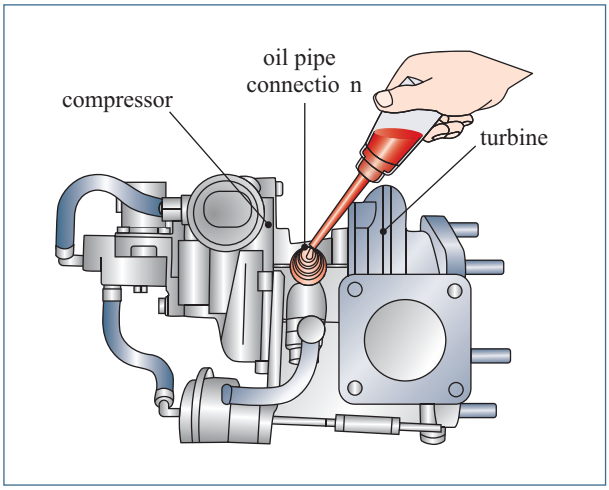


Figure 22.23 Before installing a turbocharger, add oil to the reservoir

22.14 Supercharger construction and operation

Superchargers, like turbochargers, are air pumps that generate pressures in the intake manifold that are higher than atmospheric pressure. Superchargers are used with both petrol and diesel engines.

Figure 22.24 shows a supercharger system. It has a positive displacement (Rootes-type) supercharger that is driven by a belt from the engine's crankshaft pulley.

Superchargers are driven directly from the engine and so operate at lower speeds than turbochargers. Consequently, superchargers have less lag time than turbochargers and start to provide torque at a lower speed range than an equivalent engine with a turbocharger.

In the system shown in the illustration, there are two valves—an air bypass valve (ABV) and an air control valve (ACV).

The *air bypass valve* (ABV) controls the amount of intake air that bypasses the supercharger. It is a diaphragm-type valve that is actuated by air pressure from the intake system, which is lower than atmospheric pressure. With low pressure below the diaphragm, the spring on top of the diaphragm opens the valve.

The *air control valve* (ACV) controls the introduction of atmospheric air into the vent pipes. This prevents leakage of the supercharger oil and bearing grease. This valve is solenoid operated and controlled by the ECU.

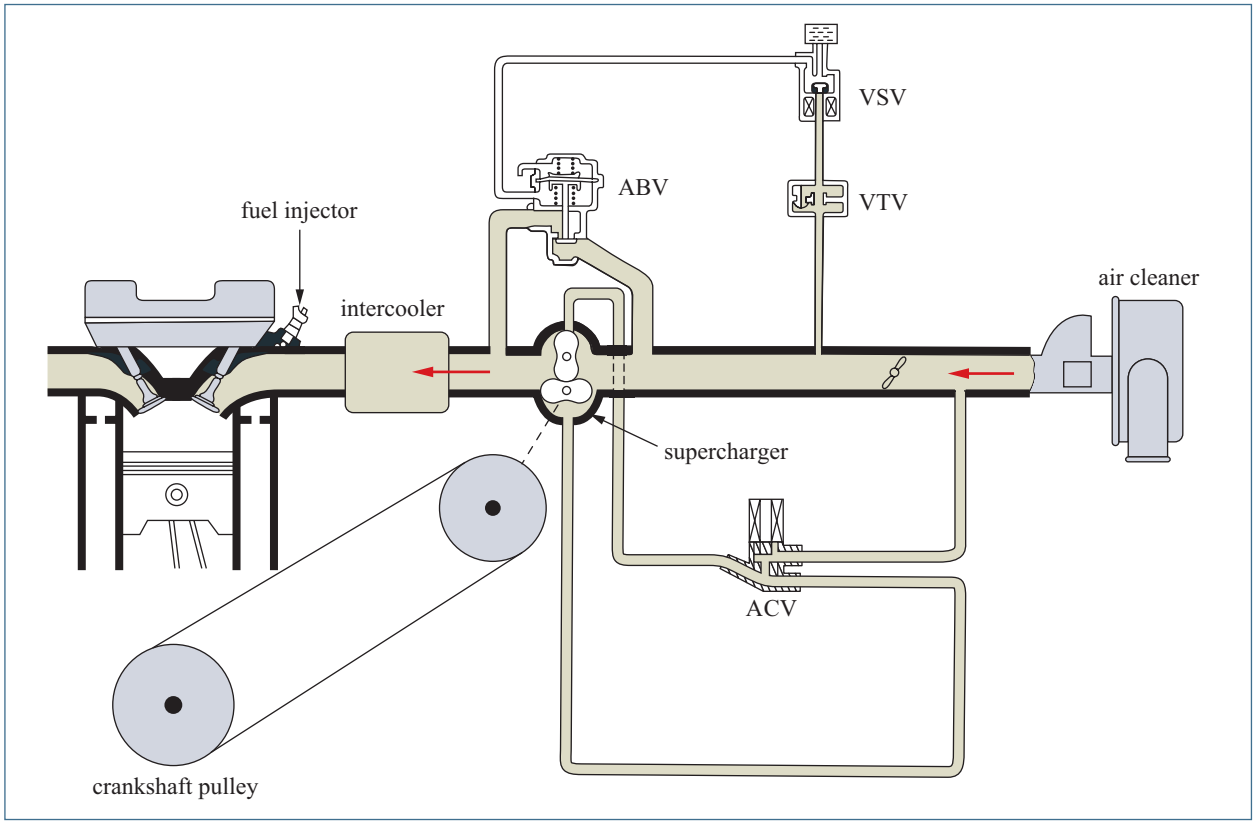


Figure 22.24 A basic Rootes-type supercharger system

Handy hint: As with a turbocharger, an intercooler is used to cool the intake air. This increases the density of the air and so improves intake efficiency.

22.14.1 Supercharger boost

Engines without a supercharger (naturally aspirated engines) operate with intake manifold pressures below atmospheric, that is, at negative pressures. Supercharged engines operate with intake manifold pressures above atmospheric. For passenger car engines, these are around 50 kPa, although for special high-performance engines the pressure could be much higher.

Handy hint: The high pressure provided by a supercharger is referred to as boost or boost pressure.

Positive displacement-type superchargers are based on the Rootes air pump or blower. This is basically a gear-type pump consisting of two rotors in an oval-shaped chamber that has an inlet on one side and an outlet on the other (Figure 22.25).

Each rotor has two lobes with a figure-8-shaped section through them. The rotor shafts are connected by gears. The rotors spin in opposite directions and have minimal clearance with one another and with the chamber walls.

As the rotors spin, they pick up air from the inlet port and move it to the outlet port. This operation can be followed in the sequence of the diagrams in the illustration.

Air is pumped out four times per rotor revolution. As air cannot move backwards in the system, the increased mass of air delivered to the intake manifold increases the manifold pressure. Air is pumped by the blower, but it is not compressed within the blower itself.

22.14.2 Supercharger operation

When in operation, air drawn in through the air cleaner at atmospheric pressure is compressed by the supercharger, cooled (and therefore increased in density) by the intercooler and then forced into the combustion chamber. This allows a greater mass of air to be mixed with a greater amount of fuel, resulting in a greater power output.

22.14.3 Air bypass valve

All superchargers have an air bypass valve that allows intake air to bypass them when boost is not required, through the provision of an alternative passage to the intake manifold.

The air bypass valve can also allow air to flow in the reverse direction to limit boost pressure. It does this by recycling air back to the air duct on the intake side of the supercharger.

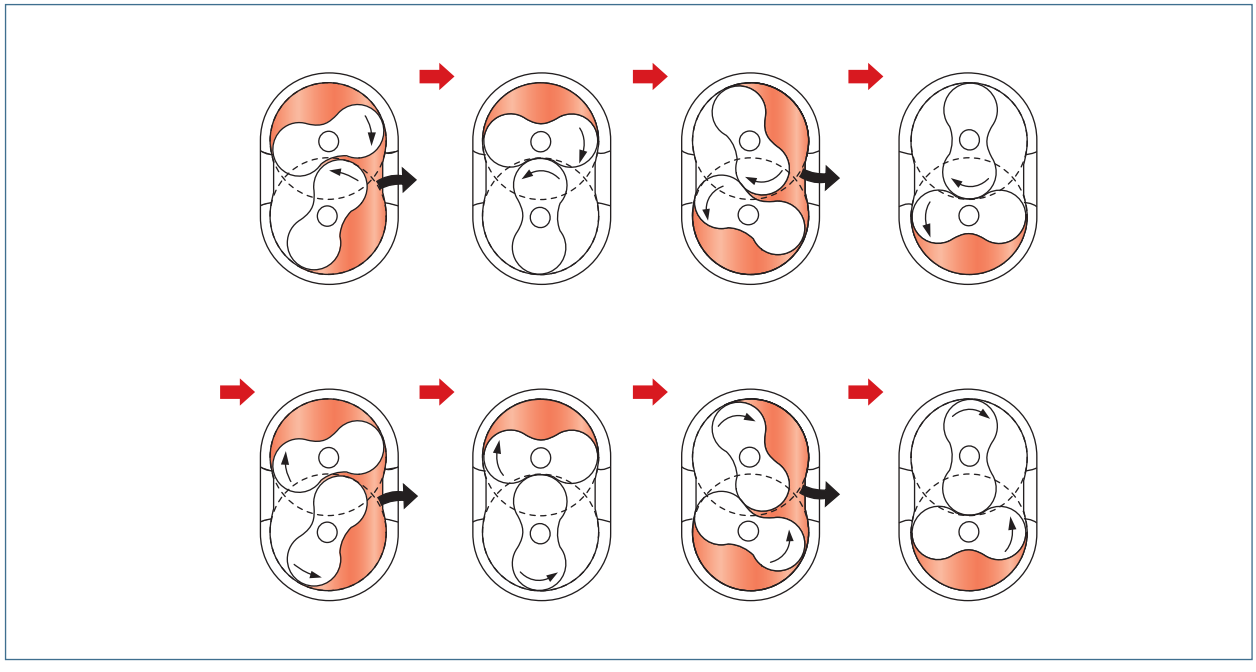


Figure 22.25 The pumping action of a Roots supercharger

22.14.4 Twin-screw supercharger operation

Figure 22.26 shows a twin-screw supercharger. This has two helical-shaped rotors, with three lobes on each. As air is pumped through the supercharger, its volume decreases, thus raising its pressure. This results in a more efficient airflow into the intake manifold.

The upper illustration shows the airflow from the supercharger rotors for a V-type engine. The lower illustration shows the air flow entering and leaving the rotor chamber, as well as the bypass valve and the actuator for controlling the supercharger.

22.15 Supercharger control

Figure 22.27 is a schematic diagram showing how supercharger boost is controlled. Air from the air cleaner is carried through the throttle body and into the supercharger, as shown by the arrows on the diagram.

With the bypass valve closed, all the air passes from the supercharger to the plenum chamber of the intake manifold. The air is then carried by the intake manifold to the cylinders of the engine. This provides full boost.

With the bypass valve open, some air is recirculated back to the supercharger intake and so there is reduced boost.

The bypass valve is operated by a pressure actuator. This has a spring-loaded diaphragm with a vacuum chamber above the diaphragm and a pressure chamber below. The spring tends to keep the bypass valve closed for full boost. Pressure applied below the diaphragm opposes the spring and opens the bypass valve for reduced boost.

Boost pressure from a take-off point at the supercharger operates the actuator. The pressure passes through a solenoid valve that is controlled by the engine's power control module (PCM).

With the solenoid valve open, pressure raises the diaphragm and there is reduced boost. With the solenoid valve closed, there is full boost. The actual boost delivered is determined by the PCM and how it cycles the solenoid valve.

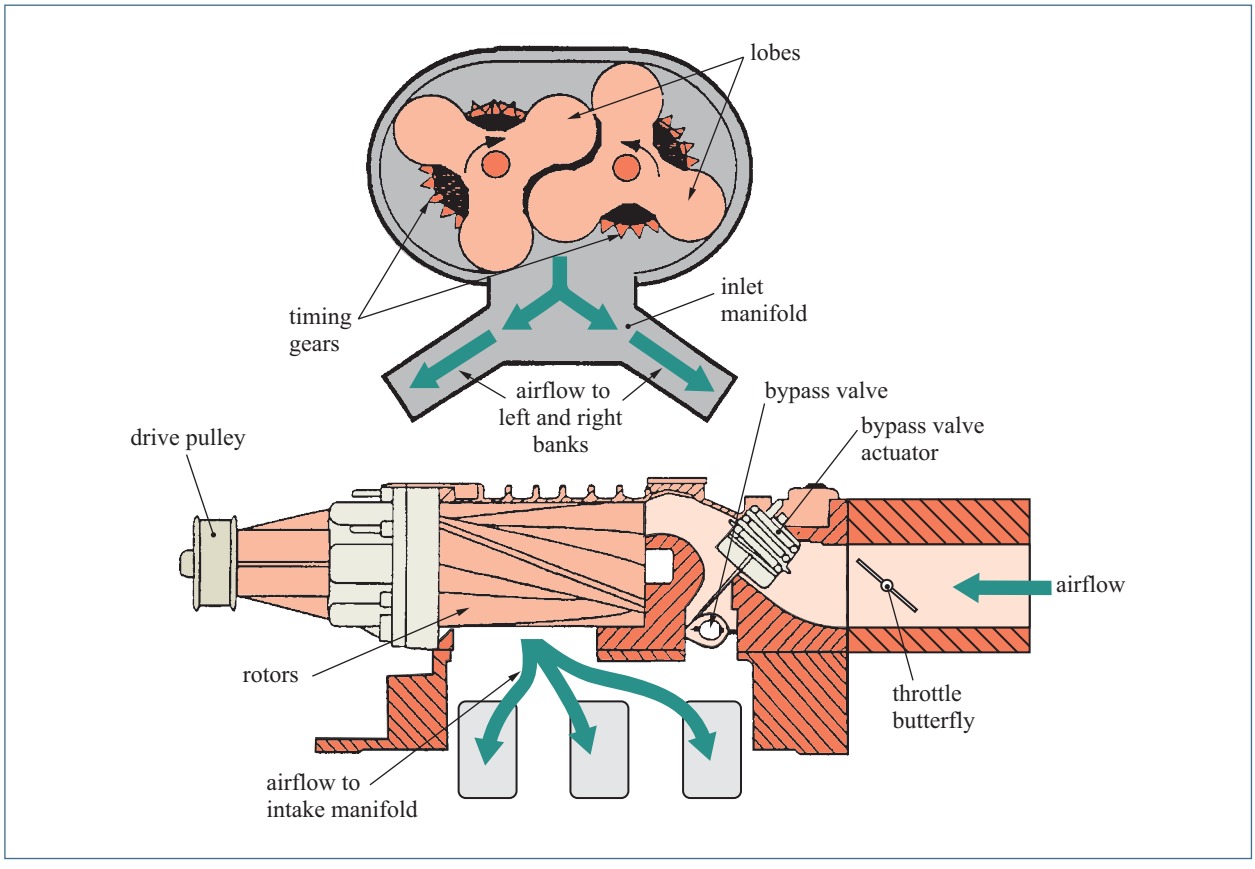


Figure 22.26 Cross-section of a twin-screw supercharger showing the airflow GM HOLDEN LTD

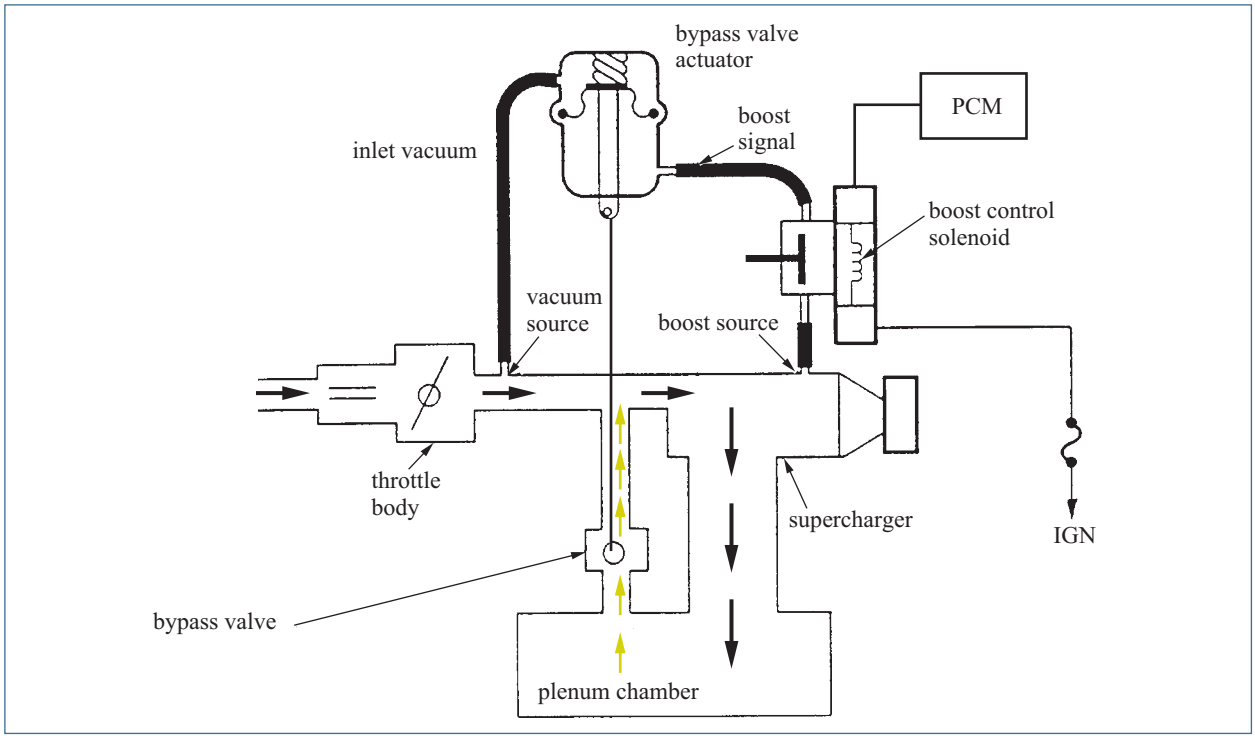


Figure 22.27 Diagram of the boost-control mechanism of a twin-screw supercharger GM HOLDEN LTD

22.15.1 Duty cycle

Under some conditions, the PCM will command the boost control solenoid to operate at 100% duty cycle (on) to allow full boost pressure. However, reduced boost pressure is desirable for engine idle, reverse gear, rapid deceleration and extremely high engine loads.

Under these conditions, the PCM commands the boost control solenoid to operate at a 0% duty cycle (off), which opens the bypass valve. With the bypass valve open, boost pressure is reduced by recirculating air to the supercharger inlet.

22.16 Service requirements for superchargers

1 Adhere to manufacturers ' recommendations for service operations and intervals.
2 Check and download fault codes from the ECU with a scan tool if a problem is suspected.
3 Check the bypass valve actuator and linkage operation.
4 Check the operation of the boost control solenoid.
5 Check for external oil and air leaks.
6 Change the lubricating oil if applicable .
7 Check the tightness of all fittings and attachments.
8 Check the condition of the drive pulley and belt.

Handy hint: Generally , small superchargers fitted to passenger cars are not repaired in service workshops. A faulty supercharger would be replaced with a new one or sent to a specialist repairer .

22.16.1 Supercharger lubrication

The supercharger usually has its own supply of oil to lubricate the bearings and timing gears. Specification of synthetic oil is a common manufacturer's recommendation.

22.16.2 Operating a supercharged engine

Specific points that apply to operating a vehicle with a supercharged engine are:

1 Warm the engine before putting it under heavy load.
2 For abnormal operating conditions, allow the engine to idle for about two minutes before shutdown.
3 If there is a sudden loss of power while driving, immediately reduce speed and drive at the lowest possible speed before shutting off the engine .

22.17 Exhaust systems

Exhaust manifolds are usually made of cast iron, which can resist high exhaust temperatures. Exhaust manifolds can also be fabricated from stainless steel, which is lighter than cast iron.

Exhaust manifolds have a number of cap branches, one for each exhaust port. These carry the exhaust gases from the exhaust ports, joining to form a flange which provides a connection for the exhaust pipe.

The exhaust manifold can be covered by a shroud. This shields other parts of the engine assembly from the heat that radiates from the manifold.

22.17.1 Parts of exhaust systems

Figure 22.28 shows an exhaust system for a V-type engine, where there is an exhaust manifold on each side so dual components are used. There are two catalytic converters and two intermediate mufflers, but only one rear muffler. Some engines have a dual system, with separate components and pipes for each side.

The engine pipe is attached to the exhaust manifold outlet by the exhaust flange. Brackets and mountings on the various parts support the system in relation to the engine and the body of the vehicle.

Exhaust systems have flexible mountings that allow for engine movement and prevent exhaust vibrations from being transmitted to the body of the vehicle. This also allows for thermal expansion of the system.

System arrangements

Exhaust pipes are designed with various shapes to suit the location of the engine and the type and design of the bodywork of the particular vehicle. Examples of exhaust installations can be seen in Figures 22.28 and 22.38, although there are many variations.

The system in Figure 22.29 is for a four-cylinder transverse engine. It has an exhaust manifold with separate branches joined to a flange. The pipes joining the components are identified from front to rear as: the engine pipe, or front pipe, the intermediate pipes, the rear pipe and the tailpipe.

Twin engine pipes are used between the manifold and the intermediate pipe. These are shaped to pass under the engine. This exhaust system has a catalytic converter and two mufflers, one in the middle and the other at the rear end of the system. Some exhaust systems have extractor pipes (one for each exhaust port). These have long sweeps that prevent back pressure. They also provide a scavenging effect, which assists in extracting the exhaust gases from the cylinders, increasing engine performance. The engine pipes in Figure 22.29 have this to some extent.

22.17.2 Exhaust-system connections

The parts of exhaust systems are joined together in different ways. Exhaust pipes and mufflers can be joined by fitting the end of one pipe into another (Figure 22.30), with a clamp holding the parts together.

Other connections are made with flanged joints. Figure 22.31 shows a joint between the exhaust flange of the manifold and a flange on the exhaust pipes. This has two engine pipes, the exhaust gas from half the engine's cylinders being fed into each. A gasket of heat-resistant material is fitted between the two flanges.

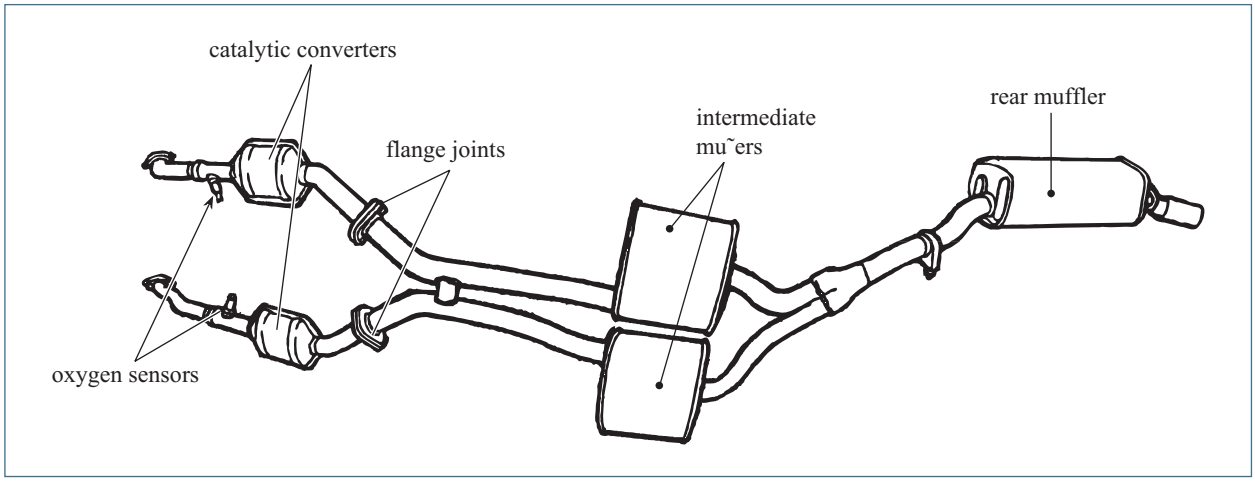


Figure 22.28 Exhaust system for a V -type engine FORD

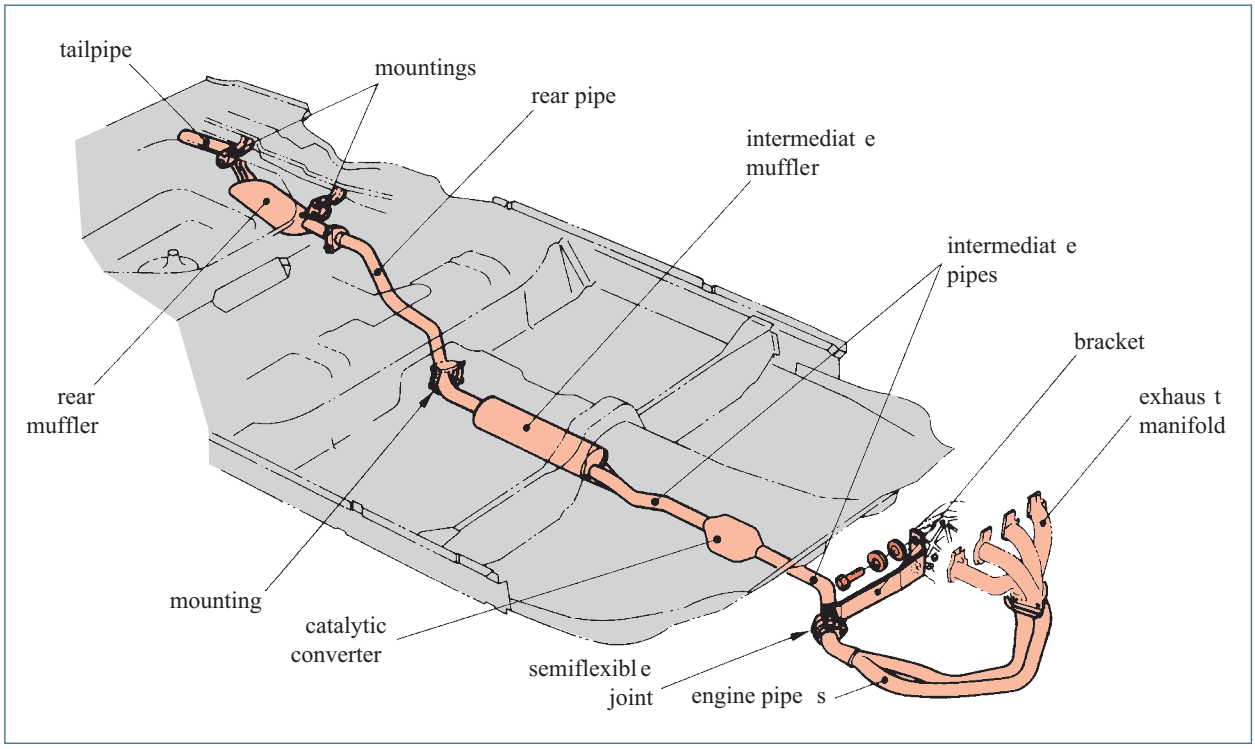


Figure 22.29 Components of an exhaust system GM HOLDEN LTD

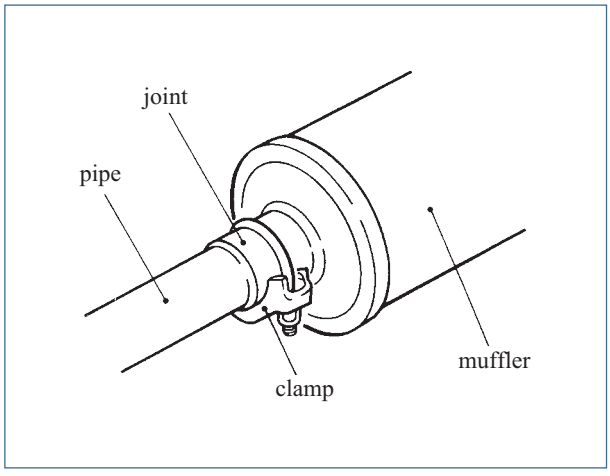


Figure 22.30 Clamping arrangement for an exhaust muffler

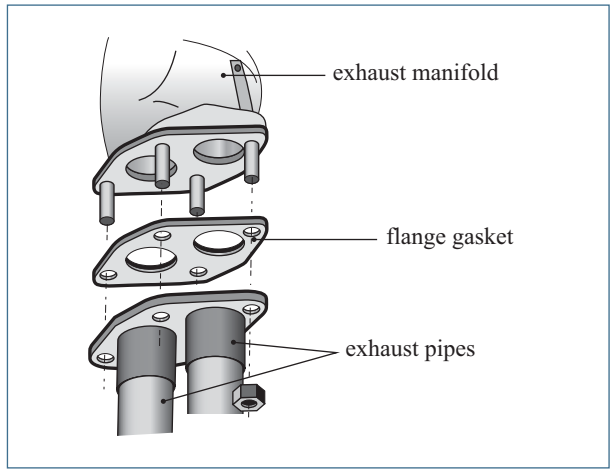


Figure 22.31 Exhaust manifold to engine pipe connection

Flexible pipe connections

With transverse engines in particular, semi-flexible connections are used between the manifold and the exhaust pipe, or as a connection between pipes. This compensates for movement of the engine in relation to the body.

Figure 22.32 shows one type of connection. This is a semi-flexible design that helps both with alignment of the pipes and with reducing vibration. In this joint, the sealing ring between the two pipes has a spherical end, which fits into a similarly shaped end of the exhaust pipe. The two bolts that hold the flanges of the pipes together are fitted with springs so that the sealing ring is held firmly onto its seat. This provides a joint that is firm, but not rigid.

Another arrangement of flexible exhaust connection is shown in Figure 22.33. A section of flexible, metal-braided pipe is inserted in the front exhaust pipe, providing a flexible connection between the parts of the exhaust system that are attached to the engine and the parts that are mounted to the bodywork.

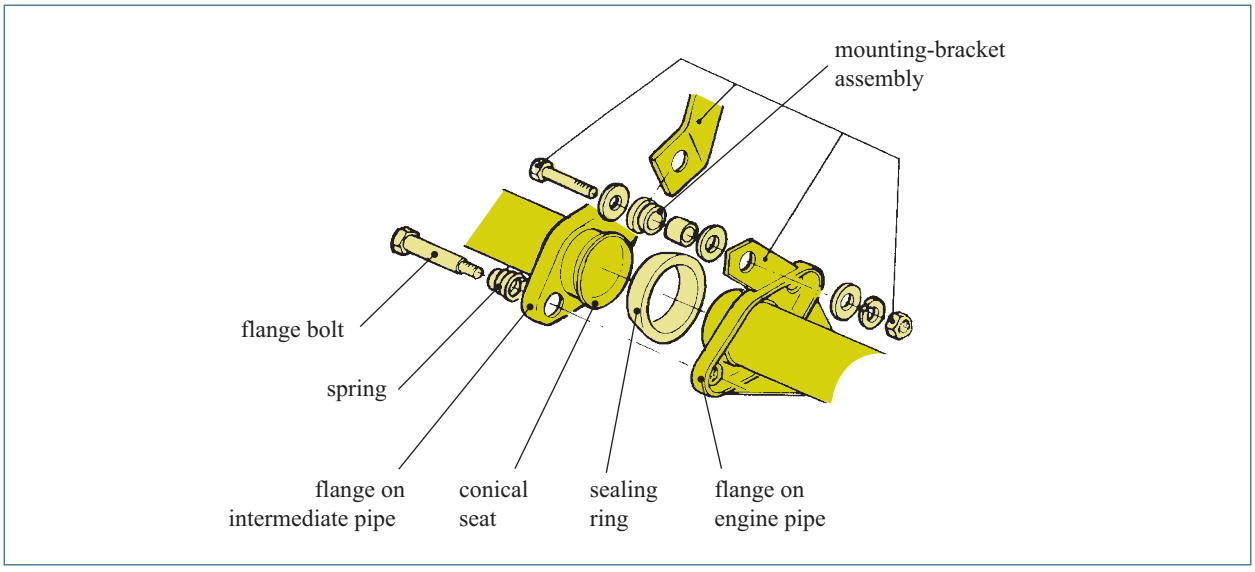


Figure 22.32 Semi-flexible connection in exhaust system

22.17.3 Exhaust mufflers

Mufflers—occasionally referred to as *resonators* and *silencers*—contain perforated pipes, baffles and resonance chambers, which are designed to break up the pulsating effect of the exhaust gases and reduce noise. This must be done with as little restriction as possible, because restrictions cause back pressure and inhibit gas flow.

Many mufflers have a combination of baffles and pipes which are perforated so that the pattern of the gas flow is altered, but not restricted.

Figure 22.34 shows the construction of a reverse-flow muffler, where the direction of flow of the exhaust gases is changed within it. Gases entering through the inlet pipe have to reverse their direction of flow before they can leave through the outlet pipe.

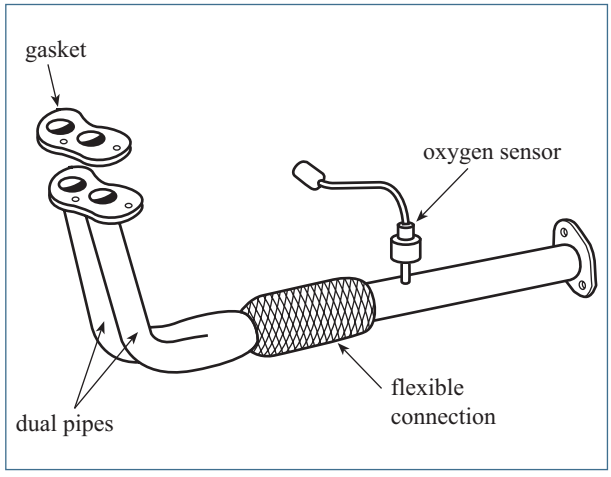


Figure 22.33 Exhaust pipe with a braided-metal flexible connection

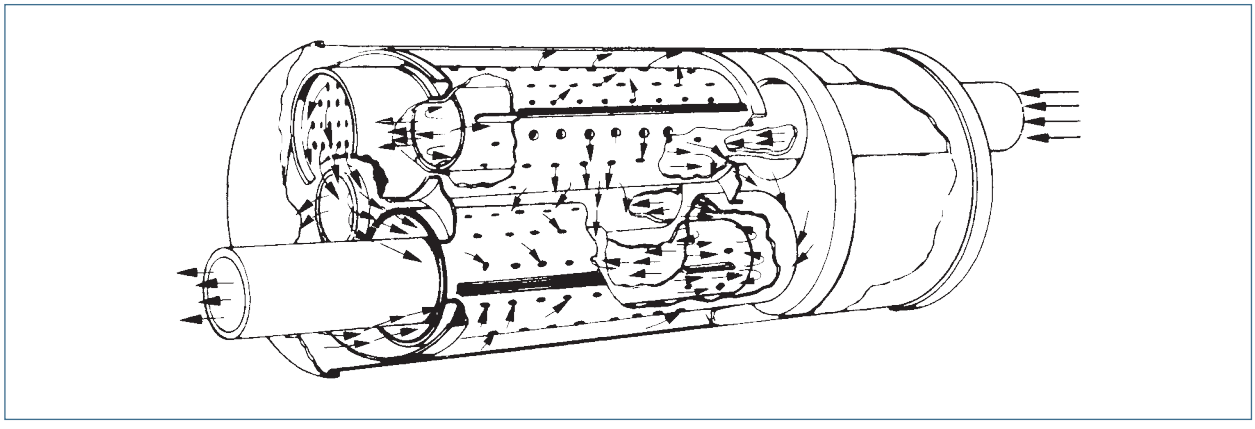


Figure 22.34 Exhaust muffler showing construction and gas flow

22.17.4 Catalytic converters

Many catalytic converters are fitted into the exhaust system in the same way as mufflers (Figure 22.35). They are used to control exhaust emissions. Chemical action with the exhaust gas as it passes through the converter reduces the emissions that are discharged from the tailpipe.

Catalytic converters operate at higher temperatures than mufflers and are fitted with a heat shield to prevent heat from radiating to the bodywork and adjacent parts.

Safety: Take care to avoid burns when working on or near a hot exhaust system, particularly with catalytic converters.

Figure 22.36 shows a different type of catalytic converter. This has a catalytic converter chamber attached to the exhaust manifold. The chamber holds a ceramic core with the catalyst and is bolted to the manifold. It can be dismantled to renew the catalyst if necessary.

Sustainability: When replacing a catalytic converter, always recycle it as these parts contain a number of precious metals.

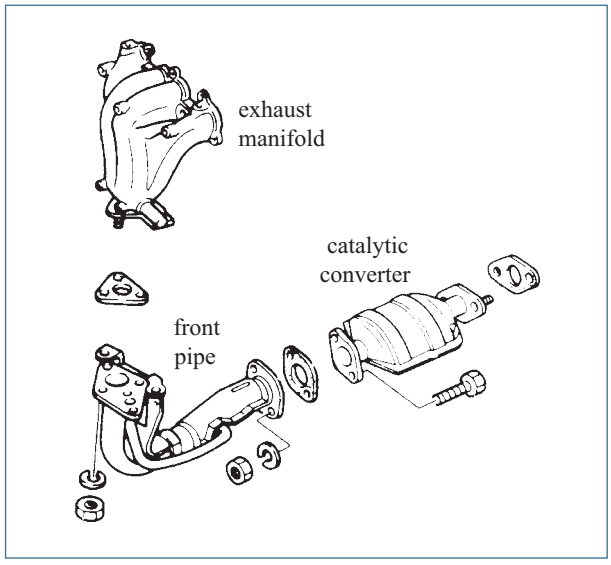


Figure 22.35 Engine end of an exhaust system with a catalytic converter FORD

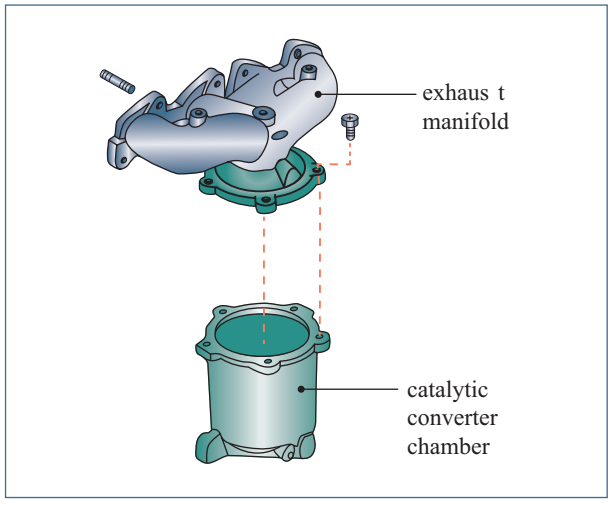


Figure 22.36 Exhaust manifold with a catalytic converter

22.17.5 Particulate filters

Diesel-powered vehicles have a diesel particulate filter fitted to the exhaust that looks like a catalytic converter (Figure 22.37). It collects the small black particles that are visible in diesel exhausts. These emissions, called particulate matter or 'soot', are mostly carbon and can be reduced by filtering the exhaust.

The filter is usually cleaned automatically by the engine management ECU through a process called regeneration. Pressure and temperature sensors are also fitted to the particulate filter to provide information to the ECU for this process.

22.18 Exhaust-system service

The exhaust system should be free of leaks, vibration and rattles. It should also offer a free passage for the exhaust gases.

Leaks can occur at joints in the system, or as a result of corrosion of the muffler or pipes. Corrosion is caused by acids in the exhaust gases that gradually corrode the metal. This can occur more rapidly in vehicles that are used on short trips because

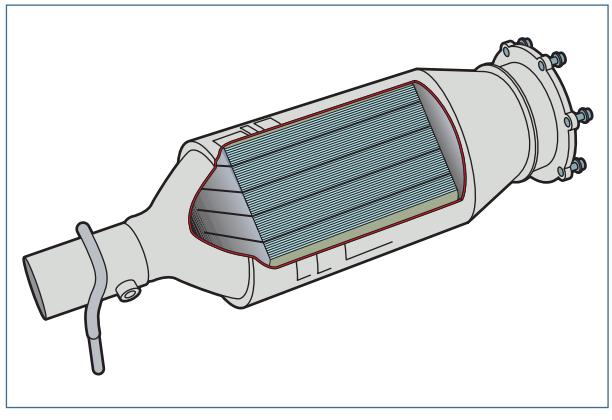


Figure 22.37 Diesel particulate filter FORD

the exhaust system does not become very hot. To reduce corrosion, many exhaust systems, including replacement systems, are made of stainless steel.

22.18.1 Removing and replacing a muffler

Removing a muffler

Mufflers and exhaust pipes are not always easy to remove because they become corroded together and the joints are hard to separate. Relevant points are:

1. Loosen or remove the clamps on the pipes.
2. Remove the mounting brackets or rubber insulators.
3. Jack up the body if necessary, to provide clearance.
4. Separate the joints and remove the muffler.

If the joints cannot be separated easily, it might be necessary to do one or more of the following:

1. Tap around the joint to free it up.
2. Use a cold chisel or special tool to expand the outer pipe at the joint.
3. Use penetrating oil.
4. If the muffler is not being used again, cut the inlet and outlet pipes at the muffler.

Replacing a muffler

When fitting a muffler:

1. Apply exhaust sealer to the ends of the pipes.
2. Slide the muffler into position over the pipes, making sure that it is positioned correctly.
3. Fit the clamps loosely.
4. Attach the brackets and insulators but do not tighten them.
5. Align the parts of the system.
6. Tighten the clamps and brackets.
7. Start the engine and check for exhaust leaks.

Safety: When working on exhaust systems, wear heat-proof work gloves and safety glasses at all times.

22.18.2 Aligning the exhaust system

The parts of an exhaust system must be installed correctly so that they are not under strain.

Where vibration is a problem, the mountings and joints should be loosened completely and the parts of the system realigned so that the supports and insulators are all in a neutral position. The flanges, joints, brackets and supports can then be retightened.

Figure 22.38 shows the various joints and supports of an exhaust system that can be adjusted to provide correct alignment of the system. Other systems might have different mountings and fittings but can be aligned in a similar way.

22.19 Exhaust-system problems

Following are some exhaust system problems and ways in which they are corrected. Refer also to Table 22.1, which shows exhaust problems and their likely causes.

22.19.1 Exhaust leaks

Leaks in the system can be located by exhaust noise, or by grey-to-white deposits on the surfaces of the pipes or muffler. Leaking joints that are otherwise in good condition can be refitted after being coated with muffler putty or sealer. If corrosion has occurred, the muffler or pipe must be replaced.

22.19.2 Vibration

Vibration of the exhaust system can be caused by loose mountings or connections, or by parts contacting the body. Loose baffles in a muffler will vibrate. These can be corrected by realigning the system.

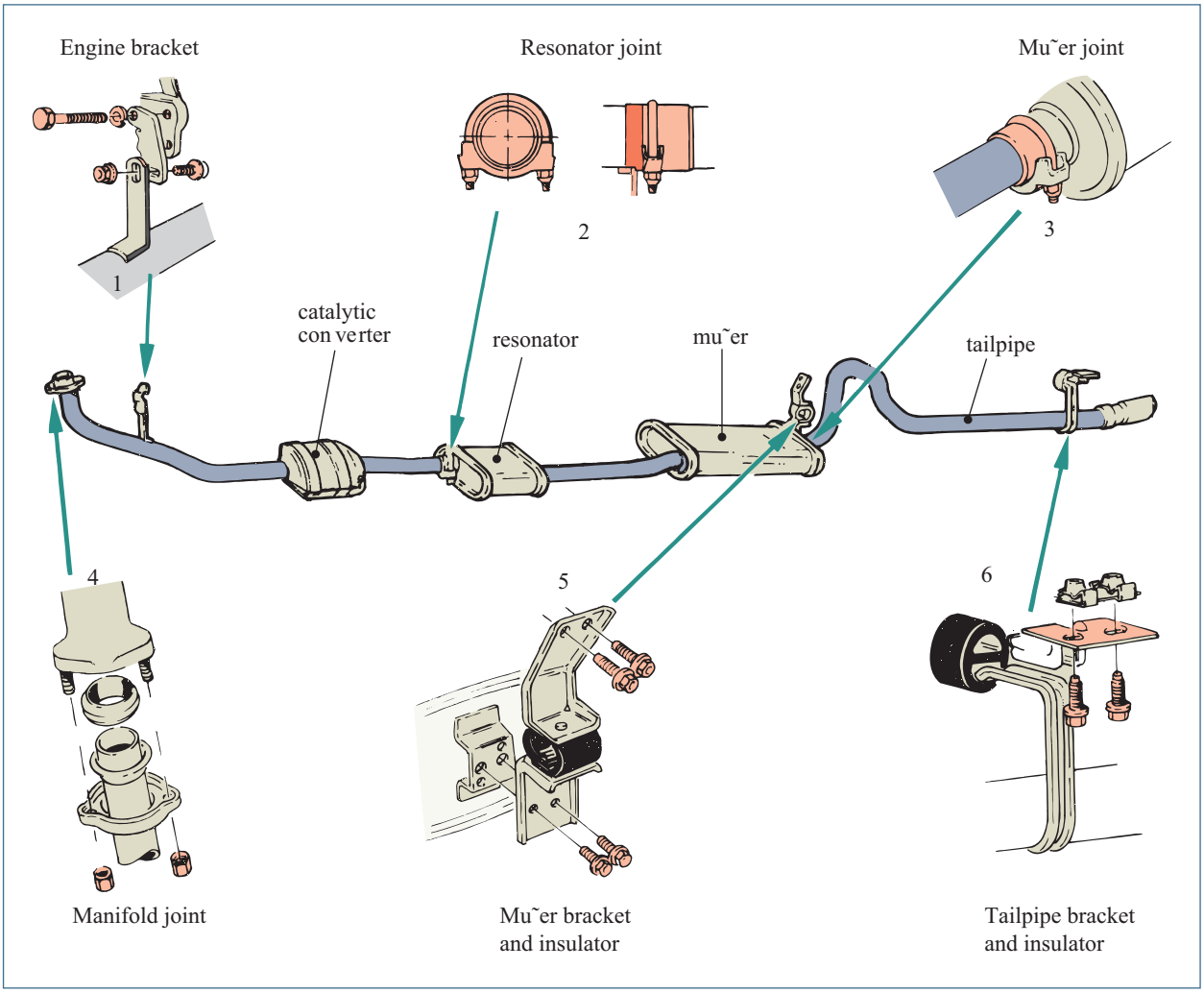


Figure 22.38 An exhaust system with its joints and mountings FORD

Table 22.1 Exhaust system problems

Problem	Likely cause
Exhaust noise	Leaks at the joint between the exhaust manifold and the pipe
Exhaust gas leak	Faulty gask et between the manifold and the cylinder head Burnt-out muffler Damaged catalytic converter Burnt-out or corroded pipe Poor pipe joints
Rattling noises	Loose muffler baffles Catalytic converter faulty Pipes contacting the body Loose or worn mountings
Engine power loss	Restricted muffler Clogged catalytic converter Damaged or restricted exhaust pipe

22.19.3 Back pressure

Back pressure in the system will prevent the free flow of gas. This can sometimes be indicated by a muffled exhaust note from the tailpipe, or dampened exhaust pulsations.

Back pressure can be caused by a blocked muffler, catalytic converter or a restricted pipe. The use of incorrect fuels, fuel additives or combustion soot can block the converter. Some engine pipes have a double wall to reduce noise, and corrosion of the internal pipe might not be obvious.

Back pressure can be measured by inserting a fitting in the exhaust pipe just after the manifold and before the catalytic converter using a pressure gauge.

22.19.4 Exhaust noise

Excessive exhaust noise from the tailpipe can be due to a muffler or resonator in which the baffles have corroded so that they are no longer effective. Leaks at the exhaust joints can emit loud noise.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify the two air cleaner types
- describe the design and functions of EFI air ducts
- explain the correct way to service and clean air filters
- describe the three main engine manifold designs
- identify turbochargers and superchargers
- state the operation of exhaust systems
- demonstrate procedures for replacing and aligning exhaust system components
- identify common exhaust system problems.

REVIEW QUESTIONS

1 Why is air cleaned before it enters the engine?
2 Name the main types of air cleaners.
3 Describe the action of one type of air cleaner.
4 How are dry-type air cleaners serviced?
5 What is the purpose of the muffler?
6 Why are some intake manifolds heated?
7 Name the parts of a multipoint EFI intake system.
8 What would be the effect of an air leak at a connection after the air cleaner?
9 What would be the likely effect of an air leak after the throttle body of an EFI intake system?
10 Name the parts of an exhaust system.
11 Why is a catalytic converter used?
12 How does a catalytic converter differ from a muffler?
13 What is a diesel particulate filter?
14 What would cause the exhaust to be noisy?
15 How can exhaust leaks be detected?
16 What are some of the points to be considered when removing a muffler?
17 What is turbocharging?
18 Explain briefly how a basic turbocharger works.
19 What is boost pressure?
20 What are the two sections of a turbocharger?
21 What is a volute?
22 Why is turbocharger lubrication important?
23 How are some turbochargers cooled?
24 What is a wastegate?
25 How does the wastegate control the turbine speed?
26 What is a wastegate actuator?
27 What type of warning indicators are used with turbochargers?
28 Explain briefly how an intercooler works.
29 Why is an intercooler fitted?
30 State the precautions that should be observed when operating a turbocharged engine.
31 Why should a turbocharged engine be allowed to idle before being stopped?
32 What are the main differences between a turbocharger and a supercharger?
33 Using the appropriate illustration, briefly explain the operation of a Rootes-type supercharger.
34 What type of tool is used to check back pressure?

PART 4

Transmissions and drives

CHAPTER 23

Clutches and service

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify operating principles of light vehicle clutch sy stems and associated components
2 state the application, purpose and operation of light vehicle clutch systems
3 follow diagnostic testing procedures for light vehicle clutch systems, including road testing procedures
4 follow repair procedures for light vehicle clutch sy stems, including procedures for removing, replacing and adjusting the systems
5 follow post-repair testing procedures for light vehicle clutch systems.

Clutches are devices that are used to engage (connect) and disengage (disconnect) one mechanical part from another . In a motor vehicle with a manual transmission or a manual transaxle , the clutch is used by the driver to engage and disengage the engine from the transmission. Automatic transmissions also have clutches, but they are engaged and disengaged automatically . These are covered in the chapters on automatic transm issions.

Service includes minor operations such as external checks or adjustments, as well as major operations for overhaul or replacement of parts. As the clutch facings wear, clearances are gradually reduced. This can lead to clutch failure unless the clearances are check ed and readjusted. Clutches with hydraulic control also need a regular check of the fluid level in the reservoir and periodic checks for possible fluid leaks.

For major clutch service , the transmission or transaxle has to be removed to gain access to the clutch. The clutch can then be dismantled for overhau l or replacement of parts.

23.1 Workplace health and safety

When repairing or replacing an automotive clutch assembly, make sure that you use personal protective equipment such as footwear, clothing, skin protection, safety glasses and an approved respirator.

Always use mechanical devices such as a vehicle hoist, floor jack and transmission hoist to reduce heavy lifting. Avoid awkward postures. Try not to work in the same position for too long.

Safety: For more information about workplace health and safety contact your state or territory government.

23.2 Environmental requirements

Clutch assemblies may contain hazardous material such as asbestos. The WorkCover website has guidelines for repairs to vehicles with asbestos. See www.workcover.nsw.gov.au for more information.

Sustainability: For more information about environmental sustainability regulations, contact your state or territory government or environmental protection authority .

23.3 Purpose of the clutch

On separation of the gearbox from the engine, vacuum or wet wipe inside the bell housing and around the pressure plate. On removal of the pressure plate and clutch plate, vacuum or wet wipe the flywheel, housing and components. Place used rags and removed components into a plastic bag, seal the bag and put it into a marked, plastic-lined disposal bin. Always adhere to environmental sustainability regulations.

An internal combustion engine needs a clutch because it has to be started and running at speed before a load can be applied. The clutch has the following functions:

1. With the vehicle stationary , it is used to disconnect the engine from the transmission, so that either first gear or reverse gear can be selected.
2. It allows the load to be applied to the engine gradually , so that the vehicle can move off steadily .
3. It is disengaged and engaged by the driver so that gearshifts can be made while the vehicle is moving forward.
4. As well as operating smoothly , the clutch must hold firmly once it is engaged, because it carries all the torque from the engine to the transmission.

23.4 Types of clutches

All types of clutches have an automotive application. The type used in cars and light commercial vehicles is a single-disc (or single plate) dry clutch with a diaphragm spring. This is the design that will be covered here–the main parts are shown in Figure 23.1.

Multidisc clutches are used in automatic transmissions and heavy mechanical equipment, as well as high-performance cars. Clutches used with manual transmissions have no lubrication between their surfaces, whereas automatic transmission clutches are lubricated.

Handy hint: The terms clutch disc and clutch plate are interchangeable .

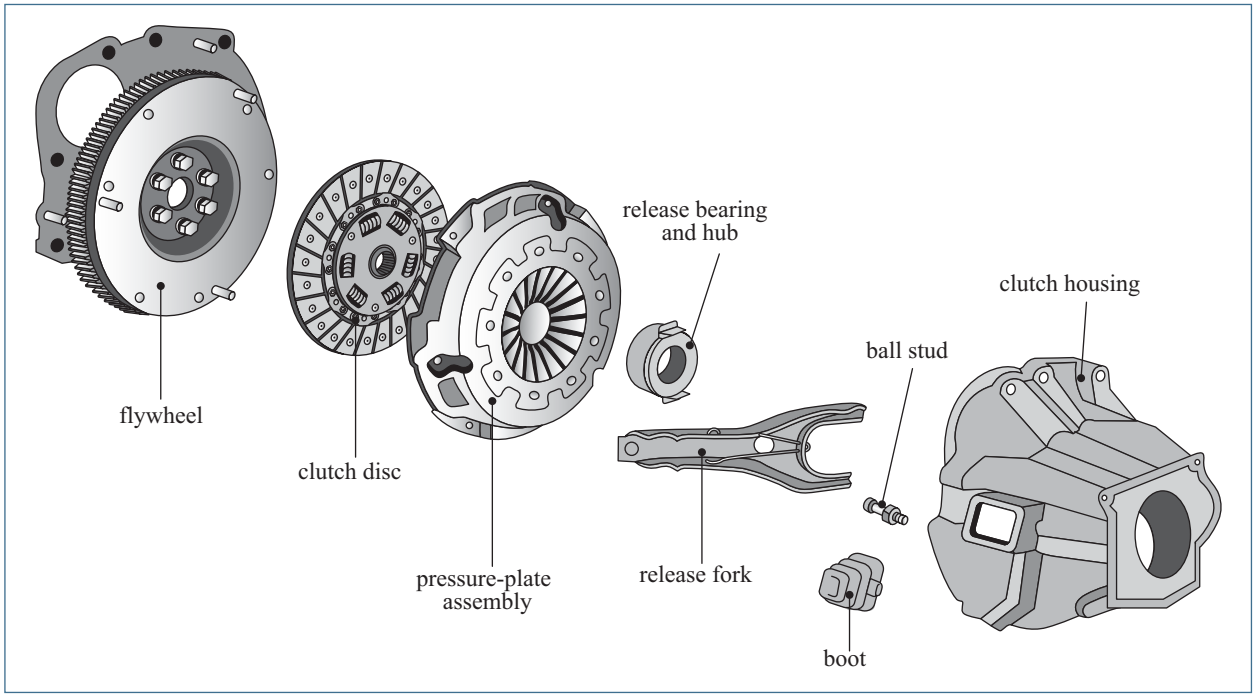


Figure 23.1 The clutch components, including the release mechan ism

23.5 The clutch assembly

A single-disc clutch assembly consists of four main parts (Figure 23.1). These are:

1 the rear face of the flywheel —the driving member
2 the clutch disc —the driven member
3 the pressure-plate assembly —also a driving member
4 the release mechanism —disengages and engages the clutch.

As well as this, there are the clutch controls between the clutch pedal and the release mechanism. The functions of these four parts are as follows.

23.5.1 Flywheel face

The rear of the flywheel has a machined surface to which the pressure-plate assembly is bolted. The flywheel provides a flat face for the clutch disc, which is held against it by the pressure plate. Some flywheels are flat; others are recessed so that the clutch is mounted into the flywheel rather than onto the flywheel face.

Friction between the flywheel and clutch disc is needed for the clutch to operate effectively. The measurement of friction between two objects like these is called the coefficient of friction, which is discussed in Chapter 6.

23.5.2 Clutch disc

The clutch disc is splined to the transmission input shaft. When the clutch is engaged, the disc is held firmly between the pressure plate and the flywheel and so carries the drive from the engine to the transmission.

23.5.3 Pressure-plate assembly

The pressure-plate assembly has a spring-loaded pressure plate which holds the clutch disc firmly against the flywheel. There are two types: pressure plates with a diaphragm spring and pressure plates with coil springs. They both perform the same function. Release levers, or fingers, allow the spring force to be relieved when the clutch is disengaged.

Diaphragm clutches are commonly used for passenger and light commercial vehicles, and this is the type of clutch that will be covered in this chapter.

23.5.4 Release mechanism

The release mechanism consists of a release fork and a release bearing. The release fork is a lever with a forked end designed to carry the release bearing. When the clutch is being operated, the release fork pivots on a ball stud which forces the bearing against the diaphragm fingers. The release mechanism can be a push-or pull-type operation.

23.6 Diaphragm clutch operation

Figure 23.2 shows a diaphragm clutch in simplified form in both the engaged and disengaged positions.

In the engaged position, the outer edge of the diaphragm exerts force against the pressure plate and this holds the clutch disc against the flywheel. The diaphragm fingers are pointing slightly away from the flywheel.

When the clutch pedal is pushed down to disengage the clutch, the release bearing comes up against the diaphragm fingers. The diaphragm is forced to pivot about the inner pivot ring and this causes it to 'dish' as shown in Figure 23.2(b). This relieves the force on the pressure plate and it is moved away from the disc by the retracting springs or retainers. This frees the disc and so the clutch is disengaged.

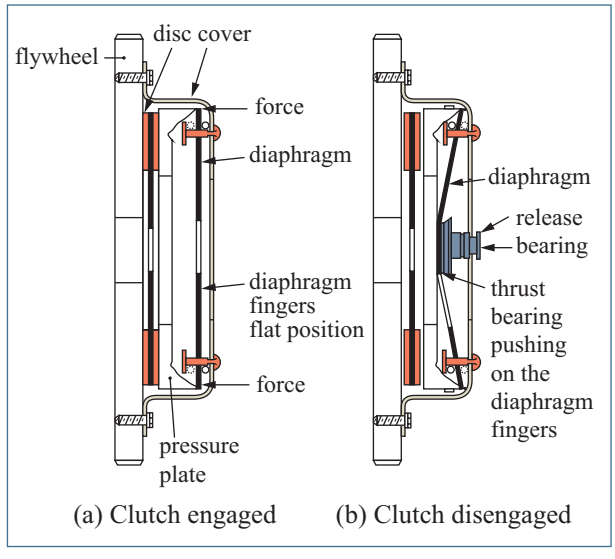


Figure 23.2 Operation of the clutch diaphragm

23.6.1 Diaphragm clutch features

One of the features of diaphragm clutches is that the spring action of the diaphragm becomes a little easier as the pedal is pressed down. This gives the driver a soft clutch which is easy to operate.

There are clutches with coil springs, but they have the opposite effect because the resistance increases as the coil springs are compressed. An assist spring is often fitted to the clutch pedal to make it easier to depress.

23.7 Diaphragm clutch components

23.7.1 Pressure-plate assembly

A diaphragm clutch pressure-plate assembly, together with its disc, is shown in Figure 23.3. This consists of the pressed-steel cover, the diaphragm spring and three straps, or retracting springs. Pressure plates of this type are not normally dismantled, and are serviced as an assembly.

Figure 23.4 shows the construction of a pressure-plate assembly and also the parts of a clutch disc. Figure 23.4(a) shows how the diaphragm is located between two pivot rings. The diaphragm is a spring steel disc. It is usually slightly coned, but it can be flat. It is slotted to form a number of fingers. The diaphragm provides the spring force for the pressure plate, and its fingers form part of the release mechanism. The parts of the pressure-plate assembly are held together by rivets and are not normally dismantled.

Handy hint: The parts that make up a clutch disc can be seen in Figure 23.4(b). These are riveted together and are not normally dismantled.

23.7.2 Clutch disc

The clutch disc is splined to the transmission input shaft so that it carries the torque from the engine to the transmission when the clutch is engaged. It remains stationary, and so transmits no torque when the clutch is disengaged. It is held between the flywheel face and the pressure plate by spring force.

A clutch disc with its parts identified is illustrated in Figure 23.5. The disc carries facings of a composite material, so that a high-friction effect will be obtained between the cast-iron surfaces of the flywheel and the pressure plate. For this reason, this type of clutch is sometimes referred to as a *friction clutch,* and the disc as a *friction disc.*

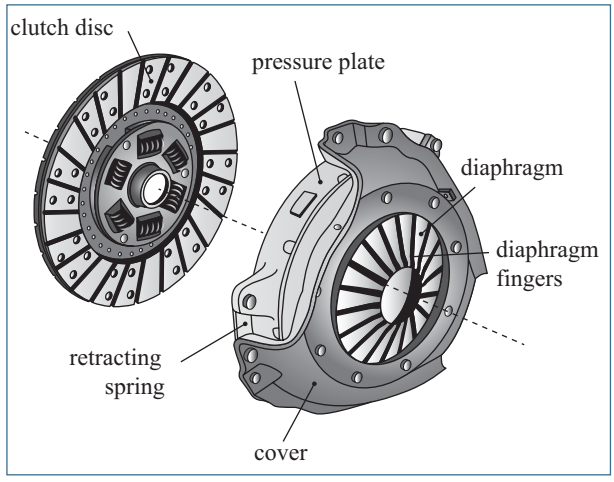


Figure 23.3 Diaphragm pressure-plate assembly and clutch disc

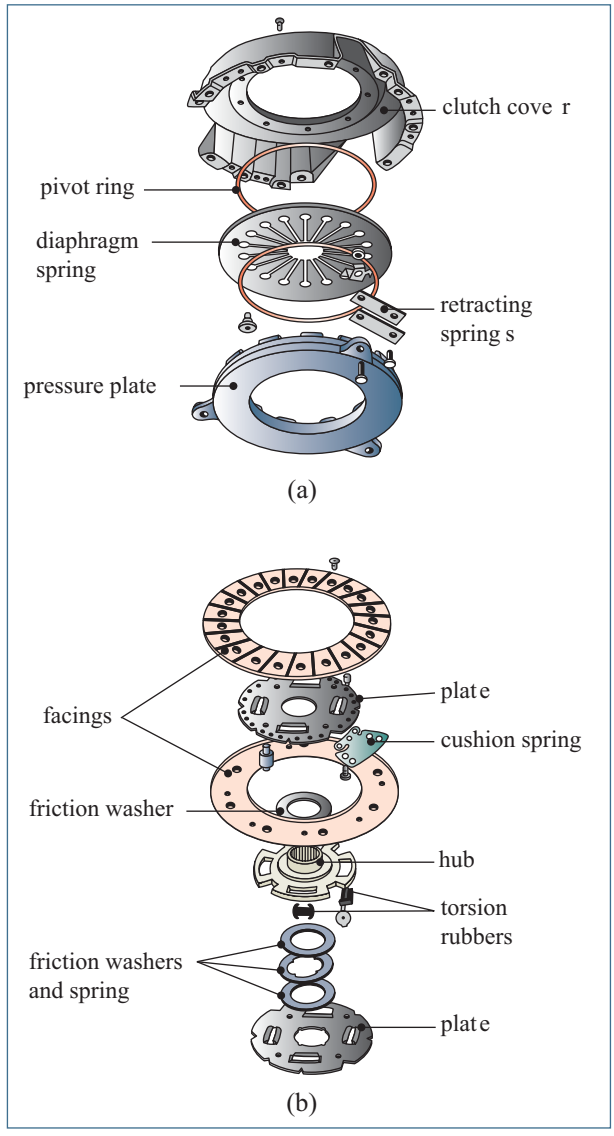


Figure 23.4 Clutch parts (a) parts of a pressure-plate assembly (b) parts of a clutch disc

The splined hub of the disc is not attached directly to the disc itself, but is mounted on a flange which is connected to the disc by a number of heavy coil springs. These act as a dampening device between the disc and the hub to absorb any *torsional*

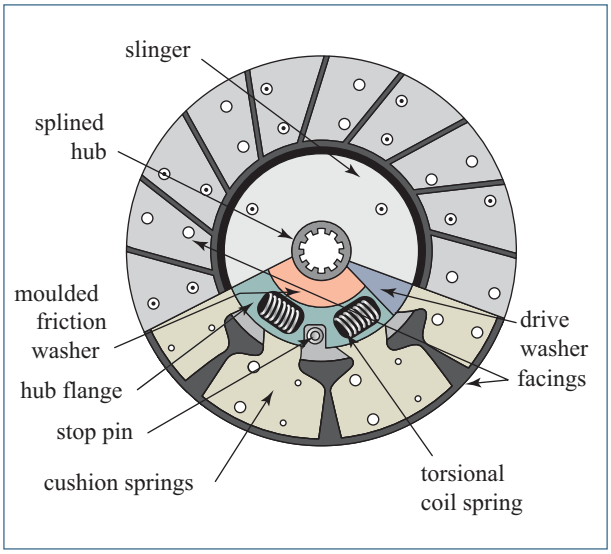


Figure 23.5 A clutch disc with part of the facing removed

(twisting) vibrations from the engine. Stop pins limit the movement between the flange of the hub and the disc. As well as this, there is a moulded friction washer between the hub flange and the drive washers of the disc, which acts as a dampener.

The outer part of the disc to which the facings are riveted is slotted and 'waved' to form cushion springs. The waves spread the facings slightly when the disc is disengaged and they compress as the clutch is engaged. This provides a cushioning effect and smooth engagement.

23.7.3 Clutch release mechanism

The operation of a clutch release mechanism with hydraulic control is shown in Figure 23.6. The operating parts are the release fork (also called a release lever) and the release bearing. The release bearing is mounted on a hub which slides on a sleeve on the front of the transmission. This is often part of the retainer for the transmission input shaft bearing.

The action of the clutch being disengaged is shown in Figure 23.6(b). When the clutch pedal is depressed to disengage the clutch, the release fork is pivoted on a ball stud which is mounted on the clutch housing. This forces the release bearing against the fingers of the diaphragm to relieve the spring pressure on the pressure plate and release the disc.

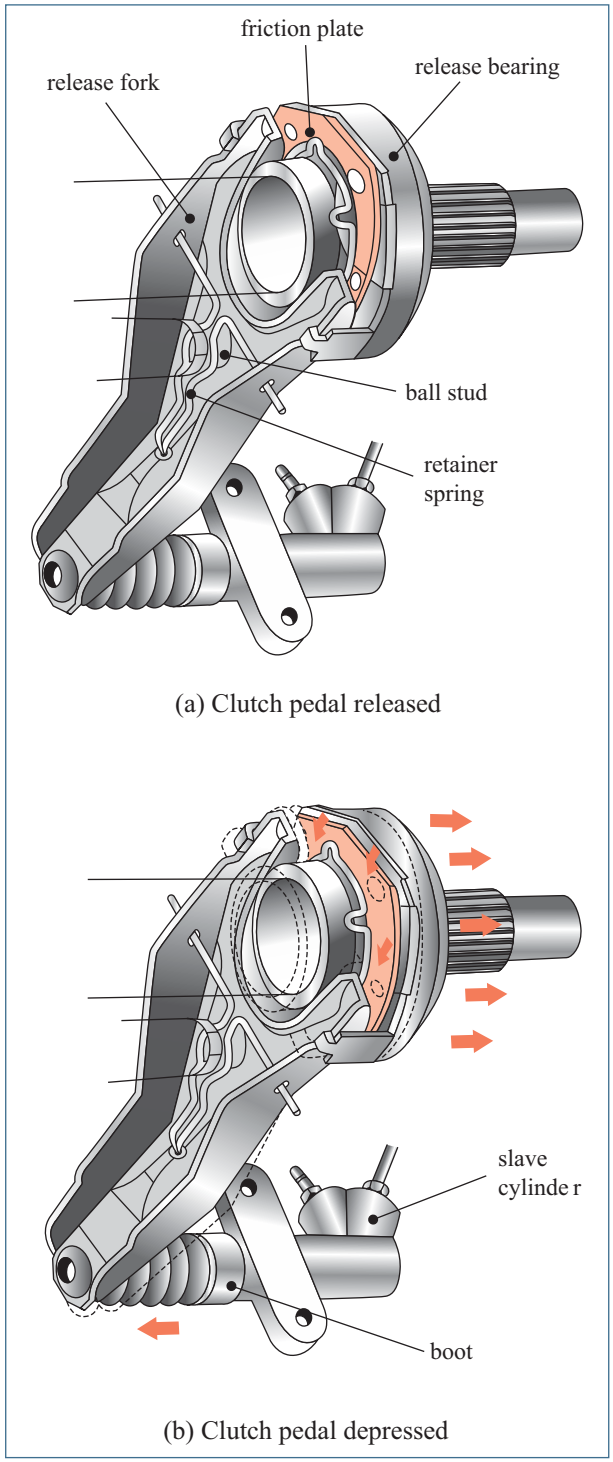


Figure 23.6 Clutch release mechanism with a slave cylinder—operation

When the clutch is re-engaged, the diaphragm spring holds the pressure plate firmly against the disc so that it carries the torque from the engine through to the transmission.

23.7.4 Other release mechanisms

There are other arrangements of release mechanisms. One of these is shown in Figure 23.7. This has a shaft mounted in bushings in the flywheel housing. The shaft carries the release fork, which operates the clutch release bearing. A return spring is fitted to the shaft to keep the release bearing away from the fingers of the diaphragm when the clutch is not being used.

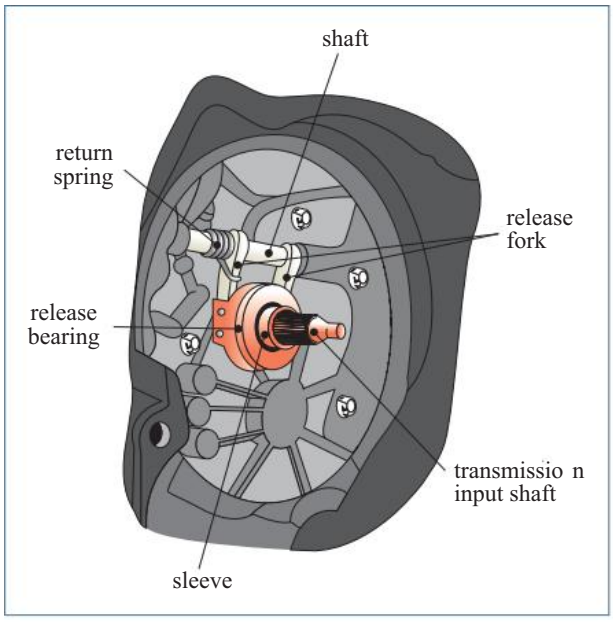


Figure 23.7 Clutch release mechanism

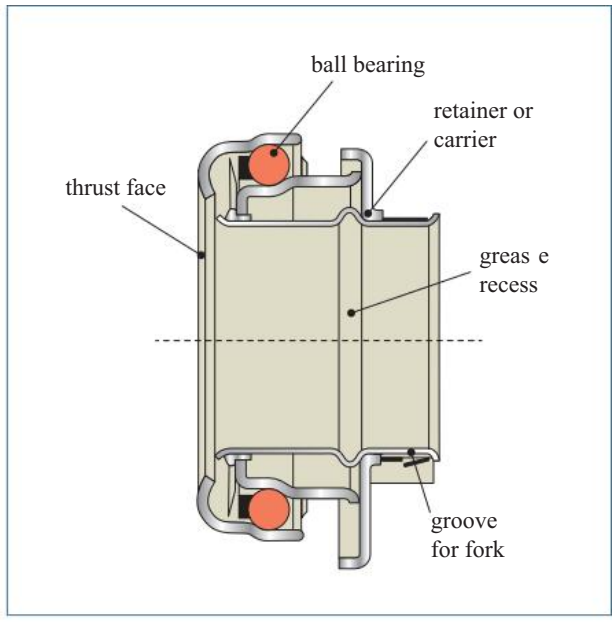


Figure 23.8 Section through a clutch release bearing

23.7.5 Clutch bearings

There are two bearings associated with the clutch, and each is used for a different purpose. They are the *clutch release bearing* and the *clutch pilot bearing*.

Clutch release bearing

Clutch release bearings are thrust-type bearings (Figure 23.8). The ball race is mounted on a carrier. In some cases, the carrier is part of the bearing assembly. The bearing carrier, in most cases, has a groove for the clutch-release fork.

Clutch release bearings are packed with lubricant during manufacture and generally cannot be lubricated in service. The bearing shown is an angular-contact bearing. This is designed to take a thrust load but it will also accept a light radial load.

Clutch pilot bearing

Figure 23.9 is a sectional view of a clutch assembly which identifies the parts, including the pilot bearing. This is a small ballrace in the rear end of the crank-shaft.

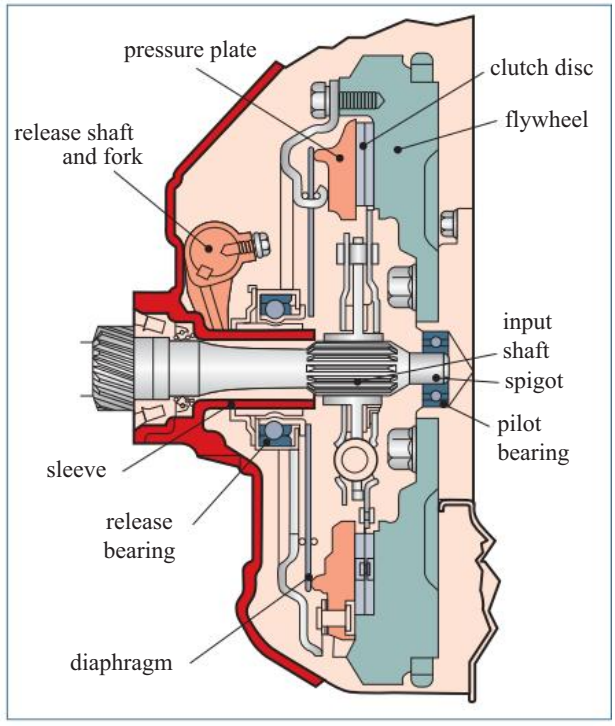


Figure 23.9 Sectional view of a clutch assembly – note that the input shaft spigot is supported in the pilot bearing

The transmission input shaft, which extends from the front of the transmission, has splines on which the clutch disc is mounted. The input shaft is carried by a roller bearing at the front of the transmission housing, but its outer end is supported by the pilot bearing in the crankshaft. The short end of the shaft that fits into the bearing is called a *spigot.*

The pilot bearing can be a ball bearing, or a roller bearing. These have seals on one or both sides and are lubricated during manufacture. Sintered bronze bushes were also used for pilot bearings; they have some self-lubricating properties and are porous enough to retain lubricant.

Handy hint: Some input shafts don't have a spigot or pilot bearing in the crankshaft. The clutch disc is supported only by the gearbox input bearing when the clutch is disengaged.

23.8 Clutch controls

There are two types of clutch controls:

1 Mechanical controls —where a cable or linkage is used between the clutch pedal and the release fork
2 Hydraulic controls —where movement from the clutch pedal to the release fork is transferred hydraulically .

Handy hint: Clutch control is also referred to as clutch actuation and clutch controls as clutch actuators.

23.8.1 Mechanical clutch control

The clutch is controlled from the driver's clutch pedal by a control cable, or by control linkage. Whatever the arrangement, its purpose is to transfer movement from the clutch pedal to the clutch release fork.

When the driver pushes the clutch pedal down, the pressure plate is moved away from the disc and so the clutch is disengaged. When the clutch pedal is released the pressure plate is again held against the disc to engage the clutch.

Cable clutch control

Figure 23.10 illustrates a cable clutch control for a front-wheel-drive vehicle. The control cable is connected between the upper end of the clutch pedal and an external lever on the clutch housing. The lever has a vertical shaft which is attached to the release fork. The release fork carries the release bearing. The cable has an adjustment at the clutch end.

In the arrangement shown, an assist spring is provided at the pedal to reduce pedal effort. This is an overcentre device with a compressed spring. It normally acts as a return spring to hold the pedal against its stop, but it assists the pedal when it is being depressed.

The overcentre action reverses the direction of the force of the spring as the pedal is being pushed down. The spring is compressed at first, but then it passes over centre and pushes the pedal to assist the driver's action.

Clutch linkage

Linkage arrangements operate in the same manner as control cables. In passenger vehicles, cables have replaced linkages as their greater flexibility absorbs engine movement that might otherwise be transmitted through linkage. Also, the cable is easier to install in the vehicle.

23.8.2 Hydraulic dutch control

The components of a hydraulically controlled clutch are illustrated in Figure 23.11. The master cylinder, operated by the clutch pedal, is connected by a pipe and flexible hose to a slave cylinder mounted on the

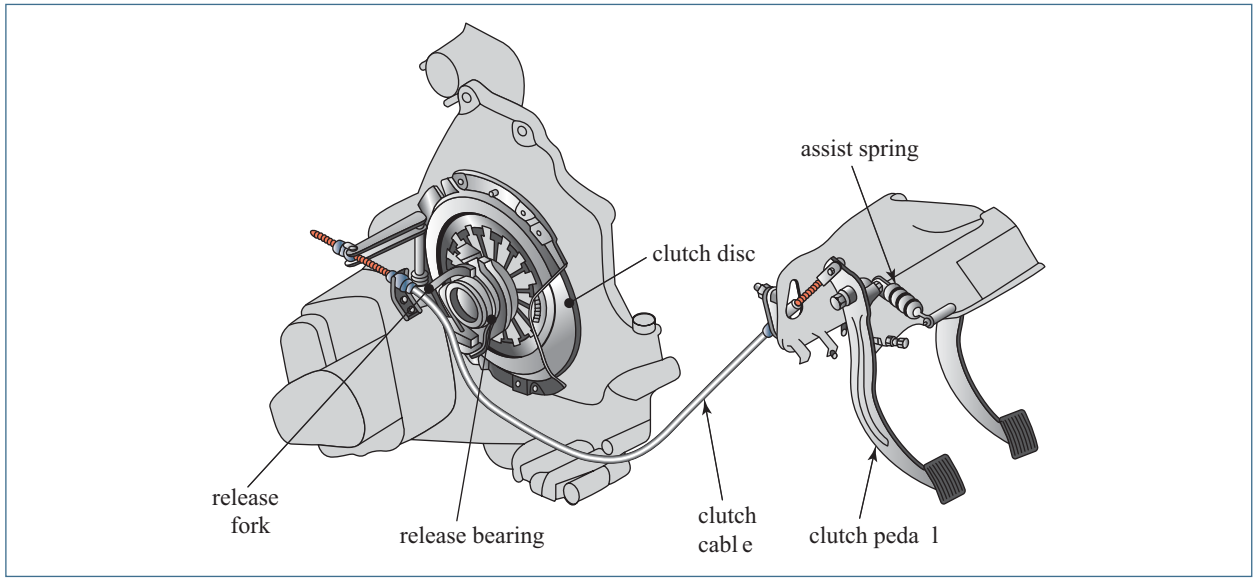


Figure 23.10 Clutch with a cable control

clutch housing. The slave cylinder operates the clutch release fork.

When the clutch pedal is pushed down, hydraulic fluid is displaced by the master cylinder piston into the slave cylinder. This moves the slave cylinder piston in its bore. Piston movement is transferred by a pushrod to the clutch release fork to disengage the clutch. When the clutch pedal is released, hydraulic fluid returns to the master cylinder so that the clutch is engaged.

There are two basic designs of master cylinders—one has a *centre valve* and the other has a *compensating port.*

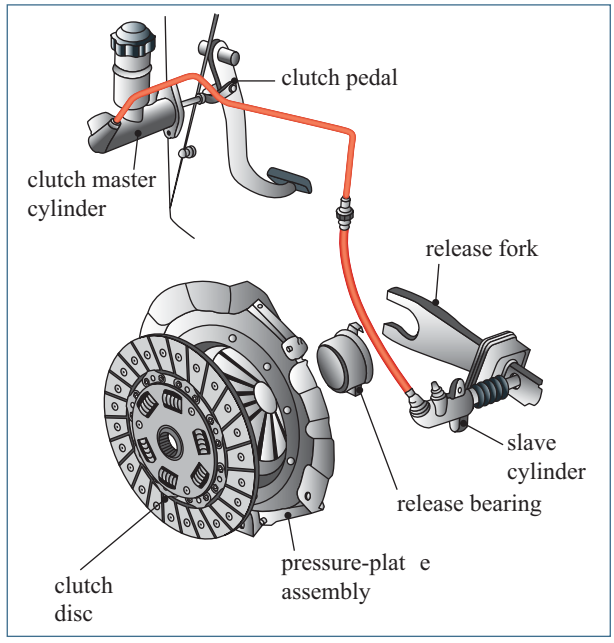


Figure 23.11 Clutch with hydraulic control

Handy hint: The names centre valve and compensating port will be used to identify the types of master cylinders.

Centre-valve master cylinder

A dismantled master cylinder of the centre-valve type is shown in Figure 23.12. The piston has a primary seal and a secondary seal. The valve assembly consists of a seal, stem, shim and spacer.

When the parts are assembled to the piston, the valve stem passes through the spring, which is partly compressed. The end of the valve stem is hooked into the spring retainer which is secured to the end of the piston by a tab.

The piston assembly is shown dismantled, but many master cylinders of this type, like the one in Figure 23.13, have a piston assembly that cannot be dismantled. Centre-valve master cylinders can often be identified by the position of the reservoir, which is at the end of the cylinder.

Centre-valve master cylinder operation

The operation of a centre-valve master cylinder is shown in Figure 23.14. This is as follows:

1 With the clutch pedal released, the centre valve in the end of the master cylinder is slightly clear of the inlet port. This allows fluid flow between the reservoir and the cylinder .
2 When the clutch pedal is pushed down, the piston is moved forward, taking the valve assembly with it. The valve closes off the inlet port to prevent fluid in the cylinder from returning to the reservoir .
3 Further pedal movement displaces fluid from the outlet port into the fluid lines to operate the slave cylinder and disengage the clutch. The valve is held on its seat by the spring which is being compressed.

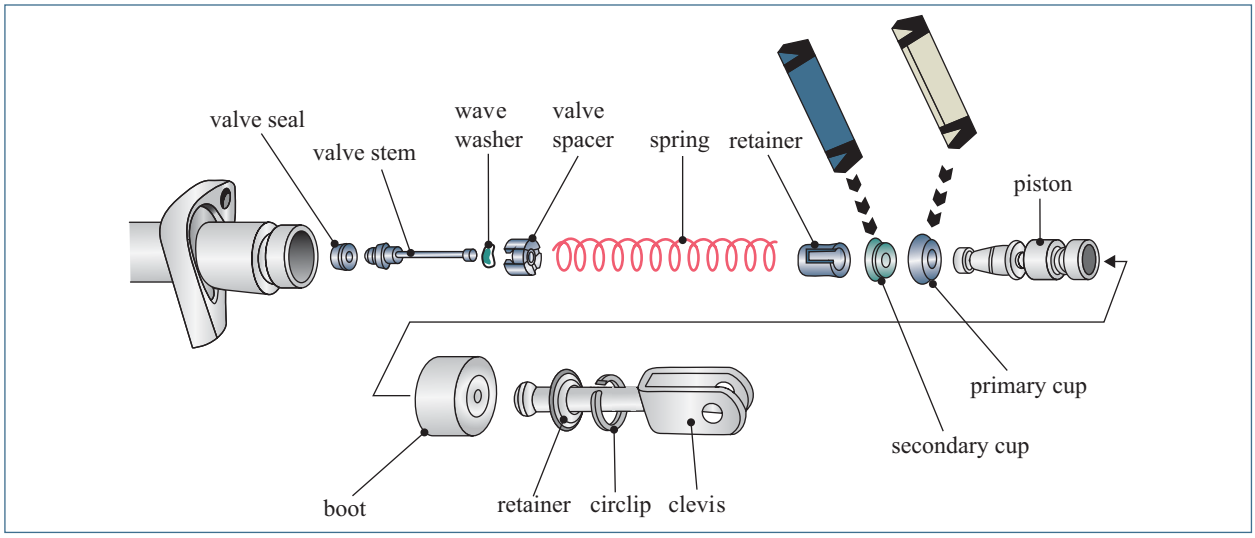


Figure 23.12 Centre-valve master cylinder—dismantled parts

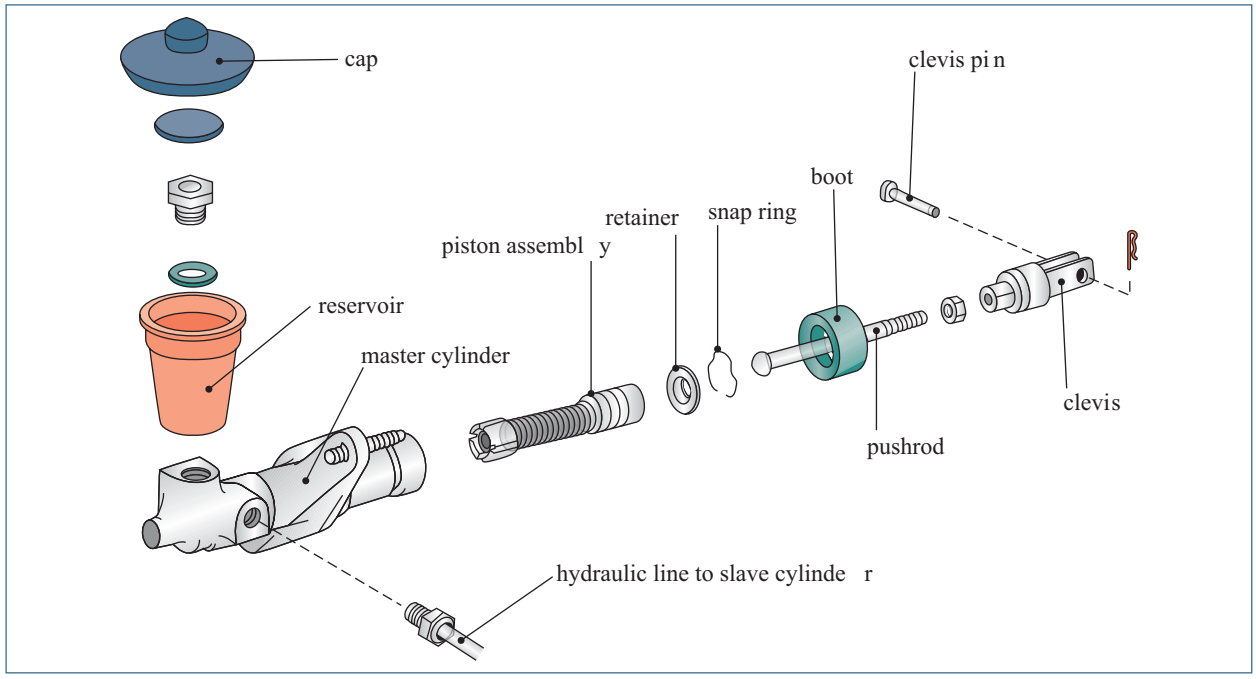


Figure 23.13 Clutch master-cylinder assembly

4 When the pedal is released, it is returned to its stop by its return spring. The piston is moved back in its bore by the spring and by pressure in the system. The valve is held slightly clear of the inlet port so that fluid can return to the reservoir .

Compensating-port master cylinder

Figure 23.15 shows a master cylinder which has its reservoir located towards the middle of the cylinder. There are two ports below the reservoir that connect the reservoir to the cylinder. These are the compensating port and the inlet port. The piston is fitted with two rubber cups (seals) and there is a piston-return spring.

When the clutch pedal is pushed down, the piston is moved down its bore. The primary cup on the piston covers the compensating port and this traps fluid in the cylinder. Further movement of the piston forces fluid through the outlet port and the hydraulic line to operate the slave cylinder.

On the return stroke, the piston is moved back in its bore by the return spring. The primary cup uncovers the compensating port and pressure is relieved from the cylinder.

Handy hint: The compensating port has a very small hole that must be clear to prevent pressure building up in the system.

Slave cylinder

A slave cylinder and its parts are shown in Figure 23.16. The assembly consists of a plain cylinder, a piston, a cup, a spring and a pushrod. A rubber boot covers the end of the cylinder.

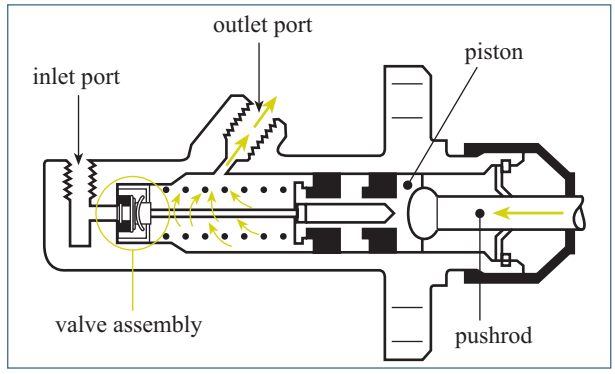


Figure 23.14 Centre-valve master cylinder showing fluid flow when the pedal is being depressed

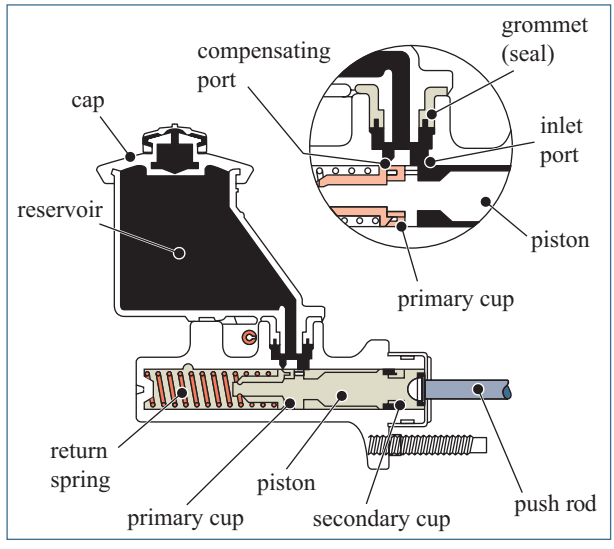


Figure 23.15 Master cylinder with a compensating port – the inset shows the small compensating port and the larger inlet port

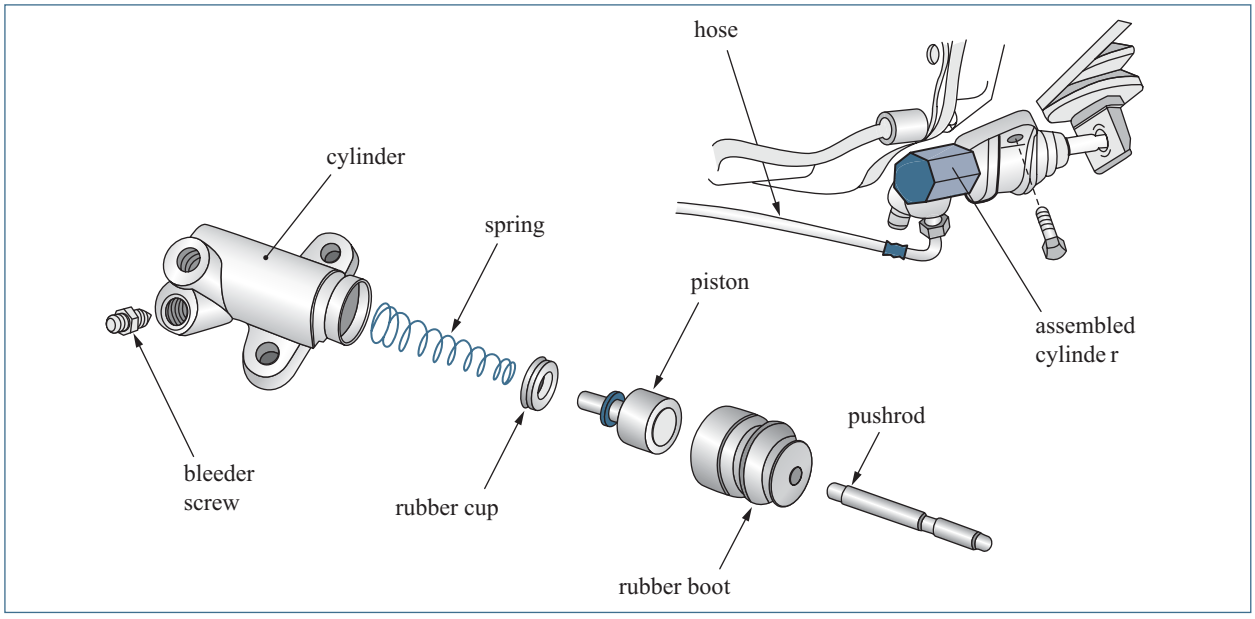


Figure 23.16 Parts of a slave cylinder—the assembled cylinder is also shown

Fluid displaced by the master cylinder piston when the clutch pedal is pressed forces the slave cylinder piston along its bore. Movement of the piston is transferred through the pushrod to the clutch release fork to operate the clutch.

23.9 Other clutch features

There are many variations of the components illustrated. Some master cylinders have the reservoir attached, others have the reservoir mounted away from the master cylinder and connected by a flexible pipe. In some instances, a common reservoir is used for the clutch master cylinder and the brake master cylinder (see Figure 23.23).

In most vehicles the clutch master cylinder is bolted to the firewall in the engine compartment, but in vans and vehicles with under-the-floor engines, the master cylinder is mounted under the dash. An example is shown in Figure 23.17.

23.9.1 Clutch safety switch

Some vehicles have a clutch safety switch that is operated by the action of the clutch pedal (Figure 23.18). Its function is to prevent the engine from being accidentally started with the transmission in gear.

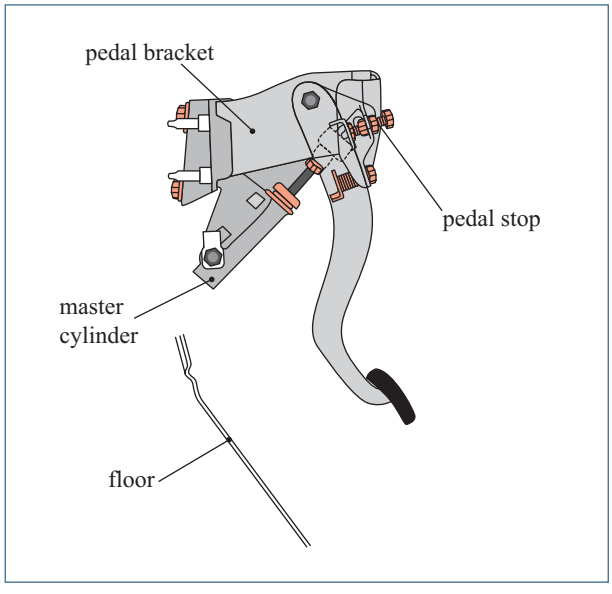


Figure 23.17 A clutch pedal with the master cylinder mounted under the dash

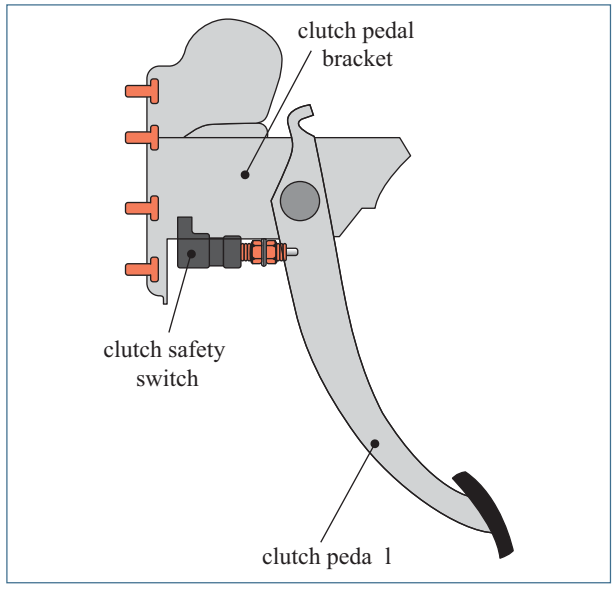


Figure 23.18 Clutch safety switch operated by the clutch pedal

With the clutch pedal in its normal (released) position, the clutch switch is 'off' so that the electrical circuit to the starter solenoid is broken. When starting the engine, the driver must hold the clutch pedal down. This disengages the clutch, but it also turns the clutch switch 'on' to complete the circuit to the starter solenoid.

A simplified electrical circuit in Figure 23.19 shows how the ignition/start switch and the clutch switch are connected in series. Before current can flow from the battery to the starter solenoid, both switches must be on—the clutch switch by pressing down the clutch pedal, and the ignition switch by turning the ignition key to the start position.

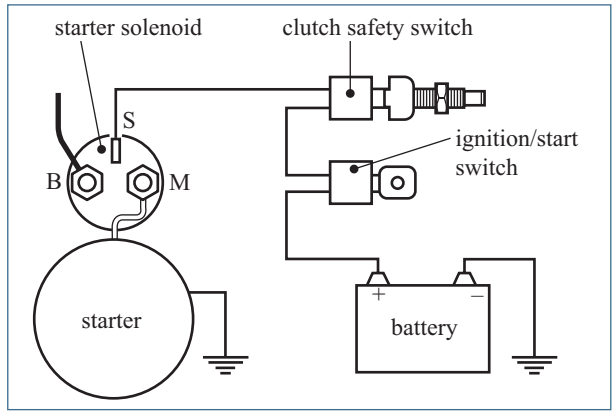


Figure 23.19 Basic electrical circuit for a clutch pedal safety switch (Battery, Switch, Motor)

23.10 Pull-type clutches

There are *pull clutches* and *push clutches*. These names refer to the way in which the clutch release operates. All the clutches covered so far have been push types, where the clutch release lever pushes against the release bearing and this pushes against the diaphragm fingers. With a pull-type clutch, the release lever pulls the release bearing and this pulls the diaphragm fingers to disengage the clutch.

Figure 23.20 is a sectional view of a pull-type clutch. The parts are similar to those of a push clutch, but the diaphragm and the release bearing are arranged differently. The diaphragm is spring-loaded against the pressure plate but its outer edge is under the clutch cover.

The fingers of the diaphragm are fitted with a release collar which carries the release bearing. It has a groove for the forked end of the release lever. This enables the fingers of the diaphragm to be pulled instead of pushed.

23.10.1 Pull-clutch operation

The operation of a pull clutch is shown in Figure 23.21. In Figure 23.21(a), the clutch is engaged and the diaphragm spring is pushing against the pressure plate. This holds the clutch disc firmly against the flywheel face.

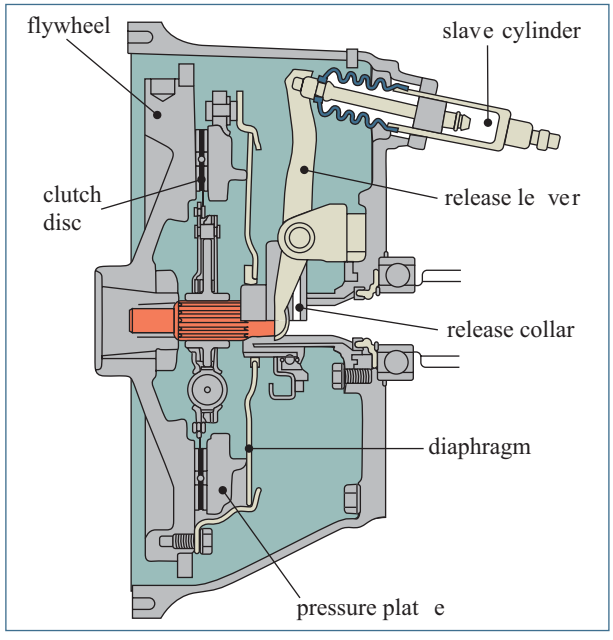


Figure 23.20 Components of a pull-type clutch assembly

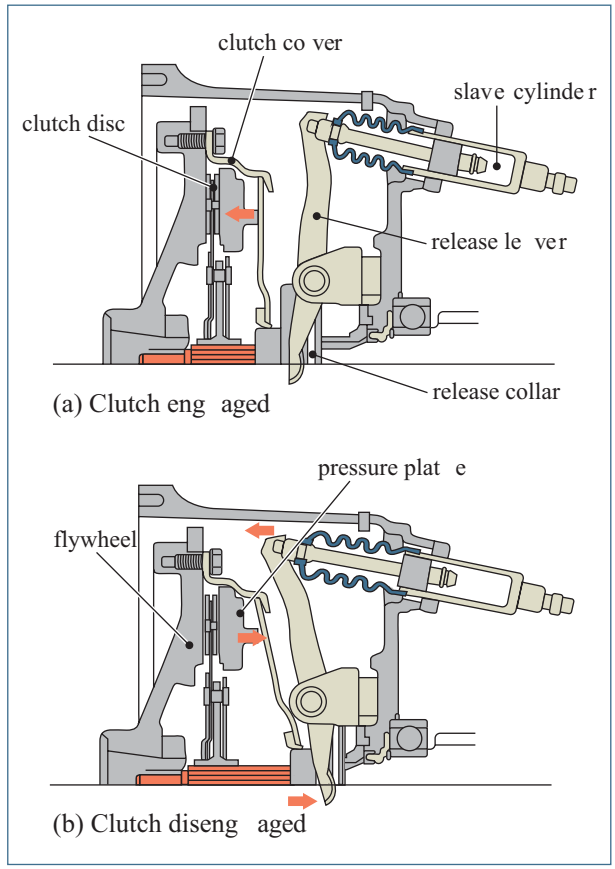


Figure 23.21 Part section of a pull clutch showing the engaged and disengaged conditions

In Figure 23.21(b), the clutch is disengaged. To do this, the slave cylinder has pushed the outer end of the release lever forward and this has moved the inner end of the release lever back towards the transmission. The release collar has pulled the diaphragm fingers back to remove the spring force of the diaphragm from the pressure plate. This has freed the clutch disc, so the clutch is now disengaged.

Clutch pedal effort

A pull-type clutch requires less pedal effort than a push-type clutch of the same size. This is because of the way in which the diaphragm is mounted in the clutch cover. Figure 23.22 shows simplified arrangements of the two pressure-plate assemblies and how their diaphragms act as levers, but in different ways.

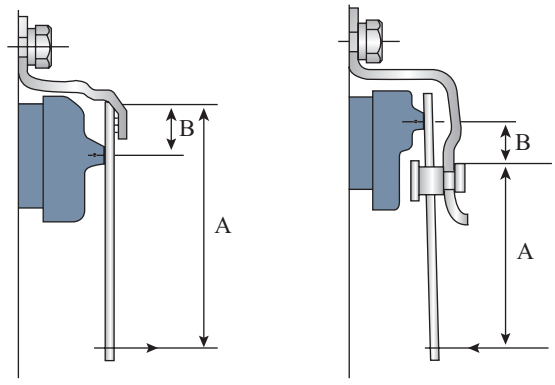


Figure 23.22 Comparison of the leverage of the diaphragm of a push-type and a pull-type clutch

The leverage ratio in both diagrams is dimension A divided by dimension B. It can be seen that the ratio of the pull clutch will be greater than that of the push clutch, so a pull clutch should be easier to operate.

23.11 Clutch with central release

The components of a hydraulically operated clutch with a central release are shown in Figure 23.23. This design of clutch control does not have a separate slave cylinder, nor a release lever and bearing. Instead, it has a central release unit that performs the same function as these parts.

The central release unit consists of an actuating cylinder that carries the clutch release bearing. The unit is bolted to the transmission case. When the clutch pedal is depressed, pressure fluid from the master cylinder

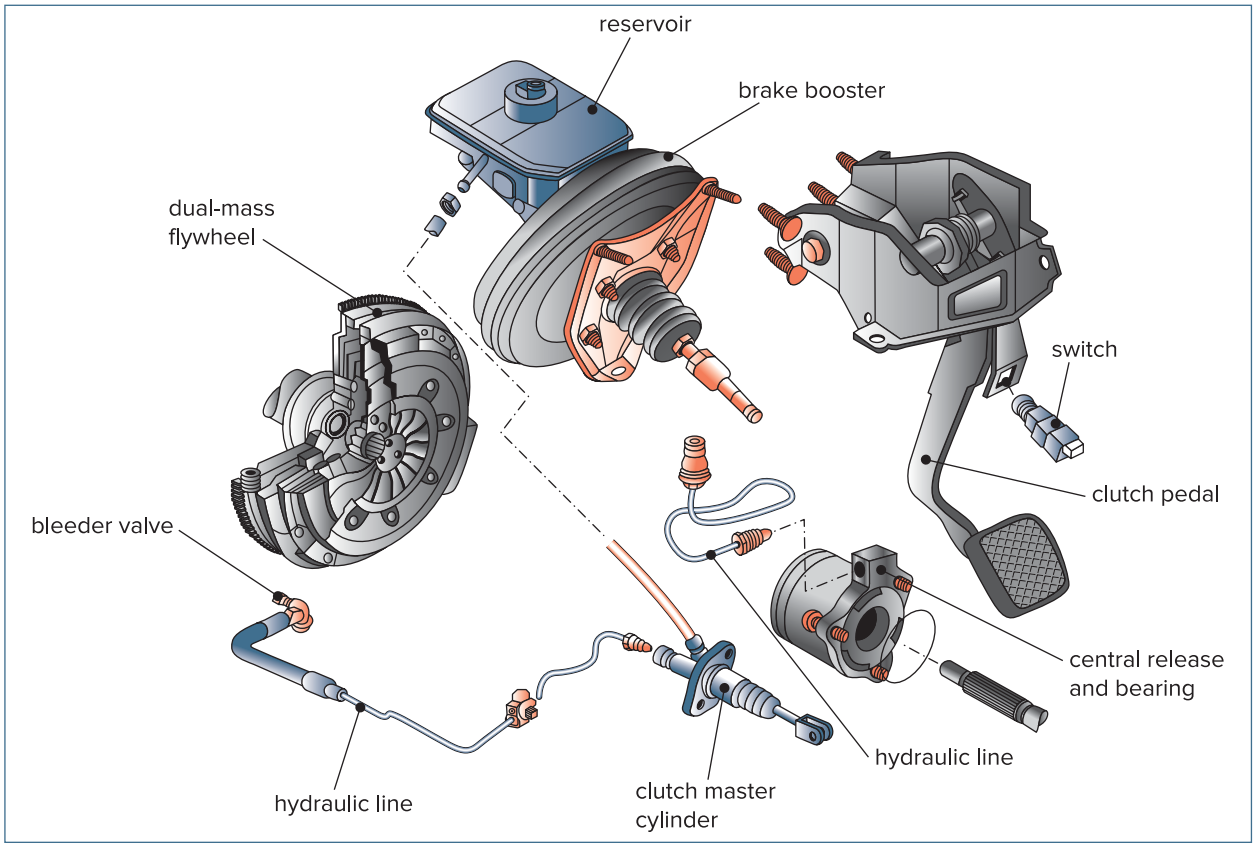


Figure 23.23 Components of a hydraulic clutch control with a ce ntral release

forces the actuator to expand. The release bearing then pushes against the fingers of the diaphragm to disengage the clutch.

A feature of the central release arrangement is that the release bearing applies a uniform pressure to the fingers of the diaphragm and this provides smooth operation of the clutch.

Other features of the clutch assembly that can be seen in the illustration are:

1 The clutch master cylinder uses the reservoir of the brak e master cylinder for its fluid.
2 The flywheel is a dual-mass type .
3 The pedal operates a clutch switch.

Handy hint: To service any part of the clutch, including the central release , the transmission has to be removed.

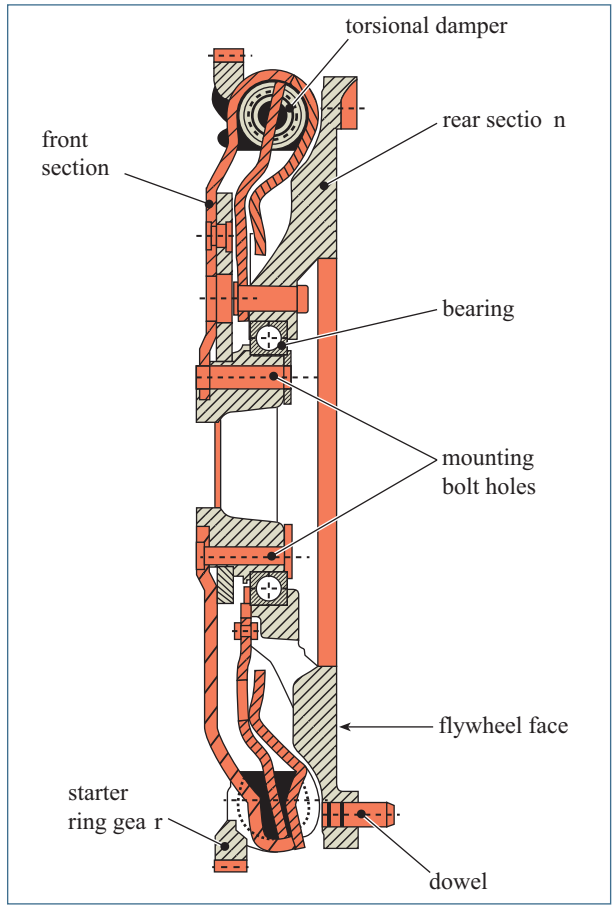


Figure 23.24 A dual-mass flywheel assembly

23.12 Dual-mass flywheel

A dual-mass flywheel is shown in Figure 23.24. It is included in this chapter because the flywheel forms an integral part of the clutch assembly.

The dual-mass flywheel assembly consists of two main parts. These are connected by springs which form part of a torsion damper system fitted between the two parts. The front part of the flywheel assembly is bolted to the crankshaft flange, while the rear part has the flywheel face to which the clutch cover is bolted.

23.12.1 Flywheel operation

A dual-mass flywheel is designed to absorb torsional vibrations. When a power impulse occurs, the crankshaft and the front part of the flywheel tend to speed up but, due to inertia, the rear part tends to lag behind. As a result, the force that produced the vibration tends to be cancelled out.

A similar effect occurs when the power impulse ceases—the inertia of the rear part of the flywheel is offset by that of the front part. Because torsional vibrations are absorbed within the dual-mass flywheel, the clutch disc that is used with this flywheel does not have damper springs.

Torsional vibrations are caused by the power impulses of the engine. The flywheel normally dampens out most of them; however, under certain conditions, vibration can be carried through the clutch and further down the drive line.

Handy hint: Simply, a torsional or twisting type of vibration occurs whenever a power impulse tries to speed up flywheel rotation.

23.13 Clutch service: general checks and adjustments

There are different adjustments for mechanical controls and hydraulic controls. However, there are two general adjustments that are common to most clutches (Figure 23.25):

1 pedal free play
2 pedal height.

23.13.1 Pedal free play

Free play (sometimes referred to as pedal lash) is the free movement of the clutch pedal before it starts to operate the clutch. When the pedal is first depressed, a small amount of pedal travel (the free play) occurs before the release bearing comes up against the diaphragm fingers (or release levers). The pedal moves

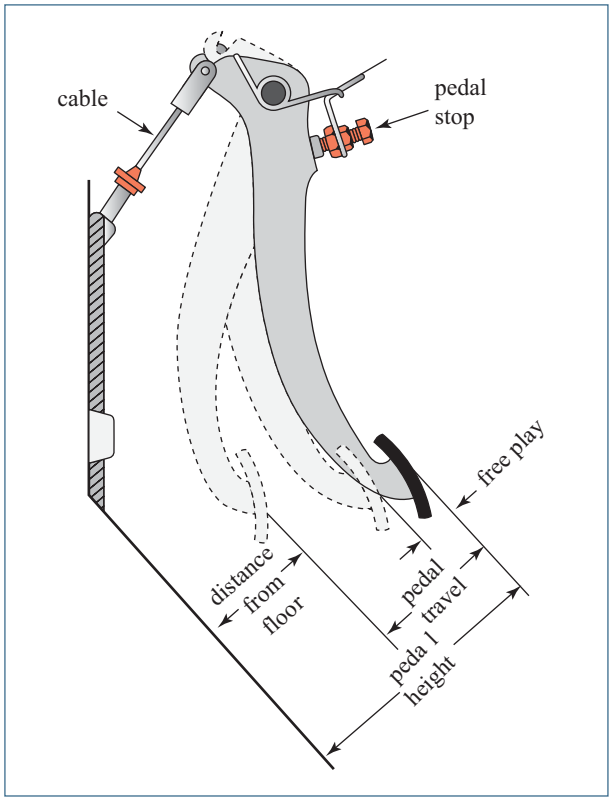


Figure 23.25 General clutch pedal checks and adjustments

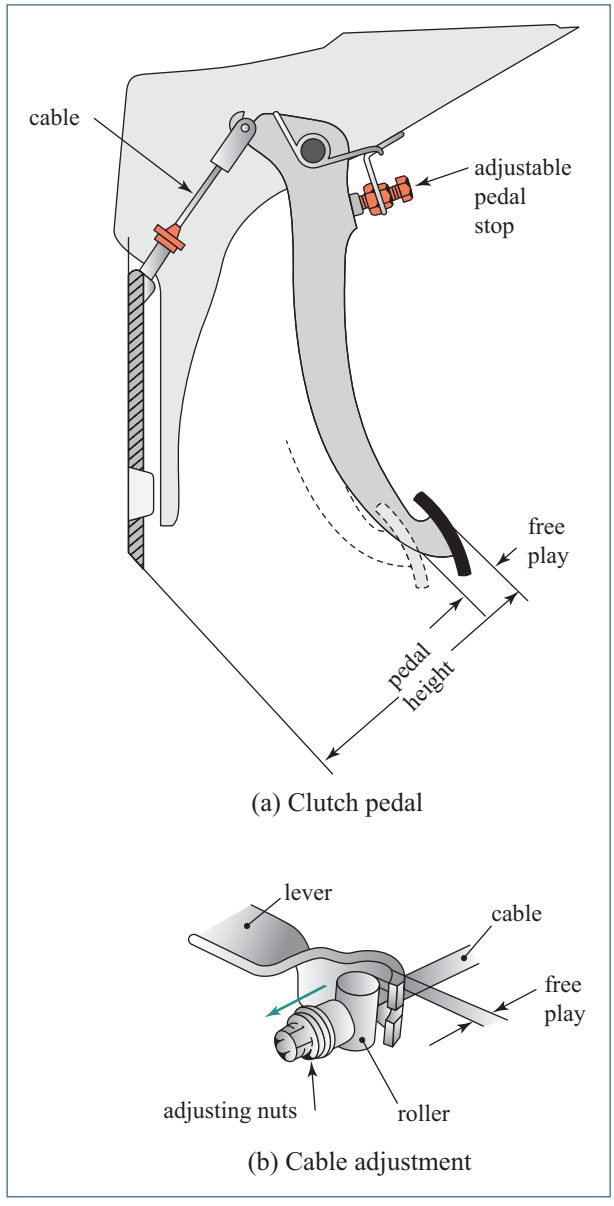


Figure 23.26 Clutch adjustments

easily during its free play but resistance can be felt once the release bearing contacts the fingers. Force is needed to move the pedal further and operate the clutch.

If there is too much free play, the clutch will not disengage properly and this will cause clutch spin, making selection of gears difficult.

If there is not enough free play, or none at all, then the clutch may not engage fully and the clutch will slip. This will result in rapid wear of the friction facings on the clutch disc and eventual clutch failure.

23.13.2 Pedal height

The pedal height is determined by measuring the distance between the top of the pedal pad and the floor pan (or in some cases the firewall) with the pedal against its return stop. If pedal travel is too great, then damage to the clutch mechanism or diaphragm can occur due to the excessive movement.

Pedal travel is sometimes specified instead of pedal height. Pedal travel is found by measuring the pedal height as before and comparing it with the height of the pedal in the fully depressed position.

23.14 Adjusting mechanical controls

23.14.1 Cable-controlled clutch adjustment

The adjustments of a cable control are shown in Figure 23.26. There are two places where adjustments can be made:

1 At the pedal stop , which determines the pedal height.
2 At the clutch end of the cable , which adjusts the pedal free play .

Pedal height adjustment

The pedal height must be checked first and, if necessary, adjusted before the free play. In the example shown, the pedal height is measured from the upper surface of the pedal pad to the floor. The pedal must be against its return stop when this measurement is taken. To achieve this, it may be necessary to back off the adjustment on the clutch end of the cable.

The specified pedal height in this clutch is 165 mm with a tolerance of plus or minus 0.5 mm.

Pedal free-play adjustment

The pedal free play is checked by depressing the pedal by hand until resistance can be felt. This is usually specified at about 15 mm to 20 mm.

Free play is adjusted by altering the position of the nuts at the cable to provide clearance between the roller on the cable and the release fork.

Handy hint: After making the adjustment, the clutch pedal should be operated a number of times and the setting recheck ed.

23.14.2 Adjusting linkage controls

Clutches with linkage controls are checked in a similar manner to those with control cables. Both free play and pedal travel are checked. A threaded adjustment is provided on one of the rods of the linkage so that it can be adjusted to provide the correct free play. The pedal travel is adjusted by the pedal stop.

23.15 Servicing mechanical controls

On mechanically controlled clutches, apart from the adjustments previously described, cables and linkages may require lubrication to ensure free operation. Worn linkage bushes may have to be replaced to reduce lost motion. Cable replacement could be necessary if the cable becomes worn or broken.

23.16 Adjusting hydraulic controls

Depending on the particular vehicle, adjustments may be provided for clutch pedal height, pedal free play, and also free play between the end of the slave cylinder pushrod and the end of the clutch release fork.

23.16.1 Pedal free-play adjustment

There must be a small clearance between the end of the master cylinder pushrod and the master cylinder piston. This provides about 6 mm of free play at the clutch pedal.

The end of the pushrod is usually threaded and fitted with an eye or a clevis and attached to the clutch pedal with a pin (Figure 23.27). This enables the length of the pushrod to be altered if the free play needs to be adjusted. Under normal circumstances, the original adjustment does not have to be altered.

If there is no adjustment provided on the pushrod, then the free play is adjusted by means of the pedal stop.

The small clearance between the end of the pushrod and the master cylinder piston is needed to make sure that the piston returns fully to the end of its bore. If it does not, then pressure will build up in the hydraulic system and the release bearing will be held against the fingers of the diaphragm.

This could prevent the clutch from engaging fully and could ruin the release bearing which would be in constant rotation. Also, there could be excessive wear of the ends of the diaphragm fingers.

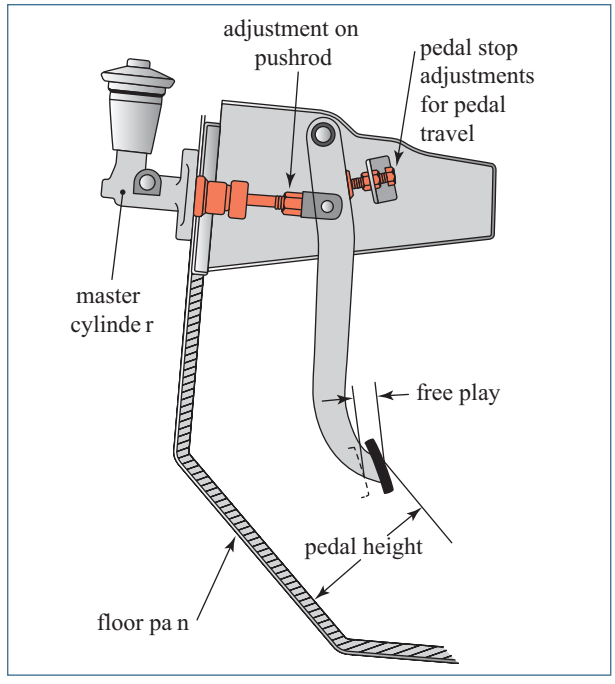


Figure 23.27 Pedal adjustments for a hydraulic clutch

23.16.2 Pedal height and travel adjustment

Pedal height is measured as previously described and, if necessary, adjusted at the pedal return stop. If pedal travel is specified, then this is also checked.

The things to be considered in relation to the pedal stop and pedal travel are:

1. The pedal travel has to move the master cylinder piston down its bore to displace enough fluid for the slave cylinder to fully disengage the clutch.
2. The master cylinder piston must also return fully in its bore so that the fluid returns to the reservoir when the pedal is released.

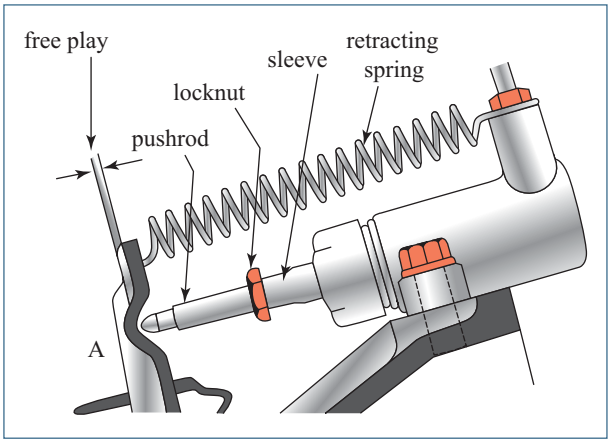


Figure 23.28 Adjustment of clutch slave cylinder—note the free play between the slave cylinder pushrod and the clutch release lever A

23.16.3 Slave cylinder adjustment

Some slave cylinders have a threaded pushrod which allows free play to be adjusted. Free play in this case is a small amount of movement of the pushrod before the release bearing comes into contact with the diaphragm fingers (Figure 23.28).

A return spring is used with some slave cylinders of this type. The spring holds the end of the release fork against the slave cylinder pushrod. This makes sure that the release bearing is kept away from the fingers of the diaphragm while the clutch is engaged.

Other slave cylinders do not have a return spring and depend on the bearing automatically having a small clearance at the diaphragm fingers.

The threaded adjustment alters the length of the pushrod and is set so that there is 2 mm to 3 mm of free play between the end of the pushrod and the clutch fork. This can be checked by moving the end of the release fork away from the pushrod until the release bearing contacts the diaphragm fingers.

Self-adjusting slave cylinders

Slave cylinders with non-adjustable pushrods do not use a return spring to keep the release fork against the pushrod. With this type of slave cylinder, the pushrod is held lightly against the end of the release fork by a spring inside the slave cylinder which keeps the piston in position.

Handy hint: This arrangement is sometimes referred to as being self-adjusting, or having automatic adjustment.

23.17 Servicing hydraulic controls

Hydraulic clutch controls may require servicing because of leaks or because of faulty operation. This could entail overhaul or replacement of the master cylinder and/or slave cylinder, and replacement of the hydraulic hose.

Handy hint: If air enters the hydraulic system due to loss of fluid or removing components, then the system will have to be bled to remove the air .

23.17.1 Removing master cylinders

A master cylinder will have to be removed and serviced if it is not operating properly, or if fluid is leaking into the boot. They are removed in five stages:

1. Attach a bleeder hose to the bleeder valve on the slave cylinder . With the valve open about one turn, operate the clutch pedal to pump the fluid out of the system into a container (Figure 23.32).
2. The fluid should be discarded, as it is unsuitable for further use .
3. Disconnect the hydraulic pipe from the outlet port of the master cylinder , and disconnect the reservoir pipe if the reservoir is not part of the cylinder .
4. Disconnect the pushrod from the clutch pedal. In some cases, this is not necessary because the master cylinder can be removed without the pushrod.
5. Remove the nuts or bolts that hold the master cylinder flange to the firewall, and remove the master cylinder .

Handy hint: There are variations to the above . Master cylinders can have either an attached reservoir , or a remote reservoir that is connected to the master cylinder by a hose .

23.17.2 Dismantling master cylinders

Figure 23.29 shows a dismantled master cylinder of the compensating-port type. The piston and associated parts are retained in the cylinder by a circlip. This cylinder has a remote reservoir which is connected to it by a tube, so the reservoir does not have to be removed.

The general dismantling procedure is:

1 Pull the boot back from the end of the cylinder to expose the circlip .
2 Using the pushrod, push the piston slightly into the cylinder to relieve the pressure against the circlip .
3 With circlip pliers, contract the circlip and remove it from the end of the cylinder .
4 Relieve the pressure on the pushrod and remove it and the boot.
5 The piston assembly will be pushed out by the return spring. If the piston sticks in the cylinder , tap it on a block of wood.
6 Separate the parts by removing the washer and the primary and secondary cups from the piston.

23.17.3 Inspecting and cleaning

Before reassembling a master cylinder, all parts should be cleaned with methylated spirits and examined for condition. The piston and cylinder bore should be checked for scores and corrosion. The bore of an aluminium alloy cylinder can be polished, but not honed.

Cylinders with deep pitting as the result of corrosion are usually replaced with a complete new cylinder, although cylinders can be reclaimed by resleeving. Scored or corroded pistons and other parts should also be renewed. New seals and rubber parts are always fitted.

23.17.4 Reassembling master cylinders

For most master cylinders, such as the one shown in Figure 23.30, the piston and associated parts are assembled and then entered into the cylinder bore. The illustration shows a compensating-port cylinder which has the reservoir attached.

Some general points about reassembling a master cylinder are:

1 All parts, including the bore of the cylinder , should be lubricated with unused brak e fluid or special rubber grease prior to installation.
2 The cups and seals must be fitted the correct way; that is, with their sealing lips pointing inwards.

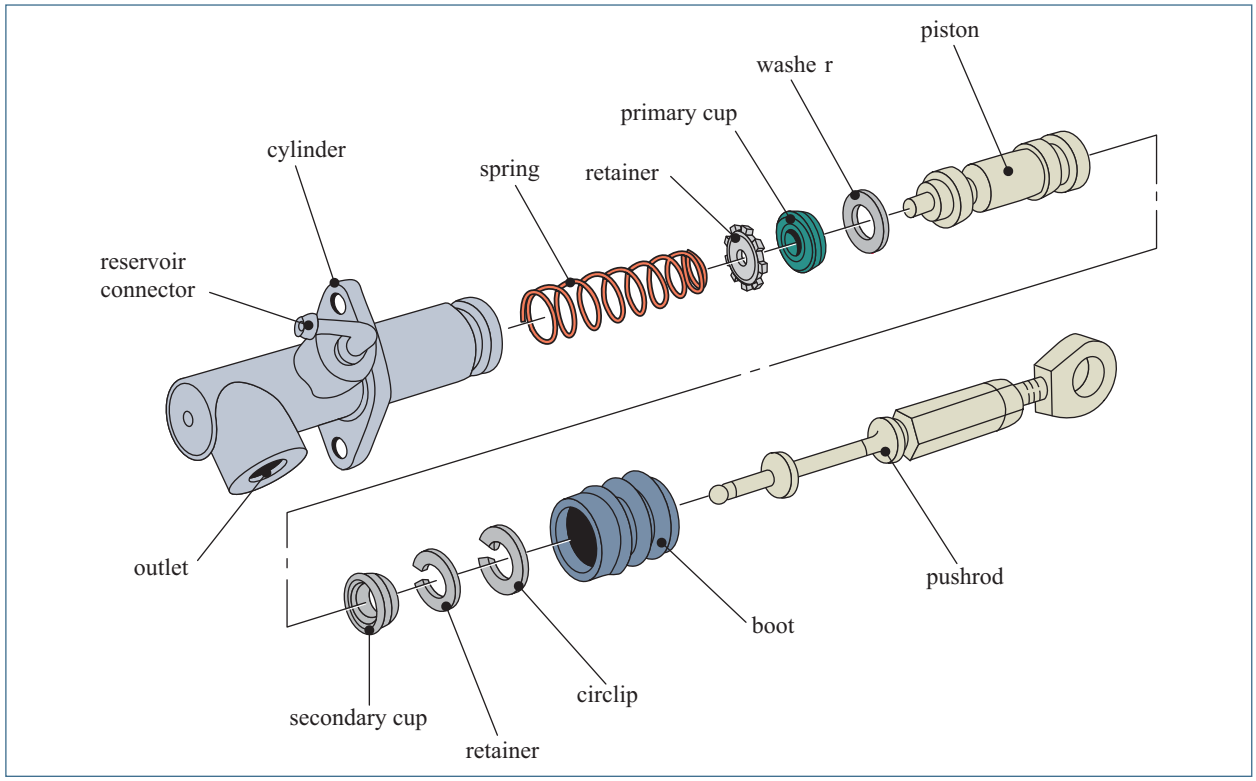


Figure 23.29 Dismantled compensating-port master cylinder—this has a remote reservoir

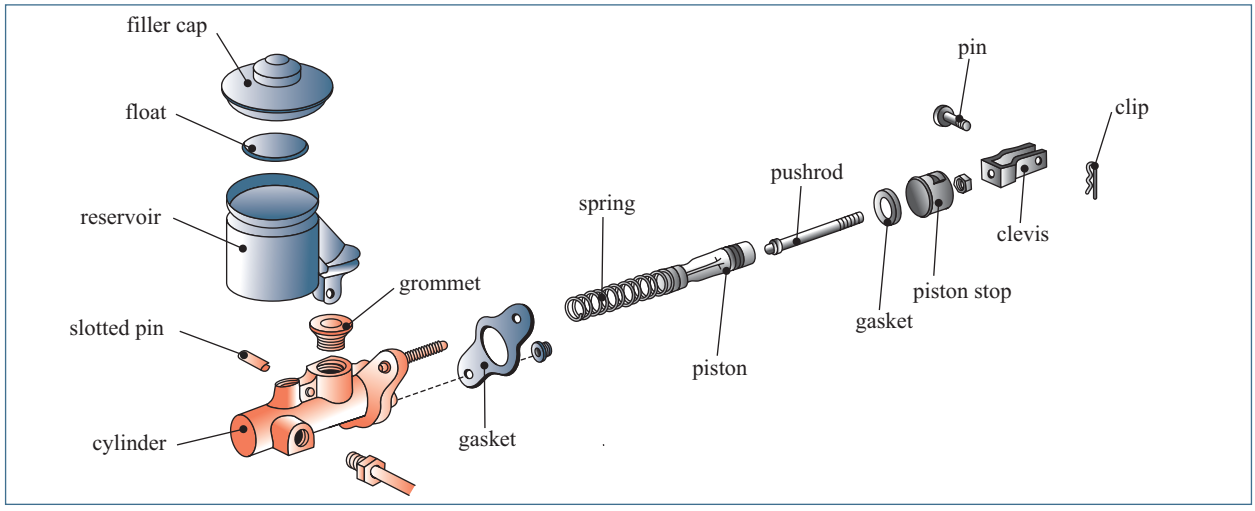


Figure 23.30 A compensating-port master cylinder to which the r eservoir is attached

3 Seals that are being fitted into grooves in the piston should be well lubricated and not overstretched.
4 With the piston assembly installed in the bore , the pushrod and retaining washer are installed and secured with the circlip .
5 The end of the cylinder and piston can be coated with rubber grease and the boot installed.
6 After the master cylinder has been reinstalled in the vehicle , check pedal free play .
7 The clevis or eye on the end of the pushrod is adjusted, if necessary , to provide free play . There should be a clearance of appro ximately 2 mm between the end of the pushrod and the piston.

Handy hint: When cups or seals are correctly installed, pressure in the cylinder will expand their sealing lips against the cylinder bore . If installed the wrong way , pressure will force fluid past the seal.

23.17.5 Servicing centre-valve master cylinders

Dismantled centre-valve master cylinders are illustrated in Figure 23.12 and Figure 23.13, earlier in this chapter.

These cylinders are dismantled in a similar way to the compensating-port cylinder previously described. The pushrod is retained by a circlip, and the retaining washer, pushrod and the piston assembly can be withdrawn from the cylinder once the circlip is removed.

The piston assembly in Figure 23.12 can be dismantled as shown. This is done by releasing the tab on the spring retainer which holds it onto the piston. The piston in Figure 23.13 cannot be dismantled and is replaced as an assembly.

23.17.6 Servicing slave cylinders

Slave cylinders are bolted to the clutch housing and can be removed after undoing the bolts or nuts. The hydraulic hose has to be disconnected and, in some instances, a return spring connected between the slave cylinder and the release fork has to be unhooked before the cylinder can be completely removed.

To dismantle a slave cylinder, such as the one shown in Figure 23.31, the edge of the boot is eased over the bead on the end of the cylinder and the boot and pushrod removed. The piston and internal spring, if fitted, can then be withdrawn from the cylinder bore.

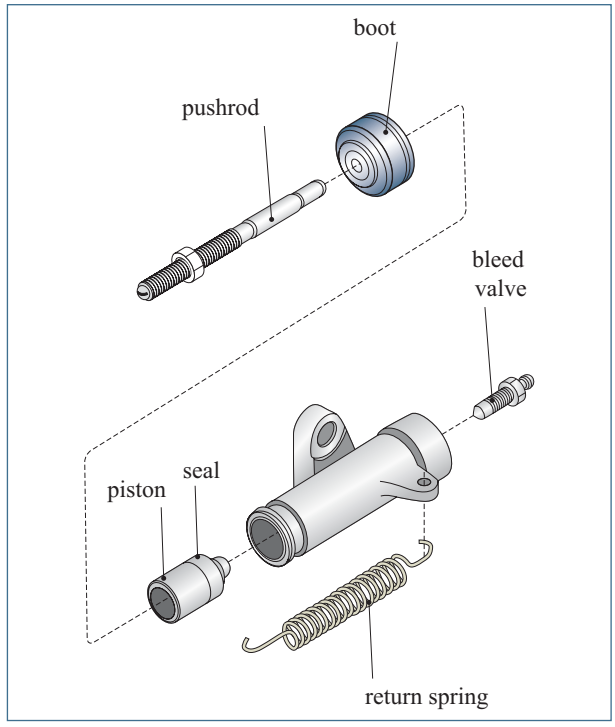


Figure 23.31 Dismantled slave cylinder

Reassembling

Before reassembling the slave cylinder, the parts should be cleaned and inspected in a similar manner to that indicated for the master cylinder.

Reassembly is done in the reverse order to dismantling, and a new piston seal and boot should be fitted. All internal parts should be dipped in clean brake fluid or coated with rubber grease prior to being installed. Care must be taken to ensure that the piston seal is installed on the piston with the sealing lips facing the right way.

23.18 Bleeding the clutch system

After any part of the hydraulic system has been dismantled, air will become trapped in the system when it is reassembled. Also, if the fluid level in the reservoir becomes too low, possibly due to a leak, air will enter the system. A hydraulic system will not operate with air present. The air will merely compress when the clutch pedal is pressed, with little or no effect on the clutch mechanism.

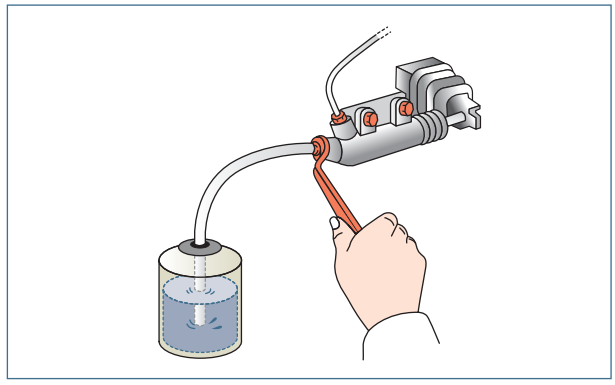


Figure 23.32 Bleeding a clutch slave cylinder—the same arrangement is used to pump fluid from the system before dismantling

23.18.1 Bleeding procedure

The general procedure for bleeding the clutch system follows. To assist in bleeding, fill the master cylinder with as much fluid as possible before it is installed on the vehicle.

1. Fill the master cylinder reservoir with fluid and maintain it at least one-quarter full throughout the operation so that air is not drawn into the system.
2. Attach a plastic hose to the bleeder valve on the slave cylinder and submerge the end of the tube in fluid in a glass jar (Figure 23.32).
3. Slacken the bleeder valve and have an assistant depress the clutch pedal slowly. When the pedal reaches the bottom of the stroke, close off the valve and allow the pedal to return to its stop.
4. Repeat the above procedure until air bubbles cease to come from the end of the bleeder tube.
5. When there is no air coming from the bleeder tube, close the bleeder valve during a pedal downstroke and remove the bleeder tube.
6. Top up the master cylinder reservoir with brake fluid to the correct level.

Handy hint: Submerging the end of the tube in fluid will prevent air from being drawn back into the slave cylinder during the pedal return stroke, and closing off the bleeder valve at the end of the stroke assists with bleeding. Always dispose of old clutch fluid in line with the requirements of environmental safety regulations.

23.19 Major clutch service

The clutch is contained within the clutch housing, which is bolted to the rear of the engine. The clutch housing can be part of the transmission case, or it can be a separate part which is bolted to the transmission case.

To gain access to the clutch, the transmission (or transaxle) has to be removed from the rear of the engine. In most cases, the clutch housing is removed with the transmission.

The clutch release fork is mounted on the clutch housing and the release bearing is supported on the bearing retainer at the front of the transmission, so that both these parts are removed with the transmission and clutch housing. This leaves the clutch assembly mounted on the flywheel and accessible.

Transmissions and clutches for rear-wheel-drive vehicles can be removed with the engine in place in the vehicle, but access to the clutch in front-wheel-drive vehicles is more difficult.

With front-wheel-drive vehicles, there is often limited space in the engine compartment. In these vehicles, the transaxle can only be removed when the engine assembly is either partly or completely removed from the vehicle.

Safety: Clutch dust around the bell housing should be treated the same way as brake dust and removed by washing or by using the correct vacuum cleaner.

23.19.1 Removing the clutch

When removing a clutch:

1 The transmission should not be allowed to hang on the clutch assembly when it is being removed (or replaced). Guide studs in two opposite bolt holes will assist in supporting the transmission and k eeping it aligned. Allowing the transmission to hang on the clutch assembly could distort the clutch disc.
2 Identification marks should be placed on the pressure-plate cover and the flywheel so that the pressure-plate assembly is reinstalled in its original position (Figure 23.33). This will help to preserve balance .
3 The pressure-plate cover is secured to the flywheel by a number of bolts. These should be loosened progressively , working on opposite bolts, so that the cover comes away evenly from the flywheel. This will prevent distortion of the cover .
4 A clutch aligning tool should be fitted when the pressure-plate assembly is being removed (Figure 23.34). This supports the clutch disc and prevents it from dropping.
5 The side of the clutch disc which fits against the flywheel should be identified because it will only fit properly if the correct side is installed against the flywheel.

The two sides of a clutch disc are not the same – one side of the hub is usually shorter than the other and the cushion springs and retainers are often offset to one side of the disc.

Handy hint: Identifying the sides of a clutch disc will prevent it from being installed the wrong way .

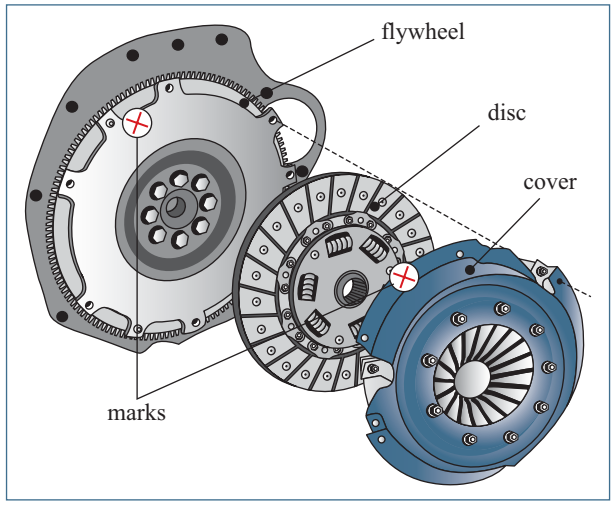


Figure 23.33 Marks placed on the pressure-plate cover and the flywheel enable the cover to be reinstalled in its original position

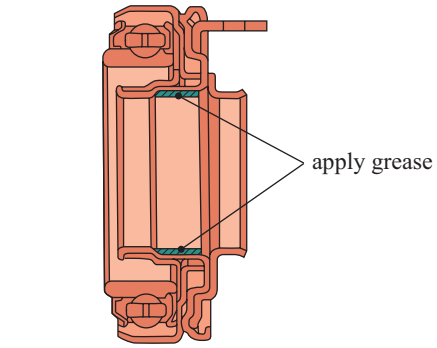
Figure 23.34 A clutch aligning tool is used to centre the clutch disc

23.19.2 Installing the clutch

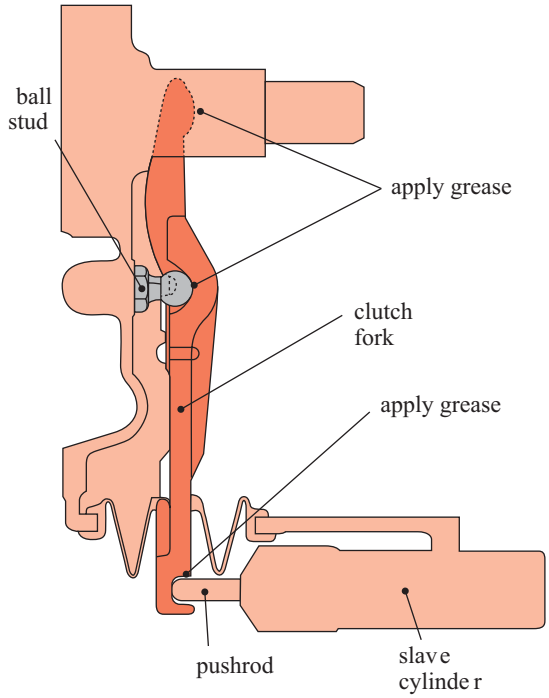
Before reinstalling the clutch to the flywheel, a serviceability check should be made of the clutch parts (see next section). Observe the following during installation:

1 Make sure that the mounting faces of the clutch housing and engine are clean.
2 Identify the side of the disc that is to face the flywheel.
3 As a check, place the disc in position and see that the facings actually contact the flywheel face and are not held clear of the face by the hub or other parts of the disc fouling the flywheel.
4 Use an aligning tool to align the hub of the disc with the pilot bearing in the flywheel (Figure 23.34). This is necessary so that the transmission input shaft will slide into place when the transmission is being installed. Many transaxle transmissions do not have a pilot bearing in the flywheel and a different aligning tool must be used. Figure 23.34 uses this type of tool.
5 Guide studs fitted to two opposite bolt holes in the flywheel can be used to support the pressure-plate assembly until the clutch cover retaining bolts can be fitted.
6 The cover retaining bolts should be tightened progressively , working on opposite bolts, so that the diaphragm is compressed evenly . Final tightening should be done with a torque wrench (Figure 23.35).
7 The release mechanism should be lubricated as shown in Figure 23.36. A light coating of molybdenum disulphide grease should be applied to the release fork pivot and ball, and to the ends of the fork which contact the release bearing retainer .

Figure 23.35 Tightening the pressure plate to flywheel bolts—a torque wrench should be used for the final tightening



(a) Release bearing



(b) Release fork

Figure 23.36 Clutch release mechanism—parts to be lubricated when installing

The recess in the bore of the release bearing retainer should be filled with grease so that it slides freely on its support.

23.19.3 Inspecting clutch parts

The various parts of the clutch assembly that can be checked for serviceability are shown in Figure 23.37 and Figure 23.38. If doubt exists as to the condition of any part of the clutch, then the part should be renewed.

Clutch disc

The clutch disc should be carefully inspected to make sure that it is suitable for reuse.

1. Facings. These should be free of oil and grease, and should not be excessively worn. The thickness of the facing material above the rivet heads is used to determine the amount of facing wear.
2. Disc. The disc should be checked for cracks and other defects, such as torsional springs that are loose or appear to have lost their tension. This can cause clutch rattle.
3. Hub. The fit of the hub on the clutch shaft should be checked. The hub should slide freely on the splines, but should not have rotary play.
4. Disc runout. The disc can be checked for runout by installing it on a shaft or mandrel mounted between lathe centres. A dial gauge set up against the clutch facings will show runout as the disc is rotated.

Pressure-plate assembly

The parts of a pressure-plate assembly that should be inspected are shown in Figure 23.38.

1. The face of the pressure plate should be checked for heat marks, scores and ridges. The surface can be cleaned with abrasive paper to remove minor defects. In some cases, the pressure plate can be refaced if scoring is not too deep. Otherwise, either the pressure plate or the complete assembly will have to be replaced.
2. The diaphragm should be checked for cracks or excessive wear on the ends of the fingers. A defective diaphragm means that the complete pressure-plate assembly will have to be replaced.

Figure 23.37 Parts of a clutch disc to be check ed

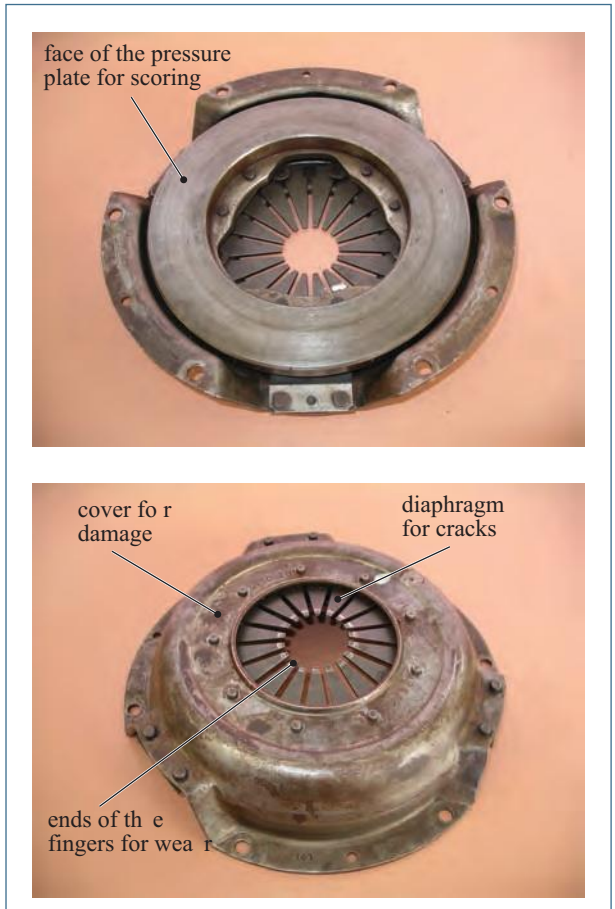


Figure 23.38 Parts of a pressure-plate assembly to be checked

Release bearing

The release bearing is a thrust-type ballrace that has been packed with grease is during manufacture. It should *not* be washed in cleaning solvent. The bearing can be wiped clean, and checked for roughness by pushing against the thrust face while rotating the bearing. If the bearing feels rough or seems loose or noisy, it should be renewed.

Pilot bearing

The pilot bearing in the end of the crankshaft can be a small ballrace, a roller bearing, or a bronze bush. The bearings are packed with grease. If necessary, the bearing can be removed or renewed.

Flywheel face

The surface of the flywheel should be checked for scores and wear and can usually be refaced. Flywheel runout is checked with a dial gauge mounted to the rear of the engine block with its button against the flywheel face as shown in Figure 23.39. The crankshaft should be rotated slowly while being held towards the front of the engine. This prevents crankshaft end-float from being mistaken for flywheel runout.

Figure 23.39 Checking flywheel runout with a dial gauge

Flywheel runout as shown on the gauge should not exceed 0.15 mm.

23.20 Repairs to pressure-plate assemblies

Most diaphragm pressure-plate assemblies are riveted together. Should a fault exist, such as a cracked diaphragm or scored pressure-plate face, a new pressure-plate assembly must be installed.

The height of the diaphragm fingers can be checked with the assembly bolted to a base plate as shown in Figure 23.40. The base plate is a special service tool. The pressure plate is installed on the base plate with

three spacer blocks, of the same thickness as a new clutch disc, between the pressure plate and the base plate.

The height of the fingers can be measured with a depth gauge and checked for variation with a dial gauge. Within limits, the height of the fingers can be set to specifications by bending. Variation in finger heights, measured at the tip of the fingers, should not exceed 0.5 mm.

Without a special base plate, a flywheel could be substituted for the base plate and an unworn clutch disc used instead of spacers under the pressure plate.

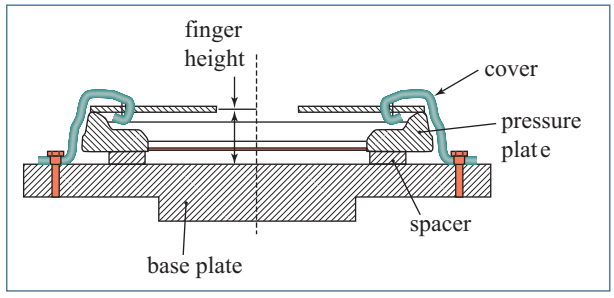


Figure 23.40 Diaphragm pressure-plate assembly mounted on a base plate

23.21 Clutch housing alignment

Where the clutch housing can be separated from the transmission, it can be bolted to the engine and checked for alignment. Checks can be made to both the face and the bore of the housing (Figure 23.41).

Clutch housing alignment should be considered when certain clutch and transmission troubles occur and there is no other apparent cause of the problem. Misalignment can produce problems such as rapid spline wear. It could place stress on the clutch disc, causing the hub to become loose, with subsequent complete failure.

Misalignment could also be responsible for chatter or drag of the clutch, making gearshifting difficult. The transmission input shaft bearing in the front of the transmission and the pilot bearing in the flywheel could be subjected to extra loading and this could cause premature wear and failure.

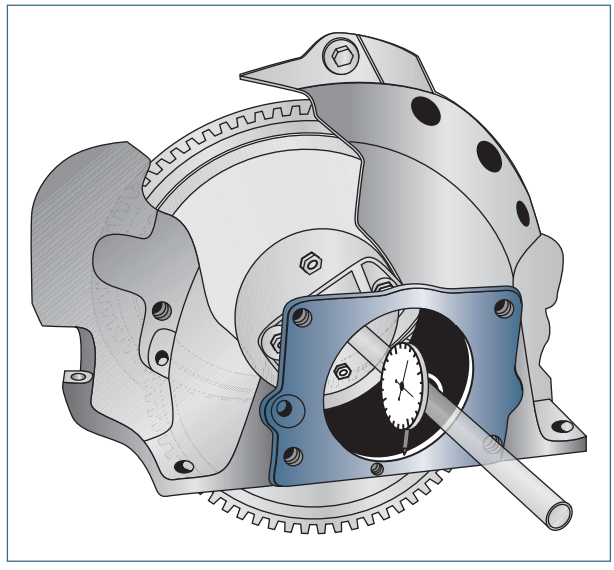


Figure 23.41 Using an arbor and dial gauge to check the alignment of the bore of the clutch housing—the gauge can also be mounted against the rear face to check its alignment

23.22 Analysing clutch problems

Clutch problems are usually evident as one of the following:

1 slip
2 spin or drag
3 chatter
4 disc-facing wear
5 stiff clutch pedal.
6 clutch noise

Handy hint: The two most common clutch problems are clutch slip and clutch spin.

23.22.1 Clutch slip

With a slipping clutch, the engine speed is much higher than normal. It is usually noticed when the vehicle is under load, such as when climbing a hill or starting off. Possible causes are:

1 incorrect cable adjustment, causing no pedal free play
2 binding of cables or linkages, with the same result as above
3 incorrect adjustment of the pedal return stop , again causing no pedal free play
4 worn clutch facings
5 weak or brok en pressure-plate springs.

23.22.2 Clutch spin (or drag)

Clutch drag is when the clutch fails to completely disengage. Possible causes are:

1. too much free play , resulting in not enough pedal travel
2. air in the hydraulic system
3. oil or grease on the facings, causing them to stick to the pressure plate or flywheel
4. a warped disc dragging on the pressure plate or flywheel
5. faulty release mechanism.

23.22.3 Other clutch problems

1. Clutch chatter or grab . This is a condition where the disc does not engage smoothly as it is being compressed between the pressure plate and the flywheel. P ossible causes are oil or grease on the disc facings, wear or rusting of the disc hub or input shaft splines. Another possible cause is ex cessive flexing of the engine mountings, which should be check ed for looseness and deterioration.
2. Disc facing wear . Some wear of the clutch disc facings is normal, but any condition that permits ex cessive clutch slip will cause rapid facing wear . The driver , as well as operating conditions, can have a noticeable effect on the life of the clutch facings.
3. Stiff clutch pedal. This could be caused by lack of lubricant or a badly aligned cable . The clutch pedal assist spring, where fitted, could be out of adjustment and not providing enough assistance when the pedal is being depressed.

23.23 Diagnosing clutch noise

Clutch noises are usually most noticeable when the vehicle is stationary and the engine is idling, or when starting off in low gear. The first thing to do is to decide whether the noise exists with the clutch engaged, or with it disengaged. This will enable certain parts of the clutch and the transmission to be isolated. When the clutch is engaged, certain parts are rotating and these become stationary when the clutch is disengaged.

Figure 23.42 is a simplified arrangement of parts of a clutch and transmission. The parts that could produce noise with the clutch disengaged are labelled accordingly. Other parts could produce noise with the clutch engaged.

23.23.1 Noise with the clutch disengaged

When the clutch is disengaged, parts of the release mechanism that were previously free are placed under load, while other parts of the clutch that were loaded are now free. Keeping this in mind can help to isolate noises.

For example, when the clutch pedal is depressed, the release bearing is brought up against the diaphragm fingers. A faulty release bearing would then produce noise that was not evident before.

When the clutch is disengaged, the clutch disc will stop rotating, so any noise that it was producing should now cease.

With the diaphragm depressed, load is removed from the pressure plate and so any noise due to wear, looseness or damage to parts of the pressure plate assembly might now be heard.

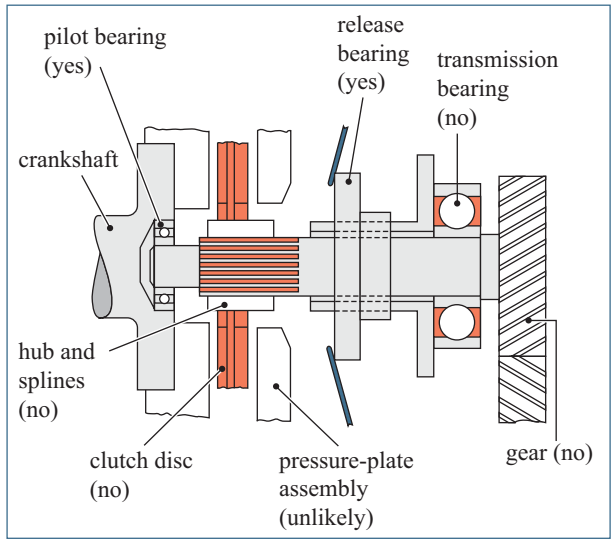


Figure 23.42 Simplified clutch and transmission shaft arrangement—the parts that could produce noise with the clutch disengaged are shown with 'yes ' (parts shown with 'no' could produce noise with the clutch engaged)

23.23.2 Noise with the clutch engaged

Noises from an engaged clutch could originate at the clutch disc. These could come from a hub that is loose on the input shaft splines, or from broken or weak damper springs.

Bearing noise or gear noise with the clutch engaged and the transmission in neutral are transmission noises. A faulty input-shaft bearing at the front of

the transmission will be noisy while the clutch is engaged and the input shaft is rotating, but the noise will disappear once the clutch is disengaged.

This will also apply to a gear noise that can be heard with the clutch engaged. The noise will cease once the clutch is disengaged and the input shaft stops rotating.

23.23.3 Pilot-bearing noise

A pilot bearing that is worn or short of lubricant will be noisy when it is rotating. This will occur with the vehicle stationary, the engine running and the clutch disengaged.

Under these conditions, the input shaft (which has a spigot in the pilot bearing) is stationary, but the crankshaft is rotating the bearing. Increasing and decreasing the engine speed may alter the noise coming from the bearing.

If the pilot bearing is a bronze bush, then wear or lack of lubricant can cause the spigot on the end of the input shaft to chatter in the bush. A dry bush can produce a squealing noise, which is likely to be heard when the clutch is being engaged to start the vehicle moving in first gear.

23.24 General clutch problems

Table 23.1 shows some general clutch problems, with possible causes and corrections.

Table 23.1 Possible clutch problems

Problem	Possible cause	Check or correction
Clutch slips	Incorrect adjustments	Adjust pedal, cable or slave cylinder
	Worn disc facings	Normal wear , replace disc
	Premature wear of facings	Incorrect adjustments, replace disc, mak e correct adjustments
	Oily disc facings	Correct oil leaks and replace disc
	Crack ed diaphragm	Replace pressure-plate assembly
	No free play at clutch fork	Adjust free play
Clutch spins	Pedal travel too short	Adjust cable or pedal stop
	Warped or damaged disc	Replace disc, check transmission alignment
	Pedal has no resistance	Check for leaks, bleed hydraulic system, check for brok en cable
	Excessive free play	Adjust free play at clutch fork
	Master cylinder faulty	Service master cylinder
	Slave cylinder faulty	Service slave cylinder
Clutch grabs or chatters	Oil on facings	Replace disc, correct oil leaks
	Disc springs weak or brok en	Replace disc
	Disc sticking on shaft splines	Clean splines of rust
	Worn splines in hub	Replace disc
	Engine mountings loose or worn	Tighten mounting bolts, renew mountings
Hard pedal action	Pedal bush dry	Lubricate bush and linkage
	Cable sticking	Lubricate cable
	Linkage dry or worn	Lubricate , replace bushes
	Assist spring inoperative	Spring brok en or misaligned
Clutch noisy at engine idle when engaged	Transmission input bearing	Bearing worn, replace
	Disc springs	Springs weak or brok en
	Clutch release bearing	No clearance between bearing and diaphragm fingers
Clutch noisy when disengaged	Clutch release bearing	Bearing worn or dry , replace
	Clutch pilot bearing	Bearing worn or dry , lubricate or replace bearing

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe and light vehicle clutch systems, including hydraulic, cable and linkage operation
- service and bleed the hydraulic system
- adjust cable and linkage systems
- apply procedures for diagnosing and replacing clutch components.

REVIEW QUESTIONS

1 What is the purpose of the clutch?
2 What is a single-disc clutch?
3 What are the main parts of a clutch assembly?
4 What is the function of the clutch pressure plate?
5 How are vibrations dampened by the clutch disc?
6 What is the purpose of the clutch release bearing?
7 What type of bearing is the clutch release bearing?
8 Where is the pilot bearing located?
9 State the purpose of the pilot bearing.
10 What are the two types of master cylinders that are used with clutch controls?
11 Explain briefly how one type of master cylinder operates.
12 What is the purpose of the slave cylinder?
13 What is a pull clutch?
14 Why is a dual-mass flywheel used on some vehicles?
15 Name the two checks and adjustments that are common to most clutches.
16 How is pedal free play checked?
17 In general terms, how is a clutch cable adjusted?
18 What adjustments are usually provided for hydraulic clutch controls?
19 What is a self-adjusting slave cylinder?
20 Why is a hydraulic clutch system bled?
21 What is a general bleeding procedure?
22 Why should a clutch pressure-plate assembly be marked before it is removed from the flywheel?
23 Name the parts of a clutch that would be inspected for wear after dismantling.
24 How would a clutch disc be checked to make sure that it was being installed the right way?
25 What is the purpose of a clutch aligning tool?
26 Indicate the parts of a clutch that would be lubricated during reassembly.
27 How can flywheel runout be checked?
28 What is the likely cause of clutch shudder? Of clutch drag? Of clutch slip?
29 When is the noise from a defective pilot bearing likely to be heard?
30 When is a noisy release bearing likely to be heard?

CHAPTER 24

Manual transmissions, transaxles, four-wheel and all-wheel drive service

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify the operating principles of light vehicle manual transmissions and transaxles and associated components
2 recall the application, purpose and operation of light vehicle manual transmissions, transfer cases and components
3 demonstrate relevant diagnostic testing procedures for light vehicle manual transmissions, including road testing procedures
4 demonstrate relevant repair procedures for light vehicle manual transmissions, including those for removing, replacing and adjusting the systems
5 apply relevant post-repair testing procedures for light vehicle manual transmissions.

A rear-wheel-drive vehicle has the transmission mounted on the rear of the engine, and a drive shaft connects it to the rear-axle assembly. The rear axle houses the final drive and differential, and this is connected by axles or drive shafts to the rear wheels.

Front-wheel-drive vehicles also have the transmission at the rear of the engine, but the final drive and differential are included as part of the transmission assembly. It is usually referred to as a transaxle. Drive shafts connect the transaxle to the front wheels.

Four-wheel-drive vehicles and all-wheel-drive vehicles use a combination of front-wheel drive and rear-wheel drive, with shafts carrying the drive from the transmission to the front as well as the rear wheels.

24.1 Purpose of a transmission

The internal combustion engine produces very little torque at low engine speeds. The primary purpose of the transmission is to overcome this by multiplying torque at low speeds. This is achieved through the lower gears (assisted by the clutch when the vehicle is starting off).

With manual transmissions, gears are selected and gearshifts made using a gear lever. With automatic transmissions, all gear shifts are done automatically, with the exception of using a lever to make the initial selection. Some automatic transmissions can also be used manually.

An engine has to operate at a high speed to produce the torque needed to move a vehicle. The transmission provides a range of gearing which allows the engine to operate at various speeds. If an engine had fixed gearing that was suitable for both starting off and low road speeds, the engine speeds would be far too high for normal driving. Conversely, if the gearing was suitable for normal driving, the engine would not have enough torque for starting off. This is why transmissions with a number of gears are used.

The purpose of the transmission is to provide:

1 neutral —so the engine can operate out of gear , without moving the vehicle
2 lower gears —for starting off and heavier operating conditions
3 higher gears —for higher speeds, lighter loads and cruising
4 reverse gear —to move the vehicle backwards.

Handy hint: A transmission provides different speeds and changes torque .

24.2 Types of gears

There are many different types of gears and gearing. Figure 24.1 shows the most common types in transmissions and transaxles.

24.2.1 Spur gears

These are the simplest and most common gears. They connect shafts that are parallel to each other and rotate in opposite directions. Spur gears have teeth that are cut straight across their face. Because of the shape of their teeth, spur gears tend to be forced apart from each other under load. This causes them to impose a *radial* load on their shafts and bearings.

24.2.2 Helical gears

Helical gears are similar to spur gears, except that their teeth are cut on an angle. This distributes the load as parts of more teeth are in contact. Helical gears are also quieter than spur gears. Under load, helical gears tend to be forced apart, but the teeth also tend to slide on each other. This imparts a thrust along the shaft which is taken by the bearings or thrust washers.

Handy hint: A helix is a spiral and a helical tooth that would, if it were long enough, form a spiral.

24.2.3 Internal gear and pinion

Internal gears are not used in manual transmissions, but they are used extensively in automatic transmissions. Also called ring gears, they are part of a planetary gear set, together with a pinion and a sun gear. (A pinion is a small gear that meshes with a large gear; a sun gear is a gear around which other gears can rotate.)

24.2.4 Bevel gears

Bevel gears connect shafts that are not parallel to each other. They are used in the differential gears of transaxles and rear axles. Spiral bevel gears are

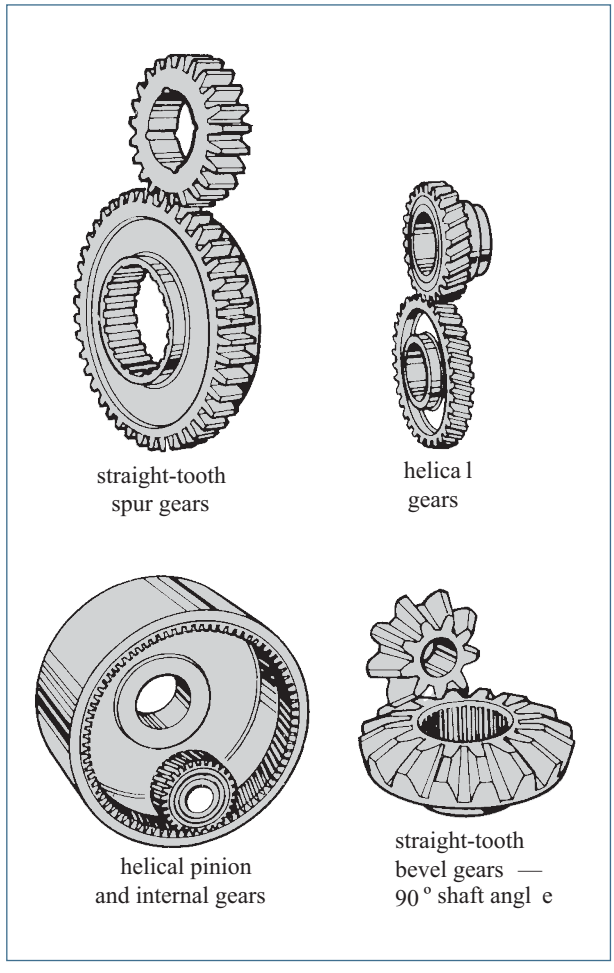


Figure 24.1 Types of gears

used in the final drives of rear axles of rear-wheel-drive vehicles. They are commonly called the *crown wheel* and *pinion*. The crown wheel somewhat resembles a crown.

24.3 Gear ratio

The gear ratio (and the speed of two gears in mesh) is determined by the number of teeth in each gear. If two gears have the same number of teeth, they will rotate at the same speed (Figure 24.2(a)). However, if one gear is smaller than the other, the smaller gear will rotate faster than the larger one. For example, a gear with 12 teeth will turn twice as fast as a gear with 24 teeth (Figure 24.2(b)).

Where gears are in mesh, one is referred to as the driver (or driving) gear, and the other as the driven gear. The rule for finding the gear ratio from the number of teeth in the gears is:

$$\text{Ratio} = \frac{\text{teeth in driven gear}}{\text{teeth in driving gear}}$$

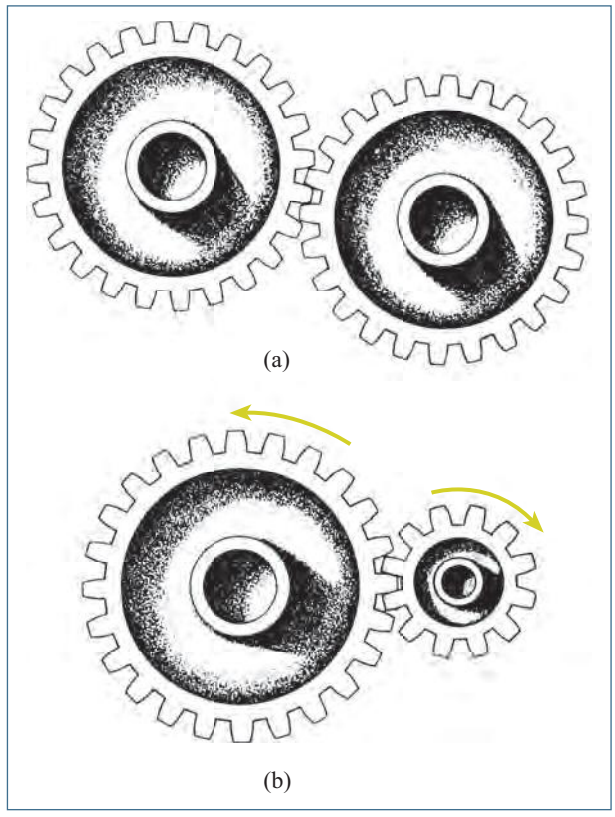


Figure 24.2 Gears in mesh (a) gears with the same number of teeth rotate at the same speed (b) the smaller gear rotates faster than the larger one

24.3.1 Simple gear trains

A simple gear train is one in which more than two gears are in mesh with each other (Figure 24.3). With a train of three gears, the first and last gears affect the gear ratio. The other gear is known as an *idler gear* or *intermediate gear*. It transfers movement between the other two gears but has no effect on the gear ratio. If the first gear is the driver, the idler will be both driven and driver, and the last gear will be the driven gear. When calculating the gear ratio, the effect of the idler is cancelled out.

Idler gears are often used to change the direction of rotation of the following gears. An example is the reverse idler in the transmission, which provides reverse gear.

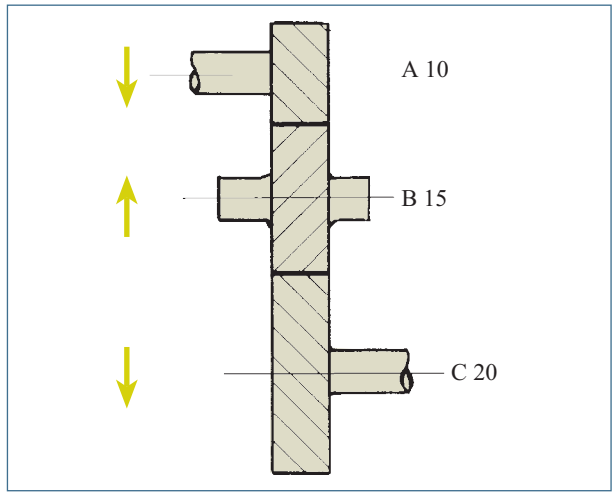


Figure 24.3 Simple gear train A driver , B idler, C driven—A and C rotate in the same direction but at different speeds

24.3.2 Compound gears

A *compound gear* is where two or more gears are joined so that they turn at the same speed. The countershaft gearing in the transmission is a compound gear which has four or more gears. This is referred to as the *cluster*. A compound gear, when meshed with other gears, provides a double gear ratio.

Figure 24.4 shows a compound gear with two gears: 12 teeth are meshed with 24 teeth, and also 10 teeth are meshed with 30 teeth. The gears with 24 teeth and 10 teeth are compounded. There are two drivers and two driven gears:

$$\text{Gear ratio} = \frac{24 \times 30}{12 \times 10}$$
$$= 6$$

The output shaft B turns at one-sixth of the speed of the input shaft A, so this is a simple reduction gearbox. It is also the principle on which a manual transmission operates. An actual transmission has many more parts, but still operates in this way.

24.3.3 Gears and torque

The gear ratios not only change speed but also change torque. When speed is reduced by the gears, torque is increased and vice versa. Gears and shafts transmit torque, and any shaft or gear that is being turned has a torque applied to it.

In a motor vehicle, the torque originates in the engine and is delivered from the crankshaft through the transmission and the final drive to the driving wheels. Torque is increased in the lower gears of the transmission and also in the final-drive gears. The drive shafts or axles for the driving wheels receive a greatly increased torque, but turn at a much slower speed than the engine.

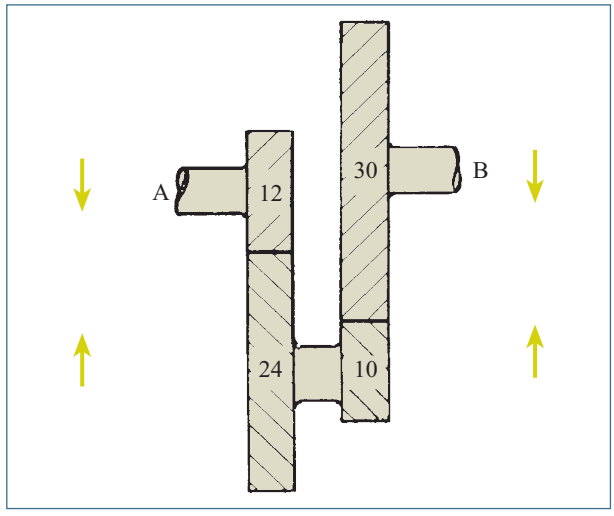


Figure 24.4 In compound gearing, the two lower gears are joined together—A is the input shaft and B is the output shaft. The numbers denote the teeth in the gears

24.4 Basic synchromesh transmission

Figure 24.5 shows the gearing of a basic three-speed synchromesh transmission for rear-wheel drive. The transmission has an input shaft, a mainshaft, a countershaft and a reverse idler. The gears on its mainshaft are in constant mesh with those on the countershaft. It has synchronisers for the three forward gears.

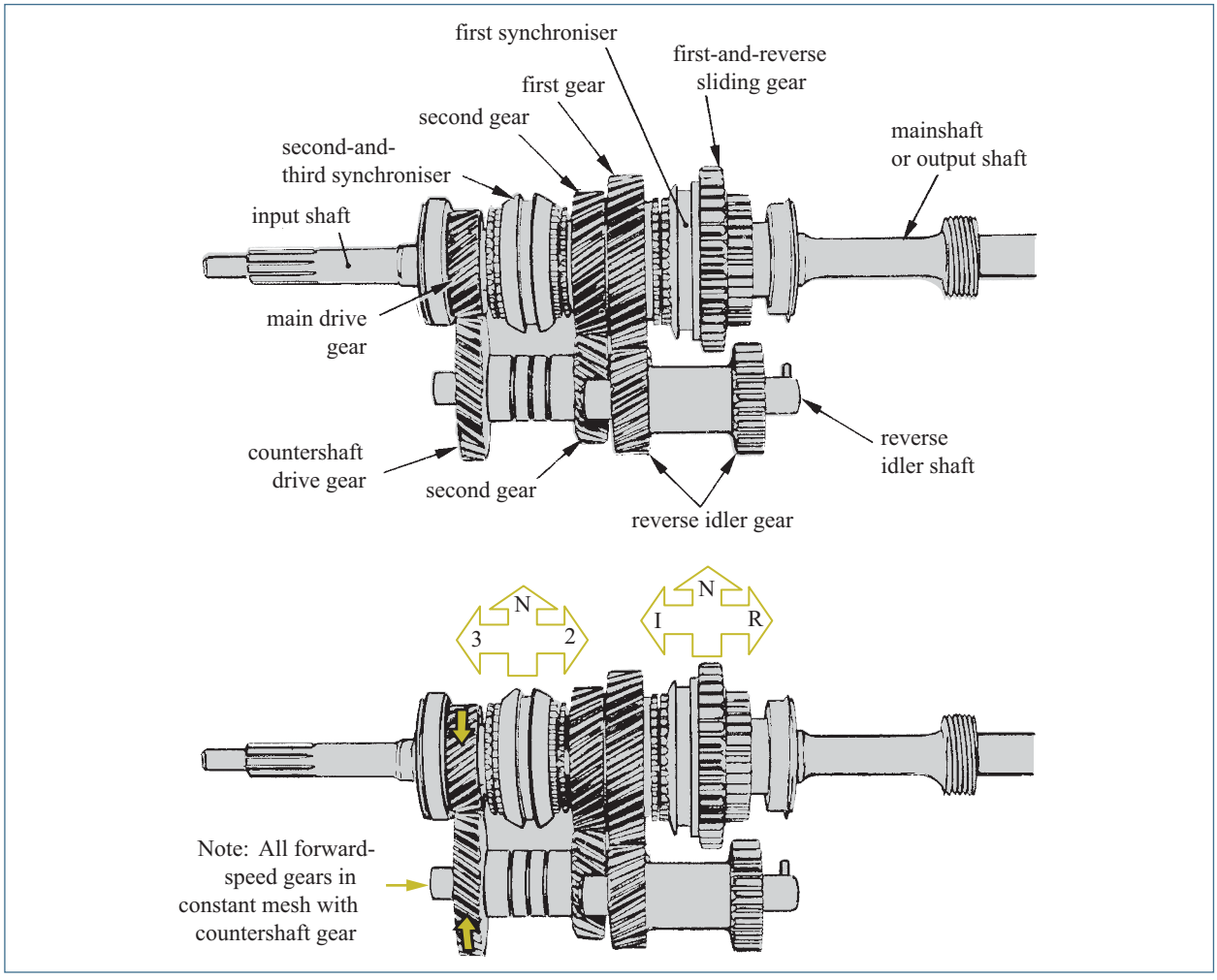


Figure 24.5 Gear arrangement of a basic three-speed synchromesh transmission FORD

The countershaft has a cluster of three gears: the countershaft drive gear, the second gear and the first gear, which is hidden behind the reverse idler gear. Reverse is a sliding gear that does not have a synchroniser. The reverse idler is a compound gear with two gears, which is mounted on its own shaft.

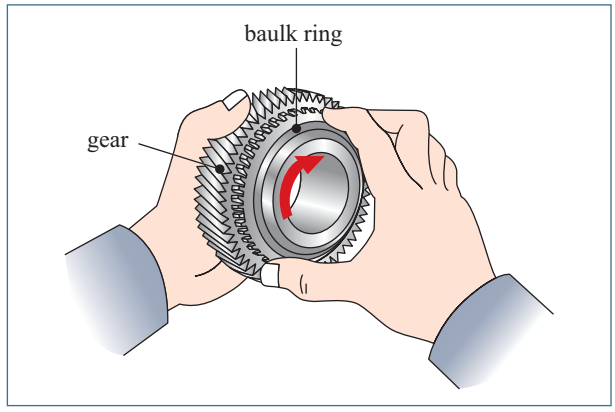


Figure 24.6 Braking action of a synchroniser—the baulk ring is forced onto the cone of the gear as shown

24.4.1 About constant-mesh gears and synchromesh

The gears on the mainshaft that are in constant mesh are not splined to the mainshaft but are free to rotate. In fact, all the gears will be rotating whenever the engine is running and the clutch is engaged. However, only the gears that are selected will be transmitting torque.

The synchroniser has a hub, which is splined to the mainshaft, and a sleeve, which can slide on the hub. A selector fork fits into a groove in the hub, which is moved backwards or forwards to select a gear.

The sleeve has internal teeth and the constant-mesh gear has small external teeth. When the sleeve is moved to select a gear, its teeth slide over the teeth on constant-mesh gear, connecting it to the mainshaft.

The synchroniser also acts as a brake or clutch between the two moving parts to bring them to the same speed. The arrangement consists of a pair of matching cones, which are forced into contact to synchronise the speed of the teeth before they are engaged. The braking action of a synchroniser cone is shown in Figure 24.6.

24.4.2 Power flow in the transmission

The power flow through the various gears of the transmission in Figure 24.5 is as follows.

Neutral

With the engine running, the input shaft will rotate at engine speed, and its main drive gear will turn the countershaft gears at a reduced speed.

The countershaft gears are in constant mesh with the first and second gears on the mainshaft, and these will be rotated at a further reduced speed. However, the mainshaft will not turn in neutral as the constant-mesh gears are all free to rotate on the mainshaft.

First gear

To select first gear, the sleeve of the first-gear synchroniser (which is part of the reverse sliding gear) is moved forwards by a selector fork (not shown) which fits into the groove in the sleeve. This operates the synchroniser and allows the teeth on the sleeve to slide over the small teeth on the first gear. With these teeth engaged, the first gear is locked to the mainshaft.

Power flow: from the input shaft, through the main drive gear to the countershaft drive gear; then from the countershaft first gear to the constant-mesh first gear on the mainshaft; through the synchroniser to the mainshaft; along the mainshaft to the rear end of the transmission.

The speed has been reduced twice, first between the main drive gear and the countershaft drive gear, and then again at the constant-mesh gears. This gives a low speed and a high torque.

Second gear

For second gear, the sleeve of the second-and-third synchroniser is moved towards the rear by the selector fork. This synchronises the speed of the sleeve and the second gear before their small teeth engage. The sleeve locks the constant-mesh second gear to the mainshaft.

Power flow: similar to that for first gear, except that the drive is carried to the mainshaft through the constant-mesh second gears. This provides a higher speed and a lower torque than first gear.

Third gear

For third gear, the second and third synchroniser is moved forwards to operate the synchroniser and then slide the sleeve over the small teeth on the back of the main drive gear. This connects the input shaft directly to the mainshaft.

Power flow: straight through the transmission with no increase in speed or variation of torque.

Handy hint: The countershaft gears and constant-mesh gears on the mainshaft will still be rotating but they will be running free and not transmitting drive to the mainshaft.

Reverse

The first-and-reverse gear on the mainshaft is a sliding gear. For reverse, it is moved to the rear on splines, so that its teeth mesh with the teeth of the rear reverse-idler gear. The front reverse-idler gear is in constant mesh with the first gear on the countershaft and so the idler gears will be rotating at all times. (The first gear is the smallest countershaft gear and is hidden by the front reverse-idler gear.)

Power flow: from the input shaft to the countershaft gears as before; then from the countershaft first gear to the front reverse-idler gear; then through to the rear reverse-idler gear and then to the first-and-reverse sliding gear on the mainshaft with which it is meshed.

Handy hint: The direction of rotation is changed by the reverse idler , so the mainshaft will now rotate in a reverse direction.

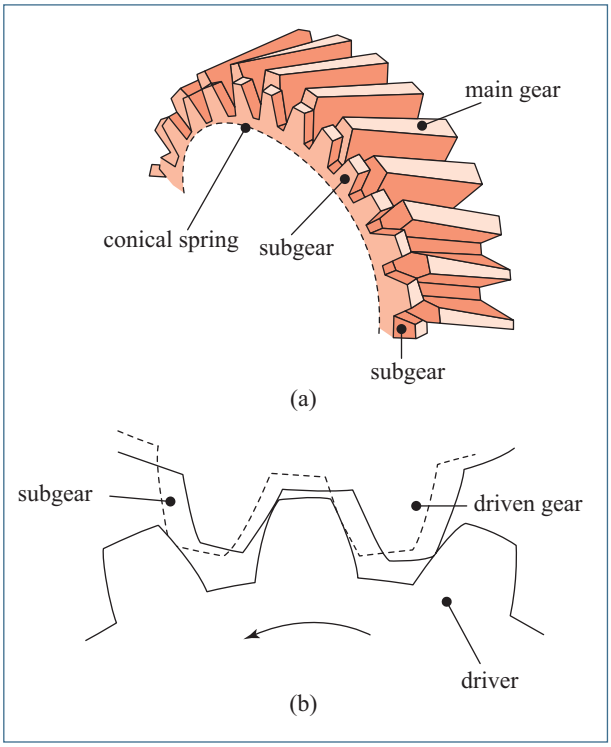


Figure 24.7 Transmission gear with a subgear (a) subgear beside the main gear (b) gear teeth in mesh

24.4.3 Subgears

Figure 24.7 shows a subgear, which is used with some transmission gears. It eliminates backlash between the teeth of the driving and driven gears, reducing gear noise.

The subgear is a thin gear beside a normal-sized gear. A conical spring between the gears creates friction between them and drives the subgear. The subgear has one more tooth than the normal gear so that it will rotate more slowly than the other gear and lag behind. The teeth of the normal gear and the teeth of the subgear will be in contact with different teeth of the driving gear with which they are meshed (Figure 24.7(b)). Any backlash between the teeth of the driver and driven gear is dampened by the subgear.

Handy hint: Backlash, or clearance , normally exists between the teeth of gears that are in mesh. Backlash noise could occur at engine idle speeds.

24.5 Five-speed synchromesh transmission

Figure 24.8 shows a five-speed transmission with synchromesh on all gears. All the gears are in constant mesh, including the reverse gear, which is in constant mesh with the reverse idler (not shown).

There are five forward speeds. Each pair of gears is identified as 1, 2, 3, 4 and 5, for first gear, second gear, etc. The synchronisers between the gears are marked S. For each of the gears, the synchroniser is moved backwards or forwards as required, to synchronise the speed of a constant-mesh gear and then connect it to the mainshaft (output shaft).

The gear ratios are related to the sizes of the mating gears as follows:

1 First gear . This has the smallest driving gear on the cluster and drives the largest constant-mesh gear on the mainshaft.
2 Second gear . This has a larger cluster gear and a smaller mainshaft gear than first gear , so there is less reduction.
3 Third gear . The cluster gear is larger and the mainshaft gear smaller than for second gear , so this has less reduction again.
4 Fourth gear . There is no gear ratio because there is a direct connection between the input shaft and the mainshaft.

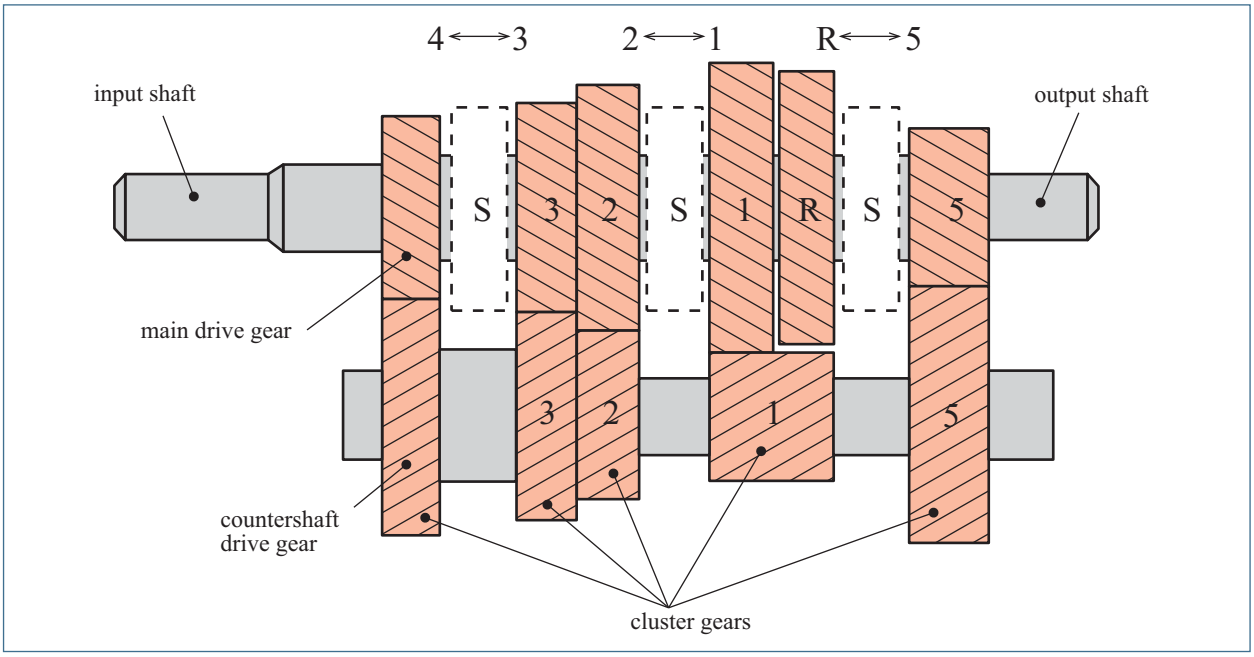


Figure 24.8 Basic arrangement of a five-speed transmission for a rear-wheel-drive vehicle—S indicates synchros, while 1 to 5 are the gears which provide the gear ratios

5 Fifth gear . This is an overdrive gear , where the cluster gear is larger than the mainshaft gear , so the speed of the mainshaft is increased.

6 Reverse gear . The reverse idler (not shown) is in constant mesh with the cluster first gear and the mainshaft first gear . This provides a low gear ratio for reverse as well as a change of direction of rotation for the mainshaft.

24.6 Power flow through a five-speed transmission

Figure 24.9 shows the gears of a five-speed transmission in more detail. The power flow for each of the gears is also shown as separate diagrams.

24.6.1 Location of gears and shafts

When working on transmissions, it is necessary to know what each part does and where each gear is located. Figure 24.10 is a sectional view of a five-speed transmission, which has a typical arrangement of the gears and shafts in the transmission case.

24.7 Six-speed transmission

The major difference between a five- and a six-speed transmission is the position of the 5–6 synchromesh unit on the countershaft extension. This is shown in Figure 24.11. Bearings are placed between first and sixth gears to support the shafts because of the extra length of the transmission. Power flows through the various gears are similar to the five-speed. Both fifth and sixth are overdrives.

Handy hint: More gear ratios in a transmission help the engine to maintain its most efficient rpm range , saving fuel and lowering emissions.

24.8 Transaxles

Figure 24.12 shows a manual transaxle and its associated components. The engine, clutch, gearing and final drive form an assembly which is mounted transversely (across) the vehicle. Engine torque is transmitted through the clutch to the transaxle input shaft, through the gears and then to the final drive. Drive shafts fitted with universal joints carry torque to the front wheels of the vehicle.

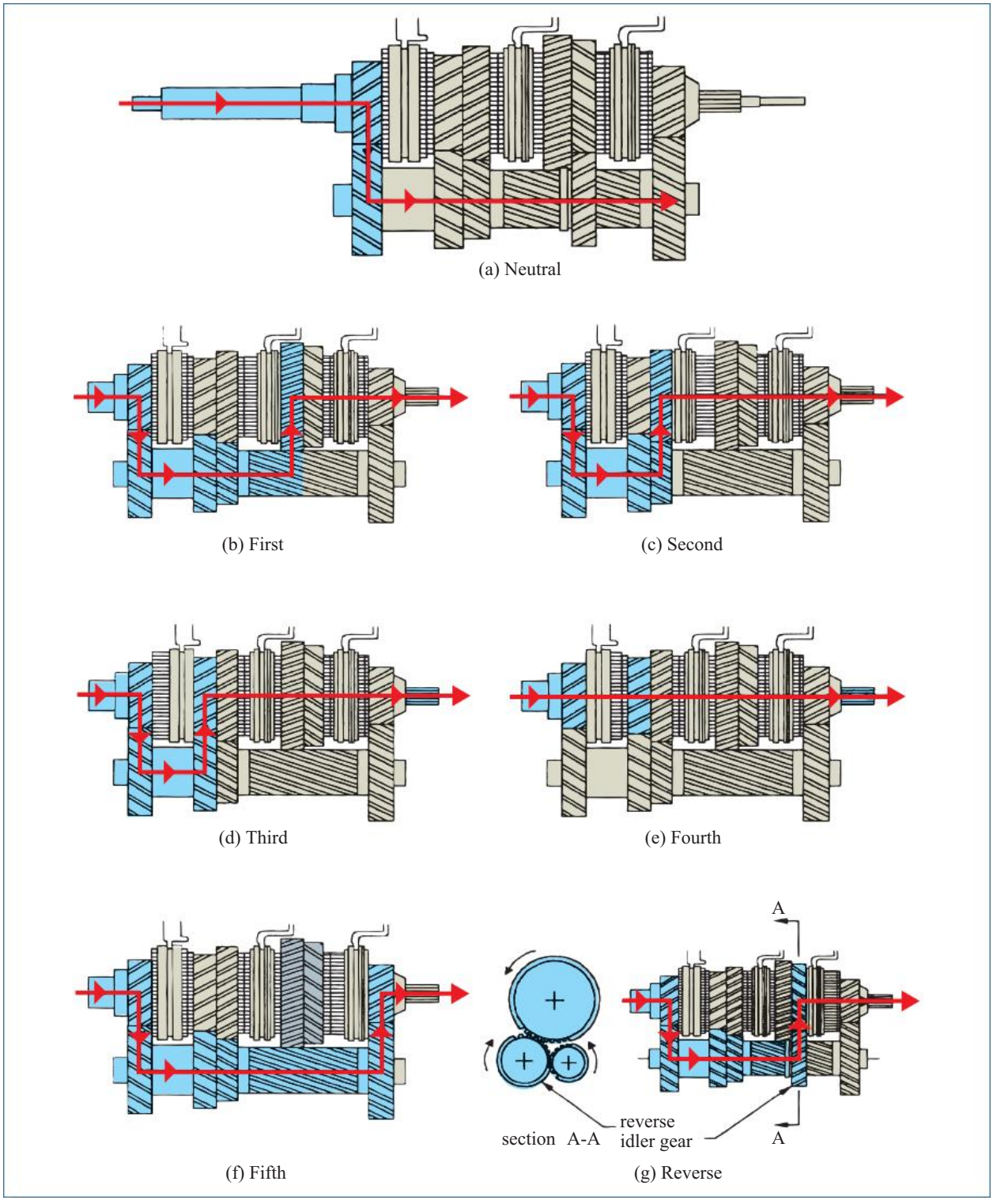


Figure 24.9 Power flow through a five-speed manual transmission GM HOLDEN LTD

Most front-wheel-drive vehicles have their engine mounted transversely because this saves space in the engine compartment. It also simplifies the final-drive gearing as the engine rotates in the same direction as the driving wheels of the vehicle.

Some vehicles with a transaxle have their engine mounted longitudinally (the same way as rear-wheel-drive vehicles). These have similar gearing to other transaxles, but use a crown wheel and pinion in their final drive. These are bevel gears, which change the drive at right angles. The arrangement is similar to the final drive of a rear axle.

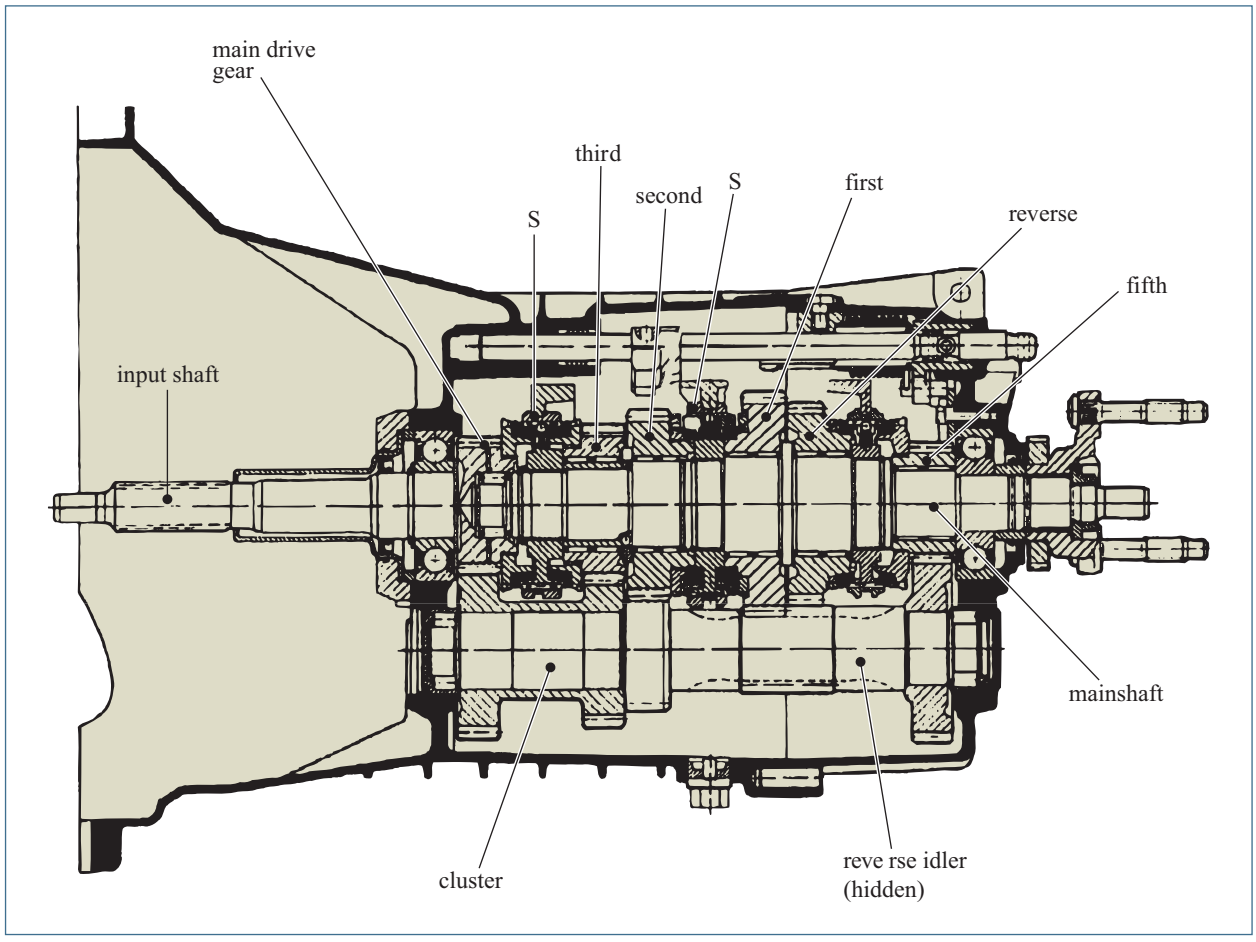


Figure 24.10 Five-speed manual transmission with the gears identified GM HOLDEN LTD

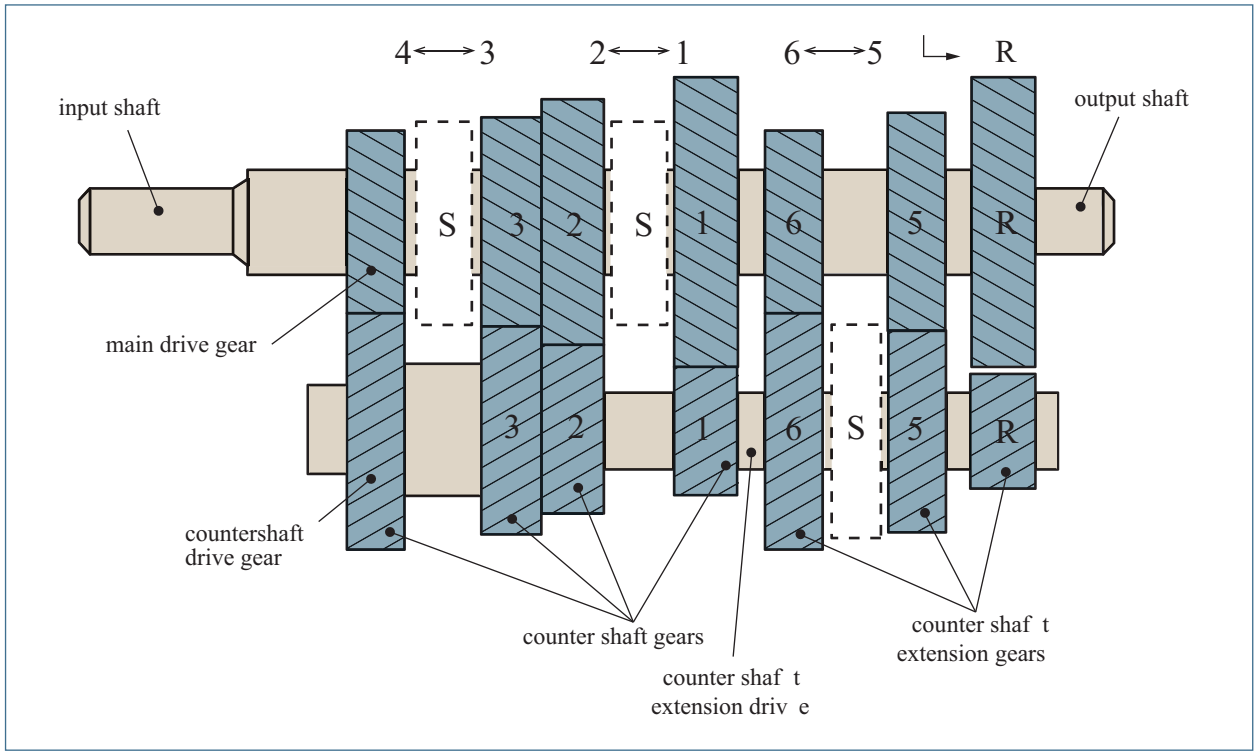


Figure 24.11 Basic arrangement for a common six-speed rear-wheel drive . Transmission with countershaft extension for gears 5 and 6 and reverse is shown

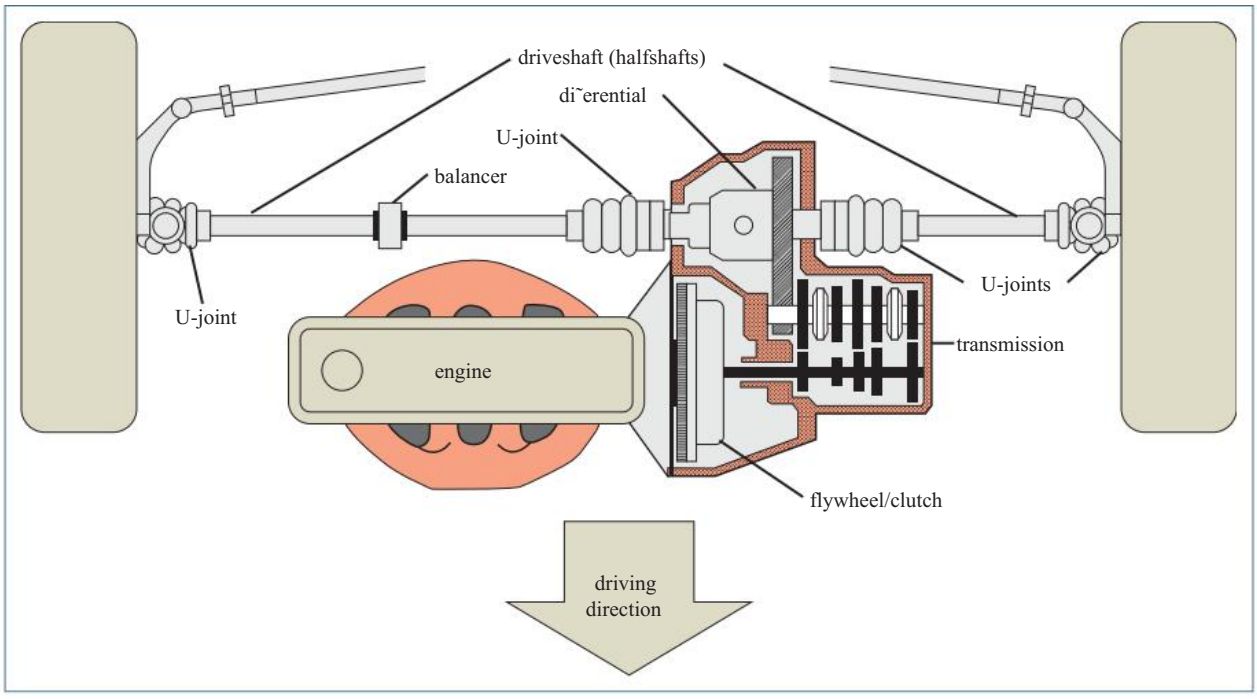


Figure 24.12 Transaxle and drive line for a front-wheel-drive vehi cle

24.9 Transaxle construction

A five-speed manual transaxle is illustrated in Figure 24.13 with its main parts identified. It has two sections:

1 the transmission or gear section
2 the final drive .

The transmission section has two shafts: a primary (or input) shaft and a secondary (or output) shaft. These carry the gears for the five forward speeds and reverse. Some of the gears are integral with their shaft, some are splined to their shaft and others are constant-mesh gears that are free to turn on their shafts.

There are three synchronisers: one on the primary shaft for third and fourth gears, and two on the secondary shaft—one for first and second gears, and one for fifth gear. Reverse is a sliding gear (idler). Most of the parts are shown in part section so that the details of the clutch, the gearing and the final drive can be seen. This is a typical arrangement, but transaxles vary in external construction and in the location of some parts. Different part names might also be used.

24.9.1 Simplified transaxle arrangement

In the simplified illustration of Figure 24.14, the parts of the transaxle are easier to identify. It also shows the difference between a four- and a five-speed transaxle. The gears and synchroniser for the fifth speed are on the left-hand side of the illustration, and the shafts which would extend to them are shown as dotted lines.

Gear section

The input (or primary shaft) and the output (or secondary shaft) both carry gears and synchromesh units. Some of the gears are fixed to the shafts and rotate with them. Other gears, which are free to rotate on their shafts, are in constant mesh with the fixed gears.

In Figure 24.14, the primary shaft has five gears of different sizes for the forward speeds. These are meshed with gears on the secondary shaft. The gears on both shafts are numbered from 1 to 5 to identify first, second, third, fourth and fifth. Each pair of gears has one fixed and one free (constant-mesh) gear. The synchronisers are labelled as A, B and C. The various parts can be located on the diagram as follows:

1 First and second gears. Gears 1 and 2 on the primary shaft are fix ed to the shaft, while gears 1 and 2 on the secondary shaft are constant-mesh gears and free to rotate on the shaft. S ynchroniser A can lock either gear to the shaft to give first gear or second gear .

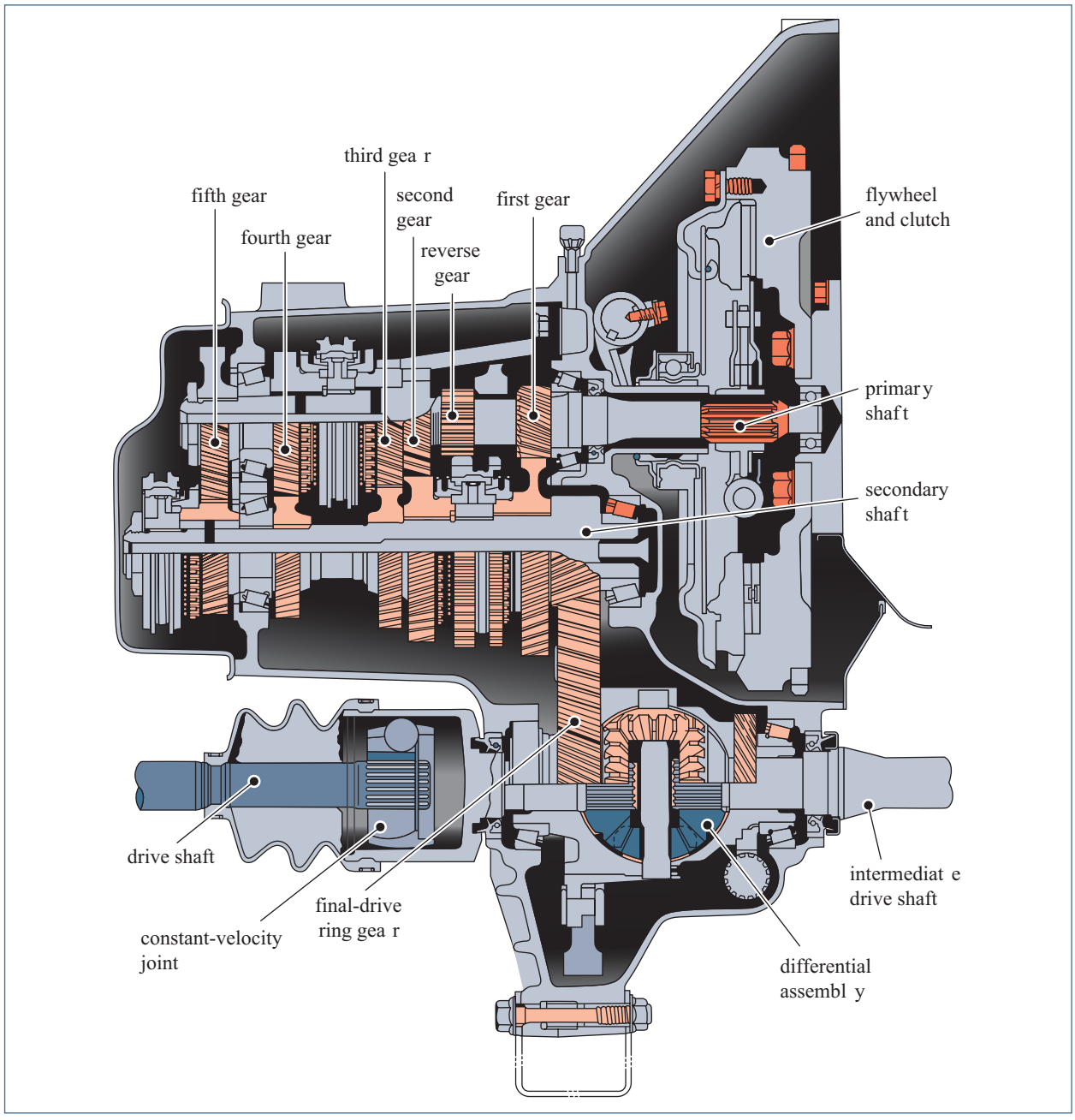


Figure 24.13 Five-speed transaxle and clutch assembly

2 Third and fourth gears. Gears 3 and 4 on the primary shaft are constant-mesh gears in mesh with the fixed gears 3 and 4 on the secondary shaft. Synchroniser B can lock either gear to the shaft to give third gear or fourth gear.

3 Fifth gear. Fixed gear 5 on the primary shaft is meshed with constant-mesh gear 5 on the secondary shaft. Synchroniser C locks gear 5 to the secondary shaft.

Handy hint: Fifth gear is an overdrive gear. The gear on the primary shaft is larger than the gear on the secondary shaft, so the secondary shaft rotates faster than the primary shaft.

Final drive

The final-drive unit consists of the drive pinion on the end of the secondary shaft, the ring gear and the differential assembly. The ring gear is a large helical gear bolted to the differential carrier. This contains the differential pinions and the side gears, which are splined to take the ends of the drive shafts.

The drive shafts, which connect the final drive to the front wheels, are fitted with constant-velocity universal joints. These provide for steering and also for front suspension and body movement. Drive shafts and universal joints are covered in Chapter 25 and differentials are covered in Chapter 26.

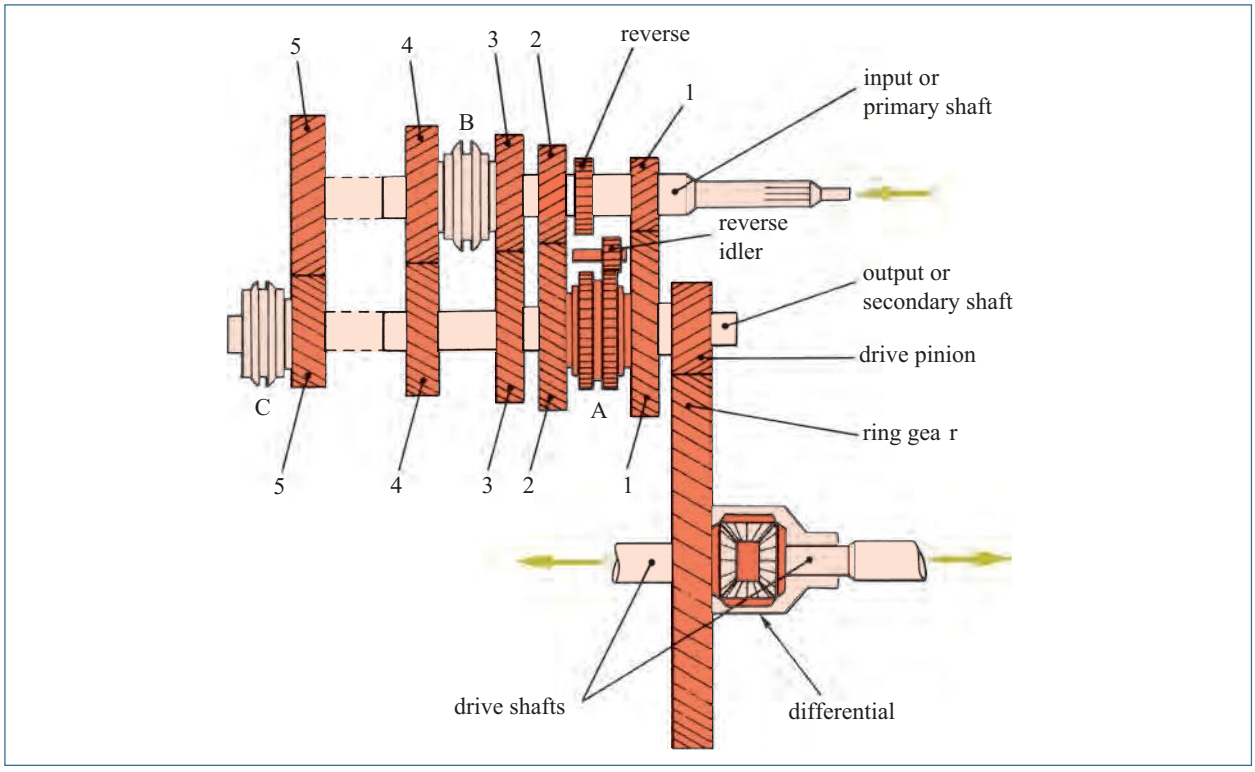


Figure 24.14 Basic four-speed and five-speed manual transaxle arrangements. The gears which provide the gear ratios are labelled 1 for first, 2 for second etc on both the input an d output shafts. The synchronisers are labelled A, B and C, and the extra gears for a five-speed transaxle are shown o n the left-hand side

24.10 Transaxle operation

Figure 24.15 has six diagrams showing the gears that are in operation and the power flow for each of the five forward speeds and reverse. When following the power flow through the gears, keep in mind that the lowest gear ratio (first gear) is obtained when the smallest gear on the primary (input) shaft drives the largest gear on the secondary (output) shaft. Also, remember that the highest gear ratio (fifth gear) is obtained when the largest gear on the primary shaft drives the smallest gear on the secondary shaft.

24.10.1 Neutral

In neutral, the primary shaft will be rotated by the clutch. The fixed gears on the primary shaft will also be rotating and will rotate their constant-mesh gears on the stationary secondary shaft. There are constant-mesh gears on the primary shaft, but they will not rotate with the primary shaft as they are meshed with fixed gears on the stationary secondary shaft. The secondary shaft will remain stationary in neutral, so there will be no power flow through the transaxle.

24.10.2 First gear

First gear (Figure 24.15(a)) is obtained when the synchroniser sleeve A is moved to the right to engage with the small teeth on the first constant-mesh gear. This causes the sleeve and the secondary shaft to rotate with the constant-mesh gear.

Power flow: from the clutch, through the primary shaft to the first gear; then to the first constant-mesh gear, to the secondary shaft, and to the pinion on the output end of the secondary shaft.

The output pinion drives the ring gear of the final drive. This is attached to the differential which rotates the drive shafts to carry the drive to the front wheels of the vehicle.

Handy hint: First gear is obtained because the smallest gear on the primary shaft is driving the largest gear on the secondary shaft.

24.10.3 Second gear

Second gear (Figure 24.15(b)) is obtained by sliding the synchroniser sleeve A to the left so that it engages with the small teeth of the second constant-mesh gear.

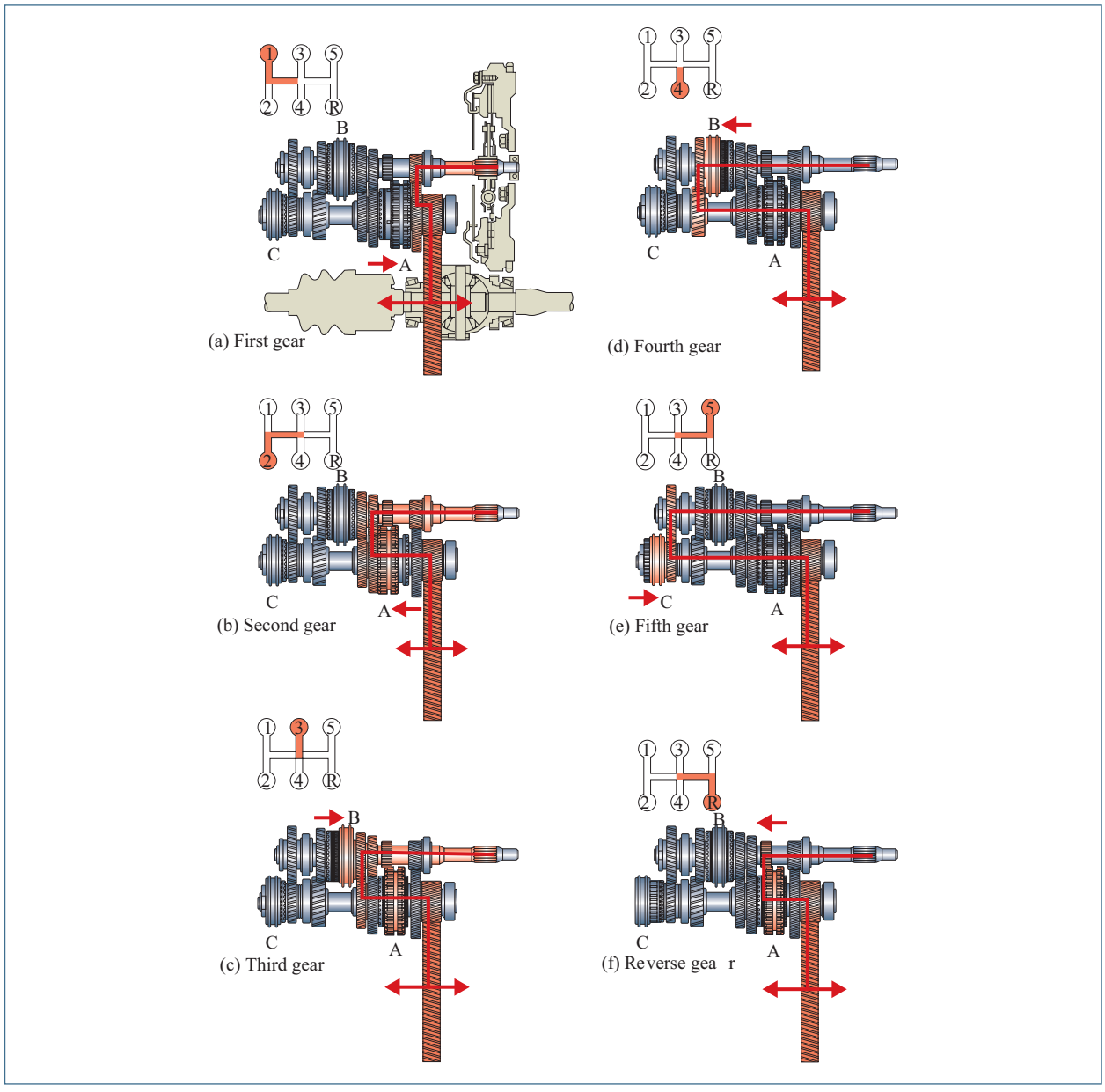


Figure 24.15 Power flow through the gears of a five-speed transaxle

Power flow: similar to first gear, except that a pair of different gears are used. These give a higher ratio than first gear.

Handy hint: On the primary shaft, second gear is larger than first gear and on the secondary shaft, second gear is smaller than first gear.

24.10.4 Third gear

For third gear (Figure 24.15(c)), the synchroniser sleeve B on the primary shaft is moved to the right to engage the small teeth of the third constant-mesh gear. This gear was free on the primary shaft, but it will now rotate with the primary shaft.

Power flow: the third constant-mesh gear on the primary shaft drives the third (fixed) gear on the secondary shaft; this rotates the secondary shaft and its pinion, which drives the ring gear of the final drive.

Handy hint: Third gear is a higher ratio than second because its gears are different in size.

24.10.5 Fourth gear

For fourth gear (Figure 24.15(d)), the synchroniser sleeve B is moved to the left to engage the small teeth of the fourth constant-mesh gear. This connects the constant-mesh gear to the primary shaft.

Power flow: drive from the primary shaft is transferred through the constant mesh gear to the fourth gear on the secondary shaft; the pinion on the secondary shaft then drives the ring gear of the final drive, and so on to the wheels.

The fourth gears are almost the same size, providing a gear ratio of approximately 1:1 (for example 0.970:1).

Handy hint: One of the gears has an extra tooth so that the ratio will not be exactly 1:1; otherwise , the same teeth would always mesh.

24.10.6 Fifth gear

For fifth gear (Figure 24.15(e)) the synchroniser sleeve C is moved to the right to engage the small teeth on the fifth constant-mesh gear. This causes the secondary shaft to rotate.

Power flow: the fifth gear on the end of the primary shaft drives the fifth constant-mesh gear on the secondary shaft and power flows through the secondary shaft to the final drive as before. Fifth gear is an overdrive gear, not a reduction gear.

Handy hint: The gear on the primary shaft is larger than the gear on the secondary shaft so an increase in speed occurs.

24.10.7 Reverse

For reverse (Figure 24.15(f)), the reverse idler slides into mesh with both the reverse gear on the primary shaft and the gear teeth on the outside of the sleeve A on the secondary shaft. (The reverse idler is not easy to distinguish on the diagram.)

Power flow: the reverse gear on the primary shaft drives the reverse idler, which drives the reverse gear on the sleeve on the secondary shaft, but in a reverse direction. The sleeve is indirectly attached to the secondary shaft, so the drive is carried by the secondary shaft to the pinion and on to the final drive as for the other gears.

Handy hint: The secondary shaft and all parts following it will be rotating in a reverse direction.

24.10.8 Final drive

The final drive provides a gear reduction of around 4:1 and a change in the direction of rotation, so the front wheels will rotate in the correct direction. The differential, which forms part of the final drive unit, allows both wheels to be driven and enables one wheel to rotate faster than the other when the vehicle is being steered around corners or curves.

24.11 Dual-clutch six-speed transmission

A dual-clutch transmission is an electronically controlled manual transmission. It can operate in semi-automatic mode where the driver selects each gear using buttons or paddles on the steering wheel or a floor shift lever. A fully automatic mode can also be selected.

The transmission has more in common with a manual transmission than an automatic. The main advantage over conventional manual transmissions is that gear changes are smooth and fast. There is also no torque converter ‘slip’, so efficiency is improved.

Handy hint: A dual-clutch transmission is also known as a direct-shift gearbo x.

24.11.1 Construction

The transmission shown in Figure 24.16 has two multiple-plate wet clutches, two input shafts and two output shafts. There is no clutch pedal because the gear shifts are controlled electronically. Clutch 1 is connected to a solid input shaft, and clutch 2 is connected to a hollow input shaft that fits over the solid shaft. This is a six-speed transmission. Clutch 1 is used for the odd-numbered gears—1st, 3rd and 5th—and clutch 2 is used for the even-numbered gears—2nd, 4th and 6th.

The two output shafts carry most of the gears. There are synchromesh units on the output shafts, which operate in the usual way. Each output shaft has an output gear (at the front of the shaft) that connects to the vehicle’s differential and final drive.

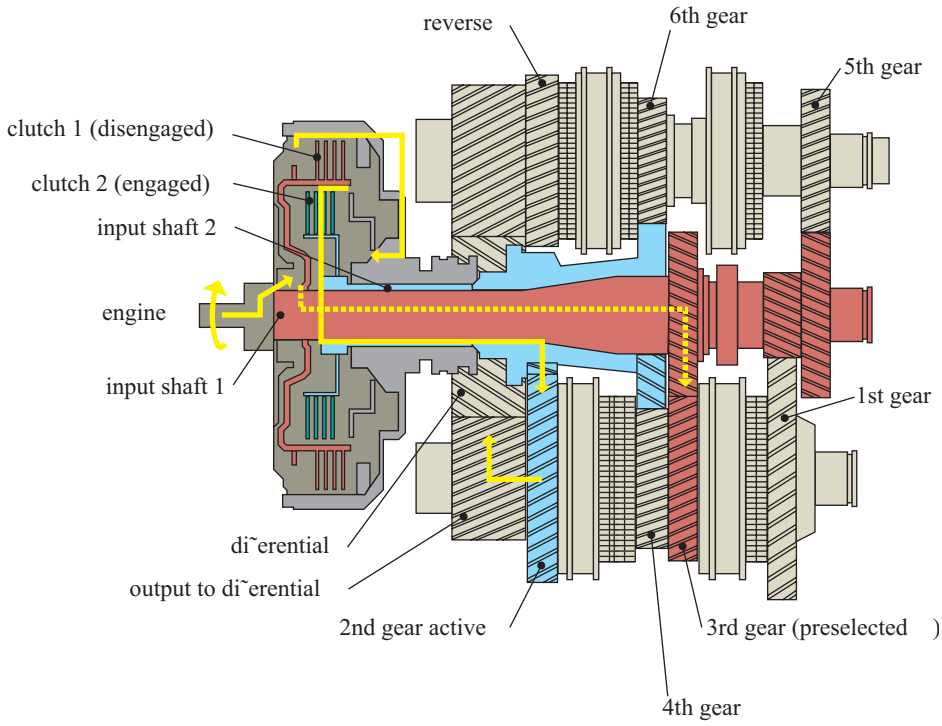


Figure 24.16 Dual-clutch transmission in second gear . The reverse shaft and controls are not shown

24.11.2 Operation

Figure 24.16 shows the transmission in second gear. Clutch 2 is engaged and driving the outer input shaft. The second synchro sleeve is engaged with second gear on the output shaft to activate the drive in second gear. The ECU has sensed an increase in rpm and throttle opening and preselected third gear by engaging the third-gear synchro sleeve. Third gear will only be activated when the driver signals the ECU. Clutch 2 is then disengaged and clutch 1 engaged, giving a fast and smooth change between gears. More information on the operation of multiplate wet clutches can be found in Chapter 29.

24.12 Synchromesh operation

Figure 24.17 shows the dismantled parts of a synchroniser. These are:

- hub
- sleeve
- baulk rings
- inserts
- springs .

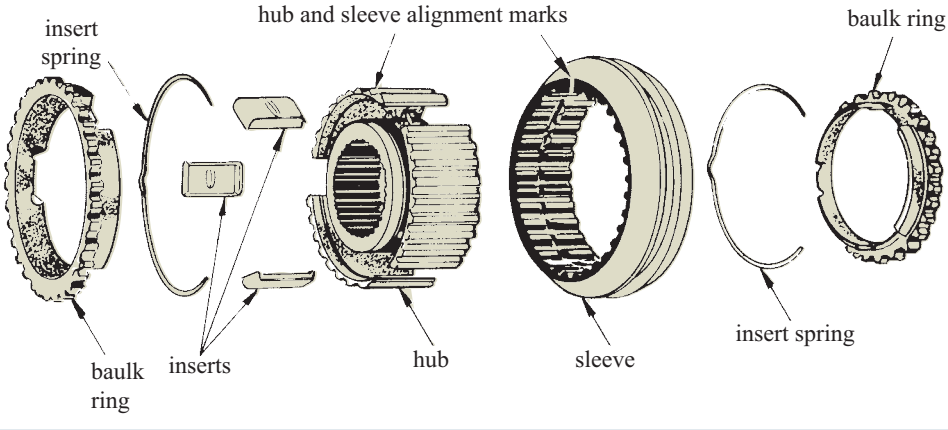


Figure 24.17 Parts of a synchroniser assembly

When the synchroniser is assembled in the transmission, the hub is splined to the mainshaft and the sleeve is splined to the hub. The inserts fit between the hub and the sleeve. They lie in slots in the hub and are held outward by a spring at each end. They have a small bead which locates them in a groove in the sleeve.

The baulk rings at each end of the hub have slots for the inserts. The baulk rings are made of bronze or aluminium and have a coned inner surface to match the steel cones on the gears. The teeth on the outer edge of the baulk rings, the small teeth on the gears and the splines inside the sleeve are all the same size. This enables the sleeve to slide over the other teeth when the gear is engaged.

The synchroniser performs two different actions during a gearshift. These are:

1 Synchronising action —brings the parts to the same speed.
2 Blocking action —prevents the parts from engaging until they are at the same speed.

24.12.1 Synchronising action

A simplified synchroniser with associated gears is shown in Figure 24.18. For simplicity, the synchroniser hub, which fits between the sleeve and the shaft, is not shown. The synchroniser operates as follows:

1 When the sleeve is moved to select a gear , the inserts also move because they are spring-loaded to hold the bead of the insert into the groove in the sleeve .
2 The ends of the inserts push the cone of the baulk ring against the cone of the gear . The friction between the two cones increases or decreases the speed of the gear so that the parts rotate at the same speed (synchronous speed).
3 Once the speed is synchronised, the sleeve can move further and slide over the small teeth of the baulk ring and the gear .
4 When the sleeve is engaged with the gear teeth, the gear will be connected to the mainshaft and the gearshift completed.

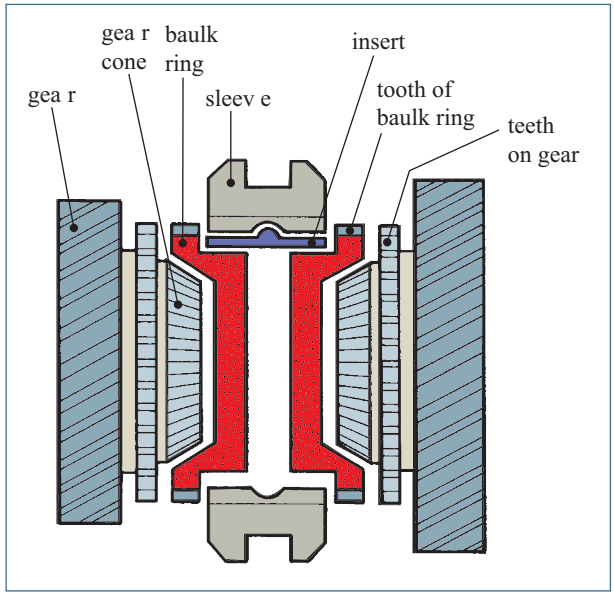


Figure 24.18 Simplified synchroniser in section view

24.12.2 Blocking action

Figure 24.19 shows the parts that provide the blocking action. For the sleeve to be able to slide over the teeth on the baulk ring as well as over the teeth of the gear, all three parts must be aligned (or in register). This is arranged so that it will only occur at synchronous speed. Unless the parts are synchronised, gearshifting will be *blocked* and the selected gear will not be engaged.

Blocking action is as follows:

1 When the baulk ring comes against the cone of the gear during a gearshift, the difference in their speeds will cause the baulk ring to be dragged around until it is stopped by the inserts.
2 The width of the insert recess in the baulk ring allows it to be turned so that its teeth are out of register with the splines of the sleeve by half a tooth.
3 Being out of register , the sleeve cannot slide over the baulk ring teeth—its movement is block ed by the teeth of the baulk ring.
4 There is drag between the baulk ring and the gear cone when a gearshift is started, but it decreases as the parts become synchronised.

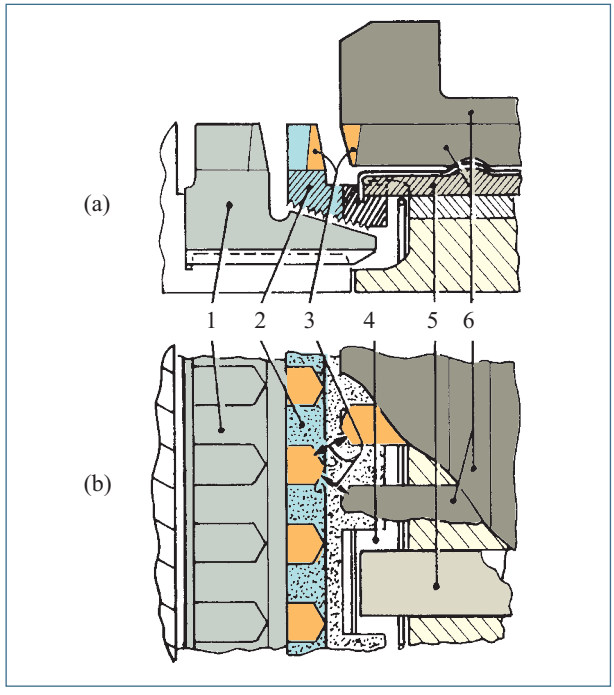


Figure 24.19 Parts of a synchroniser that produce the synchromesh action (a) section through synchroniser (b) part section—1 part of main drive gear with small teeth 2 baulk ring 3 chamfered ends of teeth 4 slot in the baulk ring for the insert 5 insert 6 sleeve

5 When synchronous speed is reached, there will be no drag. The edge of the sleeve splines forcing against the baulk ring teeth will now turn the baulk ring so that the teeth are in register . (This is helped by the chamfered edges of the teeth and the splines.)
6 With the teeth in register , the sleeve can slide over the teeth of the baulk ring and the gear to complete the gearshift.
7 Blocking action will occur whether the gear being selected is turning faster or slower than the sleeve . Engagement will be prevented until the parts are turning at the same speed and the sleeve is able to complete its movement.

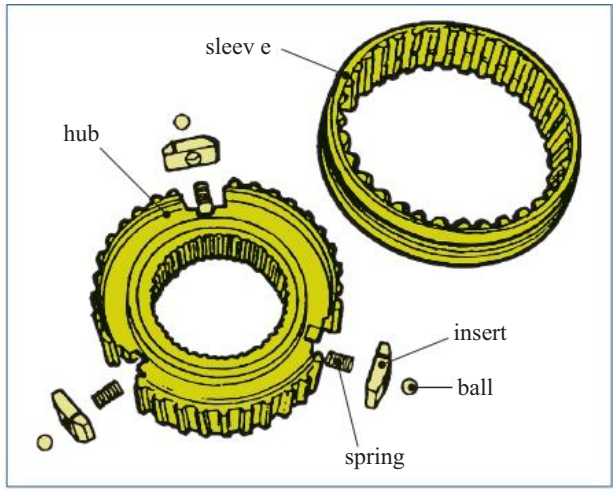


Figure 24.20 Synchroniser with inserts and spring-loaded balls GM HOLDEN ITD

24.13 Types of synchromesh

There are a number of variations in synchromesh design. Some have much shorter inserts and others have different types of springs. Baulk rings are usually made of bronze, with a coating of molybdenum or of aluminium alloy. A facing of composition material is used on the tapered surface of some baulk rings. Whatever the design, the synchromesh unit synchronises the speed of the parts by applying friction between them so that the gear teeth can be easily engaged.

24.13.1 Spring-loaded ball type

Figure 24.20 shows a type of synchromesh that uses coil springs and balls between the hub and sleeve. The balls, which fit into holes in the inserts, are held into a groove in the sleeve by the springs. Short inserts are used and so the baulk ring is designed with lugs for the inserts to push against when synchronising.

24.13.2 Double synchroniser

Figure 24.21 shows a synchroniser with double baulk rings. There are three parts, as shown in Figure 24.21(b): inner synchroniser ring, outer tapered ring and outer synchroniser ring. The outer synchroniser ring fits into the constant-mesh gear, the inner synchroniser ring fits into the end of the hub and the outer tapered ring fits in the middle. The synchroniser acts in the usual way.

Handy hint: The increase in friction area of a double baulk ring reduces shifting effort by about 50%.

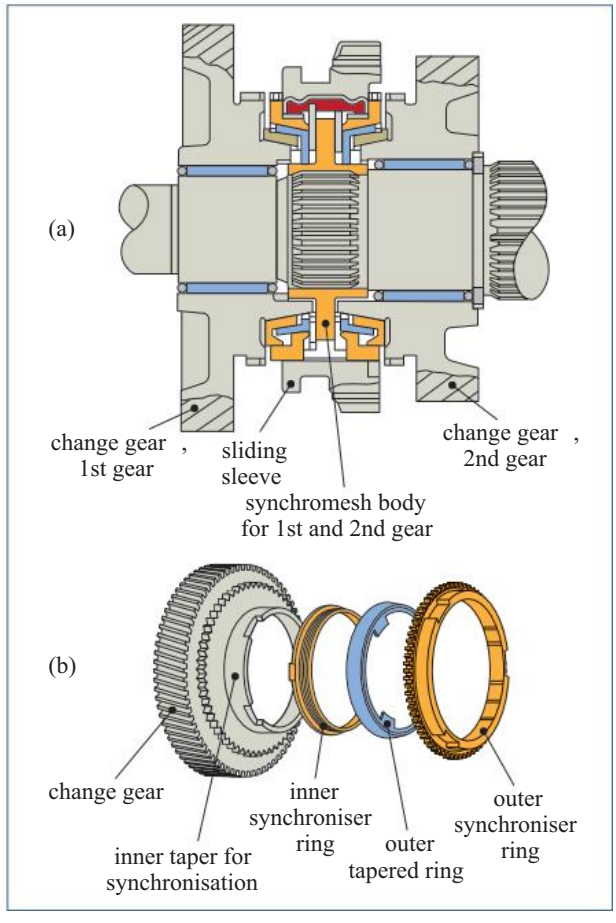


Figure 24.21 Double synchromesh unit (a) the unit assembled (b) exploded view of the friction rings

24.14 Gearshift mechanisms

The gearshift mechanism consists of a number of parts, some of which are external to the transmission and others internal. The external parts (or gearshift controls) consist of the gear lever and the linkage or cables that connect it to the actual transmission. The internal parts include the shift rails, shift forks, interlock devices and, in some cases, levers. These are operated by the gearshift controls to select and change gears.

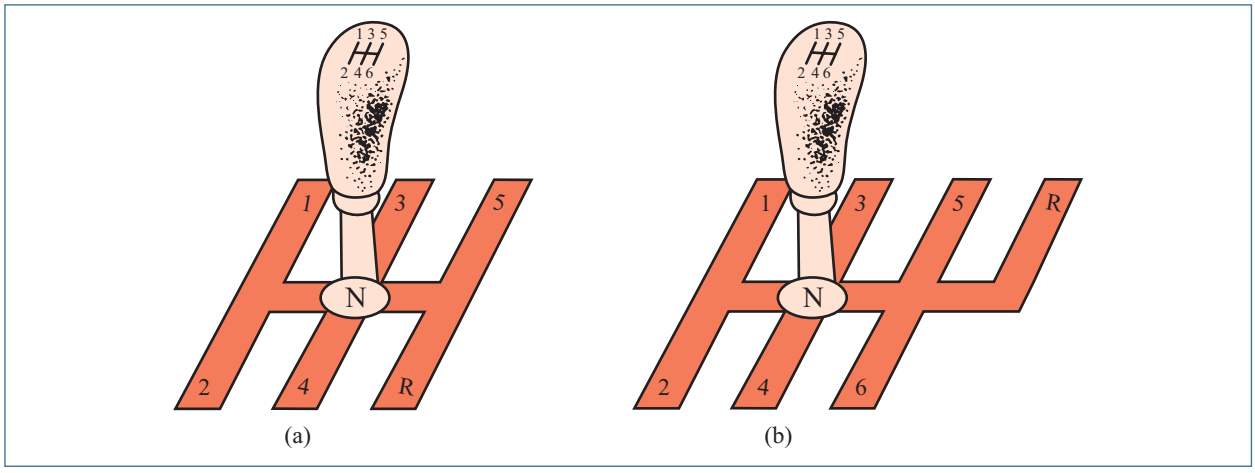


Figure 24.22 Gearshift selector positions for (a) five-speed (b) six-speed manual transmission

Figure 24.22 shows a gear lever with the standard shift positions for a five- and a six-speed transmission. Gear levers are usually located on the floor of the vehicle, but for vans and vehicles with under-the-floor engines, they can be mounted on the steering column.

There are many different designs of gearshift mechanisms, some of which are described in the following sections. Whatever its design, the gearshift mechanism performs two different functions: *selecting* and *shifting*. When the gear lever is moved to select a gear, it first *selects* the shift rail and fork for that gear and then *shifts* the fork to move the synchroniser sleeve to engage the gear.

24.14.1 Gearshift with control shaft

Figure 24.23 shows a gearshift lever mounted on the transmission extension housing. A single control rod inside the housing transfers movement from the gear lever to the shift rails inside the transmission. The control rod has a yoke on one end which accommodates the end of the gear lever. There is a short lever on the other which fits into the yokes on the end of the shift rails.

The gear lever is mounted in its housing on a ball joint. This allows it to move backwards and forwards and from side to side. Moving the gear lever sideways turns the control rod to *select* gears and moving it backwards and forwards moves the control rod to *shift* gears.

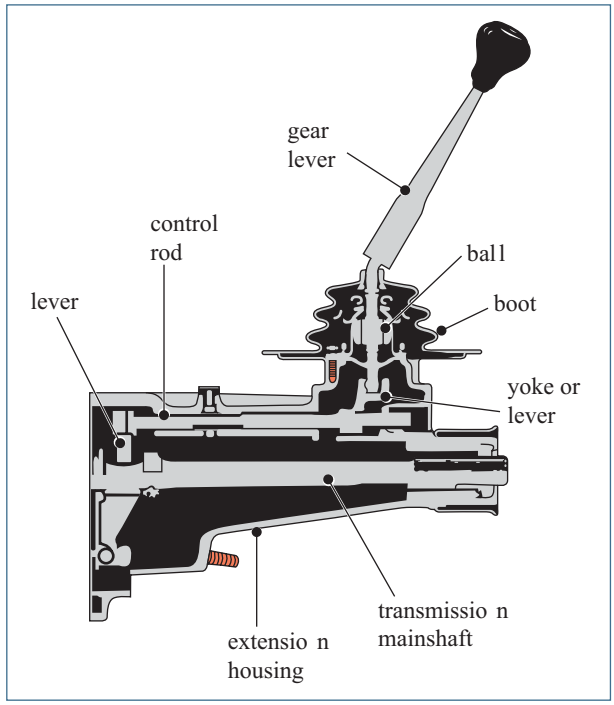


Figure 24.23 A gearshift lever and control rod as part of the transmission extension housing

Shift rails and forks

The shift rails and forks, which are inside the transmission housing, are shown in Figure 24.24. When a gear is selected, the control rod is turned to move its lever into a slot in the shift lever on the end of the shift rail. This selects the gear and then backward or forward movement of the shift rail makes the actual gearshift.

24.14.2 Detents and interlocks

Detents locate the shift rails in the transmission and interlocks prevent two gears from being selected at the same time. Figure 24.25 shows one arrangement which is used with the shift rails like those in Figure 24.24.

The detent consists of shallow grooves, or detents, in the shift rails. Spring-loaded balls in the transmission housing are held into the grooves, which correspond to the neutral positions and the engaged positions of

the shift rails. The spring-loaded balls hold the shift rails in the correct position for neutral or, when a gear is engaged, in the selected position.

The interlock has two plungers in holes in the housing between the shafts. The plungers have ball ends which fit into grooves in the shafts. These are different grooves to those for the detents.

The plungers are arranged so that, whenever a shift rail is moved, they also move to lock into grooves in the other shift rails. This holds the shift rails that are not needed and so prevents the engagement of two gears at once.

In Figure 24.25 the centre shift rail is free to move, but the upper and lower shift rails are prevented from moving by the interlock plungers in the detent grooves.

24.14.3 Gearshift with cable control

Figure 24.26 shows a transaxle gearshift control with cables. Two cables are connected between the gear lever and the selector housing on the transmission. One is a selector cable and the other is a shift cable.

Gearshift selector mechanism

The gearshift selector mechanism is shown in more detail in Figure 24.27. Its description follows:

1 There are two levers on the transmission case—a shift lever attached to the control shaft and a selector lever which operates in a groove in the control shaft.
2 The control shaft has a finger (small lever) on the inner end which operates the shift yok es on the shift rails.
3 There are three selector-lever positions and three shift-lever positions.

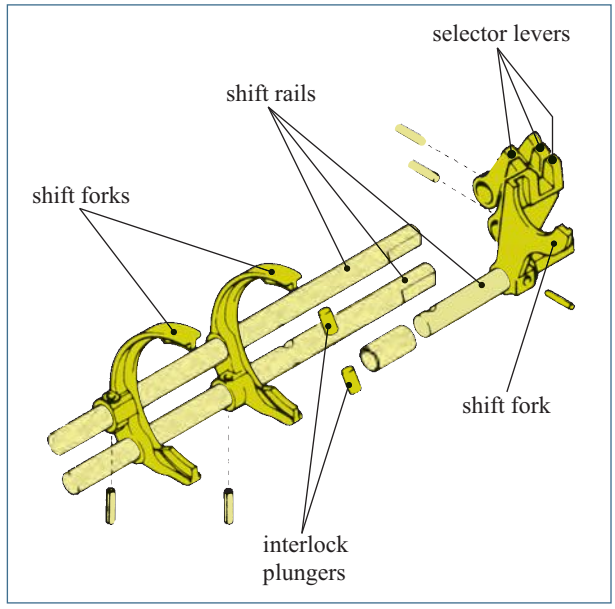


Figure 24.24 Gearshift components located inside the transmission case MITSUBISHI

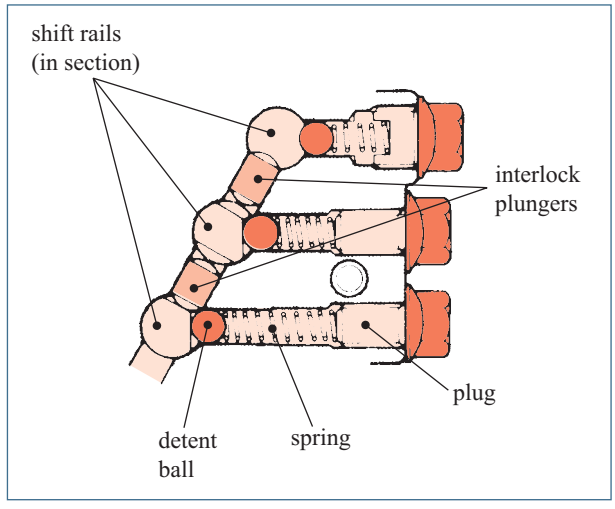


Figure 24.25 One arrangement of shift rails with interlocks and detents MITSUBISHI

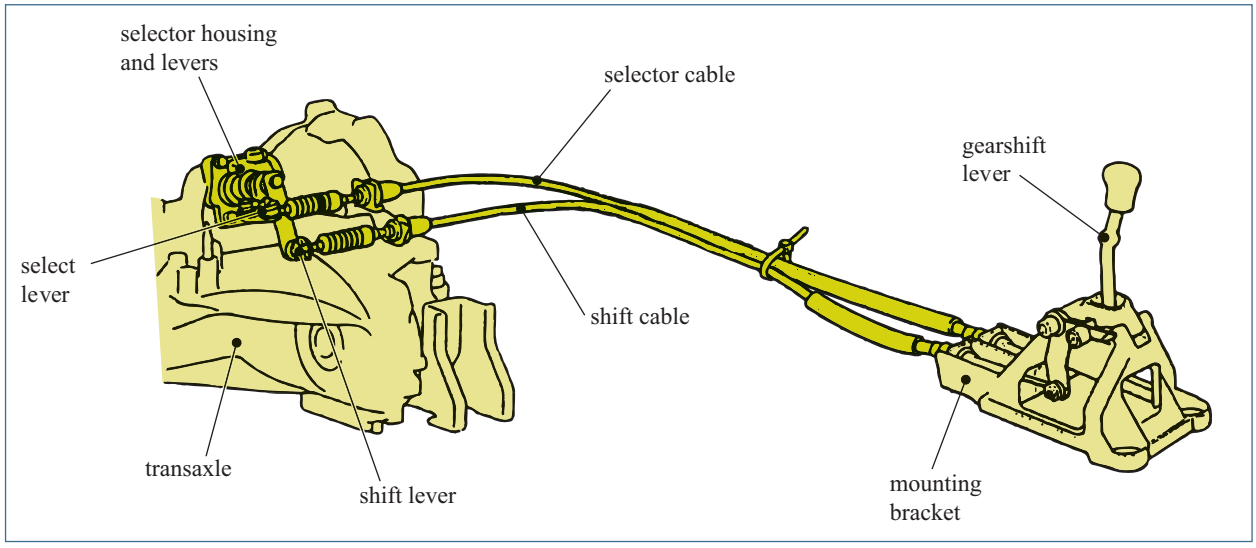


Figure 24.26 Arrangement of a cable-operated gearshift MITSUBISHI

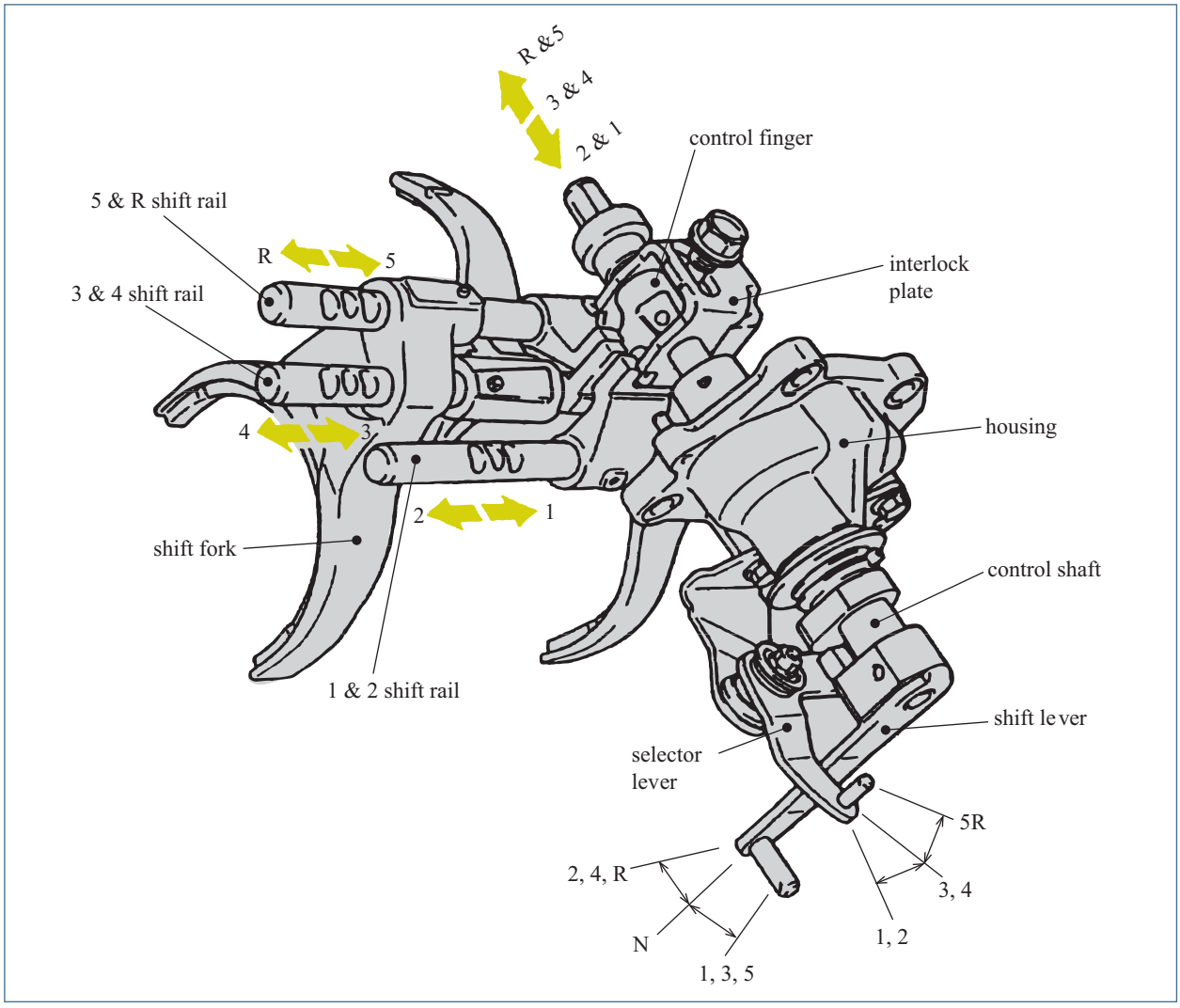


Figure 24.27 Gearshift selector mechanism for a five-speed transaxle MITSUBISHI

4 The selector lever moves the control shaft in and out, moving the control finger across the shift yok es. This enables the desired gear to be selected.
5 The shift lever turns the control shaft, and the control finger moves the shift rails and shift forks to effect a gearshift.

Interlock device

A rectangular-shaped interlock 'plate' fits around the control finger as shown in Figure 24.28, so that only one shift yoke at a time can be moved.

In Figure 24.28(a), the interlock plate shields the upper and lower shift yokes, but the centre shift yoke can be moved by the control finger, which acts as a selector lever.

In Figure 24.28(b), the control shaft has been moved inwards and the control finger has been moved to the top shift yoke. The centre and bottom shift yokes are now shielded, but the top shift yoke can be moved.

24.14.4 Gear lever assembly

There are various arrangements for the gear lever assembly. Figure 24.29 shows the gear lever and associated parts for a transaxle with two control cables. As well as the gear lever, there is a bellcrank lever which is attached to an extended pin on the side of the gear lever.

The shift cable is attached to the lower end of the gear lever, and the selector cable is attached to a pin on the end of the bellcrank lever. When the gear lever is moved from side to side, it raises and lowers the end of the bellcrank that is attached to it. The bellcrank changes this movement 90° to pull or push the selector

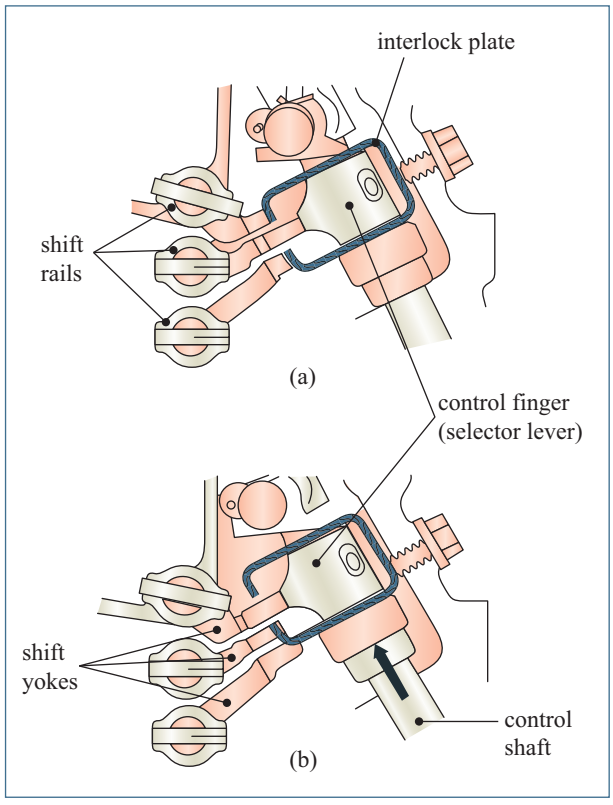


Figure 24.28 Section through an interlock mechanism with an interlock plate (a) interlock allows the centre rail to be moved (b) interlock allows top rail to be moved

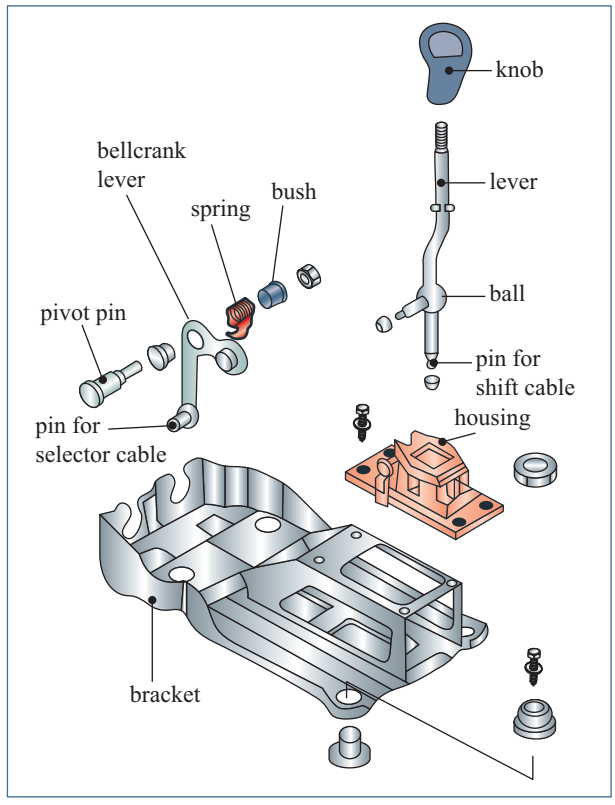


Figure 24.29 Gear lever assembly for a cable gearshift control

cable to select the gears. When the gear lever is moved backwards or forwards, it pulls or pushes the shift cable to shift the gears.

24.14.5 Steering-column gearshift

The gearshift lever of a steering-column gearshift is connected by concentric shafts to levers at the base of the steering column. Linkage or cables connect these to the transmission.

The gear lever performs the normal functions of selecting and shifting gears. Vertical movement of the gear lever selects the gear required, while horizontal movement shifts the gears (Figure 24.30).

24.14.6 Transaxle gearshift with a control rod

Figure 24.31 shows a transaxle with a control rod. It also has a stabiliser rod, which is a fixed-length rod between the gear lever mounting and the transmission case. It preserves the relationship between the two parts, playing no part in the actual gearshifting.

The external control rod is responsible for selecting and shifting the gears. It can be turned by the gearshift to select and moved backwards and forwards to shift.

The mechanism inside the transaxle housing includes a gate which controls the movement of the

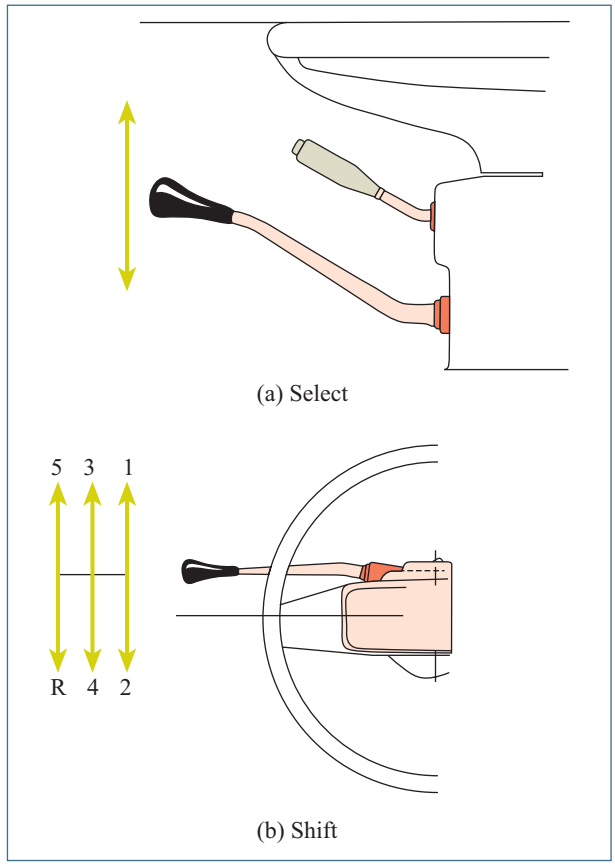


Figure 24.30 Steering-column gearshift

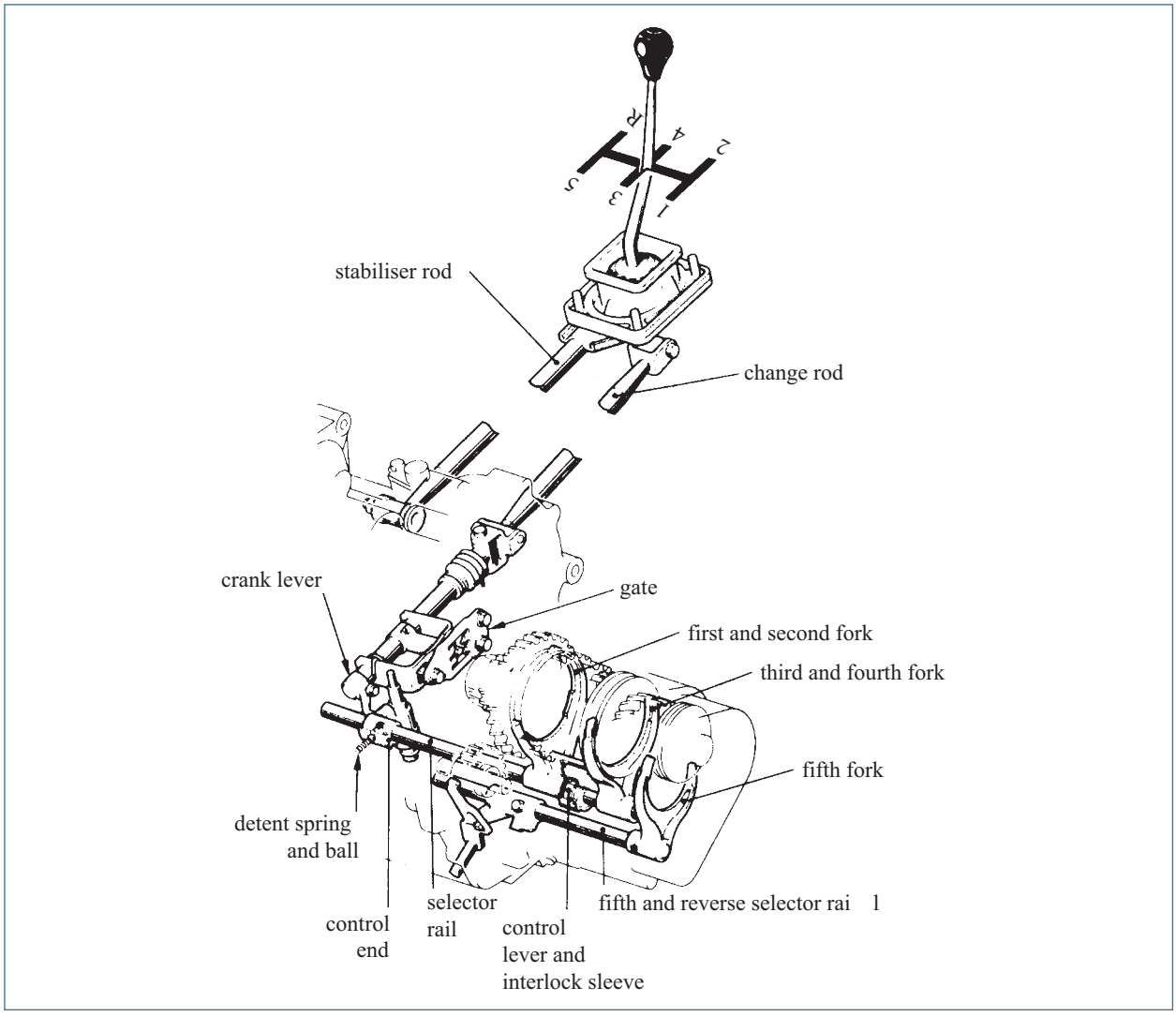


Figure 24.31 Gearshift mechanism for a transaxle FORD

internal change rod. The end of this rod is fitted with an arm which transmits change-rod movement to the selector rail through a ball-and-socket and crank lever arrangement.

The selector forks are not fixed to the rails, but are moved by them when the gears are being shifted. The control lever, which is fixed to the selector rail between the forks, is designed to move the selector forks. When the selector rail is turned to select a gear, the control lever attaches to the fork to be moved and the rail and the fork are then moved backwards or forwards as required to complete the shift. An interlock sleeve associated with the control lever prevents engagement of two gears at the one time.

24.15 Service operations

24.15.1 Lubrication

Checking the oil in the transmission (or transaxle) is part of normal maintenance. Rear-wheel-drive transmissions have a plug in the side of the transmission case. This is removed so that a finger can be inserted in the plug hole to check the oil level. The oil should be at the bottom of the plug hole, or just slightly below (Figures 24.32 and 24.33). The oil can be drained by removing the drain plug from the bottom of the transmission case. Periodic oil changes are specified for some transmissions.

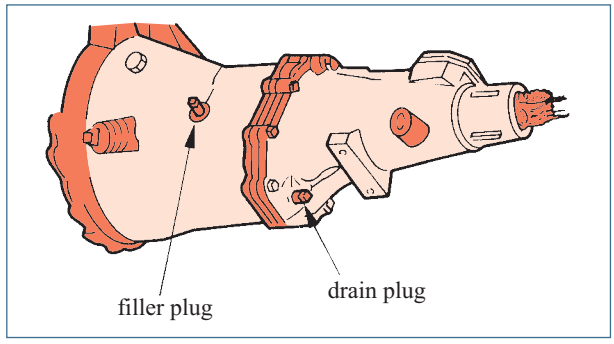


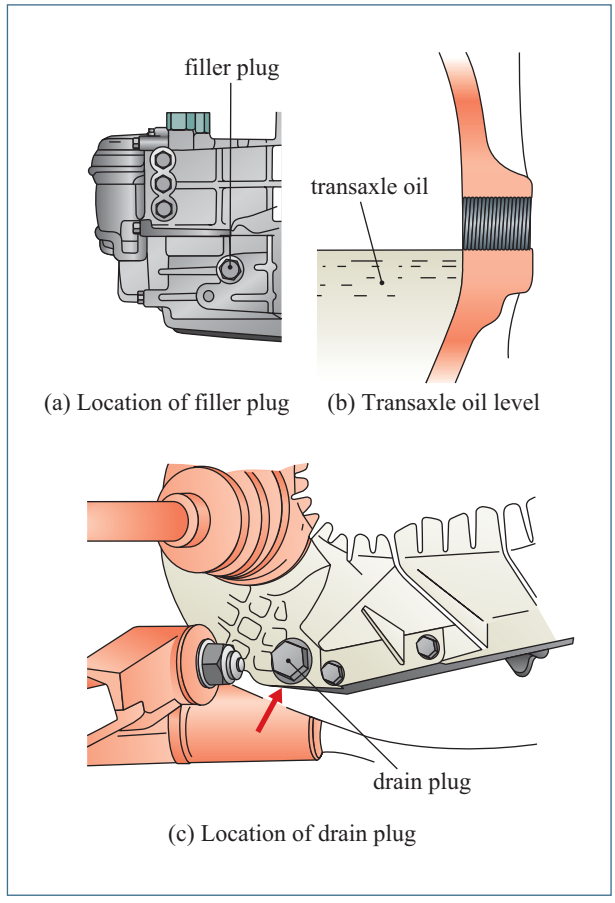
Figure 24.32 Transmission filler plug and drain plug

Transmissions use special gear oils which are formulated to provide lubrication. They also have extreme-pressure properties that resist being squeezed from between the gear teeth. A variety of transmission lubricants are used to suit the different friction materials used for synchromesh rings (see Chapter 30). Always refer to manufacturers' specifications before servicing.

Sustainability: When working on an automotive manual transmission, drain and dispose of waste gear box oil according to the requirements of your state or territory government or environmental protection authority.

Servicing a transmission requires:

1. A sound knowledge of the operating principles of transmissions
2. Familiarity with the construction of the particular transmission (consult the maker's manual)
3. Careful dismantling and reassembly
4. The careful use of soft drifts to remove shafts, with minimum force from the hammer
5. Never using pressing tools or pullers on bearings; mild-steel drifts can be used if special tools are not available, or where bearings are not otherwise accessible
6. The use of dummy shafts when removing or replacing the cluster gear and shaft
7. The careful fitting of oil seals
8. A thorough inspection of parts
9. A check of the shift mechanism for correct operation in all gears after reassembly
10. Correct road testing: know the faults that can occur in transmissions and check for them.



(a) Location of filler plug (b) Transaxle oil level

(c) Location of drain plug

Figure 24.33 Transaxle filler plug, oil level and drain plug

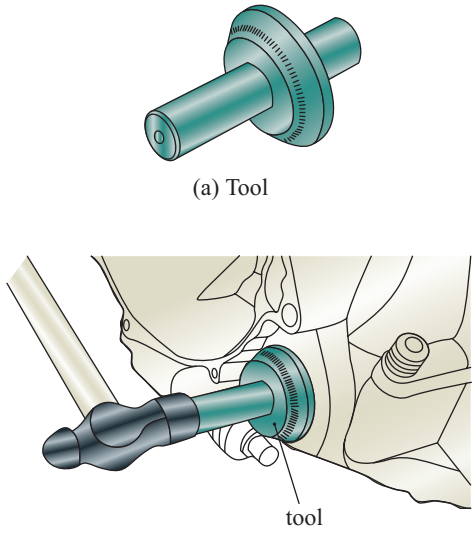
24.15.2 Adjustments

Transmissions with external control rods, such as those with steering-column gearshifts and some floor-mounted gearshifts, are provided with adjustments. Cable controls are also adjustable.

Adjustment is not a regular service item, but can be done to correct some gear-selection problems. Adjustment should be checked if the engine or transmission have been disturbed on their mountings, as this could alter the effective rod or cable length.

24.15.3 Oil leaks

Oil leaks can come from shaft seals, the speedometer or sensor drive, the drain plug or from joints between parts of the casing. Some seals, such as that in the rear of a transmission extension housing, can be replaced without removing the transmission from the vehicle. Seal-removing and seal-replacing tools are usually needed. With some transaxles, the drive-shaft seals in the final-drive housing can be replaced in a similar way while the transaxle is still in the vehicle (Figure 24.34).



(a) Tool

(b) Installing

Figure 24.34 Installing a transaxle drive-shaft oil seal

24.15.4 Reasons for transmission repairs

If a transmission or a transaxle has to be removed and dismantled for repairs, it will probably be due to one of the following:

1 noise caused by gear teeth
2 noise from worn or damaged bearings
3 jumping out of gear
4 faulty synchromesh action
5 difficult selection of gears .

Problems should be diagnosed as accurately as possible and localised to a particular gear or part of the transmission before commencing repairs. A road test should be carried out before the transmission is dismantled unless the cause of the problem is obvious, or if operating the transmission could cause further damage. The person undertaking the road test must have a sound knowledge of the transmission and how it operates. See 'Road testing and diagnosis' at the end of this chapter for more information.

24.15.5 Use of workshop manuals

To successfully work on transmissions, a knowledge of the construction and detail of the particular transmission is crucial. This can be obtained only from the appropriate workshop manual. Transmissions (and transaxles) vary greatly in design, and this affects the dismantling and reassembling procedures. However, there are a number of general points that relate to transmission and transaxle servicing, and understanding them is helpful.

24.16 Rear-wheel-drive transmissions

Some of the main variations in the design of rear-wheel-drive transmissions relate to the transmission housing (or case). Some transmissions have a three-piece housing, others a two-piece housing. In some, the clutch housing is an integral part of the transmission housing; in others it is separate. This is one of the first things to consider when servicing a transmission as the arrangement of the transmission housing and the parts attached to it will determine how it is dismantled and reassembled.

Handy hint: The terms transmission case and transmission housing are generally interchangeable .

24.16.1 Three-piece housing

Figure 24.35 shows a transmission with a three-piece housing. These are:

1 centre transmission case
2 clutch housing
3 extension housing .

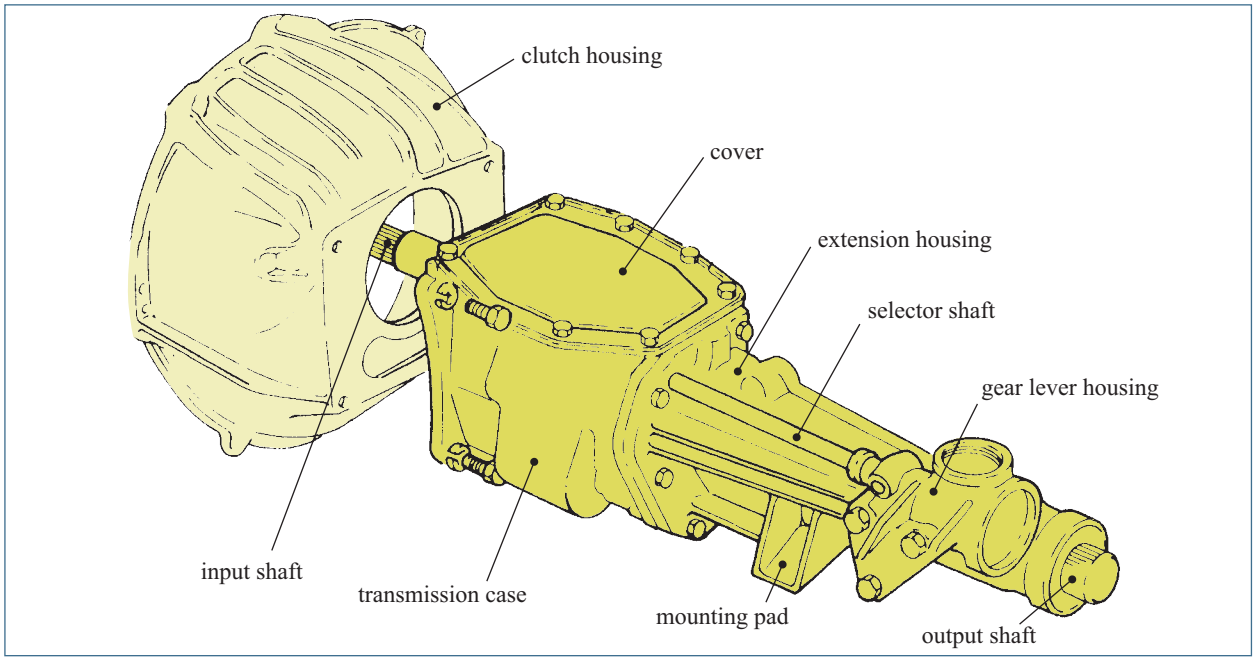


Figure 24.35 Transmission for a rear-wheel-drive vehicle FORD

These three parts are bolted together. The transmission case is the main part and it carries most of the internal parts. It can be made of cast iron or aluminium alloy. The clutch housing and the extension housing are usually of aluminium alloy.

Transmissions like this can be removed by unbolting them from the clutch housing (it is possible to remove the extension housing while the transmission is in the vehicle). The extension housing has a mounting pad which sits on a rubber mounting on a cross-member, so the rear of the engine must be supported before the transmission or the extension housing can be removed.

Figure 24.36 shows how the parts of the transmission are separated from the main transmission case. The internal parts are accessible after the cover is removed from the top (the extension housing from the rear and the input-shaft bearing retainer from the front).

The shift rails and forks are removed before the gears. Generally, there is limited space within the transmission case so parts have to be dismantled in the correct sequence and taken out of the transmission case through the opening in the top.

24.16.2 Split-case with adaptor plate

Figure 24.37 shows a five-speed transmission with a split case. Here, the rear extension is bolted to the main transmission case, with an adaptor plate between. Most of the internal parts are removed as an assembly. When dismantled, the separated parts are:

1 the main transmission case , which includes the clutch housing
2 the rear extension housing
3 an adaptor plate between the transmission case and the rear extension housing
4 the front cover (or bearing retainer) .

The main transmission case houses the components for the first, second, third and fourth gears, while the rear extension housing behind the adaptor plate contains the fifth and reverse gears. The adaptor plate carries bearings that support the rear end of the shafts. The front cover retains the input shaft bearing and the countershaft bearings.

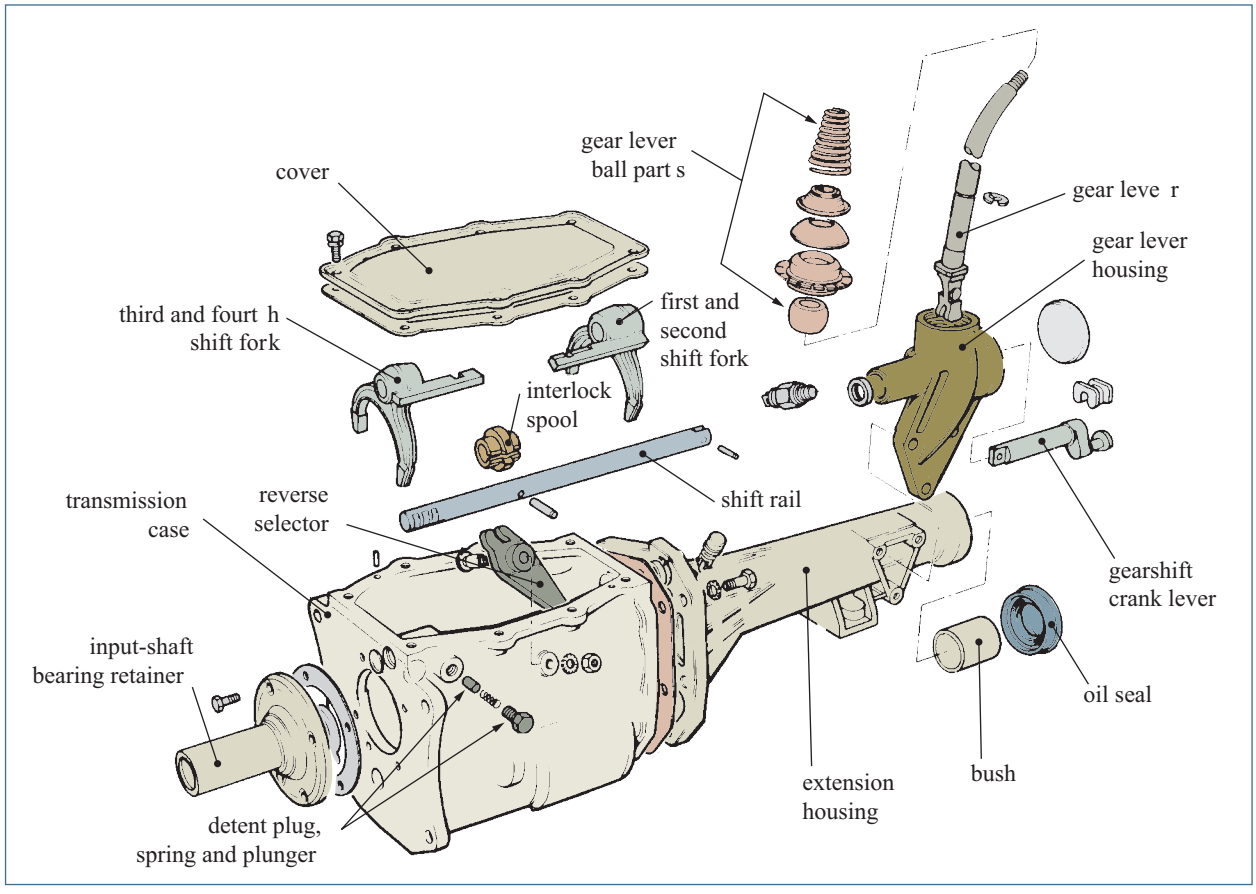


Figure 24.36 Transmission case and associated parts FORD

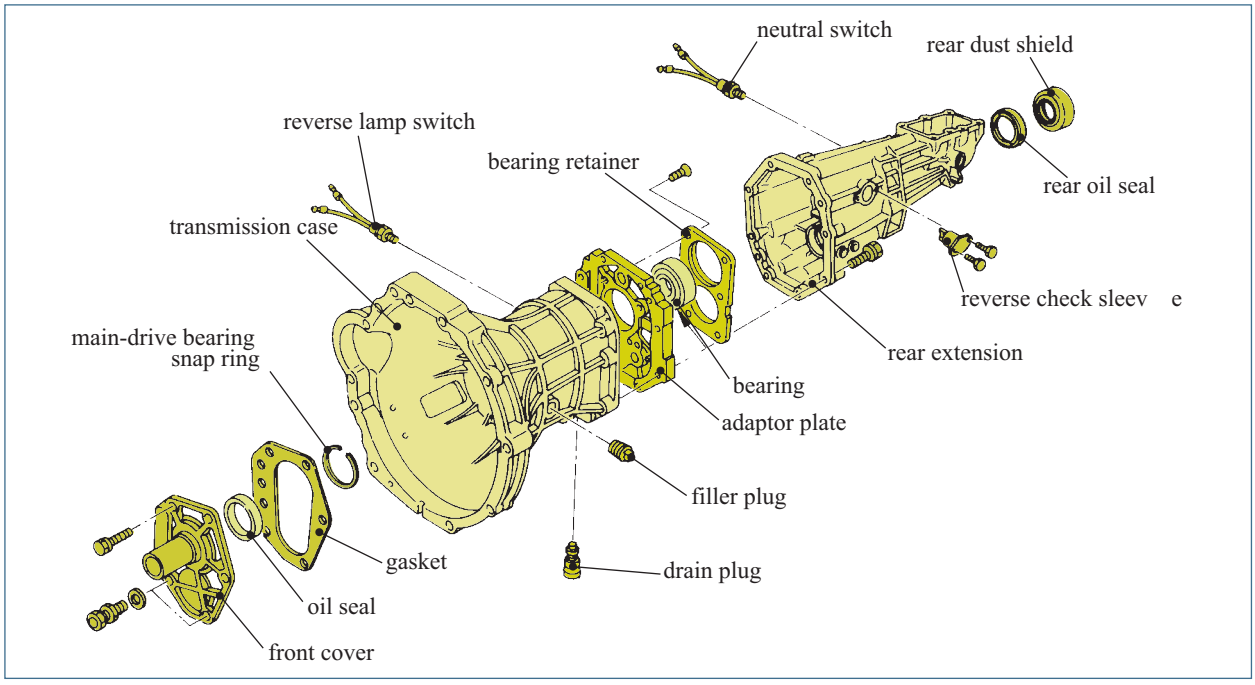


Figure 24.37 Transmission construction—shown by the separated parts of the transmission case and associated components GM HOLDEN LTD

To dismantle this design of transmission, the gear lever and the gearshift mechanism are removed from the extension housing. The parts of the case are separated by unbolting the extension housing from the rear of the main case and removing the front cover from inside the clutch housing. The adaptor plate, together with the shafts, bearings, gears and the selector mechanism, is separated from the main transmission case. The shafts and gears are then dismantled from the adaptor plate. Some of the internal parts can be seen in Figure 24.38.

24.16.3 Two-piece housing

The transmission housing (or case) has two parts: a front housing, which includes the clutch housing, and a rear housing. These are bolted together and can be separated. There is also a front housing cover that retains the clutch-release bearing sleeve and the input shaft bearing. (The complete transmission is shown as a sectional view in Figure 24.10.)

The following are features of this transmission that relate to dismantling and reassembly:

1. There is an output flange on the rear of the mainshaft that has to be removed.
2. All the components are contained within the housings, so the parts of the housing have to be separated before dismantling selectors or gears.
3. The parts of the housing may not separate easily because the mating faces of the case had sealer applied when they were assembled. The sealer will hold the housings together after the retaining bolts are removed.
4. Force must be carefully applied to separate the parts. For this transmission, there is a special tool for the input shaft. This pushes it back onto the mainshaft and helps to separate the housings.
5. When the parts of the housing have been separated, the mainshaft and gears remain with the rear housing.
6. The cluster gear does not have a separate shaft but has a bearing at each end, with a cup in each part of the housing. When the parts of the housing are separated, the cluster gear will be free .
7. With the housings separated, the input shaft can be pushed towards the rear to remove it from the main housing.
8. The internal parts that remained with the extension housing when it was separated can be removed from the housing.
9. Further dismantling of the gears from the shafts can then tak e place .

24.17 Dismantling transmissions

No single dismantling procedure covers all types of transmissions. The correct procedure must always be obtained from the relevant service manual. However, there are some general processes that can be applied to most transmissions. The following points, which relate to photos (a) to (h) in Figure 24.38, show what is involved.

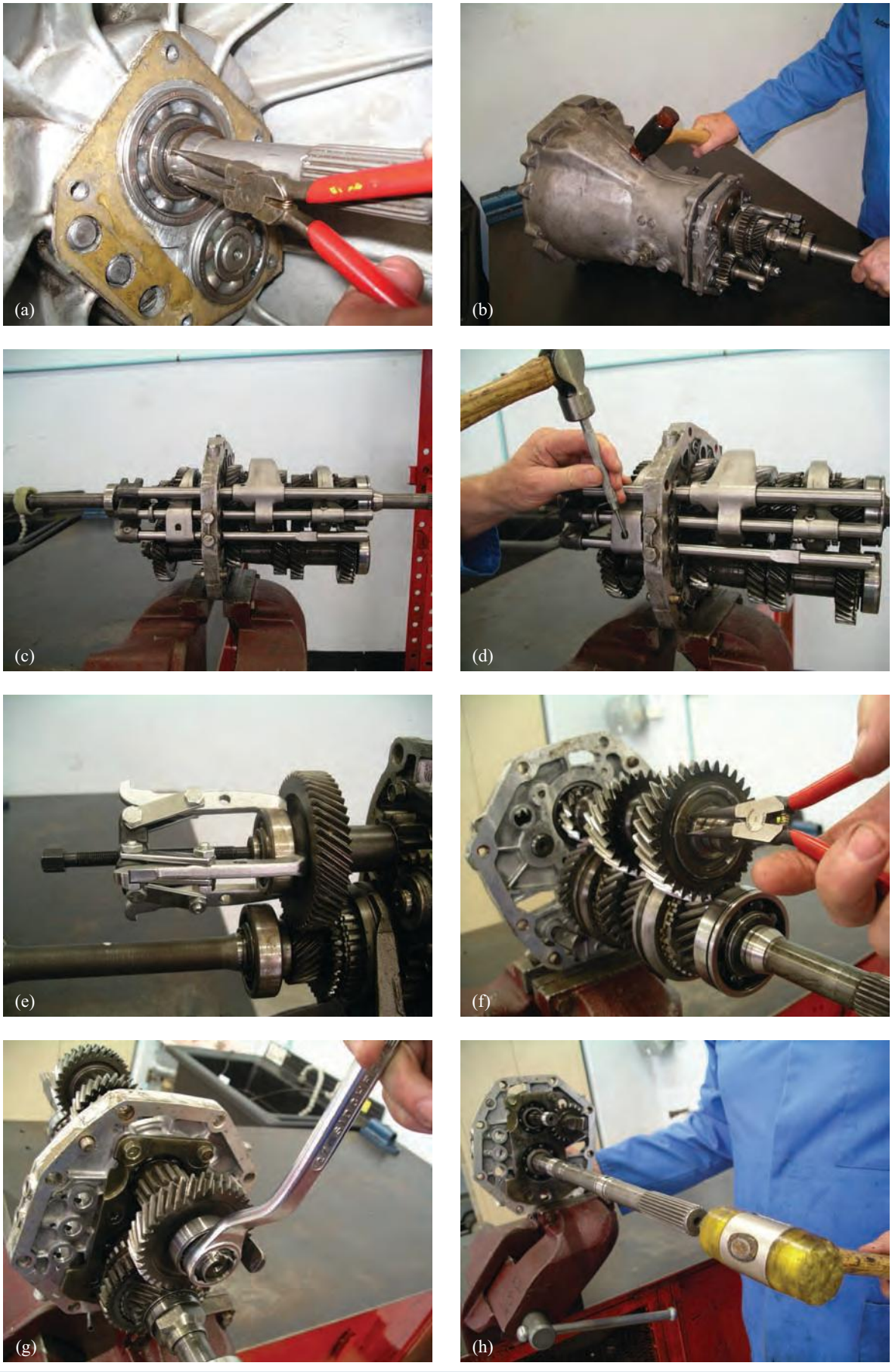


Figure 24.38 Some of the operations involved when dismantling a transmission with a split case

1 Snap rings —Figure 24.38(a). These are used in a number of locations in transmissions. The illustration shows a large snap ring being removed with snap-ring pliers. It retains the input shaft bearing in the housing. Other snap rings are used on shafts to locate bearings, gears and synchronisers.
2 Separating parts of the housing —Figure 24.38(b). A rubber hammer is sometimes needed to help separate the housings, or parts from the housing.
3 Supporting parts during dismantling —Figure 24.38(c). Parts are supported in stands to make dismantling easier. Parts that will not be damaged may be held in a vice, but soft jaws should be used. Take care to prevent marks and damage to surfaces.
4 Removing and replacing shift forks —Figure 24.38(d). Pins securing the shift forks to the shift rails are driven out with a pin punch. This enables them to be separated from the rails.
5 Using pullers —Figure 24.38(e). Some gears and bearings are an interference fit on their shafts and have to be removed with a puller.
6 Removing gears from shafts —Figure 24.38(f). Most constant-mesh gears are retained on their shaft by snap rings. Different types of snap-ring pliers are needed.
7 Nuts on shafts —Figure 24.38(g). Some transmissions have a nut on one or more shafts. When the nut is being removed, the gears have to be held by engaging two gears at the same time. When being tightened, nuts have a specified torque.
8 Removing shafts —Figure 24.38(h). Shafts are often a light fit in their bearings and can be carefully tapped out when dismantling.

Countershafts can be a firm fit in the housing and have to be carefully driven out. Other shafts, which have a tight fitting gear or bearing, can be pressed out.

24.18 Dismantling and checking components

To dismantle the gears and other parts from the shafts, the snap rings which hold them in place must be removed. Also, bearings may have to be pulled or pressed from shafts. During dismantling, identify all parts and lay them out in the correct order.

Handy hint: Take care not to mislay small parts such as detent balls, springs and snap rings. Use a magnetic tray to hold them.

24.18.1 Mainshaft

Figure 24.39 shows a mainshaft and some of the gears and synchronisers. Some of these parts are removed from the front of the shaft and some from the rear. Before completely dismantling the shaft, the end-float of each gear should be checked. This is done by inserting a feeler gauge between the gear and the shoulder

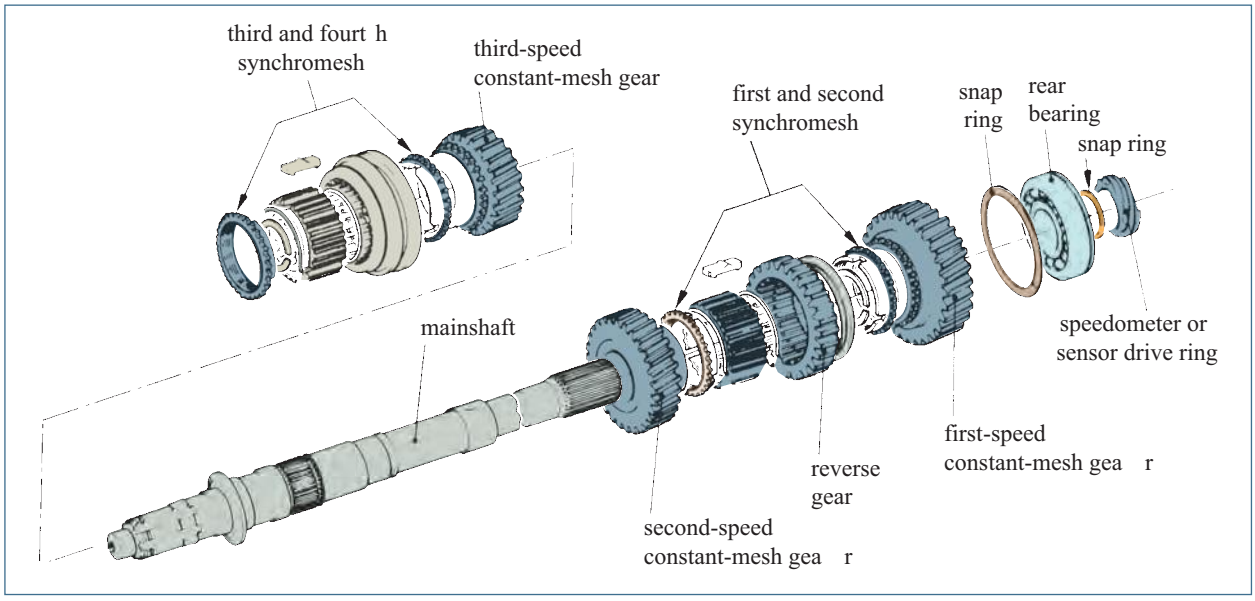


Figure 24.39 Mainshaft (output shaft) assembly FORD

on the shaft, as shown in Figure 24.40. This can sometimes be done by inserting the feeler between two gears, or between a gear and a bearing.

Constant-mesh gears are free to rotate on the shaft, but usually have a specified end-float. Excessive end-float can cause jumping out of gear or poor synchroniser action. The gear shown is retained on the shaft by a snap ring and its end-float can be adjusted by using a thicker or thinner snap ring.

Handy hint: Selecting a part of the correct thickness, such as this snap ring, is referred to as a ***selective fit.***

Figure 24.40 Checking end-float of a constant-mesh gear on the mainshaft

24.18.2 Input shaft

Figure 24.41 shows a dismantled input shaft. This has a ballrace at the front and rollers inside the shaft at the rear. The rollers run directly on the spigot on the end of the mainshaft and against the inside of the input shaft. The front bearing is removed with a pressing or pulling tool which fits behind the bearing, as in Figure 24.42. A bearing should not be disturbed unless it feels rough or is noisy.

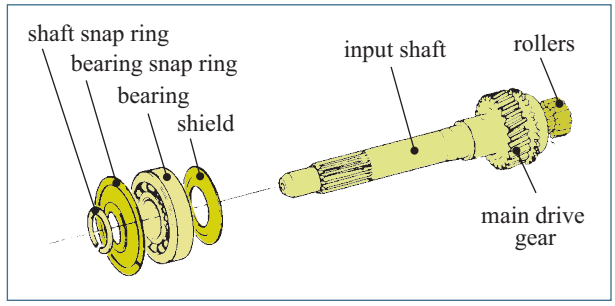


Figure 24.41 Dismantled input shaft FORD

24.18.3 Countershaft and gears

Many cluster gears are mounted on tapered roller bearings and do not have a separate countershaft. The bearing cones are fitted to spigots on each end of the cluster and the bearing cups are located in the transmission housings (Figure 24.43).

The cluster becomes free when the parts of the housing are separated. The bearings can be adjusted by shim washers behind the bearing cups.

Cluster with countershaft

Figure 24.44 shows a cluster gear with a separate countershaft. This cluster is removed by driving the countershaft from the housing with a suitable drift.

Figure 24.42 Pressing or pulling tool for removing a bearing from a shaft

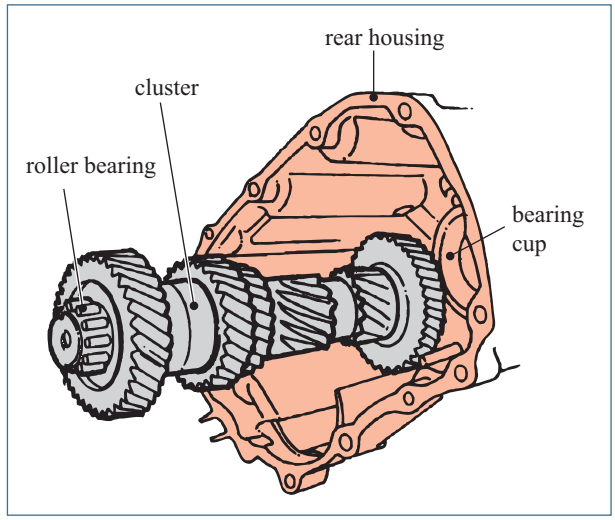


Figure 24.43 Transmission cluster gear with roller bearings at front and rear GM HOLDEN LTD

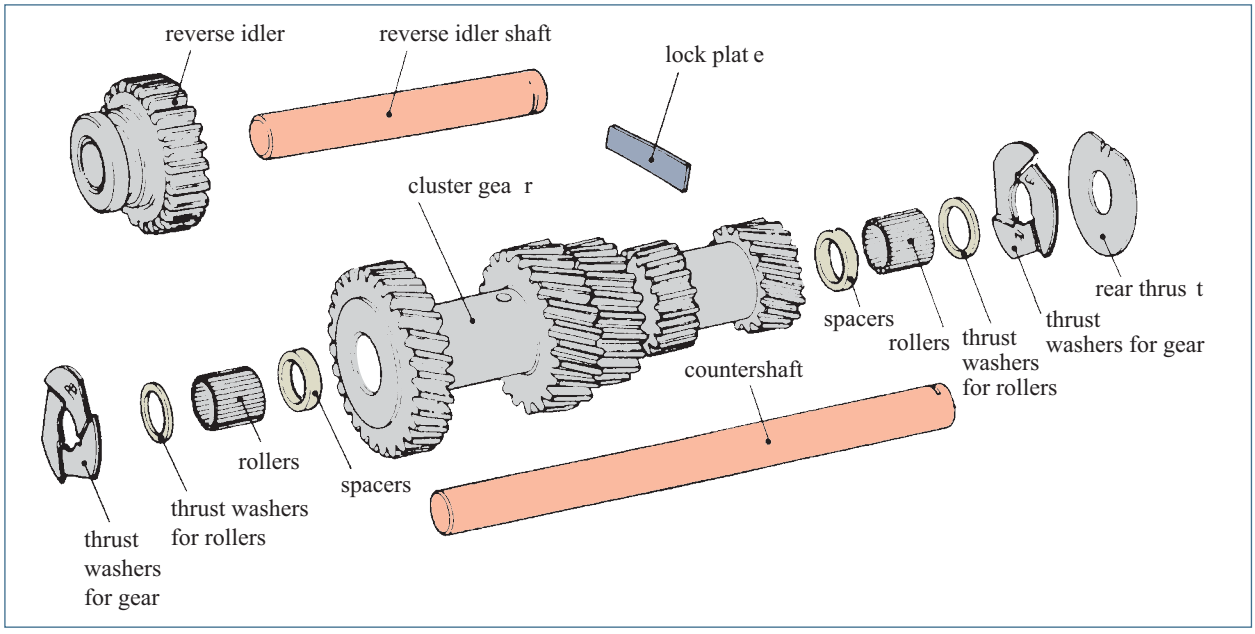


Figure 24.44 Cluster gear with a separate shaft FORD

The cluster runs on caged needle rollers. There are spacers for the bearings and thrust washers for each end of the cluster. Due to gear tooth design, the greatest end-thrust is towards the rear. With the cluster installed, the end-float can be checked with feeler gauges.

24.18.4 Synchromesh units

To dismantle a synchromesh unit, remove the springs from the inserts and slide the sleeve from the hub. Before dismantling, note the position of the springs and other parts. Mark the sleeve and hub so that they can be reassembled correctly (Figure 24.45).

Handy hint: Some synchronisers have spring-loaded balls that must be released carefully .

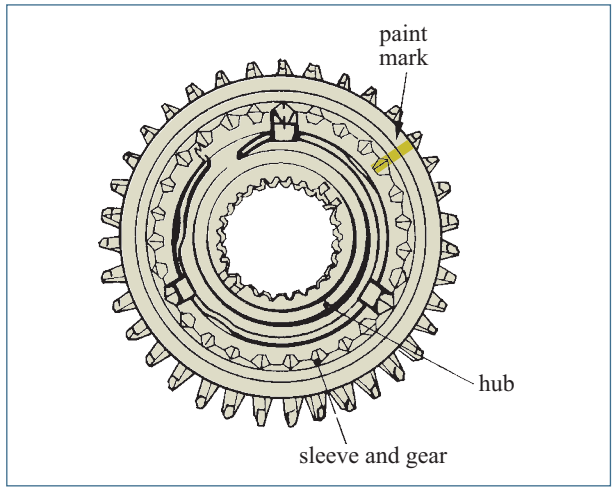


Figure 24.45 The synchroniser sleeve and hub are marked for correct reassembly

24.18.5 Selector mechanism

Figure 24.46 shows a gearshift assembly. This includes the selector rod, the shift rails and their shift forks. There are three sets of these: one for first and second, one for third and fourth and one for fifth and reverse.

The location of the various parts needs to be identified before dismantling for correct reinstallation. Mating parts can be marked if necessary.

Detent balls and springs locate the shift rails in their correct positions. The interlock balls and plunger prevent two gears being selected at once. When dismantling or reassembling, be careful not to lose the detent balls as they can unexpectedly spring out of place. The threaded detent plugs should be removed to relieve the spring pressure from the balls.

24.19 Identifying internal components of a transmission

Figure 24.47 shows all the shafts, gears, synchronisers, bearings, thrust washers and snap rings that make up the gearing section of a transmission. When identifying and naming the parts, start with the input shaft and then follow the other parts (from left to right) down through the illustration.

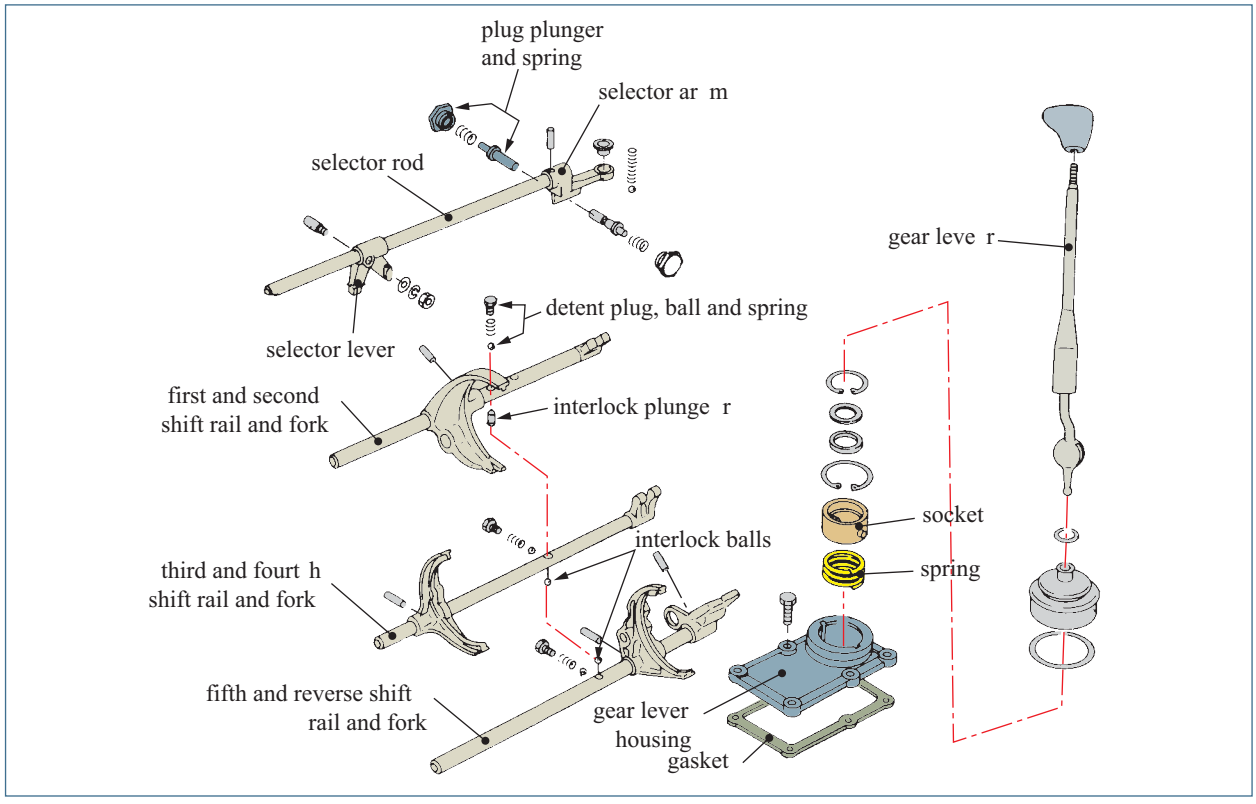


Figure 24.46 Gearshift components GM HOLDEN LTD

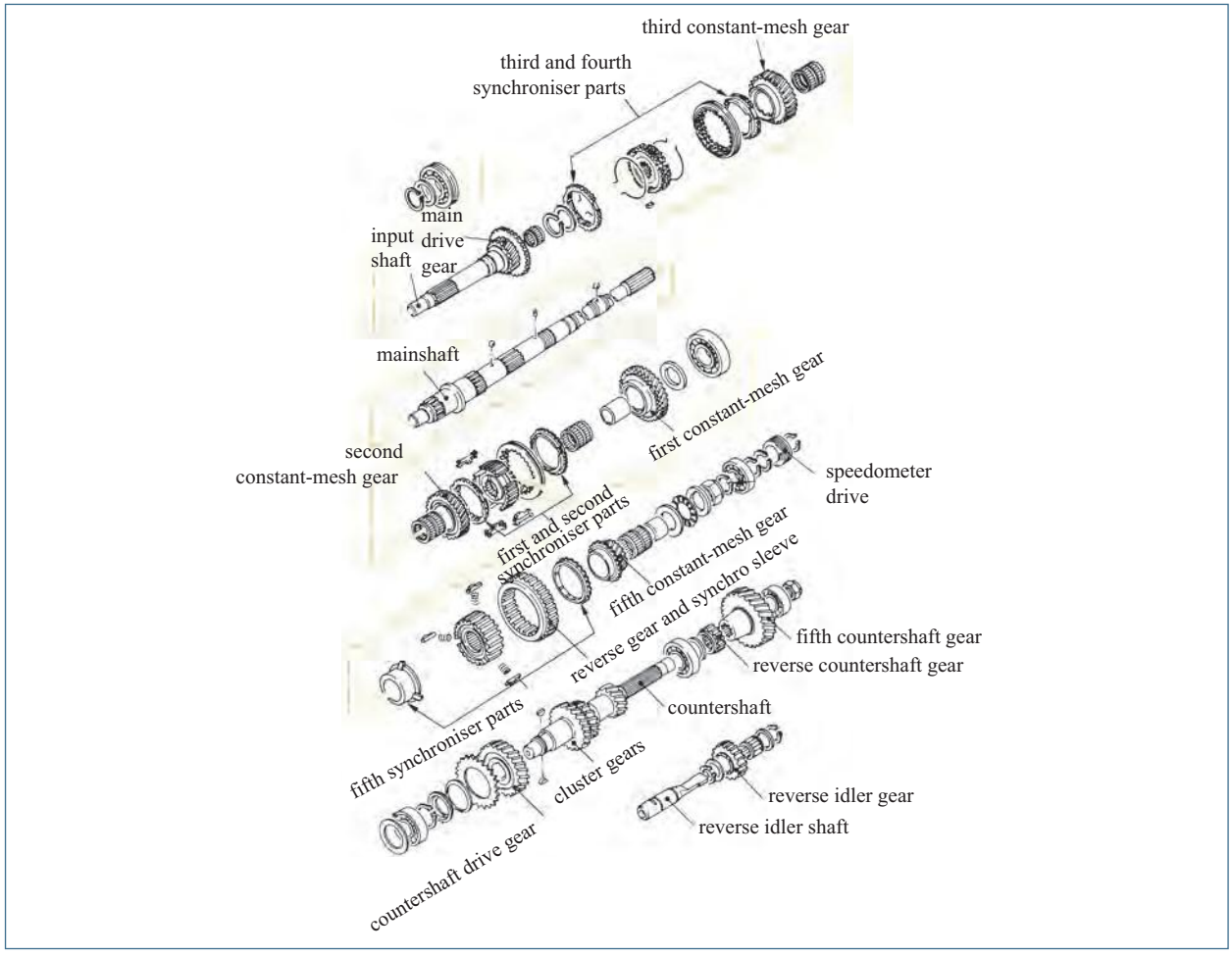


Figure 24.47 Gears, shafts and associated components GM HOLDEN LTD

To familiarise yourself with the internal parts of a transmission, check the following features and, if possible, carry out the activities suggested in brackets:

1 The input shaft runs on a ball bearing in the front of the transmission and is supported by a needle-roller spigot bearing on the end of the mainshaft. (Identify the bearings.)
2 The mainshaft also runs on ball bearings, one in the adaptor plate and the other in the extension housing. (Locate the bearings.)
3 The constant-mesh gears on the mainshaft run on caged needle roller bearings. (L ocate the gears and bearings.)
4 The mainshaft has three synchromesh units. (Identify them.)
5 This is a five-speed transmission. (Identify the five gears.)
6 Thrust washers are used with shafts and gears. A roller bearing is also used to accept thrust. (Locate them.)
7 The countershaft has gears for first, second, third and fifth gears. (Identify them.)
8 The countershaft drive gear is not part of the countershaft, but is fitted to the front end of it. (Check this.)
9 The countershaft fifth gear and the reverse gear are splined to the countershaft. (Check this.)
10 The countershaft is carried by three bearings. (L ocate them.)
11 The reverse idler gear runs on a roller bearing on the idler shaft. (Find the gear and shaft.)
12 There are a number of snap rings that retain parts. Some must be selected for correct thickness. (L ook for places where snap rings are used.)
13 There is a subgear on the countershaft. (Find it.)

24.20 Identifying the external components of a transaxle

The partly dismantled transaxle in Figure 24.48 will be used to gain an appreciation of transaxle construction. The external parts that can be identified in the figure are:

1 Clutch housing. The housing for the clutch and the front part of the transaxle housing are an integral part.
2 Transaxle case . The rear section of the transaxle housing.
3 Rear cover . Attached to the rear of the transaxle case—it covers the parts for fifth gear .
4 Rear bearing retainer . This retains the rear bearings of the shafts in the transaxle case—it is accessible when the rear cover is removed.
5 Front bearing retainer . This retains the front bearing in the clutch housing.
6 Speed sensor . This sends signals of the vehicle 's speed to the speedometer and also to the vehicle 's electronic control module .
7 Reverse light switch. A switch operated by the reverse shift rail so that the reversing lights of the vehicle are switched on when reverse is selected.
8 Shift and selector assembly . This is operated by cables that are connected to the gearshift lever—it operates the shift rails to select the required gear .
9 Differential side-bearing retainer . This carries the cup of the differential side bearing—it is bolted to the transaxle case .
10 Clutch fork and release bearing. These are not part of the actual transaxle , but are closely associated with it. They have to be removed when the transaxle is being dismantled.

24.21 Identifying the internal components of a transaxle

The internal parts of a transaxle can be seen in Figure 24.49. There are two main groups of components: an *input shaft assembly* and an *output shaft assembly.* Additionally, there is the *reverse idler*. Identify the various components and do the activities in brackets.

1 The input shaft is mounted on tapered roller bearings. (How many bearings are there ?)
2 There are five forward gears on the input shaft. (Identify the gears.)
3 There is a sleeve which, when assembled, is splined to the rear end of the input shaft. This carries the fifth constant-mesh gear and its synchroniser . (Locate these parts.)
4 The output shaft is supported by two tapered roller bearings. (L ocate them.)
5 The output shaft has one integral gear on the end of the shaft. (L ocate and name it.)
6 The output shaft has its constant-mesh gears mounted on needle roller bearings. (L ocate and find out how many gears and bearings.)

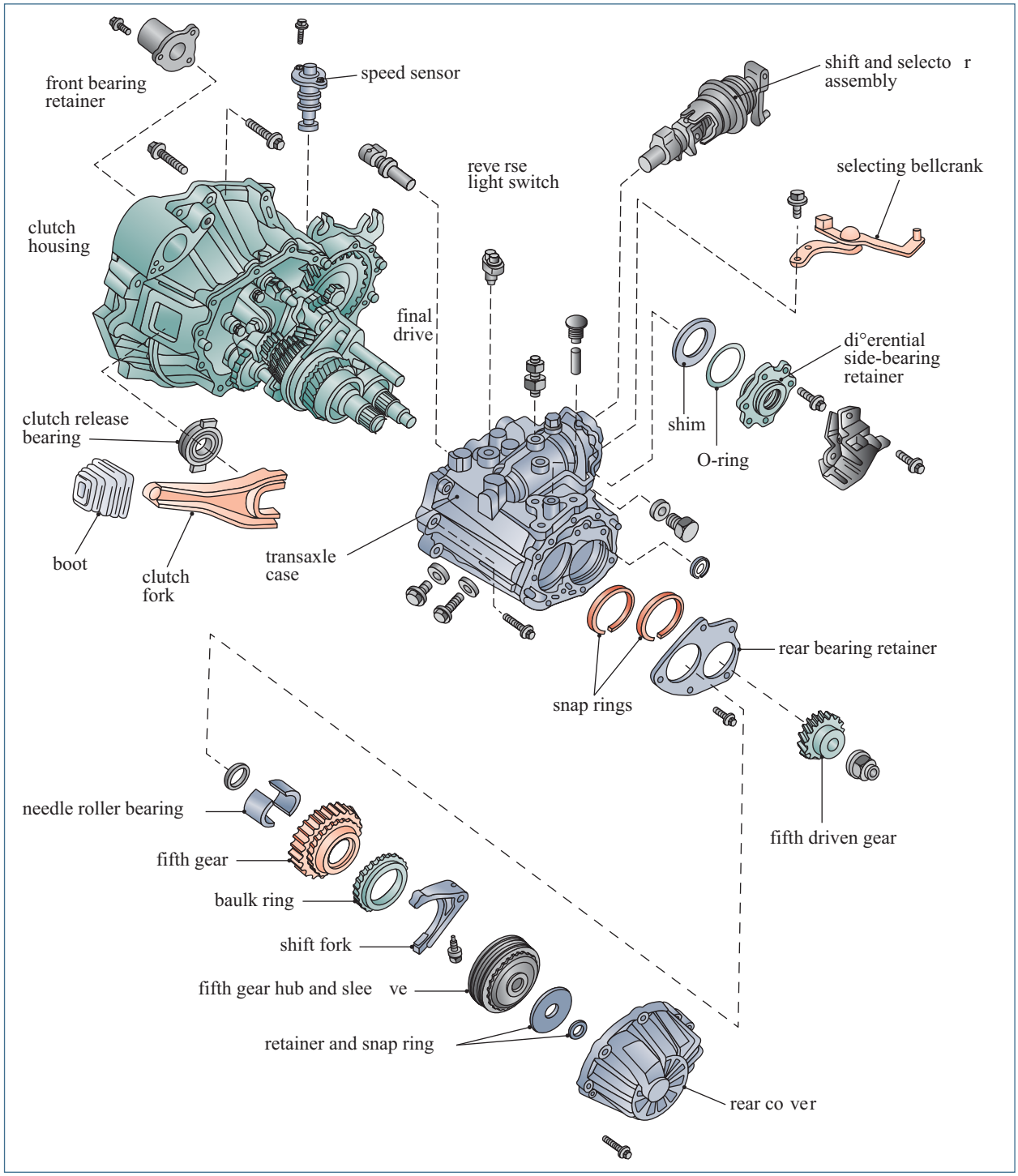


Figure 24.48 Construction of a transaxle—the three parts of the t ransaxle case have been separated to show the internal components

7 The first and the second constant-mesh gears and their synchronisers are grouped together in the illustration. When assembled, they will be at the front end of the output shaft. (Identify each gear and its synchroniser .)

8 The third and the fourth constant-mesh gears and their synchronisers are also on the output shaft. (Locate them.)

9 There is one gear right at the rear end of the output shaft. (Which gear is this ?)

10 There are three gears which provide reverse . These are located in different parts of the illustration. (Locate the three gears.)

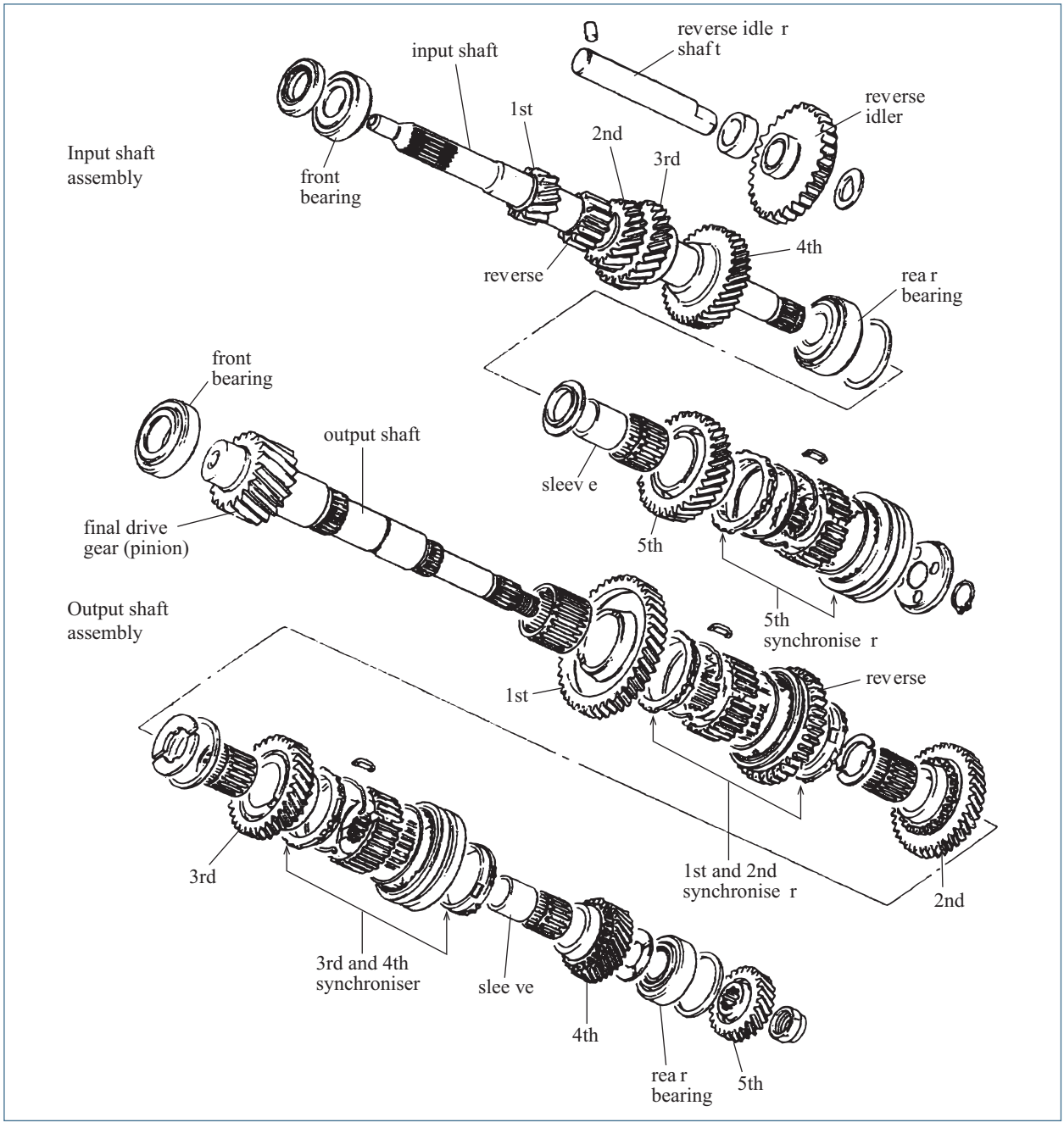


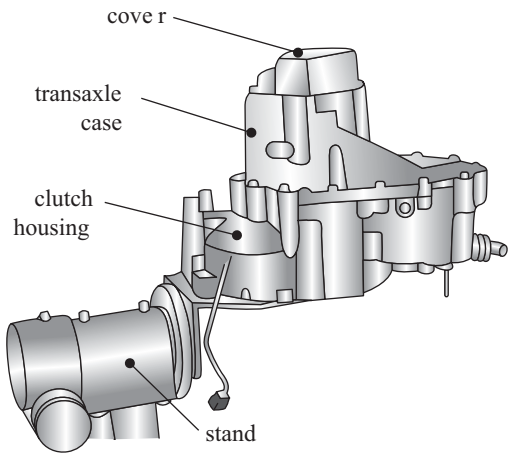
Figure 24.49 Shafts, gears, synchronisers and associated parts of a five-speed transaxle GM HOLDEN LTD

24.22 Dismantling transaxles

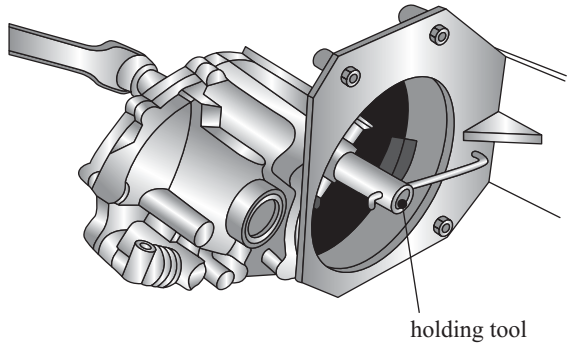
Some of the main steps in dismantling a transaxle are shown in Figure 24.50. The following points, which relate to the diagrams (a) to (f) in the figure, briefly outline what is involved.

Handy hint: Actual dismantling procedures are quite detailed and must be obtained from the relevant service manual.

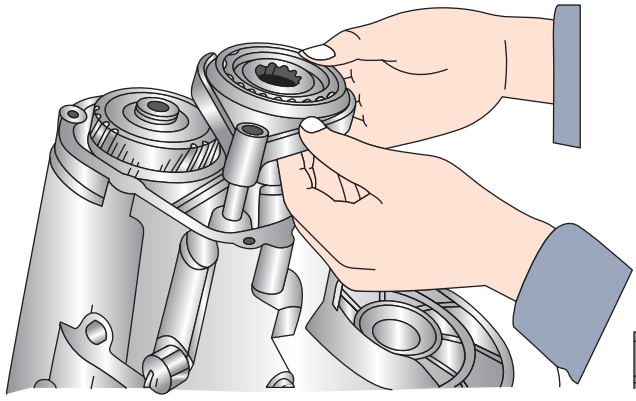
1 The transaxle is mounted on a stand (Figure 24.50(a)) or bench, with its rear end uppermost. The rear cover is removed from the transaxle case , giving access to the fifth-gear components and the ends of the primary and secondary shafts.
2 The primary shaft has to be held from turning while nuts are removed from the primary and secondary shafts (Figure 24.50(b)).
3 The fifth-gear synchroniser , shift fork and gear can now be removed (Figure 24.50(c)).



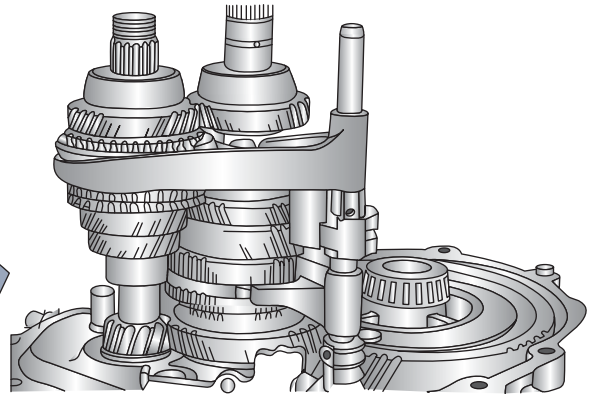
(a) Transaxle on stand



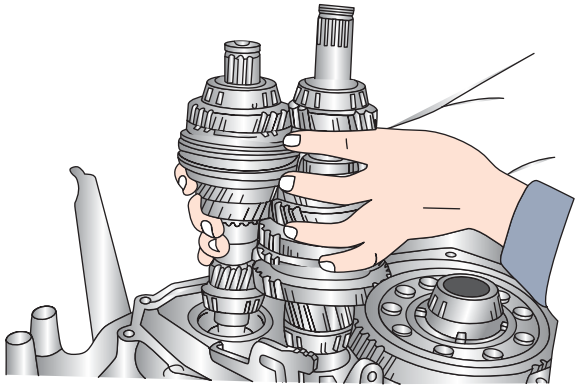
(b) Removing shaft nuts



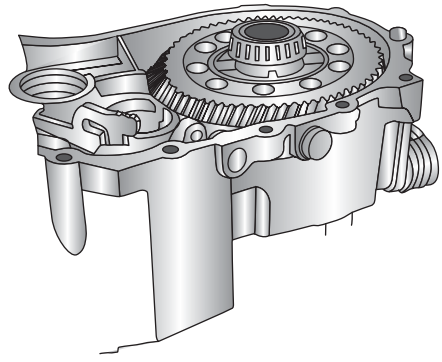
(c) Removing fifth-gear synchromesh unit and selector fork



(d) Transaxle case removed from clutch housing



(e) Removing gearing



(f) Final drive in clutch housing

Figure 24.50 The types of operations involved in dismantling a tra nsaxle

4 The primary shaft assembly , the secondary shaft assembly and the selector mechanism are exposed once the transaxle case has been unbolted and lifted away from the clutch housing (Figure 24.50(d)). The selector mechanism can be removed.
5 With the selector mechanism removed, the primary and secondary shafts are clear of other parts. They are resting in their bearings in the clutch housing and can be lifted clear as shown (Figure 24.50(e)).
6 The final-drive ring gear and differential assembly will be sitting in the housing as shown (Figure 24.50(f)). It can now be lifted out.

24.22.1 Final-drive assembly

Figure 24.51 shows the dismantled parts of a final-drive and differential assembly. In this transaxle design, the transaxle case has to be split and the gears and shafts removed before the final-drive assembly can be removed from the transaxle case.

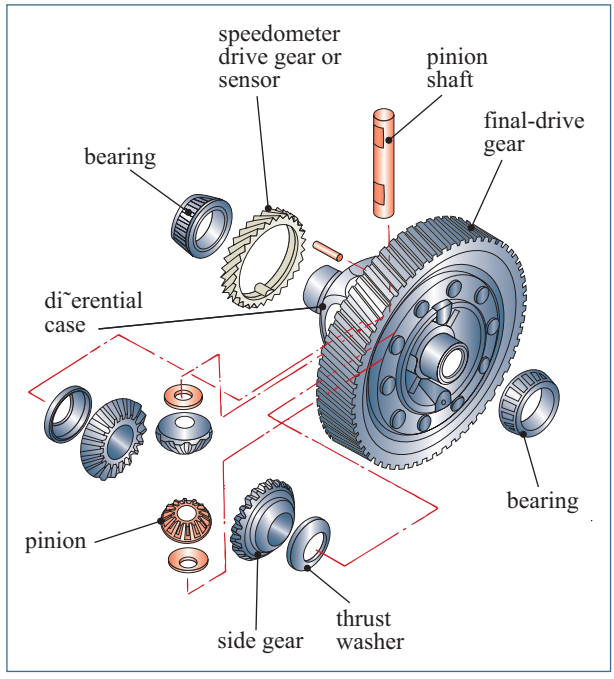


Figure 24.51 Transaxle final drive and differential assembly

24.23 Reassembling transaxles

Reassembling a transaxle is generally the reverse procedure to dismantling (but bearings may have to be adjusted). Any tapered roller bearings will have to be checked and adjusted for a light preload. External adjustment may be provided on some transaxles, but not on others.

Some transaxles have a bearing cup located in each part of the split case and there is no external means of adjustment. The bearings cannot be adjusted before the parts of the case are assembled, and they are not accessible afterwards. For these transaxles, adjustment can be done in different ways: by gauges, measurement or by checking the torque of shafts.

Bearings are adjusted by shim thickness, and usually the transaxle case and parts have to be assembled temporarily while the bearings are being checked. The parts are then dismantled and the shim adjustments made. Service manuals should be referred to for reassembly and adjustment procedures for individual transaxles.

24.24 Inspection of parts (all transmissions)

Inspection is mainly a visual check of parts for wear and damage to determine if they are suitable for reuse (Figure 24.52). Clearance of gears on shafts and gear end-float (end-play) are also checked.

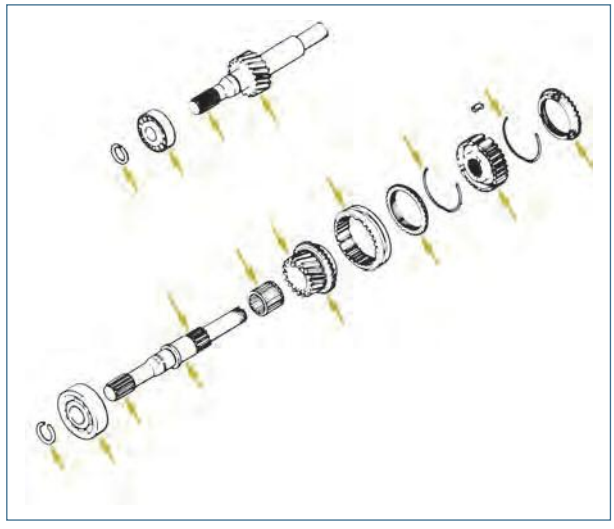


Figure 24.52 Parts that should be inspected include splines, shafts, bearings, gears and the synchroniser parts

24.24.1 Case and housing

The castings should be inspected for cracks and damage. A case with worn bearing bores may have to be replaced. Other damage, such as damaged threads, may be repairable. Any burrs on the mounting surfaces should be removed as these will affect alignment of the parts.

24.24.2 Gears

Check for burrs and chipped teeth on all gears. Using feeler gauges, check the end-play of countershaft gears and constant-mesh gears. Adjust by fitting selective thrust washers or snap rings as appropriate. The bores of gears such as the constant-mesh gears and the cluster gear should be checked to see that the bearing surface has not become worn or damaged by the roller bearings.

24.24.3 Bearings

Bearings should be cleaned with solvent, blown dry (do not spin with air) and then oiled. Examine the bearing races for cracks and check the bearing for roughness. Examine the balls or rollers for looseness, wear or pitting. Renew bearings if any defects exist.

Bearing cups in the housing often have shims under them to adjust shaft end-float, as shown in Figure 24.53. Shims should be returned to their original location.

Handy hint: Do not press bearings from shafts unless you suspect they may be defective as unnecessary removal may damage them.

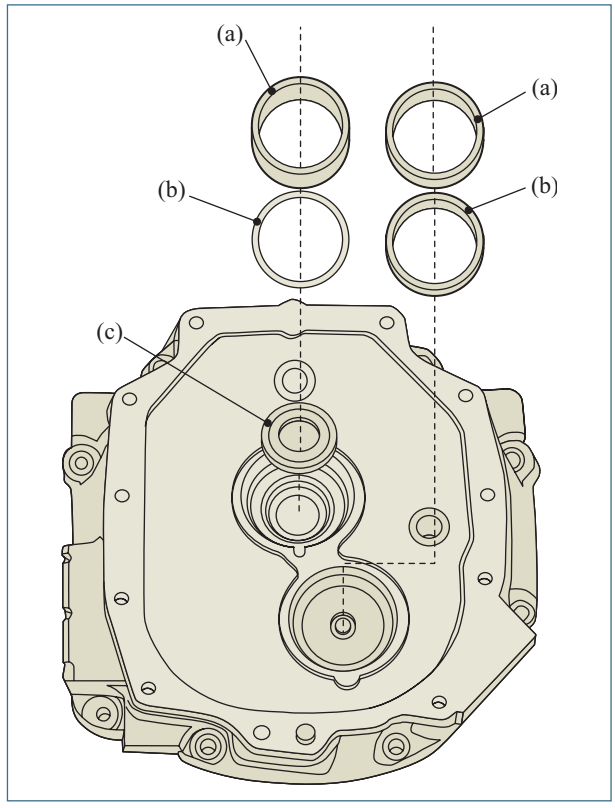


Figure 24.53 Front transmission housing with (a) bearing cups (b) shims (c) oil seal

24.24.4 Shafts

Inspect shafts for excessive wear and spline or tooth damage. Their bearing surfaces should be examined for possible wear or damage from defective roller bearings. This applies to the countershaft, the spigot on the mainshaft of rear-wheel-drive transmissions and the shafts of transaxles that carry needle rollers for the constant-mesh gears. Long shafts such as main shafts should also be checked for runout on V blocks using a dial gauge.

24.24.5 Synchromesh units

Figure 24.54 shows the parts of a synchroniser and how some of them are checked. Synchronisers should be checked as follows:

1 Examine the splines of the synchroniser sleeve and hub and check the sleeve for free movement on the hub .
2 Examine the baulk rings for wear and damage to the teeth and insert slots.
3 Check each baulk ring by holding it hard and turning it against its mating cone on the constant-mesh gear .
4 Check the gap between the baulk ring and gear with a feeler gauge . Compare this with specifications to see whether the part is still serviceable .
5 Check the insert springs and mak e sure that they are correctly installed.
6 Examine the ends of the inserts and the bead for ex cessive wear .

24.24.6 Selector mechanism

Check for wear of the selector forks where they are in contact with the synchromesh sleeves. Check the detent balls and parts of the interlock device for wear or damage. Also check the detent and interlock springs for distortion. Selector rails should be checked for condition, particularly the edges of the detent grooves which can become worn from the action of the detent balls.

24.25 Points relating to reassembly

Following are general points which relate to reassembling transmissions and transaxles. Some of these points for a transaxle are shown in Figures 24.55 and 24.56.

1 Check that parts are being installed correctly . Synchronisers may have an offset hub and must be installed facing the correct way .
2 Check the end-float of gears with feeler gauges or with a dial indicator and adjust as required.
3 Renew snap rings. Often a selective fit, these are supplied in a range of thicknesses and are selected to adjust end-play .
4 During reassembly , lubricate all moving parts (bearings, selectors and thrusts).
5 Renew all seals and gask ets. Seals should be well lubricated.
6 Where specified, apply silicone-type sealer to joints. Apply a continuous bead of sealer to one surface of the parts to be joined.
7 Tighten bolts evenly and to their specified torque .
8 Operate the selectors through all gears.
9 Check the transmission vent to mak e sure that it is clear .
10 After installing, fill the transmission to the correct level with the specified gear oil.

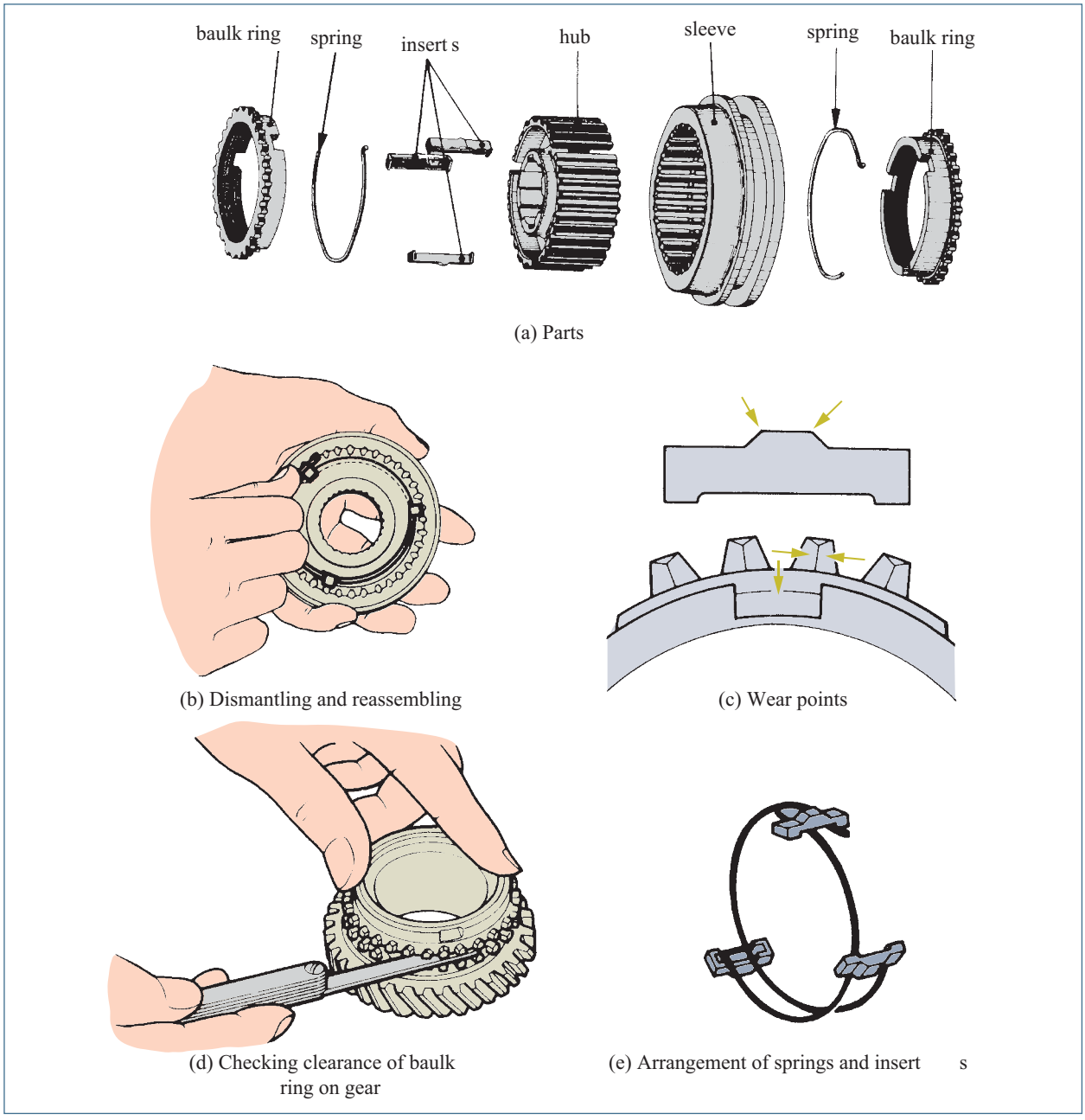


Figure 24.54 Parts of a synchroniser and checks to mak e

24.25.1 Transmission shafts

A transmission mainshaft can be checked for end float by using a dial indicator (dial gauge), as shown in Figure 24.56. End float is the free movement of a shaft backwards and forwards or, with the transmission in the position illustrated, up and down.

24.25.2 Gearshift adjustment

Some gearshifts have adjustments. This applies to steering-column gearshifts, floor gearshifts with external linkage (Figure 24.57) and cables (Figure 24.58). The basis of adjustment is to have the gear lever in the correct position, with the selector rail in the transmission also in the correct position. The rod or cable can be adjusted if necessary.

A general method of checking linkage adjustment is to disconnect the control rod and move the lever on the transmission by hand to engage a gear. The control rod can then be checked against its hole. If the rod length is correct, the end of the rod should re-enter the hole in the lever. If it does not, then the length of the rod should be adjusted appropriately.

Control cables can be checked and adjusted in a similar way.

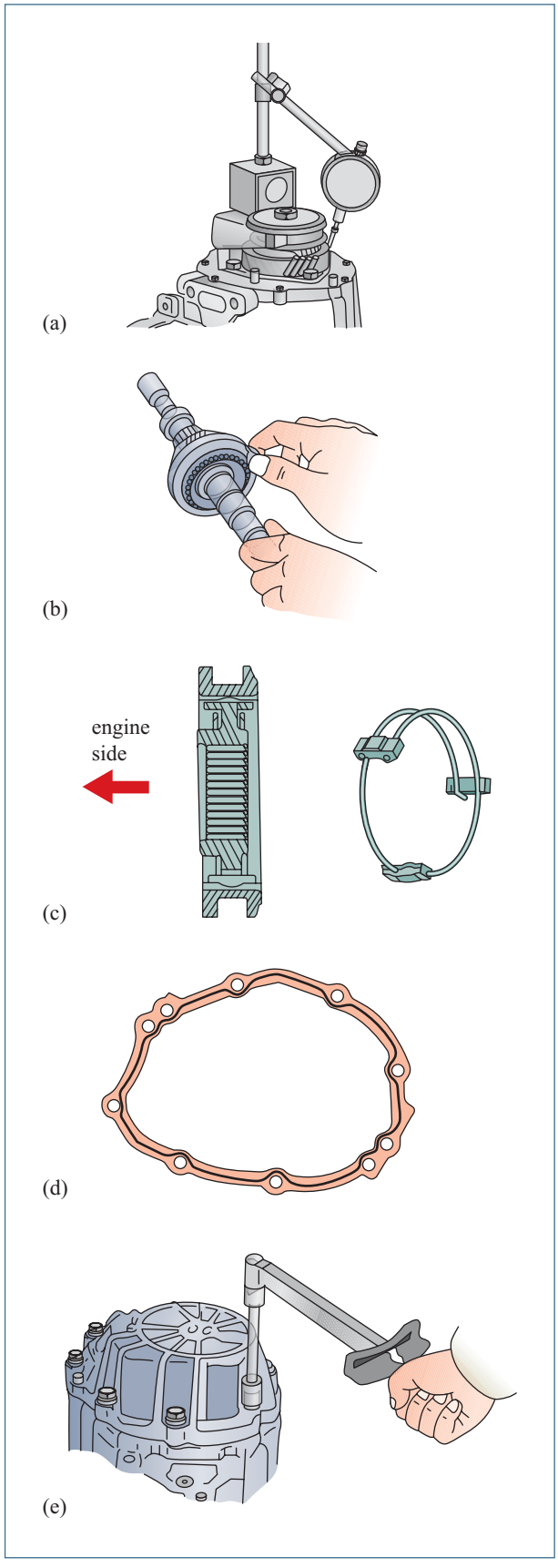


Figure 24.55 Checks during transaxle reassembly (a) checking end-float of a gear (b) selecting a snap ring (c) assembly and installation of the synchronisers (d) bead of sealer on the joint face (e) bolts tightened to correct torque

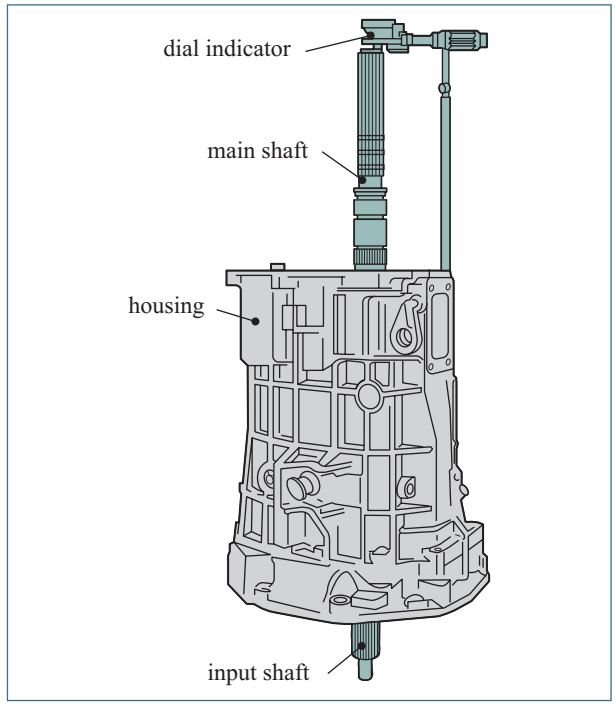


Figure 24.56 Mainshaft end float can be check ed with a dial indicator (dial gauge)

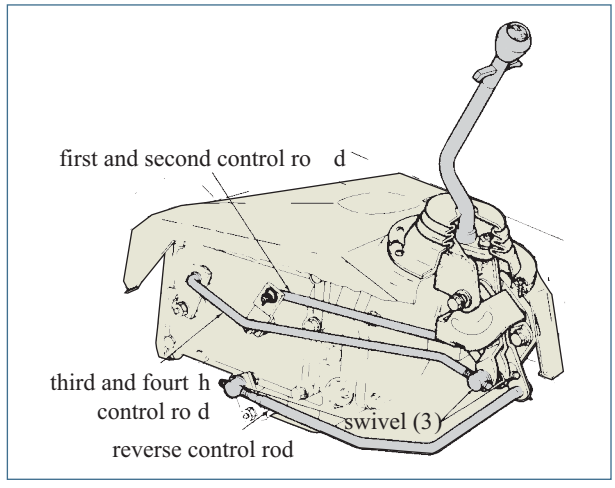


Figure 24.57 External gearshift linkage MITSUBISHI

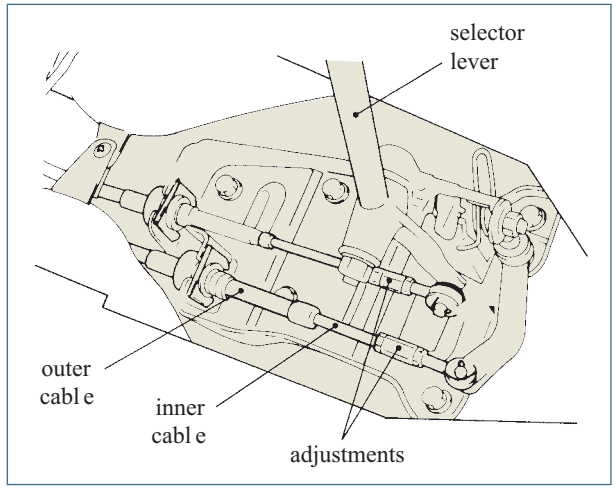


Figure 24.58 Gearshift cable and adjustments

24.26 Removing transmissions and transaxles

24.26.1 Removing transmissions

In rear-wheel-drive vehicles, the transmission can be removed and replaced with the engine in the vehicle. The vehicle should be raised on a hoist or supported on stands to give adequate working room underneath it.

The rear of the transmission is supported on a crossmember which has to be removed. In some cases, the front of the transmission is bolted to the clutch housing; in others, the clutch housing is removed with the transmission. When removing the transmission, the rear of the engine must be supported on a jack or stand, because the transmission rear mounting usually helps to support the engine.

The propeller shaft must be disconnected and removed from the extension housing. In transmissions where the front universal joint is splined to the mainshaft, gear oil will flow from the extension housing unless it is drained before the propeller shaft is removed. Alternatively, the end of the extension housing should be plugged as soon as the propeller shaft has been removed.

Other external parts to be removed are the speedometer cable or speed sensor connection and the reverse light switch. Depending on the design of the transmission, the clutch cable or slave cylinder, the gearshift lever and the gearshift linkage or cable might also have to be removed.

24.26.2 Removing transaxles

In some front-wheel-drive vehicles, there is not enough space in the engine compartment to remove the transaxle separately; the engine and transaxle have to be removed as an assembly, and the transaxle then separated from the engine. In other vehicles, the engine can be lowered or partly removed to give the necessary clearance.

Where the transmission can be removed on its own, the vehicle is raised above the floor on a hoist or placed on stands to provide working clearance underneath. The transaxle is accessible from the top of the engine compartment and from underneath. It is also accessible from under the mudguard, where splash shields can usually be removed.

The drive shafts must be removed, meaning that both front wheels have to be removed and parts of the front suspension disconnected before the ends of the drive shafts can be withdrawn from the transaxle. Other parts to be disconnected are the speedometer cable or speed sensor, the clutch cable or slave cylinder and the gearshift cables.

If the transaxle is being removed underneath the vehicle, a garage jack can support the transaxle. When external dismantling has been completed, the jack is lowered and the transaxle removed.

Four-wheel-drive vehicles have drive lines to both front and rear axles so that all four wheels of the vehicle can be driven. Some vehicles are designed for optional offroad use, where four-wheel drive is selected for rough, soft or sandy conditions. Other vehicles, mainly passenger vehicles, have all-wheel drive which can be used full time for better on-road performance.

24.27 Drive-line arrangements

In general, there are three different arrangements for four-wheel drive for passenger and light commercial vehicles:

1. Larger passenger and light commercial vehicles. These have a normal drive line to the rear wheels and an additional drive line to the front wheels.
2. Smaller passenger vehicles and those with transaxles. These have a transaxle with a normal front-wheel-drive arrangement. They also have a drive line to the rear wheels.
3. Vehicles with rear engines. These have their normal rear-wheel drive and an additional drive line to the front wheels of the vehicle .

While some vehicles have four-wheel drive as an option, others are made with only four-wheel drive.

24.27.1 Larger passenger and light commercial vehicles

Figure 24.59 shows the basic arrangement for a four-wheel-drive vehicle. The main transmission has an output shaft for the rear propeller shaft, and the transfer case has an output shaft for the front propeller shaft.

This has a four-speed or five-speed transmission of conventional design behind the engine, with a transfer case beside it. The transfer case is actually a smaller transmission with two speeds that provide a high and a low range. It has output shafts at both front and rear. The front and rear axles are both rigid axles.

Propeller shafts are connected to the output shafts to carry the drive from the transfer case to the front and rear axles. The axles then transfer the drive through the final-drive gears, the differential and the axle shafts to drive the wheels.

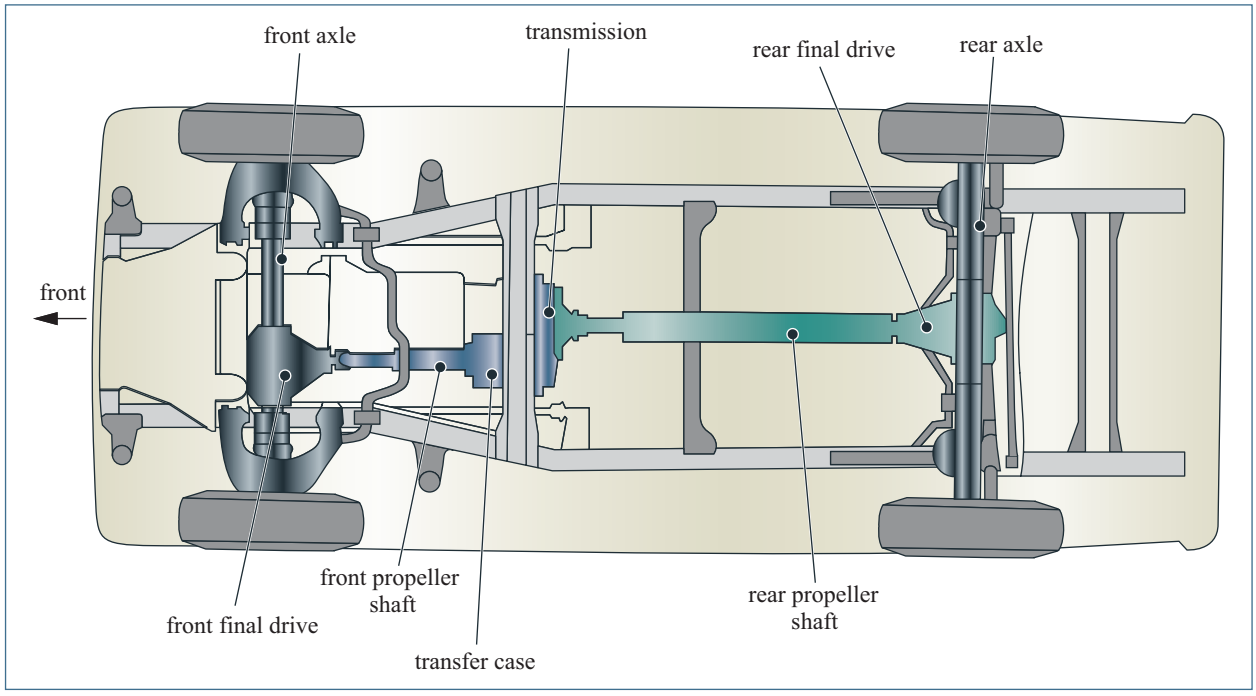


Figure 24.59 Arrangement of the drive line of a four-wheel-drive vehicle

24.27.2 Smaller passenger vehicles and those with transaxles

Figure 24.60 shows the four-wheel-drive arrangement for a smaller vehicle with a transverse engine. This has a transaxle and a normal front-wheel drive with open drive shafts. It also has a transfer case attached to the transaxle. The transfer case has an output shaft to the rear of the vehicle.

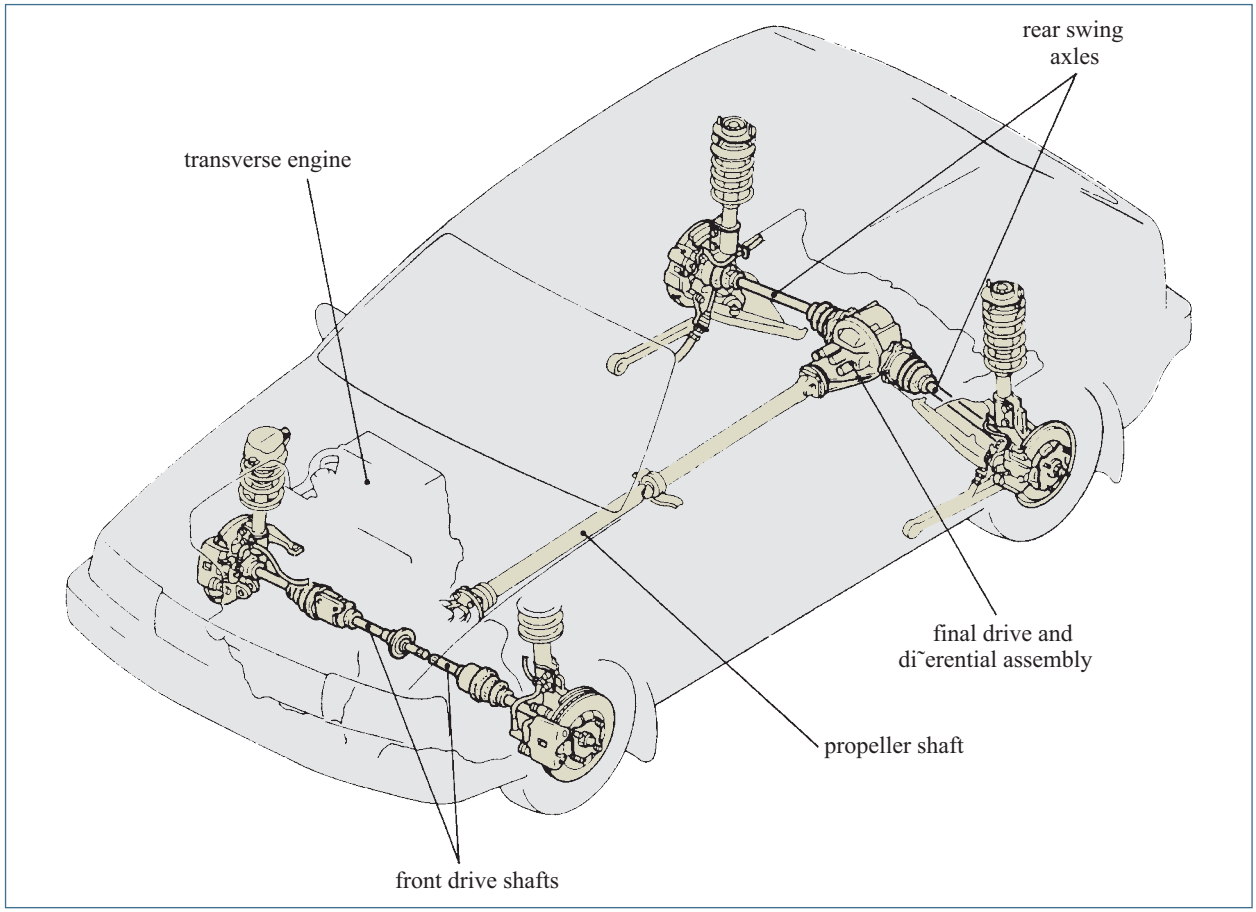


Figure 24.60 Arrangement of four-wheel drive for a vehicle with a transaxle and transverse engine FORD

A two-piece propeller shaft with a centre bearing carries the drive from the output shaft of the transfer case to the rear axle. The rear axle has a final drive and differential assembly mounted to the body of the vehicle, and swing axles connect it to the rear-wheel hubs.

24.27.3 Vehicle with rear engine

Figure 24.61 shows the arrangement of a vehicle with a rear engine. The transaxle is at the front of the engine and open drive shafts drive the rear wheels. It is a normal type of manual transmission, except that

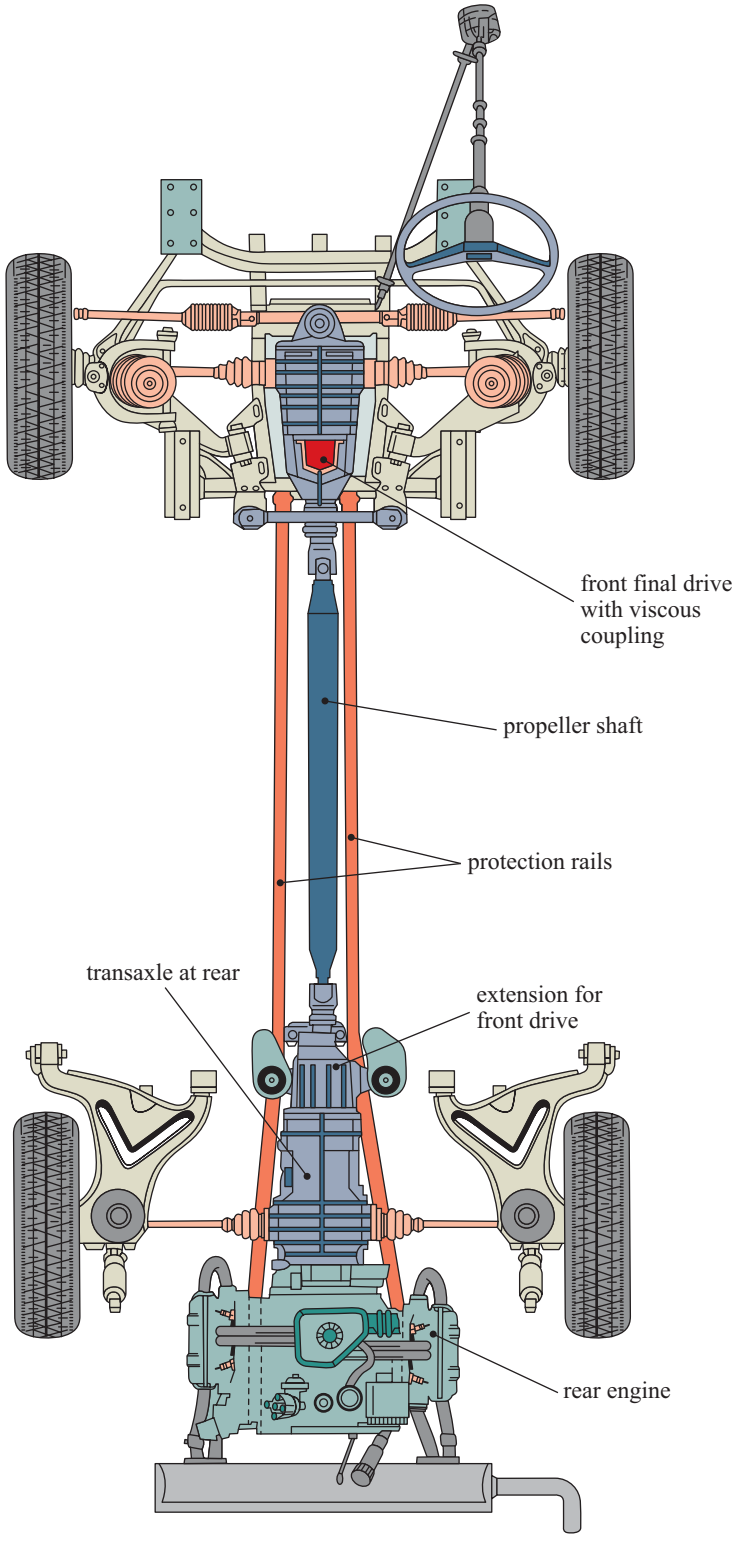


Figure 24.61 Arrangement of a rear-engine vehicle with four-whe el drive

it has extra gearing and an output shaft at the front. A propeller shaft connects the output shaft to the final drive in the front axle. The front final drive includes a viscous coupling, final-drive gears and a differential. Open drive shafts carry the drive to the front wheels.

24.28 Transmission with gear transfer

Figure 24.62 shows a transmission and transfer case with the parts identified. The transmission has four speeds that can be selected with the gear lever. The transfer gearing has two speeds that are selected with a separate lever. This provides a high and a low range. With the four speeds of the main transmission and the two speeds of the transfer, eight different forward gear ratios are available to the driver.

The main transmission is similar to that for a two-wheel-drive vehicle, except that it has an extended mainshaft with some of the transfer gears.

24.28.1 Transfer gearing

Figure 24.63 shows the arrangement of the gearing. It has to do three things:

1 provide drive for high range
2 provide a gear ratio for low range
3 transfer power to the front drive .

The transfer gearing is shown in neutral in the diagram. To obtain drive, the sliding sleeves are moved along their splines to engage with the dog teeth on one of the gears. The sliding sleeves and the dog teeth on the adjacent gears form a dog clutch. With the teeth engaged, the sleeve locks the gear to the shaft.

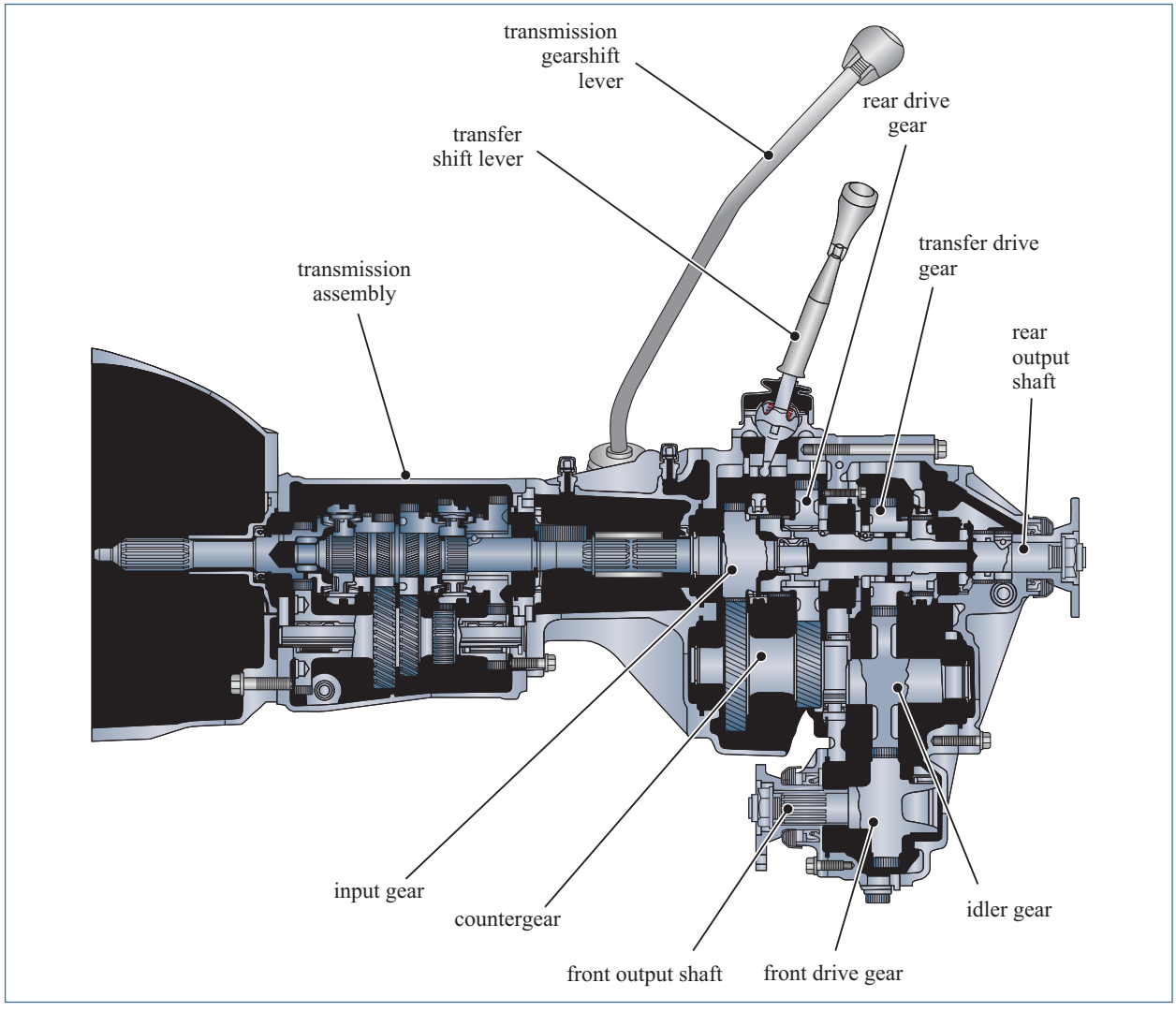


Figure 24.62 Transmission and transfer case assembly

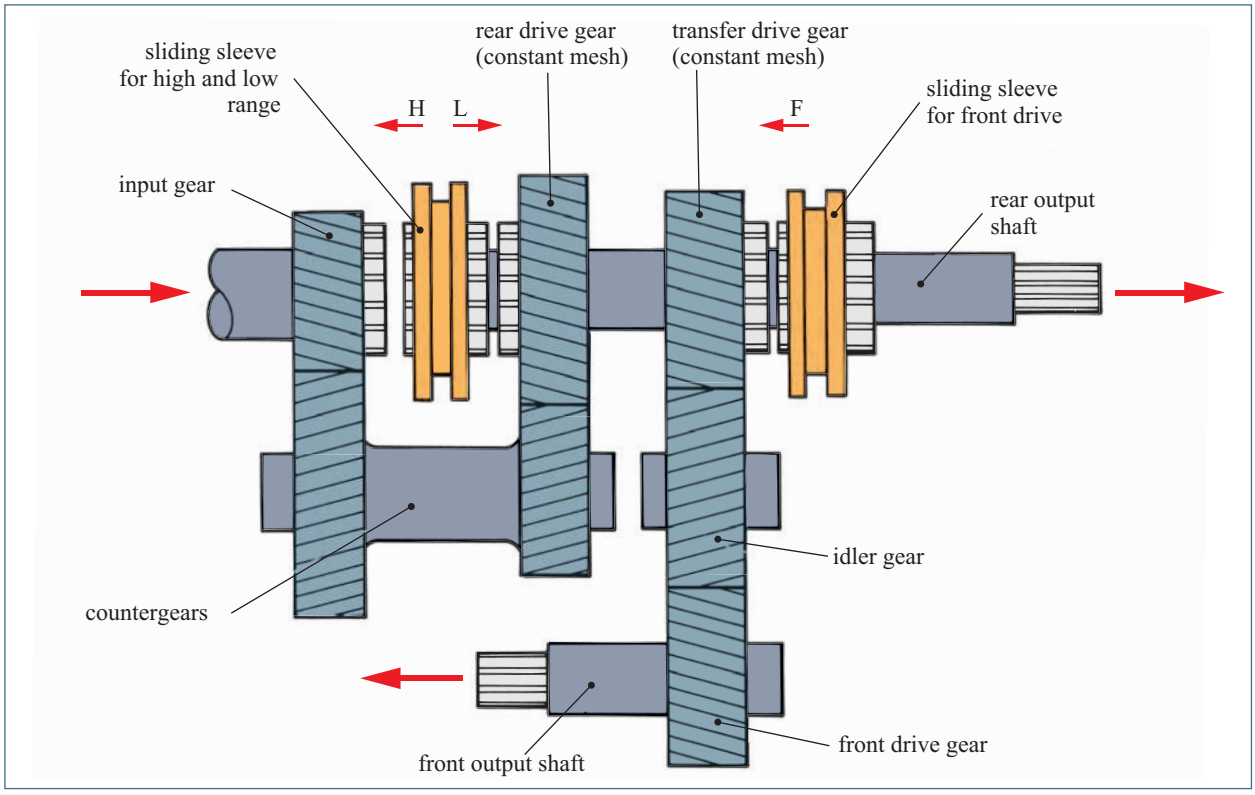


Figure 24.63 Arrangement of the gearing in a transfer case: H high range , L low range , F front drive

High range

For high range, the front sleeve is moved forwards to engage with the dog teeth on the input gear. This connects the input gear with the rear output shaft, and drive is carried straight through the transfer case. There is no gear reduction.

Low range

For low range, the front sleeve is moved to the rear. This engages the dog teeth on the rear drive gear and locks it to the rear output shaft. Drive from the input gear is now through the countergears to the rear drive gear and the rear output shaft. A gear reduction is provided by the countergears.

Transfer

For front drive, the rear sliding sleeve is moved forwards. This engages the dog teeth of the transfer drive gear and locks it to the rear output shaft. Rotation of the rear output shaft is now transferred by the transfer drive gear, via the idler gear, to the front drive gear and the front output shaft.

Front drive can be selected to give four-wheel drive whether the transfer is in high range or low range.

24.28.2 Transfer case with two output shafts

The transfer case in Figure 24.64 has a different arrangement. It has two output shafts: one for the front propeller shaft and one for the rear propeller shaft.

24.28.3 Gearshift lever positions

In manually selected transmissions with four-wheel drive, there are two gear levers: one for the normal transmission and one for the transfer case (Figure 24.65). The main transmission can have four or five gears. The transfer case has a high range and a low range for four-wheel drive (H4 and L4), a high range for two-wheel drive (H2) and also a neutral position (N). Neutral is used if auxiliary equipment is being driven from the transfer case.

The main gearshift lever is shown with common selector positions, and the transfer shift is shown with one arrangement. However, there are variations to those shown. The transfer positions will be different for a vehicle with full-time four-wheel drive.

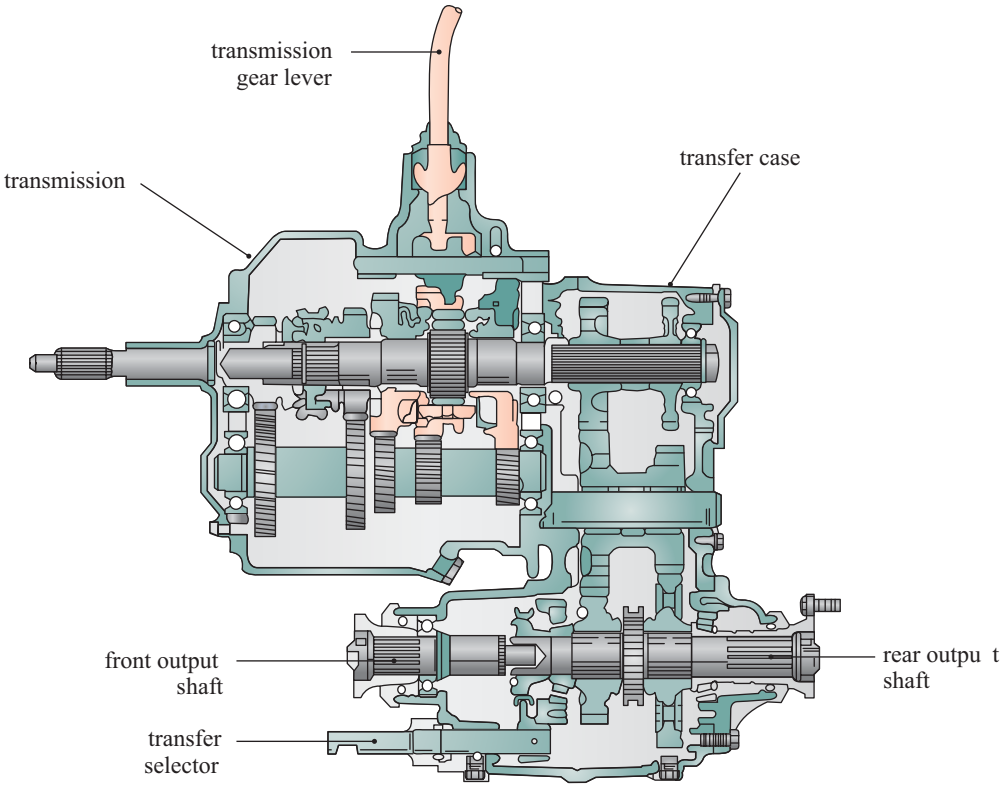


Figure 24.64 Manual transmission with a transfer case

24.29 Transfer case with chain drive

Figure 24.66 shows a transfer assembly that has a chain drive. The gearing in the transfer case provides a gear reduction of approximately 2.5:1 when low range is selected. The chain has no effect on the gear ratio. Its purpose is to transfer drive from a sprocket on the rear output shaft to a sprocket on the front output shaft.

The arrangement of the chain can be seen in Figure 24.67. The chain is a silent type, which has a number of links across its width that form teeth in the chain. The links are of normal tooth shape when the chain is flat, but are shaped so that the teeth spread as the chain passes around the sprockets. The spread teeth fill the space between the sprocket teeth so that there is no clearance between the chain teeth and the sprocket teeth—this reduces chain noise.

Handy hint: The design of the teeth mak e the chain much quieter than others, which is why it is called a silent chain .

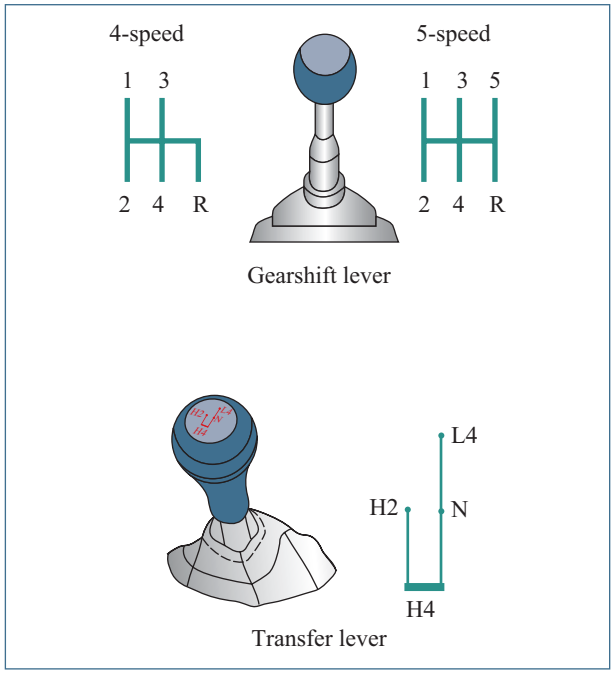


Figure 24.65 Transmission and transfer selector positions—there are also other arrangements

24.29.1 Power flow with chain drive

The diagrams in Figure 24.68 show the power flow through the transfer gearing and chain. There are three positions:

1 two-wheel drive , high range
2 four-wheel drive , high range
3 four-wheel drive , low range .

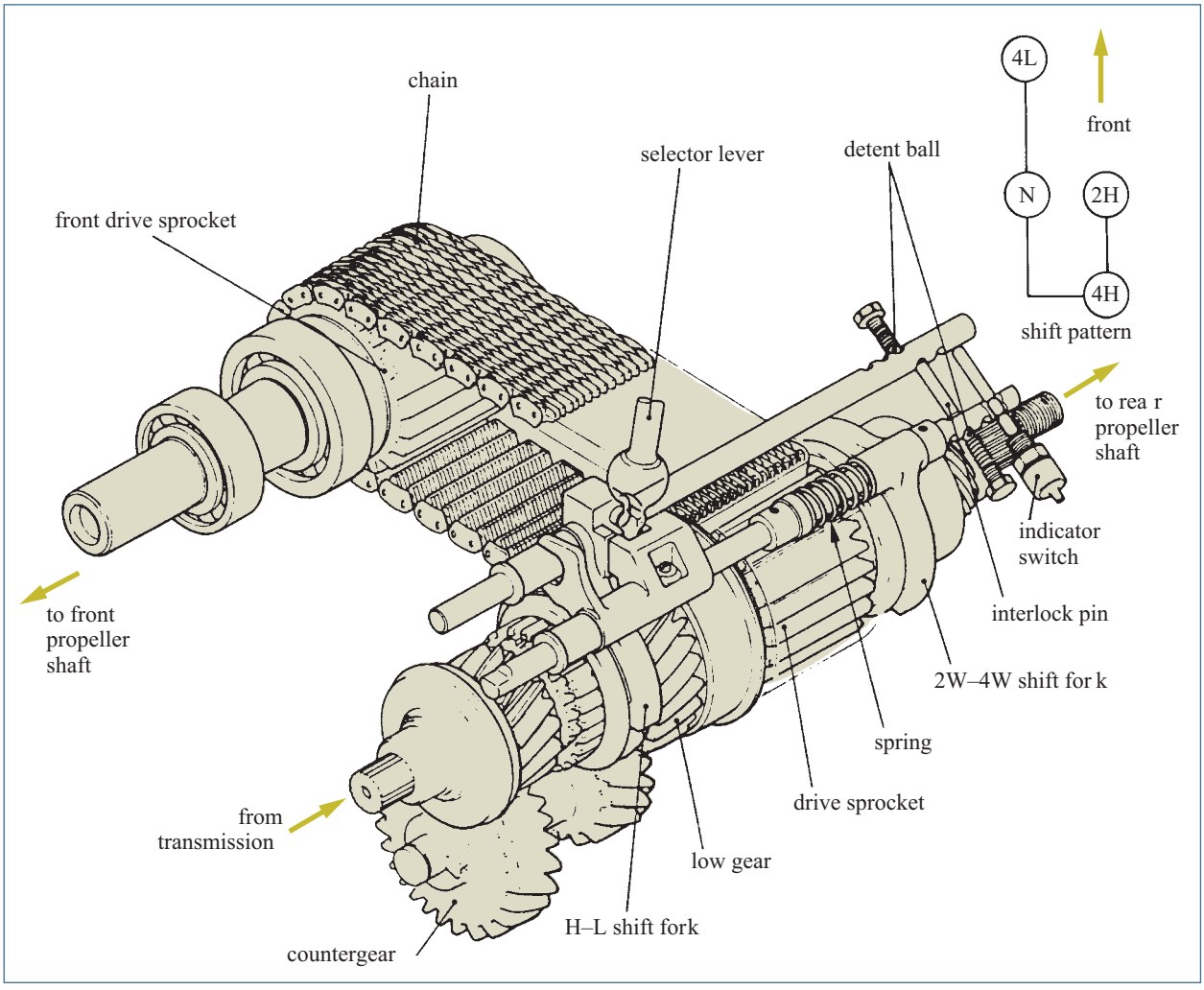


Figure 24.66 Transfer case in which a chain is used to transfer th e drive FORD

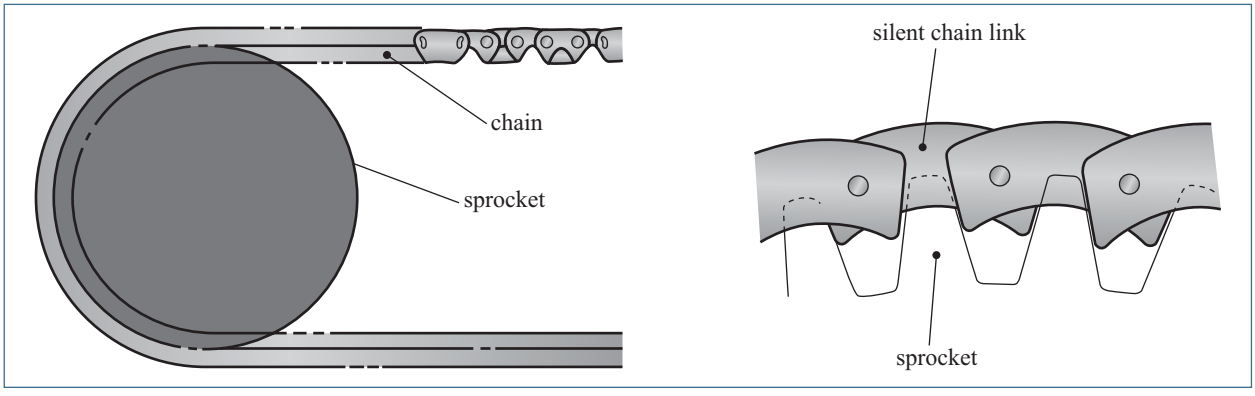


Figure 24.67 Drive chain linkage

There are two selector forks connected to the transfer shift lever. These move a sleeve which engages or disengages the dog clutches to alter the power flow through the transfer gearing.

Two-wheel drive, high range

When the transfer selector lever is moved to the 2H position, the front sleeve is moved forwards. This connects the transmission main output shaft to the transfer rear output shaft. In the transfer case, this is a straight-through drive.

Drive from the transfer case is transmitted through the propeller shaft to the rear wheels only. There is no gear reduction in the transfer case and no power to the front output shaft.

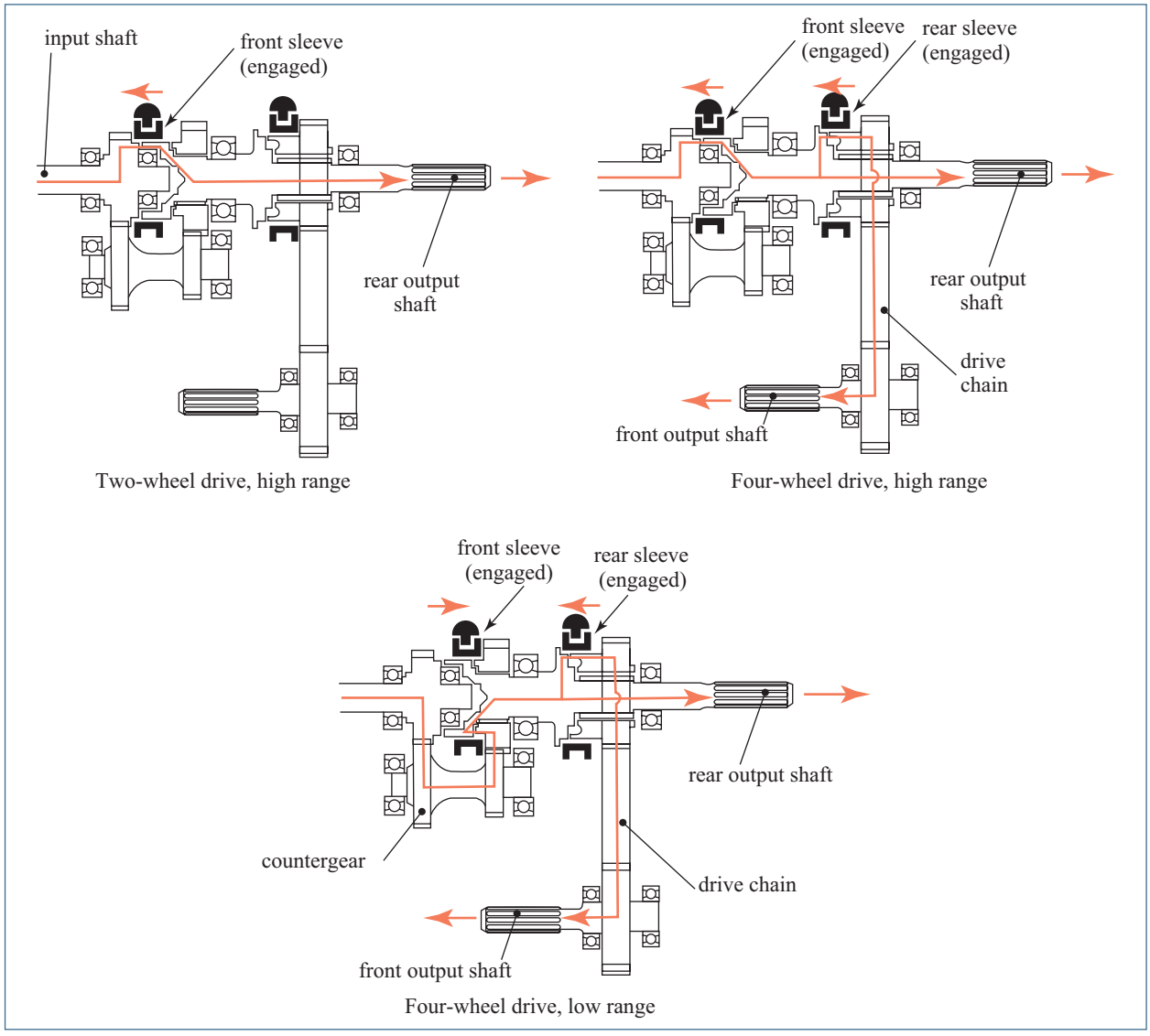


Figure 24.68 Power flow through a transfer case with a drive cha in

Four-wheel drive, high range

When 4H is selected, the rear sleeve is moved forwards. This connects the chain drive sprocket to the rear output shaft. Drive is taken through the transfer chain to the sprocket on the front output shaft. The front propeller shaft carries the drive from the front output shaft to the front axle, and the rear propeller shaft carries the drive from the rear output shaft to the rear axle.

Four-wheel drive, low range

When 4L is selected, the front sleeve is moved rearwards. This introduces the transfer countergear into the gear train. Instead of the drive going directly from the input shaft to the transfer rear output shaft, the countergear provides a reduction.

The countergear is driven by a constant-mesh gear on the input shaft, and it also drives a constant-mesh gear on the transfer rear output shaft. When the sleeve is moved, it connects the constant mesh gear to the output shaft. Drive now passes through the countergear so that the rear output shaft is driven at reduced speed. The chain also drives the front output shaft at this reduced speed.

24.30 Centre differentials

Some transmissions have a third differential. Located in the transmission, it equalises the drive between the front and rear axles, acting in the same way as a normal differential.

With a differential in the drive line, four-wheel drive can remain engaged, the centre differential preventing transmission *wind-up*. This can occur if a vehicle without a centre differential is driven in four-wheel drive

over hard-surfaced roads or through tight turns. Tyre scuffing and transmission damage could result. When a vehicle without a centre differential is operated off road, the difference in wheel speeds is handled by the loose or softer surfaces, and wind-up is not a problem.

Handy hint: A centre differential compensates for variations in speeds between the front and rear wheels.

24.30.1 Centre-differential lock

A lock is provided on some centre differentials. This locks the differential when there could be wheel spin. The rear wheels continue to drive, even if one front wheel has no traction.

24.31 Transaxle centre differentials

The arrangement of a lockable centre differential for a transaxle is shown in Figure 24.69. The transaxle centre differential and the front differential are combined into a single compact unit, which allows full-time four-wheel drive. The centre differential is always in the drive line but can be locked for bad driving conditions. The front differential is the normal transaxle differential with side gears and pinions. The side gears drive the front-wheel drive shafts in the usual way.

The centre differential has a different design. It has a simple planetary gear system which consists of internal teeth inside the final-drive ring gear, a planet carrier with pinions and a sun gear. The internal teeth are part of the final-drive ring gear, and the sun gear is connected to an intermediate gear. The final-drive ring gear is connected to the intermediate gear by the planetary gearing.

If we briefly ignore the action of the planetary gearing of the centre differential, the drive through the unit is:

1 From the output pinion of the transaxle to the final-drive ring gear
2 Through the planetary gearing to the intermediate gear

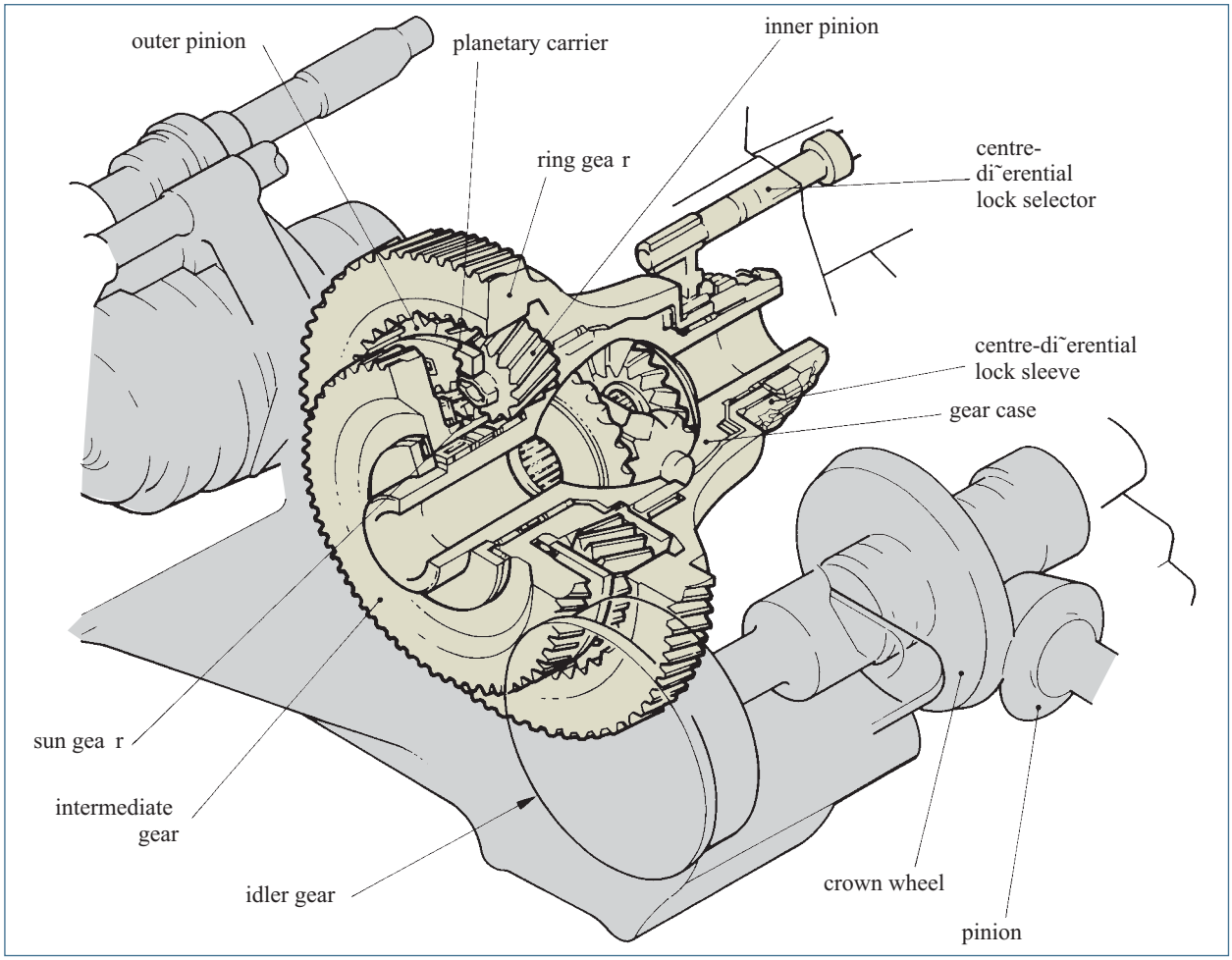


Figure 24.69 Transaxle centre differential combined with the fron t differential—the centre differential is lockable FORD

3 From there to the idler gear
4 Through the crown wheel and pinion to the pinion shaft.

The pinion shaft is connected by the propeller shaft to the rear axle, which also has a differential, and so the drive goes to the rear wheels. The side gears of the front differential drive the front-wheel drive shafts (not shown) in the usual way for a transaxle.

24.31.1 Planetary action

The planetary gearing is located between the internal teeth of the ring gear and a sun gear attached to the intermediate gear. With equal load on the front and rear wheels of the vehicle, there is no planetary action. The gearing merely transfers drive from the final-drive ring gear to the intermediate gear without any change in speed.

Whenever there is a difference in speed between the front and rear wheels, planetary action occurs. This allows the ring gear and the intermediate gear to rotate at different speeds. While the gears are arranged differently, the action is similar to that of the gears in a normal differential—the planetary gearing carries drive between the final-drive ring gear and the intermediate gear while still allowing movement between the two gears.

24.32 Viscous couplings

A viscous coupling can be used with a centre differential, a rear differential or a front differential. It limits the difference in speed between the front and rear drives, acting like a limited-slip clutch for the centre differential. It allows a small difference in speed between the front and rear drives, but acts automatically to prevent any great differences.

Figure 24.70 shows the construction of a viscous coupling. It consists of a number of plates, with one set of plates splined to the coupling casing and the other set splined to its hub. Spacer rings locate the plates in the casing. The coupling contains silicone oil and has X-shaped seals. These retain the oil under operating pressure.

The coupling operates whenever there is a difference in rotational speed between the hub and the casing. Slots in the plates cause shearing of the silicone oil, creating a fluid-coupling effect.

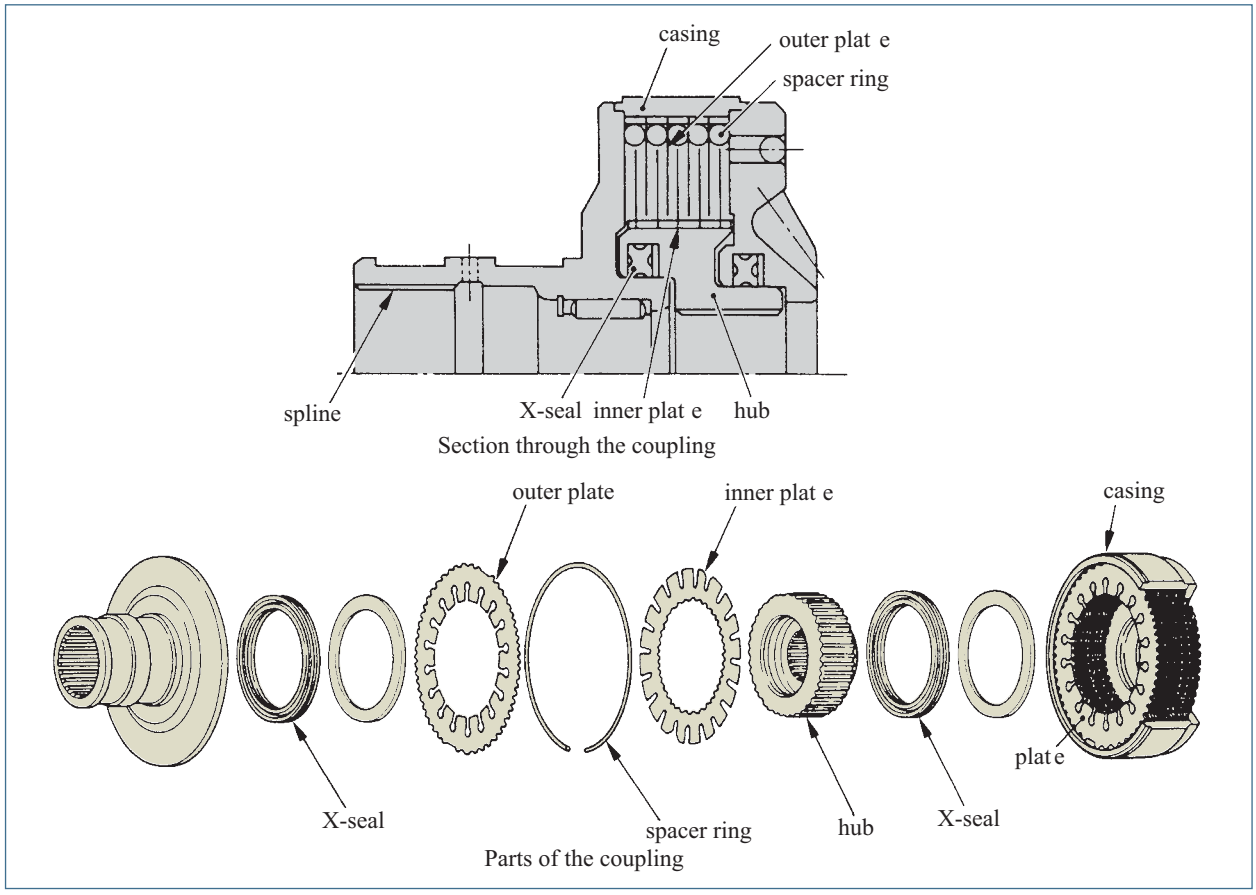


Figure 24.70 Construction of a viscous coupling SUBARU

Handy hint: The plates of a silicone coupling do not come into contact with each other; they are separated by the silicone oil.

24.32.1 Centre viscous coupling

Figure 24.71 shows a viscous coupling fitted to the centre-differential assembly of a transaxle.

24.32.2 Transaxle with crown wheel and pinion and viscous coupling

The transaxle in Figure 24.72 is used with a longitudinally mounted engine. It has a crown wheel and pinion, a centre differential and a viscous coupling. The front drive shafts are connected to the differential assembly at the front of the transmission in the normal way. The propeller shaft to the differential at the rear of the vehicle is connected to splines on the output shaft that extends from the rear of the transaxle.

The viscous coupling and the differential are, in effect, an extension of the countershaft of the transmission.

24.33 Transfer unit with chain and viscous coupling

The transfer unit in Figure 24.73 has planetary reduction gearing, a transfer chain, a centre differential and a viscous coupling. So there are three actions to consider: gearing, differential and coupling.

24.33.1 Gearing

The planetary gearing provides a high range, a low range and neutral. The ring gear is fixed to the casing. Input to the gearing is from the transmission output shaft to the sun gear of the planetary gearing. The gearing functions as follows.

Neutral

The sun gear drives the planet pinions, and these walk around inside the ring gear. No drive is transmitted.

High range

The coupling sleeve is moved to the right so that the sun gear is connected to the chain drive sprocket. Drive is transmitted by the chain to the driven sprocket on the differential assembly.

Handy hint: The sprocket ets are the same size , so there is no reduction.

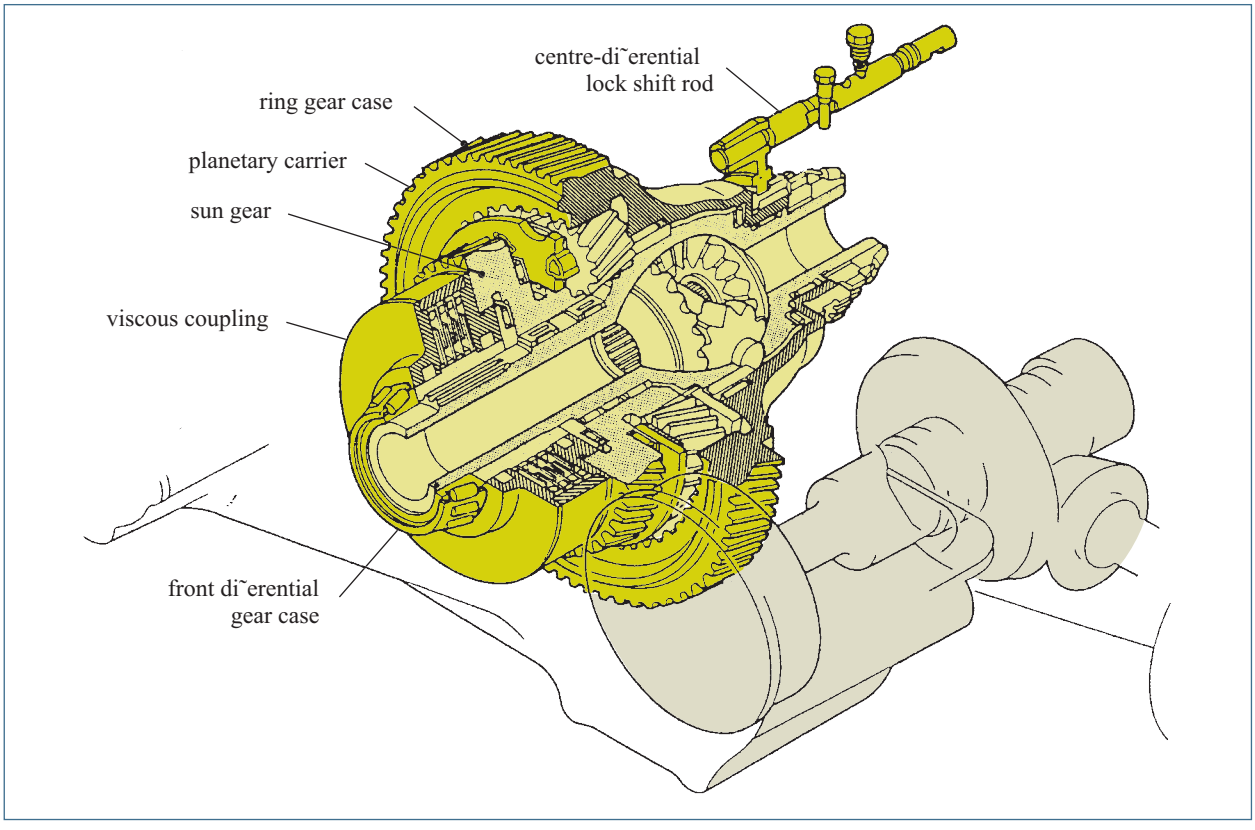


Figure 24.71 Centre differential with a viscous coupling and a differential lock FORD

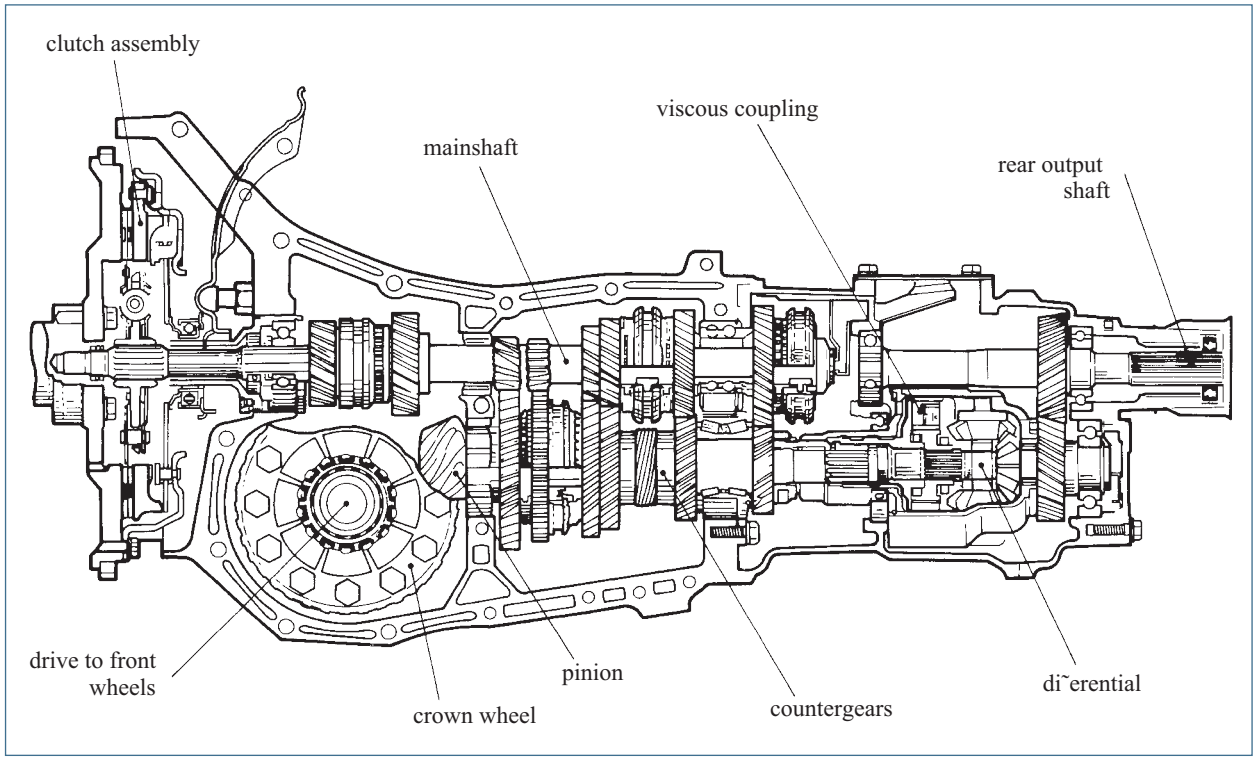


Figure 24.72 Full-time four-wheel-drive transaxle has a centre differential and viscous coupling. It also has a crown wheel and pinion for the front-wheel drive SUBARU

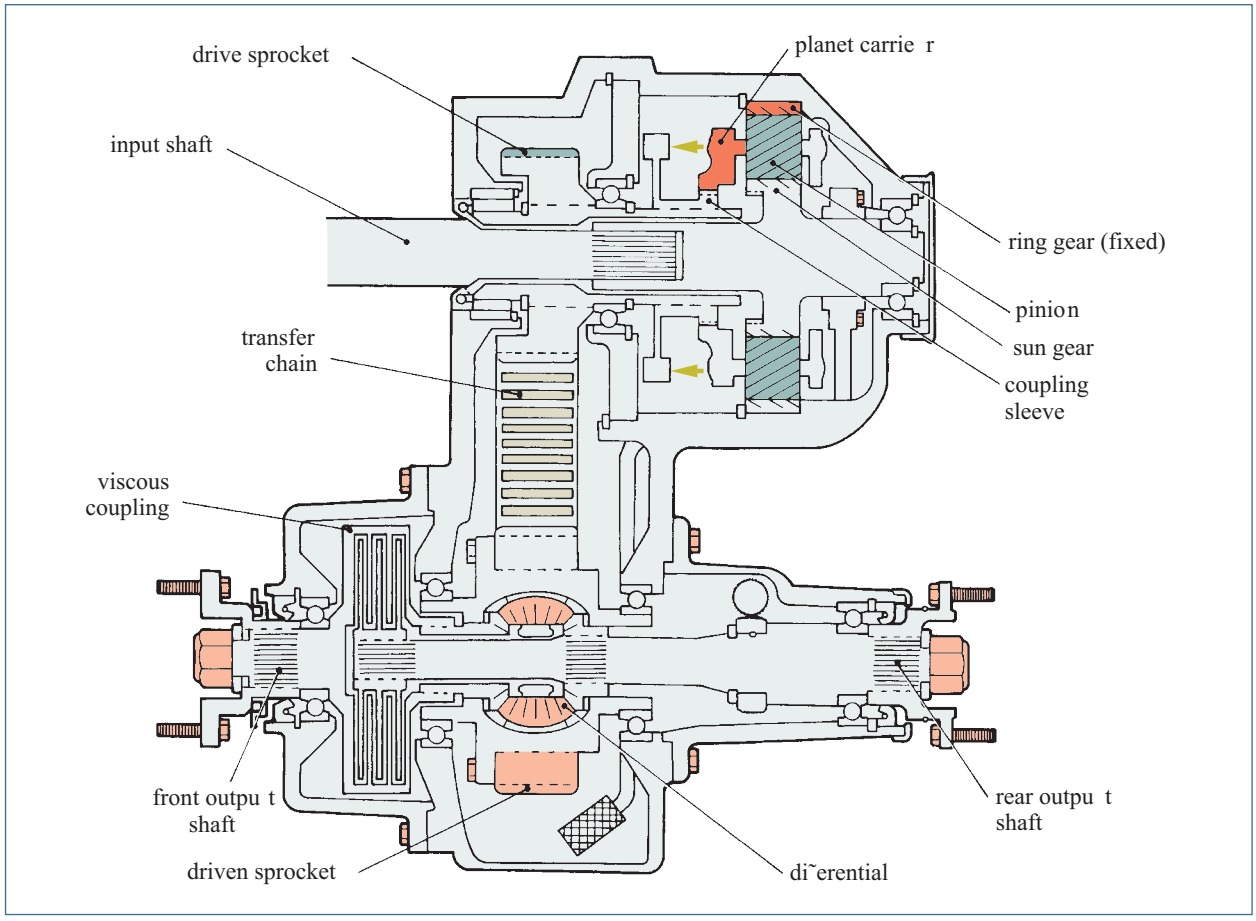


Figure 24.73 Transfer case with planetary gearing, a transfer chain and a viscous coupling (low range is selected)

Low range

The coupling sleeve is moved to the left so that the carrier is connected to the chain drive sprocket. There is now a reduction in speed in the planetary gearing. This occurs between the sun gear and the planet carrier. This will reduce the speed of the chain sprocket, the chain and the differential assembly.

24.33.2 Differential

The differential has the chain-driven sprocket attached to its case. Ignoring the viscous coupling, the differential side gears are connected to the front and rear output shafts, and this provides normal differential action.

24.33.3 Viscous coupling

The viscous coupling is connected between the two output shafts. One side gear has internal splines for the rear output shaft, which also extends into the hub of the coupling. The other side gear has external splines which carry the viscous-coupling casing. The casing is joined to the front output shaft.

With the vehicle being driven on a dry, sealed road surface, there will be little movement between the plates in the coupling. The differential will act normally to compensate for slightly different speeds between

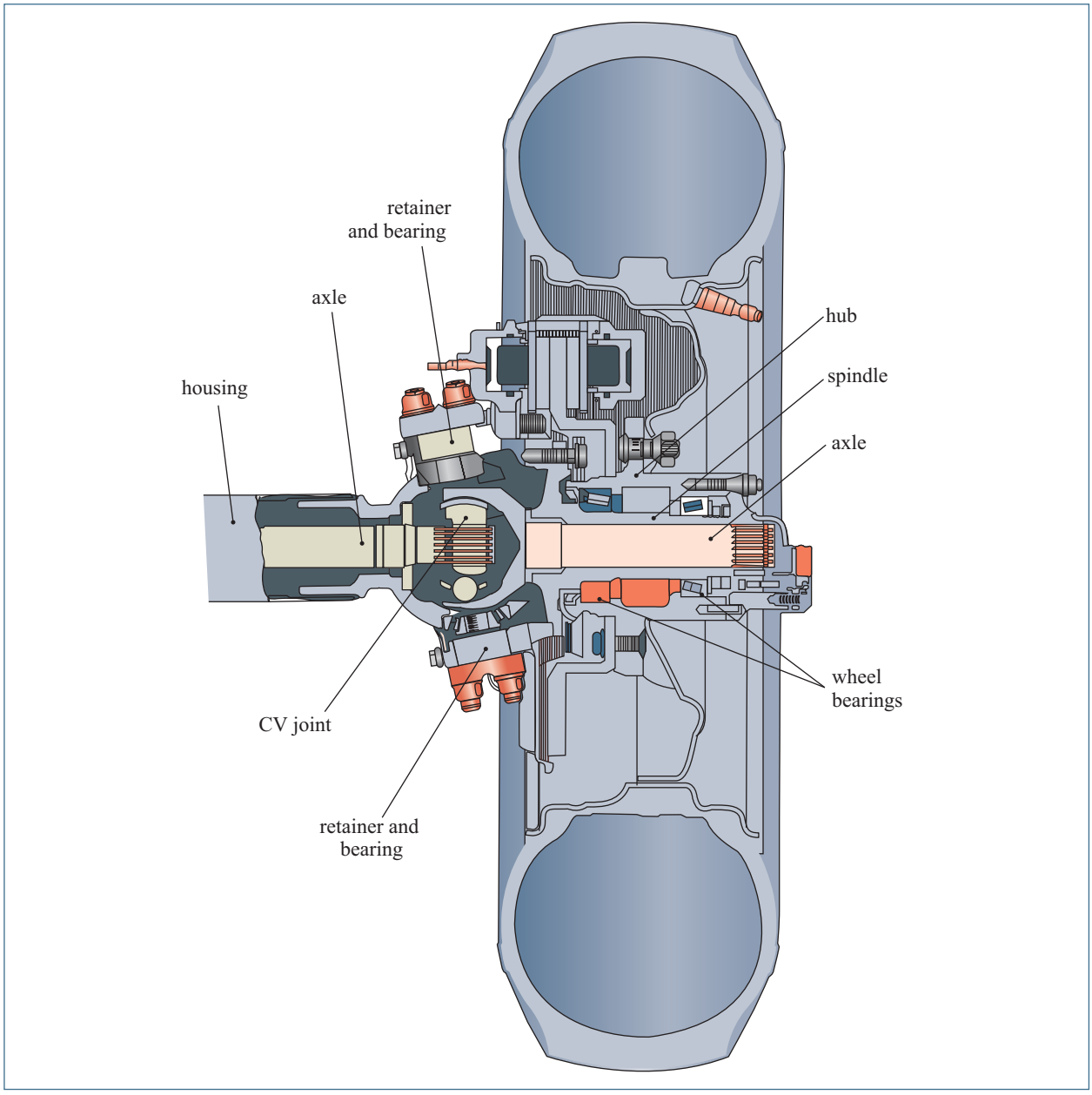


Figure 24.74 Steering knuckle , hub and wheel assembly for a four-wheel-drive front axle

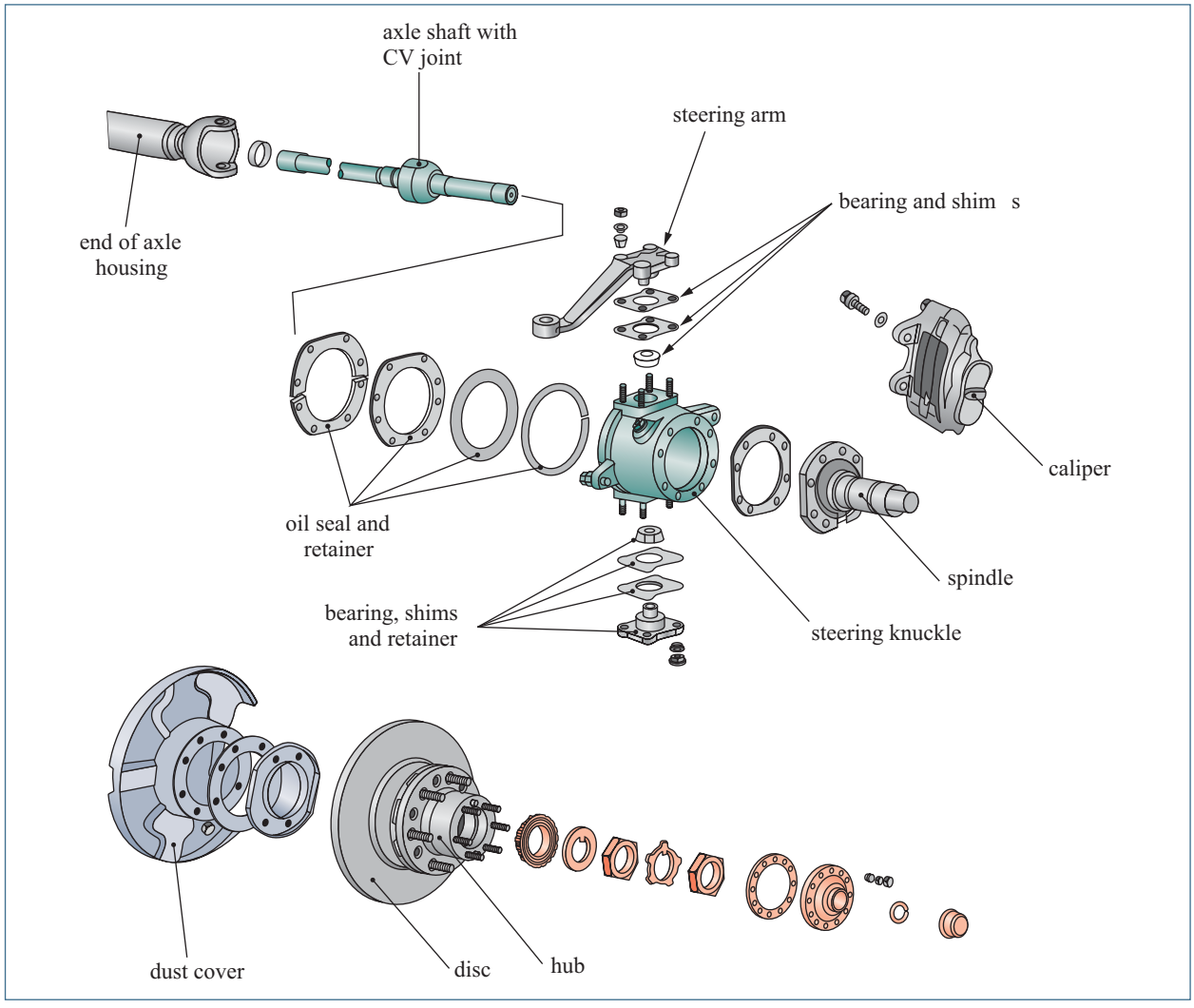


Figure 24.75 Parts of a dismantled steering-knuckle assembly

the front and rear input shafts. When there is a difference in speeds between the output shafts, the silicone coupling will automatically hold to prevent wheel spin.

Figure 24.74 shows a section through the end of a rigid axle and wheel assembly. The steering knuckle is pivoted on tapered roller bearings on the ball end of the axle housing. The drive shaft is fitted with a Birfield constant-velocity (CV) joint.

Handy hint: Birfield-type joints are one of the types of C V joints used with front-wheel-drive vehicles.

Components

The parts of a dismantled steering knuckle and axle shaft assembly are identified in Figure 24.75. The main parts shown are the end of the axle housing, the axle shaft, the steering knuckle, axle spindle, hub and disc assembly and the disc brake caliper.

24.33.4 Freewheel hubs

Special freewheel hubs can be fitted to the front wheels (Figure 24.76). This enables the drive to be disconnected at the wheels when front-wheel drive is not being used. The front part of the drive train is not needed and remains stationary. Without freewheel hubs, parts of the drive train would rotate, but not carry load, even though front-wheel drive is not engaged. Most freewheel hubs are locked and unlocked manually by turning the centre of the hub to the free position. Some hubs have an automatic lock.

Safety: Both hubs must be in either the lock or free positions.

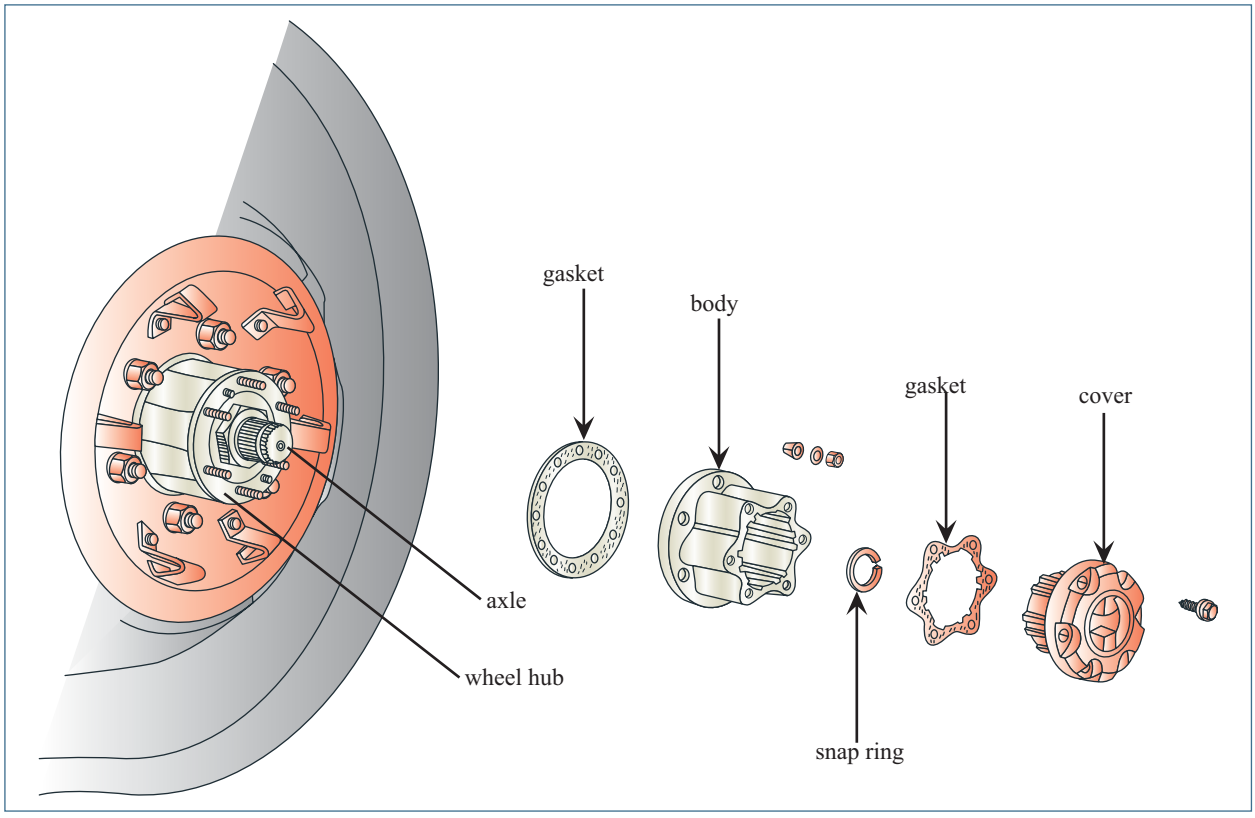


Figure 24.76 Parts of a freewheel hub for the front wheel of a four-wheel-drive vehicle

24.34 Four-wheel-drive service

Four-wheel-drive vehicles have the same service requirements as two-wheel-drive vehicles, except that extra cleaning and attention is needed for offroad vehicle use. Relevant points include:

1. Protection against corrosion is needed where the vehicle is used on beaches.
2. Air cleaners will require more frequent service where a vehicle is operated in dusty conditions.
3. The engine oil and the oil filter will need changing more often for offroad operation.
4. Offroad vehicles and light commercial vehicles usually have grease nipples, or plugs for grease nipples, on steering and suspension ball joints. These need regular lubrication.
5. Universal joints are usually fitted with grease nipples so they can be easily lubricated (Figure 24.77).

24.34.1 Four-wheel-drive operation

Following are lists of general do's and don'ts for a four-wheel-drive vehicle. Some of these apply generally to all four-wheel drives; others will vary according to the particular vehicle—especially full-time drives.

Do's

1. Do lock freewheel hubs, where fitted, before engaging four-wheel drive .
2. Do turn freewheel hubs to 'free ' when four-wheel drive is not to be used.
3. Do select low range for extreme offroad conditions or wherever low-speed manoeuvring is needed.
4. Do use engine braking for sharp descents. Select a low gear so that the vehicle moves slowly .
5. Do reduce the tyre pressures if driving on marshy ground or sand. This will improve traction by increasing tyre flotation.
6. Do lock the centre differential when negotiating rough tracks where wheel spin could occur .
7. Do dry out brak es after driving through water . This can be done by driving a short distance with the brak es applied.

Don'ts

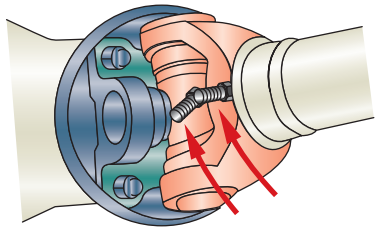
1. Don't engage four-wheel drive with the rear wheels spinning.
2. Don't engage the differential lock unless the wheels are stopped.

3 Don't lock the differential on hard-surfaced roads.
4 Don't engage four-wheel drive on hard-surfaced roads.
5 Don't let the engine labour before changing to a lower gear .
6 Don't change to low ratio with the vehicle moving.
7 Don't use the clutch as a footrest.

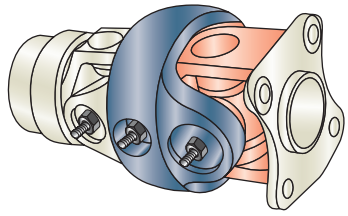
24.35 All-wheel drive

All-wheel drive provides drive to all four wheels of a passenger vehicle. Because the drive is permanently connected to both front and rear wheels, vehicles of this type are often referred to as having full-time four-wheel drive.

The main difference between all-wheel drive for passenger vehicles and four-wheel drive in other vehicles is the gearing arrangement. Vehicles classed as four-wheel drives have some form of transfer case or gearing. This provides low gear ratios and allows the four-wheel drive to be disconnected, so the vehicle can be operated in either two- or four-wheel drive.



Cross-type joint



Double Cardan joint

Figure 24.77 Lubrication points on universal joints

All-wheel drive vehicles have standard gear ratios and many have permanent all-wheel drive. This cannot be disconnected, but the ratio of drive can be split between front and rear drive in various ways.

Handy hint: The way that the drive is split is a function of the system and is not directly controlled by the driver .

24.35.1 Advantages of all-wheel drive

Traditionally, passenger vehicles have either front-wheel drive or rear-wheel drive. Both systems have advantages and disadvantages. For example, attempting to drive a front-wheel vehicle up a steep slope could be compromised by weight transfer from the front to the rear wheels, as shown in Figure 24.78(a). A rear-wheel-drive vehicle attempting to reverse up the slope, as shown in Figure 24.78(b), could encounter a similar problem for the same reason. In both instances, if all four wheels were driving, the vehicle would negotiate the slope more successfully.

All-wheel drive also improves traction and stability for normal driving. With two-wheel-drive passenger vehicles, it could be difficult to prevent wheel spin during acceleration, particularly on wet and loose surfaces. With all the wheels driving, wheel spin is avoided, except in unusual circumstances.

Another way to prevent wheel spin is by traction control (TC). Traction control systems use the vehicle's antilock braking system (ABS) to apply the brake to prevent a wheel from spinning. Traction control, with the aid of the engine management system, also reduces the engine torque. With both systems operating, all-wheel drive gives improved

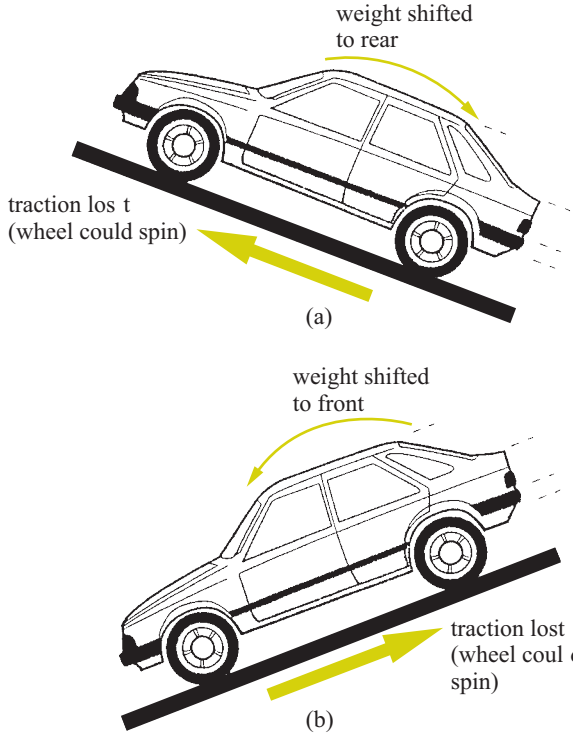


Figure 24.78 Vehicle being driven on a slope
(a) front-wheel-drive vehicle being driven up the slope
(b) rear-wheel-drive vehicle reversing up the slope

traction during normal driving, and traction control generally helps prevent wheel spin under particular operating conditions.

Handy hint: All-wheel drive and traction control are both used on some vehicles.

24.36 Transmission and transaxle fault diagnosis

Table 24.1 sets out categories of transmission and transaxle problems.

Table 24.1 Transmission and transaxle fault diagnosis (general)

Complaint	Possible cause	Check or correction
Hard gear shifting	Clutch not releasing fully	Adjust
	Gearshift linkage out of adjustment	Adjust
	Incorrect lubrication of linkage	Lubricate
	Shift fork bent	Replace or straighten
	Sliding gear tight on splines	Clean splines or replace
	Synchromesh unit damaged	Replace defective parts
	Interlock sticking	Free or replace parts
	Incorrect lubricant	Change lubricant
Sticking in gear	Clutch not releasing	Adjust
	Gearshift linkage out of adjustment	Adjust
	Incorrect lubrication of linkage	Lubricate
	Detent balls (selector) stuck	Free up
Slipping out of gear	Gearshift linkage out of adjustment	Adjust
	Weak detent springs	Replace
	Excessive mainshaft end-play	Replace parts or adjust
	Gear teeth worn	Replace gears
	Synchromesh unit worn or defective	Replace worn parts
	Excessive end-play of gears	Replace gears or thrusts
No power through transmission	Clutch slipping	Adjust or replace parts
	Clutch disc worn or broken	Replace parts
	Cable or linkage defective	Replace cable or repair
	Shifter fork or other part broken	Replace parts
	Gear or shaft broken	Overhaul transmission
Noisy in neutral	Input shaft bearing faulty	Replace bearing
	Gears worn	Replace gears
	Countershaft or bearings worn	Dismantle and replace shaft and/or bearings
Noisy in gear	Mainshaft bearings worn	Replace bearings
	Gear teeth worn	Replace gears
	Constant-mesh gear bearings worn	Replace bearings
	Final-drive gears	Check or adjust
	Differential side bearings worn	Replace
	Drive shaft components loose or dry	Replace and lubricate
Gears clash in shifting	Clutch not releasing fully	Adjust clutch
	Synchromesh unit defective	Replace parts
	Driver forcing a gearshift	Shift correctly
	Interlock faulty	Adjust
Oil leaks	Lubricant level too high	Correct level
	Drain plug leak	Tighten or replace washer
	Gaskets broken or missing	Renew gasket or sealing
	Oil seals damaged or worn	Replace seal
	Bearing retainer bolts loose	Tighten
	Transmission case damaged	Repair or replace
	Vent blocked	Clean vent

24.37 Road testing and diagnosis

A road test will check the serviceability of a transmission, diagnose a fault or check a repair. Figure 24.79 shows checks that can be made on the road. (During a road test, the clutch should also be checked.)

Gears should engage without noise, synchromesh units should provide clean shifts and there should be no unusual noises in any gear. Check operation in all gears, on both drive and overdrive. Also check for noises and for jumping out of gear.

Handy hint: Drive is when accelerating, and overdrive is when decelerating.

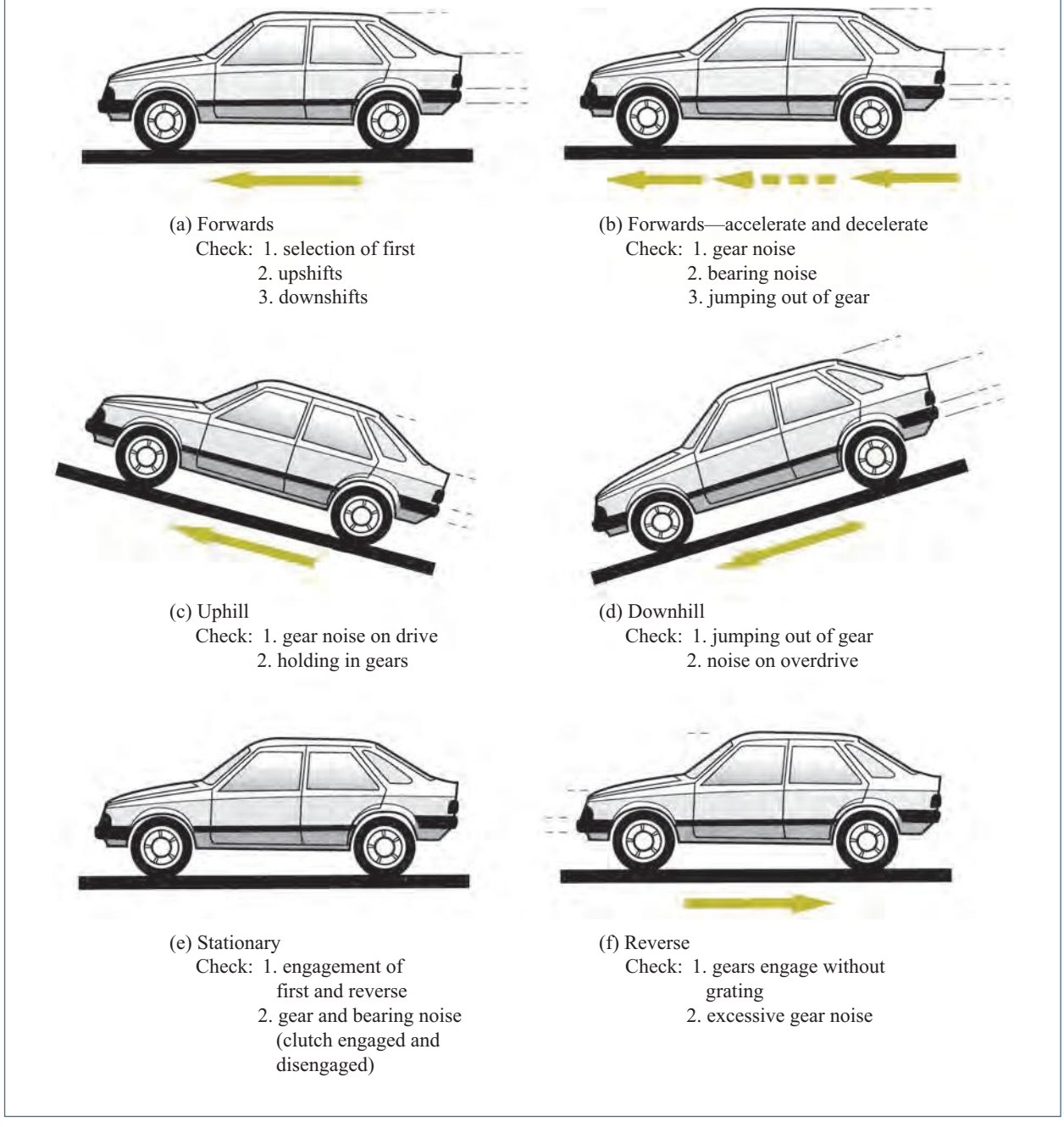


Figure 24.79 Road testing a manual transmission or transaxle

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify manual transmissions, transfer cases and components
- describe the function of manual transmissions, transfer cases and components
- describe the operating principles of light vehicle manual transmissions, transfer cases and associated components
- name the types and applications of manual transmissions and transfer case lubricants
- apply inspection procedures for manual transmissions and transfer cases
- apply service and adjustment procedures for manual transmissions and transfer cases, including lubricating components as required
- apply diagnostic testing procedures for light vehicle manual transmissions, including road testing procedures that include drive shaft noise and vibration
- apply repair procedures for light vehicle manual transmissions, including procedures for dismantling manual transmissions, inspecting manual transmissions and reassembling
- apply post-repair testing procedures for light vehicle manual transmissions.

REVIEW QUESTIONS

1 Why is a transmission used in a motor vehicle ?
2 What are the common types of gears ?
3 What is gear ratio ?
4 If a gear with 45 teeth is meshed with a gear with 18 teeth, what is the effect?
5 What is the relationship between torque and speed for the different gear ratios of a transmission ?
6 Name the gears that are under load in a simple three-speed transmission when it is operating in first gear .
7 What are constant-mesh gears ?
8 Where are sliding gears used?
9 What is the main drive gear in a transmission ?
10 What is a transaxle ?
11 State the components being driven when a dual-clutch transmission is in second gear .
12 What additional parts are used in a transaxle compared with other transmissions ?
13 Explain briefly how a synchroniser operates to synchronise the speed of the gears.
14 Why are detents used?
15 What is an interlock ?
16 Why is a workshop manual needed when working on a transmission or transaxle ?
17 What are the four general problems that would make it necessary to dismantle a transmission ?
18 How is the oil checked in transmissions and transaxles ?
19 Where are transmission or transaxle oil leaks likely to come from ?
20 Describe how a synchroniser is reassembled.
21 How would constant-mesh gears be checked on their shaft?
22 Why is correct end-play (end-float) necessary with transmission parts ?
23 What types of bearings support the output of a transaxle ?
24 What type of bearings are used with constant-mesh gears ?
25 Which bearings of a transaxle are given preload?
26 In general terms, how is preload adjusted?
27 Describe how you would inspect the main parts of a transmission or transaxle .
28 What are some of the things that could cause transmission noise ?
29 State the various checks that would be made during a transmission road test.
30 What are some important points that relate to removing and reinstalling a transmission or transaxle ?

CHAPTER 25

Drive lines and shafts

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify operating principles of light vehicle drive shaft s and associated components
2 recall the application, purpose and operation of light vehicle drive shafts and associated components
3 follow relevant diagnostic testing procedures, including road testing procedures
4 follow relevant repair procedures, including those for removing, replacing and adjusting the systems
5 follow relevant post-repair testing procedures.

There are three general arrangements of drive lines: rear-wheel, front-wheel and four-wheel. Most rear-wheel-drive vehicles have the engine at the front and use a drive shaft (also called a propeller shaft) to connect the transmission to the final drive at the rear. Axles, or in some cases drive shafts, connect the final drive to the rear wheels.

In front-wheel-drive vehicles, the final drive is part of the transaxle assembly , and drive shafts carry the drive from the transaxle to the front wheels.

Four-wheel-drive and all-wheel-drive vehicles have two drive lines. One connects the transmission or transaxle to the rear axle to drive the rear wheels; the other connects the transmission or transaxle to the front wheels.

This chapter relates to rear-wheel drives and front-wheel drives. Four-wheel drive and all-wheel drive vehicles are discussed in Chapter 24.

25.1 Rear-wheel drive

With conventional rear-wheel drives, the engine and transmission are mounted lengthwise at the front of the vehicle. The propeller shaft carries the drive from the transmission to the rear axle.

With a rigid rear-axle assembly, the design of the drive line takes into account that the engine and transmission are firmly mounted to the body subframe or chassis at the front of the vehicle, while the rear-axle assembly is attached by springs. As the vehicle moves up and down in relation to the rear axle, the angle and length of the propeller shaft will change with body movement (Figure 25.1).

To compensate for this, the propeller shaft is fitted with universal joints which permit changes in the angle of drive. It also has slip splines at the front of the shaft which allow the length of the shaft to vary as the angle changes.

A vehicle with independent rear suspension (IRS) does not have a rigid rear axle, having instead a separate differential assembly and external drive shafts. The differential assembly is mounted on a subframe attached to the body of the vehicle, and the drive shafts connect it to the rear wheels. The differential assembly moves up and down with the body. However, the propeller shaft still needs universal joints for alignment and to accommodate flexing of the engine, transmission and rear-end mounts.

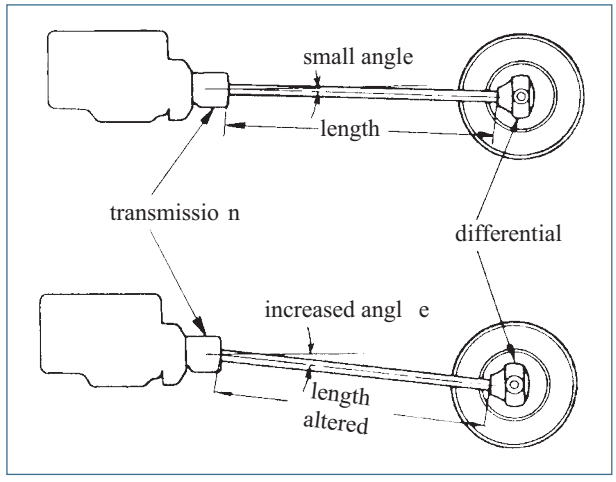


Figure 25.1 Movement of the rear-axle housing changes the angle and length of the propeller shaft

25.1.1 Propeller shaft

A typical propeller shaft is shown in Figure 25.2. It is tubular with a universal joint at each end. The rear universal joint is bolted to the pinion flange, and the front universal joint has a sleeve with slip splines that fits into the rear of the transmission.

Many vehicles have a single shaft similar to the one shown, although some larger passenger cars and light trucks have a two-piece shaft, making balance and vibration easier to control. A single, long propeller shaft is more difficult to balance.

A two-piece propeller shaft for a passenger car is shown in Figure 25.3. This has three universal joints, one of which is known as a constant-velocity joint (CV joint). It has a centre bearing supporting the rear end of the front shaft, and this is mounted to a crossmember attached to the body subframe.

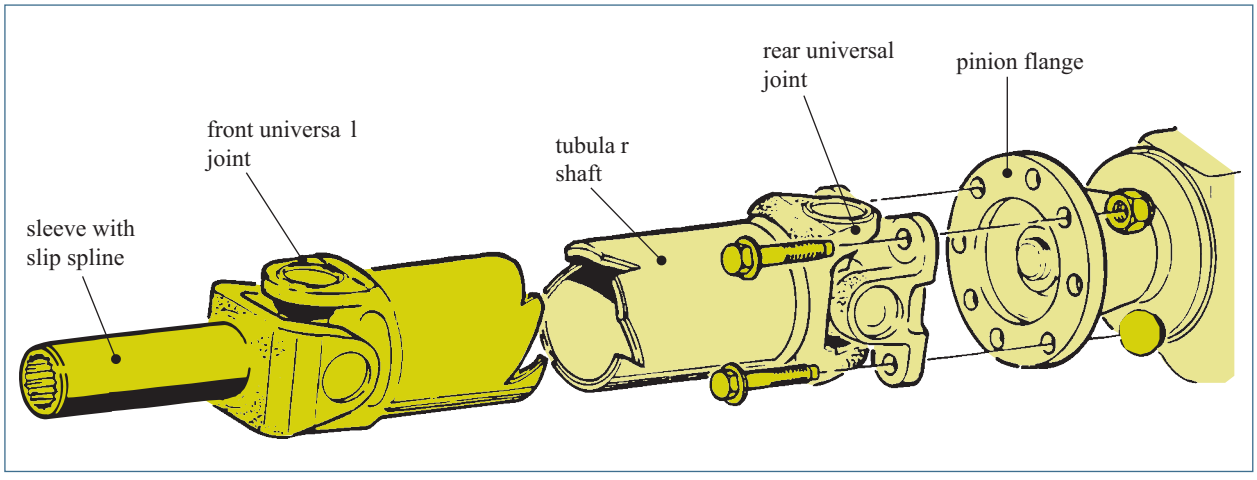


Figure 25.2 A single-piece propeller shaft with its parts identified FORD

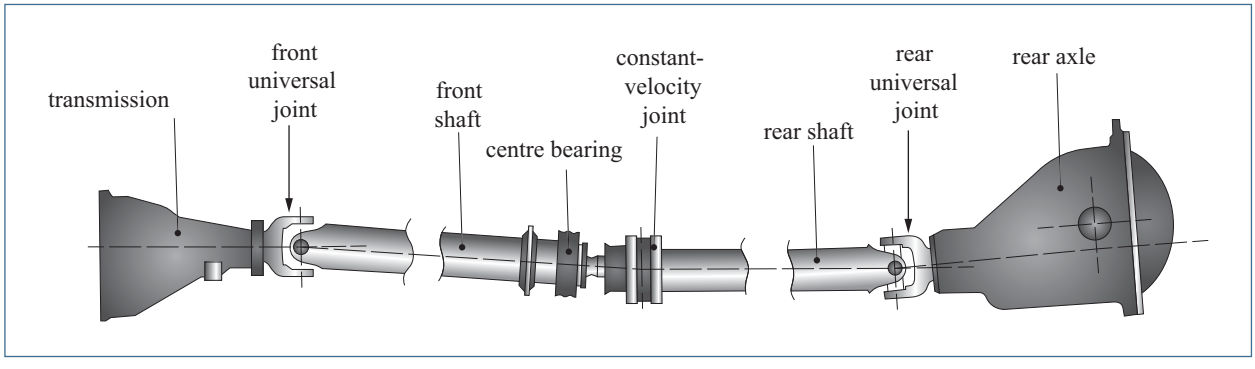


Figure 25.3 Two-piece shaft for a passenger car

25.2 Universal joints

A simple universal joint is illustrated in Figure 25.4. This was originally named a *Hooke's joint* or a *Cardan joint,* after its designers. It consists of two yokes attached to a spider, or cross, with the parts free to move in relation to each other. When fitted between two shafts, the arrangement enables the shafts to operate at an angle, the drive being transferred through the universal joint. The principle of the simple universal joint applies to cross-and-yoke-type universal joints, which are used in the drive line of rear-wheel-drive vehicles.

Other universal joint designs include constant-velocity (CV) joints, which are used with front-wheel-drive vehicles and drive shafts of independent rear suspensions.

25.2.1 Cross-and-yoke joint

The parts of a cross-and-yoke joint are shown in Figure 25.5. This has two yokes with a cross in between. Needle rollers are carried in bearings cups. The cups fit into the yokes and over the ends of the cross so that the needles operate on the cross trunnions.

This type of universal joint is commonly used at the front and rear of the propeller shaft of rear-wheel-drive vehicles, although there are some variations in the actual design.

The front yoke of the universal joint on the front of the propeller shaft has slip splines. These fit over mating splines on the transmission output shaft. The rear end of the propeller shaft is bolted to the pinion flange at the rear axle.

25.2.2 Rubber-type coupling

Figure 25.6 shows a flexible rubber coupling that connects the transmission output shaft to the front of the propeller shaft. The transmission output shaft and the propeller shaft both have flanges with three arms. The rubber coupling is bolted between the flanges. This type of coupling can absorb some of the noises and vibrations that would be transferred by a metal coupling.

25.2.3 Velocity of universal joints

The commonly used cross-and-yoke universal joint will rotate the shaft that it is driving at a constant

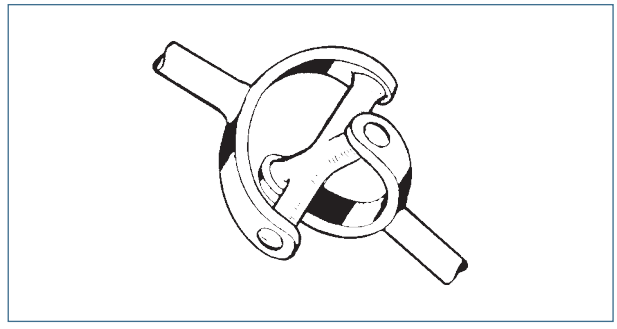


Figure 25.4 Simple universal joint

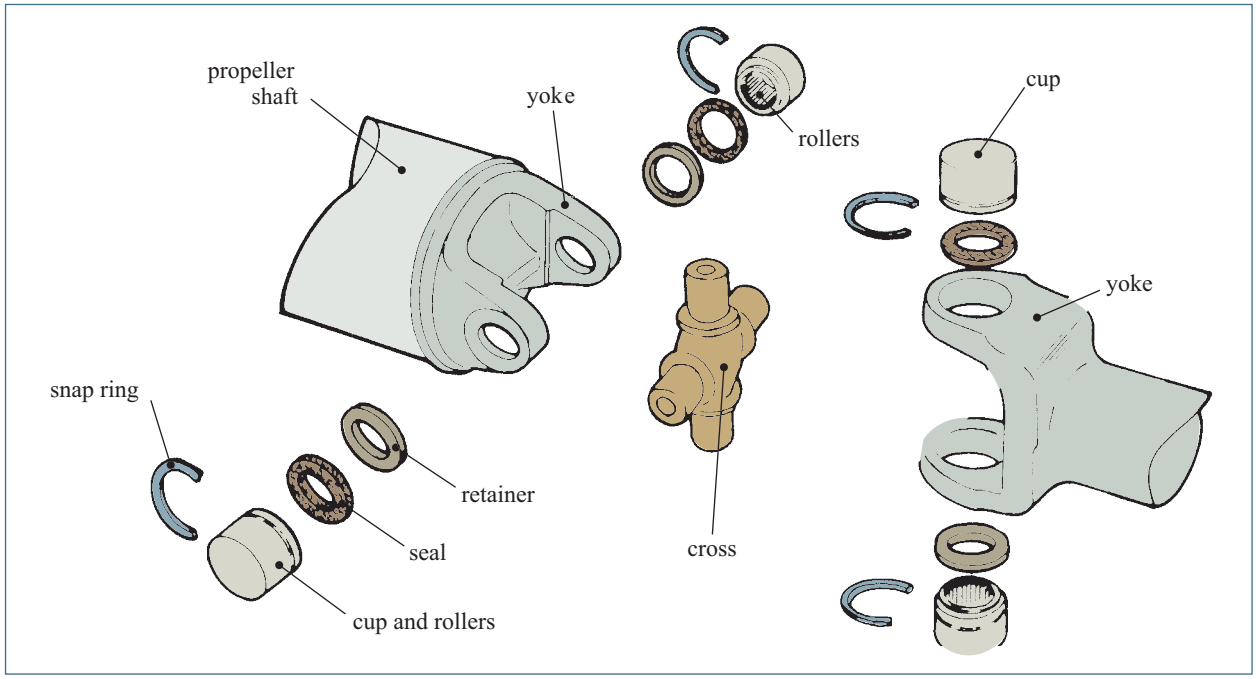


Figure 25.5 Parts of a cross-and-yok e universal joint MITSUBISHI

speed only as long as the two shafts that it connects are in a straight line.

When a change of angle occurs between the shafts, the joint will impart rotation at a varying speed; the rotational speed of the shaft will increase slightly and then decrease slightly as the universal joint rotates. This is called velocity fluctuation and it occurs because of movement within the parts of the joint. It causes momentary acceleration and deceleration of the driven shaft that can cause noticeable shaft vibration.

Handy hint: The greater the angle of drive , the greater will be the effect that causes vibrations.

25.3 Constant-velocity joints

Constant-velocity joints are special types of universal joints designed to transmit rotary motion to shafts at a constant velocity (speed) and so eliminate vibration.

The drive shaft in Figure 25.3 has a Löbro constant-velocity joint at the front end of the rear shaft as well as two cross-and-yoke universal joints. The constant-velocity joint is used to reduce the shaft vibration that could occur due to the angle between the two parts of the shaft.

Constant-velocity joints are used on the propeller shafts of some rear-wheel-drive vehicles; on the rear-axle drive shafts of rear-wheel-drive vehicles with independent rear suspension; and on the drive shafts of front-wheel-drive vehicles. There are a number of different designs.

25.3.1 Double Cardan joint

A double Cardan joint is similar to two cross-and-yoke universal joints combined (Figure 25.7). Although not common, it is used in some light commercial vehicles and some four-wheel-drive vehicles.

This joint allows greater shaft angularity than a normal cross-and-yoke joint. It has the characteristics of a constant-velocity joint because one part of the joint cancels out the vibrations of the other part.

25.3.2 Löbro constant-velocity joint

A Löbro constant-velocity joint is shown in section in Figure 25.8. This has an outer race, an inner race and a cage with steel balls (Figure 25.9). The outer race is bolted to the flange of the front propeller shaft, the inner is splined to the front end of the rear propeller shaft. The joint is enclosed by a dust shield and boot. The front shaft is supported by a centre bearing.

This type of joint allows changes in both propeller shaft angle and length. Both the inner race and the outer race have angular grooves for the balls.

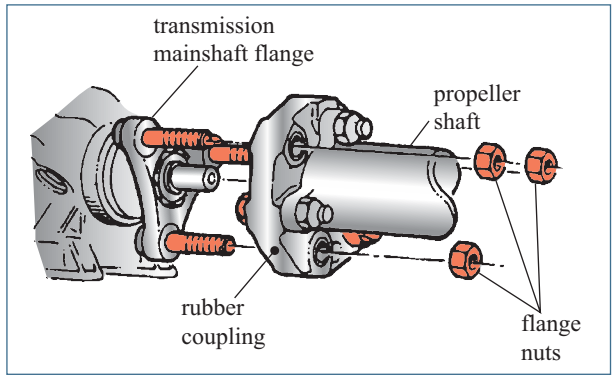


Figure 25.6 Propeller shaft with a flexible rubber coupling GM HOLDEN LTD

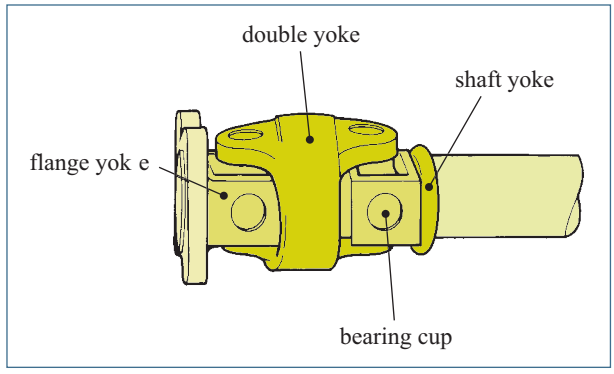


Figure 25.7 Double Cardan joint

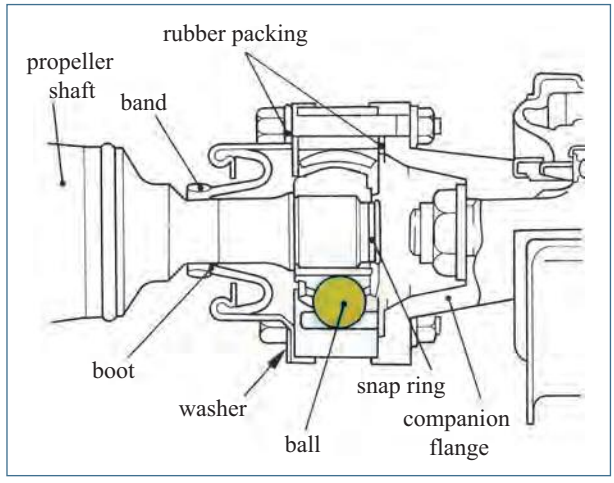


Figure 25.8 Löbro constant-velocity universal joint MITSUBISHI

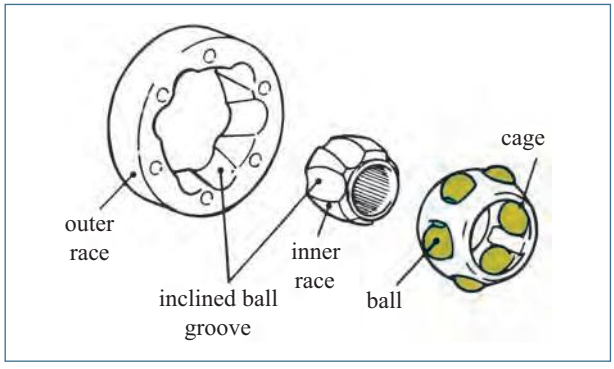


Figure 25.9 Internal parts of a Löbro constant-velocity joint MITSUBISHI

The balls transfer drive from one race to the other but the inner race is able to move in or out in the grooves or change its angle.

25.4 Alignment of universal joints (RWD)

Alignment of cross-and-yoke joints prevents excessive vibration of the shaft. Sometimes alignment can be disturbed during dismantling, so care must be taken to realign the yokes by matching up the slip splines correctly.

25.4.1 Slip splines

There are two different arrangements of slip splines. The usual passenger car design has an internally splined sleeve as part of the front yoke of the front universal joint (Figure 25.10). The sleeve enters a bush in the transmission extension housing and slides directly on the splines of the transmission output shaft. The yokes are welded to the shaft and their alignment cannot be altered.

The other design has a splined sleeve as part of the rear yoke of the front universal joint. This fits onto splines on the front end of the propeller shaft, allowing for changes in the shaft length.

The sleeve must be fitted to the shaft splines so that the universal joint yokes align correctly. The shaft and sleeve sometimes have arrows showing the correct alignment position (Figure 25.11). These should be looked for prior to dismantling, and aligned during assembly. (Also see Figure 25.22.)

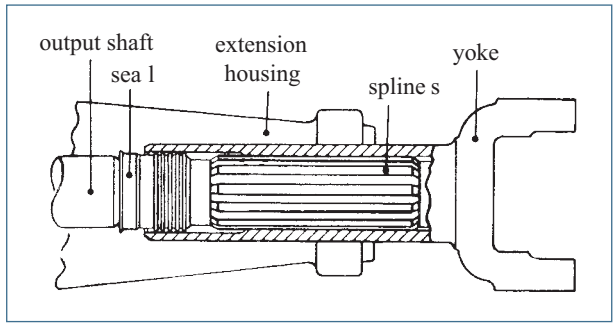


Figure 25.10 Universal joint yok e with slip splines FORD

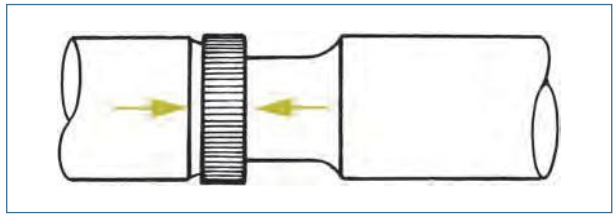


Figure 25.11 Alignment marks on a propeller shaft slip joint

25.4.2 Alignment of yokes

When the yokes are aligned, any increase in speed imparted to the shaft by the front joint is cancelled out by a similar decrease in speed transmitted to the pinion shaft by the rear joint. Together they cancel out any torsional shaft vibrations. If the yokes are misaligned, both universal joints could be increasing speed at one instant and decreasing speed the next, resulting in excessive vibrations of the shaft.

Alignment of a two-piece shaft

Figure 25.12 is a two-piece shaft with a centre bearing. This type of arrangement is used for some light trucks. The illustration shows how the yokes of the universal joints are aligned. The pinion shaft is

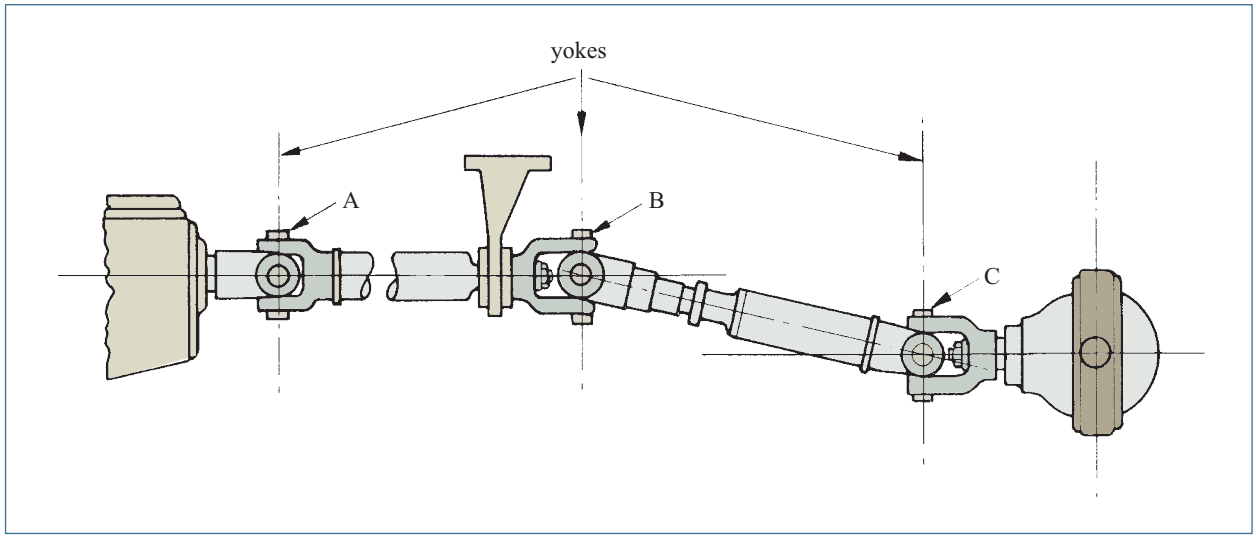


Figure 25.12 Yoke alignment of a two-piece shaft—correct alignment of the yok es at A, B and C is important

shown parallel to the transmission. This would be the ideal arrangement for the rear shaft because the angle of its front universal joint is the same as the angle of its rear joint. Each joint will have changes in speed, but these will balance out to provide constant speed at the pinion shaft.

25.4.3 Drive shafts for independent rear suspension

The drive shafts for vehicles with independent rear suspension are a solid steel shaft with a universal joint at each end. They connect the differential carrier, which is fixed to the body, to the rear wheels (see Figure 25.24).

Constant-velocity joints are used here. Usually ball-type joints, they can be similar to the Löbro joint or the ball joints in front-wheel drives. As well as allowing angular movement of the shaft, the universal joints also allow changes in shaft length.

25.5 Removing and replacing propeller shafts

Sustainability: When repairing or replacing an automotive drive shaft, drain and dispose of waste gear box oil according to regulations.

A single-piece propeller shaft on a passenger car is removed by disconnecting the rear universal joint at the rear axle. The rear flange of the rear universal joint is attached to a mating flange on the pinion shaft at the rear axle (Figure 25.13). The drive shaft is removed by unbolting the flanges.

The propeller shaft can then be pulled to the rear to slide the front slip splines from the transmission output shaft. The extension housing should be plugged to prevent oil loss.

Before removing the propeller shaft, mark the mating parts. This will enable the shaft to be reinstalled in its original position and preserve the balance of the shaft and associated parts.

An alternative method of securing the rear universal joint is with U-bolts. These hold two of the bearing cups to the rear yoke, as shown in Figure 25.14. The yoke is splined to the pinion shaft. Care should be taken when the shaft is being removed so that the cups and bearings do not drop off the cross.

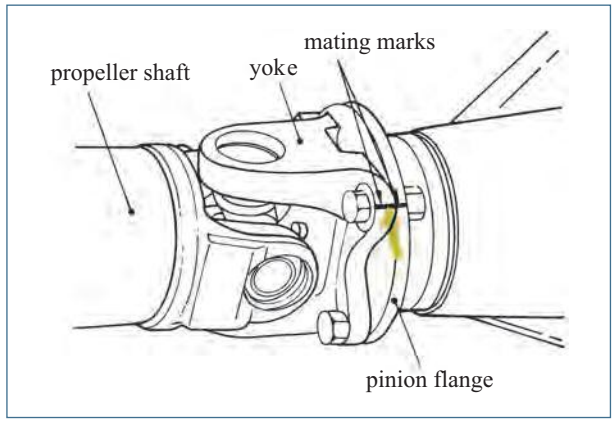


Figure 25.13 Flanges and other mating parts should be marked before being separated MITSUBISHI

Safety: When working on the drive-line , be constantly aware of rotating shafts, especially when operating the vehicle on a hoist.

25.5.1 Removing a centre bearing

Where a centre bearing is used with a two-piece drive shaft, its mounting must be disconnected from the reinforced part of the body or subframe to which it is attached.

A mounting for a centre bearing is shown in Figure 25.15. The carrier and mounting should be marked so that the shaft alignment will be maintained on reassembly.

A two-piece shaft is usually removed as an assembly (the two parts of the shaft are removed, complete with the centre bearing). The rear shaft can be removed first, then the centre bearing, and then the front shaft. The constant-velocity joint would only be dismantled if it were faulty (this would be done on the bench).

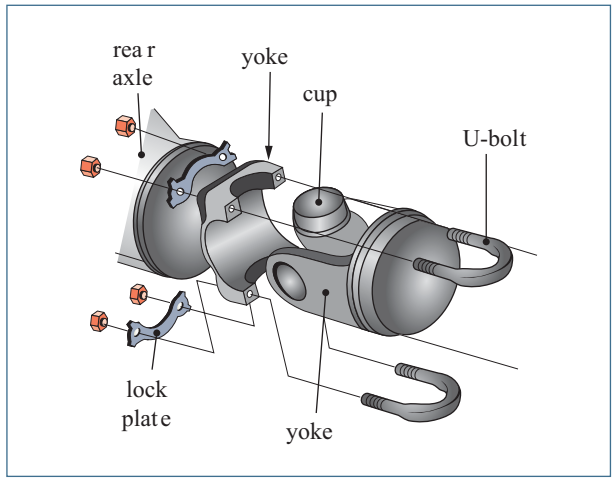


Figure 25.14 Attachment of a rear universal joint to a pinion flange on the rear axle

25.5.2 Replacing propeller shafts

Points to remember are:

1 Make sure that all mounting faces are clean and free from burrs.
2 Clean the end of the extension housing to prevent dirt entering.
3 Align the universal joint yok es on shafts with slip splines.
4 Align marks that were made before the shaft was removed.
5 Enter the end of the shaft into the extension housing carefully to avoid damage to the oil seal.
6 Tighten the universal joint bolts and centre bearing bolts correctly .

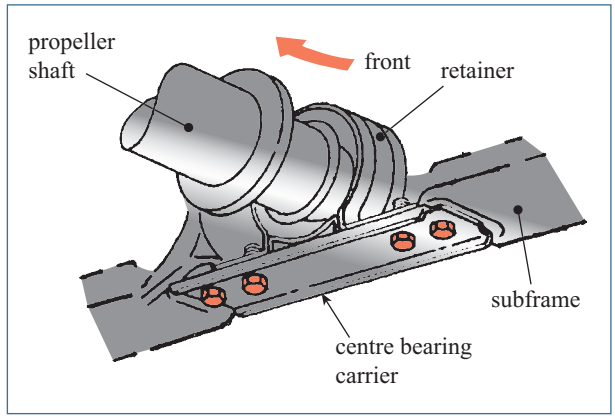


Figure 25.15 Propeller shaft centre bearing and its mounting

25.6 Servicing cross-and-yoke joints

Most cross-and-yoke-type universal joints can be dismantled for replacement of worn parts (repair kits include replacement parts). These parts can be seen in Figure 25.16.

Dismantling involves removing the bearing cups from the yokes to free the cross. Most bearing cups are a light press fit in the yokes, and are retained by a snap ring. The paint, dirt and burrs should be removed from the holes in the yokes to ensure easy extraction of the bearing cups.

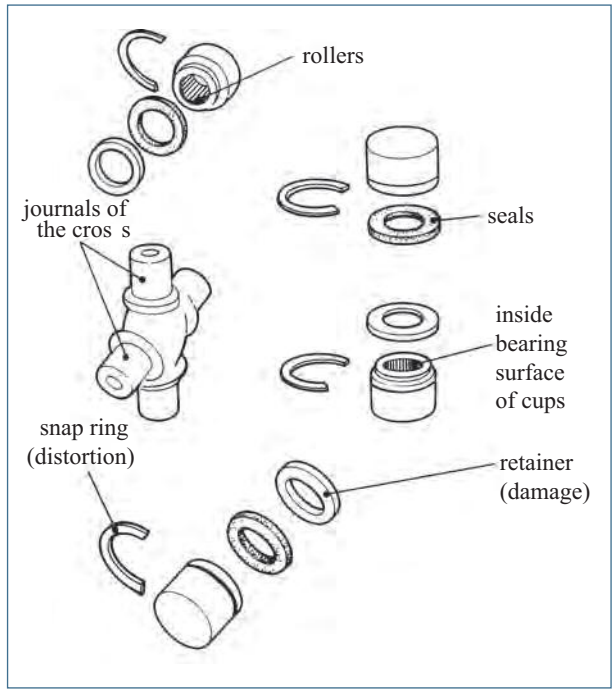


Figure 25.16 Parts of a universal joint—the parts that wear are labelled

25.6.1 Dismantling cross-and-yoke joints

Figure 25.17 shows a method of dismantling a cross-and-yoke universal joint. This involves supporting one of the yokes and carefully using a hammer on the other.

The general procedure is as follows:

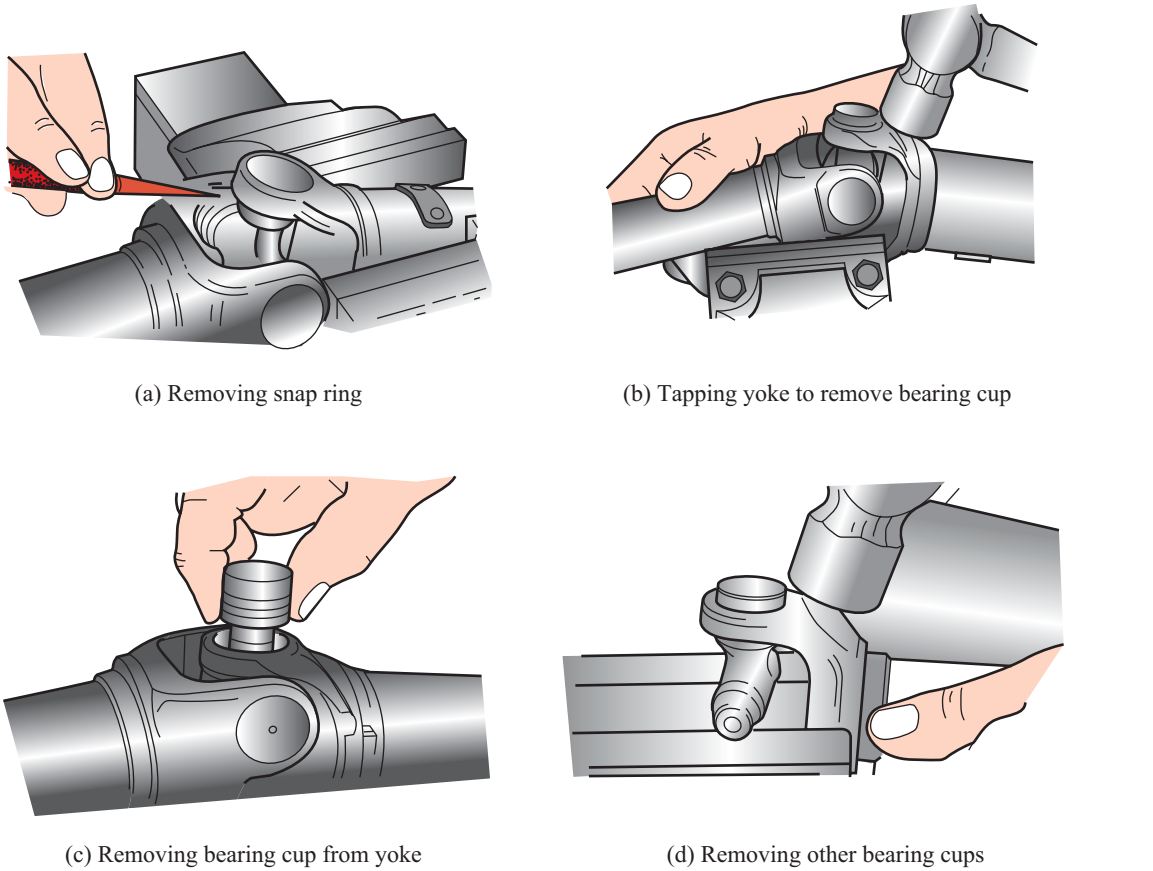
1 Remove the snap rings which retain the bearing cups in the yok es (Figure 25. 17(a)).
2 Support the yok e in one hand, or rest it between the jaws of a vice . With a hammer , tap the radius of the yok e adjacent to the bearing cup which is to be removed (Figure 25. 17(b)). The cross will force the bearing cup from the yok e.
3 When the cup is almost out, remove it (Figure 25. 17(c)) while ensuring that the needle bearings do not fall from the bearing cup .
4 Use a similar procedure on the opposite side of the yok e to extract its bearing cup . The yok es can then be separated, with the cross remaining in one yok e.
5 With the ends of the cross supported on a vice (Figure 25. 17(d)), tap the yok e to remove the bearing cup . Repeat the procedure on the other side of the yok e to remove the last bearing cup and free the cross.

Universal joint dismantling tool

Another method of dismantling involves a universal joint tool (see Figure 25.18). This is a large hollow punch, the hole being just large enough to fit over the bearing cup. With one yoke supported on the jaws of a vice, the tool is used as a punch (Figure 25.18(a)) to drive the other yoke down and so remove the bearing cup.

The tool is also slotted so that it can be used in the vice as a clamping tool (Figure 25.18(c)) to hold a bearing cup which has been partly removed.

Handy hint: If the parts of the universal joint are lik ely to be re-used, then the jaws of the vice should be protected to prevent damage to the surfaces of the cross.



(a) Removing snap ring

(b) Tapping yoke to remove bearing cup

(c) Removing bearing cup from yoke

(d) Removing other bearing cups

Figure 25.17 Dismantling a cross-type universal joint GM HOLDEN LTD

25.6.2 Inspection

Universal joints are usually only dismantled when they are worn or dry and are causing noise or vibration. The needle rollers and the journals of the cross are the parts most likely to wear (see Figure 25.16).

When dismantling a universal joint, fit new parts as otherwise serviceable parts can be damaged in the process. If an inspection shows that the universal joint is suitable for reuse, all the old lubricant should be removed and the cavities in the cross packed with lubricant. The bearings will need to be cleaned and relubricated and the sealing washers renewed.

Cause of universal joint failure

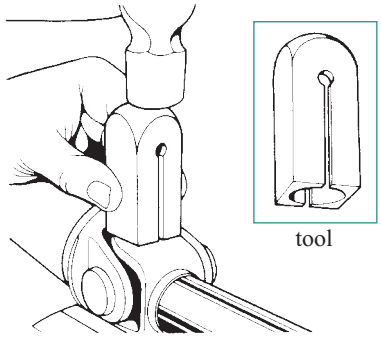
The roller bearings are subjected to a very limited movement and this will eventually cause pitting of the bearing surfaces and damage to the needle rollers. Usually, the wear is only on the thrust side. Bearings such as these, which are subjected to such a small movement, suffer from what is known as *fret corrosion.*

The probable cause of this is that the rollers have such limited movement that they do not roll on the molecules of the lubricant. This allows them to come into dry contact with the bearing surfaces, resulting in wear and damage.

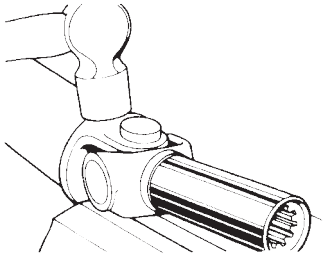
25.6.3 Reassembly

The method of reassembly is the reverse of dismantling, and runs as follows:

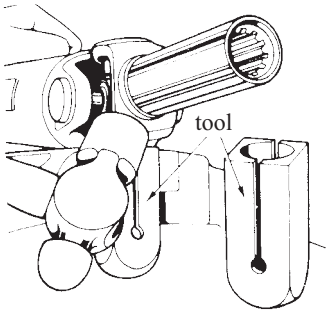
1 Insert the cross into the yoke.
2 Using a soft drift slightly smaller in diameter than the bearing cup, tap the cup into position. Alternatively, lightly press the cup into position.
3 Repeat this for the other three bearing cups, and refit the snap rings.
4 If the joint appears to bind after reassembly, it can be tapped lightly with a soft-faced hammer to relieve any pressure from the cross.
5 Where applicable, reassemble the slip splines, making sure that the yokes are in correct alignment.



(a) Tool driving yoke



(b) Tapping yoke



(c) Tool clamped in vice

Figure 25.18 Dismantling with a universal joint tool

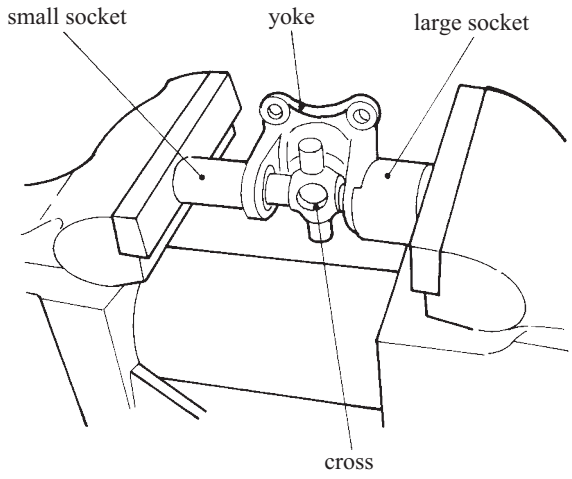


Figure 25.19 Dismantling a universal joint using a vice and sockets as pressing tools MITSUBISHI

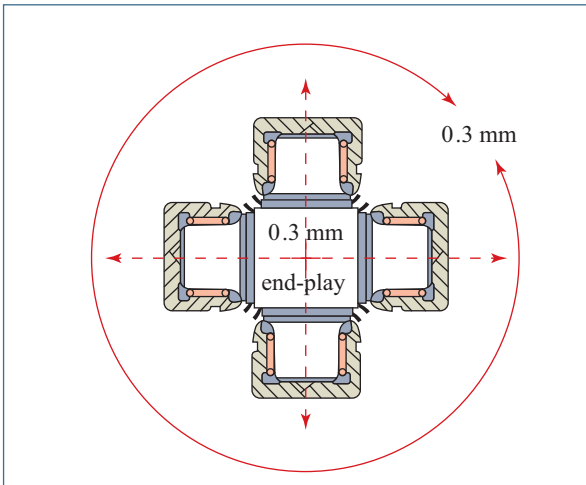


Figure 25.20 The universal joint wear can be checked as shown by the direction of the arrows

Using a vice

A heavy vice can be used for dismantling and reassembly. When removing or replacing the bearing cups, a large socket spanner makes a good supporting tool, and a smaller socket spanner can be used as a pressing tool.

Much of the sequence detailed above can be done with a vice, as shown in Figure 25.19, using socket spanners or similar suitable tubular pressing tools. A light press can also be used.

25.6.4 Checking universal joints (RWD)

Universal joints can be checked with the propeller shaft in the vehicle. Attempting to lift the shaft up and down will reveal end-play, and rotating the shaft will reveal wear or looseness. The wear limits for a cross-and-yoke joint are shown in Figure 20.20.

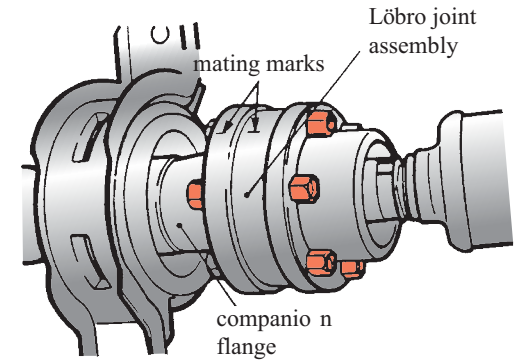
A dial gauge can be mounted against the shaft to determine universal joint wear and shaft runout although, for accurate checking and balancing, the propeller shaft must be removed from the vehicle. Specialised equipment is required for balancing propeller shafts.

25.7 Servicing a Löbro joint

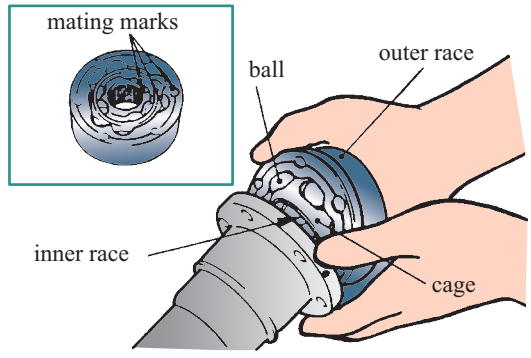
Löbro joints can be dismantled for servicing (Figure 25.21). The outer race is bolted to the propeller shaft flange and, after the bolts are removed, the flange can be removed from the race. This exposes the balls, the retainer and the inner race. The inner race is splined to the shaft and retained by a snap ring. After removing the snap ring, the inner race can be pressed from the shaft.

Before dismantling, the outside of the joint and the shafts should be marked so that the joint is correctly replaced. Internal parts are only separated if necessary, and they should also be marked before dismantling. The position of the balls should also be identified to ensure that they operate in their same grooves when reassembled.

After dismantling, the joint should be cleaned and inspected, and then packed with molybdenum disulphide grease before being reassembled.



(a) Assembled joint



(b) Dismantled joint

Figure 25.21 Servicing a Löbro constant-velocity joint MITSUBISHI

25.7.1 Servicing truck joints

Some universal joints on four-wheel drives and light trucks have grease nipples so the joints can be periodically lubricated without dismantling. One arrangement for a light truck is shown in Figure 25.22. This is a two-piece propeller shaft with slip splines and a centre bearing. The centre bearing is mounted on a crossmember that forms part of the chassis of the vehicle.

Smaller light commercial vehicles have propeller shafts and universal joints similar to larger passenger cars.

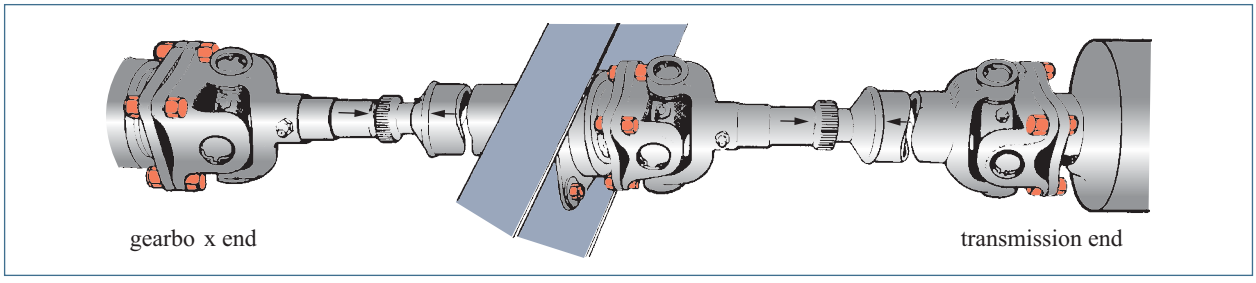


Figure 25.22 Arrangement of a light-truck propeller shaft—the sh afts have slip splines and grease nipples

25.8 Front-wheel drive

Passenger cars with transverse engines and front-wheel drive have drive shafts that connect the final drive in the transaxle assembly to the front wheels. The drive shafts are fitted with constant-velocity joints.

A front-wheel-drive system can be seen in Figure 25.23. This has two drive shafts of equal length, and an intermediate shaft to compensate for the off-centre position of the transaxle. In some instances, mainly in smaller cars, shafts of unequal length are used and so an intermediate shaft is not required.

Shafts of equal length operate at the same angle. This prevents pull on the steering wheel, known as torque steer, which can occur during rapid acceleration with shafts of unequal length.

Where the drive shafts are of different lengths, the longer shaft is often fitted with a dynamic balancer. This is a metal ring, mounted on moulded rubber and located in the centre of the shaft (Figure 25.24). It is used to absorb torsional vibrations. The drive shafts are steel forgings, with a constant-velocity joint at each end. The parts are shown in Figure 25.25.

The constant-velocity joint at the transaxle end has a short splined shaft which engages with the splines in the differential side gear in the final drive, and the constant-velocity joint at the wheel end of

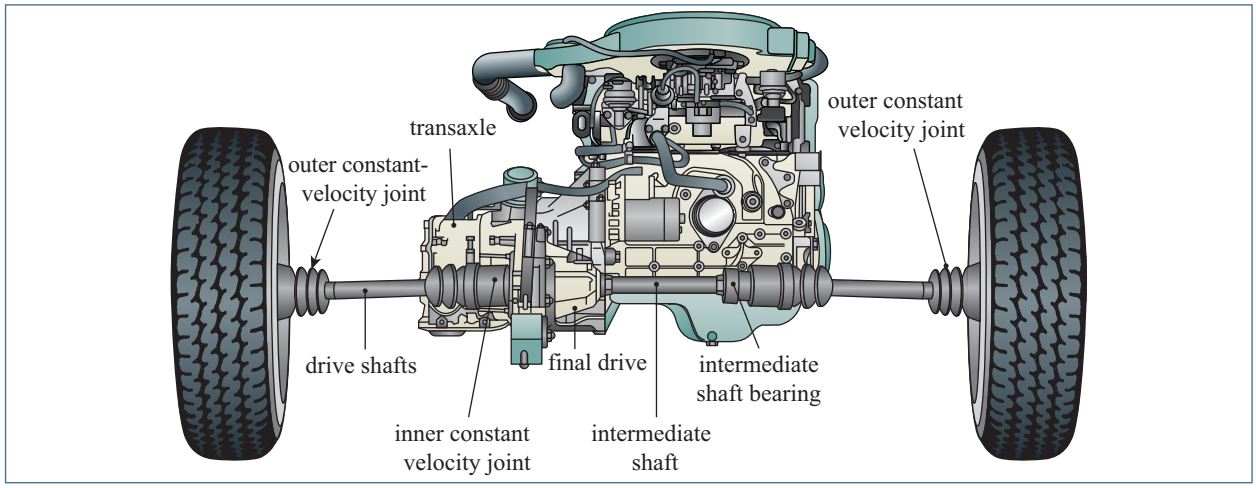


Figure 25.23 Arrangement of a transverse engine and front-wheel drive

the drive shaft has a splined shaft that fits into the wheel hub. The shaft is secured in the wheel hub by a large nut.

The intermediate shaft has one end splined into the differential side gear. The outer end fits into the inner constant-velocity joint.

25.9 Constant-velocity joints (FWD)

The constant-velocity joints for front-wheel-drive vehicles not only provide for suspension movement and for the front wheels to be steered, but they also transmit drive at a constant velocity. Without that, vibrations of the drive shafts would make steering and operation of the vehicle very difficult.

25.9.1 Types of constant-velocity joints

The types of constant-velocity joints that are used with front-wheel drive are:

1 Birfield
2 double-offset
3 tripod.

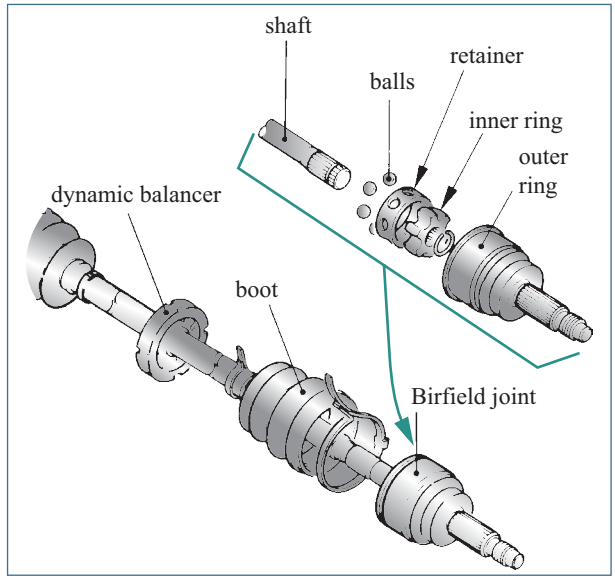


Figure 25.24 Drive shaft with a dynamic balancer and a Birfield joint

While all transmit drive at a constant velocity, some also allow *axial movement*. This is necessary because the drive shaft lengthens and shortens with suspension movement. The outer constant-velocity joint provides swivel action only, but the inner constant-velocity joint provides both swivel and axial movement.

Handy hint: Axial movement is movement of the shaft lengthwise , or in the direction of its axis.

25.9.2 Birfield joint

A Birfield joint (Figure 25.26) is used as the outer constant-velocity joint on the drive shaft. It consists of an outer ring or housing, an inner ring and a caged set of balls. (This joint is similar to the propeller shaft constant-velocity joint in Figures 25.8 and 25.9.)

The outer ring (or race) has a short splined shaft which fits into the front-wheel hub, and the inner ring has internal splines to fit over the splines on the drive shaft.

The balls are retained in a cage, but they also fit into axial grooves in the rings. This enables torque to be transmitted from the outer ring, through the balls, to the inner ring.

The grooves in the rings are contoured to permit the balls to roll in the rings as the angle of the shaft changes. Because there are a number of balls and they all rotate in the same plane (which changes with the angle of the shaft), the driven part of the joint is not subjected to torsional vibrations, so its velocity will be constant.

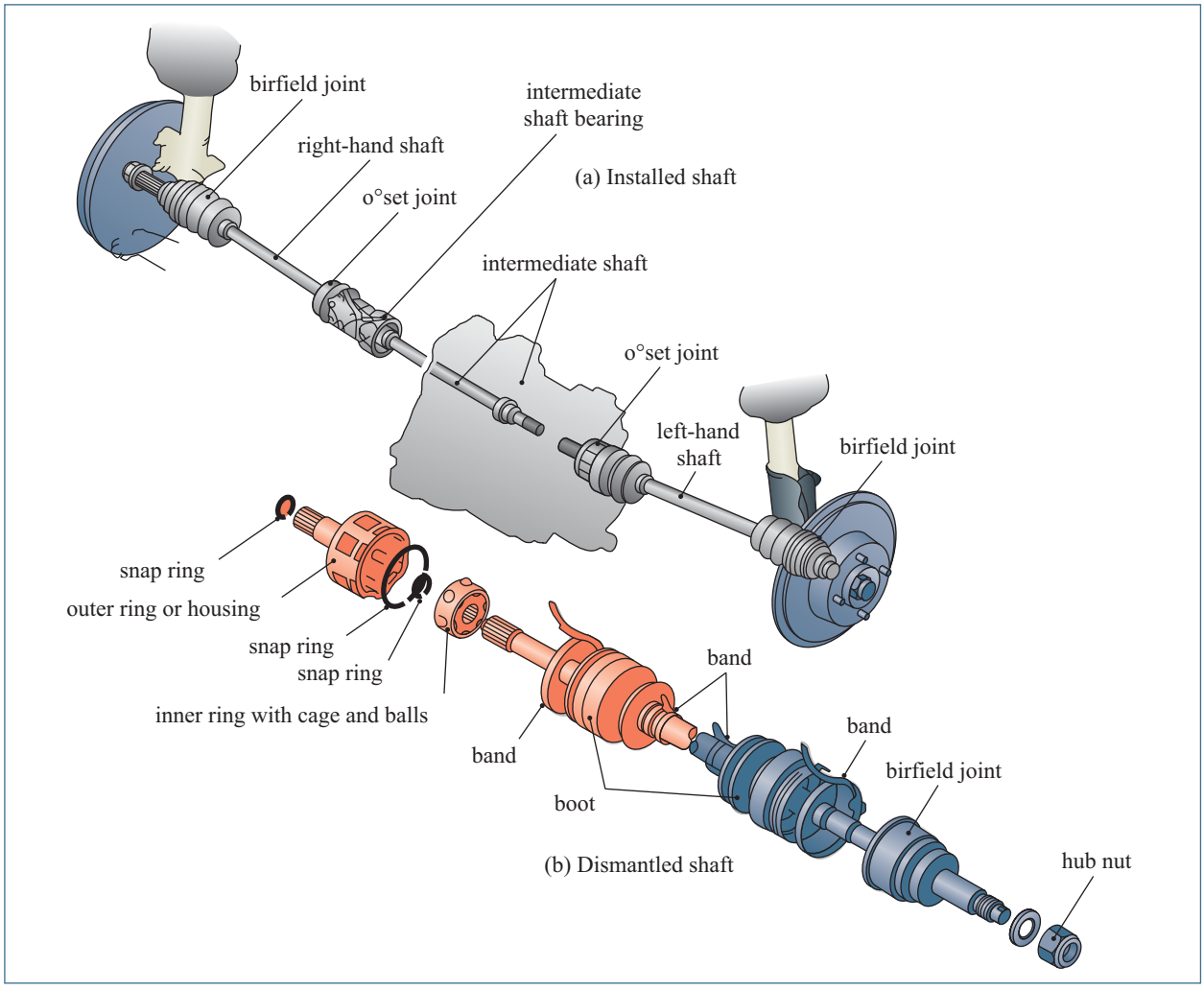


Figure 25.25 Drive shafts for front-wheel drive

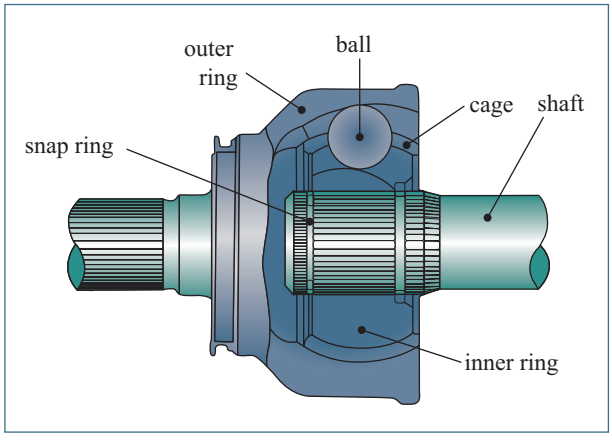


Figure 25.26 Birfield constant-velocity joint in section

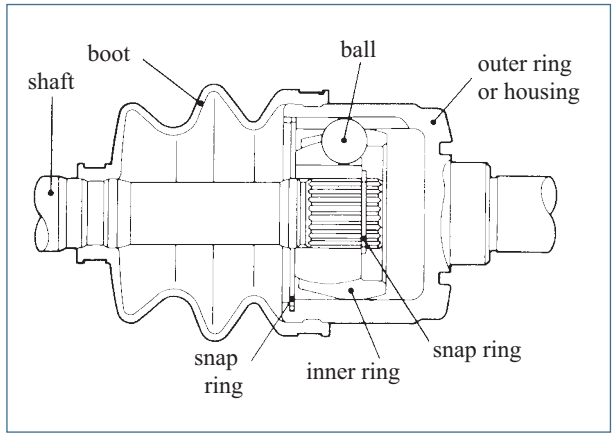


Figure 25.27 Double-offset joint FORD

25.9.3 Double-offset joint

A double-offset joint (Figure 25.27) is of similar construction to the Birfield joint, although the outer ring, or housing, is longer. This provides longer grooves for the balls and allows them to move axially to compensate for changes in drive shaft length.

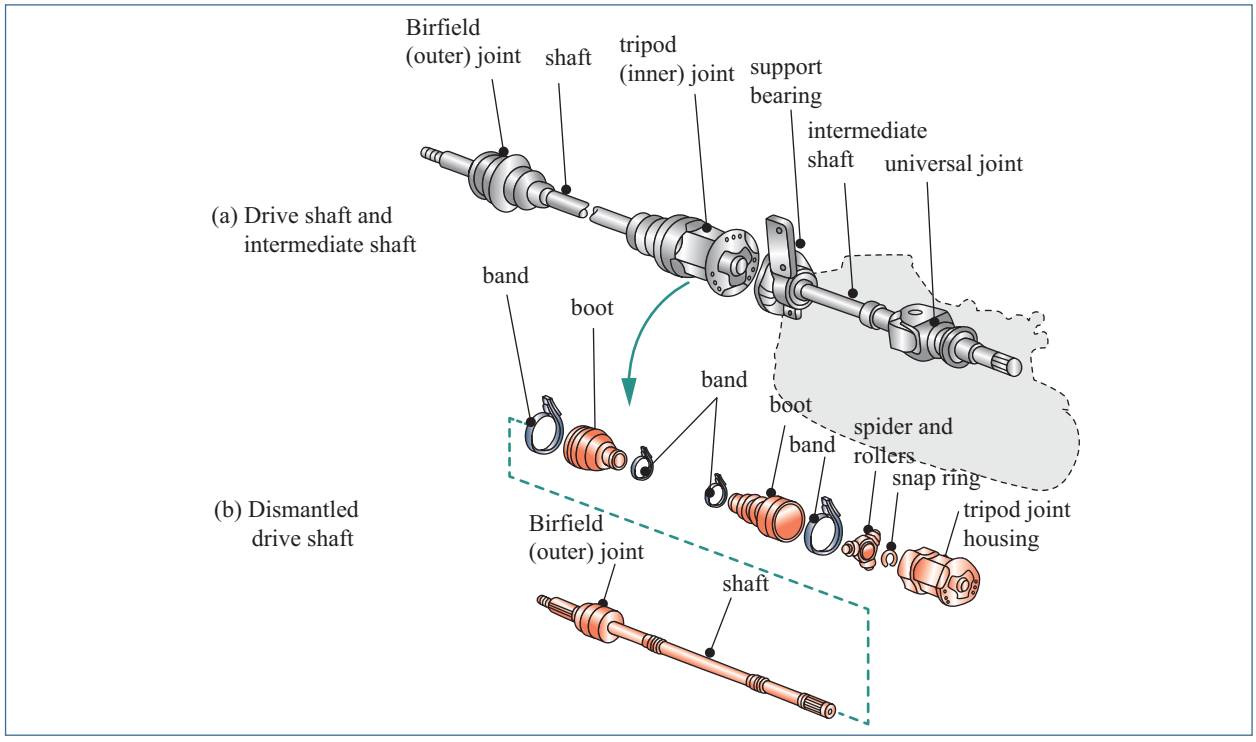


Figure 25.28 Arrangement of drive shafts and joints

25.9.4 Tripod joint

A tripod joint consists of a housing and a spider which carries three spherical-shaped rollers on needle bearings. The spider is splined to the drive shaft, and the rollers fit into grooves in the housing. The arrangement enables the assembly to operate as a constant-velocity joint. It also allows the spider rollers to slide in the housing, providing for axial movement of the drive shaft. (The parts can be seen in Figure 25.32.)

A drive shaft with a tripod constant-velocity joint, as well as other joints, is shown in Figure 25.28. It has a tripod joint at the inner end and a Birfield joint at the wheel end.

The arrangement includes an intermediate shaft between the differential side-bearing in the transaxle and a supporting bearing on the engine block. A cross-and-yoke universal joint is provided on the inboard end of the intermediate shaft to assist with its alignment.

25.10 Servicing constant-velocity joints (FWD)

The drive shafts of front-wheel-drive vehicles have to be removed to service their constant-velocity joints.

Removal of a drive shaft entails the release or removal of some of the lower parts of the front suspension and removal of the nut that secures the drive shaft to the front wheel hub. This allows the lower end of the suspension to be pulled outwards so that the splines in the wheel hub are withdrawn from the splines on the shaft, thereby freeing the outer end of the shaft (Figure 25.29). In some instances, a puller is required to extract the hub from the shaft.

The inner end of the shaft, which is splined to the differential side gear, can be pulled from the transaxle housing. The shaft is held into the side gear by a snap ring (see Figure 25.25). The snap ring is fitted to the splined end of the shaft and it expands inside the side gear. Its resistance has to be overcome when the shaft is being removed.

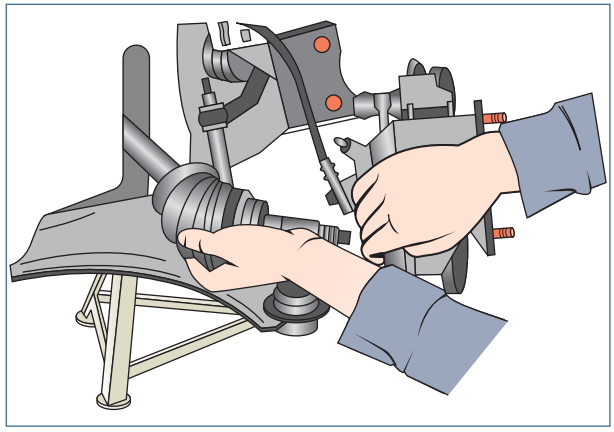


Figure 25.29 Removing the outer end of the drive shaft from the front wheel hub

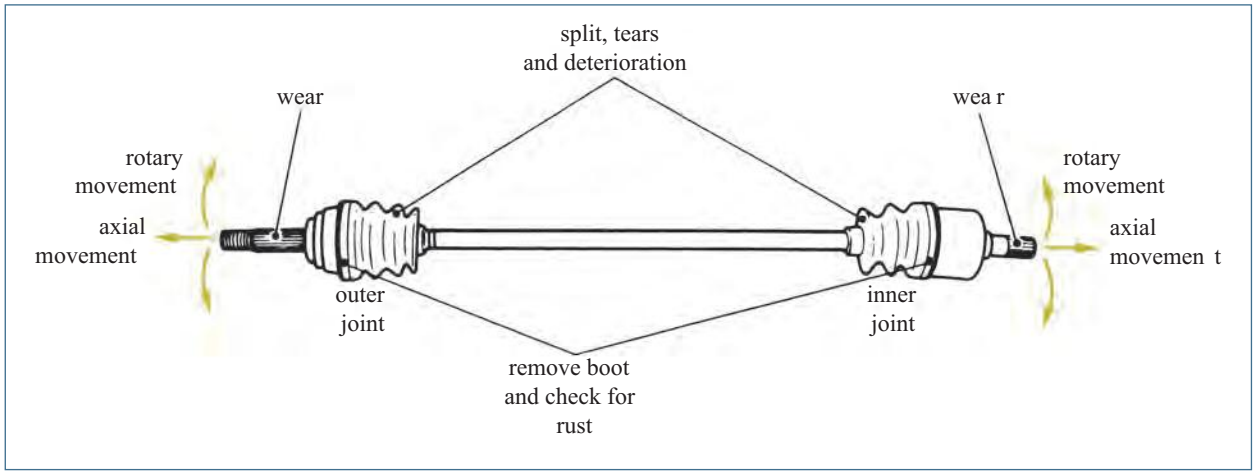


Figure 25.30 Inspection of drive shaft components MITSUBISHI

25.10.1 Inspection of drive shaft parts

The condition of the joints can be checked visually for wear or damage. They can also be checked by holding the shaft in a vice and trying to move the parts as indicated in Figure 25.30. There should be no excessive movement.

The outer (Birfield) joint is checked for any rotary or axial movement. The inner (double-offset or tripod) joint is checked for rotary movement and also to ensure that the shaft is free to slide axially.

The boots should be examined for deterioration or damage. If they need renewing, the joints will need to be checked and repacked with grease. A special molybdenum disulphide grease is used for most constant-velocity joints, but not for tripod joints with needle bearings.

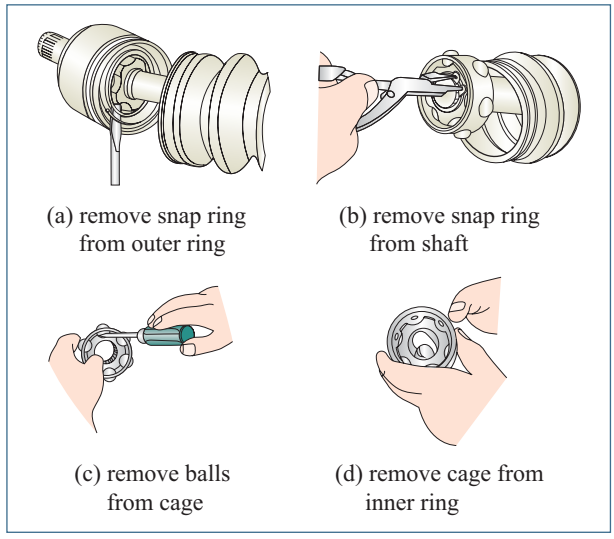


Figure 25.31 Dismantling a double-offset joint

Double-offset and tripod joints can be dismantled for service, but most Birfield-type joints are not. Servicing is confined to replacement of the boot, wiping out old grease and introducing new lubricant into the joint.

25.10.2 Servicing double-offset joints

These can be dismantled for service as shown in Figure 25.31. An outline of the procedure is:

1 Remove the bands from each end of the boot and move it along the shaft, clear of the joint.
2 Remove the snap ring from the outer ring, as shown in Figure 25.31(a), so that the shaft, complete with the inner ring and balls, can be removed from the outer ring.
3 Remove the snap ring from the end of the shaft, as shown in Figure 25.31(b), allowing the inner ring, balls and cage to be removed from the shaft as an assembly .
4 Remove the balls by prying them carefully from the cage with the end of a flat screwdriver (Figure 25.31(c)).
5 Separate the cage from the inner ring by rotating it appro ximately half a turn (Figure 25.31(d)).
6 Slide the boot from the shaft.

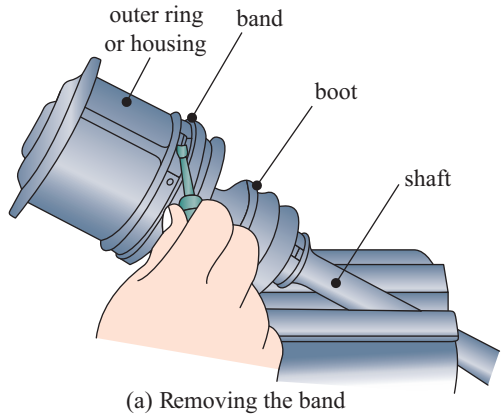
Handy hint: Mating marks must be placed on all the parts before they are dismantled so that they can be reassembled correctly .

Inspection and reassembly

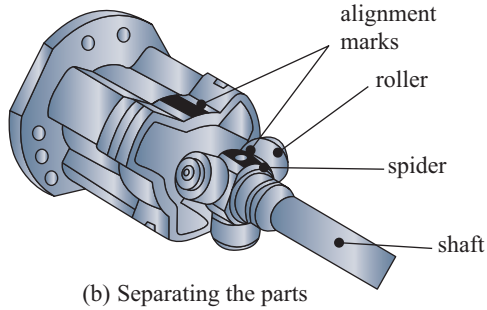
Remove all old grease and clean all parts, inspecting them for wear. Boots are usually renewed, and temporarily wrap the splines on the ends of replacements' shafts in tape to prevent damage.

Reassembly is the reverse of dismantling:

1 Fit the boot onto the shaft. The outer joint usually has a shorter boot.
2 Replace the cage over the inner ring with the mating marks aligned. Load the balls into their holes in the cage .
3 Install the inner ring on the shaft, with the marks aligned, and secure it with the snap ring.
4 Install the end of the shaft, with the inner-ring assembly , into the outer ring. Secure by fitting the snap ring into the groove in the outer ring.
5 Coat the parts liberally with special grease before installing and pack the outer ring with grease before the boot is fitted.
6 Secure the ends of the boot with the straps. The joint should be able to slide without distorting the boot.



(a) Removing the band



(b) Separating the parts

Figure 25.32 Servicing a tripod joint

25.10.3 Servicing tripod joints

A tripod joint can be dismantled by removing the boot from the housing and then separating the parts as shown in Figure 25.32.

1 Remove the bands from each end of the boot (Figure 25.32(a)).
2 Slide the boot along the shaft away from the housing.
3 Mark the housing and spider for reassembly and withdraw the spider and rollers from the housing (Figure 25.32(b)).

The spider is splined to the shaft and retained by a snap ring. It can, together with the rollers, be removed from the shaft after the snap ring has been removed.

After dismantling, clean and inspect its parts. Partly fill the housing with grease, and then install the shaft and spider, applying more grease. Install the boot and fit its clamps, positioning the boot so that it is not stretched or distorted.

Handy hint: Tripod joints have needle bearings between the rollers and the spider , necessitating the use of special grease .

25.11 Diagnostic testing procedures noises and vibration

Vibration can come from sources other than the drive line; looseness and misalignment in the drive line can produce vibration and noise, but so can a faulty wheel or tyre. Road testing will isolate the problem.

If an out-of-balance drive shaft is suspected, a small mass can be attached to the rear of the shaft and its effect noted (a worm-type hose clip can be used for this). Any alteration in vibration or noise could either confirm or eliminate the shaft as the cause of the problem.

Once the drive shaft has been repaired or replaced, always road test the vehicle to make sure that the fault has gone.

Handy hint: The exhaust system can also produce noise and vibration from a faulty muffler , a misaligned pipe that is resting against the body or a faulty exhaust mounting.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify and describe the function of drive shaft components
- explain the operating principles of light vehicle drive shafts and associated components
- list the types and applications of drive shaft lubricants
- describe and apply the inspection procedures for drive shafts
- describe and apply the service and adjustment procedures for drive shafts
- describe and apply the repair procedures for light vehicle drive shafts, including procedures for dismantling drive shafts, inspecting them and reassembling and aligning components
- describe and apply the post-repair testing procedures for light vehicle drive shafts
- describe and apply the diagnostic testing procedures for light vehicle drive shafts, including road testing procedures that include those for drive shaft noise and vibration.

REVIEW QUESTIONS

1 What is the function of a propeller shaft?
2 Why does a propeller shaft have a slip joint?
3 Why are universal joints needed?
4 Name the types of universal joints used with rear-wheel-drive vehicles.
5 When is a centre bearing used?
6 How does the drive line of a light truck differ from that of a small car?
7 What is a constant-velocity joint ?
8 Why is the alignment of universal joints on a propeller shaft important?
9 How can a universal joint be checked for wear?
10 Briefly describe how a cross-and-yoke joint is dismantled.
11 How is a double-offset joint dismantled?
12 What is a Birfield joint?
13 What is a tripod joint ?
14 Why are constant-velocity joints used with front-wheel drive ?
15 What is the main difference between the joints used on the inner end and those used on the outer end of the drive shaft of a front-wheel drive ?
16 Which of the following would be used as the inner joint of a front-wheel drive shaft: Birfield, double offset, or tripod?
17 Name the parts that would be visually checked on a drive shaft of a front-wheel drive after it has been removed.
18 What type of lubricant is generally used in constant-velocity joints ?
19 What are the functions of a transfer case ?
20 How many gear ratios are usually in a transfer case ?
21 What is the purpose of the chain (where one is used) in a transfer case ?
22 What type of chain is used in a transfer case ?
23 What is the purpose of a centre differential?
24 What is a viscous coupling ?
25 Explain briefly how a viscous coupling is used.
26 How is planetary gearing used in a transfer case ? Refer to the appropriate illustration.
27 How is steering arranged for a rigid front axle of a four-wheel-drive vehicle ?
28 What is a freewheel hub ?
29 Name some of the particular maintenance requirements of a four-wheel-drive vehicle .
30 Using common terminology , what is the difference between all-wheel drive and four-wheel drive ?

CHAPTER 26

Rear axle and final drive service

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify operating principles of light vehicle rear axles, final drives and associated components
2 recall the function and operation of light vehicle rear axle and final drive components
3 follow relevant diagnostic testing procedures, including road testing procedures
4 follow relevant repair procedures, including those for removing, replacing and adjusting these systems
5 follow relevant post-repair testing procedures.

This chapter relates mainly to two-wheel drives. (Four-wheel drives have similar components: a drive line to the rear and another to the front. They have two final drives, enabling all four wheels to be driven.) The rear-axle assembly on rear-wheel-drive vehicles includes the final drive gears, the differential assembly and the driving axles or shaf ts that carry the drive to the rear wheels.

Servicing rear axles and final drives can involve removing and installing axle shafts, drive shafts, bearings or oil seals. It can also include dismantling and reassembling the differential carrier assembly to renew gears or bearings or carry out adjustments. The need for a service usually arises because of oil leaks or noise from gears or bea rings.

26.1 Basic rear-axle assembly (RWD)

Figure 26.1 shows a basic rear-axle assembly for a rear-wheel-drive vehicle. The axle housing contains the crown wheel and pinion, the differential case and gears and the axle shafts. The pinion, crown wheel and the differential are usually considered to form the final drive unit, although the axles can also be included. The function of these parts is as follows:

1 The crown wheel and pinion change the direction of drive by 90 °, and also provide a gear reduction.
2 The differential case encloses the differential gears. The differential divides the torque between the driving wheels and also allows the wheels to rotate at different speeds.

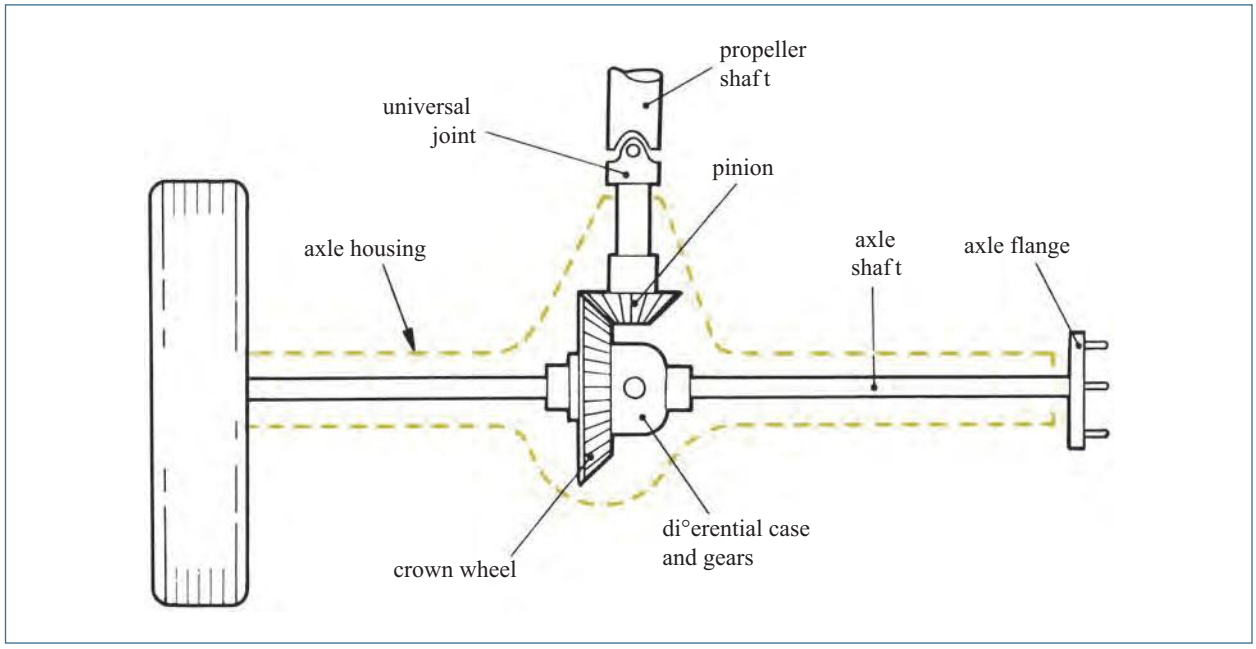


Figure 26.1 Basic components of a rear-axle assembly

3 The axle shafts carry the drive from the differential to the rear wheels. The flanges on the outer end of the axle shafts carry the wheel studs.
4 The axle housing encloses the components and provides mountings for their bearings and the rear suspension.

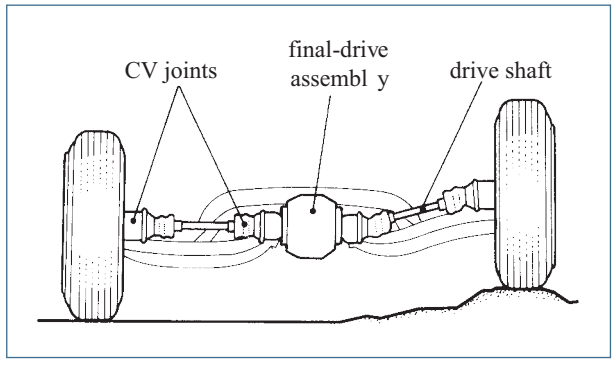


Figure 26.2 Arrangement of a swing axle

Drive from the engine reaches the rear-axle assembly through the propeller shaft, which is connected to the pinion by the universal joint. Inside the axle housing, drive is from the pinion to the crown wheel, then through the differential to the axle shafts and rear wheels.

There are two basic designs of rear axles with final drives: rigid axles and swing-type axles (Figure 26.2), where the drive shafts are exposed. There are variations of these two designs and their suspension systems.

Handy hint: The term *drive* denotes rotary movement. The various parts of the drive line transmit torque as well as rotation.

26.2 Rigid rear axles

A rigid rear axle has the advantage of a housing that always holds the rear wheels in their correct position. Its disadvantage is that it has a large unsprung mass, and that road shocks are transferred between the wheels. A rigid rear axle with coil spring suspension can be seen in Figure 26.3.

Rigid axles are used on larger passenger cars, station wagons and commercial vehicles. There are two basic designs: banjo-type and unitised.

26.2.1 Banjo-type rear axle

The rear-axle assembly in Figure 26.4 is known as a banjo-type rear axle because the housing itself is 'banjo' shaped. The housing is made of pressed steel and has the differential housing (or carrier), which carries the pinion, crown wheel and the differential gears, bolted to its front. This can be removed for servicing without removing the complete rear-axle assembly from the vehicle.

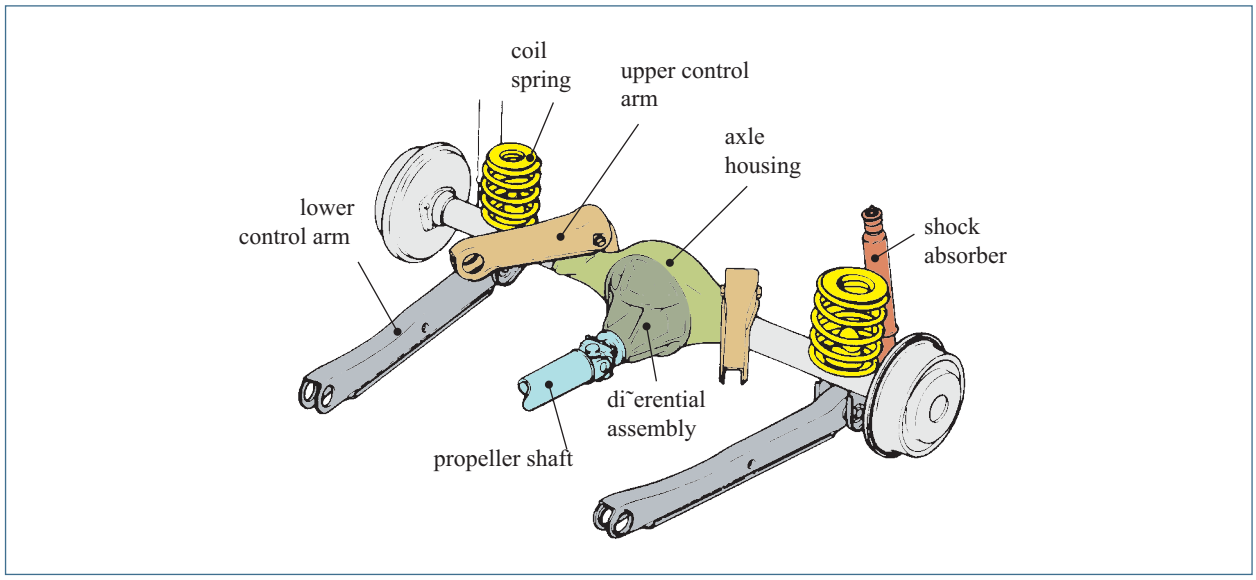


Figure 26.3 A rigid rear axle with coil spring suspension GM HOLDEN LTD

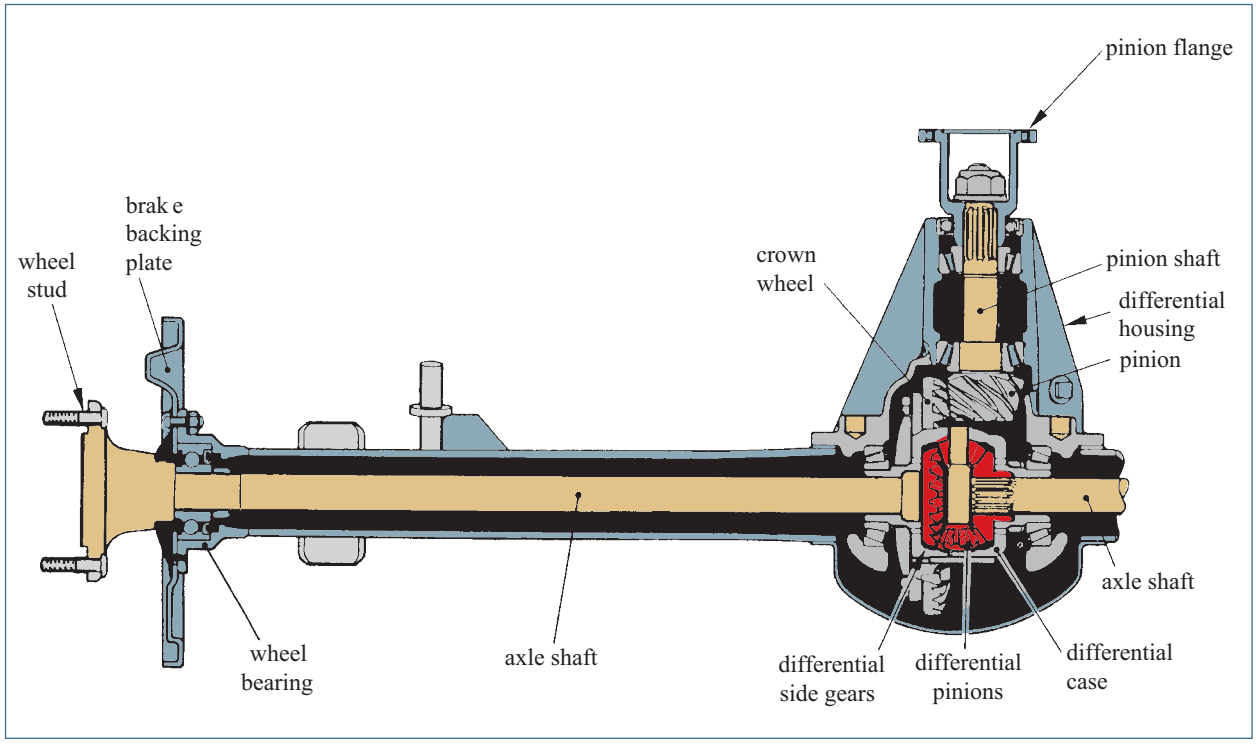


Figure 26.4 Sectional view of a banjo-type rear-axle assembly

Handy hint: The terms differential housing and differential carrier tend to be interchangeable. They refer to the housing in which the differential case (and gears) are mounted.

26.2.2 Unitised rear axle

The rear axle in Figure 26.5 is a unitised type, sometimes called a Salisbury rear axle. The differential carrier is a malleable iron casting which is cast onto the tubular side sections of the housing during manufacture, making it an integral part of the axle housing. A cover is bolted to the rear of the housing, and this can be removed to gain access to the crown wheel and differential.

Rear axles of this type can be serviced in the vehicle, with the vehicle on a hoist, but it is usually easier to remove the complete rear-axle assembly.

The housings of banjo rear axles and unitised rear axles are different but have the same internal components.

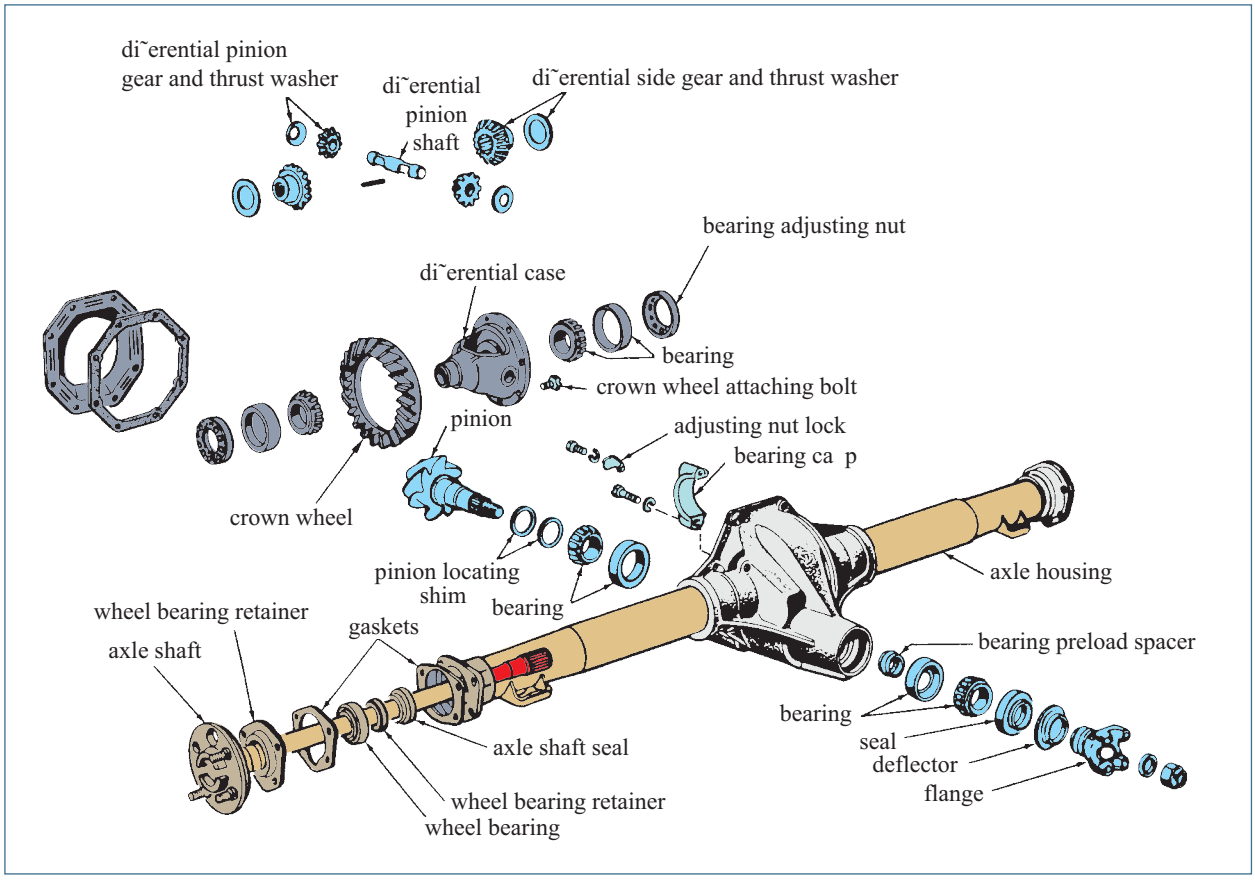


Figure 26.5 Unitised or Salisbury-type rear-axle assembly

26.3 Final drive and differential

A typical differential carrier assembly is shown in Figure 26.6 with its various parts identified. These include the final drive gears (the crown wheel and pinion), the differential case and the differential gears. These parts, which are all supported by bearings in the differential carrier, are usually referred to as the *differential assembly.*

26.3.1 Final drive gears

The crown wheel and pinion are the final drive gears in a rear-wheel-drive vehicle. They are also referred to as rear-axle gears, or simply as the crown wheel and pinion. They are *hypoid gears,* a special design of spiral bevel gear that has the centreline of the pinion below the centreline of the crown wheel. The difference can be seen in Figure 26.7, where two sets of gears are illustrated. One advantage for passenger cars is that the propeller shaft is lower and the body of the car is lower to the ground.

Hypoid gears are used in the rear axles of commercial vehicles as well as passenger cars. Their tooth shape provides a greater area of tooth contact and therefore greater strength, although correct adjustment is needed to prevent gear noise.

Lubrication

Hypoid gears have high tooth loadings. The teeth roll against each other and also have a wiping action. This requires the use of special hypoid gear lubricants with high-pressure additives.

Figure 26.8 is a section through a differential assembly. It shows the position of the crown wheel and pinion, the shape of the gear teeth and the differential gears inside the differential case. The arrows show how gear oil in the housing is picked up by the crown wheel and circulated to the pinion and bearings.

Handy hint: Limited-slip differentials require their own special lubricants, which are different from hypoid gear lubricants.

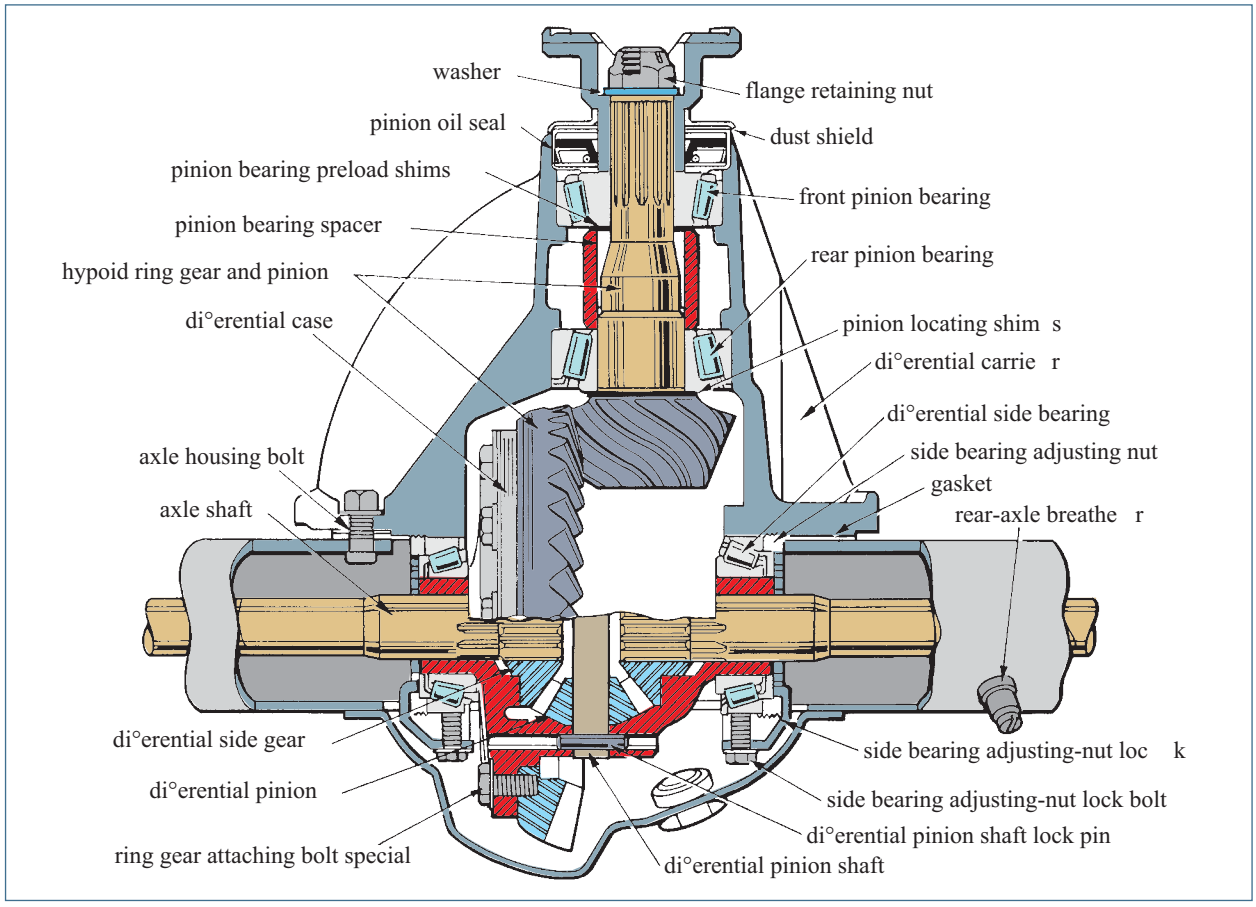


Figure 26.6 Typical differential assembly for a banjo-type rear axl e

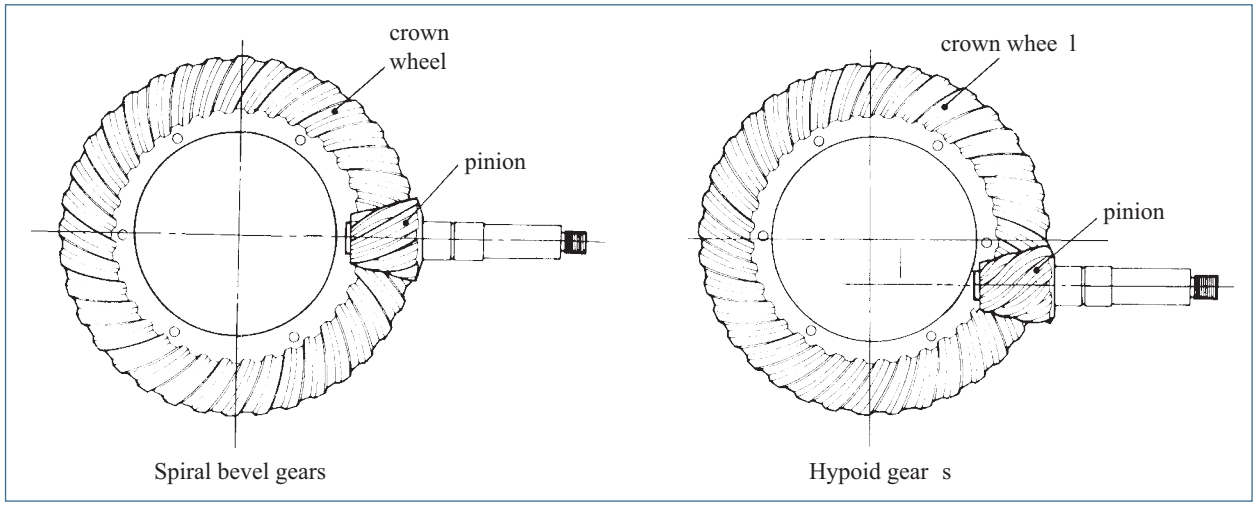


Figure 26.7 Final drive gears (crown wheel and pinion)—spiral bevel and hypoid gears shown

26.3.2 Crown wheel and pinion terminology

The terms associated with a crown wheel and pinion are shown on the parts of the gears in Figure 26.9. These are used for crown wheel and pinion adjustments:

1 Clearance . The distance between the top of the tooth and its mating gear .
2 Backlash. The space between the teeth in mesh, or the distance that one gear can move backwards before it will cause the other gear to move .

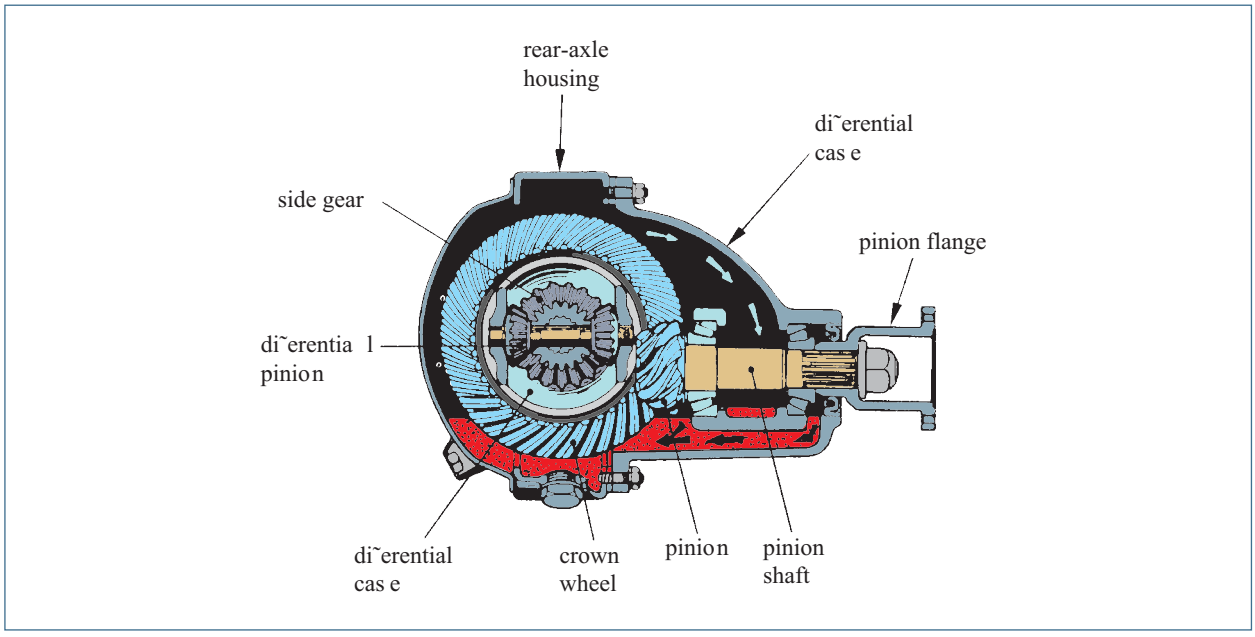


Figure 26.8 Differential assembly

3 Toe. The small end of a gear tooth.
4 Heel. The large end of a gear tooth.
5 Face . The upper part of a tooth.
6 Flank. The lower part of a tooth.
7 Drive side . The convex or outward-curving side of a tooth.
8 Coast side . The concave or inward-curving side of a tooth.

26.3.3 Rear-axle ratio

The gear ratio of the crown wheel and pinion is referred to as the *rear-axle ratio*. Rear-axle ratios depend on the type of vehicle, engine type and size. Rear-axle ratios from around 3.5:1 to 5:1 are used for passenger cars. For trucks, the ratios are around 9:1.

26.3.4 Crown wheel and pinion sets

The crown wheel and pinion are matched during manufacture and so must always be treated as a *set of gears*. Replacement gears are supplied only as a set and both gears have to be installed, even if only one is worn or damaged. If an old and a new gear were used together, it would be impossible to adjust them correctly.

Numbers are etched on the crown wheel and pinion (Figure 26.10) so that the two gears that make up a set can be identified.

26.3.5 Hunting and non-hunting gears

There are two different types of gear sets as far as the number of teeth in the gears is concerned: hunting and non-hunting.

1 Hunting gears. With these , any one pinion gear tooth will come into contact with all the crown

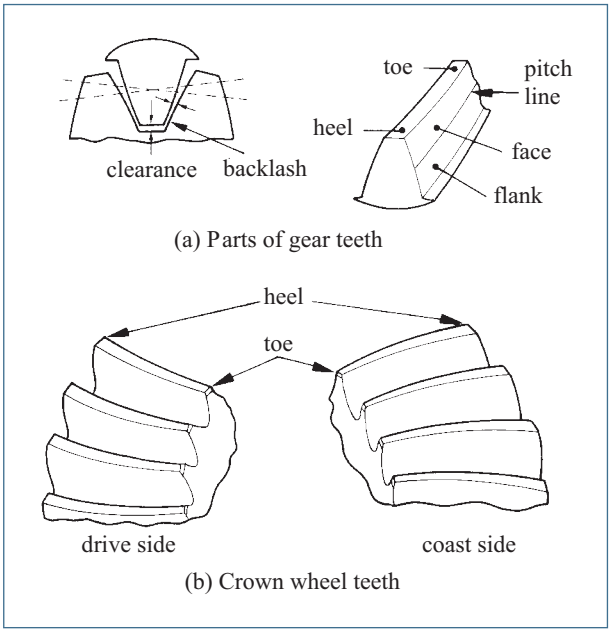


Figure 26.9 Crown wheel and pinion terminology

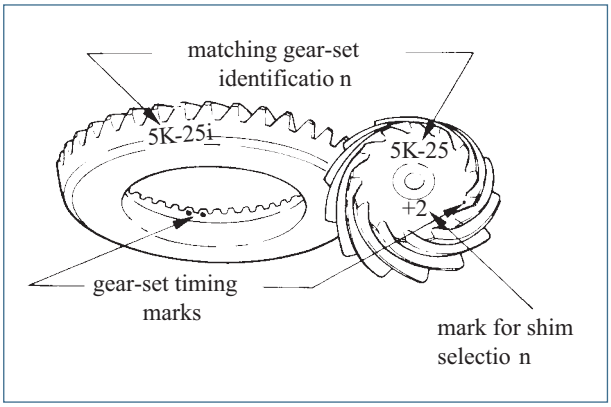


Figure 26.10 Crown wheel and pinion markings FORD

wheel teeth at some time , as the gears rotate . However , a number of revolutions of the crown wheel will be needed before this is achieved. Most rear-axle gears are hunting gears.

2 Non-hunting gears. With these , any one pinion tooth will come into contact with only a few of the crown wheel teeth. All the tooth combinations that are possible occur with only one revolution of the crown wheel. Non-hunting gear sets have timing marks on the gear teeth.

Handy hint: Hunting gears will have an uneven ratio , such as 2.89:1. Non-hunting gears will have a single-number ratio , such as 2:1.

26.4 Axle shafts for rigid rear axles

There are two general types of axle shafts: dead axles, where the wheel rotates on a stationary axle; and live axles, where the axle and wheel rotate together. The front wheels of a rear-wheel-drive vehicle are on a dead axle, while the rear wheels are on a live axle.

Three types of live axles work with rigid rear-axle assemblies: *semifloating, three-quarter floating* and *full floating* (Figure 26.11). The greatest stress on axles is due to torque, but they also carry other types of loads.

26.4.1 Semifloating axle

These are used in most cars and light commercial vehicles. The wheel end of the axle shaft is supported by a single bearing in the axle housing.

The axle shaft not only transmits the driving torque, but it resists bending caused by forward motion of the vehicle as well as side thrusts during turns. As the end of the axle also carries the mass of the vehicle, this type of axle is subjected to high stress.

26.4.2 Three-quarter floating axle

With these, the bearing is mounted on the outside of the axle housing and into the wheel hub, so that the axle supports very little of the vehicle's mass.

The axle shaft transmits torque, but still has to resist some bending from forward movement and side thrusts. As the axle shaft is relieved of most of the vehicle's mass, stresses are reduced.

26.4.3 Full-floating axle

Full-floating axles are used in some light commercial vehicles and on large trucks. They have two tapered roller bearings between the axle housing and the wheel hub. The hub mounts directly onto the housing and is independent of the axle shaft.

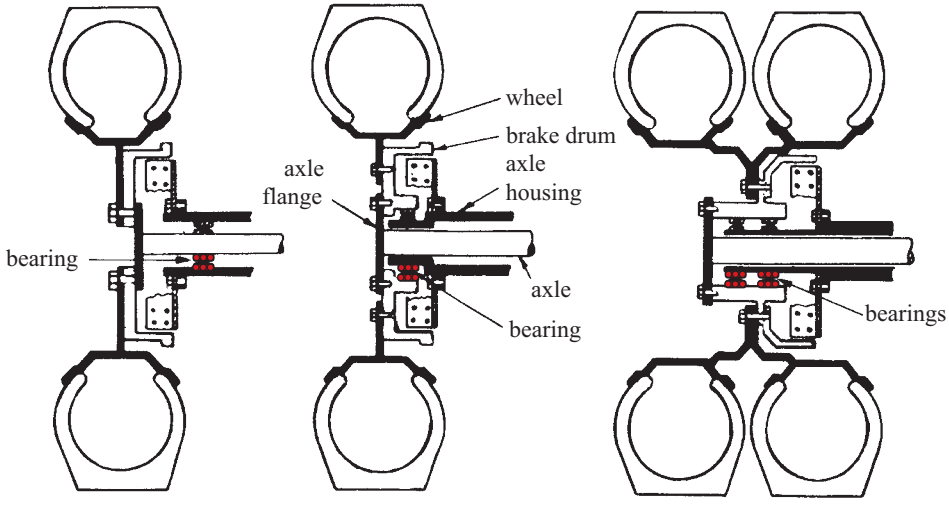


Figure 26.11 Types of rear-axle shafts

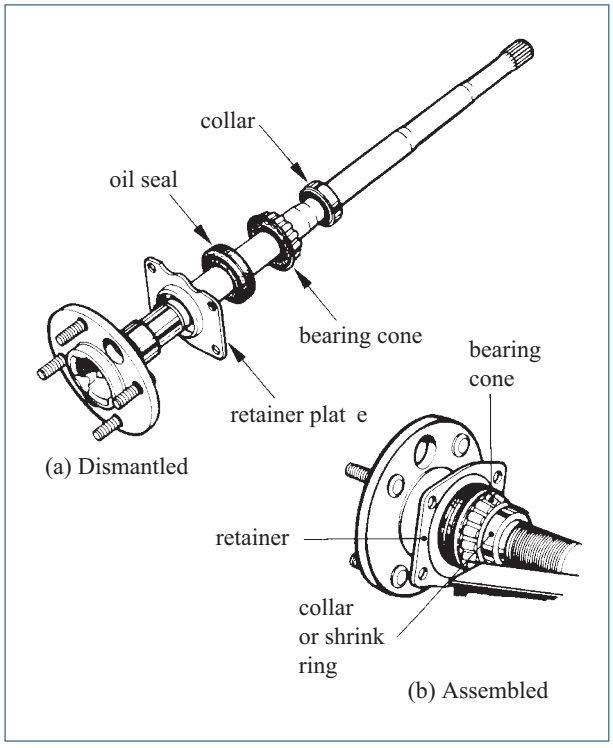


Figure 26.12 Semifloating rear-axle assembly

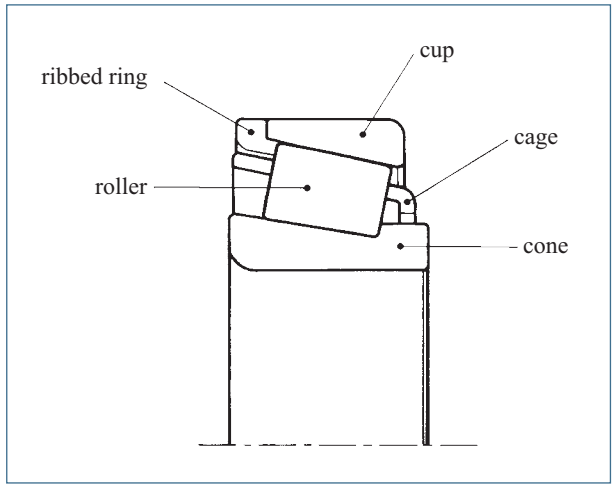


Figure 26.13 Arrangement of a unitised roller bearing

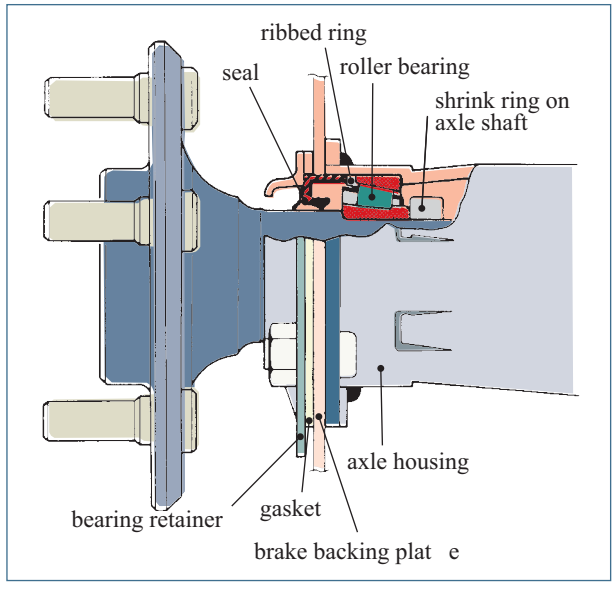


Figure 26.14 Outer end of a rear-axle housing showing the axle shaft and bearing installation FORD

The mass of the vehicle, the forces from forward motion and all side thrusts are transferred from the wheel directly to the axle housing through the tapered roller bearings. The axle shaft is relieved of all these forces and is used only to transmit torque.

26.5 Rear-axle bearings

Many passenger cars and light commercial vehicles have semifloating rear axles with axle shafts similar to the one in Figure 26.12. This carries the cone of a tapered roller bearing. The bearing cup (not shown) fits into the end of the axle housing. Ball bearings are also used for axle bearings; the axle shaft in Figure 26.4 has a ballrace.

Rear-axle bearings carry the major load in a radial direction, but must also accept some side thrust. A ballrace will carry both these types of loads, but will accept higher radial loads than thrusts.

A single tapered roller bearing will normally accept thrusts in only one direction, although it will carry higher loads than a similar-sized ballrace. A pair of tapered roller bearings, when mounted back to back, will carry high radial loads and accept thrusts in both directions.

26.5.1 Unitised roller bearing

Figure 26.13 shows the parts of a unitised roller bearing, which is specially designed for a rear-axle shaft. This can take both radial and thrust loads. Radial loads are taken in the usual way. Thrust loads are taken in one direction by the shoulder on the stepped cone, and in the opposite direction by the ribbed ring.

The unitised roller bearing in the rear-axle housing (Figure 26.14) has the ribbed ring to the outside. When assembled in the housing, the cup and ribbed ring are clamped together and held there by the retaining plate and the seal. The bearing is retained on the axle shaft by the shrink ring, which is also referred to as a *retaining ring* or *collar*.

New bearings of this type are supplied as a unit, with the ribbed ring held in the cup with adhesive, although the ring and cup are likely to become separated when the axle shaft is removed for service.

26.5.2 Other axle and wheel bearings

See Figure 26.36 for the bearings of a three-quarter floating axle and Figure 26.38 for a full-floating axle. Wheel and axle bearings are treated as part of the suspension system in Chapter 26.

26.6 Differential

The differential divides the torque between the rear wheels and also enables the driving wheels to rotate at different speeds when a vehicle is turning. Figure 26.15 shows the distances that the wheels will travel on a particular turn. Without a differential, the driving wheels would have to skid whenever the vehicle was steered.

26.6.1 Differential arrangement

The parts of a simple differential are shown in Figure 26.16(a) to (d), where the differential is built up in these stages:

1. The rear wheels are attached to axle shafts, which have their inner ends splined into small bevel gears known as side gears (Figure 26. 16(a)).
2. The differential case has been added (Figure 26.16(b)). This encloses the two side gears, which face each other . The bevel gear between the side gears is known as a differential pinion. This can transfer rotation from one shaft to the other .
3. Two pinions are mounted in the case by a shaft (Figure 26. 16(c)). They mesh with the two side gears. The axles are no longer free of the case . If the case is rotated, the complete assembly will also rotate .
4. To drive the differential assembly , the crown wheel, or ring gear , is fitted to the differential case , and the drive pinion is connected to the propeller shaft (Figure 26. 16(d)). These two gears provide a gear reduction and also change the direction of drive , but have no differential action. They are part of the final drive and not part of the differential.

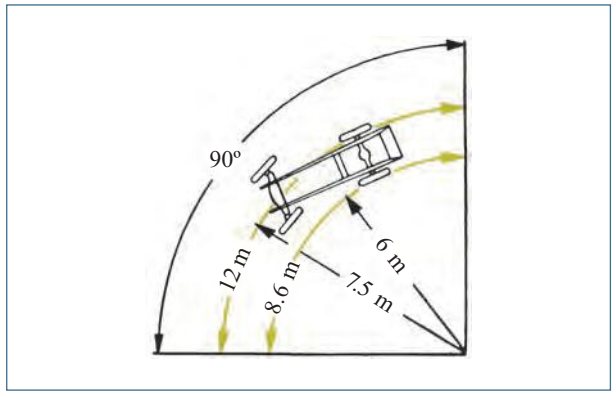
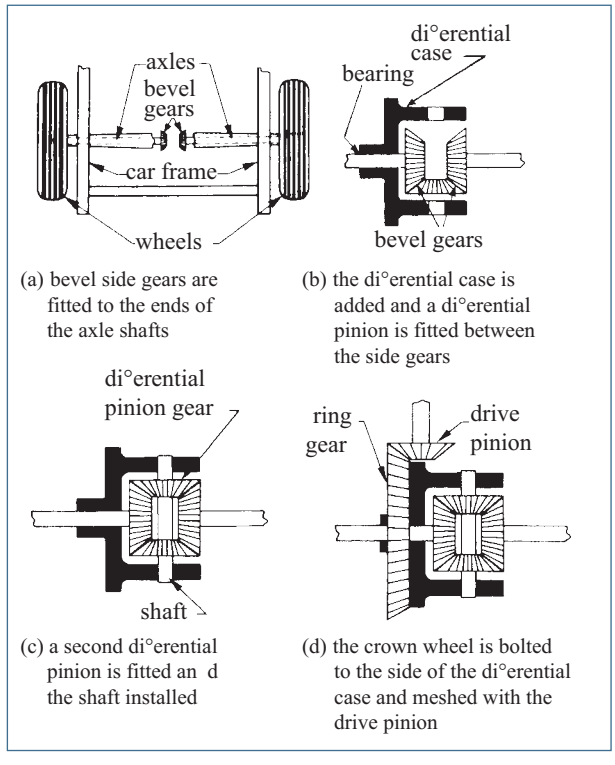


Figure 26.15 Difference in wheel travel on a 90 ° turn with the inner rear wheel on a 6 m radius



(a) bevel side gears are fitted to the ends of the axle shafts

(b) the di°erential case is added and a di°erential pinion is fitted between the side gears

(c) a second di°erential pinion is fitted an d the shaft installed

(d) the crown wheel is bolted to the side of the di°erential case and meshed with the drive pinion

Figure 26.16 Building up a differential step-by-step

Driving straight ahead

When driving straight ahead, the propeller shaft rotates the drive pinion and this rotates the crown wheel and differential case. The differential case and its gears rotate the axle shafts, driving the rear wheels. There is no movement between the gear teeth.

The differential gears are not required under these conditions. A solid block of metal would perform the same function—as long as the vehicle was moving only in a straight-ahead direction.

Driving on turns

When the vehicle is steered in any direction other than straight ahead, the difference in driving-wheel speeds is accommodated by movement of the differential

gears—the differential pinions will be rotated slowly on their shaft by the side gears so that forward movement is transferred from one side gear to the other.

The inner wheel will be able to slow down and travel a shorter distance, while the outer wheel will be speeded up by an equivalent amount to travel a longer distance. The loss of one side balances the gain of the other. Differential action is therefore taking place, with movement from one axle to the other being transferred through the gears.

Handy hint: The drive pinion and the differential pinions are entirely different. The former (usually referred to only as a pinion) drives the crown wheel, while the latter transfer movement between the side gears.

Other driving conditions

Under normal conditions, with good road surfaces, the torque from the crown wheel is divided equally between the driving wheels. However, with loose road surfaces or in mud, sand or snow, one wheel can have less traction than the other and will spin. This makes driving difficult, or can even prevent the vehicle from moving, and all the drive goes through the differential to the free wheel, which spins.

One side gear will be held stationary, but the other side gear, together with its axle shaft and wheel, will be made to spin. The differential case will carry the pinions around, causing them to 'walk' around the stationary side gear and rotate at the same time. In doing so, the pinions will drive the side gear of the wheel that is free to turn at twice its normal speed. When the gears are operating in this way, they are said to have 'planetary action'.

Handy hint: The differential action described is for the rear axle of a rear-wheel-drive vehicle . However , the same principles apply to all differentials, whether they are in rear axles, front axles or transaxles.

26.6.2 Differential construction

Figure 26.17 shows the components that make up a typical differential assembly for a passenger vehicle with rear-wheel drive. The case can be separated as shown. This differential has two pinions which mesh with the side gears, but some larger passenger vehicles and light trucks have four pinion gears.

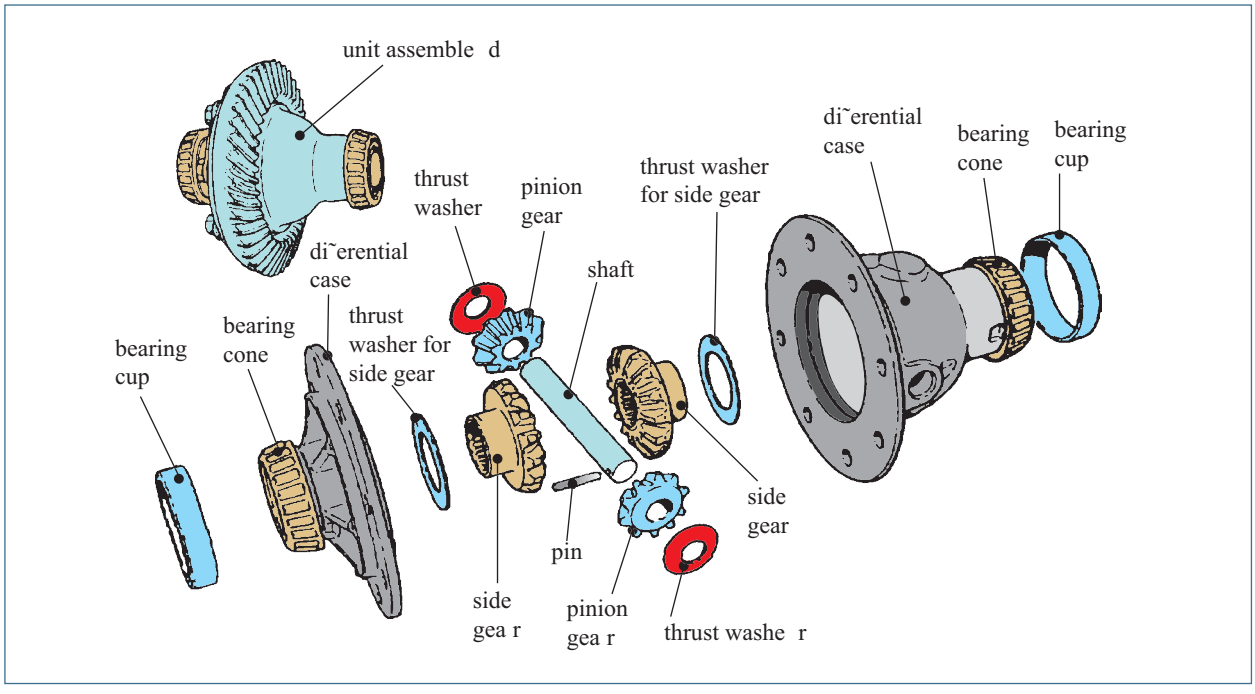


Figure 26.17 Parts of a differential assembly FORD

26.7 Limited-slip differentials

Some vehicles are fitted with limited-slip differentials. These prevent the wheels from spinning on loose surfaces and give directional stability. Under normal driving conditions, differential action occurs in the same manner as in a conventional differential. When conditions are not normal, differential action is reduced or prevented so that the wheels do not spin.

26.7.1 Limited-slip differential with plate clutches

Figure 26.18 shows a limited-slip differential which uses plate clutches to limit differential action. Each clutch consists of two sets of plates. One set of plates is splined to the side gear, the other set to the differential case.

The clutches are applied by movement of the differential pinions. The pinion shafts sit loosely in notched holes in the differential case. Normally, the shafts are in the centre of the holes and the clutch plates are only in light contact with each other. However, when the pinions are placed under load, the shafts are forced against the notches, moving the side gears sideways to apply the clutches.

The pinions will move sideways only when they are unevenly loaded, and this will only occur if the wheels have different traction. This means that the clutches will only be applied when the vehicle is turning or if there are road conditions that would allow one wheel to spin faster than the other. Figure 26.19 shows how the power flows through the differential for these conditions.

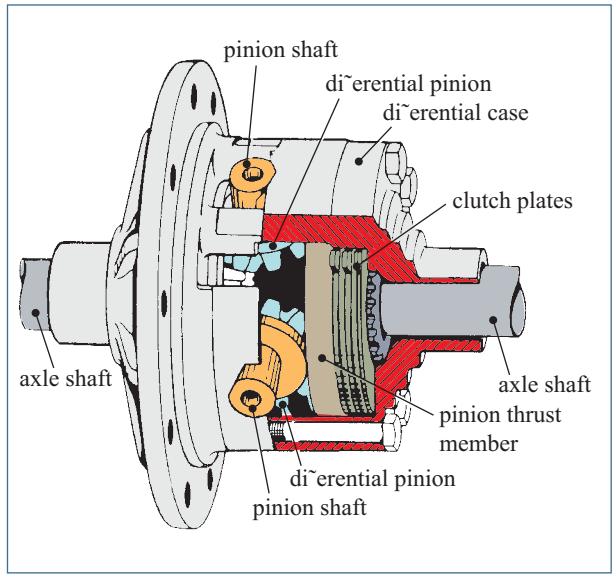


Figure 26.18 Sectional view of a differential case and components of a limited-slip differential with clutch plates

26.7.2 Limited-slip differential with cone clutches

The parts of a limited-slip differential with cone clutches are illustrated in Figure 26.20. These operate in a similar way to plate clutches.

The friction cones at the back of the side gears fit into conical mating surfaces in the differential case. These and the side gears are splined to the axle shafts.

Springs push the side gears apart and hold the cones in light friction contact with the differential case. Cone friction is increased when load is applied to the differential pinions and side gears.

The load on the gear teeth forces the gears away from each other, pushing the side gears against the cones. This forces the cones harder against the differential case to prevent normal differential action and reduces wheel slip.

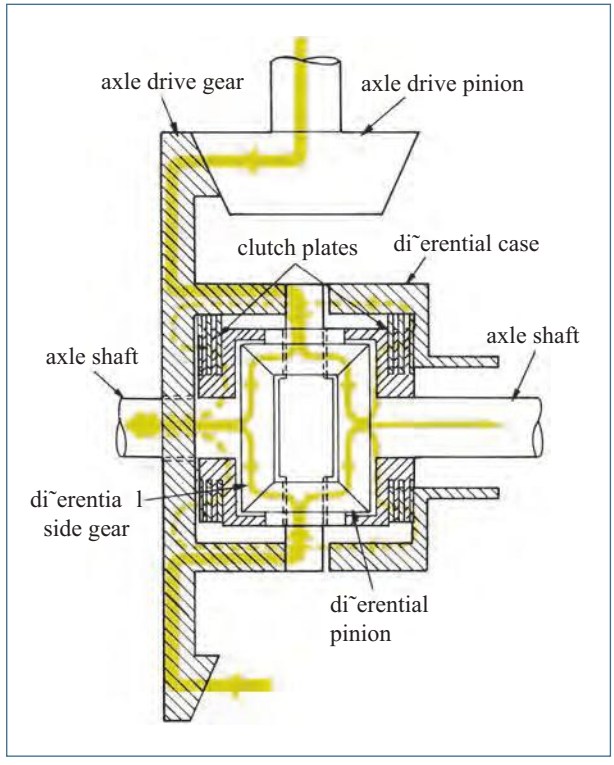


Figure 26.19 Power flow through a limited-slip differential when on a turn—the full line represents normal power flow; the dotted line indicates how power is transferred from the right to the left side during a right turn

26.7.3 Differential with viscous coupling

Figure 26.21 shows a simplified arrangement of a differential with a viscous coupling between the differential case and the left side gear.

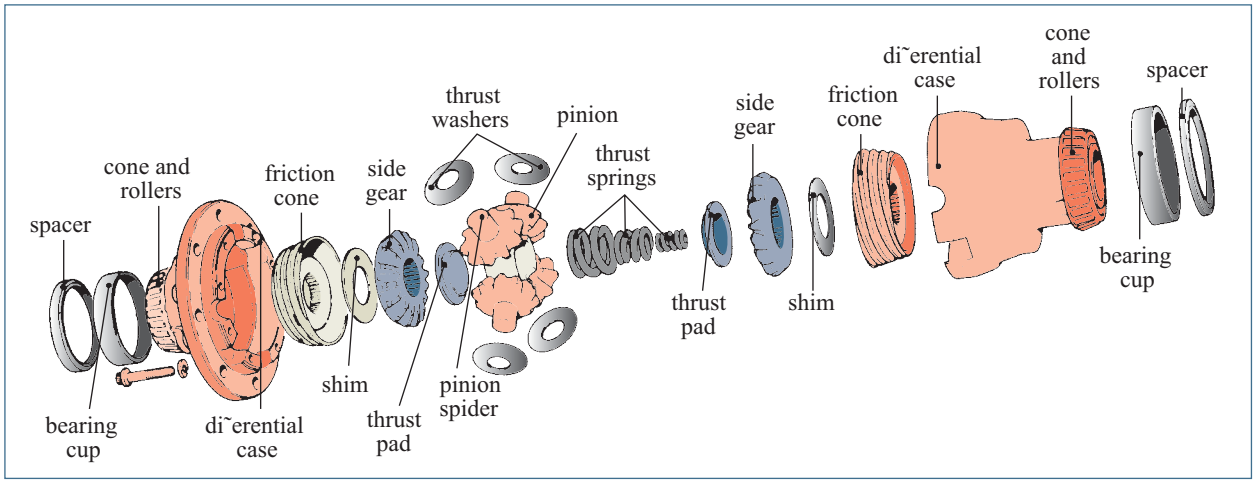


Figure 26.20 Parts of a limited-slip differential with cone clutches FORD

The viscous coupling consists of a number of thin steel plates, with alternate plates splined to the differential case and the hub of the side gear. There is a small space between each plate. The coupling is sealed and contains a special silicone oil. It operates as follows:

1 When there is no differential action, the differential case and the side gear rotate at the same speed, so there is no movement between the plates. All the parts rotate together and the coupling does not operate .
2 When there is a little differential action, there will be some relative movement between the plates, but they will rotate in the oil without operating the coupling.
3 When differential action occurs, there will be a difference in speed between the differential case and the side gear . The plates then rotate in relation to each other .

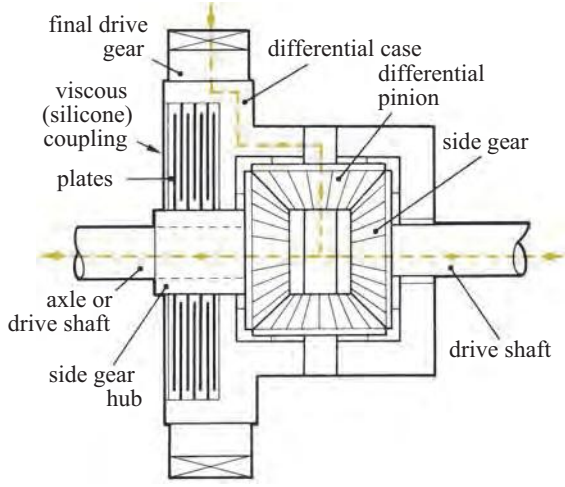


Figure 26.21 Simplified viscous (silicon) coupling; normal drive is shown by the arrows

4 As the plates rotate , they 'shear' the silicone oil. This produces heat and causes the pressure in the coupling to increase . The silicone oil is affected by both heat and pressure , and its viscosity increases rapidly . The thick oil is more difficult for the plates to shear and so the coupling commences to lock up .
5 When the coupling is lock ed, the differential housing and side gears are connected through the silicone oil and so differential action is prevented.

Under normal conditions, the clutch plates do not make direct contact with each other, but they do have slots or holes to increase their shear effect on the silicone oil.

Handy hint: The viscosity of the silicone oil increases (thick ens) as it becomes hot and subjected to pressure . This is the opposite effect to that of engine oil, which would become thinner under similar conditions.

26.8 Rear axles for independent rear suspension

A rear-axle assembly with independent rear suspension is shown in Figure 26.22. The differential carrier assembly is mounted on a crossmember attached to the body subframe. Open drive shafts carry the drive to the rear wheels. The drive shafts are sometimes referred to as swing axles because of their action.

Constant-velocity joints at each end of the shafts allow them to move in relation to the differential assembly. The drive shafts are similar to those used for front-wheel-drive vehicles.

With independent rear suspension (IRS), movement of one wheel does not affect the other. Separating the differential assembly from the drive shafts also has the advantage of reducing the unsprung mass and

so improving vehicle ride. The wheels must be kept in alignment, though, and this is done by the suspension.

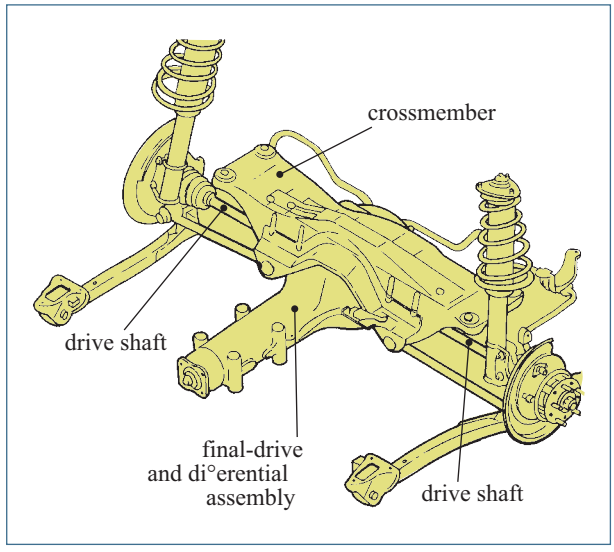


Figure 26.22 Rear-axle assembly with independent rear suspension SUBARU

26.8.1 Final drive units for IRS

Figure 26.23 shows a differential carrier assembly for a final drive for independent rear suspension. This has an extended housing with bolt holes for mounting it to the crossmember. Its long pinion shaft is supported by three bearings.

There are short spindles in the differential side gears to which the drive shafts are attached. This particular unit is used with the rear axle of an all-wheel-drive vehicle.

The final drive's separation from the driving axles removes some of the loads that are carried by a rigid axle. A rigid rear axle is subjected to a torque reaction which occurs against wheel rotation: the axle tries to turn in the opposite direction to the wheels. Torque reaction is resisted by the suspension. There is also a reaction against the torque of the propeller shaft. With the final drive mounted securely on a crossmember attached to the body and open drive shafts, these forces are removed from the suspension and absorbed by the final drive housing and the crossmember on which it is mounted.

Handy hint: Newton 's third law of motion states that for every action there is an equal and opposite reaction. This also applies to torque: whenever it is applied, there is an equal and opposite torque , or a 'torque reaction '.

One of the original designs of swing-type rear axles is the *de Dion drive* (or de Dion axle). It had a type of rigid axle which connected the wheels but did not carry the differential assembly.

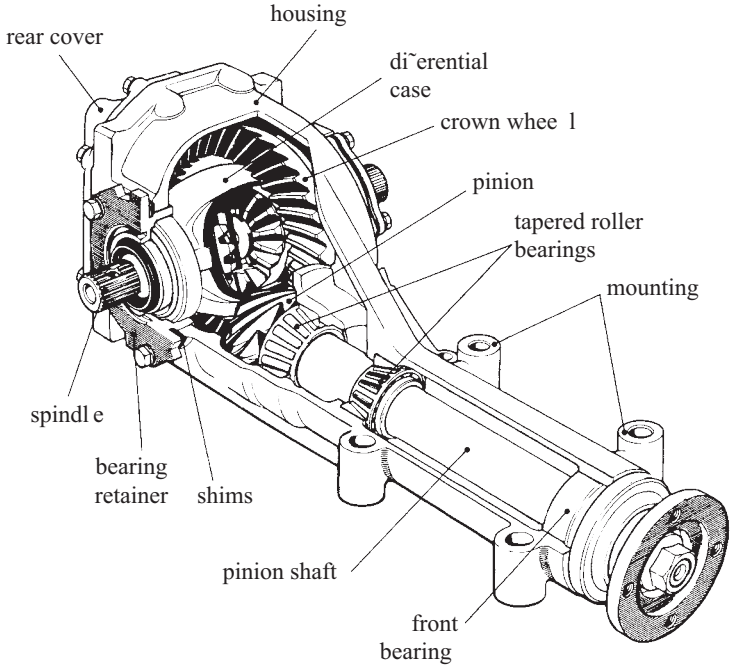


Figure 26.23 Final-drive assembly for an independent rear suspension SUBARU

26.8.2 Differential carrier assembly

Figure 26.24 is a part-section view of a differential carrier assembly. It has five mounting points that bolt it to the crossmember.

This unit has a limited-slip differential with cone clutches. It has short inner-axle shafts with a flange on the outer end and splines on the inner ends that fit into the side gears. The flanges carry toothed sensor rings for the antilock braking system (ABS).

The drive shafts that connect the differential carrier assembly to the rear wheels are not shown. They have a ball-type constant velocity joint at each end. These have flanges that bolt on to mating flanges on the inner-axle shafts and the rear-wheel trunnions.

Figure 26.25 shows the rear crossmember assembly and how the final drive unit is bolted to the crossmember. The suspension trailing arms are also attached to the crossmember.

Rear-axle hubs and bearings

The parts of the rear-wheel hub assembly are shown in Figure 26.26. The rear-wheel bearing and trunnion assembly are carried in a housing on the end of the trailing arm.

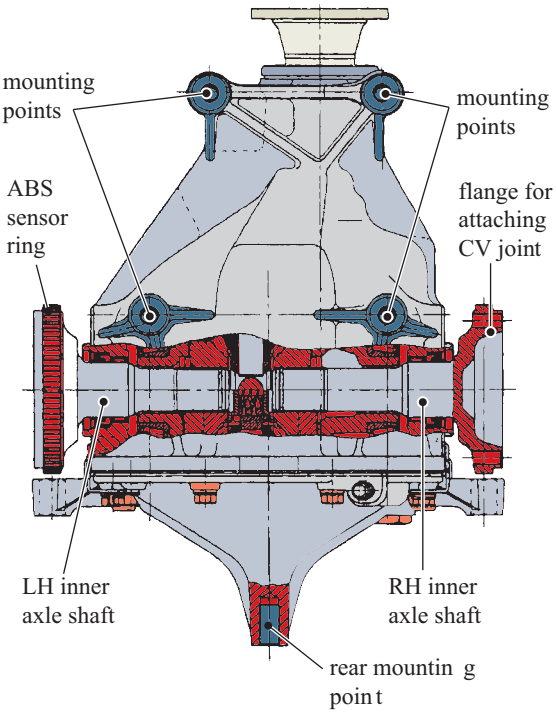


Figure 26.24 Differential carrier for an independent rear suspension

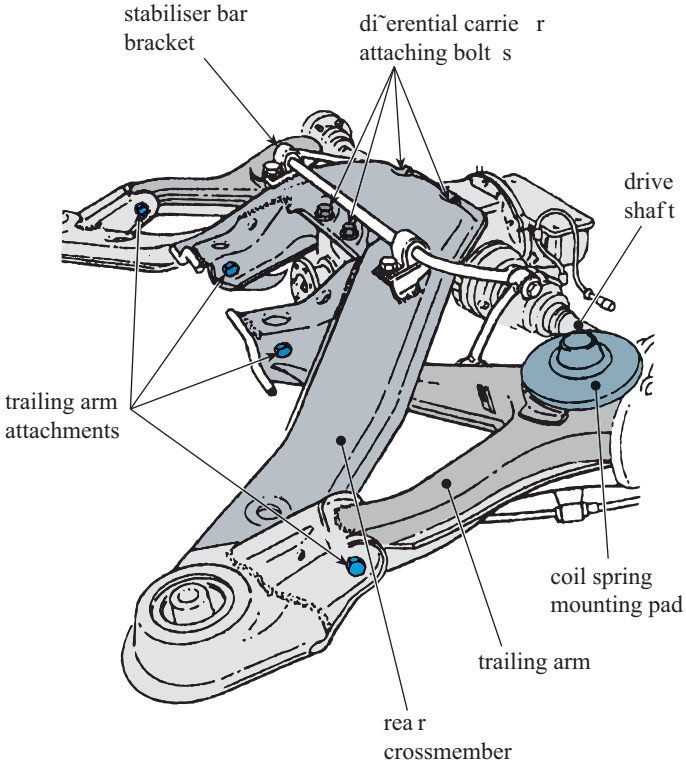


Figure 26.25 Rear suspension crossmember with mountings for the differential carrier and attachments for the trailing arms GM HOLDEN LTD

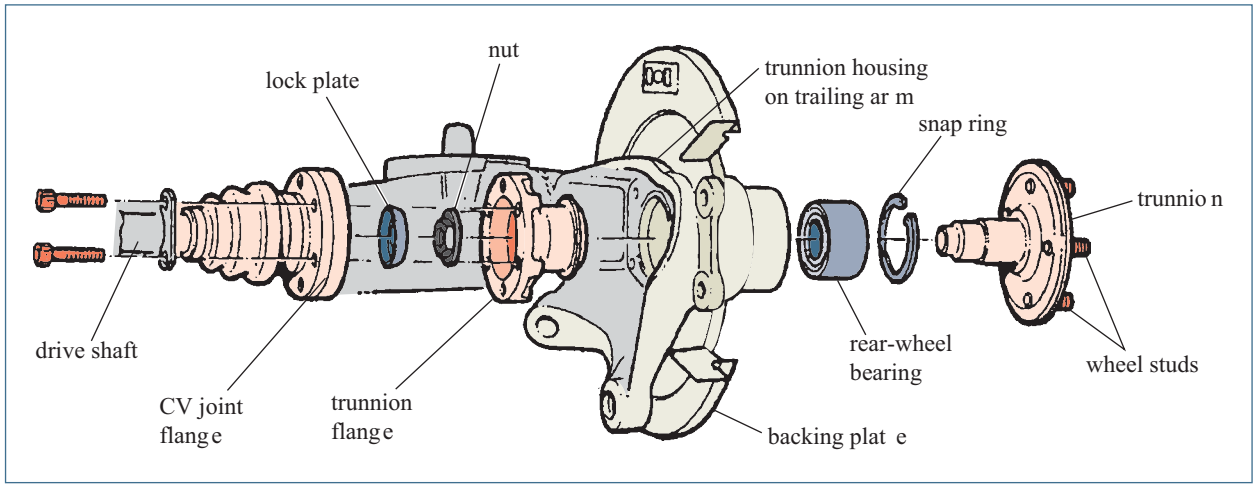


Figure 26.26 The components at the outer ends of an independen t rear suspension—they include the bearing and trunnion that carry the wheel GM HOLDEN LTD

The outer flange of the trunnion has wheel studs and forms the hub for the rear wheels. The inner flange is bolted to the flange of the constant-velocity joint on the outer end of the drive shaft.

When assembled, the bearing is retained in the housing by a snap ring. The trunnion shaft fits into the bearing with the trunnion flange splined to its inner end and secured with a nut and lock plate.

26.9 Transaxle final drive

Figure 26.27 shows the final drive for a transaxle. This is for a front-wheel-drive vehicle and is part of the transaxle assembly. The differential has similar components and operates in the same way as a differential in a rear axle, although other parts of the final drive are different.

The assembly does not have a crown wheel and pinion as its transverse engine provides drive in the right direction for the driving wheels. Instead, it has a large helical gear, known as a ring gear or final drive gear. This is driven by a helical pinion in the transmission (not shown).

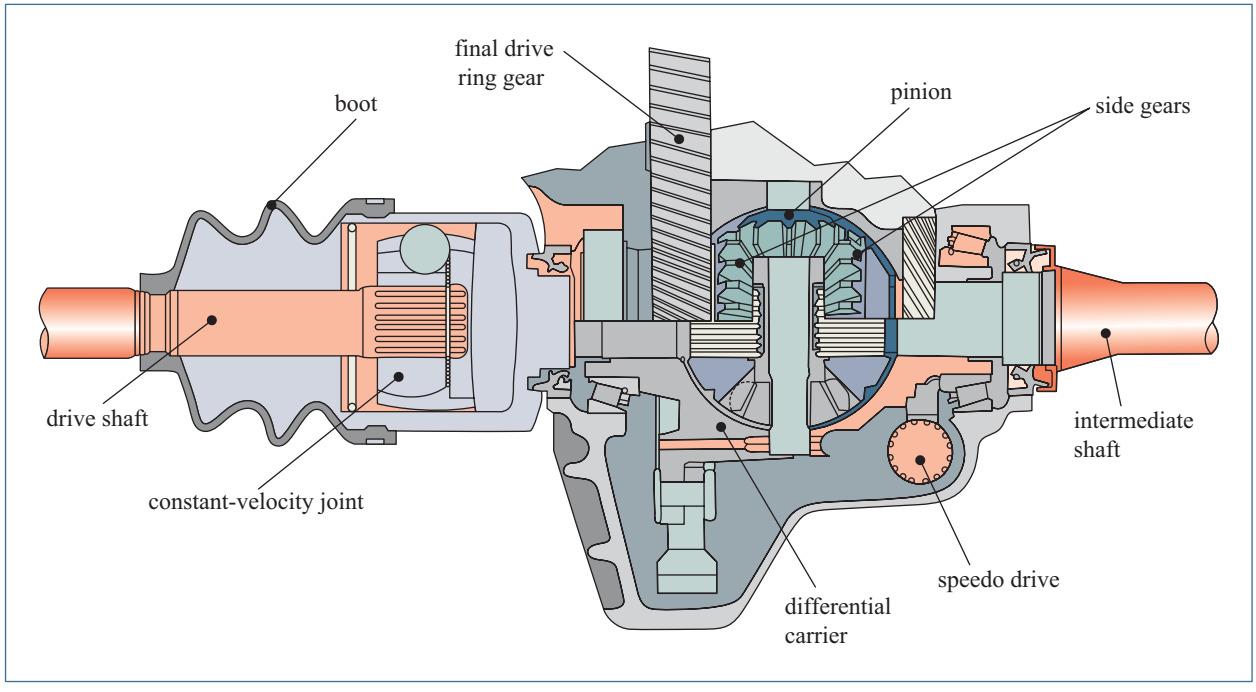


Figure 26.27 Final-drive assembly of a transaxle shown in part section

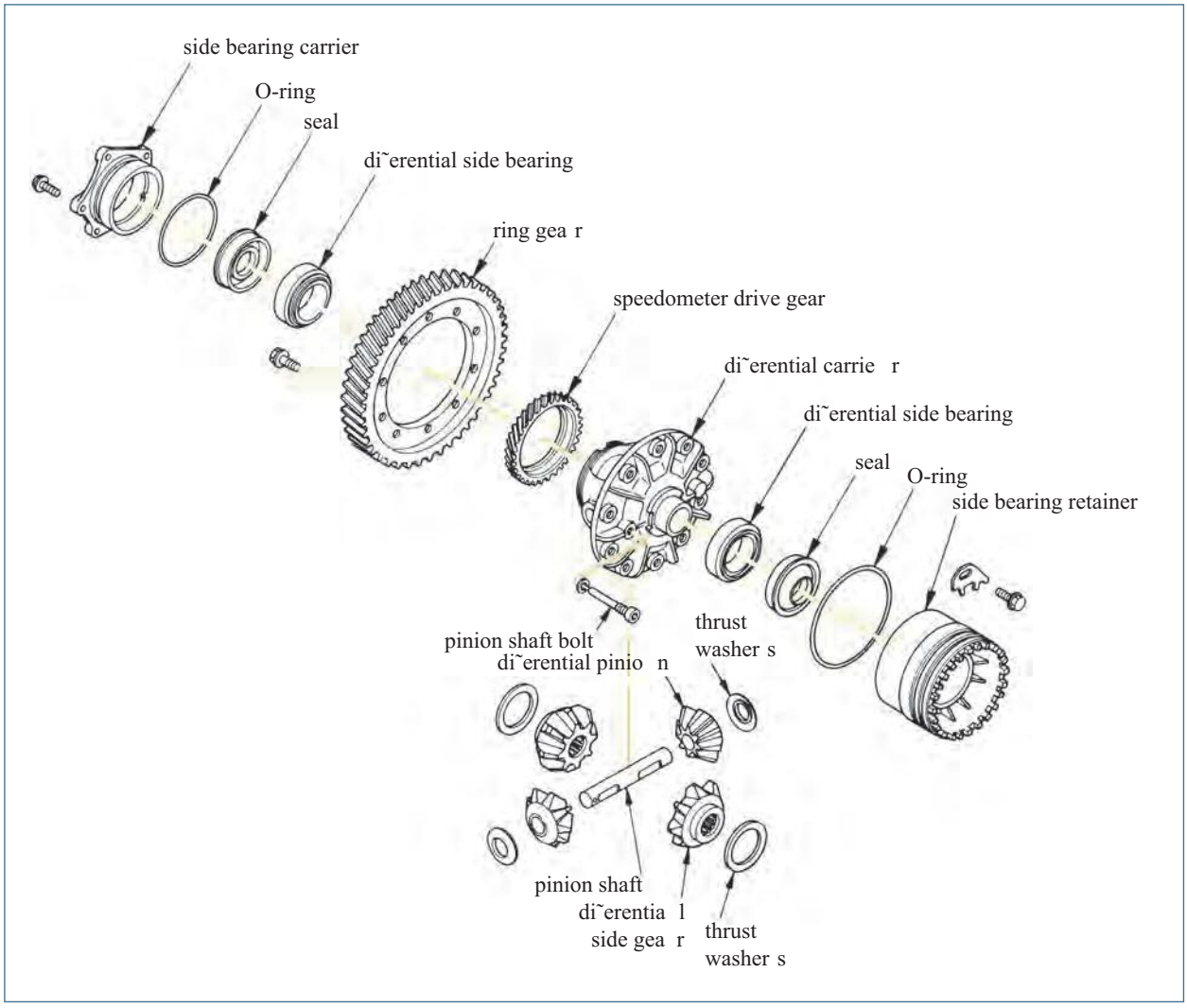


Figure 26.28 Transaxle differential assembly GM HOLDEN LTD

There is an open drive shaft with a constant-velocity joint on one side and an intermediate shaft connected to a constant-velocity joint and drive shaft on the other side. The ends of the shafts are splined into the differential side gears. Figure 26.28 shows the dismantled components of a transaxle differential.

26.9.1 Transaxle rear-wheel drive

Figure 26.29 shows the arrangement of a rear-axle assembly for a vehicle which has rear-wheel drive and its engine at the rear. The engine and transaxle are in line, with the front of the engine facing towards the rear of the vehicle.

The engine and transaxle assembly are mounted to the body subframe, and open drive shafts carry the drive from the transaxle to the rear wheels. The design includes independent rear suspension with trailing arms and coil springs. Four-wheel drives and all-wheel drives are covered in Chapter 24.

26.10 General rear-axle service points

There are various servicing procedures for rear axles and final drives. With banjo- and unitised-types, the axle shafts, axle bearings and oil seals can be removed and installed with the rear axle in the vehicle.

With independent rear suspension, the swing-type axles (drive shafts) can be removed without disturbing the differential assembly and, in some cases, without disturbing the rear-axle hubs.

For major servicing, the main differences are:

1 Banjo-type rear axle . The differential carrier can be removed from the rear-axle housing for service without having to remove the complete rear-axle assembly .

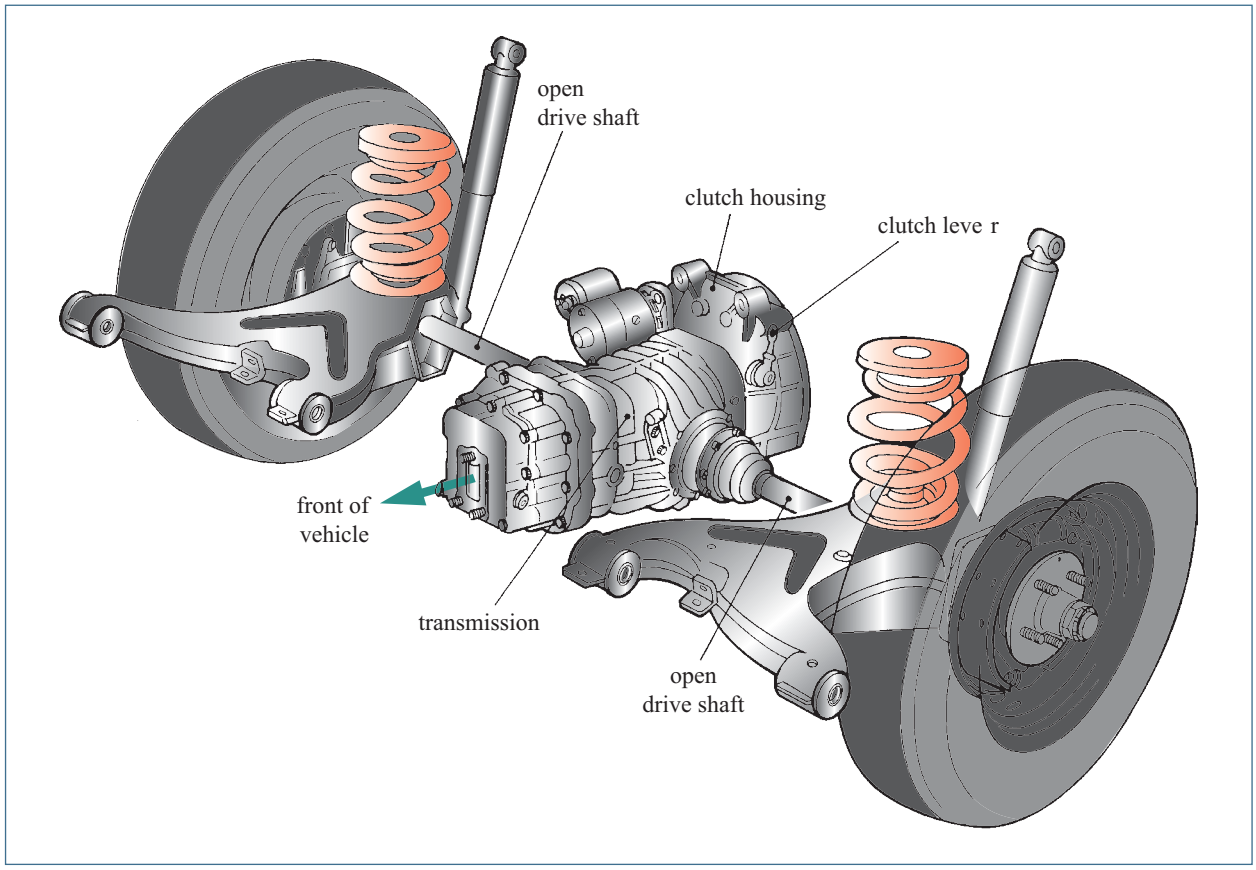


Figure 26.29 Transaxle for a rear-engine rear-wheel-drive vehicle

2 Unitised-type rear axles. The differential carrier is an integral part of the rear-axle housing. The differential assembly can be serviced on the vehicle, but the complete rear-axle assembly is often removed if there is major work to be done.

3 Swing-type axles. The differential carrier assembly can be removed from the rear crossmember or subframe as an assembly, but the drive shafts must be disconnected or removed first.

26.10.1 Maintenance and lubrication

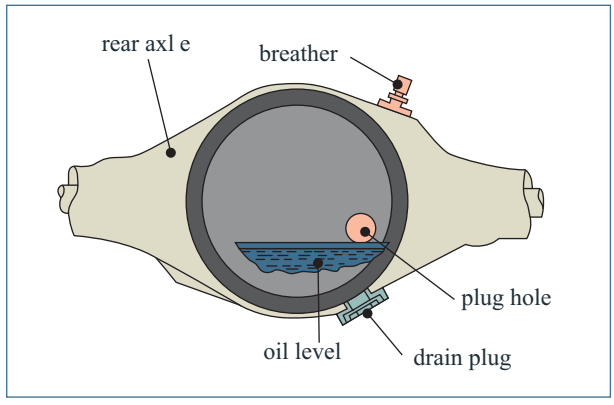


Figure 26.30 The oil level in a rear axle should be at, or close to, the bottom of the plug hole

The lubricant level in the rear axle should be checked periodically. This is done through the filler plug hole. The oil should be at or near the bottom of the hole, as shown in Figure 26.30. If the level has dropped, the pinion oil seal (at the front of the pinion shaft) and the axle or drive shaft oil seals should be checked for leaks.

A breather is fitted to the axle housing. This should be checked to make sure that it is clear. A blocked breather will cause oil to leak.

On a rigid rear axle, the breather is on the high part of the axle housing. With an independent rear suspension, the breather is on top of the differential carrier.

The lubricant used in most standard rear axles is an SAE 80 or SAE 90 (API GL-5) gear oil, which is designed for hypoid gears. Rear axles with limited-slip differentials, with plate or cone clutches, generally require a special oil.

Some rear-axle oils are mineral oils and others are synthetic. Always use the lubricant specified for the particular vehicle; incorrect lubricants could cause premature gear wear. Incorrect oil in the rear axle of a limited-slip differential could cause poor operation of the plates or cones.

There is a specified oil change period for some rear axles; this will depend on the type of service the vehicle is used for.

Sustainability: When repairing or replacing an automotive rear axle or final drive , drain and dispose of waste gear oil according to regulations.

26.11 Removing axle shafts and bearings

Axle shafts are removed to renew oil seals or bearings. They are also removed as part of the dismantling procedure so that the differential assembly can be removed from the axle housing. Different procedures are used for removing semifloating, three-quarter floating and full-floating axles, and for the drive shafts of independent rear suspensions.

26.11.1 Semifloating axle shafts

With semifloating rear-axle shafts, the bearing fits into a recess in the end of the axle housing. In most axles, the bearing is held in place by a retainer bolted to the flange of the axle housing. Before removing the axle shaft, raise the wheel and remove it, along with the brake drum (or brake disc).

With some drum brakes, the nuts attaching the bearing retainer to the axle housing are accessible through holes in the flange of the axle shaft, as shown in Figure 26.31. Removing the nuts releases the retainer and the brake backing plate assembly. The axle shaft can then be removed from the housing.

The retainer nuts are accessible once the caliper and the brake disc have been removed. After removing the nuts, the bearing retainer and brake caliper bracket can be removed, and then the axle. Figure 26.32 illustrates the dismantled parts.

Once accessible, the axle shaft can often be removed by hitting the housing and shaft with a soft-faced hammer while pulling on the shaft. If the axle is difficult to remove, attach a slide hammer to the axle shaft flange, as shown in Figure 26.33. The bearing will come away with the shaft, although the cup of a tapered roller bearing could remain in the housing.

Semifloating axle shaft with retainers

Figure 26.34(a) shows an axle shaft with a retainer at its inner end. The retainer is horseshoe-shaped so that it can slide into a groove in the end of the shaft.

The differential assembly is shown in Figure 26.34(b). The splined ends of the axle shafts fit into the side gears which are recessed for the retainers. A spacer, which acts as a thrust block, is fitted to the pinion shaft. It sits between the ends of the axles, with a small thrust clearance.

The axle bearings, on the outer end of the shafts, are plain rollers which take no thrust. Side thrusts are transferred through the axles and taken by their inner ends against the spacer.

When removing an axle, remove the pinion shaft and spacer first. The axle is then pushed inwards so that the retainer is clear of the recess in the side gear. The retainer can then be taken from its groove so that the axle is free to be removed.

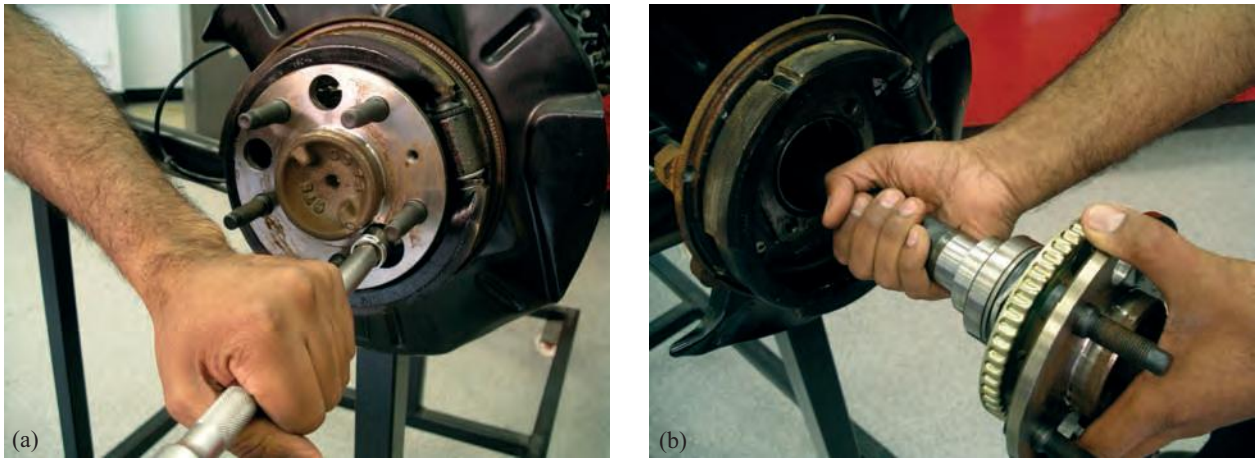


Figure 26.31 Removing a rear-axle shaft (a) Removing nuts from the bearing retainer (b) Removing the rear axle from the housing

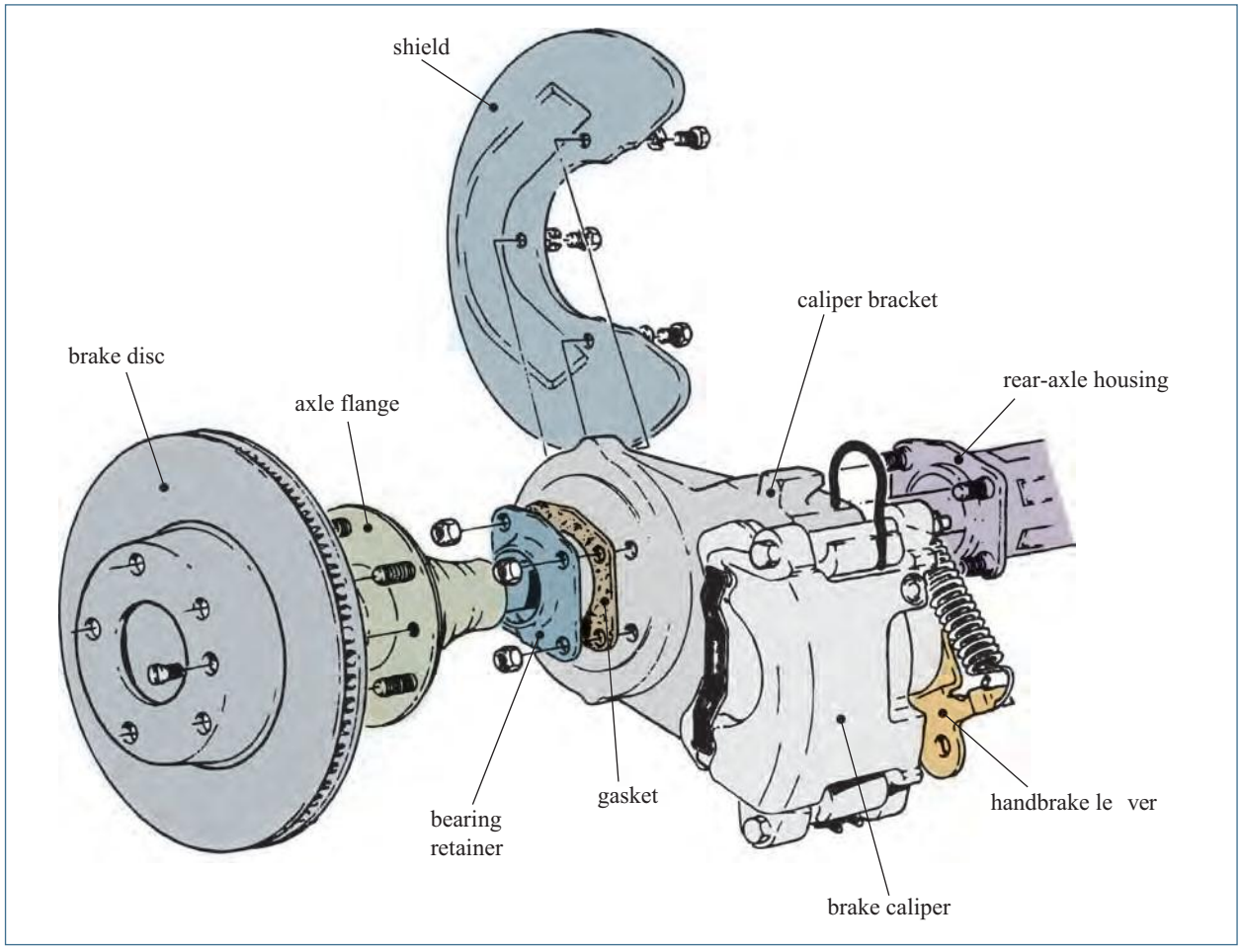


Figure 26.32 A rear-axle hub assembly and associated parts FORD

26.11.2 Removing and replacing axle bearings

Although the bearing of a semifloating axle is a light press fit on the axle shaft, it still has to be held in place. Often, a collar (sometimes called a shrink ring) is used. It is a tight fit on the shaft and has to be expanded before it can be removed. Rest the shrink ring on a solid metal surface, making two or three cross cuts around it with a cold chisel (Figure 26.35). The cuts will expand the ring, allowing it to be removed.

Handy hint: Heat should not be used on the collar as this would affect the original heat treatment of the axle .

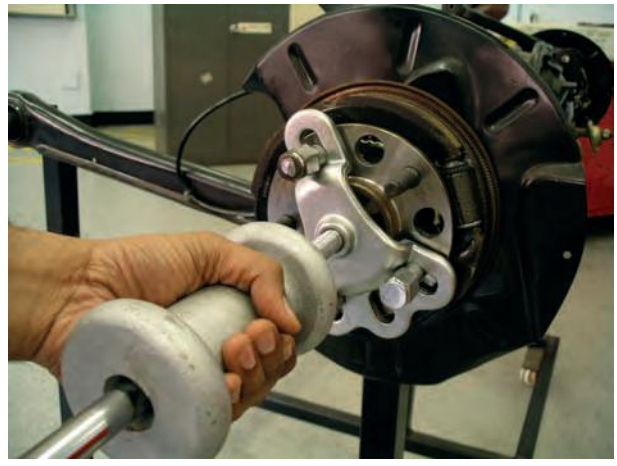


Figure 26.33 Removing an axle shaft with a slide hammer

When reassembling, install the parts on the shaft in the correct sequence: bearing retainer first, then the oil seal, bearing and collar. Press the bearing onto the shaft, but only apply force to the cone or inner race of the bearing. A new collar must be used and is fitted after the bearing.

Another method of retaining the bearing on the axle is with a large nut that is threaded on the axle shaft. With the nut removed, the bearing can be pressed from the shaft, or reinstalled on the shaft.

The axle bearing should be lubricated before the axle shaft is installed in the housing. The bearing should be repacked with grease (new ballraces are usually prepacked and sealed).

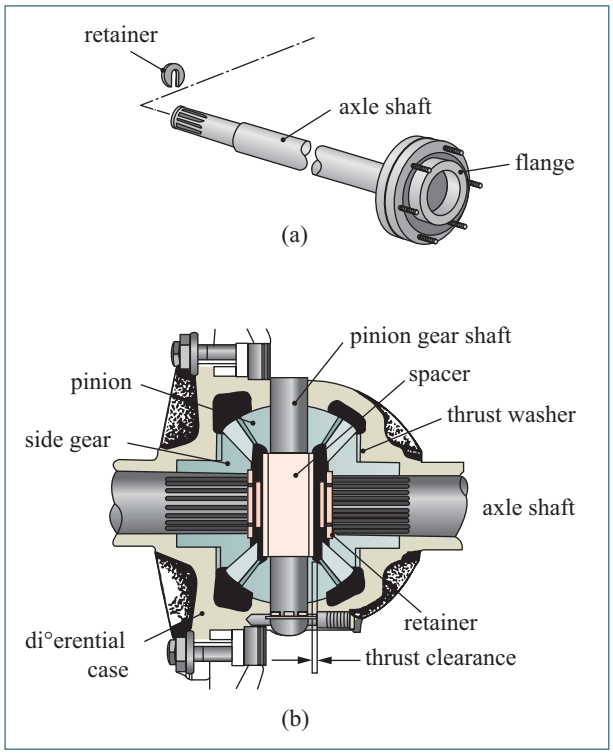


Figure 26.34 Rear-axle parts (a) axle shaft (b) differential assembly

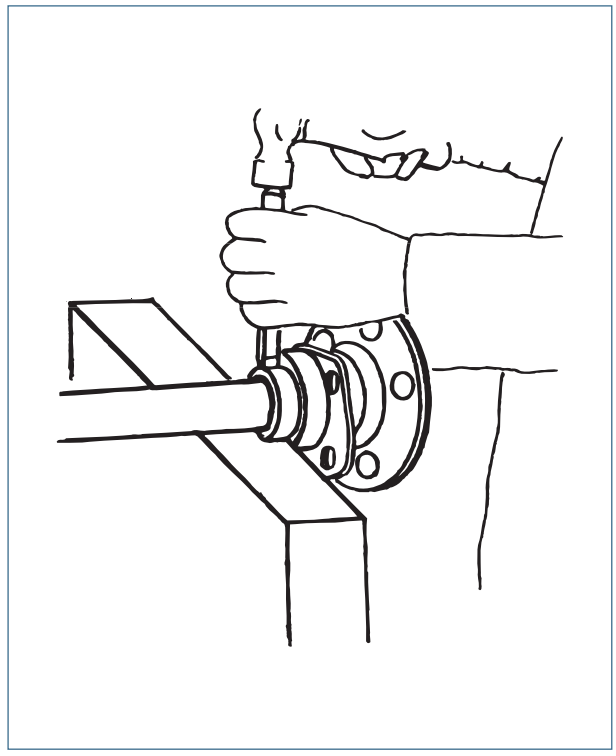


Figure 26.35 Removing a rear-wheel bearing collar prior to removing the bearing

26.11.3 Three-quarter floating axle shaft

The construction of this type of axle, which has little application in modern vehicles, is shown in Figure 26.36. The axle shaft can be removed without disturbing either the hub or the bearing. The bearing is mounted between the hub and the outside of the rear-axle housing. The hub can be removed to renew the bearing or the oil seal. The outer end of the axle housing is threaded and a large nut retains the hub bearing. Unscrewing the nut allows the hub and bearing to be removed.

26.11.4 Full-floating axle shaft

With a full-floating axle assembly, the axle shaft can be removed with the wheels on the ground (Figure 26.37) by removing the nuts, washers and cones from the studs in the hub.

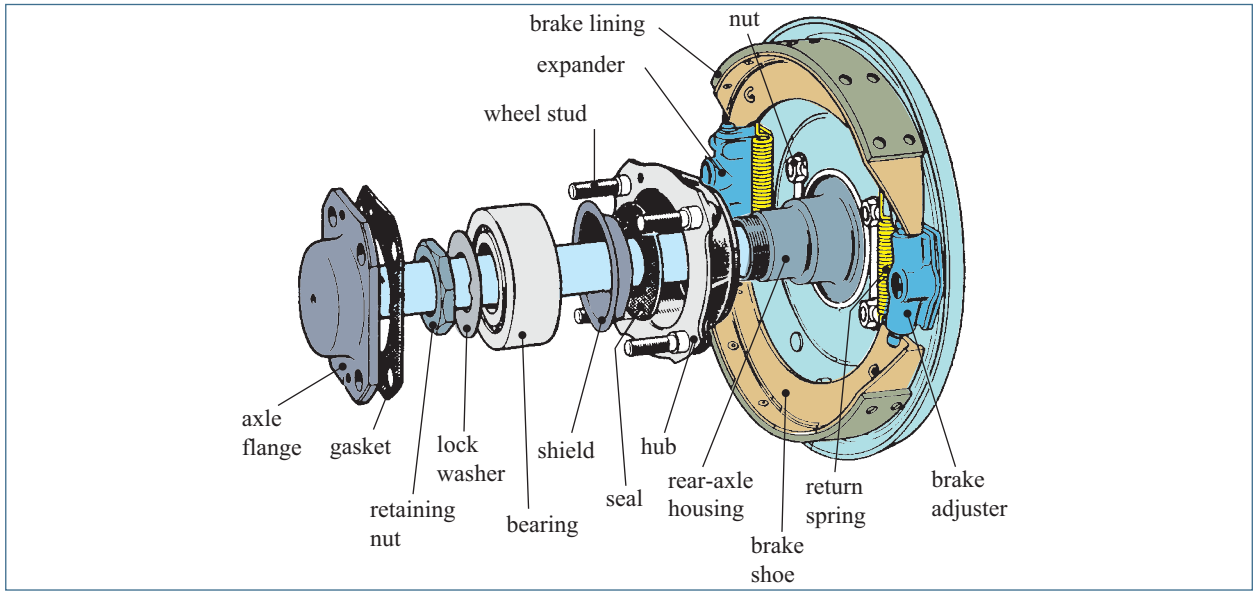


Figure 26.36 Three-quarter floating rear-axle assembly

Two extracting bolts are used to remove the axle shaft. These are inserted into threaded holes in the flange. Their ends push against the face of the hub as they are tightened, separating the axle flange from the hub.

A gasket between the hub and the flange prevents rear-axle lubricant leakage. This should be renewed whenever the axle shaft is removed. Sealant is sometimes used on the faces.

Figure 26.38 shows an axle shaft and a dismantled hub and bearings. The latter are retained on the axle housing by large nuts threaded on the end of the axle housing. To remove the hub and bearings, remove the locknut first, then the lock washer and the adjusting nut.

The tapered roller bearings must be adjusted during reassembly (they should be neither tight nor loose). To seat the bearings, tighten the adjusting nut while the hub is being rotated until resistance is felt. Then slightly back off the nut before fitting the lock washer and locknut. This should be done with the wheels removed.

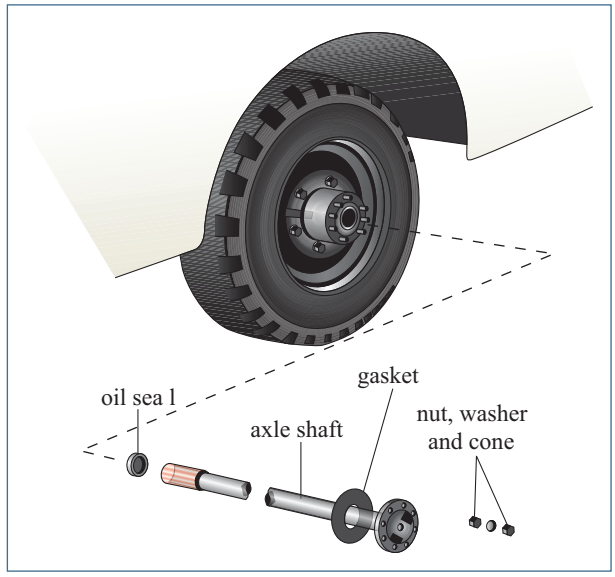


Figure 26.37 Full-floating rear-axle shaft with wheel and hub assembly

After the vehicle has been given a short run, the wheels should be jacked up and checked for any looseness. A lever under the tyre can be used for this.

26.11.5 Drive shafts and hubs for IRS

Figure 26.39 shows a rear-wheel hub and bearing assembly of a rear axle with independent rear suspension (IRS). The outer end of the open drive shaft is splined into the wheel hub. The tapered roller bearing, which fits between the wheel hub and the housing on the suspension, has a double row of rollers and is non-adjustable. Seals and shields retain lubricant and keep out dirt.

The inner hub is splined to the drive shaft, and these are retained in place in the housing by a nut on the outer end of the shaft. The drive shafts have constant-velocity joints and are similar to the shafts for front-wheel drives (as covered in Chapter 19).

Handy hint: **A different design of drive shaft and hub assembly for IRS is illustrated in Figure 26.26.**

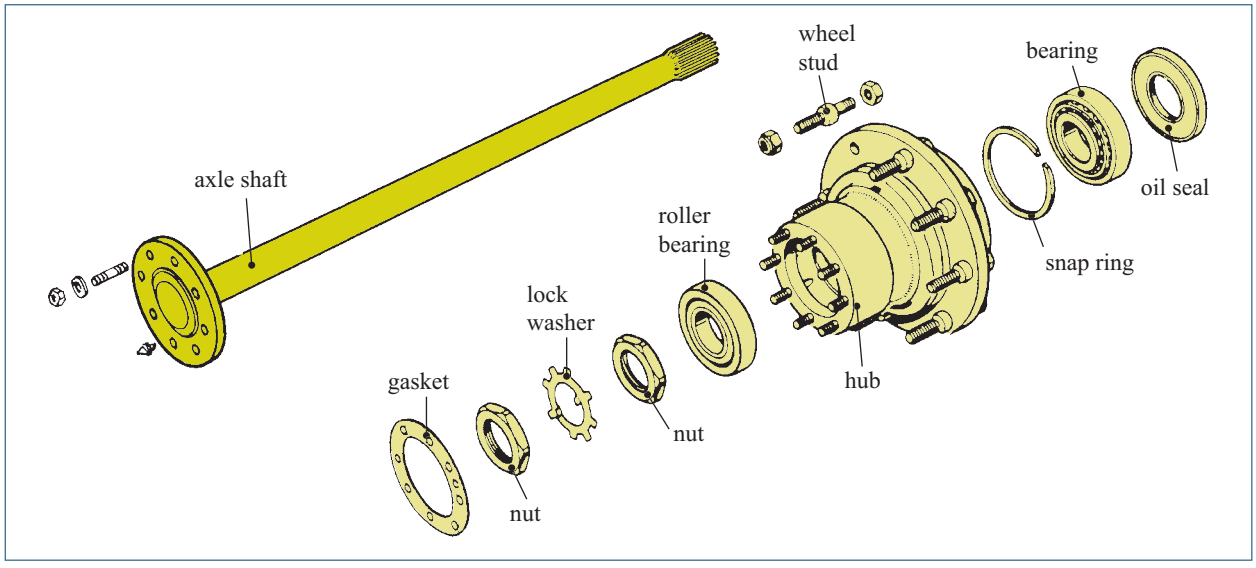


Figure 26.38 Parts of a full-floating rear-axle assembly MITSUBISHI

26.12 Servicing differential assemblies

While differential assemblies have various designs, there are common settings and adjustments. The main differences in servicing relate to removing and replacing the differential assembly and the way in which the differential case is supported in its side bearings.

The differential assembly of a banjo-type rear axle is removed from the axle housing and held in a bench fixture or vice for dismantling. There are screw adjustments for the differential case side bearings.

The complete rear-axle assembly is usually removed for major work and then dismantled. The differential side bearings have shim or spacer adjustments.

The differential assembly of an independent rear suspension is removed from its mounting on the crossmember or subframe for major repairs. Some differential side bearings have screw adjustments, while others have shim adjustments.

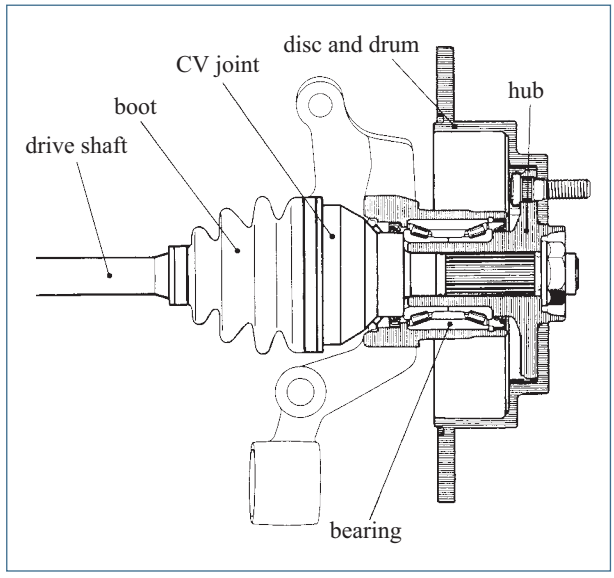


Figure 26.39 Drive shaft and hub of a swing-type rear axle SUBARU

26.12.1 Reasons for dismantling a differential assembly

The main reason for dismantling a differential assembly is noise caused by one or more of the following:

- worn or damaged bearings
- worn or damaged gear teeth
- loss of bearing preload
- incorrect tooth contact
- incorrect backlash.

Handy hint: Some of these faults are the result of others, such as worn bearings affecting preload and preload affecting backlash and tooth contact. All items should be systematically check ed during dismantling.

Figure 26.40 Differential carrier assembly for a banjo-type rear axle—the bearing caps and adjusting nuts are mark ed before dismantling

26.13 Servicing a banjo-type axle differential

The following sections cover the procedures for servicing a differential assembly. They generally relate to the type of differential assembly shown in Figure 26.40, which is from a banjo-type rear-axle housing, but there are similar procedures for other differential assemblies.

The differential carrier of a banjo-type rear axle is removed from the axle housing and held in a bench fixture for dismantling. Alternatively, the flange of the differential carrier can be held in a vice, but soft jaws are needed to prevent damage.

During dismantling, the differential case is removed from the differential carrier. As a separate operation, the pinion is removed from the carrier. The crown wheel is removed from the case, the case is separated and the pinion and side gears can then be removed.

Handy hint: Adjustments and checks are covered in the procedures that follow . There are a number of different methods, and these are discussed later in this chapter .

26.13.1 Pre-dismantling checks

The assembly should be checked both before and during dismantling to determine the condition of the parts, identify suspected faults and aid reassembly.

Before dismantling:

1 Rotate the crown wheel and pinion by hand, noting any preload or harshness that could indicate faulty bearings.
2 Check that backlash exists between the crown wheel and pinion and look for tooth damage.
3 Measure the backlash using a dial gauge against a crown wheel tooth (Figure 26.41). A check at three different locations will indicate if runout is excessive.
4 Mark three or four teeth with red oxide and oil, and check the tooth contact (as described later).
5 Check the pinion nut, crown wheel bolts and bearing cap bolts for signs of looseness.

26.13.2 Removing the differential case

1 Mark the right-hand and left-hand bearing caps and adjusting nuts in relation to the bearing mounting (as shown in Figure 26.40). The bearing caps and bearings are not interchangeable.
2 Remove the locking plates and loosen the bearing cap bolts slightly.
3 Back off the side bearing adjusting nut to the point where the bearing cup ceases to turn with the nut. If the preload is correct, the cup should turn two to three notches with the nut and then stop (see Figure 26.59).
4 Remove the cap bolts and the bearing caps, and then lift the differential case, complete with crown wheel, from the carrier. Keep the side bearing cups to their original sides.

26.13.3 Removing the drive pinion

1 Check the pinion bearing preload by means of a pulley and spring scale or with a torque wrench (see Figure 26.56).
2 Remove the pinion nut. Then remove the universal joint flange with a puller, or tap it off the pinion shaft with a soft-faced hammer.
3 Remove the pinion from the carrier by tapping its front end with a soft-faced hammer. The pinion bearing spacer will follow. Any shims should be carefully stored.

26.13.4 Dismantling the differential case

1 The crown wheel is bolted to the differential case. After removing the bolts (Figure 26.42(a)), it can be tapped off the case (b).
2 The differential case is usually in two parts that are bolted together. After removing the bolts, the parts of the case can be separated.
3 The differential gears remain in one part of the case. The pinion shaft is held in the case by a pin which can be driven out with a pin punch. The pinion shaft can then be driven from the case (Figure 26.43(a)).
4 After the shaft has been removed, the thrust block and pinions can be removed from the case (Figure 26.43(b)), and then the side gears. The thrust washers behind the gears are also removed.

Figure 26.41 Checking crown wheel backlash with a dial gauge

Figure 26.42 Removing a crown wheel from the differential case

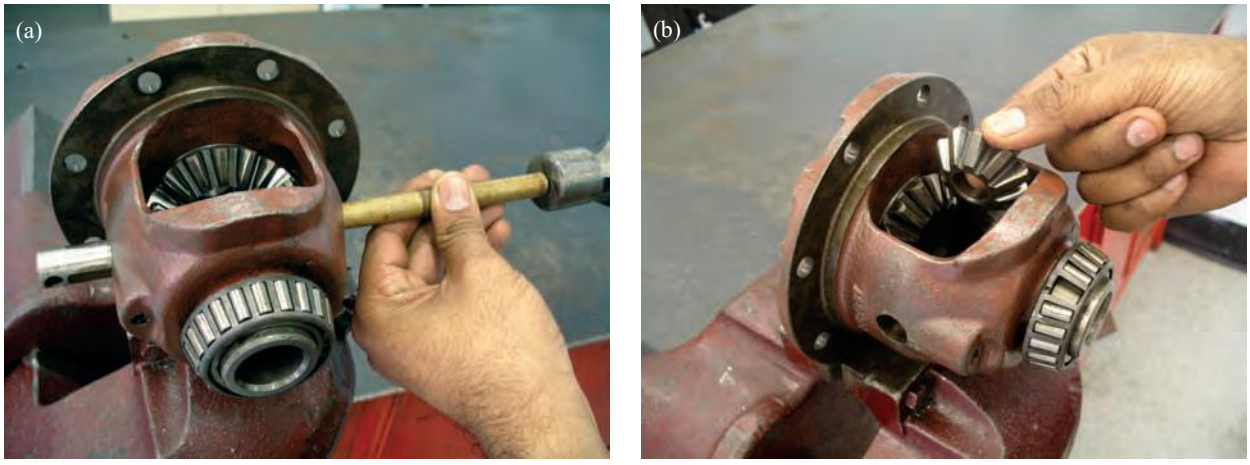


Figure 26.43 Dismantling the differential gears (a) removing the pinion shaft (b) removing the gears

There are various arrangements of pinion shafts and gears. Figure 26.43 has a thrust block, but is not shown. Figure 26.48 has a thrust block between the gears and one long shaft and two short shafts to carry its four pinions.

Handy hint: The differential shown in **Figure 26.17 has a single shaft with two pinions, while the limited-slip differential in Figure 26.20** has a spider that carries four pinions.

26.13.5 Removing and replacing bearings

The side bearing cones are a press fit on the differential case and normally would only be removed if they had to be renewed. A puller is required to prevent damage to the bearing and case (Figure 26.44(a)).

The same applies to the cone of the rear pinion bearing, which is a press fit on the pinion shaft. A press with a suitable pressing tool and press plates is used (Figure 26.44(b)).

Handy hint: In all cases, force should be applied only to the bearing cone and not through the rollers or cage .

26.13.6 Inspection of differential parts

Inspect the parts as follows:

1 Bearings and bearing surfaces. Check their condition and lubricate all bearings after cleaning and before reassembly .
2 Crown wheel and pinion. Examine the teeth of the crown wheel and pinion for wear . If there is any, the gears must be replaced as they will not operate quietly .
3 Differential gears. Examine the thrust faces of the gears and case , the pinion shaft and the thrust washers for wear or damage .
4 Pinion flange . Examine the sleeve portion of the flange for wear from the oil seal.
5 Crown wheel mounting face . Temporarily install the differential case in the differential carrier . Mount a dial gauge against the face and check runout. This should not ex ceed 0 .1 mm.

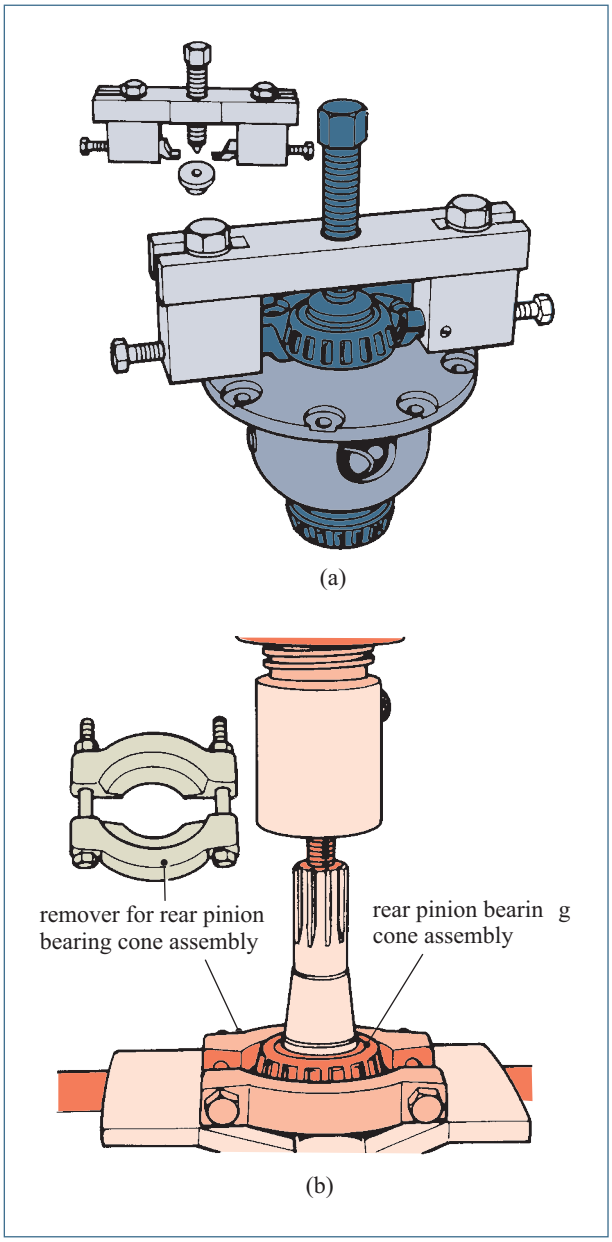


Figure 26.44 Method of removing bearings (a) from the differential case (b) from the pinion

26.13.7 Reassembling the differential

Reassembling is basically the reverse of dismantling, but with particular attention to adjustments and settings. Using gauges similar to those shown in Figure 26.45 speeds up the job. Without gauges, it may be necessary to partly dismantle and reassemble several times until satisfactory tooth contact is obtained.

Assembling the differential case

The differential gears are installed in the case and the pinion shaft is fitted, with the lock pin securing it in place.

To assemble the crown wheel, guide studs can be used so that the bolt holes in the crown wheel line up with the threaded holes in the differential case.

If the crown wheel is a neat fit, it can be heated on a hotplate (not with a flame). When it is hot to the touch, it should have expanded sufficiently to fit easily over its mounting spigot on the differential case.

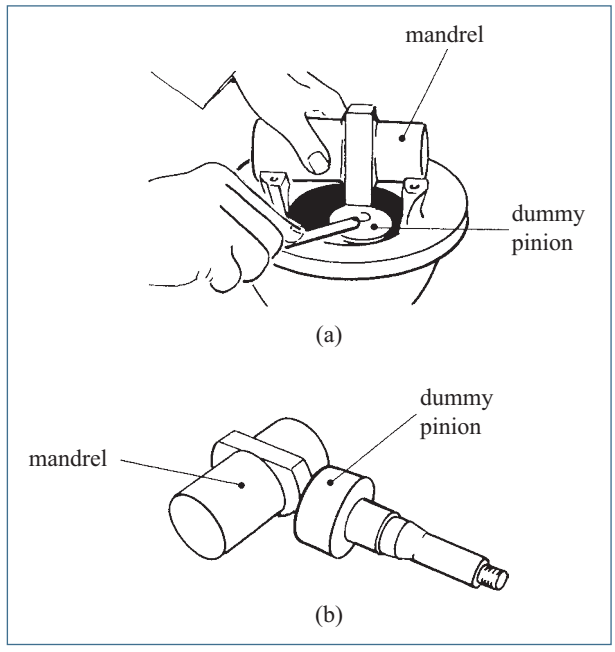


Figure 26.45 Reassembly (a) Using feeler gauges between the mandrel and dummy pinion to determine the shim thickness (b) mandrel and dummy pinion

Installing the drive pinion

1. Install a dummy pinion and mandrel in the differential carrier .
2. Using feeler gauges as shown in Figure 26.45(a), determine the thickness of shim needed under the pinion head.
3. Remove the dummy pinion and mandrel.
4. Refit the rear bearing to the pinion shaft with the correct thickness of shim under the head of the pinion.
5. Reassemble the pinion in the differential carrier .
6. Where a collapsible spacer is used, tighten the pinion nut to collapse the spacer to give the specified preload to the pinion bearings (see Figure 26.58).
7. Where a solid spacer and shims are used (see Figure 26.57), adjust the shim thickness to give the required preload. The original preload reading will give a guide to the shim thickness required.

Handy hint: Where a dummy pinion and mandrel are not available , the original shim pack should be used. Subsequent pinion adjustment might be needed when the tooth contact markings have been check ed.

Installing the differential case in its carrier

1. Sit the differential case , with the crown wheel, into the pedestals of the differential carrier .
2. Replace the bearing cups over the bearing cones and fit the adjusting nuts into the threads in the pedestals, making sure the nuts turn easily and the threads are not crossed.
3. Refit the bearing caps and bolts, tightening the bolts only lightly until adjustment is completed.
4. Screw the adjusting nuts in until they bear against the bearing cups, using the marks made prior to dismantling. There should be backlash between the crown wheel teeth and the pinion teeth.
5. Tighten the nuts two three notches to adjust the side-bearing preload.
6. Check and adjust the backlash, using a dial gauge .
7. Check the gear tooth contact and adjust if necessary .
8. Tighten the cap bolts to the specified torque and fit the locking plates and bolts.

Handy hint: The backlash is adjusted within specified limits (for example , 0.15 to 0.25 mm). Bearing preload is maintained by backing off one nut and then tightening the other the same amount.

26.14 Servicing unitised rear-axle differentials

Unitised rear axles have shim or spacer adjustments for the differential case side bearings, which influences dismantling and reassembly. There are different methods for removing and installing the crown wheel and differential case in the housing and for adjusting the bearings.

26.14.1 Dismantling the differential assembly

The differential side bearings are preloaded and this holds the differential case firmly in the housing. When dismantling, the bearing mountings are usually spread slightly to relieve the preload so that the differential case with the crown wheel can be easily removed. The sequence is shown in Figure 26.46.

1. Mark the left-hand and right-hand bearing caps to identify their positions for reassembly (Figure 26.46(a)).
2. Remove the bearing cap bolts and bearing caps.
3. Fit a spreader tool to the differential housing (Figure 26.46(b)).
4. Adjust the nut on the spreader tool so that the crown wheel and differential case can be removed from the carrier (Figure 26.46(c)).
5. Remove the crown wheel and differential case and release the spreader .
6. Identify right and left bearing cups and shims or spacers so they can be correctly located for reassembly .
7. Remove the pinion from the housing.

Handy hint: To avoid overspreading the housing with the spreading tool, a dial gauge is installed as shown (Figure 26.46(b)) so that the amount of spread can be measured.

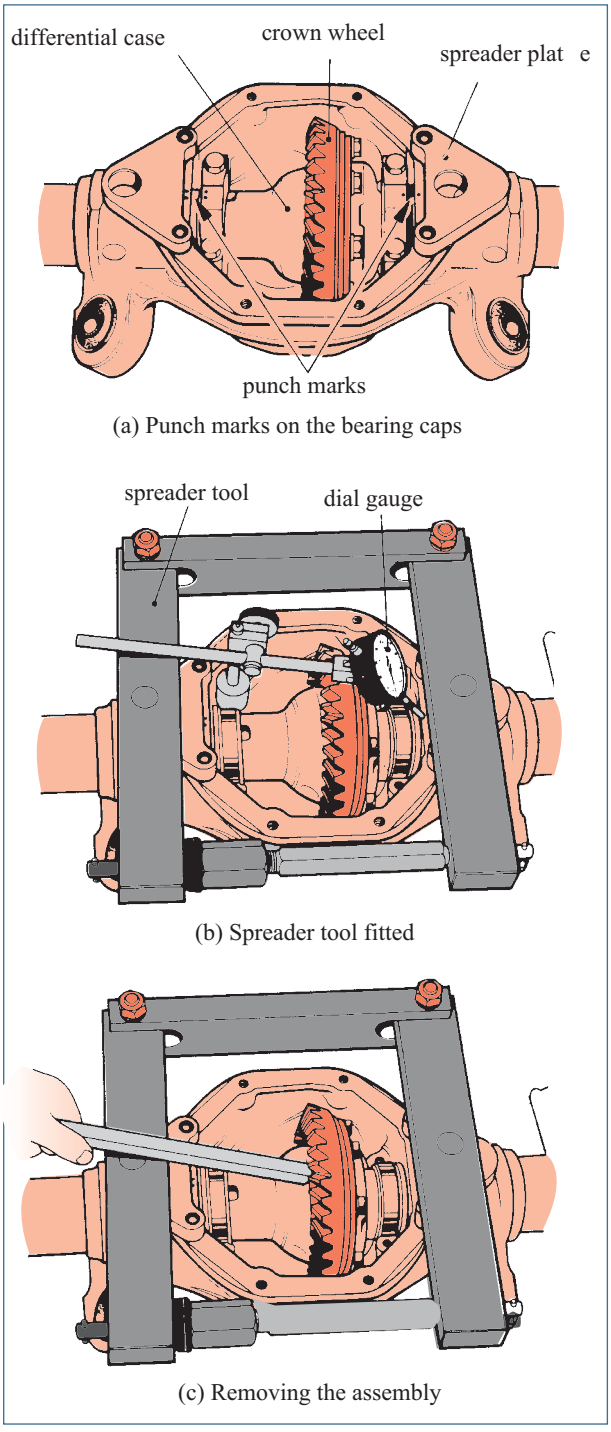


Figure 26.46 Removing the crown wheel and differential case from a unitised rear-axle housing MITSUBISHI

26.14.2 Reassembling the differential assembly

The side bearings have to be given a specified preload. Before the pinion is installed, the differential case is temporarily mounted in the housing so that side-bearing preload can be checked and adjusted. After this is done, normal reassembly can proceed.

Adjusting side-bearing preload

1. Select two spacers or sets of shims for the side bearings. These should be less than the thickness required for final assembly .
2. Check the side clearance of the bearing cups with feeler gauges as shown in Figure 26.47 and determine the total spacer thickness required to remove the bearing side clearance . Add 0 .05 to 0.10 mm for bearing preload.
3. Install the additional spacer or shims and check the preload with a cord and pull scale .

Reassembling

After the preload has been determined, the differential case and crown wheel are removed from the housing so that the actual reassembly can proceed as follows:

1. Install the drive pinion and adjust its preload (this is check ed with a pull scale or torque wrench, as in Figure 26.56).
2. Reinstall the differential case and crown wheel and check the crown wheel backlash with a dial gauge (see Figure 26.41).
3. Spacers or shims are selectively fitted to each side bearing to obtain the required backlash, but the total spacer thickness must be maintained to preserve the preload that was previously determined.
4. Make a final check with the bearing caps fitted and the cap bolts tightened to the specified torque .

The spreader tool is used when installing the differential case, although some units have thick side-bearing spacers which can be tapped into place without having to spread the housing. The spacers are available in various thicknesses so that thin shims do not have to be used.

26.15 Servicing IRS final drives

The dismantled components of a differential assembly for an independent rear suspension are shown in Figure 26.48. (Figures 26.24 to 26.26 also relate to this). The features that should be identified are:

1 The differential carrier is mounted to the rear crossmember of the vehicle . There are four mounting points on the carrier and one on the rear cover .
2 A collapsible spacer is used for the pinion bearing preload adjustment.
3 The pinion depth adjusting shim is located behind the bearing cup .
4 The differential case is in two pieces.

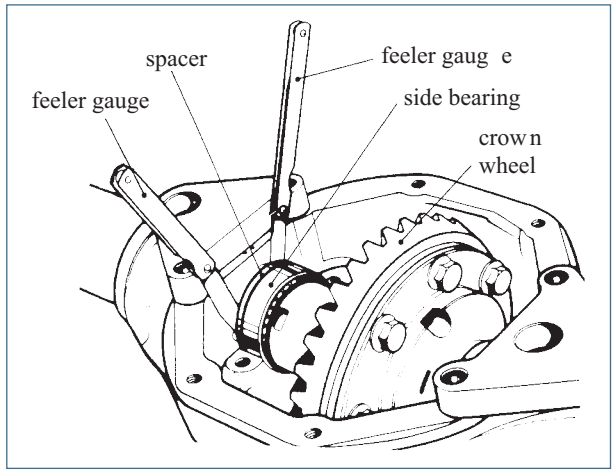


Figure 26.47 Feeler gauges being used to measure side bearing clearance MITSUBISHI

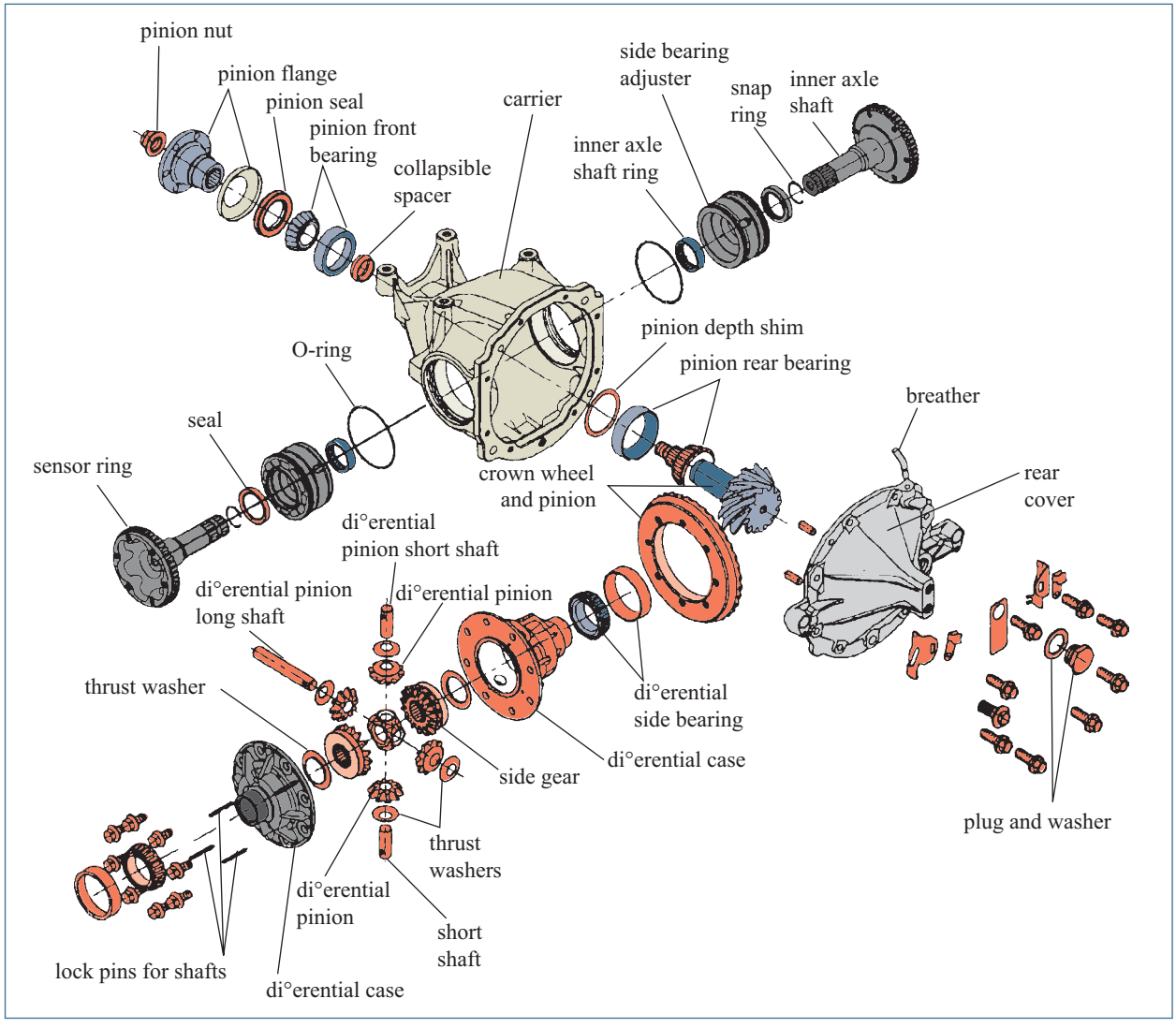


Figure 26.48 Differential assembly for an independent rear suspension GM HOLDEN LTD

5 There are four differential pinions, which are mounted on one long pinion shaft and two short pinion shafts.
6 There are thrust washers behind the pinions.
7 The two side gears also have thrust washers.
8 The side bearing adjusters carry the side bearing cups. The adjusters are threaded into the differential carrier and are used to adjust preload and crown wheel backlash.
9 The short inner axle shafts pass through the side bearing adjusters and are supported in bearings. The shaft has a flange for the drive-shaft constant-velocity joint and a toothed ring for an ABS brak e sensor .
10 The axle shafts are retained in the side gears by an expanding snap ring on the inner end of the shaft.
11 There are oil seals for the axle shafts, O-rings for the bearing adjusters and an oil seal for the pinion shaft.
12 The rear cover is bolted to the rear of the carrier .

26.15.1 Dismantling the differential assembly

1 Remove the inner axle shafts and unscrew the side bearing adjusters from the differential carrier .
2 Remove the side bearing cups with the adjusters, so the differential case , with the crown wheel, is free to be removed and further dismantled.
3 Remove the drive pinion from the differential carrier in a similar way to other pinions, as previously described.

Reassembling the differential assembly

1 Check the pinion depth with a dummy pinion and mandrel.
2 Check the pinion preload with a pull scale , adjusting it with a collapsible spacer .
3 Check the preload of the side bearings with a pull scale and adjust the preload and backlash with the screw-type side bearing adjusters.

26.16 Crown wheel and pinion adjustments

The crown wheel and pinion must be adjusted (positioned) for correct tooth contact. This will determine whether the gears operate at an acceptable noise level. A crown wheel and pinion in mesh are shown in Figure 26.51. Arrows show the different ways that the gears can be moved:

1 The pinion depth can be adjusted—it can be moved backwards and forwards in the differential carrier , often referred to as 'in ' or 'out'.
2 The crown wheel can be moved from side to side , to adjust its distance from the pinion.

The pinion has a spacer or shims between its head and its rear bearing. This determines its position in the carrier. Adding shims will move the pinion deeper 'in', and removing shims will move the pinion 'out'. The position of the pinion is set first and the crown wheel is adjusted to it.

The position of the crown wheel is adjusted either by screw adjustments or by shim and spacer adjustments. This also adjusts the side bearing preload and the backlash between the crown wheel and the pinion.

26.16.1 Pinion depth setting

During manufacture, special equipment is used to set the crown wheel and pinion in their best position for tooth contact and noise. The position of the pinion is then identified by placing a plus (+) or minus (−) mark on its head.

The pinion in Figure 26.49 is marked (+2), which means it is set 0.02 mm deeper than a standard pinion. This is allowed for during assembly by subtracting 0.02 mm from the standard (nominal) shim thickness under the pinion head.

Handy hint: Metric dimensions are used in this example , but pinions on some older vehicles could still be mark ed in imperial measurement.

Interpretation of markings

Figure 26.50 shows how the marks on a pinion head indicate the position of the pinion in relation to the centreline of the crown wheel:

1 A plus (+) mark shows that a pinion is mounted deeper than standard, and the number on its head must be subtracted from the standard shims.

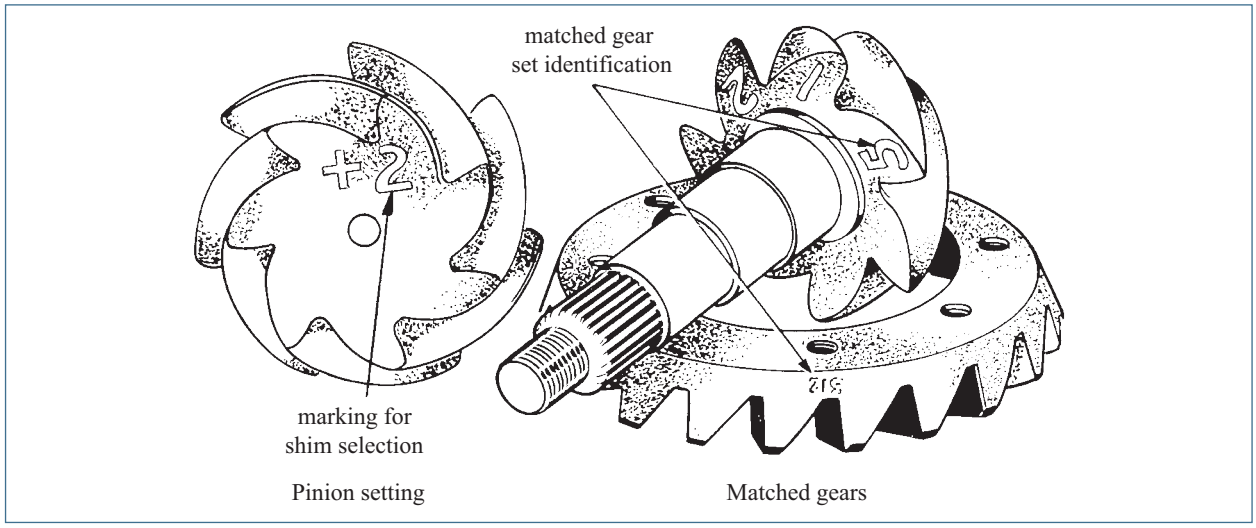


Figure 26.49 Manufacturer's markings on a crown wheel and pinion FORD

2 A zero (0) mark shows that it is a standard pinion and needs standard shims.
3 A minus (−) mark shows that a pinion is not as deep as standard, and the number must be added to the standard shims.

Standard assembly dimension

Figure 26.51 shows the standard assembly dimension for a pinion from under the head of the pinion to the centreline of the crown wheel. This is the dimension when the nominal (standard) thickness of shim pack is fitted under the pinion head.

During adjustment, shim packs of different thicknesses move the pinion in or out. The standard dimension is not measured during adjustment, but is checked with gauges.

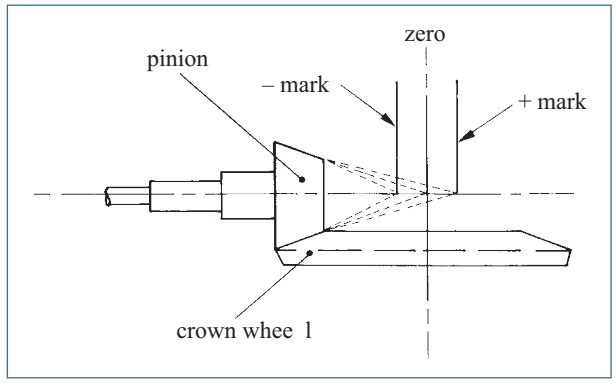


Figure 26.50 Interpretation of plus and minus marks on a pinion head: zero is standard, plus is deeper than standard and minus is less than standard FORD

26.16.2 Setting pinion depth by gauges

A set of pinion depth gauges is shown installed in a differential carrier in Figure 26.52. There are two parts: a dummy pinion and a mandrel. The dummy pinion is similar to an actual pinion, except that it has a flat head without teeth and a shank which is slightly smaller in diameter to allow the bearings to be fitted easily.

The dummy pinion is installed in the carrier instead of the pinion (without the shim pack), and the mandrel is installed in the differential side-bearing mountings. The gauges enable the standard assembly dimension to be checked.

With the gauges in place, feeler gauges measure the space between the head of the dummy pinion and the mandrel. This is the nominal thickness of shims needed, but it must be adjusted as described previously.

26.16.3 Setting pinion depth by standard shims

This method can be used where gauges are not available and the pinion head has a plus (+) or minus (−) dimension mark. If a new pinion is being installed and happens to have the same mark as the original, then the original shim thickness is used. However, if the new pinion has a different mark, the thickness of the shims will have to be determined. To do this, three dimensions are needed:

1 the thickness of the original shim pack
2 the mark on the old pinion
3 the mark on the new pinion.

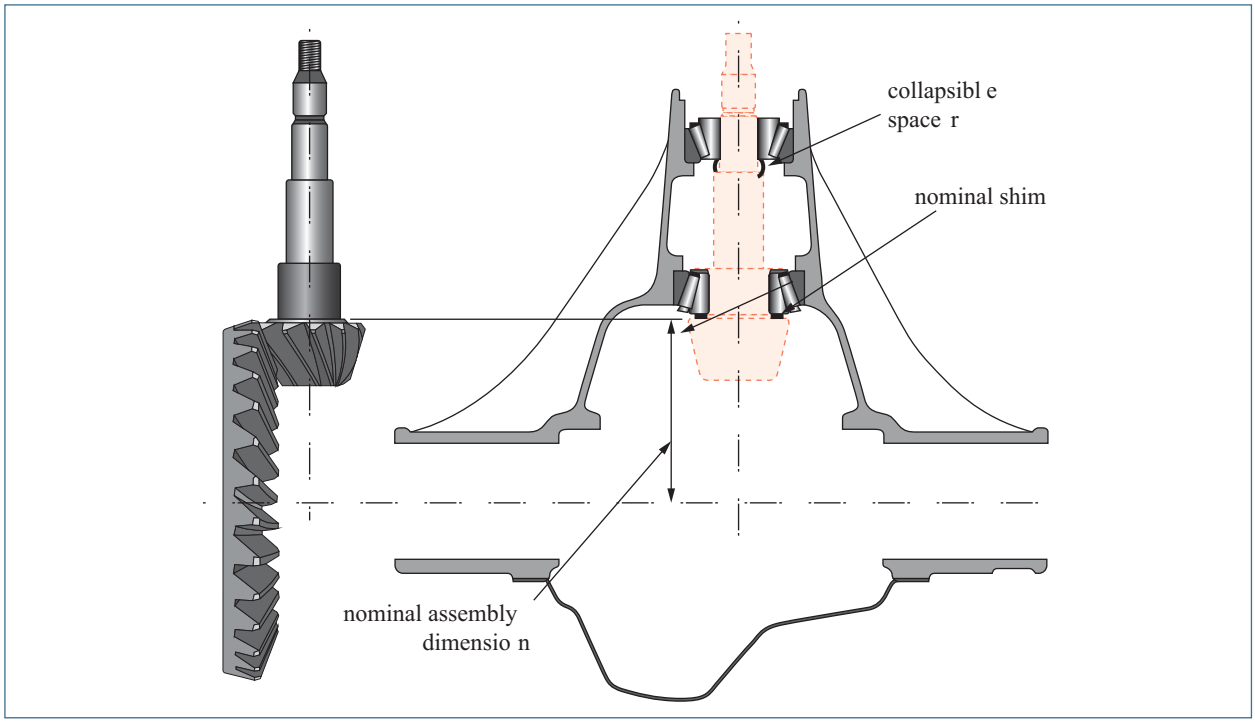


Figure 26.51 Standard assembly dimension of a pinion in relation to the centreline of the crown wheel. The arrows show the directions in which the crown wheel and pinion can be a djusted

Example:

Original shim thickness: 0.52 mm
Original pinion mark: −2
New pinion mark: +4

This gives the standard shim thickness and then the shim thickness for the new pinion can be calculated.

1 The original pinion was mark ed (−2) and so had a shim pack 0 .02 mm thick er than standard. The standard shim pack is therefore 0 .50 mm.
2 The new pinion is mark ed (+4) so needs a shim pack 0 .04 mm thinner than standard, which is 0.46 mm. The original shim pack should therefore be reduced by 0 .06 mm.

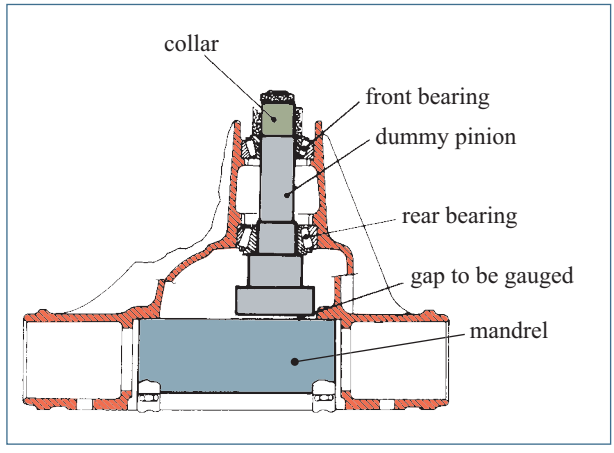


Figure 26.52 Dummy pinion installed in a differential carrier of a unitised rear axle

26.16.4 Crown wheel and pinion backlash

After installing the pinion and crown wheel, check the backlash between the gears. To check the backlash, mount a dial gauge against the heel of a crown-wheel tooth and then rock the crown wheel back and forth without moving the pinion (Figure 26.41). The backlash is specified with a minimum and maximum, such as 0.15 to 0.25 mm, and adjustment is made to give the best tooth contact within this range. The crown wheel is adjusted sideways by screw adjustments or by adjusting shims, depending on the design.

Handy hint: While backlash is needed to give the gear teeth working clearance , it also affects the area of tooth contact. A very small change in backlash will cause a noticeable change in tooth contact.

26.17 Checking gear tooth contact

To obtain a contact marking on the gear teeth, mix a small quantity of red oxide and oil to a smooth light paste and brush a coating of the paste over three or four crown wheel teeth (Figure 26.53).

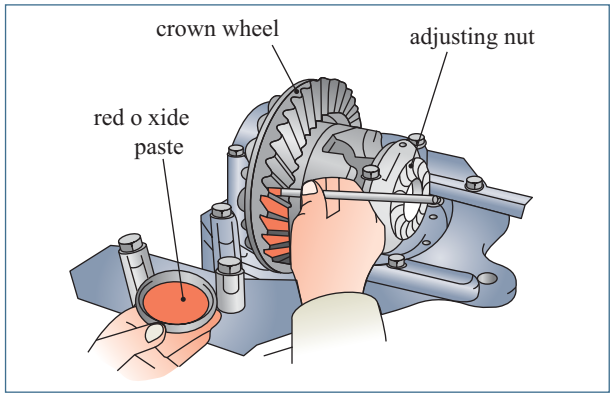


Figure 26.53 Crown wheel teeth being painted with red oxide paste

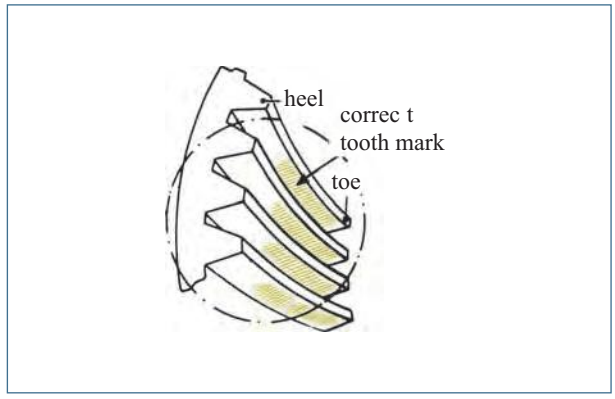


Figure 26.54 Gear tooth contact marking on crown wheel teeth—the drive side is illustrated

Using a socket spanner and speed brace on the pinion nut, rotate the pinion and, at the same time, apply a load to the crown wheel. The load can be applied by using a piece of flat steel as a lever against the smooth edge of the crown wheel; alternatively, the axle shafts can be slipped into the splines of the differential side gears, and a load applied by a second person holding against these.

The pinion should be rotated in both directions to obtain a tooth marking for both the drive and coast side of the crown wheel teeth. Red oxide will be transferred from the painted teeth to the unpainted teeth to show the tooth contact. On the painted teeth, this will be the area where red oxide has been wiped off (Figure 26.54).

26.17.1 Interpreting gear tooth markings

The marks on the gear teeth will show whether the gears are correctly adjusted. The marks can be used as a check or, if no other facilities exist, they can be used as the sole guide when adjusting the gears.

Workshop manuals supply illustrations of different tooth markings. Figure 26.55(a) to (e) illustrates a number of typical crown-wheel markings.

There is a short verse about adjusting tooth contact, which goes like this:

Toe or heel —move the wheel
Contact toe —wheel must go ,
Face or flank —move the crank.

This rhyme can be used in conjunction with Figure 26.55:

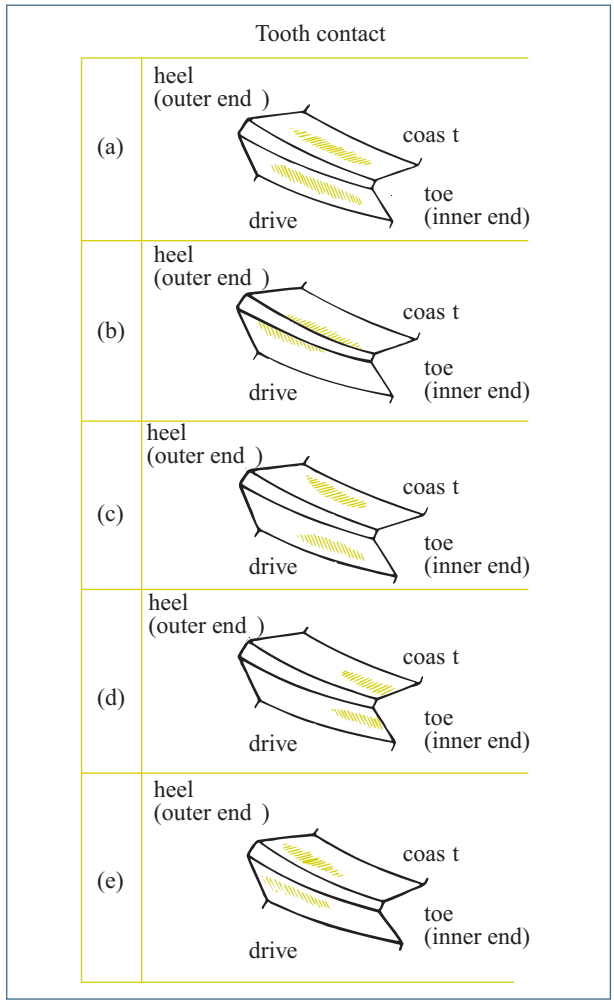


Figure 26.55 Specimen markings on crown wheel teeth

1 Toe or heel refers to toe or heel contact, as shown on the crown wheel. For heavy toe contact (Figure 26.55(d)), the crown wheel must be moved away from the pinion to increase the backlash. For heavy heel contact (Figure 26.55(e)), the crown wheel must be moved towards the pinion to decrease the backlash.

2 Face or flank refers to the upper and lower face of the teeth, respectively . The word crank is used here to denote the pinion which cranks, or turns, the crown wheel. Face or flank markings indicate that the pinion is incorrectly positioned.

If the pinion is too far out of mesh with the crown wheel, a mark will appear high up on the crown wheel tooth, that is, on the face (Figure 26.55(b)). If it is too far into mesh with the crown wheel, then the mark will appear deep into the tooth, that is, on the flank (Figure 26.55(c)).

A correct tooth mark will be closer to the toe than the heel, as shown by Figure 26.55(a). Under load on the road, the mark will move towards the heel, because the crown wheel is being forced away from the pinion; that is, the backlash will increase to change the mark.

Handy hint: New gears will usually provide better tooth marks than used gears.

26.18 Bearing preload – pinion and side bearings

The pinion bearings and differential carrier side bearings are adjusted so that they have preload. With no preload, there will be end-float because the bearings will not be seated in their cups. With excess preload, the bearings will be overloaded, causing early bearing failure.

26.18.1 Checking and adjusting pinion bearing preload

Pinion bearing preload is measured by the torque required to rotate the pinion shaft. A pull scale and cord are used. The cord is wrapped around the pinion flange, or around a pulley attached to the flange (Figure 26.56).

The torque, in newton metres (Nm), is the pull in newtons multiplied by the flange or pulley radius in decimals of a metre.

When checking the rolling torque, the breakaway torque will be greater than the rolling torque, so read the scale while it is being pulled. If the oil seal is fitted, make allowance for the resistance of the seal.

Another method is to use a torque wrench and socket spanner on the pinion nut. The wrench should have a dial so that the torque can be read while it rotates the pinion.

Figure 26.56 Checking pinion bearing preload with a spring scale (note the oil seal has been removed)

Handy hint: If a kilogram scale is used, the reading can be multiplied by ten to convert it (appro ximately) to newtons.

Solid bearing spacer

A spacer on the pinion shaft separates the cones of the pinion bearings. Its length determines how hard the cones are pushed into their cups (that is, how much the bearings are preloaded). Shims are used with a solid spacer and the pre-load is adjusted by altering their thickness. Adding shims decreases the preload and removing shims will increase it. See Figure 26.57 for shim locations.

Collapsible bearing spacer

Collapsible bearing spacers are often used (Figure 26.57). The spacer gradually shortens (collapses) as torque is applied to tighten the pinion nut. The nut is tightened gradually and readings taken until the desired preload is reached. A torque of 140 Nm or more is needed to collapse the spacer, so the nut is quite tight.

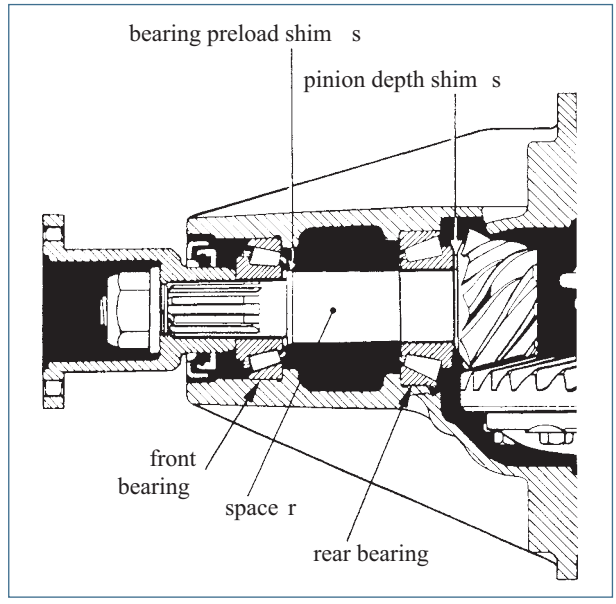


Figure 26.57 Section through a differential carrier showing the pinion mounting—the bearings have a solid spacer

26.18.2 Checking and adjusting differential side bearings

The differential side bearings are preloaded so that the bearing cups are held firmly into their cones. This has the effect of spreading the bearing caps slightly and is referred to as *capspread*.

As previously mentioned, there are two types of adjustments for the side bearings—screw adjustments and shim or spacer adjustments.

The preload can be measured with a pull scale and cord in the manner that was shown for a unified rear axle. This is done with the differential case installed in the carrier, but without the pinion. Wrap the cord around the differential case, using the pull scale to show the force needed to rotate it. Take the reading as the case is turning.

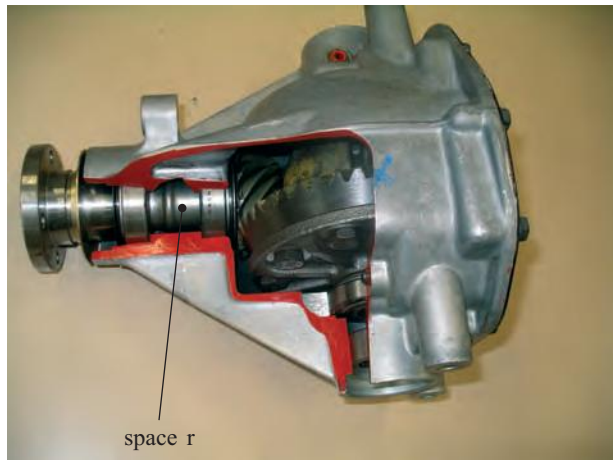


Figure 26.58 Pinion with a collapsible spacer between the bearing cones

Screw adjustments

The adjusting nuts on each side bearing position the crown wheel in relation to the pinion to give the correct backlash. They are also used to adjust the bearing preload. A special tool is used with the nuts. Figure 26.59 shows this for a differential assembly from a banjo-type rear-axle housing.

Figure 26.59 Adjusting differential carrier bearings with screw adjustments

One method of adjusting preload is to screw the nut up against the bearing cup and then tighten it an extra two or three notches. This forces the bearing caps slightly apart and provides capspread.

The point where the bearing starts to be preloaded can be found by watching the bearing cup while tightening the adjusting nut. The nut will come up against the bearing cup and the cup will then start to turn. At this point, the bearing is being preloaded and the nut is turned an extra two or three notches.

The method used for differential assemblies for some independent rear suspensions is the cord and pull scale, as described previously. The side-bearing nuts are then adjusted to suit the scale readings.

Shim and spacer adjustments

Shims and spacers are located between the bearing cups and the differential carrier or housing. Where spacers only are used, they are a selective fit and available in a range of sizes.

The position of the crown wheel is adjusted by varying the thickness of the spacers on each side, and preload is adjusted by using spacers thick enough to provide capspread.

Adjust the crown wheel backlash first, then check the tooth marking. Spacers or shims, which eliminate side clearance of the bearing cups, are used until the crown wheel is correctly positioned. Then preload is adjusted by fitting shims or spacers to give an extra 0.05 to 0.10 mm on each side, giving capspread.

Feeler gauges can be used to find the thickness of the spacers needed, as shown previously in relation to Figure 26.47.

26.19 Limited-slip differential service

Servicing a rear axle with a limited-slip differential is the same as for a conventional differential, except for the limited-slip clutches, which can become inoperative through wear of the clutch plates or cones. The differential will continue to operate, but will act like a conventional rear axle.

Limited-slip differential operation can be checked as shown in Figure 26.60. One wheel is raised and an adaptor bolted to the wheel studs. The transmission should be in neutral, the parking brake released and the front wheels chocked.

A torque wrench and an adaptor rotate the axle. The wrench should show a specified torque reading, caused by the resistance of the clutch. The breakaway torque and the torque required to continuously rotate the wheel can both be checked.

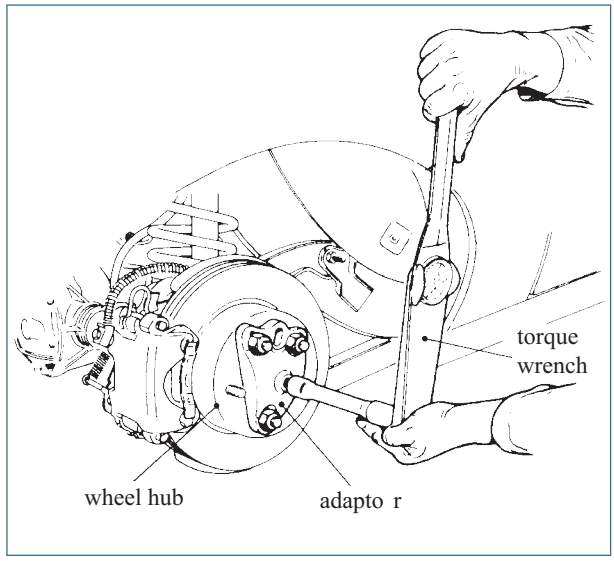


Figure 26.60 Checking a limited-slip differential FORD

26.20 Transaxle final drive service

Figure 26.61 shows the construction of a differential assembly for one design of transaxle which is used with a transverse engine. It should be compared with the construction of a differential assembly in a rear axle.

Here the differential case fits into the differential housing, which is part of the transaxle housing. The right-hand side bearing fits into the housing and has a bearing cap. The left-hand side bearing has a retainer, which is bolted to the housing. Bearing preload is adjusted by shims.

The ring gear is a helical gear and this is meshed with a helical pinion. There is some side thrust because of the helical shape of the gear teeth, which is why bearing preload is needed.

In this type of transaxle, the position of the gears is fixed and there is no adjustment for tooth contact or backlash. While the bearings have preload, this is not as critical as the preload for bearings for differential assemblies with a crown wheel and pinion.

Handy hint: **Figure 26.27 shows the construction of a transaxle final drive, while Figure 26.28 shows** the dismantled parts of a transaxle with a screw-type side-bearing retainer .

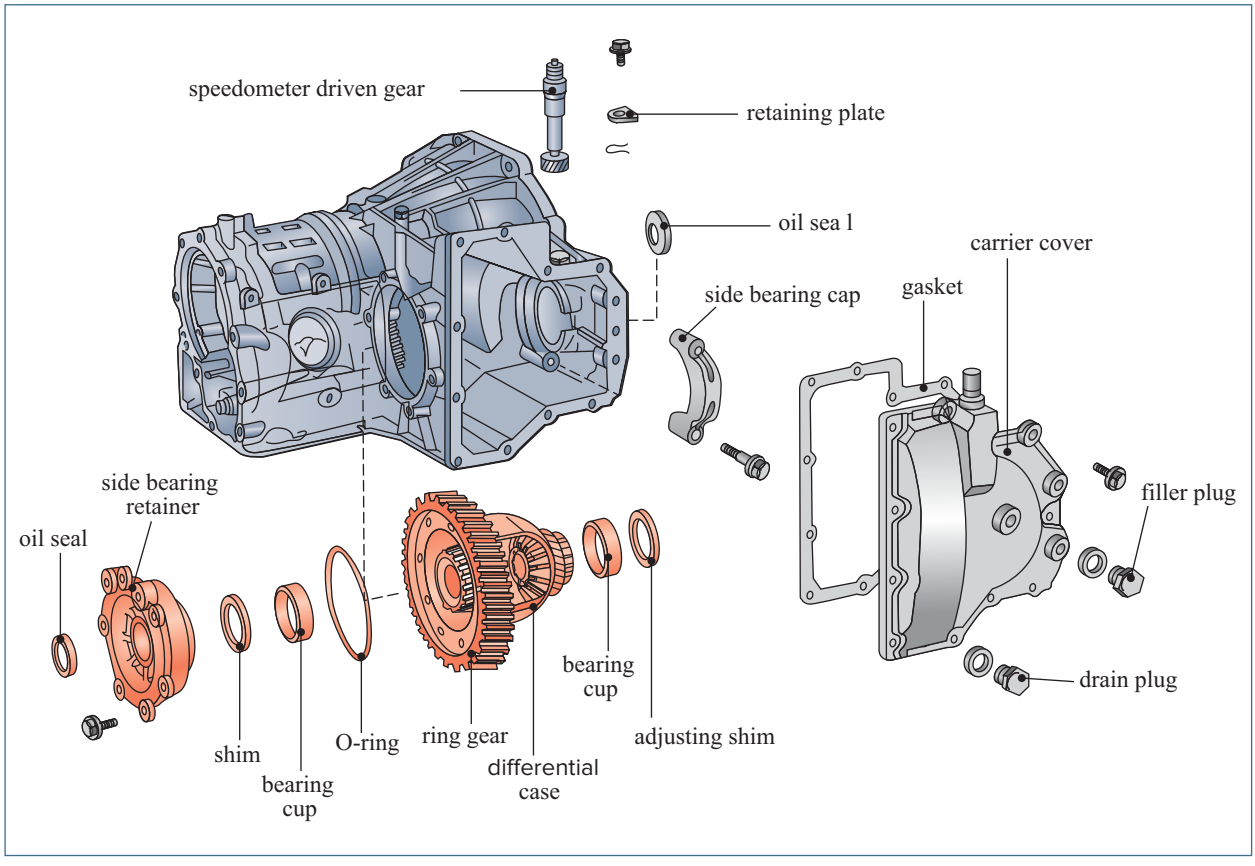


Figure 26.61 Components of a transaxle final drive assembly

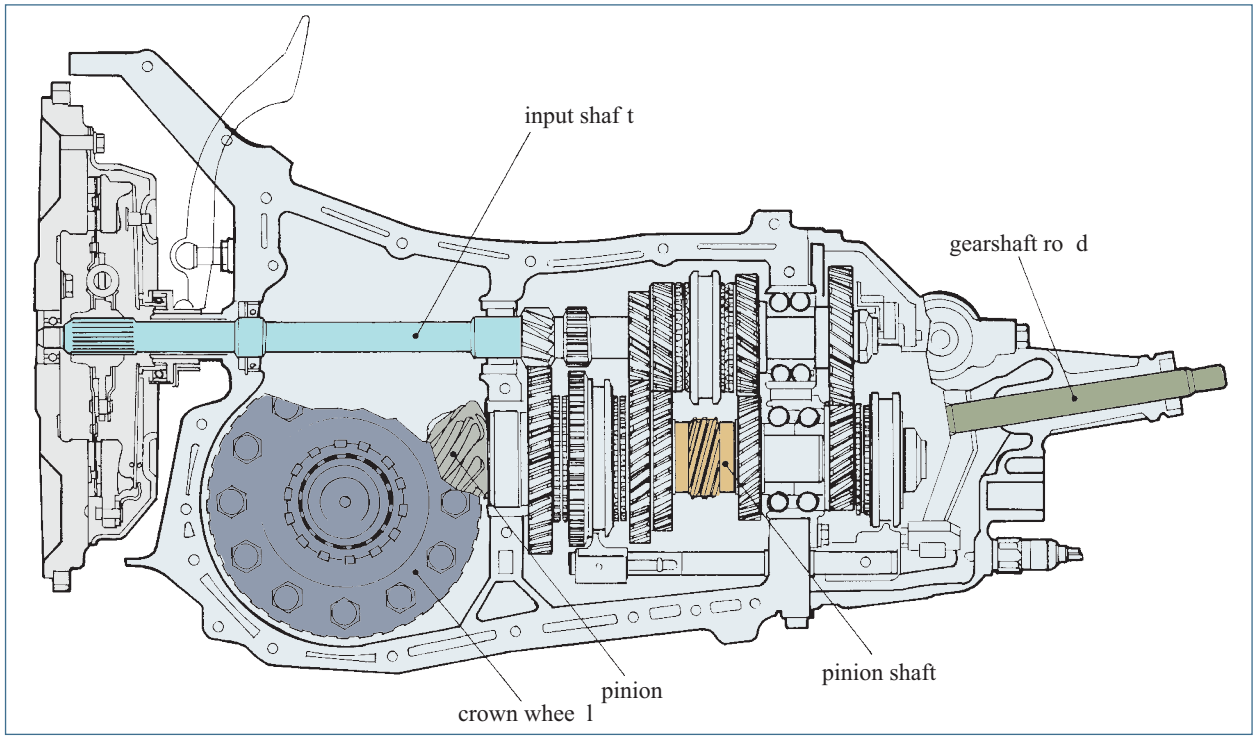


Figure 26.62 Arrangement of a transaxle with a crown wheel and pinion final drive SUBARU

26.21 Transaxle with crown wheel and pinion

Figure 26.62 shows a transaxle assembly with a crown wheel and pinion. It is mounted lengthwise in the vehicle and so needs a change in the direction of drive for the front wheels (which is obtained by using a crown wheel and pinion).

The gear section of the transaxle is similar to a conventional five-speed manual transmission. It has a mainshaft and a countershaft. The countershaft is referred to as the drive pinion shaft because it carries the drive pinion on its front end. The transaxle includes the final drive, with the crown wheel and differential case being supported in side bearings in the transaxle housing.

26.22 Summary of differential adjustments

There are five adjustments and checks on rear axles and final drives:

1 pinion depth (the position of the pinion in the differential housing)
2 preload of the pinion bearings
3 backlash between the crown wheel and pinion teeth
4 preload of the differential case side bearings
5 correct tooth contact between the crown wheel and pinion.

26.22.1 Relationship of adjustments

The adjustments are interrelated as follows:

1 Preloading the bearings holds the crown wheel and pinion in their correct positions and preserves the tooth contact under working conditions.
2 Under load, the shape of the gear teeth forces the gears away from each other , increasing backlash.
3 Also under load, the rear pinion bearing is forced into its cup , while the front pinion bearing is forced away from its cup . This reduces pinion bearing preload.
4 Similarly, the crown wheel forces one differential side bearing into its cup , and the other away from its cup , reducing preload.

In operation bearing preloads will decrease and backlash between the crown wheel and pinion will increase. Without any preload, the bearings would be loose and the gears would move out of position, causing poor contact, noise and excessive wear.

26.23 Diagnosis of rear-axle noises

Noises in the rear axle can come from either gears or bearings. Start the diagnostic process with a thorough mechanical inspection of all components and fluid levels. Check final drive and suspension mounting bolts for looseness and feel for movement and roughness in pinion and axle bearings. Then perform a road test to confirm faults.

All gears in mesh will make some noise and hypoid gears can be noisy. However, if the noise is an obvious one, it is usually an indication of trouble. The following points are a guide to noise diagnosis.

26.23.1 Tyre noise

Tyre noise changes with road surfaces, while rear-axle noise does not. When coasting out of gear, tyre noise is usually more noticeable than rear-axle noise, which is not usually heard at lower speeds. Inflating the tyres to a higher pressure, or changing them, helps locate tyre noise.

26.23.2 Front-wheel bearing noise

Worn, damaged or incorrectly adjusted front-wheel bearings can cause a noise similar to tyre noise. However, it is a constant noise, noticeable on drive, overdrive and when coasting in neutral.

26.23.3 Rear-axle bearing noise

Faulty rear-axle bearings produce a growling noise, which is hard to distinguish from a differential noise. However, a differential noise varies under load on drive and coast, while a rear-axle bearing noise is fairly constant, persisting when coasting in neutral.

26.23.4 Crown wheel and pinion noise

This originates from poor tooth contact and may be noticed at variable levels on drive, overdrive or float. Drive noise is most pronounced when accelerating, as the gear teeth are under load. The bearings are also under load so any lack of preload will allow the gear teeth to change their area of contact.

Noise on overdrive occurs as the vehicle decelerates from medium speeds, while float noise occurs under light cruising conditions.

26.23.5 Differential side-bearing noise

Worn or rough bearings will produce noise, and tend also to magnify crown wheel and pinion noise. Worn bearings will not hold the gears in the correct location, and the tooth contact will change under different load conditions to produce noise on drive, overdrive and float.

26.23.6 Pinion bearing noise

Rough pinion bearings will produce a continuous whine, which will persist when coasting in neutral, right down to low speed. If the pinion bearings have end-play, this can produce a noise on overdrive from the gears, as the pinion tends to feed back into the crown wheel. This should be followed by a road test to confirm repairs.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- state the operating principles of light vehicle rear axles, final drives and associated components
- identify and explain the function of rear axle and final drive components
- identify the types and applications of rear axle and final drive lubricants
- describe the inspection procedures for rear axles and final drives
- apply service and adjustment procedures for rear axles and final drives, including lubricating components
- apply diagnostic testing procedures for light vehicle rear axles and final drives, including road-testing procedures that include rear axle and final drive noise
- apply repair procedures for light vehicle rear axles and final drives, including procedures for dismantling rear axles and final drives, inspecting rear axles and final drives and reassembling and aligning components
- apply post-repair testing procedures for light vehicle rear axles and final drives.

REVIEW QUESTIONS

1 Name the main parts of a rear-axle assembly for a rear-wheel drive vehicle .
2 What is the function of the crown wheel and pinion ?
3 What are hypoid gears ?
4 Why are hypoid gears used?
5 Why are special lubricants used with hypoid gears ?
6 What is backlash as related to gears ?
7 Name the parts of the gear teeth of a crown wheel.
8 What is a full-floating rear axle , and on what type of vehicle is this generally used?
9 What is the purpose of the differential?
10 What is the action of the differential pinion gears when driving on a straight road?
11 What occurs with the differential pinion gears when driving around a curve ?
12 What is a limited-slip differential ?
13 What are some of the advantages of a rear-axle assembly with independent rear suspension ?
14 Where is the final drive located in a front-wheel-drive vehicle ?
15 How is the bearing usually secured on the axle shaft of a semifloating rear axle ?
16 How would the bearing be removed from a semifloating axle shaft?
17 Why can a full-floating rear-axle shaft be removed with the wheel still in position ?
18 How is a full-floating axle shaft held in place in the axle housing ?
19 What is the most lik ely reason for a differential assembly having to be dismantled?
20 Why would checks be made before dismantling, and also while dismantling a differential assembly ?
21 Why would the parts of a differential be mark ed before dismantling ?
22 When would a spreading tool be used on a rear-axle housing ?
23 What is gear tooth contact , and how is this check ed?
24 If a crown wheel had a heavy tooth contact mark on the 'toe ', how would this be altered?
25 What occurs to the tooth mark if crown wheel backlash is reduced?
26 What is pinion depth ?
27 A pinion has a plus mark followed by a number . What does this indicate ?
28 Why are differential bearings given preload?
29 What is a collapsible spacer ?
30 How is pinion bearing preload check ed and adjusted?
31 What would cause 'loss ' of pinion bearing preload?
32 How is backlash measured?
33 What types of adjustments are provided on differential side bearings ?
34 How can a limited-slip differential be check ed?
35 What is the main difference in the final drive of a transaxle compared to a rigid rear axle ?
36 How would a suspected faulty rear-axle bearing be correctly diagnosed?

CHAPTER 27

Automatic transmissions: torque converters

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify operating principles of light vehicle automatic transmissions, torque converters and associated components
2 recall the application, purpose and operation of light vehicle automatic transmissions, torque converters and associated components
3 identify operating principles of torque multiplication.

An automatic transmission means that the clutch and gearshift operations that are carried out by the driver of a vehicle with manual transmission are not necessary. As well as automatic gearshifts, the transmission has a torque converter that acts both as a fluid coupling and a form of variable gear ratio that automatically adjusts to the operating conditions of the vehicle.

This chapter provides an introduction to automatic transmissions and the operation of torque converters. For information on inspection, service and adjustment or post-service testing procedures, refer to Chapter 30.

27.1 Automatic transmissions and transaxles

The term *automatic transmission* is usually used for transmissions for rear-wheel-drive vehicles. Automatic transmissions are fitted to most modern vehicles. The term *automatic transaxle* is used for front-wheel-drive vehicles. An automatic transmission, or a transaxle, has three basic sections:

1 A torque converter. This is a form of hydraulic coupling.
2 Gearing. This is arranged for automatic control.
3 Hydraulic system. This can include electronic control.

These form a transmission that can operate automatically. Automatic transaxles also include a final-drive unit. Figure 27.1 shows an automatic transmission that is bolted to the rear of the engine. It replaces the flywheel, clutch, clutch-control mechanism and manual transmission.

Figure 27.2 shows an external view of an automatic transaxle. It has a different shape from the rear-wheel-drive automatic transmission, but contains similar parts and operates in a similar manner. The final drive

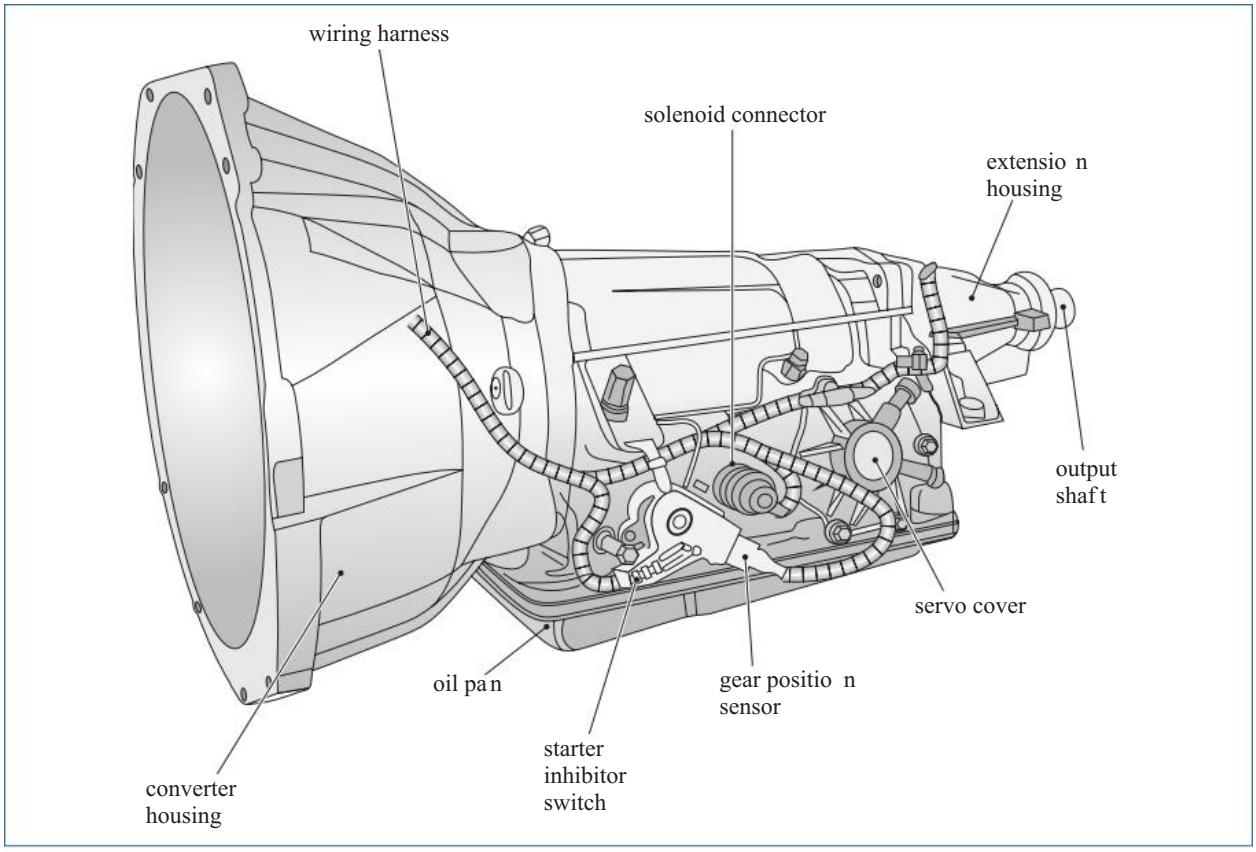


Figure 27.1 External parts of an automatic transmission for a rear-w heel-drive vehicle

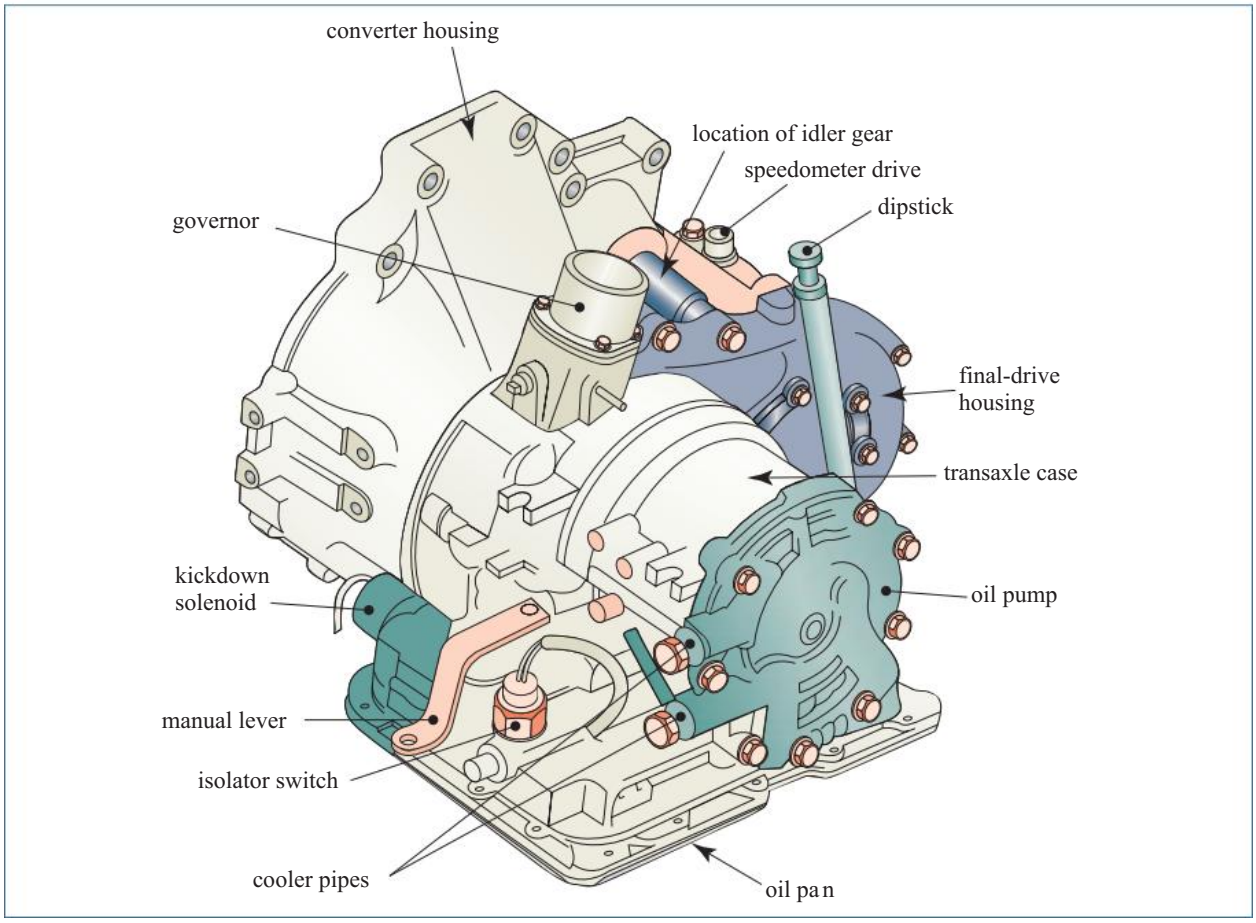


Figure 27.2 External view of an automatic transaxle for a front-wh eel-drive vehicle with a transverse engine

and differential assembly are within the transaxle housing. As these transaxles have to fit beside the engine in the engine compartment, they are more compact than transmissions for rear-wheel drive.

27.1.1 Function of an automatic transmission

The function of any transmission is to transmit engine torque to the driving wheels. It must also vary torque. In a manual transmission, this is done by the various gear ratios. In an automatic transmission, it is done by gearing (usually planetary gearing) and by the torque converter. For information on identification, function and basic operation of automatic transmission components, see Chapters 28 and 29.

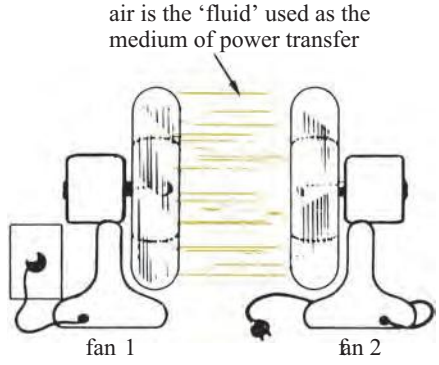


Figure 27.3 Two fans can form a simple fluid coupling

27.2 Hydraulic couplings

There are two basic types of hydraulic couplings: those that transmit torque and those that transmit and increase torque (referred to as *torque converters*). A simple fluid coupling can be made with two electric fans, as in Figure 27.3. The air from one fan causes the blades of the other to rotate. The air is the 'fluid', but because the fans are not enclosed, much of it escapes and the coupling is not very efficient.

A fluid coupling is more efficient. It has two members with vanes or blades (Figure 27.4) mounted close together in a housing. The housing is partly filled with oil, which is the coupling fluid. One member is the driving member and the other is the driven member.

When the driving member of the fluid coupling is rotated, it throws oil against the driven member, causing it to rotate (Figure 27.5). Torque is thus transmitted through the coupling. However, this is still not very efficient as there is a great deal of turbulence in the oil, tending to oppose rotation of the driven member.

27.2.1 Fluid couplings and torque converters

Fluid couplings and torque converters work in a similar way. However, the fluid coupling only transmits maximum torque when both its members are rotating at the same speed. This is not the case with a torque converter.

When the driving member of a fluid coupling turns faster than the driven member, oil thrown onto the latter bounces back against the former and opposes rotation. When there is a big difference in speed between the two members, a large part of the driving torque is used to overcome this, causing a torque loss.

Handy hint: In a torque converter , torque is not reduced; it is increased.

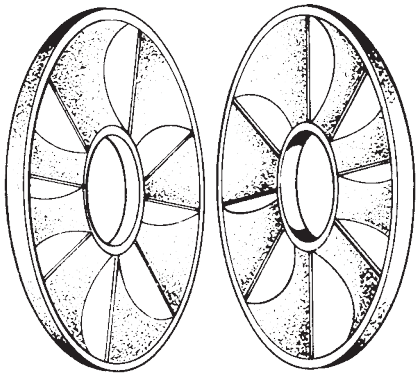


Figure 27.4 Simplified version of two members of a fluid coupling

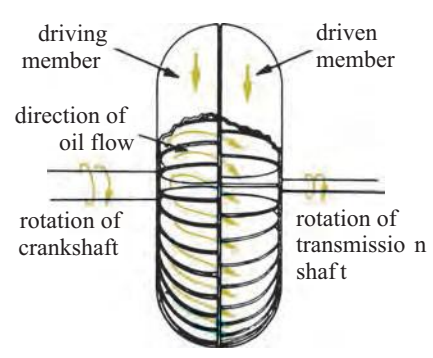


Figure 27.5 Fluid coupling in action—oil is thrown from the driving member into the driven member

27.3 Torque converter construction

The torque converter in Figure 27.6 has a pressed-steel housing welded to a front cover. Made as an assembly, it is not designed to be dismantled (although it can be opened up for repair with special facilities).

The torque converter front cover has three or four bosses, which are bolted to the drive plate. This in turn is bolted to the crankshaft flange (Figure 27.7). When the engine is running, the complete torque converter rotates with the crankshaft. The engine does not have a conventional flywheel, having instead the drive plate and torque converter.

A basic torque converter has three parts (Figure 27.8). These are:

1 Impeller. This is the driving member , which is rotated by the engine .
2 Turbine . This is the driven member , which is driven by fluid from the impeller . It is attached to the input shaft of the transmission.
3 Stator . This is mounted on a stationary shaft on a one-way clutch.

All three parts are enclosed within the converter housing and cover. The converter operates completely full of oil (automatic transmission fluid).

Handy hint: A basic torque converter is sometimes called a three-element converter .

The parts of the converter are shown in simple form in Figure 27.9:

1 Figure 27 .9(a) shows the impeller , which has blades attached to the inside of the converter housing. As the impeller rotates, oil is thrown outwards by the blades. The impeller is sometimes referred to as a pump .
2 Figure 27 .9(b) shows the turbine and the impeller . The turbine is connected to the input shaft of the gear section of the transmission and is driven by fluid from the impeller . The fluid strik es the turbine blades and then flows inwards to the centre of the converter .
3 Figure 27 .9(c) shows a stator added to the other two parts. It is mounted on a fix ed shaft (the stator shaft) on a one-way clutch. This allows it to turn in one direction, but locks automatically to stop it turning in the opposite direction. The fluid flows from the impeller to the turbine and then to the stator .

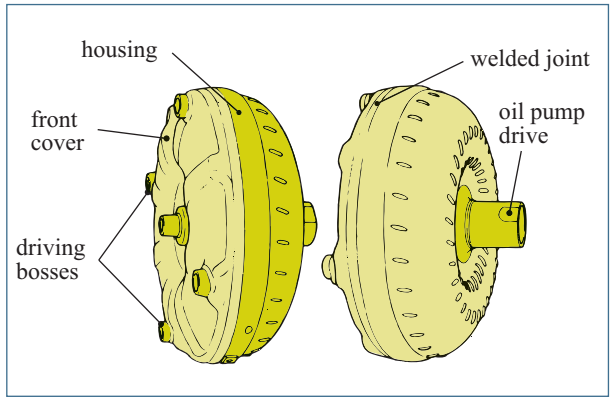


Figure 27.6 Torque converter , external view

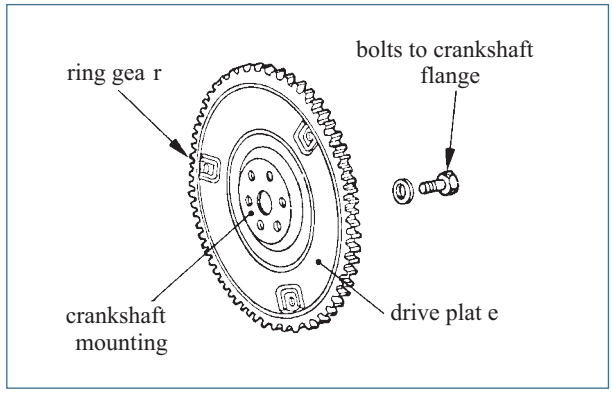


Figure 27.7 Torque converter drive plate

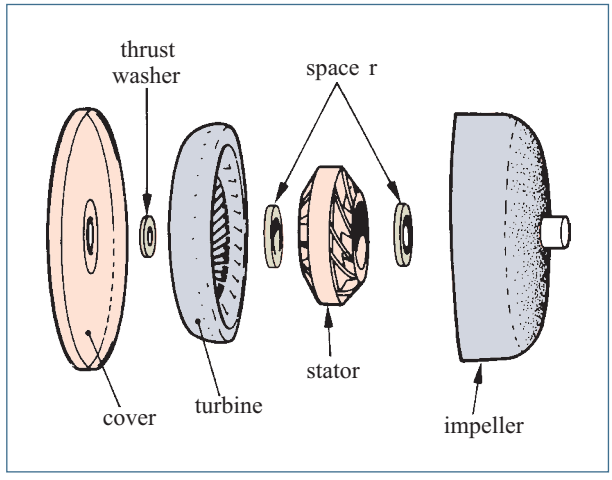
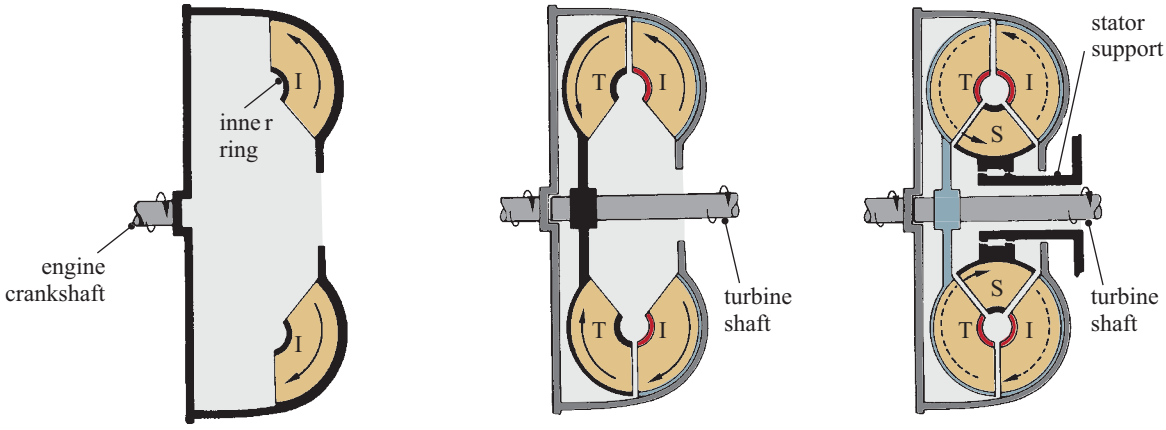


Figure 27.8 Parts of a torque converter

27.4 Torque converter operation

The torque converter can transmit torque at ratios varying from approximately 2:1 at stall point to approximately 1:1 at coupling point.



(a) Impeller and housing (b) Turbine has been added (c) Impeller, turbine and stator

Figure 27.9 Torque converter construction (I impeller, T turbine, S stator)

With gears, speed reduction means torque multiplication. This principle also applies to a torque converter. Speed reduction within the converter results in an increase in torque. Torque multiplication is achieved by the action of the stator.

Handy hint: Having a torque converter is like having an extra gear with a 2:1 ratio.

27.4.1 Fluid flow in the converter

Figure 27.10 shows how the fluid flows from the impeller to the turbine, and from there through the stator and back to the impeller. When the converter is rotating, fluid flow is as follows:

1. Fluid is thrown outwards in the impeller by centrifugal force. The impeller blades direct the fluid from the impeller into the turbine, causing it to turn. This is shown in Figure 27.10(a).
2. Fluid entering the turbine is directed from the outside towards the centre and, because of the curved blades, the fluid leaves the centre of the turbine in the opposite direction to that at which it enters.
3. Fluid from the centre of the turbine is directed onto the blades of the stator as shown in Figure 27.10(b).
4. The direction of the fluid is again changed by the stator blades so that it enters the impeller in the direction in which the impeller is rotating. The force of fluid therefore acts on the rear face of the impeller blades, assisting rotation.
5. The fluid is again thrown from the outside of the impeller into the turbine to repeat the cycle.

The stator and the shape of its blades are the key to torque converter operation, as illustrated in Figure 27.11, which shows the oil flow through the stator and the turbine. This is the basic principle of torque multiplication. If the oil flow was not redirected by the stator blades, it would work against the impeller blades and oppose rotation. For information on types and applications of transmission fluids, see Chapter 30.

Handy hint: Oil opposing rotation would cause a torque loss, not an increase.

27.4.2 Rotary and vortex flow

Fluid flow in the torque converter runs in two different directions (Figure 27.12):

1. Rotary flow. The fluid is carried around in a rotary direction with rotation of the impeller.
2. Vortex, or spiral flow. The fluid is circulated in a spiral direction through the passages between the blades of the three members of the converter.

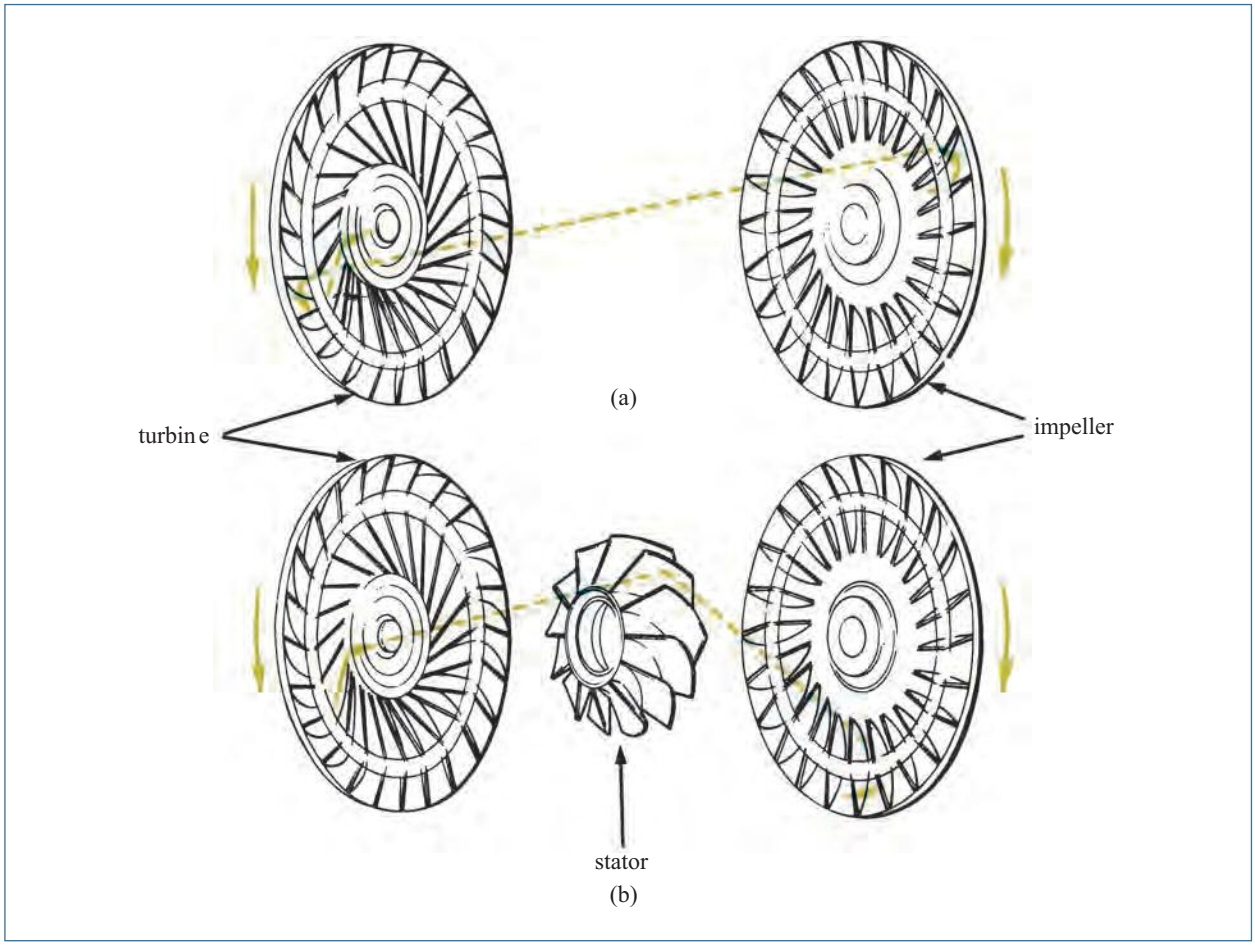


Figure 27.10 Fluid flow in the converter (a) flow from impeller to the turbine (b) flow from the turbine through the stator to the impeller

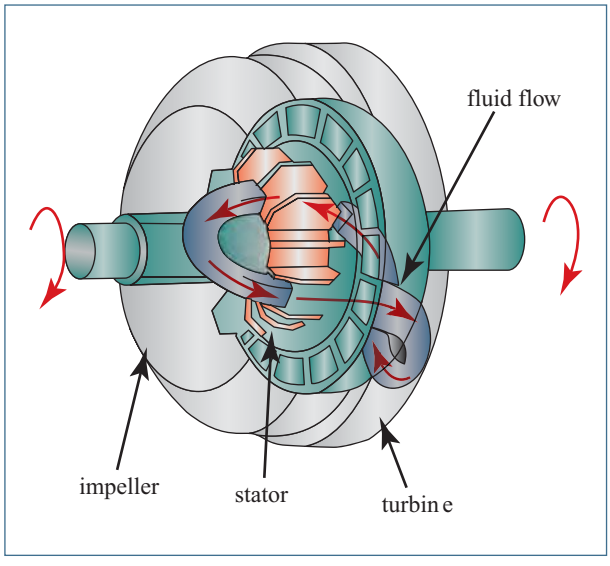


Figure 27.11 Fluid flow through the turbine and stator

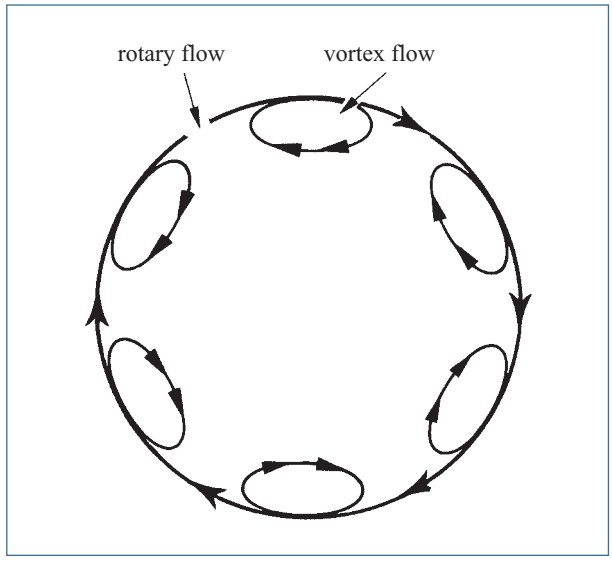


Figure 27.12 Representation of fluid flow in a converter

Fluid flow depends on the operating conditions of the vehicle. When it is just starting to move, or at slow speeds under load, there will be a large vortex flow. Under light-throttle conditions there will be very little vortex flow. The rate of vortex flow will depend on the difference in speed between the impeller and the turbine.

Handy hint: Torque is related to vortex flow—the greater the flow , the greater the increase in torque .

27.5 Torque multiplication

With the selector lever in D (drive) and the engine idling, the fluid in the converter does not leave the impeller blades with enough force to turn the turbine and move the vehicle.

When the throttle is opened, the engine speed increases and the oil is thrown into the turbine with great force. At this point, there is maximum torque multiplication.

As the vehicle speed increases, the difference in speed between the impeller and the turbine is quickly reduced. A point—known as the *coupling point*—is reached, where their speeds are almost the same.

27.5.1 Coupling point

At coupling point, there is no torque increase and the converter acts simply as a fluid coupling.

27.6 Stator and one-way clutch action

Below coupling point, the force of fluid against the stator blades causes the stator one-way clutch to lock and hold the stator, preventing it from rotating backwards. When coupling point is reached, there is very little flow through the blades and no force to lock the clutch. At this point, the stator rotates with the impeller and the turbine.

The function of the one-way clutch is to prevent power loss within the converter. If the stator was not allowed to rotate at coupling point, oil would drag against it, resulting in power loss.

The torque converter remains in the coupled state for all cruising conditions, but if load increases or the throttle is opened to increase engine power, fluid will again flow from the impeller to the turbine. The stator one-way clutch will lock and the torque converter will again provide a torque increase.

The torque converter operates over a range of conditions between turbine stall and coupling point. At turbine stall, the torque increase is approximately 2:1. At coupling point, the torque transfer ratio is approximately 1:1.

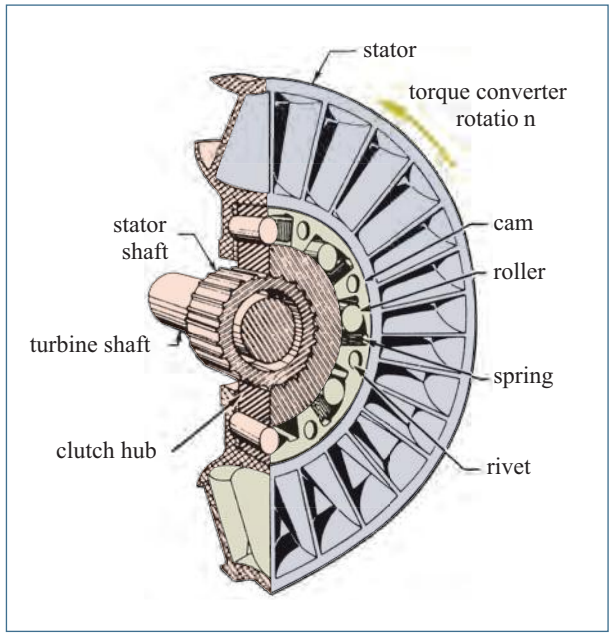


Figure 27.13 Cam-and-roller one-way clutch used to support a stator in a torque converter MITSUBISHI

27.6.1 One-way dutches

There are two types of one-way clutch: *roller clutches* and *sprag clutches*. One-way clutches are also known as *freewheel clutches* or *overrunning clutches.*

Roller clutch

Figure 27.13 shows a roller-type clutch. It has a number of rollers mounted between the clutch hub and the cam. These lock the two parts together by a wedging action when the fluid applies force to the stator blades. At coupling point, the rotary motion of the fluid against the back of the blades releases the clutch so that the stator can rotate along with the rest of the torque converter.

Sprag clutch

This uses sprags between an outer and inner race (Figure 27.14). The sprags allow rotation between the parts in one direction and lock up in the other direction via a tilting action that is assisted by a retainer spring.

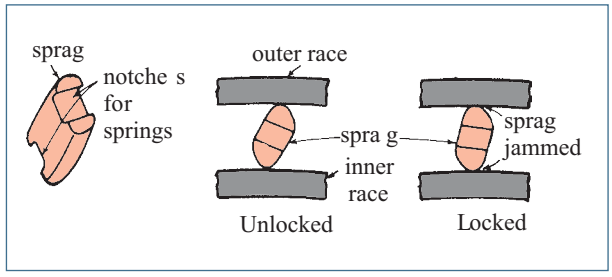


Figure 27.14 Action of a sprag in a one-way clutch

27.7 Lock-up torque converters

Torque converter action is needed in the lower gears and at lower speeds. It is not needed for light-load

and cruising conditions, where it makes sense to eliminate converter 'slip' and provide a solid coupling. This conserves engine power and allows for overdrive gearing to deliver more efficient running. To achieve this, some torque converters are fitted with a clutch. These are referred to as lock-up converters. Figure 27.15 shows a cut-away view of a lock-up converter.

Lock-up converters can have two different clutch arrangements:

1 Piston-operated clutch
2 Centrifugal clutch.

Handy hint: Converters of this design are sometimes called four-element converters.

27.7.1 Converter with piston-operated clutch

Figure 27.16 shows a section through a lock-up torque converter with a piston-operated clutch. The lock-up clutch consists of a large piston (which is free to move on the turbine hub) and the clutch plate. The centre of the clutch plate is attached to the turbine hub and to the outer edge of the piston through damper springs. With the clutch applied, drive is transmitted directly from the front cover through the clutch plate to the input shaft. Figure 27.16 shows the clutch in the released position.

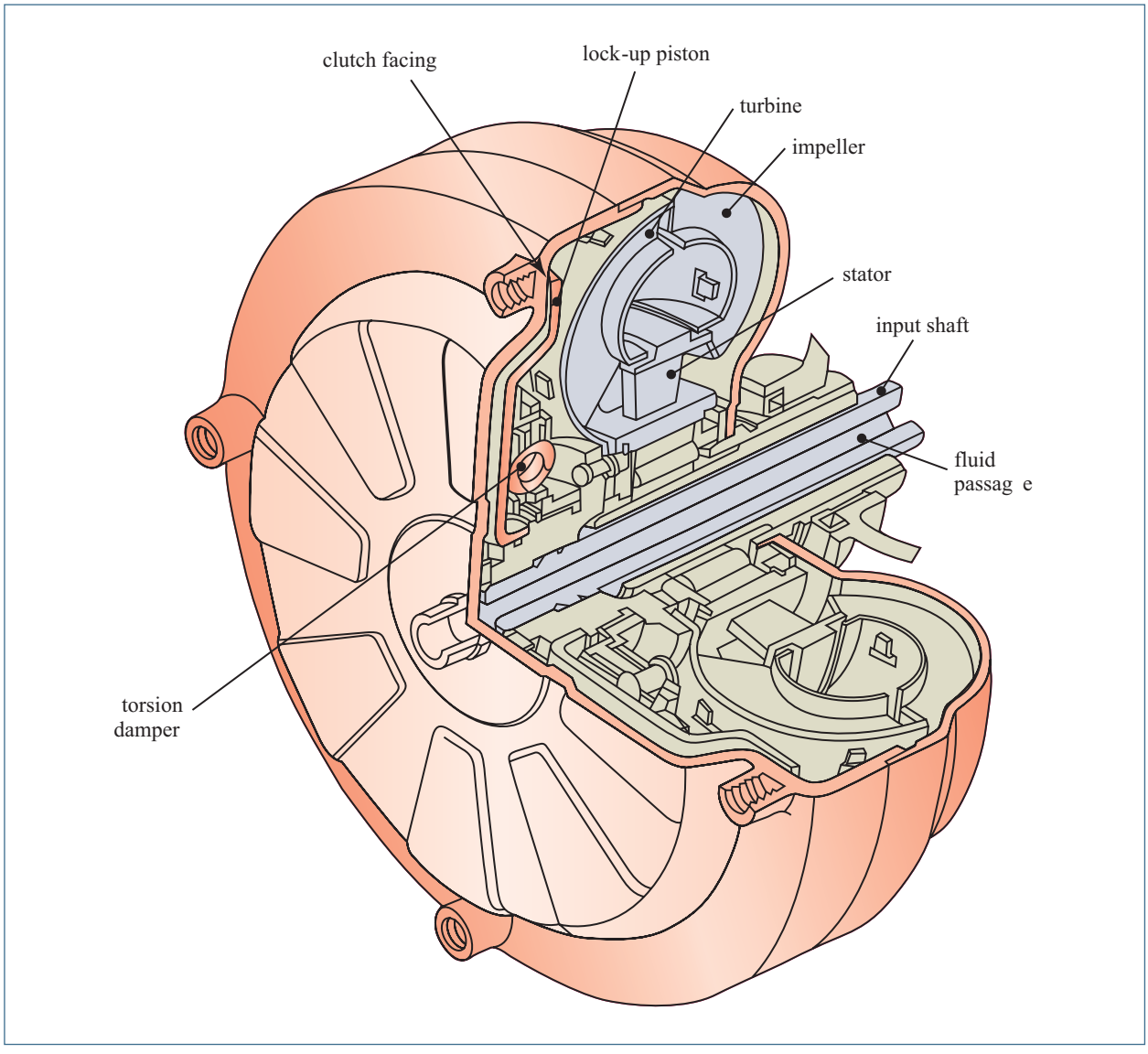


Figure 27.15 Internal detail of a torque converter with a lock -up clutch

Clutch operation

Figure 27.17 shows the hydraulic arrangement for applying the clutch. The torque converter normally contains fluid under pressure and has fluid circulating in and out for cooling purposes. The pressure in the converter and the direction of flow are used to apply and release the clutch.

In Figure 27.17, fluid is being directed into the converter through passage B, as shown by the arrows. This applies pressure to the back of the piston and applies the clutch. A certain amount of fluid is allowed past the piston to flow from the converter through passage A.

Figure 27.18 shows the hydraulic arrangement for releasing the clutch, whereby the direction of the fluid flow is changed, flowing in through passage A and out through passage B. This pushes the clutch plate away from the front cover and normal converter action takes over. Fluid circulates through the converter for cooling and maintains normal converter pressure.

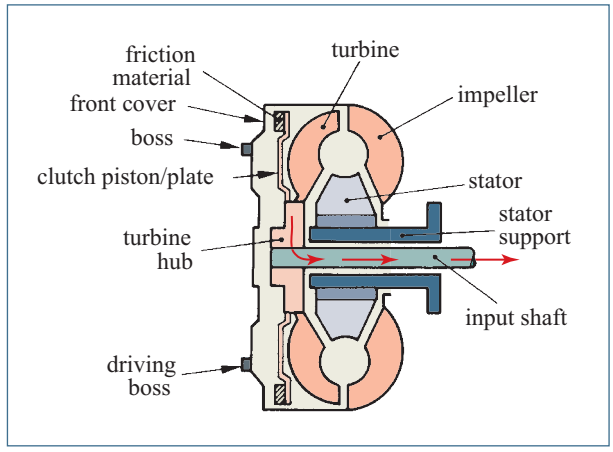


Figure 27.16 Simplified arrangement of a converter with a lock-up clutch

27.7.2 Converter with centrifugal clutch

A torque converter with a centrifugal clutch is shown in Figure 27.19. The clutch assembly consists of a damper plate with clutch shoes around its edge. The clutch plate is mounted on the input shaft on a one-way clutch. It has damper springs that absorb engine torsional vibrations when the clutch is engaged.

The damper clutch operates automatically above a certain turbine speed. As the turbine rotates, centrifugal force on the shoes moves them outwards until they contact the inside of the converter housing. This connects the converter housing to the transmission input shaft.

Handy hint: The clutch shoes can be fully engaged so that there is direct drive or they can allow some slip, depending on operating conditions.

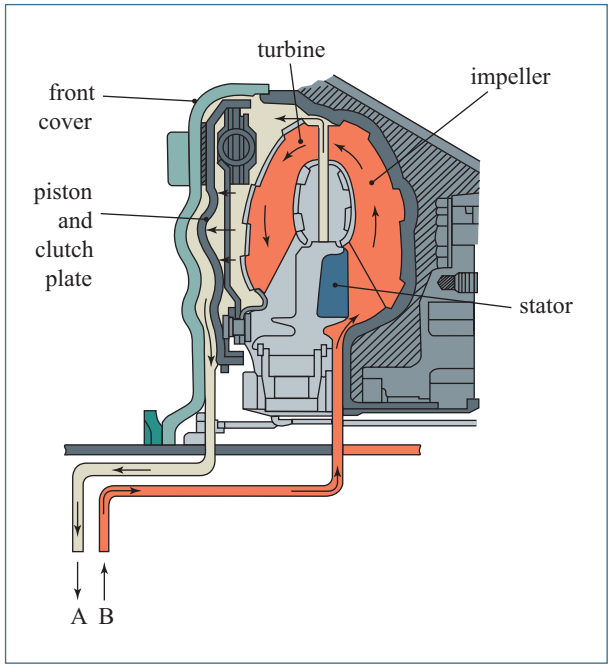


Figure 27.17 Hydraulic operation of a converter clutch in the lock ed position

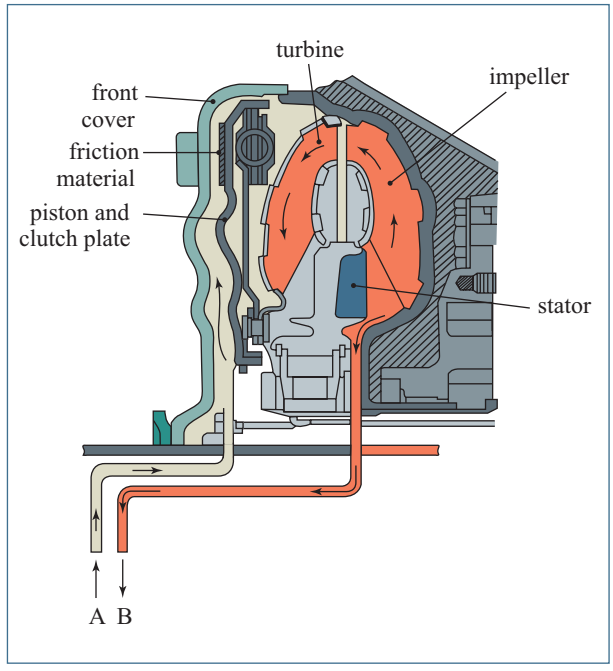


Figure 27.18 Hydraulic operation of a converter clutch in the unlock ed position

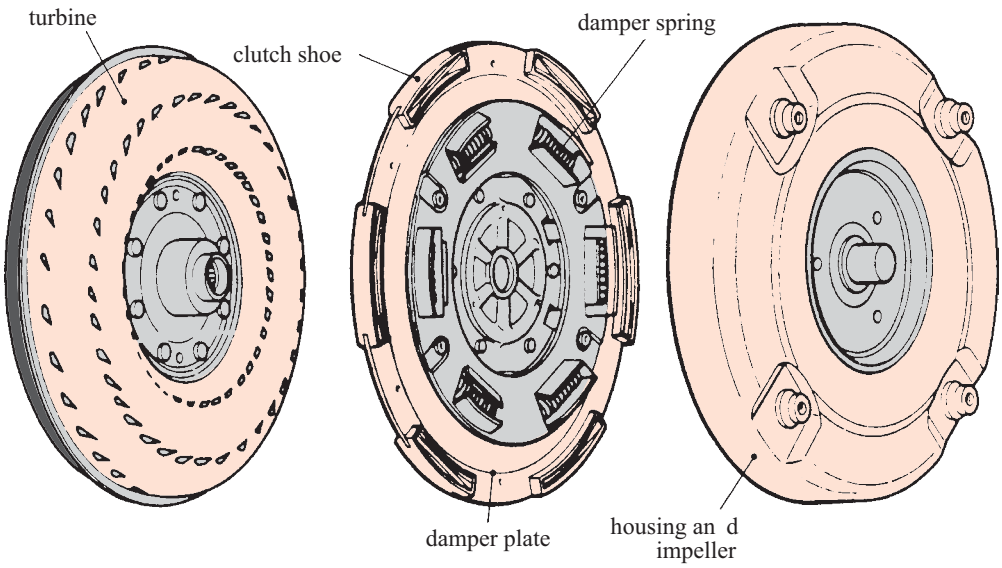


Figure 27.19 Parts of a torque converter with a centrifugal lock-up clutch FORD

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify light vehicle torque converters and their components
- explain the functions and operating principles of light vehicle torque converters and their components
- state the principles of torque multiplication.

REVIEW QUESTIONS

1 What is a fluid coupling?
2 What is the name given to a hydraulic coupling that increases torque?
3 Name the main parts of a torque converter.
4 Explain the operation of each part of the torque converter.
5 Describe how torque is increased by the torque converter.
6 Explain the operation of the stator.
7 What is rotary flow?
8 What is coupling point?
9 What is vortex flow?
10 Explain how a one-way clutch works.
11 What is the purpose of a torque converter?
12 Why do some converters have a clutch?
13 Explain how a lock-up clutch works.
14 What is torque multiplication?

CHAPTER 28

Automatic transmissions: mechanical

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify operating principles of light vehicle automatic transmissions, planetary gears and associated components
2 recall the application, purpose and operation of light vehicle automatic transmissions, planetary gears and components
3 identify operating principles of planetary gears
4 follow inspection procedures for light vehicle automatic transmissions and planetary gears.

The mechanical section, or gear section, of an automatic transmission consists of gears and shafts, together with brake bands and clutches which operate the gears to provide various gear ratios. Both planetary and helical gears are used in automatic transmissions, planetary gears being more common. The torque converter couples the engine to the transmission, also assisting the gearing by providing an increase in torque of up to 2:1, which is equal to another gear.

28.1 Transmission and transaxle arrangements

Figure 28.1 shows the components of an automatic transmission for a rear-wheel-drive vehicle. The impeller in the torque converter is rotated by the engine crankshaft, which operates the turbine that is attached to the transmission input shaft.

The transmission shown has two clutches, two brake bands and a one-way clutch. It has planetary gearing for three forward gears and reverse gear. The clutches are engaged to connect and drive parts of the gearing. The bands and the one-way clutch hold other parts of the planetary system stationary.

Gear ratios are obtained in both forward and reverse rotation by using different combinations of clutches and bands.

28.1.1 Transaxle arrangement

Figure 28.2 shows a schematic arrangement of an automatic transaxle. It has three sections:

1 the torque converter and its housing
2 the planetary gearing and shafts
3 the final drive, which includes the differential assembly.

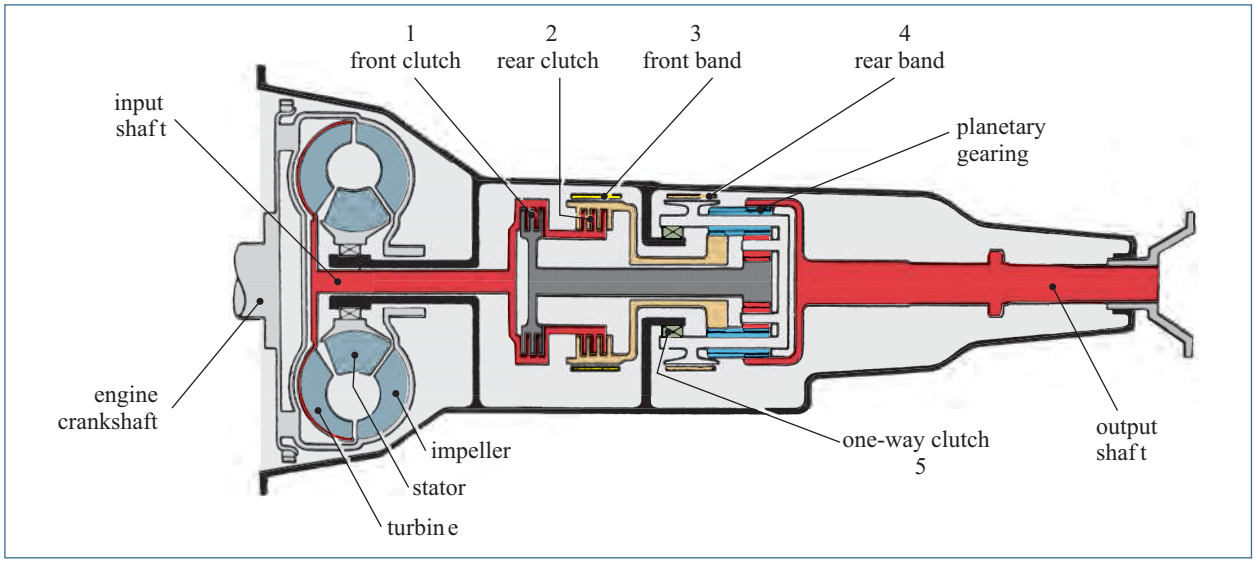


Figure 28.1 Arrangement of the torque converter and mechanical components in an automatic transmission for a rear-wheel-drive vehicle FORD

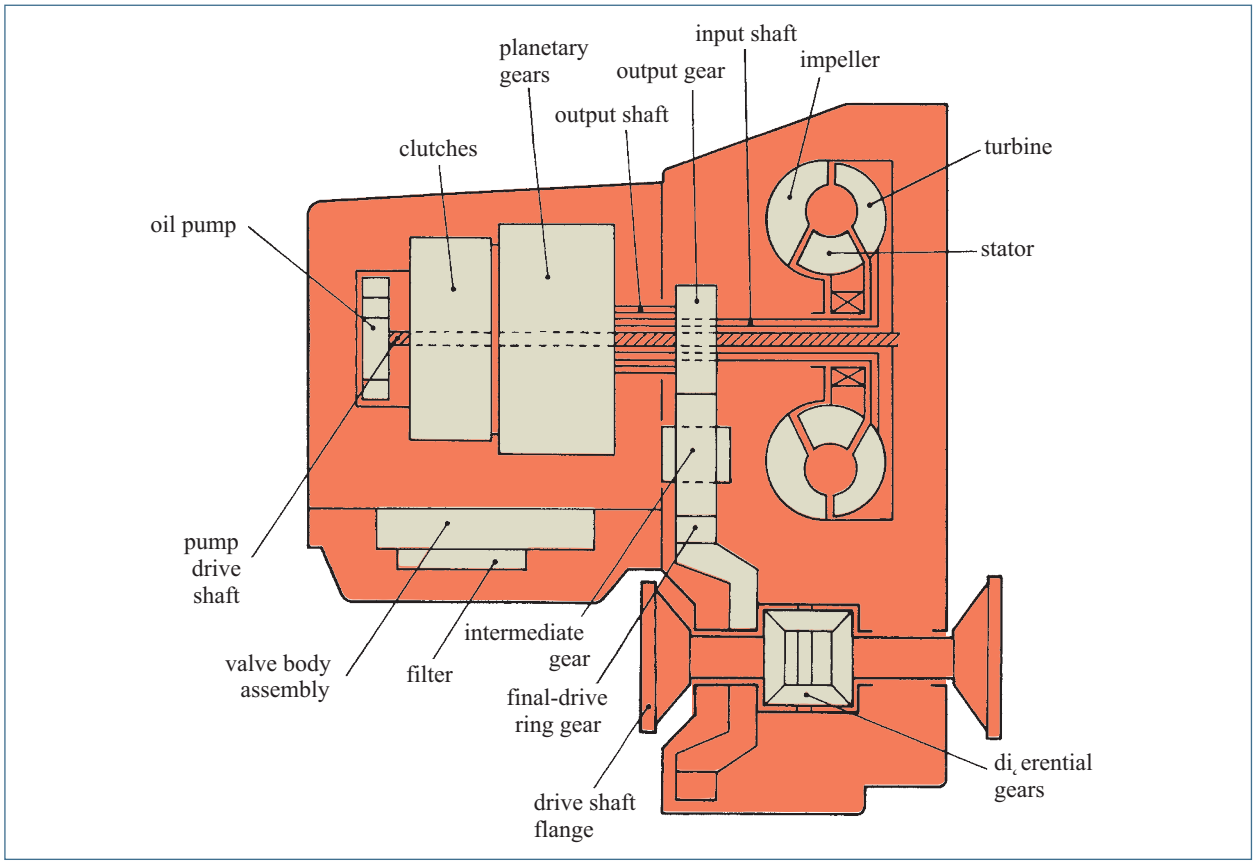


Figure 28.2 Automatic transaxle, schematic arrangement

The torque converter, gearing and clutches are in line with the engine's crankshaft. The final-drive unit is separated from the main section by the intermediate gearing. In operation, drive is carried from the turbine into the gear section of the transmission by the input shaft. After passing through the gears, it is transferred to the final-drive ring gear by the intermediate gear. Normal differential action occurs within the final drive, the drive being transmitted by the differential side gears to the drive shafts and so to the front wheels.

28.2 Planetary gears

The planetary gears used in automatic transmissions have three main parts (Figure 28.3):

- the ring gear
- the planet carrier and pinions
- the sun gear .

All three parts are concentric. The pinions connect the ring gear to the sun gear. The pinions not only rotate on their shafts, but can also walk around the teeth of the sun gear and the ring gear. All the gears are in constant mesh and do not slide. The gear ratios are obtained by holding one of the parts stationary with a brake. One of the other parts then acts as the driver, and the third part is driven.

Planetary gears get their name from the way in which the pinions rotate and revolve around the sun gear. This is similar to the planets in our solar system, which revolve around the sun.

28.2.1 Planetary gear operation

Figure 28.4 shows parts of a planetary gear set: a sun gear, a pinion with part of its carrier and a ring gear. A planetary gear set can operate in either of two ways: non-planetary and planetary, depending on which part is held and which part is the driver.

Non-planetary action

If the carrier is held, the pinion acts as an idler between the sun gear and the ring gear. The pinion revolves on its own shaft, transmitting drive between the other two gears. There is no planetary action.

If the sun gear is the driver, the ring gear will be driven at a reduced speed because a small gear is driving a large one. If the ring gear is the driver, the sun gear will be driven at an increased speed because a large gear is driving a small one.

Planetary action

Planetary action occurs whenever the sun gear or the ring gear are held. In both cases, the pinions will walk around the stationary gear to provide planetary action.

1 If the ring gear is held and the sun gear is the driver , the sun gear will try to rotate the pinion.
2 The pinion will try to rotate the ring gear , but cannot do so because the ring gear is held stationary .
3 However , the pinion must rotate , so it is forced to walk around inside the stationary ring gear , taking the carrier with it.
4 The combined effect is that the sun gear drives the carrier at a reduced speed.

The gear ratio between the sun gear and the carrier depends on the number of teeth in the sun gear and the 'equivalent' number of teeth in the carrier. The carrier has more equivalent teeth than the sun gear so, with the sun gear as driver, there will be a gear reduction between the two parts. (The equivalent number of teeth in the carrier is the number of teeth that it would have if it were an actual toothed gear.)

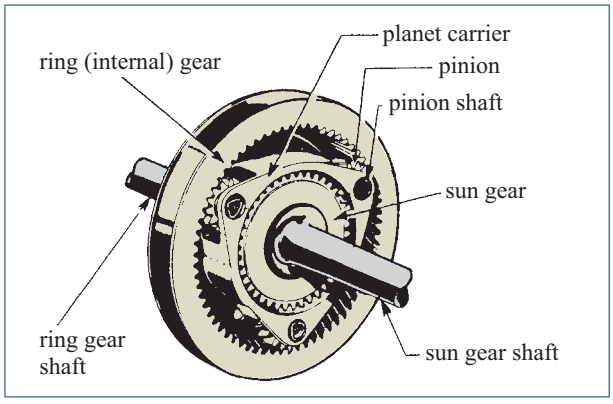


Figure 28.3 Parts of a planetary gear system—the three gear parts are the ring gear , the planet carrier and the sun gear

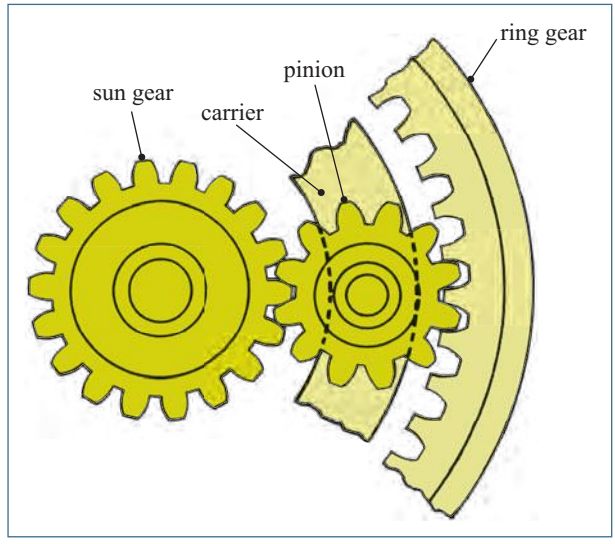


Figure 28.4 Parts of a planetary gear set—with the sun gear as driver and the ring gear held, the carrier will be driven by planetary action

Direction of rotation of gears

Gears with external teeth in mesh will rotate in opposite directions. With internal teeth in mesh, they will rotate in the same direction. For planetary action, the carrier will rotate in the same direction as the gear that is the driver.

Handy hint: Figures 28.4, 28.5 and 28.6 show only one planetary pinion. Planetary systems usually have three or four .

28.3 Simplified planetary gear operation

Planetary gears are a simple train of three spur gears, as in Figure 28.5. The spur gears provide similar ratios to a planetary gear set which has a sun gear with 20 teeth and a ring gear with 40 teeth. As the size of both these gears affects the gear ratio, the carrier can be treated as a gear with 40 + 20 = 60 teeth. (This is the equivalent number of teeth previously mentioned.)

In Figure 28.5, if the ring gear is held and the sun gear is the driver, there will be a 20-tooth gear driving a 60-tooth (equivalent) gear. This gives a reduction of 3:1. The spur gear train and planetary gear set produce different directions of rotation. In the simple gear train, all the gears have external teeth. With planetary gears, there are internal teeth on the ring gear.

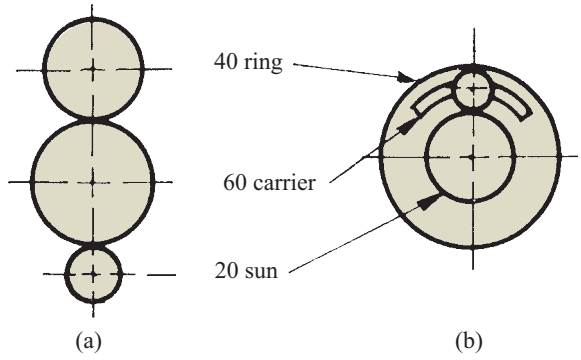


Figure 28.5 Simplified gear trains (a) train of spur gears (b) equivalent planetary gear set—numbers represent the number of teeth on each gear

Table 28.1 Planetary gear conditions

Condition	Ring gear	Carrier	Sun gear	Speed
1	H	DN	DR	Red.
2	DR	DN	H	Red.
3	DN	H	DR	Red. (R)
4	DR	H	DN	Inc. (R)
5	DN	DR	H	Inc.
6	H	DR	DN	Inc.
H – Held		DR – Driver		DN – Driven
Red. – R eduction		Inc. – Increase		(R) – Reverse

28.3.1 Planetary gear conditions

Table 28.1 shows the six different conditions that can be produced by a simple planetary gear set. Three give a speed reduction, and three give a speed increase. With two, a reversal of rotation takes place. The table can be used with Figure 28.5 to follow the operation of the gears. Condition 1 has already been shown to give a reduction of 3:1.

28.3.2 Direction of planetary gear rotation

The rotation of the gears in a simple planetary gear set is shown in the three diagrams in Figure 28.6. The direction of rotation of gears depends on whether external teeth or internal teeth are in mesh. The diagrams should be used to become familiar with what each part does, whether there is an increase or a decrease in speed, and also the direction of rotation.

28.4 Compound planetary gears

A compound planetary gear set is shown in Figure 28.7. Also referred to as *Ravigneaux planetary gearing,* it consists of:

1 a primary (small) sun gear
2 a secondary (large) sun gear
3 a ring or internal gear
4 a pinion carrier with a set of long (secondary) pinions and a set of short (primary) pinions .

The long pinions connect the secondary sun gear to the ring gear, while the short pinions connect the primary sun gear to the ring gear through the secondary pinions.

Handy hint: One advantage of a planetary system is that all the radial forces are contained by the **ring gear**.

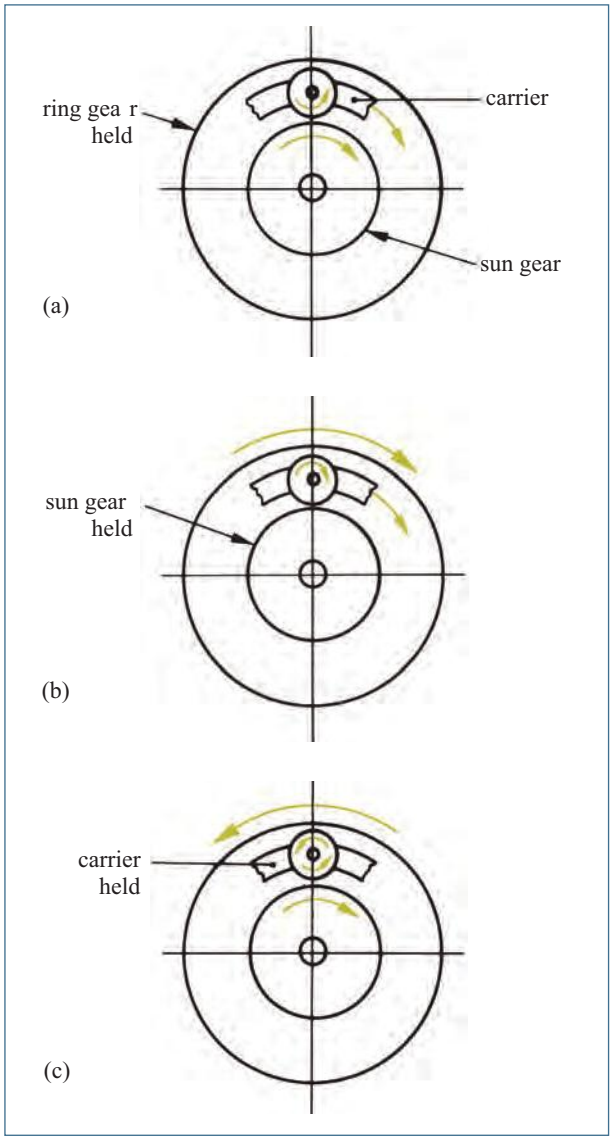


Figure 28.6 Simple planetary gears showing rotation (a) ring gear held, sun gear driver, carrier driven (b) sun gear held, ring gear driver, carrier driven (c) carrier held, sun gear driver, ring gear driven in reverse direction

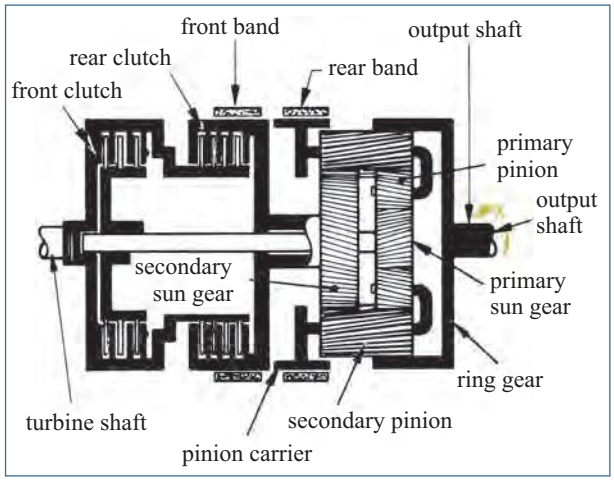


Figure 28.8 Simplified sectional view of compound planetary gears of an automatic transmission (the one-way clutch is not shown) FORD

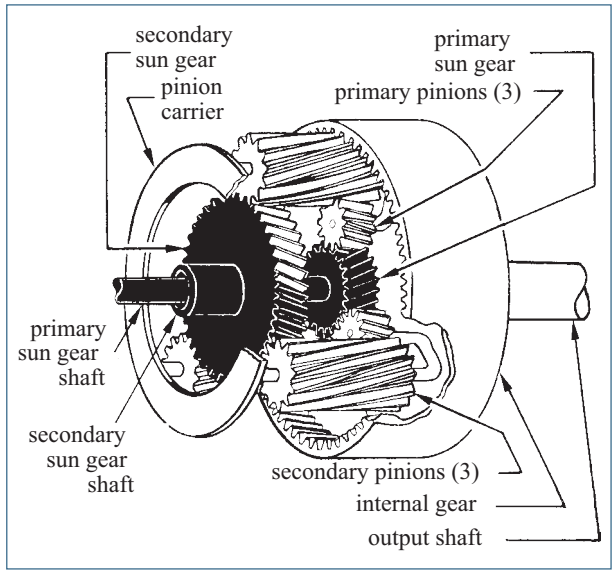


Figure 28.7 Compound (or R avigneaux) planetary gear set used in an automatic transmission

28.4.1 Operation

Bands, brakes and a one-way clutch hold parts stationary, while clutches drive shafts and gears. In the arrangement in Figure 28.7, the drive from the input shaft on the left goes to either the primary sun gear or the secondary sun gear, then through the primary and/or secondary pinions to the ring gear and so to the output shaft on the right.

The pinions can operate in three different ways:

1 They can operate as idlers. When the carrier is held stationary, the pinions rotate on their own shafts and can transfer drive from either of the sun gears to the ring gear.
2 They can walk around a sun gear. When either sun gear is held stationary, its pinions will walk around the outside of the gear, taking the carrier with them.
3 The secondary pinions can walk around inside the ring gear. This occurs when the ring gear is held stationary. The secondary pinions will walk around the inside of the ring gear, taking the carrier with them.

28.5 Transmission with compound planetary gears

Figure 28.8 shows a simplified sectional view of compound planetary gears of an automatic transmission for a rear-wheel-drive vehicle. The front clutch, rear clutch, front band, rear band and one-way clutch are the operating parts for the gearing.

The bands (also referred to as brakes) contract around the drums to hold a gear part. The multiplate clutches drive parts of the gears. The bands and clutches are applied hydraulically. The one-way clutch locks automatically when a load is applied.

Applying the clutches and bands has the following effects:

1 Front clutch. Connects the input shaft to the primary (small) sun gear .
2 Rear clutch. Connects the input shaft to the secondary (large) sun gear .
3 Front band. Holds the secondary sun gear stationary so that the pinions walk around the sun gear to give planetary action.
4 Rear band. Holds the carrier stationary so that the pinions act as idlers, and rotate only on their own shafts.
5 One-way clutch. Performs the same function as the rear band by locking against the reaction of the carrier to hold the carrier stationary .

Table 28.2 Bands and clutches applied

Ratio	Applied	
First	Front clutch	Rear band or one-way clutch
Second	Front clutch	Front band
Third	Front clutch	Rear clutch
Reverse	Rear clutch	Rear band

Handy hint: A band can only hold components stationary . It cannot lock components together and rotate , as can a clutch.

28.5.1 Clutch and band application

Table 28.2 shows the clutches and bands that are applied for the various gear ratios. If they are numbered from 1 to 5, as in the above list, and as they are located in the transmission, the larger numbers represent the lower gears (see Figure 28.1).

The front clutch (1) is used with the rear band (4), or with the one-way clutch (5), for first. The front clutch (1) and the front band (3) are used for second, and the front clutch (1) and the rear clutch (2) are used for third. With this transmission, the units are applied progressively from rear to front. The rear clutch and the rear band are applied for reverse.

28.6 Power flow in compound planetary gearing

To understand how various gears can be obtained in an automatic transmission, the drive or power flow must be followed through the various parts of the gearing. This is shown in the illustrations of the compound planetary gear sets in Figures 28.9 to 28.12. These show the gear section of Figure 28.8.

Handy hint: The parts of the gearing that are being used are shown dark er than the others in **Figures 28.9 to 28.12.**

28.6.1 First gear

In Figure 28.9 the carrier is held, and the primary sun gear is the driver. The power flow through the gears is from the primary sun gear to the primary pinions, on to the secondary pinions, and then to the ring gear and so to the output shaft.

Gear operation is as follows:

1 The primary sun gear rotates in the direction of engine rotation.
2 The primary sun gear turns the primary pinions in the opposite direction to engine rotation.
3 The primary pinions turn the secondary pinions in the direction of engine rotation.
4 The secondary pinions turn the ring gear (with its internal teeth) in the direction of engine rotation.
5 The ring gear is attached to the output shaft, which is also turned in the direction of engine rotation.

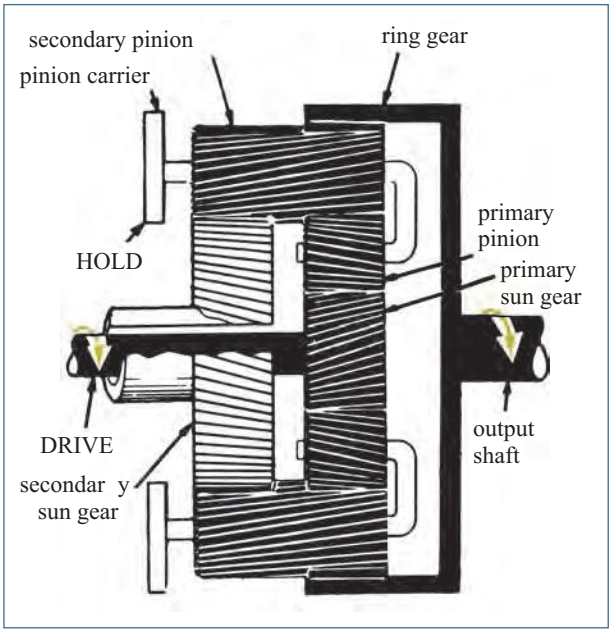


Figure 28.9 Compound planetary gears in low: the carrier is held, and drive from the primary sun gear is transferred by both sets of pinions to the ring gear and so to the output shaft FORD

The pinions act only as idlers to transfer drive from the primary sun gear to the internal gear. They have no effect on the gear ratio, which is caused by the difference in size or number of teeth between the primary sun gear and the ring gear. The same gear ratio would be obtained if the primary sun gear and the internal gear were directly in mesh.

Handy hint: The front clutch drives the **primary sun gear and the one-way clutch holds the planet carrier stationary**.

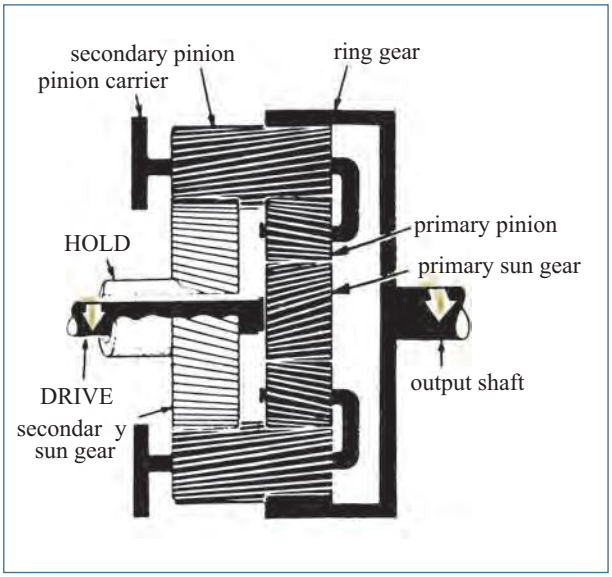


Figure 28.10 Compound planetary gears in second: the secondary sun gear is held, and drive from the primary sun gear is transferred by the pinions to the ring gear—the secondary pinions walk around the stationary secondary sun gear FORD

28.6.2 Second gear

In Figure 28.10, the secondary sun gear is held, and the primary sun gear is the driver. The power flow through the gearing is from the primary sun gear to the primary pinions, then to the secondary pinions, which have planetary action, and so to the ring gear and the output shaft. Gear operation is as follows:

1 The primary sun gear turns the primary pinions in the opposite direction to engine rotation.
2 The primary pinions turn the secondary pinions in the direction of engine rotation.
3 The secondary pinions try to turn the secondary sun gear in the opposite direction to engine rotation. They cannot do so because it is held.
4 The secondary pinions are forced to walk around the outside of the secondary sun gear , taking the carrier with them.
5 The secondary pinions rotate the ring gear in the direction of engine rotation, but they also tak e the carrier forward with them as they walk around the secondary sun gear .
6 The ring gear drives the output shaft in the direction of engine rotation.

The output shaft is rotated faster in second than in low because of the combined effect of the pinions driving the ring gear and the forward rotation of the pinion carrier due to the planetary action.

Handy hint: The front clutch drives the primary sun gear and the front band holds **the secondary sun gear stationary**.

28.6.3 Third gear

In Figure 28.11 both the primary sun gear and the secondary sun gear act as drivers. This locks the parts of the gearing together so that there is a direct drive and no gear reduction. The complete gear assembly turns at engine speed in the direction of engine rotation.

Handy hint: The front clutch locks the input shaft to the primary sun gear and the rear clutch locks the input shaft to the secondary sun gear .

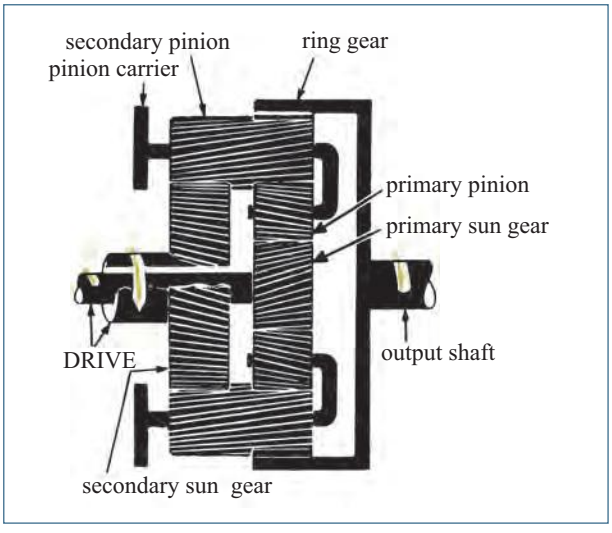


Figure 28.11 Compound planetary gears in third: the shafts of both sun gears receive drive , and all parts of the gearing rotate together FORD

28.6.4 Reverse

In Figure 28.12 the pinion carrier is held, and the secondary sun gear is the driver. The power flow is from the secondary sun gear to the secondary pinions, then to the ring gear and so to the output shaft. Gear operation is as follows:

1 The secondary sun gear rotates in the direction of engine rotation.
2 The secondary sun gear turns the secondary pinions in the opposite direction to engine rotation.
3 The secondary pinions turn the ring gear in the opposite direction to engine rotation.
4 The ring gear and the output shaft turn in a direction opposite to engine rotation to provide reverse .

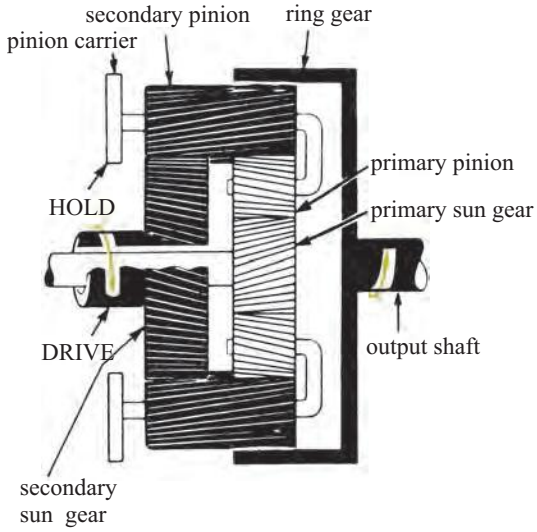


Figure 28.12 Compound planetary gears in reverse: the carrier is held, and drive from the secondary sun gear is transferred by the secondary pinions to the ring gear FORD

The gear ratio is the difference in size between the secondary sun gear and the ring gear. There is no planetary action in reverse—the secondary pinions act only as idlers, as they did in low gear. The difference between reverse and low is that the secondary sun gear is larger than the primary sun gear, so the gear ratio is higher in reverse. With one less pinion in operation, the direction of rotation is reversed.

Handy hint: The rear clutch locks the input shaft to the secondary sun gear and the rear band holds the planet carrier stationary .

28.7 Planetary gears with a common sun gear

In this design, also known as *Simpson planetary gearing,* two simple gear sets are used. These are connected by a long sun gear. Figure 28.13 shows the gear arrangement schematically. The input shaft is at the left-hand side, the output shaft at the right-hand side. Two clutches drive the gears, and two bands and a one-way clutch hold parts of the gearing as required.

The gear sets, as well as having a common sun gear, are connected by each having a part attached to the output shaft. The ring gear of the rear set and the carrier of the front set are both attached to the output shaft. This is arranged by having the output shaft extend forward through the hollow sun gear.

28.7.1 First gear

In Figure 28.13, in first gear, the rear carrier is held by the one-way clutch or, if first is manually selected, by the rear band. Applying the rear clutch connects the input shaft to the front ring gear. Both gear sets provide a gear ratio. They act as follows:

Front gear set

1 The rear clutch is applied to connect the input shaft to the front ring gear .
2 The front carrier is stationary , and the ring gear drives the sun gear through the pinions. (The carrier is attached to the output shaft and is held stationary until the vehicle begins to move .)

Rear gear set

3 The one-way clutch, or the rear band, is applied to hold the carrier .
4 The common sun gear is being driven from the front gear set.
5 The sun gear drives the ring gear through the pinions, and the ring gear drives the output shaft. This provides a gear reduction.

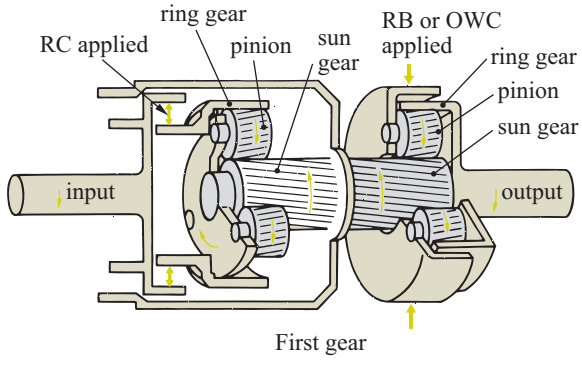


Figure 28.13 First-gear operation (RC rear clutch RB rear band, O WC one-way clutch). The arrangement has two planetary gear sets with a common sun gear FORD

The action of the front gear set is not as simple as described. The carrier is a reaction member which applies torque to the output shaft to which it is attached. At the same time, the pinions are turning the sun gear. The overall effect is to produce an increase in torque in the front gearing, which reduces as vehicle speed increases.

28.7.2 Second gear

In Figure 28.14, in second gear, the rear clutch is still applied to connect the input shaft to the front ring gear. The front band is applied to hold the sun gear stationary. The gear ratio is provided by the front gear set only. The one-way clutch releases automatically.

Front gear set

1 The ring gear drives the pinions, which walk around the stationary sun gear , turning the carrier .
2 There is a gear reduction between the ring gear and the carrier .
3 The carrier transfers the drive to the output shaft to which it is attached.

Rear gear set

4 The rear carrier is released automatically by the one-way clutch, or by the rear band.
5 Parts of the rear gear set rotate but carry no load.

All the gear ratio is provided by the front gear set. This acts as a simple planetary gear train, with the sun gear held, the ring gear as the driver and the carrier being driven.

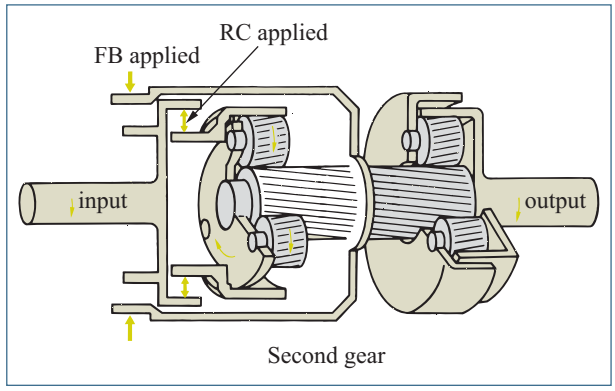


Figure 28.14 Second-gear operation (FB front band RC rear clutch). A gear reduction is obtained in the front gear set FORD

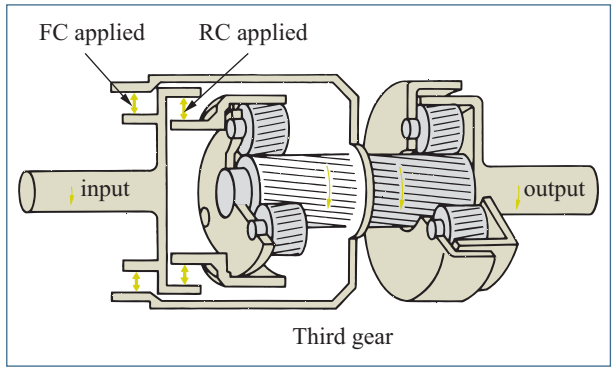


Figure 28.15 Third-gear operation (FC front clutch RC rear clutch). All parts are locked together to give direct drive FORD

28.7.3 Third gear

In Figure 28.15, in third gear, the rear clutch remains on. The front clutch is applied and the front band released.

1 The rear clutch connects the input shaft to the front ring gear , and the front clutch connects the input shaft to the sun gear .
2 Two parts of the front gear set are now connected to the input shaft. This locks up the gears so that the drive goes directly from the input shaft to the output shaft without any reduction.

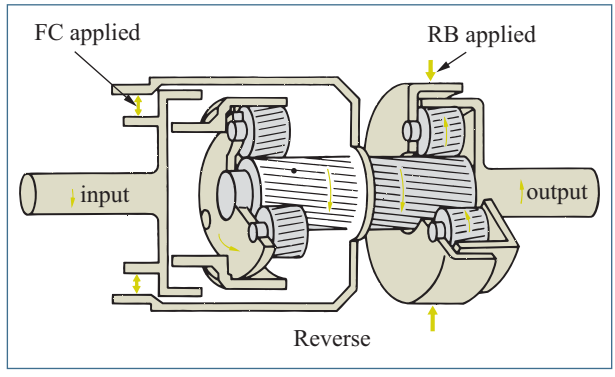


Figure 28.16 Reverse gear operation (FC front clutch RB rear band). The rear gear set provides a reduction and reversal of rotation FORD

28.7.4 Reverse

In Figure 28.16, in reverse, the rear gear set is used. The front clutch is applied to connect the input shaft to the sun gear. The rear band is applied to hold the rear carrier.

Rear gear set

1 The sun gear drives the pinions, and the pinions drive the ring gear . There is a gear reduction between the sun gear and the ring gear .
2 The ring gear carries the drive to the output shaft.
3 A change in direction of rotation for reverse occurs between the sun gear and the pinions (as shown on the diagram).

28.7.5 Neutral

In neutral and in park position, no bands or clutches are applied, so drive is not transmitted through the transmission. Some parts of the gearing will rotate when the engine is running, but will not transmit drive.

28.7.6 Park

In park position, the gearing is the same as in neutral, but a parking pawl is engaged with a parking gear to lock the transmission. This is necessary because, unlike a manual transmission, there are no gears that can be left in mesh to prevent the vehicle from rolling (Figure 28.17).

Handy hint: Most manufacturers recommend applying the parking brake prior to engaging the park position to prevent possible damage.

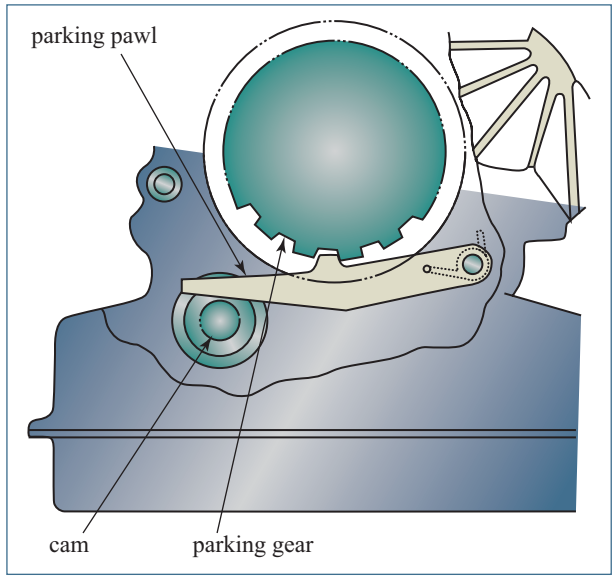


Figure 28.17 When park is selected, the parking pawl engages with the parking gear

28.8 Transaxle gearing with a common sun gear

Figure 28.18 shows the arrangement of a transaxle that has two planetary gear sets with a common sun gear. The same principles of operation apply to the planetary gearing, whether it is used in a transaxle or in a transmission for rear-wheel drive. However, the arrangement of the shafts and gears is different.

28.8.1 Features of transaxle

Some of the features of this transaxle are as follows.

Front of transaxle

In this transaxle, the opposite end to the converter has been designated the 'front'. This is the right-hand end in the illustration. This enables the same names to be used for parts which perform similar functions, whether they are in a transaxle or a transmission.

Shafts

A hollow turbine or input shaft goes through the centre of the transaxle, carrying drive from the turbine in the torque converter to the clutches at the front. A drive shaft for the oil pump passes through the hollow input shaft.

The output shaft is also hollow, as it fits over the input shaft. It is connected to the front carrier and the rear ring gear. The output gear, which is attached to the rear of the output shaft, is meshed with the intermediate or idler gear.

Clutches

Two multiplate clutches are used. The front clutch connects the input shaft to the common sun gear, the rear clutch connecting the input shaft to the front ring gear.

Brakes

A band brake holds the sun gear. A disc brake holds the rear carrier when the selector lever is in the '1' position, a one-way clutch doing a similar job when the selector lever is in the drive (D) position.

Handy hint: A disc brake is a multiplate clutch with one set of clutch plates attached to the transmission case.

28.8.2 Power flow

Figure 28.18 shows the sequence in which power flows through the various parts of the gearing. The clutches and brakes that are applied to obtain the three forward gears and reverse are shown in Table 28.3, and an outline of the power flow in each of the gears follows.

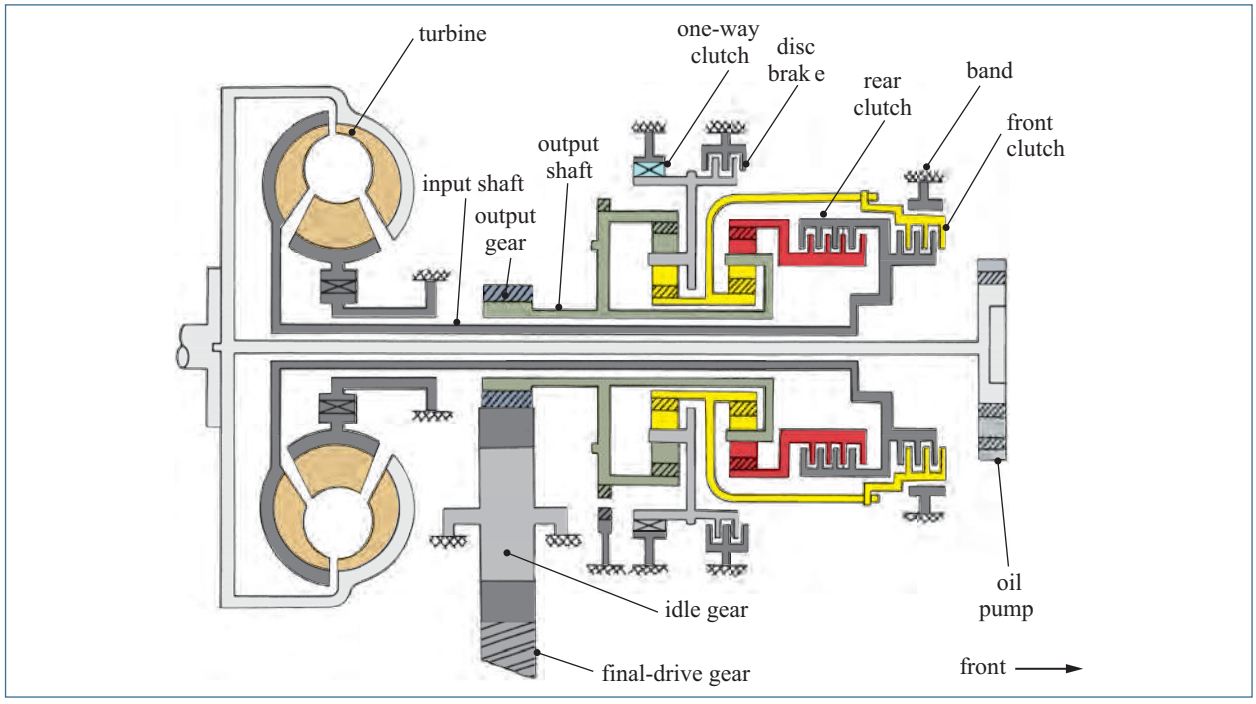


Figure 28.18 Arrangement of transaxle with two gear sets using a common sun gear
First-gear power flow: turbine → input shaft →rear clutch → front ring gear → front pinions (carrier retarded by output shaft) → sun gear rear pinions (carrier held by the disc brake or one-way clutch) → rear ring gear → output shaft → output gear → idler gear → final-drive gear on differential assembly

Second-gear power flow: turbine → input shaft → rear clutch → front ring gear → front pinions → front carrier (sun gear held by brake band) output shaft → output gear → idler gear → final-drive gear

Planetary action occurs in the front gear set. The ring gear drives the pinions, which are forced to walk around the stationary sun gear. The sun gear is held by the brake band. The rear gear set is in a neutral condition with the ring gear and carrier rotating and the one-way clutch freewheeling.

Third-gear power flow: turbine → input shaft → front clutch and rear clutch (sun gear locked to the front ring gear) → output shaft → output gear → idler gear final-drive gear

With the front and rear clutches applied, the sun gear and front ring gear are locked together so that the input-shaft speed and output-shaft speed are the same. However, a gear reduction does occur in the drive gears – between the output gear and the final-drive gear on the differential case.

Reverse power flow: turbine → input shaft → front clutch → connecting shell → sun gear → rear pinions (carrier held by the disc brake) → rear ring gear → output shaft → output gear → idler gear → final-drive gear

Reversal of rotation occurs if the sun gear rotates in the direction of engine rotation, then the pinions will rotate in the opposite direction. The ring gear and output shaft will also rotate in that direction to provide reverse. FORD

Table 28.3 Application of brakes and clutches in transaxle

Selector A position	Front clutch	Rear clutch	Disc brake	Brake band	One-way clutch
D – 1		X			X
– 2		X		X	
– 3	X	X			
1		X	X		
2		X		X	
R	X		X		

First gear

With the driver's selector lever in the drive position, the rear clutch is applied to carry input to the front ring gear, and the one-way clutch is locked by the reaction of the rear carrier. With the selector lever in '1', the disc brake is also applied to hold the rear carrier. This provides engine braking by preventing the one-way clutch from overrunning.

In first gear, both the front and rear gear sets provide a reduction in speed and an increase in torque, so the output gear rotates at less than engine speed. The idler gear has no effect on the gear ratio, being used merely to transmit drive to the final-drive gear.

The final-drive gear, only part of which is shown in the illustration, is larger than the output gear. This provides a further reduction before the drive reaches the drive shafts which carry drive to the front wheels.

Second gear

In second gear, the rear clutch remains applied and the brake band is applied to hold the sun gear. The one-way clutch is automatically released. Planetary action occurs in the front gear set. The front ring gear drives the pinions, which walk around the stationary sun gear, taking the front carrier with them.

The carrier is attached to the output shaft, which will be rotated at a speed that is reduced but faster than for low gear. The drive is carried from the output gear (on the output shaft) through the idler gear to the final-drive gear.

The rear gear set is in a neutral condition, with the ring gear and carrier rotating but not under load. The one-way clutch is freewheeling because there is no longer a reaction of the carrier to cause it to lock.

Third gear

In third gear, both the front and rear clutches are applied. This locks the sun gear and the front ring gear together so input-shaft speed and output-shaft speed are the same. There is now a direct drive through the planetary gears, but a gear reduction still occurs between the output gear and the final-drive gear.

Handy hint: When two members of a planetary system are lock ed together , this locks the entire planetary system.

Reverse

In reverse, the front clutch and the disc brake are applied. The front clutch carries drive to the sun gear, and the disc brake holds the rear carrier stationary. The gear reduction occurs in the rear gear set only; the sun gear rotates the pinions which, in turn, rotate the rear ring gear and the output shaft.

The sun gear rotates in the direction of engine rotation, and the pinions rotate in the direction opposite to engine rotation. The pinions will rotate the ring gear and output shaft, also in the direction opposite to engine rotation, to provide reverse gear.

28.9 Four-speed transmissions

Four-speed transmissions and transaxles have the same general arrangements as three-speed transmissions, but with additional components for fourth gear. Some use extra gears; others use extra brakes or clutches to obtain fourth gear without additional gearing.

The first three gears operate in the same way as the gears in a three-speed transmission, with third gear being a straight-through drive. However, fourth gear is different as it is an overdrive. This increases the transmission output speed above its input speed.

Overdrive reduces the engine rpm, giving economical operation, particularly for cruising conditions. An overdrive cancel switch is usually provided on the driver's selector lever so that overdrive can be held out during city driving (Figure 28.19).

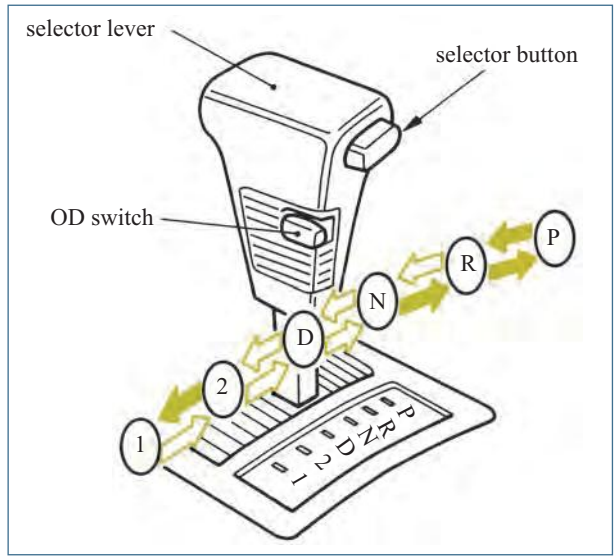


Figure 28.19 Transmission selector lever with overdrive (OD) switch—the selector button is held in to allow movement shown by the solid arrows FORD

28.9.1 Four-speed transmission with overdrive gearing

Figure 28.20 shows the mechanical arrangement of three-speed and four-speed transmissions of the same design. The four-speed transmission has an extra set of gears at the front of the transmission for fourth (overdrive). It also has a brake band and clutch to operate the gears.

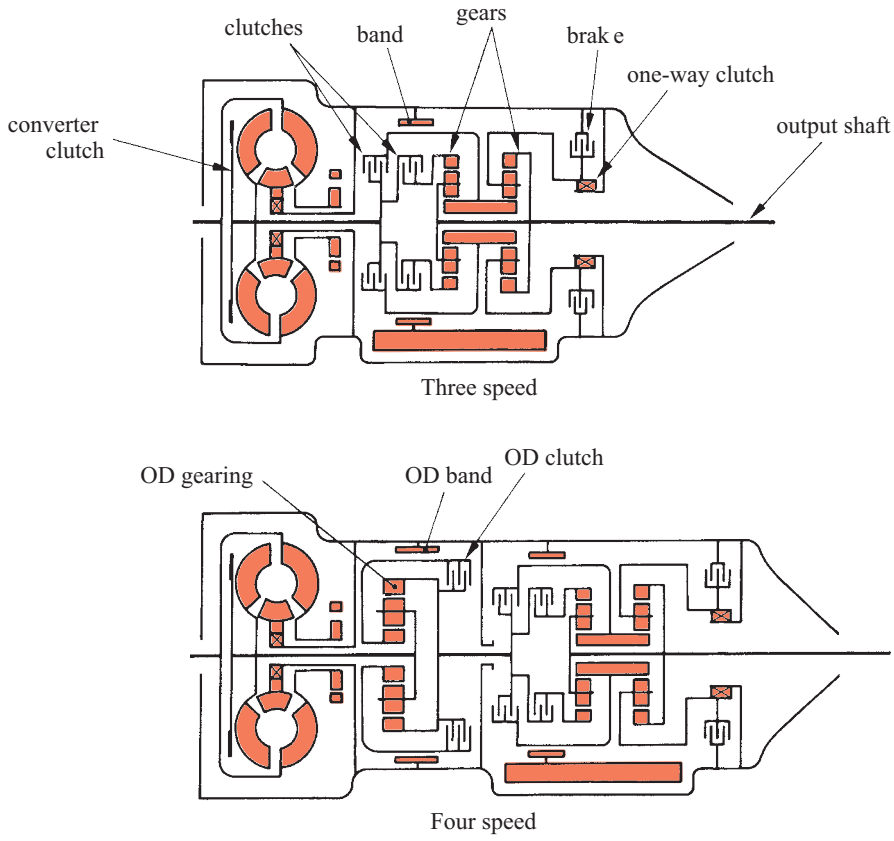


Figure 28.20 Diagrams showing the arrangement of three-speed and four-speed automatic transmissions
one-way clutch

The clutch is applied only during first, second and third gear operation. It locks the ring gear to the sun gear so that the overdrive gears do not operate in the lower gears but carry drive to the three-speed section of the transmission.

The band holds the sun gear stationary for fourth gear. With the band applied, the carrier drives the ring gear at an increased speed. This is faster than engine speed, and this rotation is carried right through the transmission to the output shaft.

28.10 Four-speed automatic transmission with compound planetary gears

The mechanical arrangement of a four-speed automatic transmission with a compound planetary gear set is shown in Figure 28.21. The four forward speeds and reverse are all obtained from the one set of gears.

The transmission has four multiplate clutches, two one-way clutches (OWC) and two bands. It also has a lock-up clutch in the torque converter. The bands and clutches that provide the gears are shown in Table 28.4.

Handy hint: The compound planetary gearing operates in the same way as a three-speed transmission, but this one has an extra overdrive gear .

28.10.1 First (drive) gear

First gear is obtained as follows:

1 C2 is applied to drive the primary (forward) sun gear via the 3–4 O WC.
2 The sun gear drives the primary (short) and the secondary (long) pinions, which rotate the ring gear and the output shaft.
3 The 1–2 O WC prevents the planetary carrier from rotating backwards due to the reaction force of the gears.

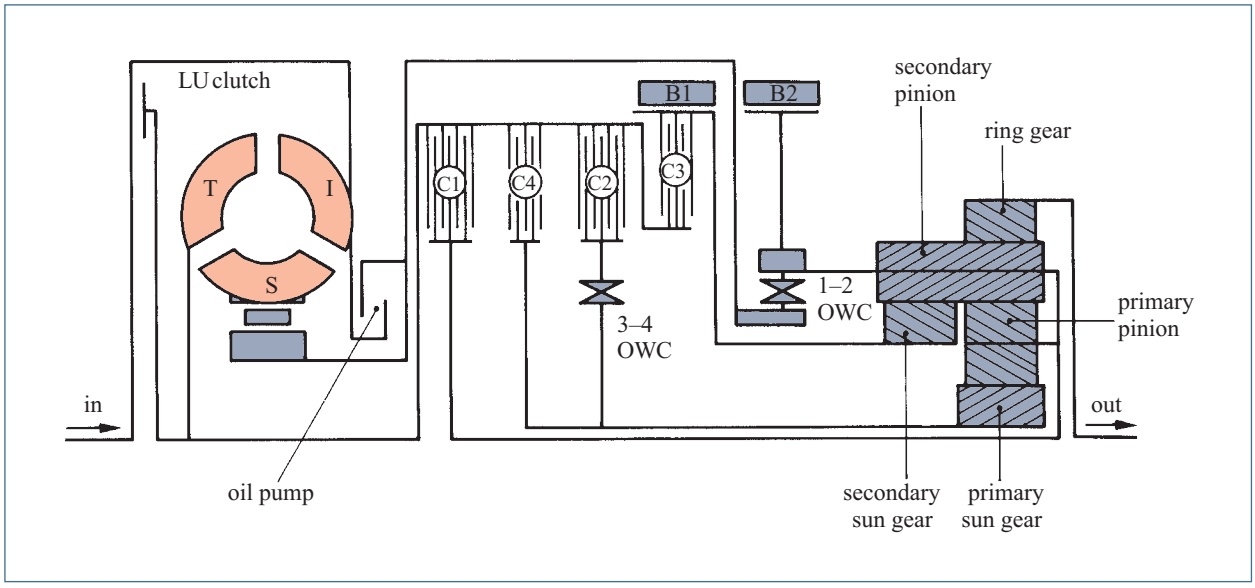


Figure 28.21 Diagram of the power flow of a four-speed automatic transmission (C clutch B band O WC one-way clutch LU lock-up clutch I impeller T turbine S stator) FORD

Table 28.4 Components (from Figure 28.21) used to produce the gears (four-speed automatic transmission)

Gear	C1	C2	C3	C4	B1	B2	1–2 O WC	3–4 O WC	LU clutch
1st		X					X	X	
2nd		X		X	X			X	
3rd	X	X		X				X	
4th	X	X			X				X
Reverse			X			X			
Manual									
1st		X		X		X		X	

28.10.2 Second (drive) gear

Second gear is obtained as follows:

1 C2 remains applied, as for first gear , to drive the primary sun gear .
2 B1 is applied to hold the secondary (reverse) sun gear stationary .
3 The secondary pinions walk around the stationary secondary sun gear , taking the carrier with them.
4 C4 is applied to bypass the 3–4 O WC, and so provide engine braking on the overrun.

28.10.3 Third (drive) gear

Third gear is obtained as follows:

1 C2 is applied, as for all forward gears, to drive the primary sun gear .
2 C1 is applied to drive the carrier .
3 With two clutches applied, the gearing is lock ed up and provides a straight-through drive .

28.10.4 Fourth (overdrive) gear

Fourth gear is obtained as follows:

1 C1 is applied to drive the carrier .
2 B1 is applied to hold the secondary sun gear stationary .

3 The carrier is driven and the secondary pinions walk around the secondary sun gear .
4 This turns the gear and the output shaft in a forward direction, but faster than the input shaft of the transmission.
5 C2 is applied to reduce the speed across the 3–4 O WC.
6 The lock -up (LU) clutch comes into operation under suitable operating conditions to lock up the converter .

Handy hint: Lock -up converters usually come into operation prior to the selection of overdrive to prevent ex cess converter heat being generated.

28.10.5 Reverse gear

Reverse gear is obtained as follows:

1 C3 drives the secondary sun gear .
2 B2 holds the carrier stationary .
3 The secondary sun gear drives the secondary pinions as idlers.
4 These drive the ring gear and the output shaft. The direction of rotation of the ring gear is reversed (compared with first) because only one pinion is in operation.

28.10.6 Manual first gear

In addition to those for first (drive), C4 is applied to prevent the 3–4 OWC from operating, and so provides engine braking. B2 is applied to prevent the 1–2 OWC from operating.

28.11 Four-speed automatic transaxle with compound planetary gears

Figure 28.22 shows the mechanical arrangement of a four-speed automatic transaxle. This has three multiplate clutches, a one-way clutch, a brake band and a disc brake. Table 28.5 shows how these components are applied to obtain the various gears.

The transaxle has compound planetary gearing, which provides all the gears, including fourth (overdrive) gear. This type of gearing has already been covered for other transmissions, so only fourth gear will be outlined here.

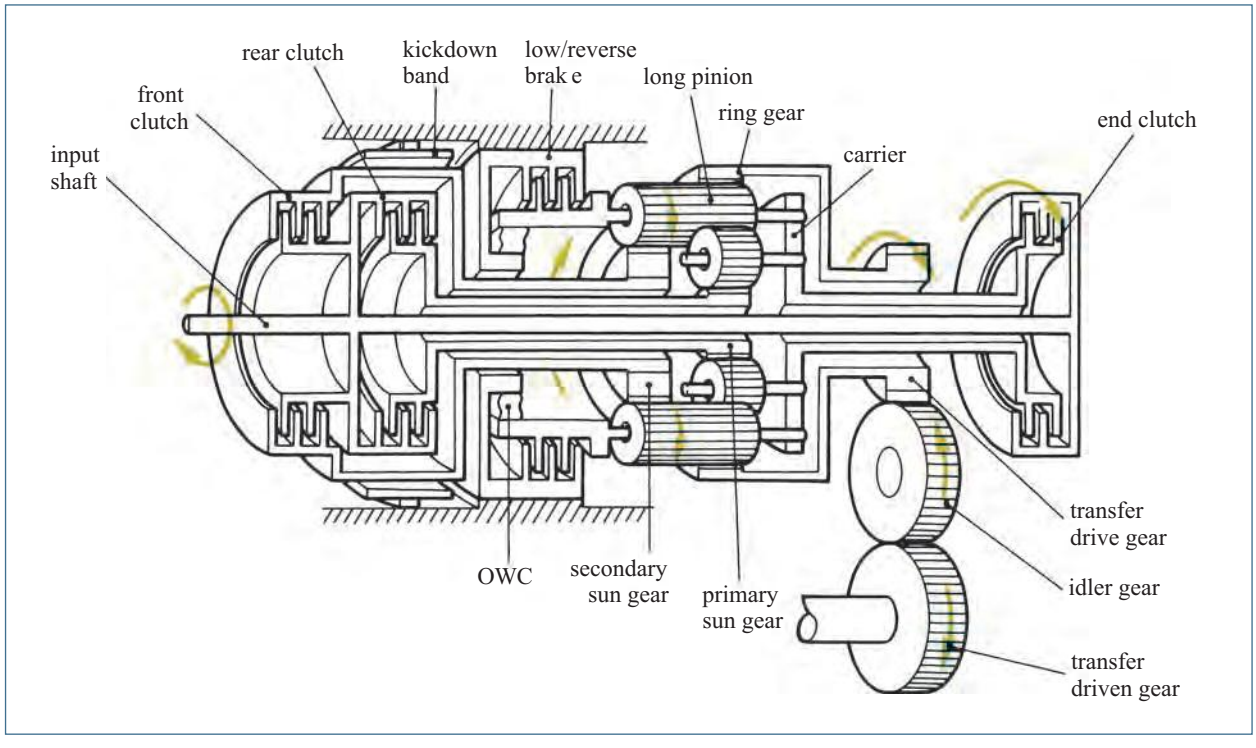


Figure 28.22 Four-speed automatic transaxle with a compound planetary gear set—arrows show fourth gear MITSUBISHI

Table 28.5 Components (from Figure 28.23) used to produce the gears (four-speed automatic transaxle)

Gear	Rear clutch	Front clutch	OWC	Kickdown band	Low/reverse brake	End clutch
1st	X		X			
2nd	X			X		
3rd	X	X				X
4th				X		X
Reverse		X			X	

28.11.1 Fourth gear operation

Fourth gear operates as follows:

1. The end clutch is applied to carry drive from the input shaft to the pinion carrier .
2. The kick down band holds the secondary sun gear stationary .
3. Drive from the input shaft is carried by the clutch to the pinion carrier .
4. The long pinions, which are in mesh with the stationary secondary sun gear , are forced to walk around the sun gear . This provides a planetary action, with the pinions driving the ring gear at an increased speed. This gives a ratio of appro ximately 0 .7:1.
5. The ring gear is attached to the transfer drive gear on the output end of the transaxle .
6. Drive is carried by the idler gear , the transfer driven gear and the transfer shaft to the final-drive gears (not shown).

28.11.2 Other gears

For the other gears, use Table 28.5 to see which components are in operation. Then follow the power flow in Figure 28.22 from the input shaft at the front of the transaxle to the transfer gear at the rear.

28.12 Transaxle with helical gears

Figure 28.23 shows an automatic transaxle which uses helical gears in a similar way to a manual transmission. The transaxle has a torque converter with a lock-up clutch which carries the drive from the engine to the mainshaft of the transaxle. The gear section of the transaxle has a mainshaft, which is in line

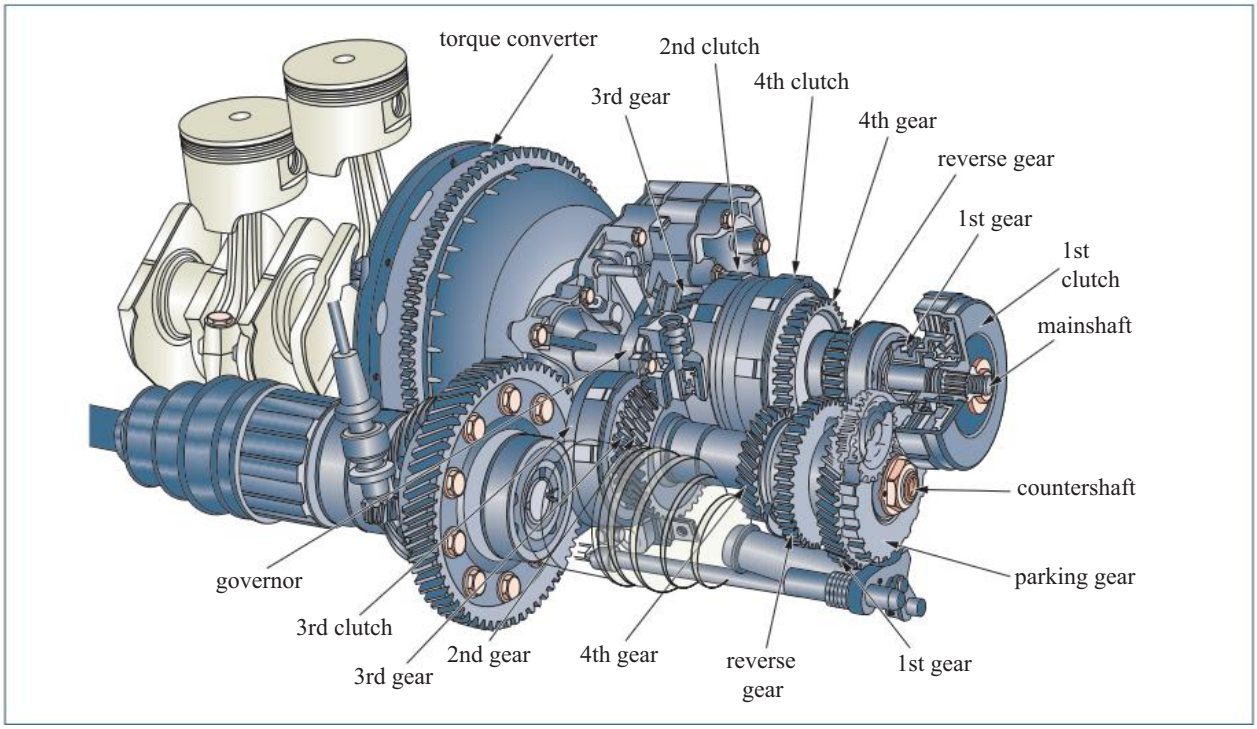


Figure 28.23 Components of a four-speed automatic transaxle with helical gearing

with the crankshaft, and a parallel countershaft. These carry the helical gears for the four forward ranges, and also spur gears for reverse. Reverse has a separate idler to change direction of rotation.

The final-drive unit, which includes the differential, carries the drive from a pinion on the end of the countershaft to the front wheels. The countershaft has a parking gear which is locked by a parking pawl when the selector is moved to.

There are four sets of constant-mesh gears and four clutches:

1 The mainshaft has gears for third, second, fourth, first and reverse .
2 The countershaft has corresponding gears which are in constant mesh with the gears on the mainshaft.
3 The mainshaft has clutches for second, fourth and first.
4 The countershaft has a clutch for third.

The clutches are operated hydraulically, performing a similar function to the synchromesh units in a manual transaxle. A one-way clutch is located between the first gear on the countershaft and the countershaft.

Handy hint: Clutches connect components while brak es stop components from turning even though their operation is similar .

28.13 Complete automatic transaxles

There are a number of different transmissions and transaxles.

28.13.1 Three-speed automatic transaxle

Figure 28.24 shows a compact automatic transaxle as used in smaller vehicles. This is a three-speed transaxle with electronic control. A throttle sensor, a vehicle-speed sensor, a computer and solenoid valves control the gearshifts. The gearing consists of two simple planetary gear sets with a common sun gear. These provide the three forward gears and reverse. The arrangement is shown in Figure 28.25. It has two clutches, two brakes and a one-way clutch. The clutches and brakes that are applied for the different gears are shown in Table 28.6.

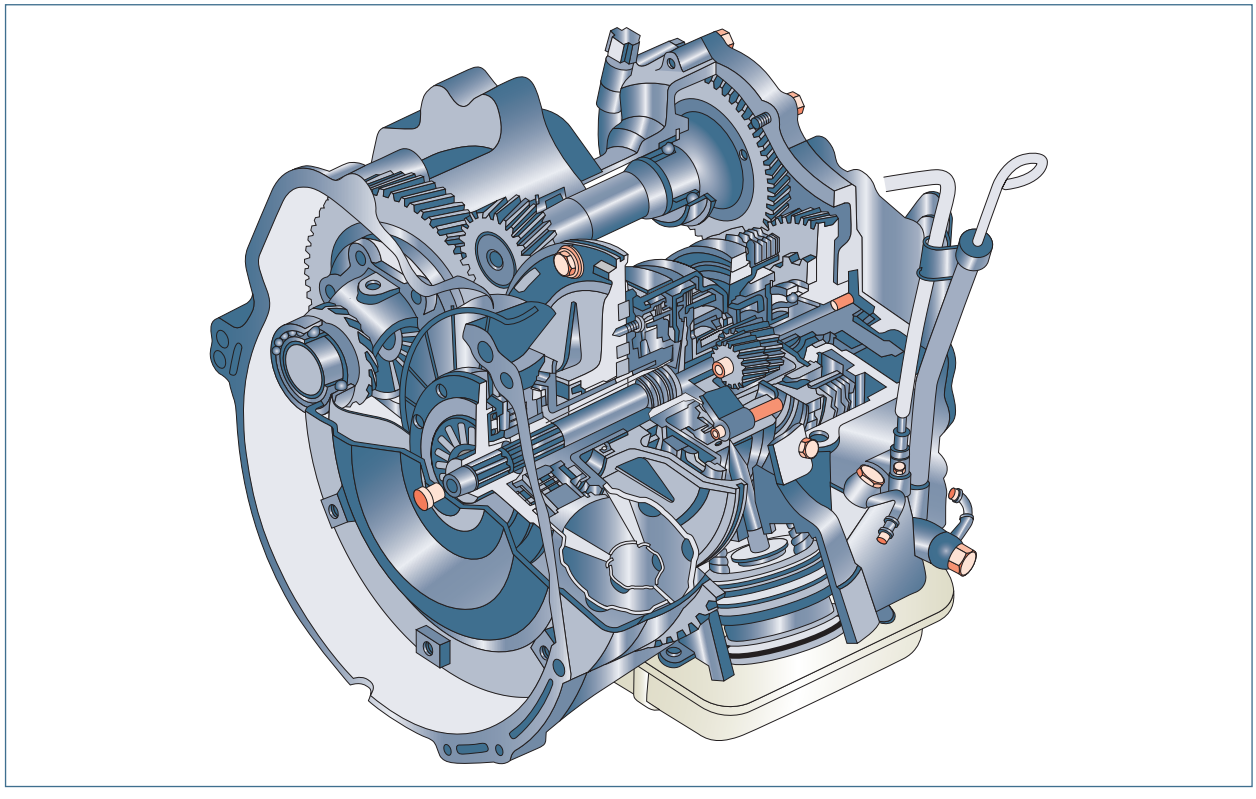


Figure 28.24 Sectional view of a three-speed automatic transaxle with planetary gearing

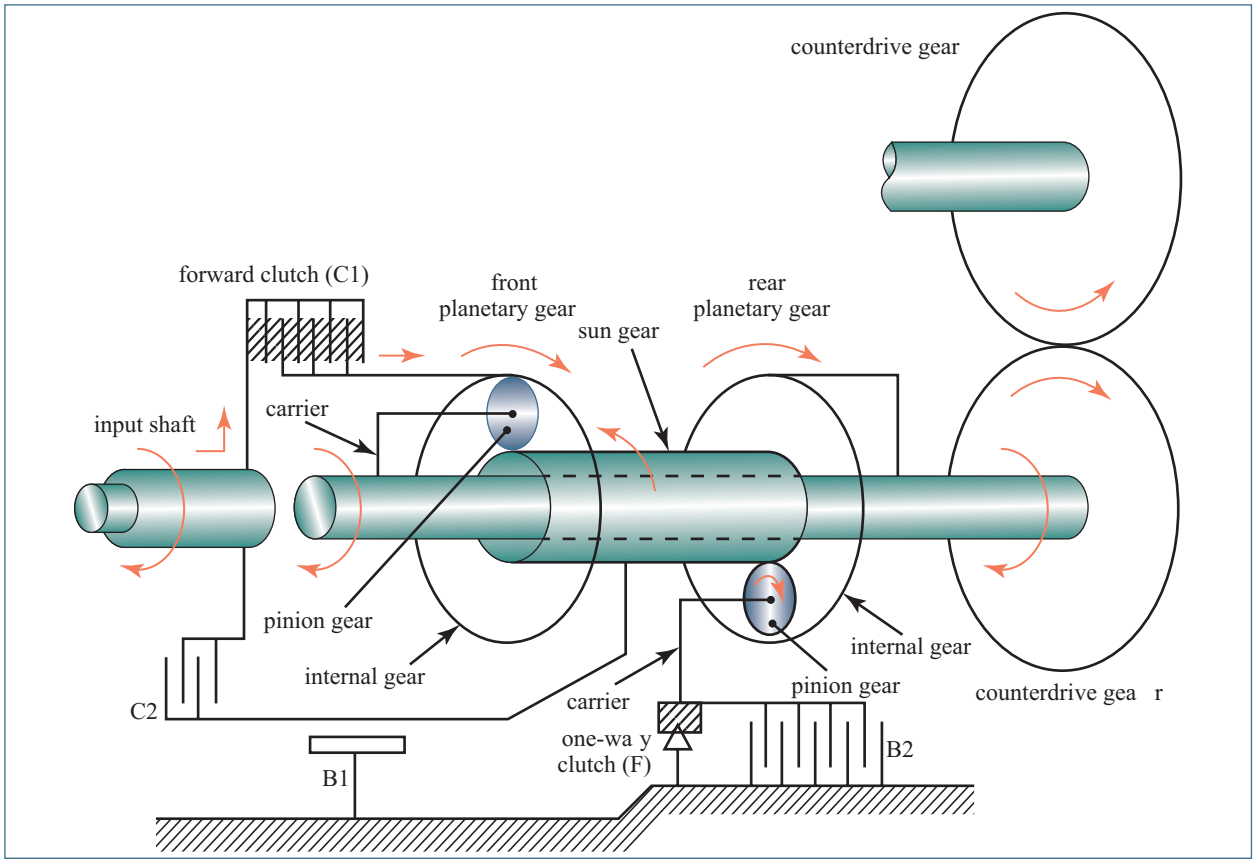


Figure 28.25 Schematic diagram of the gearing of the three-speed transaxle

Table 28.6 Bands and clutches for the different gears (three-spee d automatic transaxle)

Gear	Clutch 1	Clutch 2	Brake 1	Brake 2	One-way clutch
Neutral					
1st	X				X
2nd	X		X		
3rd	X	X			
Reverse		X		X	
2	X		X		
L	X			X	X

28.14 Continuously variable transaxle (CVT)

A continuously variable transmission does not have a series of fixed gear ratios. The gear ratio continuously adjusts to deliver variable ratios and stepless speed changes. In the arrangement in Figure 28.26, hydraulic pressure acts on two split pulleys, varying the groove width of each. This causes a steel belt to alter input or output speed. The pressure applied to the pulleys is controlled by the electronic control unit (ECU), taking into account engine speed, engine torque, accelerator pedal position, etc. An electronically controlled magnetic clutch provides drive between engine and transmission. Forward-to-reverse changeover is by conventional synchroniser mechanism.

28.14.1 System components and functions

The transaxle in Figure 28.26 consists of four main sections:

1 electromagnetic powder clutch
2 forward and reverse synchromesh changeover system
3 steel belt and pulleys
4 final drive and reduction gears .

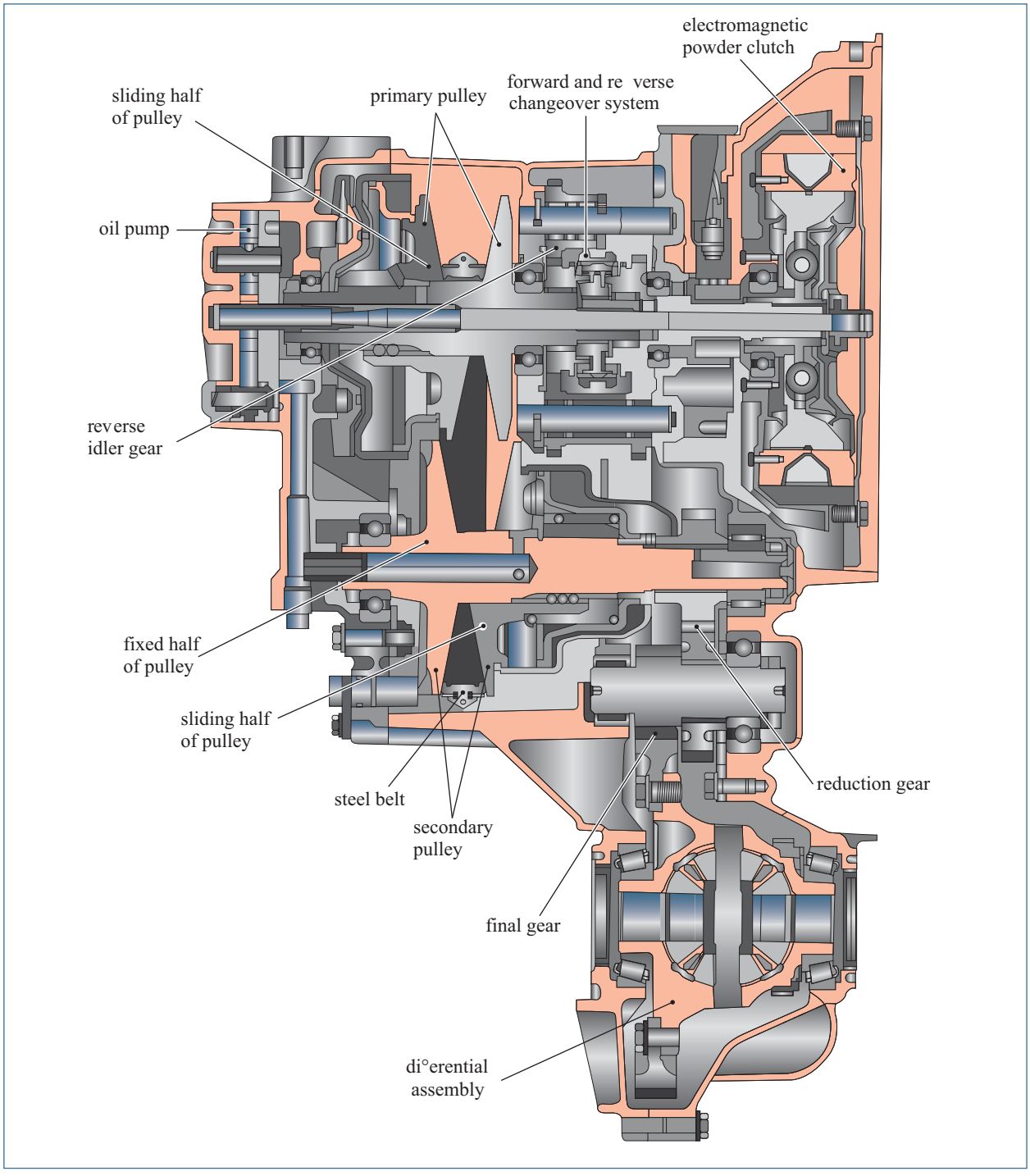


Figure 28.26 Sectional view of a continuously variable transaxle (C VT)

Electromagnetic powder clutch

Figure 28.27 shows the operation of the electromagnetic powder clutch. The small gap between the drive and driven members is filled with iron powder. When the current is applied to the coil, magnetic flux is created. The powder is magnetised, the particles become linked in chain fashion and the powder 'solidifies'. The members become connected and engine torque (drive) is transmitted.

The amount of grip between the drive and driven members varies with the amount of current supplied. With a low current, there is less solidification of the powder, less grip and consequently some slip in the clutch. As the current is increased, there is more solidification, more grip and eventually the clutch locks.

Forward and reverse synchromesh changeover system

The forward and reverse changeover system utilises a dog clutch provided with a synchromesh mechanism. It is linked with the selector lever via a push–pull cable.

Steel belt and pulleys

The system drives through a belt-and-pulley arrangement. This consists of an input (primary) pulley, an output (secondary) pulley and a steel belt with angled sides that fit the groove of the pulleys. The sloping sides of the pulleys and the belt have an angle of 11°. Both input (primary) and output (secondary) pulleys consist of a fixed half and a sliding half (Figure 28.28).

The pulley groove widths can be varied in the axial direction on each pulley. As the groove of a pulley gets narrower, the belt is forced up the groove, increasing the diameter of the pulley. As the groove on a pulley gets wider, the belt drops down in it, decreasing the diameter of the pulley. The combination of the increasing and decreasing diameters of the pulleys gives continuous (stepless) speed changes from low to overdrive.

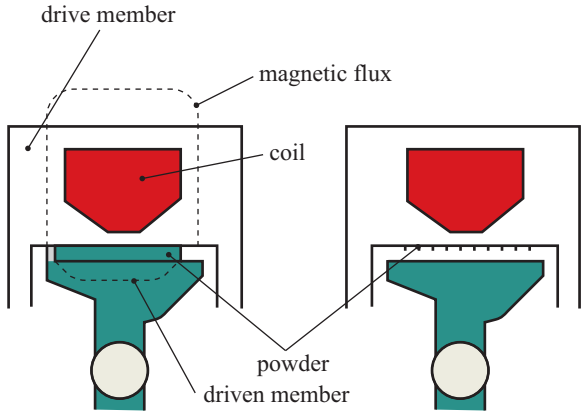


Figure 28.27 Operation of electromagnetic powder clutch

Handy hint: Groove width is determined by hydraulic pressure in the chamber in the sliding half of **the pulley**.

The steel drive belt in this system consists of 280 steel blocks supported by two laminated steel bands. Figure 28.29 shows its construction. When hydraulic pressure is applied to the output (secondary) pulley, the steel blocks are forced upwards, creating a tension in the bands. Power is therefore transmitted by compression of the steel blocks, with the laminated bands maintaining the necessary friction force.

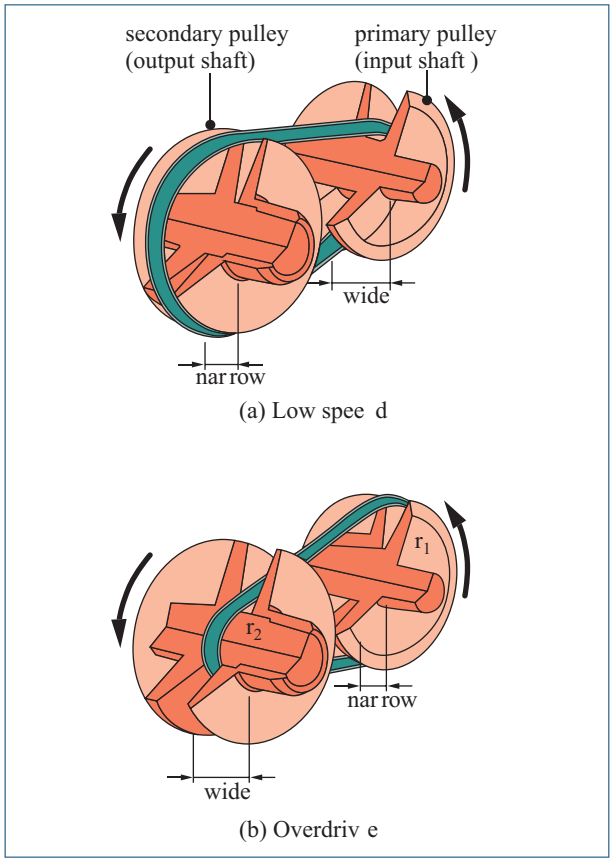


Figure 28.28 Steel belt and pulley operation for a continuously variable transaxle (C VT)

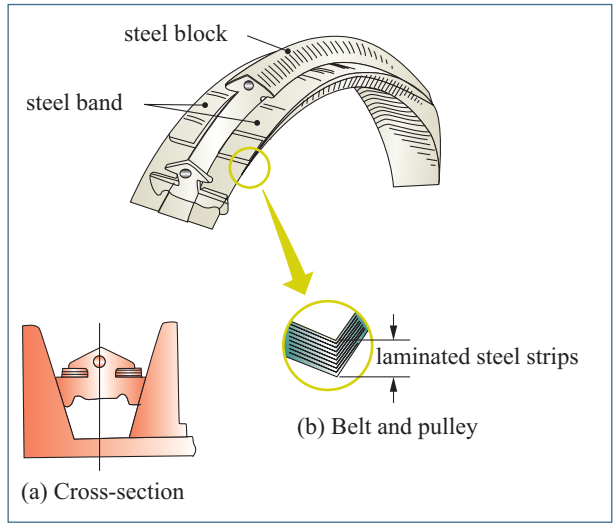


Figure 28.29 Steel-belt construction

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe the mechanical aspect of the automatic transmission, including conventional rear-wheel-drive transmission and front-wheel-drive transaxle assembly which houses a final drive unit
- explain how ratios are obtained through planetary gearing, including which part of the planetary gear is held to multiply torque
- list the similarities and differences between automatic transaxles with helical gears and manual transmissions with hydraulic clutches instead of a synchromesh assembly for gear selection
- describe the design and operation of a continuously variable transaxle which doesn't have planetary or helical gearing, but instead has a series of pulleys that change their radius then change the drive ratio to the driving wheels.

REVIEW QUESTIONS

1 How do planetary gears differ from other gears?
2 What is planetary action?
3 Why are planetary gears used in automatic transmissions?
4 Name the three main parts of a planetary gear set.
5 Explain how various gear ratios can be obtained from a simple planetary gear set.
6 Name the parts of a compound planetary gear set.
7 What is a sun gear?
8 What is a common sun gear?
9 What is the purpose of the clutches in an automatic transmission?
10 What is a one-way clutch?
11 What are the bands used for in an automatic transmission?
12 Explain how park operates in an automatic transmission.
13 What are the main differences in the construction of an automatic transmission for rear-wheel drive and a transaxle?
14 How does an automatic transmission with helical gears differ from a manual transmission, which also has helical gears?
15 In a continuously variable transaxle, what varies?
16 How is the pulley diameter changed in a CVT?
17 What type of clutch is used to change a CVT from forward to reverse?
18 What material is used to transfer the drive from one pulley to the other in a CVT?

CHAPTER 29

Automatic transmissions: hydraulics and controls

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify operating principles of light vehicle automatic transmissions' hydraulic and electronic controls and associated components
2 state the application and purpose of light vehicle automatic transmission's hydraulic and electronic controls and components

All automatic transmissions and transaxles operate hydraulically. Hydraulic pressure is used to apply and release the brake bands and clutches, and as a means of control. Some transmissions have full hydraulic operation, which includes control of the transmission upshifts and downshifts. Other transmissions have electronic controls that work with the hydraulics.

Understanding the hydraulics that operate in the transmission is essential for understanding hydraulic control. This then provides a basis for understanding electronic control.

29.1 Automatic transmission control

The hydraulics and controls of an automatic transmission are shown as a simple block diagram in Figure 29.1. The system functions automatically, although the driver has overall control. Points relating to the hydraulic section of the diagram are:

1 Fluid in the oil pan is delivered by an oil pump to the control valves.
2 Various valves are included in the system. Some of these regulate the fluid pressure in the system, while others direct fluid to the various parts of the system.
3 Fluid is directed to the torque converter, where it is used for power transmission.
4 Fluid is directed to the friction elements—the clutches and the brakes—where it is used to obtain the gear range selected and for automatic gearshifting.
5 Fluid is circulated through the passages of the lubricating circuit to lubricate bearing surfaces and other parts.
6 Fluid returning from the torque converter is directed through the cooler, where it is cooled before being returned to the oil pan. Heat is generated mainly in the torque converter and at the clutches and brakes.

The parts noted above are internal. However, to control the system, there are certain external inputs that can be considered as signals. These are in blocks at the left of the diagram. They are manual control, engine load, road speed, kickdown and electronic controls. They function as described in the following paragraphs.

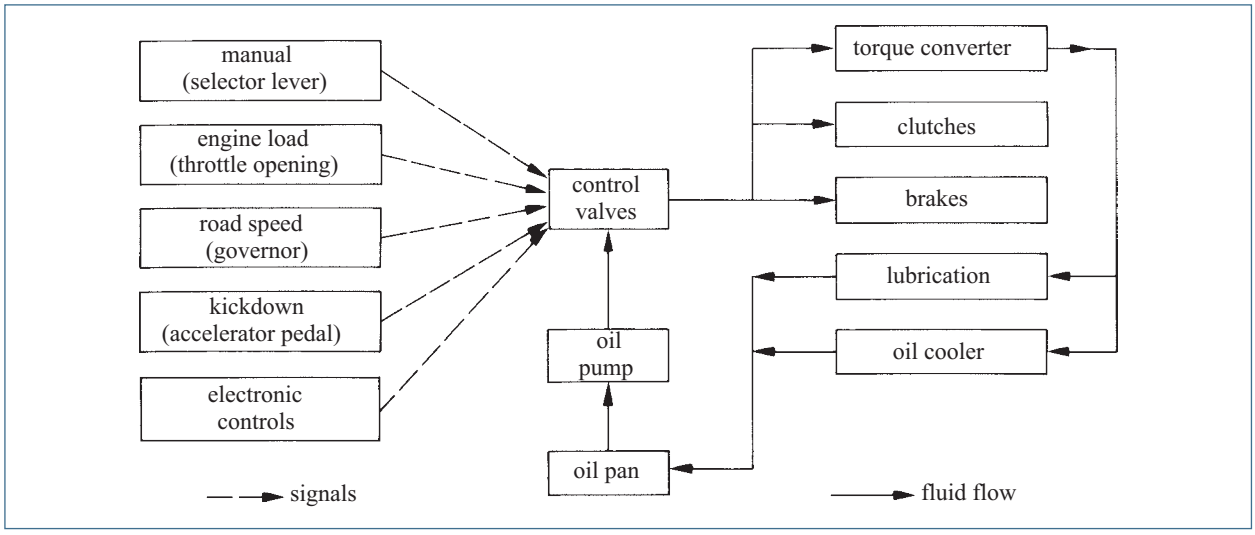


Figure 29.1 Block diagram of the hydraulic system and controls for an automatic transmission

29.1.1 Manual control

The driver has manual control through the selector lever. A number of selector lever positions are provided: P, R, N, D, 3, 2 and 1 (Figure 29.2). When D is selected, the transmission will automatically upshift and downshift through the full range of gears. When 3 is selected, it will automatically upshift and downshift between 1 and 3. When 2 is selected, it will upshift and downshift between 1 and 2. When 1 is selected, it will remain in first gear.

The selector lever can be moved from one forward-gear position to another while the vehicle is in motion, but should not be done under conditions which would cause the engine to overspeed. The selector lever should not be moved between any forward position and reverse while the vehicle is in motion.

Safety: Park should be selected only when the vehicle is stationary . The selector lever should not be placed in neutral and the vehicle coasted.

29.1.2 Engine load

The load on the engine, as determined by the throttle opening, provides a signal for upshifting or downshifting. Under light-throttle conditions, upshifts occur at low speeds, but under wide-throttle conditions (where the engine is under load or operating at high speeds) upshifts are delayed and the transmission will remain longer in the lower gears. With wider throttle openings, the transmission will downshift sooner than otherwise.

With hydraulic control, fluid pressure, known as *throttle pressure*, is used as the engine load signal. With electronic control, electrical signals operate solenoids in the transmission.

29.1.3 Road speed

The governor valve provides a signal in the form of governor pressure that varies in relation to road speed. Governor pressure causes upshifts to occur. Governor pressure and throttle pressure are both variable, with the former opposing the throttle pressure, so gearshifts do not always occur at the same road speeds or throttle openings.

Handy hint: Hydraulic governors are operated by centrifugal force produced by rotation.

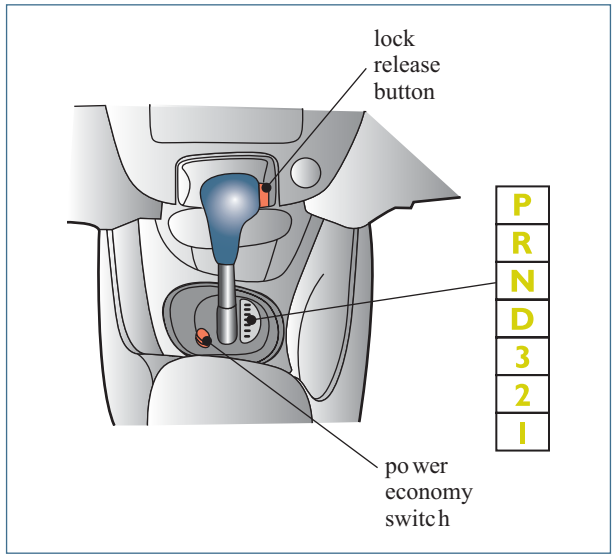


Figure 29.2 Selector lever and selector lever positions—the engine will start only in N (neutral) and P (park) FORD

29.1.4 Kickdown

Forced downshifts, often referred to as *kickdown*, can be made by the driver depressing the accelerator fully. This provides a signal similar to throttle pressure, which forces the transmission to downshift.

29.1.5 Electronic controls

Transmissions with electronic controls have sensors which supply information to the electronic control unit (ECU). This processes the information and sends signals to electrical solenoids in the transmission, which then operate hydraulic valves.

29.2 Simple hydraulic system

Figure 29.3 shows the essential parts of the hydraulic system in simplified form. The fluid is contained within the oil pan and pumped by the oil pump to the regulator valve which regulates the pressure by bypassing surplus fluid, which it returns to the oil pan.

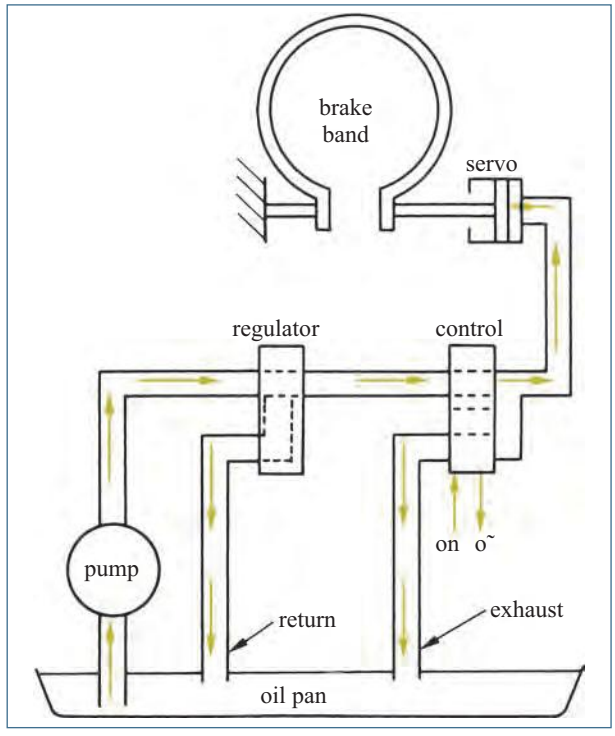


Figure 29.3 Schematic arrangement of a simple hydraulic system of an automatic transmission

The pressure beyond the regulator valve is referred to as *regulated pressure* or *line pressure.* This is maintained within certain limits, irrespective of the oil pump speed. Line pressure is directed to the control valve, which is an on–off valve. When the valve is moved upwards to the position shown, fluid passes through it to the servo piston. Fluid pressure against the servo piston forces it to move in its cylinder and apply the brake band.

To release the band, the control valve is moved downwards. This closes off the passage to the servo but opens a passage from it which enables fluid from the servo to drain back to the oil pan. Pressure is relieved and the band is released. In this way, the band can be applied or released by movement of the control valve.

Handy hint: Control valve movement can be achieved mechanically , hydraulically or electrically .

Figure 29.3 shows a servo and a brake band, but the same arrangement can operate the piston of a multiplate clutch. It can be expanded with more valves, another servo and band, two clutches and a torque converter to form a basic hydraulic system for an automatic transmission.

29.3 Hydraulic system components

The operating components of the hydraulic system include the oil pump, servos, clutches and the valve-body assembly which carries various valves. Fluid is circulated by the oil pump and sent to the valve body, where it is directed to various parts of the transmission including the valves, clutches and brake bands.

The main fluid passages are shown in the diagram in Figure 29.4. These consist of drillings and passages in the housings and shafts. Seven different oil circuits are shown:

1 Oil pump circuit. This carries fluid from the oil pan through the suction line (2) to the oil pump . The pump delivers fluid under pressure back to the valve body through line (3) where it is redirected by the valves to various parts of the transmission.
2 Front clutch (C2) circuit. Fluid from the valve body is directed through line (1) to the clutch C2 via the front cover , valve body and a passage in the shaft.
3 Rear clutch (C1) circuit. Fluid from the valve body is directed through line (6) via the front cover and pump housing to the clutch C1.
4 Servo circuit. Fluid from the valve body is directed to the apply and release sides of the brak e servo through lines (7) and (8).
5 Torque converter . Fluid is supplied to the torque converter from the valve body through line (5) so that the torque converter remains full. It also circulates the fluid so that it does not become overheated. Fluid is also supplied to operate the converter clutch (not shown on the diagram).

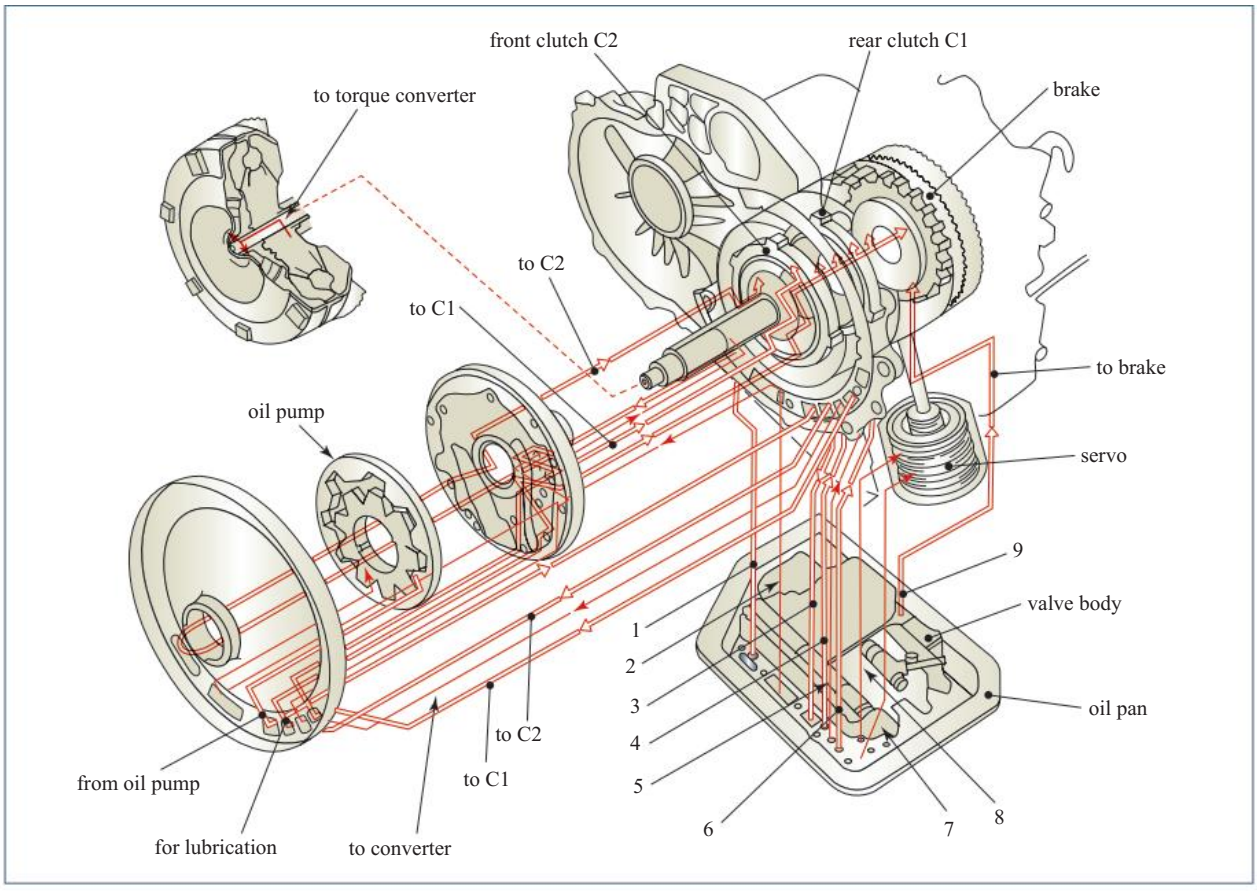


Figure 29.4 Fluid passages in an automatic transaxle (1 clutch C2 2 oil pump suction 3 oil pump pressure 4 lubrication 5 torque converter 6 clutch C1 7 servo apply 8 servo release 9 brake)

6 Brake circuit. The brake at the rear of the transaxle is supplied with pressure from the valve body through passage (9).
7 Lubrication. Passage (4) supplies fluid to various parts of the transmission to lubricate the bearings, thrusts, gears, clutches and other parts.

29.4 Hydraulic valve operation

Knowing how hydraulic valves operate is essential to understanding hydraulic systems. There are two general types: flow control valves and pressure regulator valves. There are other types, such as check valves and orifices, which assist the hydraulic operation of the transmission. Most of the valves in the hydraulic system are spool valves—Figure 29.5 shows a typical example. It has lands, valleys and faces, and also a spring.

29.4.1 Flow control valve operation

A flow control valve controls the flow of fluid to a clutch, servo or even to another valve. It can be considered as an on–off valve, opening or closing passages to let the fluid flow or cause it to be blocked off. Figure 29.6 shows simple control valves that operate in bores (holes) in housings. Passages in the housing allow fluid to flow to and from the valves. Control valves can be operated in different ways, as the following paragraphs describe.

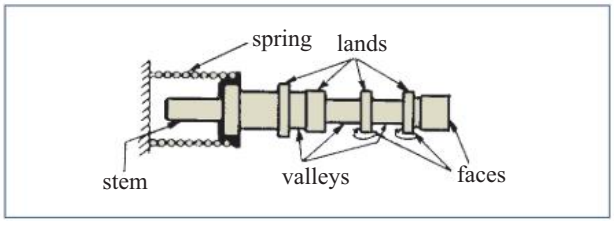


Figure 29.5 Typical spool valve

Handy hint: Flow control valves are referred to simply as control valves which describes their function.

Manual operation

1 Fluid under pressure received at passage A passes through the groove or valley in the valve to passage C (Figure 29 .6(a)). The pressure can be used to apply a brak e or clutch.
2 When the valve is moved by the lever so that passage A is closed by the land of the valve and passage B is opened, pressure will exhaust through passage B and the brak e will be released.

Hydraulic pressure on one end of the valve

1 When pressure is applied to the end of the valve through passage D , it overcomes the spring force and moves the valve to the position shown (Figure 29.6(b)). Fluid flows from A to C.
2 With no pressure at D , the return spring will hold the valve to the left so that fluid from passage A is block ed off by the land of the valve .

Hydraulic pressure on both ends of the valve

1 Pressure through the passage D will open passage A, as before , to allow fluid to flow through the valve to passage C (Figure 29 .6(c)).
2 If pressure is also applied through passage E, the valve will move to the left under spring force to close off passage A and open passage B.

Hydraulic pressure and the solenoid

This has spring pressure on one end of the valve and solenoid-controlled hydraulic pressure on the other.

1 When the solenoid is sealing passage D from the exhaust, pressure through passage D will move the valve to open passage A, as before (Figure 29.6(d)). This will allow fluid to flow through the valve from passage A to passage C.
2 When the solenoid opens passage D to exhaust, the valve will move to the left under spring force to close off passage A and open passage B.

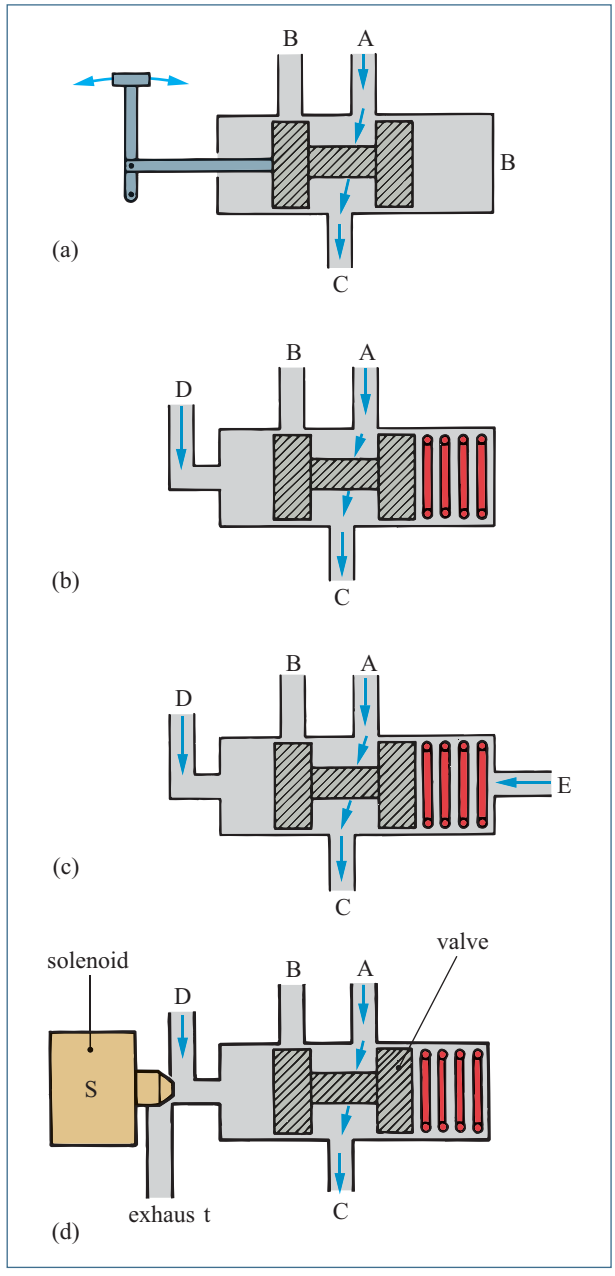


Figure 29.6 Basic control valve (a) manually operated (b) operated by fluid pressure at D (c) operated by fluid pressure at D but spring force can be varied by fluid pressure at E (d) solenoid used to operate a control valve

29.4.2 Solenoid operation of control valves

Figure 29.7 is a diagram of an electrical solenoid that operates a control valve. When the solenoid coil is de-energised (off), the spring holds the plunger down so that the tapered valve is on its seat and flow of fluid is blocked. When the solenoid coil is energised by the electronic control unit of the transmission, the plunger is attracted into the coil to open the valve so that fluid can pass. The solenoid in Figure 29.6(d) operates in this way.

Handy hint: Like most spool valves, flow control valves have no seals—they rely on an extremely low valve-to-bore clearance .

29.4.3 Pressure regulator valve operation

Figure 29.8 shows a simple pressure regulator valve, which operates as follows:

1 Fluid under pressure from the pump enters passage A and passes over the head of the valve into the system through passage B. The fluid pressure also acts against the head of the valve (D).
2 Surplus fluid from the pump that is not needed to maintain system pressure is exhausted to the oil pan, or to the pump intak e through the return passage C.

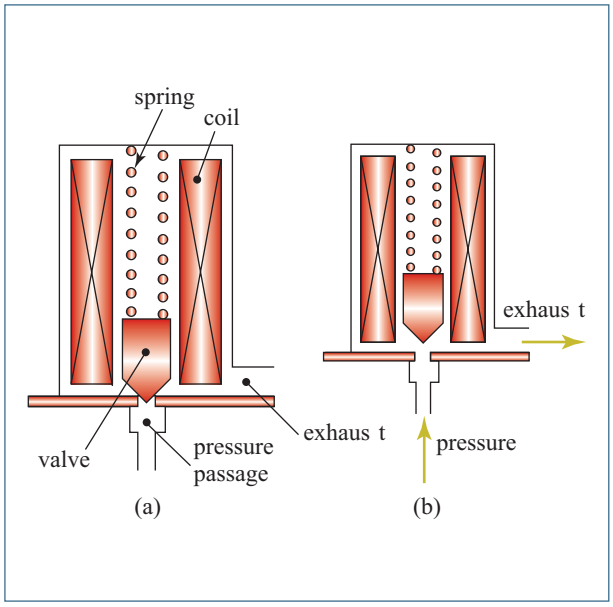


Figure 29.7 Solenoid operation (a) solenoid de-energised (off) and valve closed (b) solenoid energised (on) and valve open

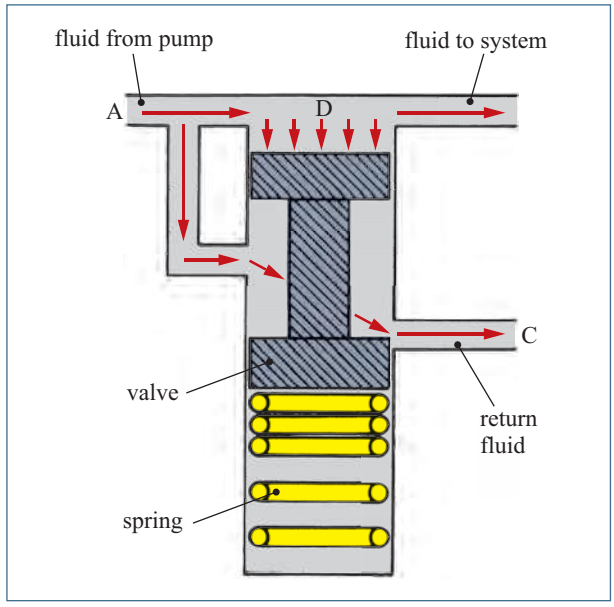


Figure 29.8 Operation of a simple spool-type pressure regulator valve

3 The valve is balanced in its bore by spring force on one end and fluid force on the other (D). The spring tries to close off the return passage C, while the fluid force tries to k eep it open. The valve will tak e up a position in its bore with these two forces in balance .

4 The position of the valve determines how much the port to the return passage C is open and the quantity of fluid that is exhausted. The quantity of fluid being exhausted determines the regulated pressure in the system.

If the strength of the spring is increased, the valve will move upwards to close off the return passage C so that less fluid is exhausted and the pressure is increased. If the spring is weakened, the port will open further and the pressure will drop; the fluid pressure is determined by the strength of the spring.

Handy hint: Valves of this type , which are balanced between spring force and fluid pressure , are referred to as balanced valves .

29.4.4 Check valves and restrictions

Figure 29.9 shows fluid flow under different conditions. Steel and Teflon balls are used as check valves. (A check valve is a small ball resting on a seat which acts as a one-way valve.) When fluid flows in one direction, the ball is lifted from its seat to allow it to flow; when it tries to flow in the opposite direction, the ball is forced back onto its seat to block it.

Restrictions and orifices reduce fluid flow, decreasing the pressure in the part of the system beyond the orifice. There must be some restriction in a hydraulic system to create pressure. Fluid delivered

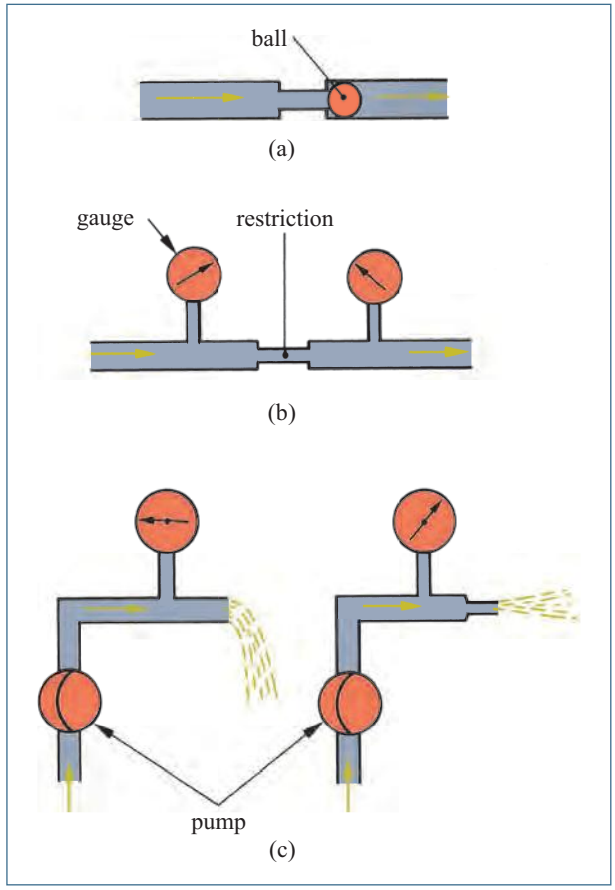


Figure 29.9 Fluid flow under different conditions (a) ball check valve (b) pressure on each side of a restriction (c) effects of a restriction on pump pressure

straight from an oil pump will have virtually no build-up of pressure, but there will be a large flow. However, if the outlet is restricted, there will be less fluid flow and pressure will build up ahead of the restriction. This effect is shown in Figure 29.9(c).

29.5 Hydraulic system diagram

The arrangement of the oil pump, valves and passages form the hydraulic system. Its main parts can be easily identified in the actual transmission, but not the individual passages. For this reason, hydraulic circuit diagrams appear in workshop manuals. (Figure 29.15 is an example of a hydraulic circuit diagram.)

A simplified circuit diagram is shown in Figure 29.10. This is a block diagram with the parts shown as symbols and the fluid passages as single lines. This diagram enables the relationship of the various parts to be clearly seen. The diagram does not represent the transmission as operating in any particular gear or under any particular condition. However, the arrows show how pressure fluid is applied to the valves and the direction in which it would flow when the valves operate. Figures 29.22 to 29.25 and 29.27 show how the hydraulic system provides the various gears.

29.6 System components: oil pumps

The oil pump operates whenever the engine is running, taking fluid from the oil pan and delivering it to the primary regulator valve. There is a filter at the pump intake to prevent entry of foreign material. The oil pan acts as a reservoir for automatic transmission fluid, which drains back to it after being circulated through the system.

Handy hint: Running the engine with low , or no , fluid in the transmission will damage the oil pump .

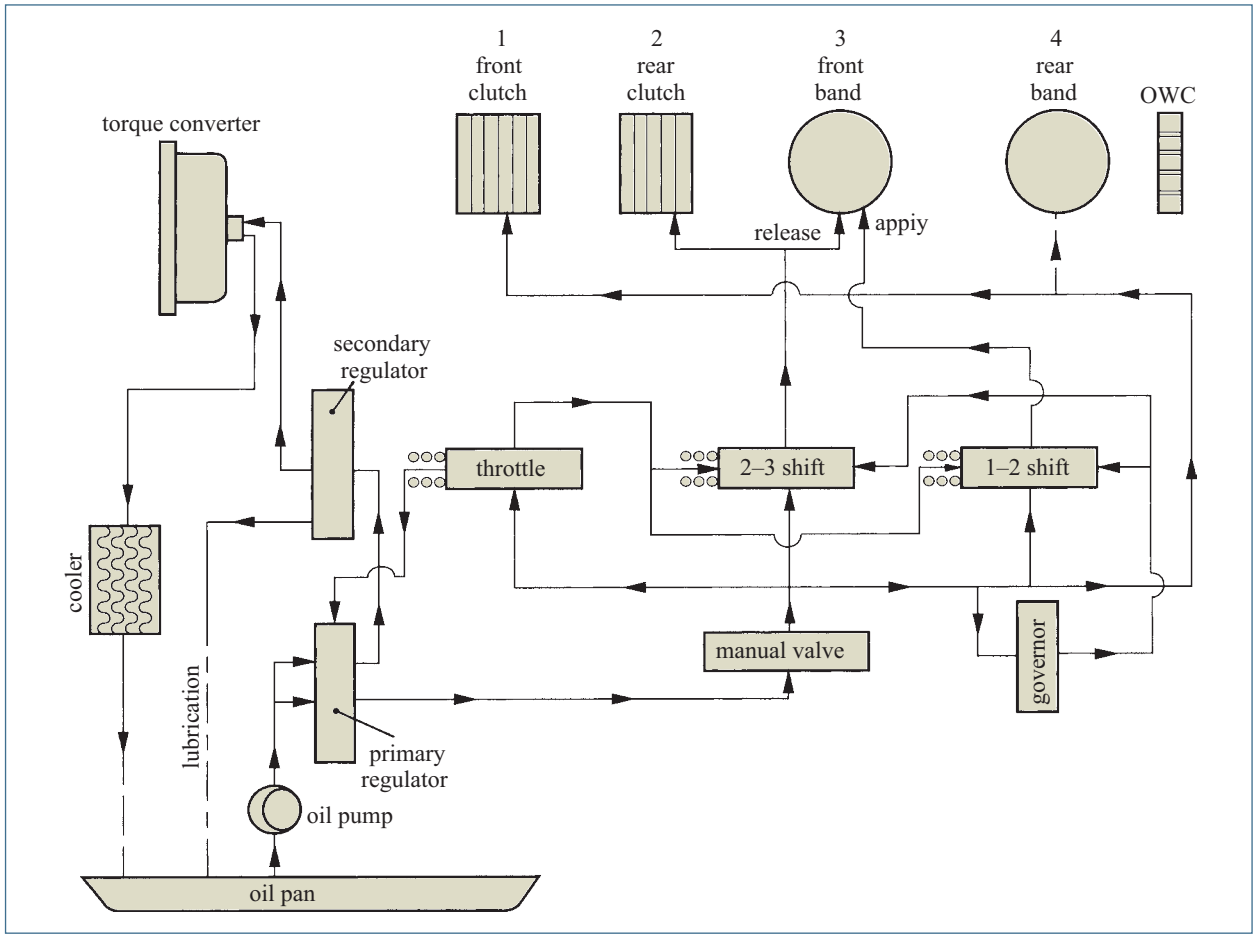


Figure 29.10 Simplified hydraulic circuit—the lines represent fluid passages and the arrows show the direction in which fluid flows

29.6.1 Crescent oil pump

Figure 29.11 shows a gear-type oil pump that is referred to as a *crescent pump*. The outer gear has internal teeth which mesh with the external teeth of the inner gear. The crescent-shaped land between the gears gives the pump its name.

The inner gear is driven by lugs on the torque converter, so the pump is driven whenever the engine is running. Fluid is taken in through the intake and carried around between the teeth and the crescent to be discharged from the discharge port (Figure 29.12). A pressure-regulator valve in the valve body regulates pump pressure.

Handy hint: Pumps with gears, such as crescent pumps, are constant-displacement-type pumps .

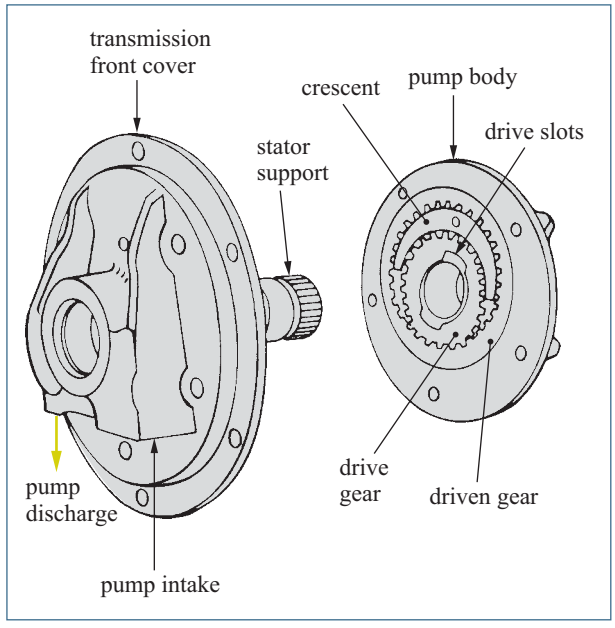


Figure 29.11 Crescent-type gear pump for an automatic transmission FORD

29.6.2 Vane oil pump

Figure 29.13 shows a type of vane pump called a *variable-displacement pump*, meaning that the size of its pumping chamber can be varied. The pump output is not directly related to speed, as is the case with gear pumps.

The pump has a rotor with slots for the vanes, which rest against the guide rings. The outer edges of the vanes operate against the slide and not directly against the pump body. Fluid taken into the pump is carried around between the vanes and the slide, and is discharged through the outlet port.

The displacement of the pump can be varied by moving the slide in the body. When it is moved to the left, the pumping chamber is increased; when it is moved to the right, the chamber is decreased.

Handy hint: Regulating the volume of fluid being pumped also regulates the pressure in the system.

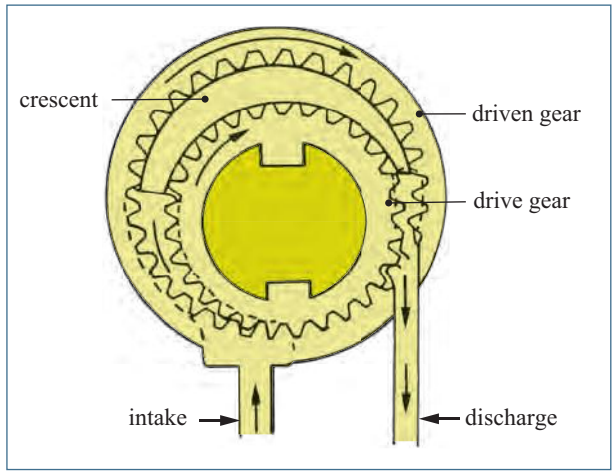


Figure 29.12 Operation of a crescent-type oil pump

Pump regulation

When the engine is stopped, the priming spring pushes the slide towards the side of the body and increases the size of the pumping chamber. When the engine is started, the pump provides line pressure to the system and to the regulator valve (Figure 29.14).

When specified line pressure is reached, the regulator valve directs fluid pressure to the space between the slide and the pump body. The pressure against the slide opposes the spring force and reduces the size of the pumping chamber. This reduces pump output and, consequently, line pressure.

With a variable-displacement pump, only the volume required is being pumped, so energy is being conserved. A constant-displacement pump, such as a crescent pump, could pump more fluid than is needed.

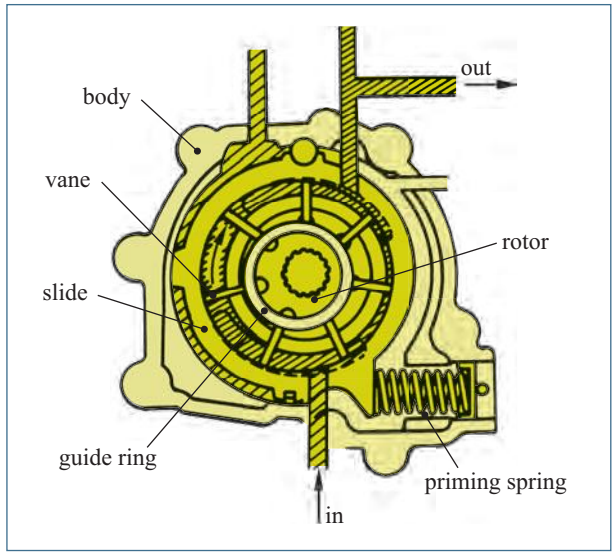


Figure 29.13 Parts of a vane-type oil pump GM HOLDEN LTD

29.7 Hydraulic system: valves

The main parts of the hydraulic system can be seen in Figure 29.15. The valves are shown in their true shape and can be identified in the illustration. Some valves are an essential part of the hydraulic system, while other valves are used as refinements. As previously indicated, there are two general types of hydraulic valves—control valves and regulator valves. Their operation is covered under the following headings.

29.7.1 Primary regulator valve

The primary regulator valve is the main pressure-regulating valve in the system. It takes the fluid under pressure from the pump, passes sufficient fluid on to the system to maintain the system pressure, and exhausts the surplus fluid back to the oil pan through the return line.

Fluid in the system beyond the primary regulator valve is at regulated pressure (called *line pressure* or *control pressure*). Line pressure is directed to the manual valve for redistribution to other valves and components.

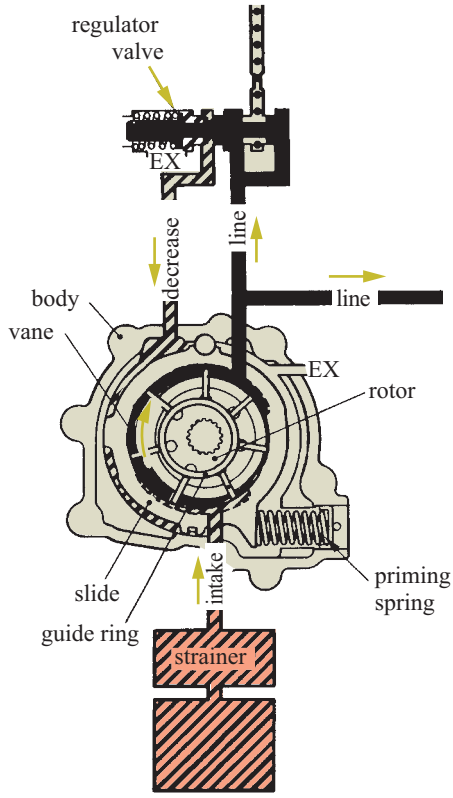


Figure 29.14 Vane-type pump and its pressure-regulator valve GM HOLDEN LTD

Safety: Pumps have to be regulated, otherwise an increasing volume of fluid would be forced into the system. Excessive pressures would be created and components would be damaged.

29.7.2 Secondary regulator valve

Fluid from the primary regulator valve is directed to the secondary regulator valve, which provides *converter pressure* for the torque converter. The fluid passing from the torque converter is directed to the oil cooler in the radiator. Some fluid from the secondary regulator valve is used to lubricate various parts of the transmission.

29.7.3 Manual valve

The manual valve is the system's main control valve. It is connected to the driver's selector lever so that P, R, N, D, 2 or 1 can be selected. Line pressure from the primary regulator valve is blocked at the manual valve when the selector lever is in N or P, but can pass the valve when the selector lever is moved to D, 2, 1 or R.

29.7.4 1–2 shift valve

Shift valves are control valves that are moved by fluid pressure to apply or release bands or clutches to make upshifts or downshifts. With hydraulic controls, governor pressure is used. With electronic controls, it is pressure controlled by a solenoid valve.

In Figure 29.15, line pressure is blocked by the 1–2 shift valve when the transmission is in low gear until governor pressure causes it to move. When this occurs, line pressure reaches the apply side of the front servo, giving second gear. When governor pressure drops, the 1–2 shift valve will return to its original position and the transmission will downshift to low gear.

29.7.5 2–3 shift valve

The 2–3 shift valve controls the gearshifts between second and third gears. It operates in a similar manner to the 1–2 shift valve. In the illustration, the 2–3 shift valve allows the line pressure to apply the rear clutch and release the front band.

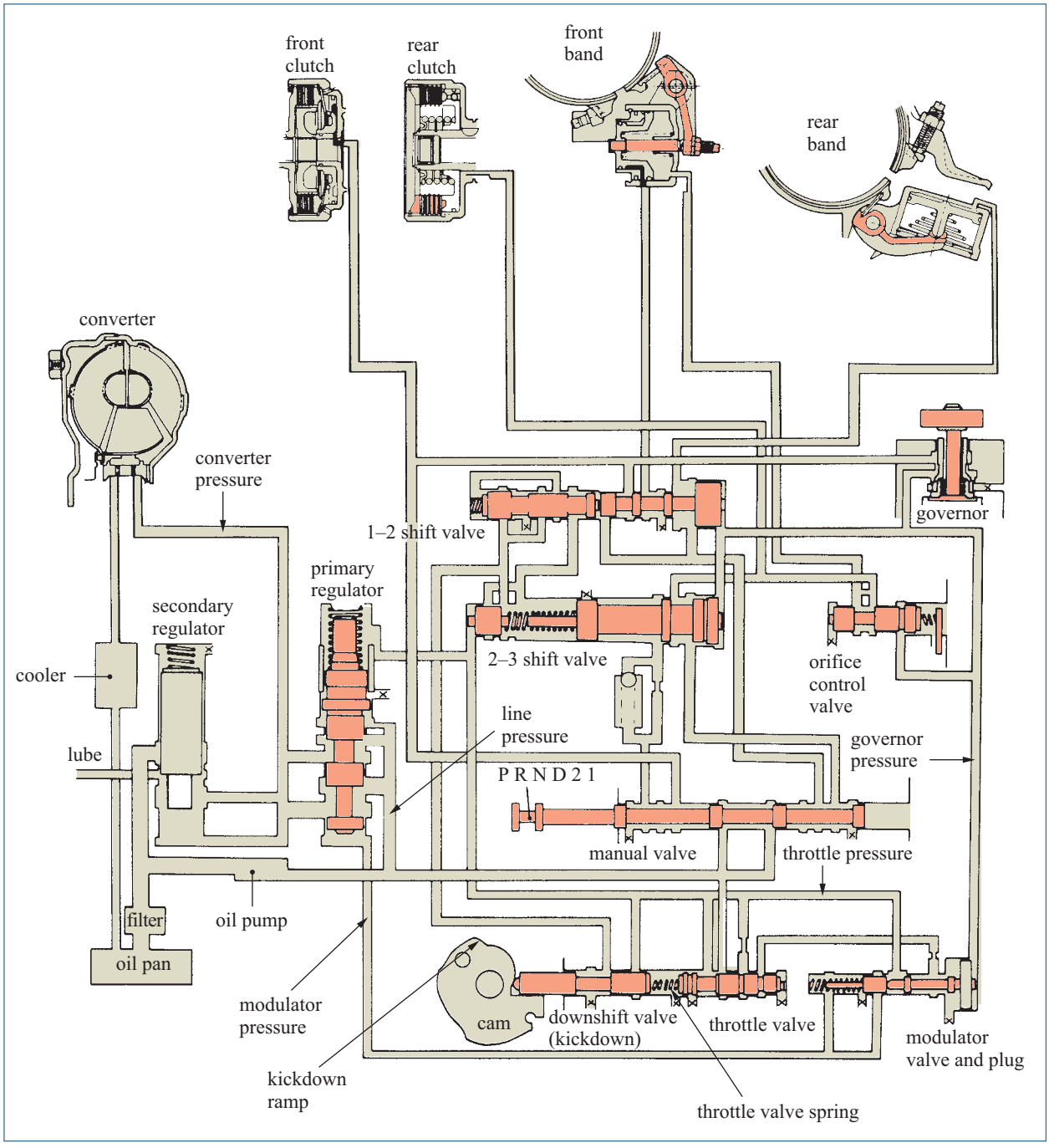


Figure 29.15 Schematic diagram of the hydraulic system of an automatic transmission

29.7.6 Throttle valve

This is a regulator valve operated through the accelerator pedal. A cable is often used between the throttle linkage and the transmission, but vacuum control is also used. The throttle valve provides throttle pressure which increases with throttle opening.

Throttle pressure versus governor pressure

Throttle pressure is directed to the opposite end of the shift valve to governor pressure. Throttle pressure opposes governor pressure and tries to keep the gears in the downshifted condition. This opposition causes the gearshifts to occur at varying speeds. For example, at light throttle, when throttle pressure is low, upshifts will occur early; at wider throttle openings, upshifts will be delayed.

Throttle pressure is also directed to the primary regulator valve. This increases line pressure for wider throttle openings. Higher line pressures prevent band and clutch slip under high engine torque.

Handy hint: High engine loads require high pressure in the transmission; light engine loads need a much lower pressure .

Figure 29.15 has a cam-operated throttle valve—the cam is connected to the throttle by a cable. As the throttle is opened, throttle pressure is increased by the cam rotating clockwise. Cam rotation pushes the downshift valve to the right against the throttle valve spring, increasing the throttle pressure.

29.7.7 Downshift or kickdown valve

The downshift valve is operated when the accelerator pedal is pushed down to the floor. The kickdown ramp on the cam forces the downshift valve to move (to the right in the illustration), directing throttle pressure into the kickdown passage. The kickdown passage directs the pressure to the 2–3 and the 1–2 shift valves to make a forced downshift.

29.7.8 Modulator valve

The modulator valve is responsible for varying the setting of the primary regulator valve and the secondary regulator valve for different operating conditions. The bands and clutches must be applied with sufficient force to prevent slip, and this requires a high line pressure. However, with light operating conditions the pressure can be reduced to conserve engine power.

For similar reasons, the converter requires a high pressure to prevent slip under heavy loads, but it can operate at a lower pressure under lighter loads. Control of the pressure in the converter and the system is by the action of the modulator valve.

The modulator valve in Figure 29.15 is influenced by both throttle pressure and governor pressure and reduces the former in accordance with a rise in the latter. The resulting pressure is called modulator pressure, and this is directed to the end of the primary regulator valve opposite the spring. The modulator pressure pushing on the primary regulator valve causes line pressure reduction as the governor pressure is increased. That is, as the speed of the vehicle increases, the value of the line pressure decreases.

29.7.9 Orifice control valve

This is a control valve used in conjunction with an orifice. It is located in the front servo release passage and controls the flow rate of fluid to the release side of the servo. This controls the speed at which the band is released.

When the valve is in one position, fluid can pass freely through it, but when it is moved, fluid is blocked by it and can pass only through the orifice. This reduces the fluid flow and causes the band to release more slowly than before.

Valves of this type assist with the timing of the gearshift. If a band or clutch is applied too soon, the transmission could bind up. If a band or clutch is applied too late, slipping could occur, resulting in *engine flare* during the gearshift. (An orifice control valve is shown in Figure 29.15.)

29.7.10 Control valve body and valves

Most of the valves in an automatic transmission are contained within a valve-body assembly. Figure 29.16 shows a dismantled valve-body assembly with the main valves identified. The fluid passages in the valve body are actually cast channels and drillings. Some of these can be seen in the lower half of the assembly, on the right of the illustration. The lower half of the assembly has been separated from the upper half to expose the passages which are formed in the casting.

29.8 Hydraulic system: governors

Governors used with hydraulic controls produce a pressure (governor pressure) that is related to road speed. Transmissions that have electronic controls do not have a governor, although they do have a sensor that conveys information about road speed.

29.8.1 Hydraulic governor

The governor is a regulator valve. The governor shown in Figure 29.15 is driven by the output shaft so that it provides pressure in direct proportion to road speed. Governor pressure is directed to the right-hand end of the shift valves. As road speed increases, governor pressure will increase and move the 1–2 shift valve

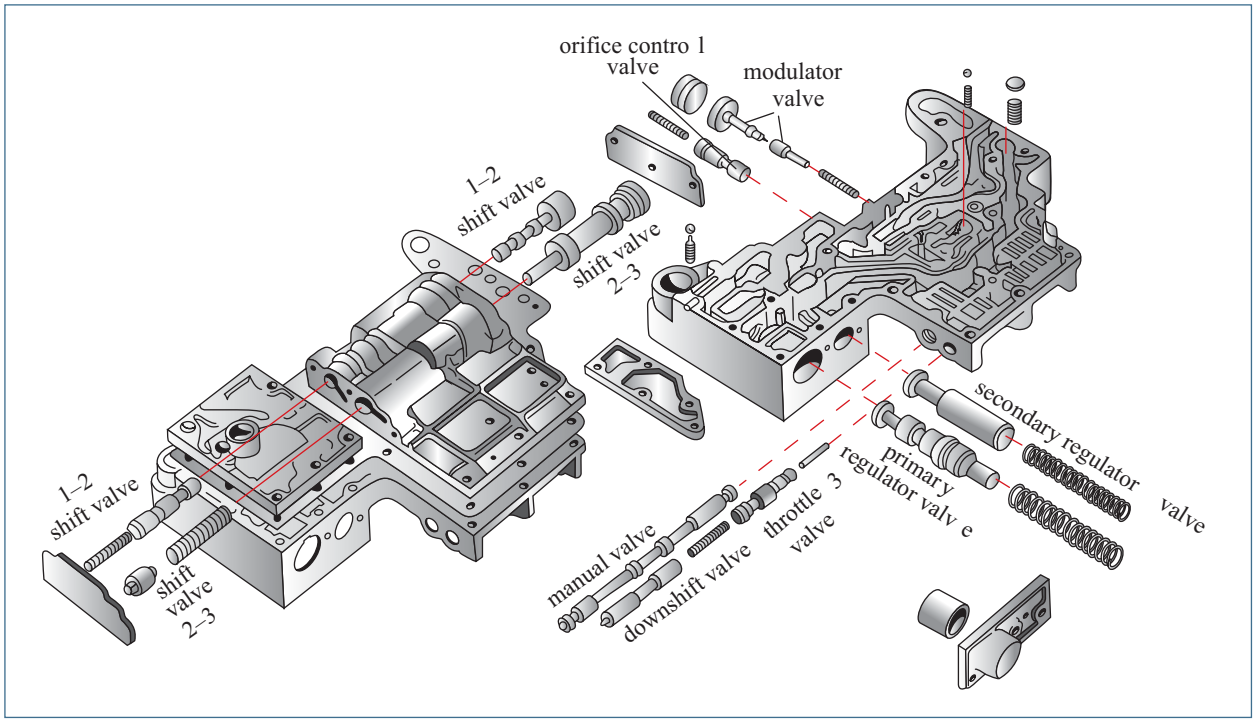


Figure 29.16 A control valve-body assembly with the main valves shown

to the left to cause an upshift to second gear. As the pressure rises further, governor pressure will move the 2–3 shift valve to the left to cause an upshift to third gear and so on.

Handy hint: Increases in governor pressure will produce upshifts and decreases in pressure will produce downshifts.

Governor operation relies on centrifugal force produced by its rotational speed. In rear-wheel-drive transmissions, the governor is mounted on the output shaft and rotated with the shaft. In transaxles, the governor often has its own shaft and is usually driven from a gear on the output shaft. In both cases, the governor rotates only when the vehicle is moving.

Operation of a governor

A basic governor on an output shaft is shown in Figure 29.17. Passages in the shaft and governor body carry fluid to and from the governor valve. Line pressure from passage 1 is regulated by the governor to become governor pressure in passage 2.

With the vehicle stationary, line pressure is blocked off by the land of the governor valve, but as the vehicle begins to move, the governor is rotated and centrifugal force acts on the valve to move it outwards. This opens the port of passage 1 so that fluid passes the edge of the valve land to become governor pressure in passage 2.

The land of the valve will progressively open the port as governor rotational speed increases and an

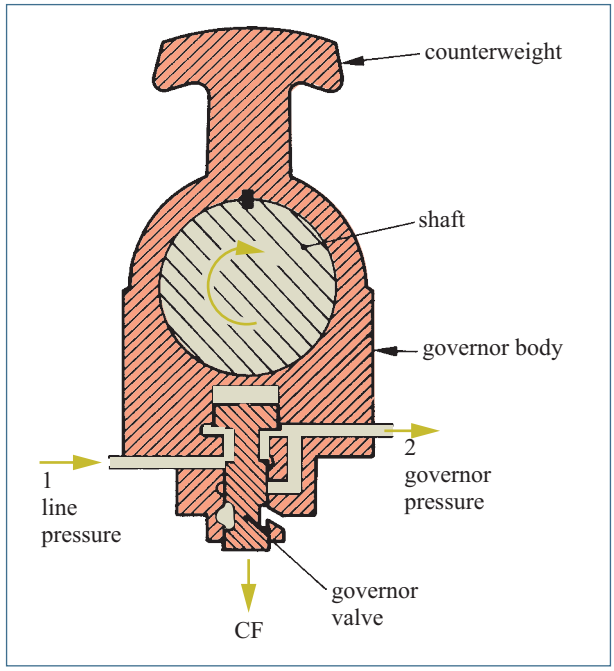


Figure 29.17 An automatic transmission governor provides governor pressure in relation to road speed (CF = centrifugal force)

increasing quantity of fluid will pass through the valve to provide an increasing governor pressure.

29.8.2 Flyweight governor

Figure 29.18 illustrates another type of governor. It consists of a shaft with a gear, two check balls, a primary flyweight and spring, and a secondary flyweight and spring. The weights are pivoted at the top of the shaft and held outwards by the springs. This, through lever action, holds the check balls on their seats. When the vehicle is moving, centrifugal force acting on the flyweights provides additional force to hold the balls on their seats. Governor pressure is determined by the amount of fluid that passes the balls.

At low road speeds, centrifugal force on the flyweights will not be very great, and fluid pressure will lift the balls off their seats. Fluid will be exhausted from the governor circuit, so low governor pressure will be provided. At higher road speeds, centrifugal force will be much greater, and the balls will be held harder against their seats. Less fluid will be exhausted and so governor pressure will rise, increasing with road speed.

The governor just described is a two-stage governor—the primary weight is heavier than the secondary weight, so the primary weight is more sensitive at low road speeds.

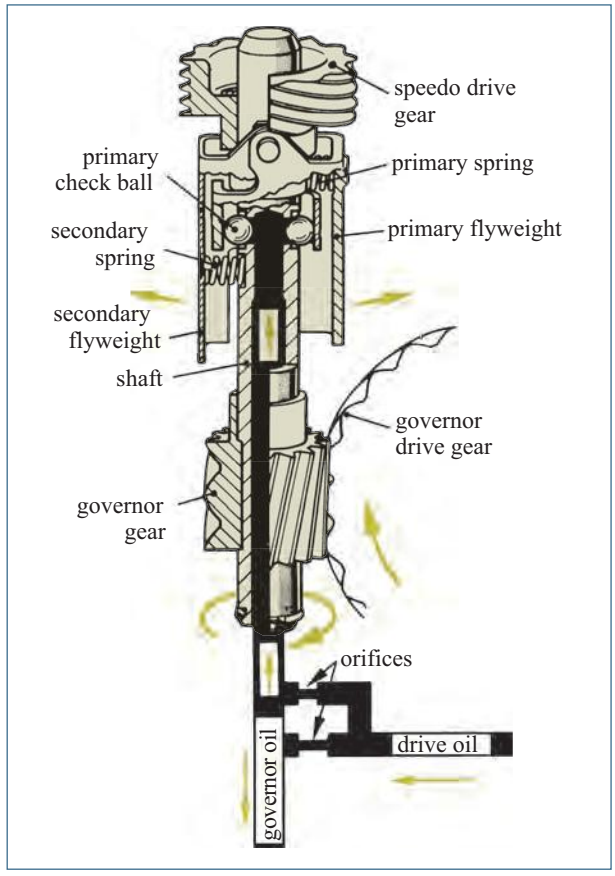


Figure 29.18 Transaxle governor with weights
GM HOLDEN LTD

Handy hint: If the governor becomes inoperative, upshifts will not occur.

29.9 Hydraulic actuators

The line pressure in the system applies the bands and clutches to provide the various gear arrangements. Servos and pistons are used for this purpose. These vary in design, and some examples are covered under the following headings.

29.9.1 Servos and brake bands

Brake bands are operated by servos. Some increase their force by means of a lever, others act directly against the band. Figure 29.19 shows a direct-acting servo. It consists of a cylinder with a piston that operates against the band. When fluid pressure is directed by the control valve to the piston, the band is applied to hold a part of the planetary gear set stationary. When the fluid supply to the piston is cut off, the spring in the cylinder will force the piston back so that the band is released. Figure 29.15, shows a single-acting servo on the rear band, which is applied by fluid pressure through a passage from the 1–2 shift valve.

Handy hint: The band can be applied or released by controlling fluid pressure from the shift valve.

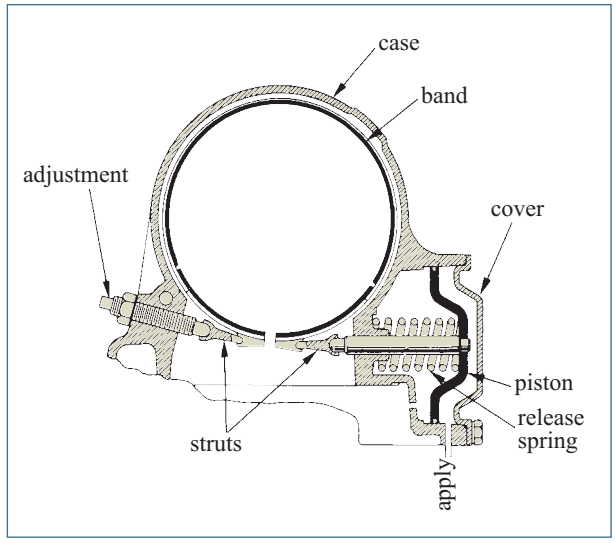


Figure 29.19 Single-acting servo and band assembly—pressure to the servo applies the band FORD

Double-acting servo

Figure 29.20 shows a servo which has a double-acting piston. The band is applied by fluid pressure directed to the apply side of the piston in a similar manner to a single-acting servo, but the method of release is different.

The pressure can be directed to either side of the piston. The areas of the two sides of the piston are not the same size, the release side being larger than the apply side. The servo can be controlled in the following ways:

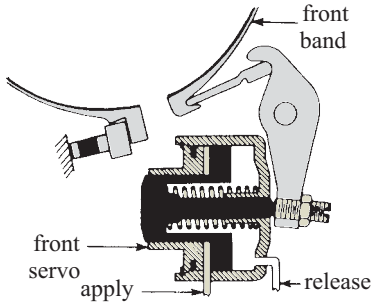


Figure 29.20 Servo with a double-acting piston and apply and release sides FORD

1 When fluid pressure is directed to the supply side , it overcomes the return spring and applies the band.
2 When this pressure is exhausted, the return spring moves the piston to release the band.
3 With pressure to the apply side of the servo applying the band (as for point 1), pressure to the larger release side will provide a greater force to release the band.
4 If pressure is being applied to both sides of the piston, and the pressure is exhausted from the release side , the band will be reapplied by the pressure on the apply side .

The front band in Figure 29.15 is controlled by a double-acting servo, which is applied by fluid pressure from the 1–2 shift valve and released via the orifice control valve.

Handy hint: The operation of this servo is a good example of how basic hydraulic principles can be applied.

29.9.2 Multiplate clutch

A multiplate clutch has a cylinder with a ring-shaped or annular piston and a return spring (Figure 29.21). Fluid pressure on the piston forces the clutch plates together to apply the clutch. When the fluid is exhausted, the clutch is released and the large return spring returns the piston back into its cylinder.

The clutch connects parts of the planetary gears. The fluid under pressure reaches the clutches through oil holes and passages in the transmission shafts. Referring again to Figure 29.15, the front clutch is supplied with fluid pressure by the manual valve and the rear clutch from the 2–3 shift valve via the orifice control valve. In some transmissions and transaxles, a form of multiplate clutch is used as a brake to hold a part of the gearing stationary. This performs a similar function to a servo and band.

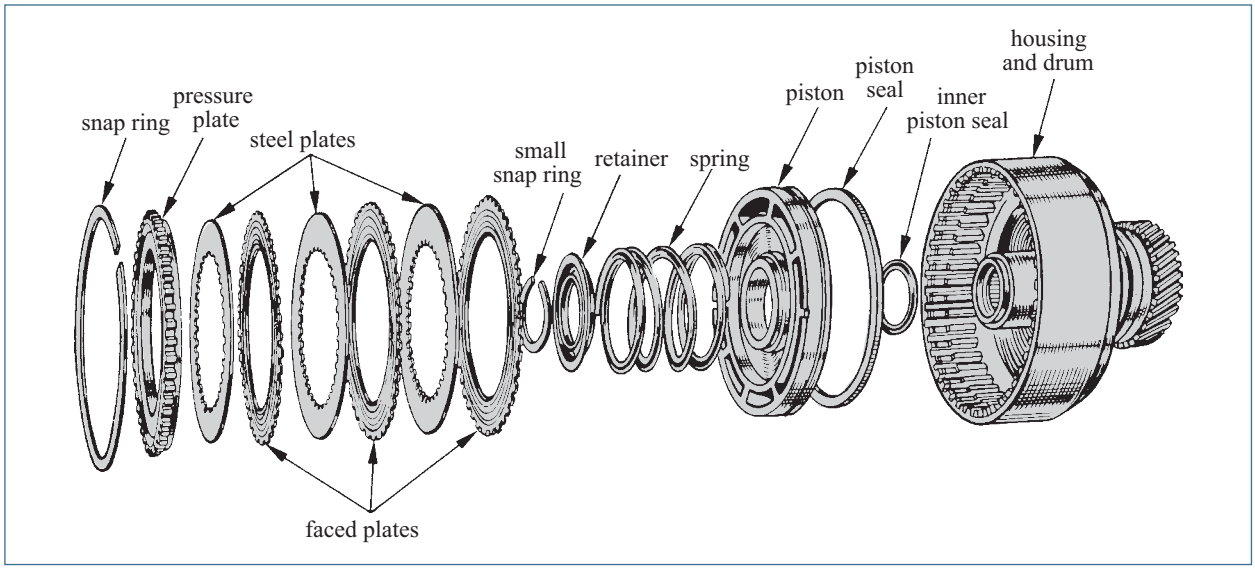


Figure 29.21 Exploded view of a rear clutch MITSUBISHI

29.10 Hydraulic circuit diagrams

To understand the hydraulic system, the fluid flow must be considered for the different gearshifts. A series of basic circuit diagrams for a three-speed transmission will be used, showing the parts as symbols and the passages as single lines. The diagrams contain only the main valves. There are others, but these have been omitted for simplicity.

The hydraulic system applies bands and clutches to obtain the gear required. For the diagrams, they are applied as shown in Table 29.1.

29.10.1 Neutral and park

For neutral and park, the hydraulic system operates as follows (Figure 29.22).

1 With the engine running, the oil pump will deliver fluid to the primary regulator valve . This regulates pump output to provide line pressure . In neutral and park positions, line pressure is block ed off at the manual valve so that there are no bands or clutches applied and no gear ratio .
2 Fluid from the primary regulator valve is directed to the secondary regulator valve , which provides converter pressure . The secondary regulator valve also provides fluid which lubricates the various parts of the transmission before dropping into the oil pan.
3 Fluid circulating through the torque converter gains heat and is tak en from the converter to the cooler , usually located in the lower radiator tank. Heat is extracted from the fluid as it passes through the cooler and returns to the oil pan. This means that some of the fluid is always being cooled.

Table 29.1 Bands and clutches applied

Ratio	Applied	
1st	Front clutch	Rear band or one-way clutch
2nd	Front clutch	Front band
3rd	Front clutch	Rear clutch
Reverse	Rear clutch	Rear band

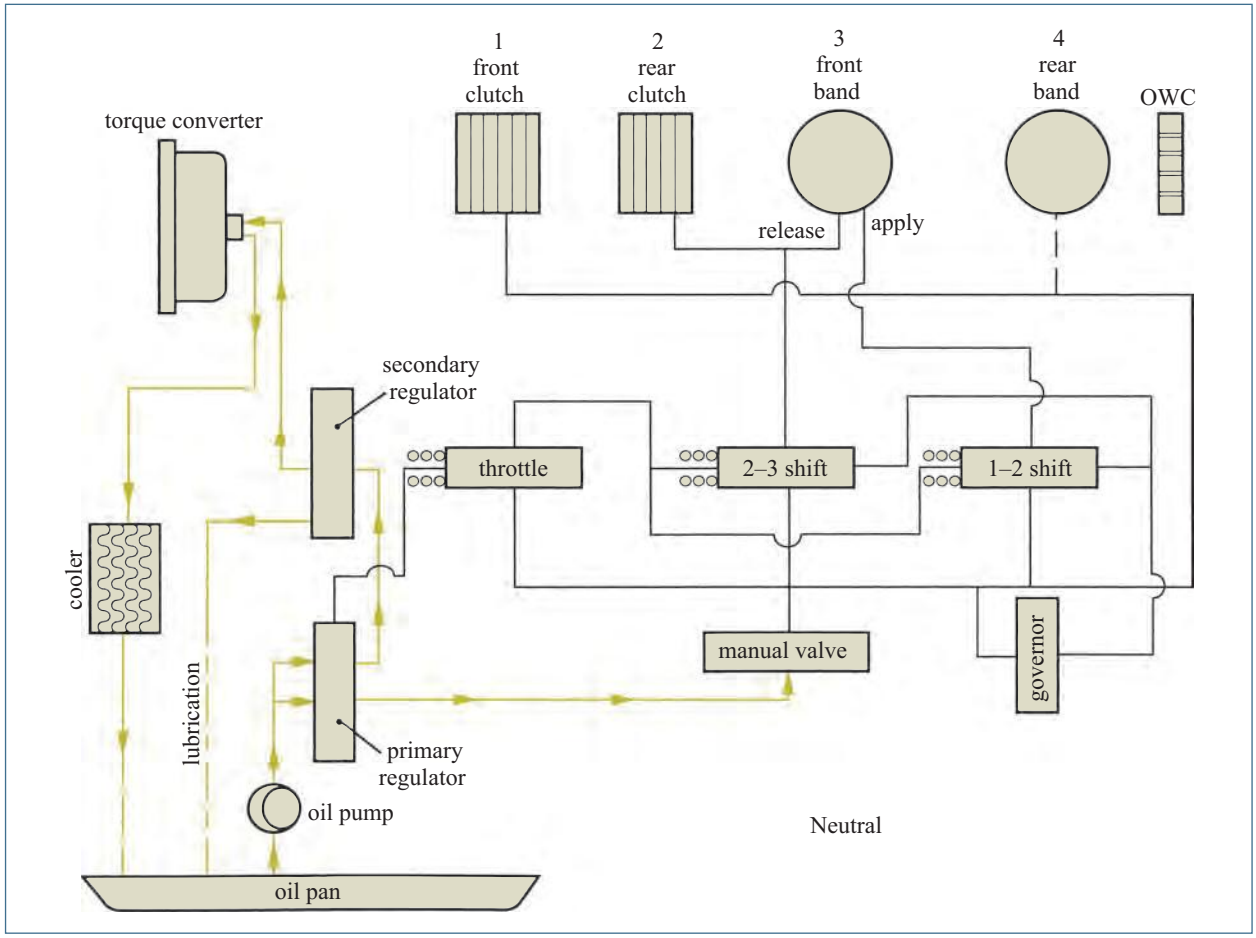


Figure 29.22 Hydraulic system for neutral: the parts of the circuit that are functioning are in colour—the manual valve blocks the flow to most of the system

29.10.2 First gear

If D is selected, the transmission will shift into first gear and automatically change to second and then third as the road speed increases (Figure 29.23). If 1 is selected, the transmission will remain in first gear.

For first gear, the hydraulic system operates as follows.

1 When D is selected, the manual valve is moved to allow line pressure to pass to the front clutch. With the front clutch applied and the one-way clutch locked, the transmission is in first gear.
2 The one-way clutch automatically locks under load to hold the planet carrier stationary for first gear. It automatically unlocks when the load is removed in second gear.
3 When 1 is selected instead of D, the manual valve allows line pressure to reach the rear-band servo, and this, instead of the one-way clutch, holds the planet carrier. With the band applied, the transmission will be held in first gear and will not be allowed to upshift.
4 Line pressure is also directed to other valves at this time so that they are ready for use when needed. These are the throttle valve, the shift valves and the governor valve. The governor will provide pressure when the vehicle starts to move, and the throttle valve will provide pressure when the accelerator is pressed.

29.10.3 Second gear

For second gear, the hydraulic system operates as follows (Figure 29.24):

1 As road speed increases, governor pressure against the end of the 1–2 shift valve increases until the shift valve moves. This allows line pressure to pass through the 1–2 shift valve to the apply side of the front servo. This applies the front band for second gear. The front clutch is also needed, but this has already been applied in first gear.
2 Throttle pressure is also directed to the 1–2 shift valve, but to the opposite end to governor pressure. The shift valve now acts as a type of relay valve, its movement being influenced by both throttle and governor pressure.

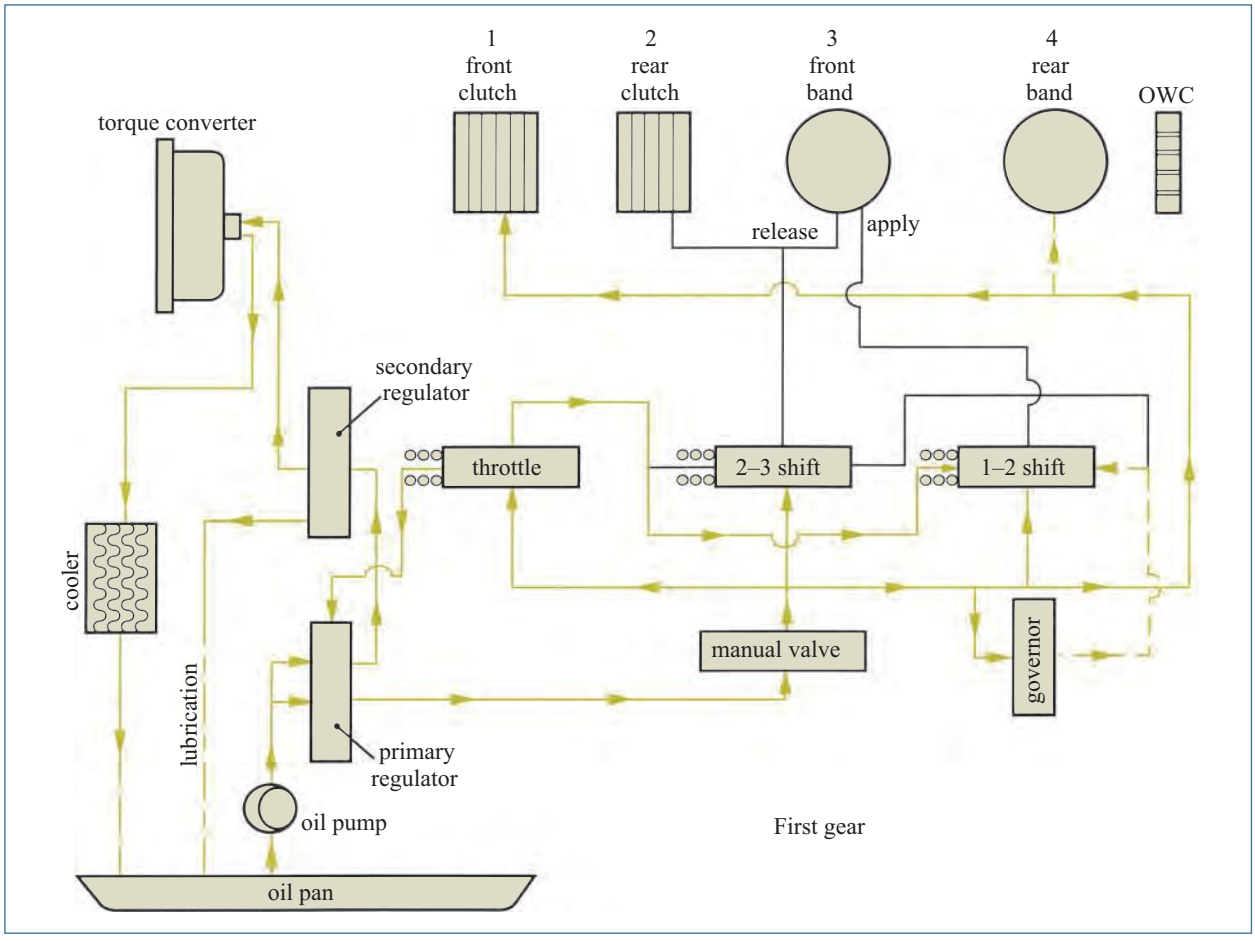


Figure 29.23 Hydraulic system for first gear—the manual valve has been moved to allow pressure to the front clutch and to the valves

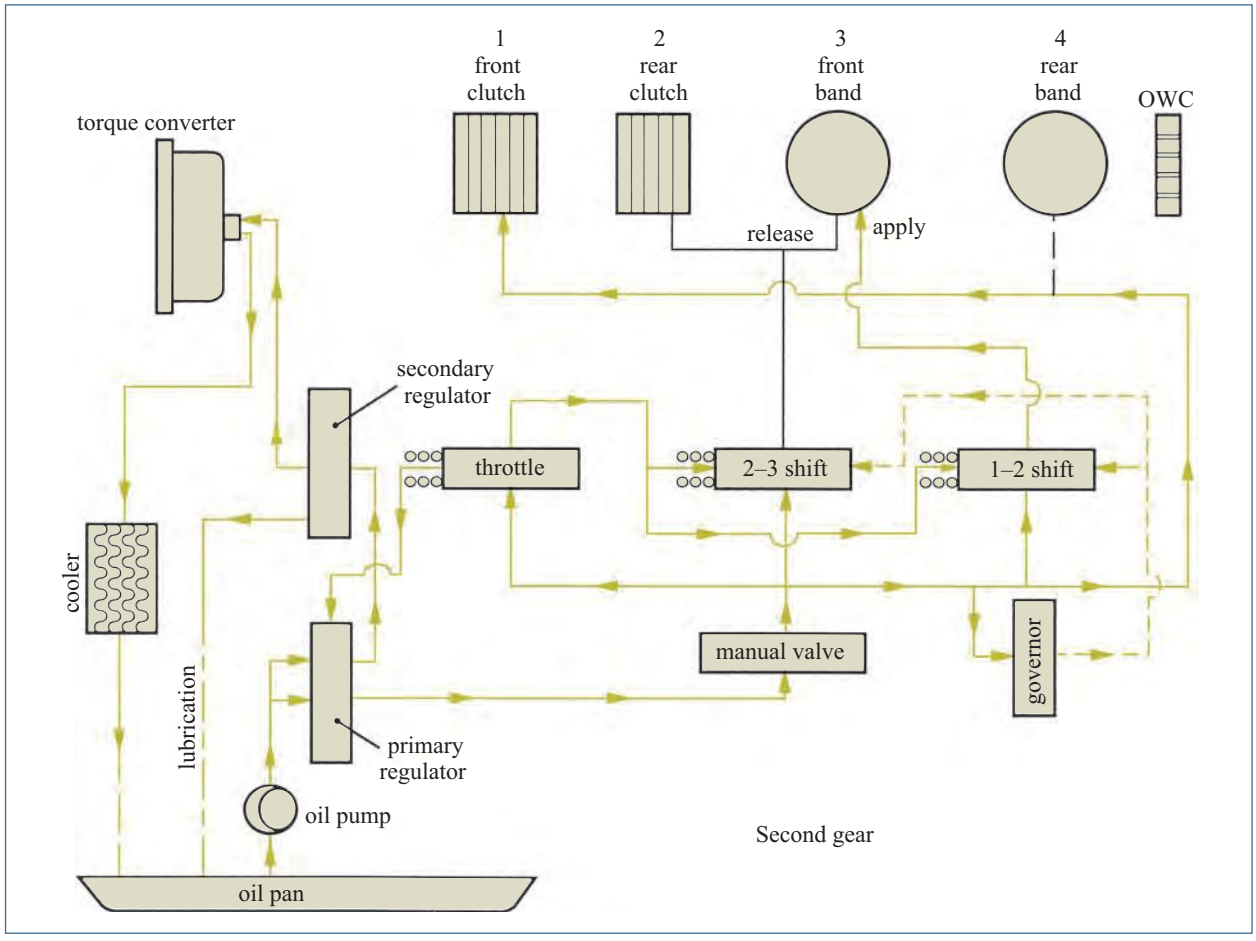


Figure 29.24 Hydraulic system for second gear—governor pressure has moved the 1–2 shift valve to apply the front band

3 At light throttle openings, throttle pressure will be low and governor pressure high, so upshifts will occur at low road speeds. At wider throttle openings, throttle pressure will be higher than governor pressure, so upshifts will be delayed and will occur at higher road speeds.
4 Downshifts are the reverse of upshifts. When governor pressure drops, the spring will move the shift valve back to its original position to cut off line pressure from the servo and release the band. Downshifting will also be affected by throttle pressure.

29.10.4 Third gear

For third gear, the hydraulic system operates as follows (Figure 29.25):

1 Governor pressure and throttle pressure operate on the 2–3 shift valve in the same way as on the 1–2 shift valve. At the right road speed, governor pressure will move the 2–3 shift valve to allow line pressure to reach the rear clutch, which is needed for third gear.
2 At the same time, line pressure is also directed to the release side of the front servo to release the band because it is no longer required. The servo is double-acting, with the release side larger than the apply side, so the pressure does not have to be released from the apply side to release the band.
3 The gearshifts can occur over a wide range of road speeds (controlled by the governor) and according to the driver's desires (controlled by the accelerator). Downshifts occur in the opposite manner to upshifts.
4 Kickdown, or forced downshifts, will occur when the accelerator is pushed fully down to produce high throttle pressure.

Handy hint: The transmission will not kick down unless the accelerator is providing full throttle.

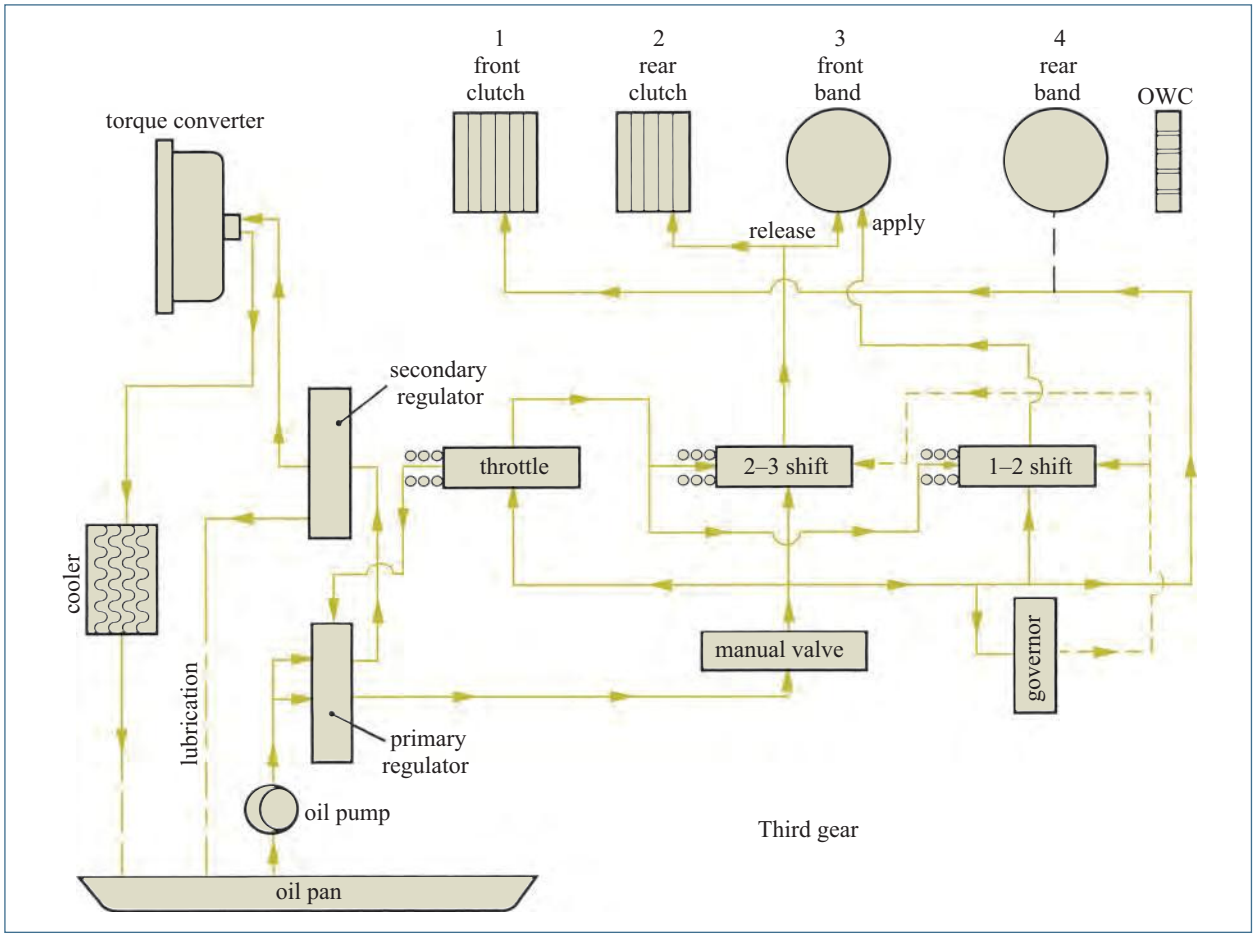


Figure 29.25 Hydraulic system for third gear—governor pressure has released the front band and applied the rear clutch

29.10.5 Reverse

For reverse, the hydraulic system operates as follows.

1 When R is selected, the manual valve is moved so that line pressure reaches the rear clutch and the rear servo . When these two are applied, the gearing provides reverse .
2 The hydraulic circuit for reverse is similar to that for neutral, ex cept that there is pressure in the rear clutch apply and front band servo release circuit.

29.11 Electronic control of transmission

While all automatic transmissions have some degree of internal hydraulic control, the external signals required for gearshift control can be provided electronically. Automatic transmissions with electronic control use a wide range of sensors whose inputs are processed by an electronic control unit (ECU) sending signals to the transmission. These energise and de-energise solenoids which actuate the hydraulic valves.

Handy hint: The transmission can have its own ECU , but transmission control is often a function of the power control module (PCM).

29.11.1 Basic hydraulic circuit with electronic control

Figure 29.26 shows a basic hydraulic circuit with electronic control. The diagram is similar to those used above for a transmission without electronic control; the fluid flow can be followed on this diagram in the same way. The diagram has a solenoid for each shift valve and one for the pressure-regulator valve. S1 will be used as an example of how the solenoids can operate:

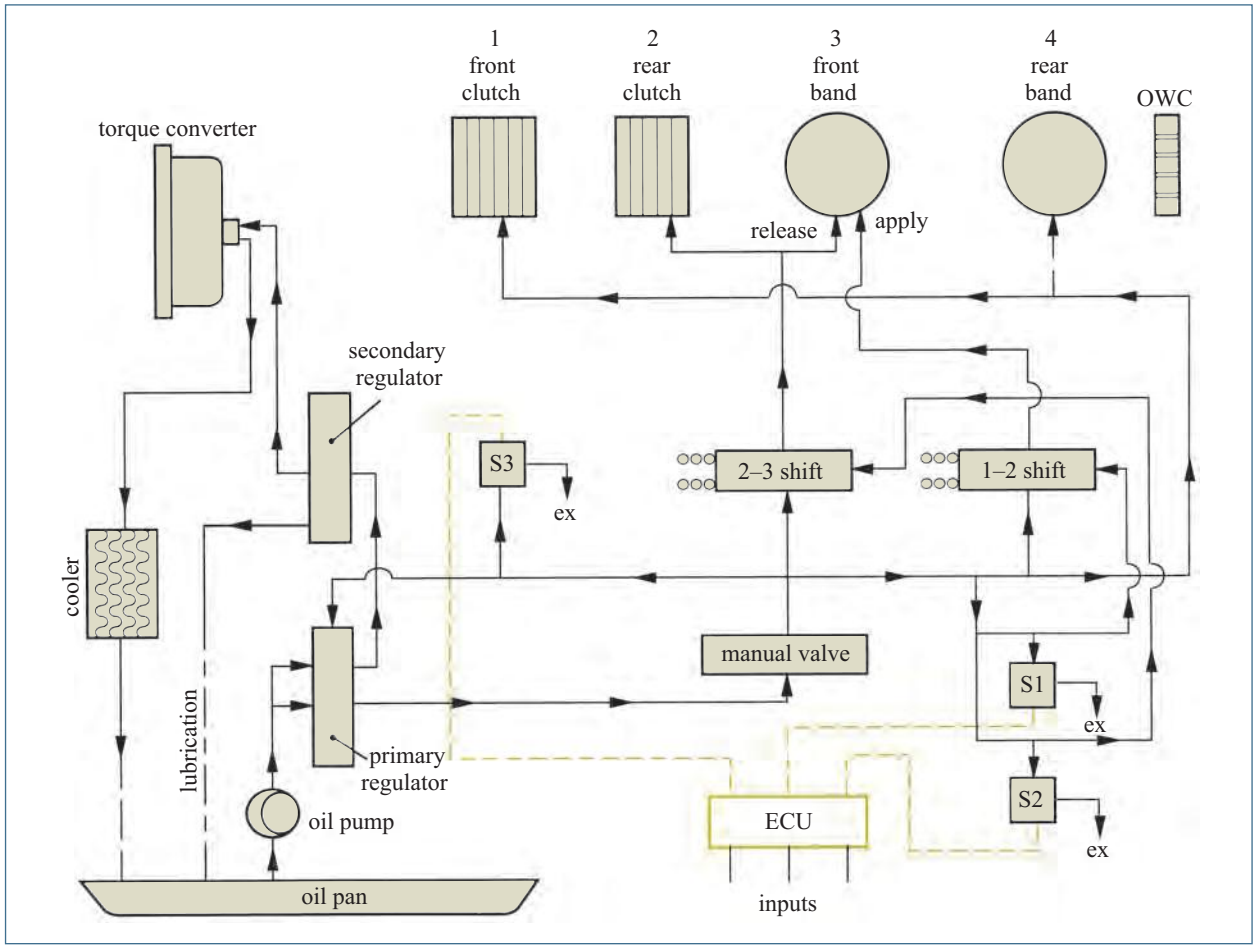


Figure 29.26 Basic hydraulic circuit with electronic control: arrows show the direction in which fluid flows (ECU = electronic control unit, S = solenoid)

1 The solenoid S1 is normally off and its valve closed. Pressure builds up in the line to the end of the 1–2 shift valve, and this pressure holds it against the spring and prevents fluid passing to the apply side of the front servo.
2 When the time is right for an upshift to second gear, the ECU sends a signal to the solenoid S1. This energises the solenoid and opens the solenoid valve.
3 Pressure in the line is exhausted through the solenoid valve and the spring takes over to move the shift valve.
4 The shift valve now allows fluid to pass to the apply side of the servo. This causes an upshift from first to second gear.

The operation of solenoid S2 can be checked in a similar way in relation to the 2–3 shift valve. Only three speeds are shown. For four speeds, a 3–4 shift valve and solenoid would be needed.

The regulator valve has its own solenoid. This can be switched off or on by the ECU and can also be made to pulse. Each provides a different fluid pressure against the end of the regulator valve, producing a different regulated (line) pressure in the system.

29.12 Electronic control systems

An electronic control system is shown schematically in Figure 29.27, together with a skeleton illustration of the mechanical parts of a transaxle. The diagram shows a number of sensors which provide input signals to the ECU. The ECU provides output signals that operate the solenoids in the valve body. The solenoids control the valves for shift timing, shift quality and the operation of the converter clutch.

A description of the operation of the parts of the system follows.

29.12.1 Electronic control unit (ECU)

The transmission can have its own ECU or can be controlled by the same unit that operates the engine's electronic fuel-injection system. The ECU is usually under the dash (Figure 29.28). In some transmissions, its functions are provided by the power control module (PCM).

The ECU includes a signal processor which receives input signals from the various sensors. It may boost signals or modify them to make them more suitable. The input signals are compared with the data in the memory. The control unit then sends output signals to operate the solenoids.

Handy hint: The ECU can also be called the electronic control module (ECM), power control module (PCM) or transmission control module (TCM).

29.12.2 Sensors

The sensors provide information to the ECU on the vehicle's operating conditions and the driver's requirements continuously while the vehicle is operating. The number and types of sensors vary with different transmissions.

Throttle-position sensors

The sensor can be on the throttle body or at the accelerator pedal (Figure 29.29). It is either a variable resistor or a switch with contacts. It sends the computer a signal that indicates the throttle opening, throttle position and rate and direction of movement.

Pulse generators

Pulse generators on the transmission produce weak electrical signals (pulses) related to road speed. They are used for timing the upshifts and downshifts.

Engine-speed sensor

A connection to the low-tension side of the ignition system provides pulses that are used as a signal for engine speed. Alternatively, there could be a sensor on the crankshaft.

Vehicle-speed sensor

Most transmissions have a vehicle-speed sensor attached, but others have a sensor at the back of the speedometer. This consists of a reed switch and a rotating permanent magnet. Rotation of the magnet operates the reed switch which produces pulses related to road speed.

Coolant-temperature sensor

This sensor is fitted into the water-jacket of the engine. It provides a temperature signal which enables the control unit to compensate for hot or cold engine conditions.

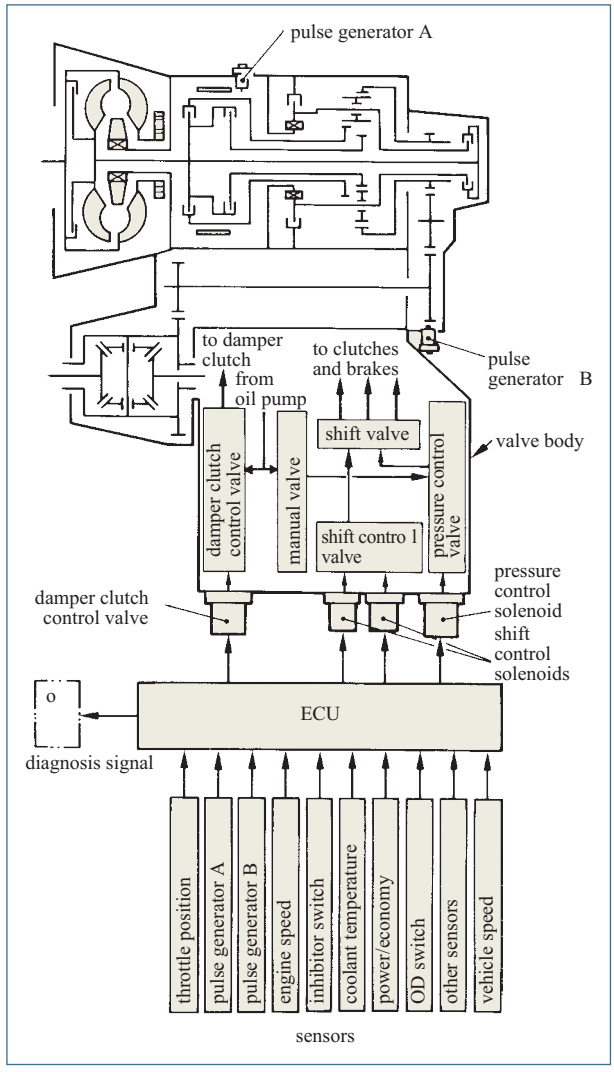


Figure 29.27 Schematic arrangement of the electronic control of an automatic transaxle MITSUBISHI

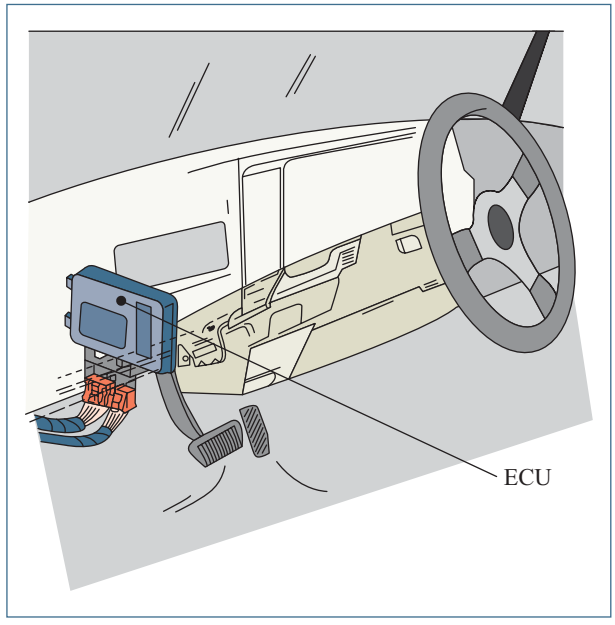


Figure 29.28 An electronic control unit is mounted under the dash

Other sensors

Other sensors that are used with electronic control are as follows:

1 Converter turbine-speed sensor . Located near the transmission input shaft, it is used with the engine-speed sensor to monitor and control converter clutch slip . In conjunction with the output-shaft speed sensor , it monitors and controls shift duration and quality . This sensor is often a pulse generator .
2 Output-shaft speed sensor . Located on the output shaft of the transmission, it is used with the turbine-speed sensor to monitor clutch and band slip.
3 Fluid temperature sensor . A sensor in the transmission oil pan which allows the ECU to monitor the fluid temperature .
4 Brake sensor . Using a sensor in the braking circuit, the ECU receives signals when the brakes are applied.
5 Air-conditioning sensor . Located in the air-conditioning circuit, it informs the ECU of the status of the air-conditioning compressor .

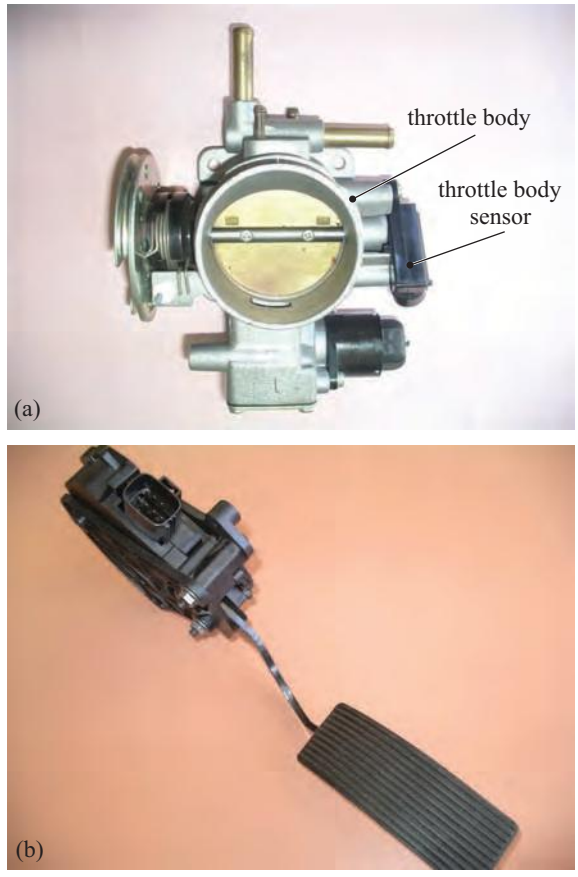


Figure 29.29 (a) The throttle-position sensor , attached to the throttle body , senses the throttle opening (b) The accelerator position sensor attached to the accelerator pedal

29.12.3 Isolator switch

The isolator switch on the transmission is operated by the selector linkage. It prevents the engine from starting in any position other than N or P. With electronic control, it also signals the selector position to the control unit. The control unit needs this information to know whether gearshifts are required or not.

Handy hint: This switch is also known as an inhibitor switch or a transmission range sensor .

29.12.4 Overdrive switch

An overdrive switch is located on or near the driver's selector lever (Figure 29.30). It is an on–off switch that gives the driver the option of using fourth gear. When switched off, the computer will not upshift to fourth gear. The switch also operates an indicator lamp to show whether the overdrive switch is on or off.

29.12.5 Power and economy modes

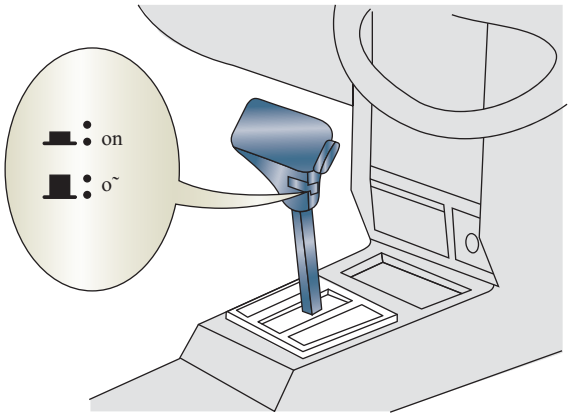
The ECU controls the upshifts and downshifts using the program that is in its memory. The program often has two modes, referred to as the *economy* and *power* modes. These have different shift patterns which can be selected by the driver. (A selector switch is shown in Figure 29.30.)

29.12.6 Solenoids

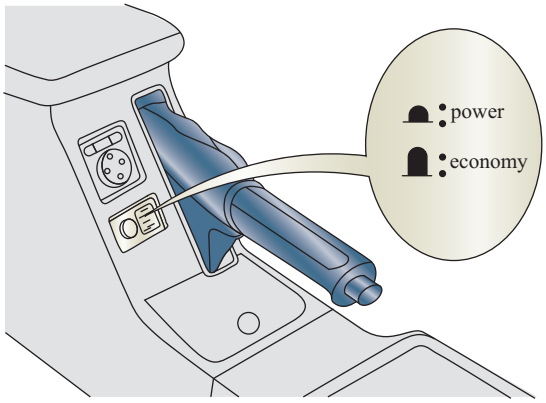
Solenoids are located on the valve body (Figure 29.31). They are on–off valves which close to hold pressure or open to allow flow and relieve pressure. Some solenoids, such as those which control the shift valves, operate either on or off. Others regulate pressure and have a duty cycle, pulsing on and off and varying pressure. The number of solenoids and the way they are applied varies with different transmissions.

29.12.7 Pulse generators

There are different types of pulse generators, but they are all used to generate a very small electrical pulse which can be translated and used by the ECU. Figure 29.32 shows two pulse generators at different places on the transaxle. Pulse generator A is activated by holes in the rotating brake drum,



(a) Overdrive switch



(b) Power/economy switch

Figure 29.30 Selector lever with overdrive switch, and a console with a power-economy switch

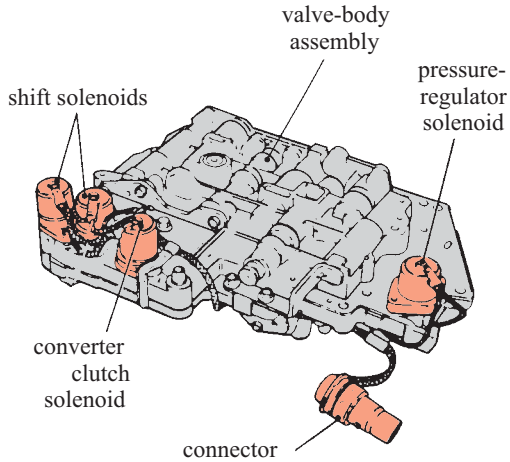
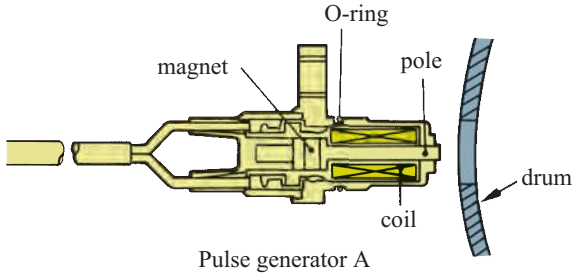
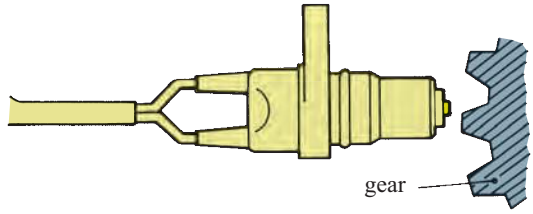


Figure 29.31 Valve-body assembly with solenoids for electronic control MITSUBISHI



Pulse generator A



Pulse generator B

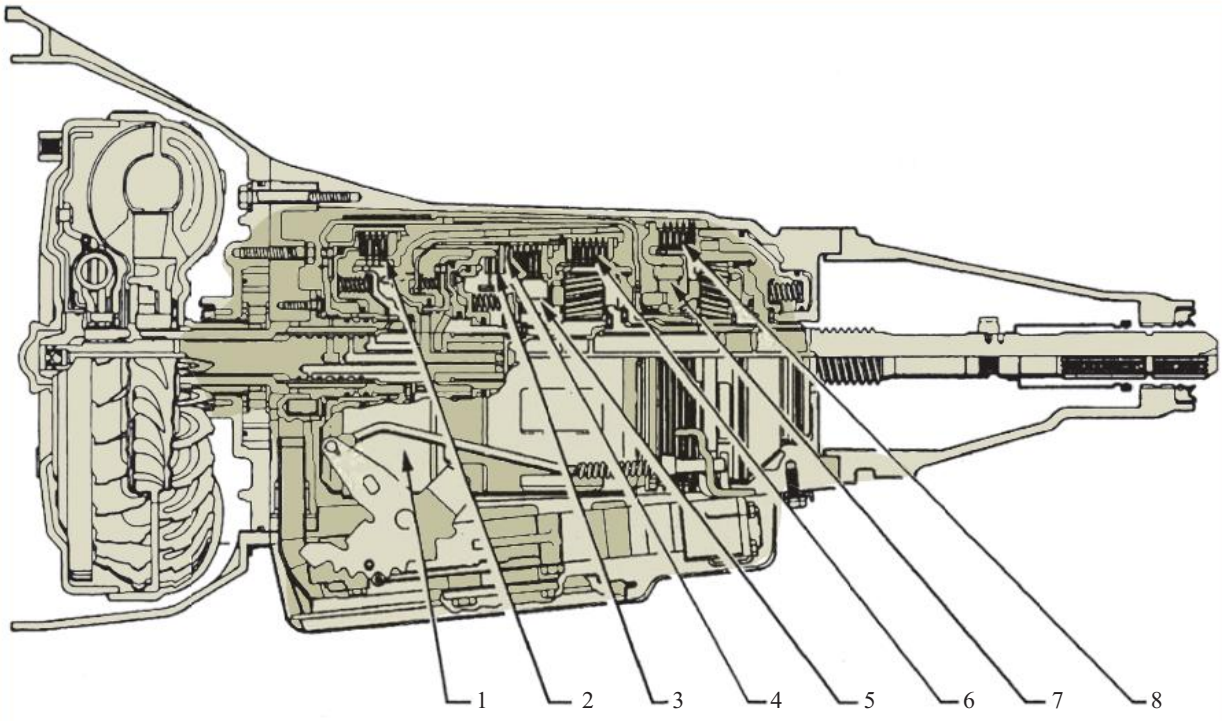
Figure 29.32 Operation of a pulse generator on a transaxle

while pulse generator B is activated by gear teeth. Each time a hole or tooth passes the pole of the pulse generator, the magnetic field of the pulse generator is disturbed, inducing a low-voltage pulse into the coil. The pulses are transferred to the ECU by electrical cables.

29.13 Solenoid-operated shifts

Figure 29.33 shows a transmission with the components that are responsible for gearshifts. These are labelled 1 to 8 on the illustration and are listed below. Some are applied by hydraulic pressure and others lock by reaction when placed under load.

1 2–4 band. Applied by solenoid action.
2 Reverse input clutch. Applied by the manual valve .
3 Overrunning clutch. Applied by torque reaction.
4 Forward clutch. Applied by solenoid action.
5 Sprag clutch. Applied by torque reaction.
6 3–4 clutch. Applied by solenoid action.
7 Low roller clutch. Applied by torque reaction.
8 Low/reverse clutch. Applied by the selector valve .



Range	Gear	Shift solenoid 1–2	Shift solenoid 2–3	2–4 band (1)	Reverse input clutch (2)	Overrun clutch (3)	Forward clutch (4)	Sprag clutch (5)	3–4 clutch (6)	Low/ roller clutch (7)	Low/ reverse clutch (8)
Park		on	on								Applied
Reverse		on	on		Applied						Applied
Neutral		on	on								
D	1st	on	on				Applied	Holding		Holding	
	2nd	o˜	on	Applied			Applied	Holding			
	3rd	o˜	o˜				Applied	Holding	Applied		
	4th	on	o˜	Applied			Applied		Applied		

Figure 29.33 Automatic transmission with gearshift operating components: the table shows the solenoid logic for park, reverse , neutral and D GM HOLDEN LTD

29.13.1 Table of shifts

The table in Figure 29.33 shows which components are applied or released to produce the different gears. Selection occurs by movement of the manual valve to direct pressure fluid to a band or clutch. Changes between ranges occur by the on–off action of the solenoid valves.

For example, when D is selected, the transmission will be in first (1st) because:

1 The manual valve directs pressure fluid to apply the forward clutch, which remains on for all the gear shifts.
2 Both solenoids are on to release the 2–4 band and also the 3–4 clutch (as in neutral).
3 The sprag clutch and the low roller clutch, both one-way clutches, are holding due to the torque reaction of the gearing.

In second (2nd) the 1–2 solenoid will be switched *off* and this will apply the 2–4 band needed for this gear. The low roller clutch will automatically release because it will not be under load. The solenoids will be switched *on* and *off* as required for third (3rd) and fourth (4th) as shown in the table. Switching will apply or release the appropriate band or clutch. The table is an actual example of the solenoid logic for the gear shifts of an electronically controlled transmission. It shows that in D, shifts from first to fourth are performed by just two solenoid valves.

Handy hint: Solenoid logic is a term that is used for the on–off pattern of switching the solenoids.

29.14 Electronic control of converter clutch

The parts of a hydraulic system that operate the converter clutch are the pressure-reducing valve, the clutch control valve and the solenoid. The converter clutch is applied by directing pressure to the rear of the clutch plate and is released by reversing the direction of oil flow. The clutch is shown applied in Figure 29.34. This is a good example of how electronics and hydraulics operate together in a transmission.

29.15 Determining shift points

The ECU controls upshifts and downshifts via a program called the shift map. This is a pre-programmed table which dictates the road speeds at which the transmission will change gear, that is, the *shift points*. Figure 29.35 is one example of a shift map. They are designed to suit the particular transmission and vehicle. The program usually has two maps, the *economy mode* and the *power mode* (sometimes called *sports mode*).

The power and economy modes have different shift patterns. When the transmission is in the power mode, upshifts will occur at higher road speeds than when it is in the economy mode. The diagram shows that the transmission will upshift from 2 to 3 within a range of road speeds and throttle positions.

The economy mode is used for normal driving, while the power mode is used for driving in hilly country or when towing. A switch near the selector lever allows the driver to select either mode. A power mode indicator lamp will light when the transmission is switched to the power mode.

Figure 29.35 shows the shift maps for both power and economy for a 2–3 upshift. For the power mode, upshifts could occur with the throttle opening at any position between A and C and the road speed anywhere between 30 km/h and 80 km/h.

For the economy mode, upshifts could occur with the throttle opening at any position between B and D and the road speed anywhere between 20 km/h and 60 km/h. Only the upshifts are shown; the shift map would also include downshifts.

29.16 Adaptive shift strategy

With only two information sources available, the shift choices that the transmission can make are limited. That is, at a particular throttle opening the transmission will always change up at the same speed. To overcome this limitation some transmissions have an *adaptive shift strategy* which adapts the shift points to suit the driver. Figure 29.36 shows a transmission with five shift maps.

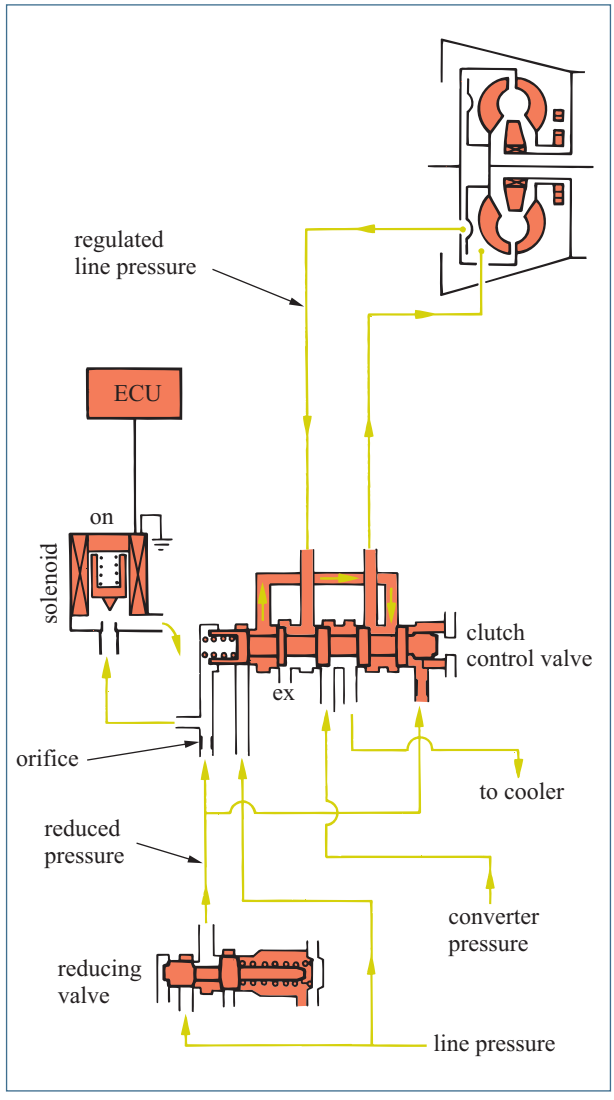


Figure 29.34 Electronic control of a converter clutch—the diagram shows the clutch engaged MITSUBISHI

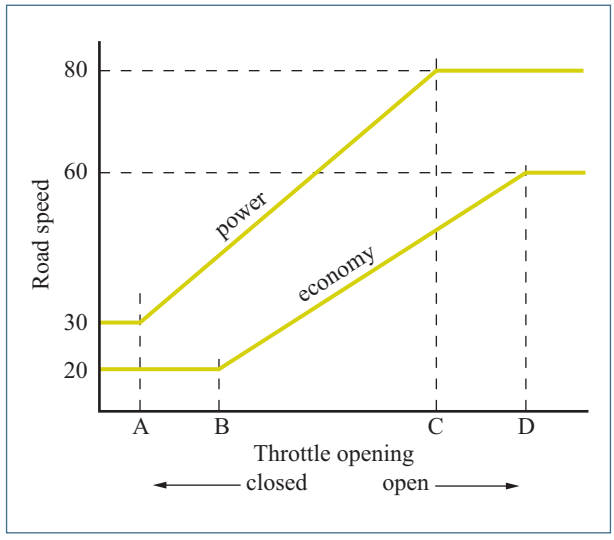


Figure 29.35 Graph representing the shift maps for power and economy modes—only the 2–3 gearshift is shown

Adaptive shift strategy utilises many more parameters than the power/economy system to determine the shift points. Some common parameters include:

1 the position of the throttle at the start of a shift
2 the throttle position against vehicle speed
3 engine speed
4 the speed at which the accelerator is operated
5 the frequency of downshifts
6 the frequency of gears skipped during kick down
7 driving resistances, such as climbing or descending a hill
8 steering wheel turn
9 brak e operation .

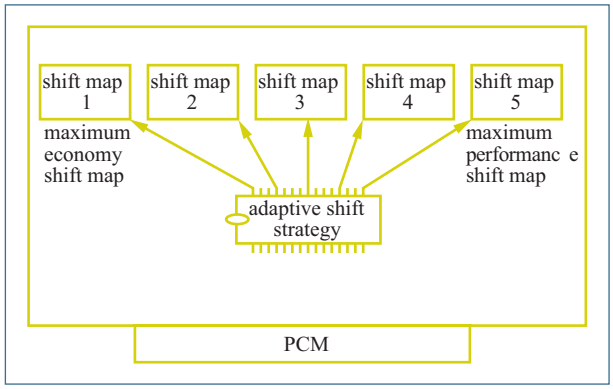


Figure 29.36 An electronic control unit (PCM) with five shift-map options

By continuously monitoring this information, the ECU recognises the combination of these parameters as a distinctive driving style and adapts the gearshift points to suit that style.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain how the hydraulic and control section is designed to select a gear ratio to suit driving conditions, whether the vehicle is under load or at light throttle
- explain the function of oil pumps and why the correct oil pressure is vital in the operation of automatic transmission
- describe how the valve body relies on inputs from road speed and throttle position (load) and then directs fluid to a clutch or brak e band to select the required gear ratio
- describe the operation of electronic control, lock -up torque converters and sensors and actuators which control the shift pattern in the transmission
- explain adaptive shift and how it changes the shift pattern to suit repetitive driving conditions lik e continuous downshifting or hill climbing.

REVIEW QUESTIONS

1 Name the main parts of the hydraulic system.
2 What is a control valve ?
3 What is the purpose of a solenoid valve ?
4 Name two types of oil pumps and explain how one of these operates.
5 What is the function of the manual valve ?
6 What function do shift valves perform ?
7 What is a servo ?
8 Where are servos used?
9 What is a double-acting servo ?
10 What is the purpose of a multiplate clutch ?
11 What is the purpose of the hydraulic control system ?
12 What are sensors ?
13 Name the sensors that are used with automatic transmissions, and state the purpose of each.
14 What is the function of the ECU?
15 What is an isolator switch ?

16 What does PCM stand for?
17 Explain the operation of one type of pulse generator .
18 Name some of the solenoids that are used in an automatic transmission.
19 What is a shift point ?
20 What is a shift map ?
21 What is an adaptive strategy ?
22 What is shift duration ?

CHAPTER 30

Automatic transmission service

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 state the servicing principles of light vehicle automatic transmissions and associated components
2 state the purpose of servicing light vehicle automatic transmissions
3 select correct lubricants for automatic transmissions
4 apply service procedures for light vehicle automatic transmissions
5 correctly diagnose automatic transmission faults.

The many variations in the design of automatic transmissions and transaxles affect dismantling and servicing methods. However , there are some common servicing requirements, and these are covered in this chapter . Reference to the appropriate service manual for each particular transmission is essential.

30.1 Maintenance

Automatic transmissions and transaxles require a regular fluid level check. They also need more detailed service at regular intervals. Some manufacturers specify service on a time and kilometre basis, for example, every three years or 60 000 kilometres; others specify only a time period. However, all manufacturers state that services should be more frequent if the vehicle is operating in adverse conditions. For a passenger vehicle with normal use, where no definite service period is specified, a service every 50 000 kilometres is reasonable.

A service could include draining and replacing the fluid in the transmission and converter, removing and cleaning the oil pan, cleaning or replacing the filter, adjusting the bands and linkage and road testing to check performance.

Increased power and under-bonnet temperatures mean that automatic transmission fluids in modern motor vehicles are subjected to increasingly severe operating conditions. Regular replacement of transmission fluid is more important now because it:

1 removes dirt, metal particles and condensation
2 removes fluid contaminants caused by high fluid temperatures
3 restores the correct balance of additives such as anti-corrosives and detergent/dispersants.

30.1.1 Cleanliness

Cleanliness is essential when working on automatic transmissions. They contain a large number of valves, seals and passages, and any dirt or foreign material in the transmission will cause malfunction and possible damage. The correct type of fluid must be used, and all containers and dispensing equipment must be perfectly clean.

30.2 Checking and changing the fluid

The level of fluid in the transmission is checked with a dipstick. This has full-level and low-level marks and may have different levels marked for hot and cold fluid. The level of the fluid is checked while the engine is idling and at normal operating temperature, with the selector lever in the drive or park position.

Handy hint: Unless the fluid level is check ed by the recommended method, a false level will show on the dipstick.

30.2.1 Checking the fluid level with a dipstick

A typical method for checking the fluid level with a dipstick is as follows:

1. Have the vehicle on a level floor with the transmission at operating temperature .
2. Move the selector lever through all positions and then select P .
3. Allow the engine to idle for about two minutes.
4. With the engine idling, remove the dipstick and wipe it with a non-fluffy rag or clean paper .
5. Insert the dipstick, then withdraw it immediately and check the fluid level.

If the fluid level is low, add the correct type of fluid to bring it up to the full mark, but do not overfill. If frequent topping up is necessary, a leak is indicated. This must be rectified immediately as a low fluid level will cause erratic operation and damage to the transmission. When checking the dipstick, both the level and the condition of the fluid should be checked (see 'Dipstick information').

30.2.2 Checking the level with a level plug

Some transmissions do not have a dipstick, in which case a fill plug should be removed from the side of the transmission to allow the fluid level to be checked and topped up if necessary. Overfilling will occur if the transmission oil level is checked when cold. A scan tool will determine the correct operating temperature of the transmission.

Sustainability: When repairing or servicing an automotive transmission, drain and dispose of waste oil according to regulations. These can be found by contacting your local state government or environmental protection authority .

30.2.3 Fluid change

Some transmissions have a drain plug that enables the fluid to be drained without removing the oil pan (Figure 30.1(a)). Others have no drain plug and the oil pan has to be removed to change the fluid. This allows additional servicing such as filter cleaning or replacement to be carried out.

When the transmission is drained, fluid will also drain from the torque converter. However, it will not drain completely because some fluid remains in the lower part of the converter. When removing an oil pan that has not been drained, leave a bolt in each corner. Loosen the front bolts but unscrew the rear ones a number of turns. The back of the oil pan can be lowered onto the bolts so that most of the fluid can be drained before it is completely removed. The oil pan will probably be stuck to the transmission case and may have to be hit with a rubber hammer to break the joint. Hit the edges or corners so that the oil pan is not damaged.

After the oil pan is removed and before it is cleaned, examine it for deposits (Figure 30.2). The colour of the fluid and the amount and types of deposits in the oil pan and filter will indicate the condition of the

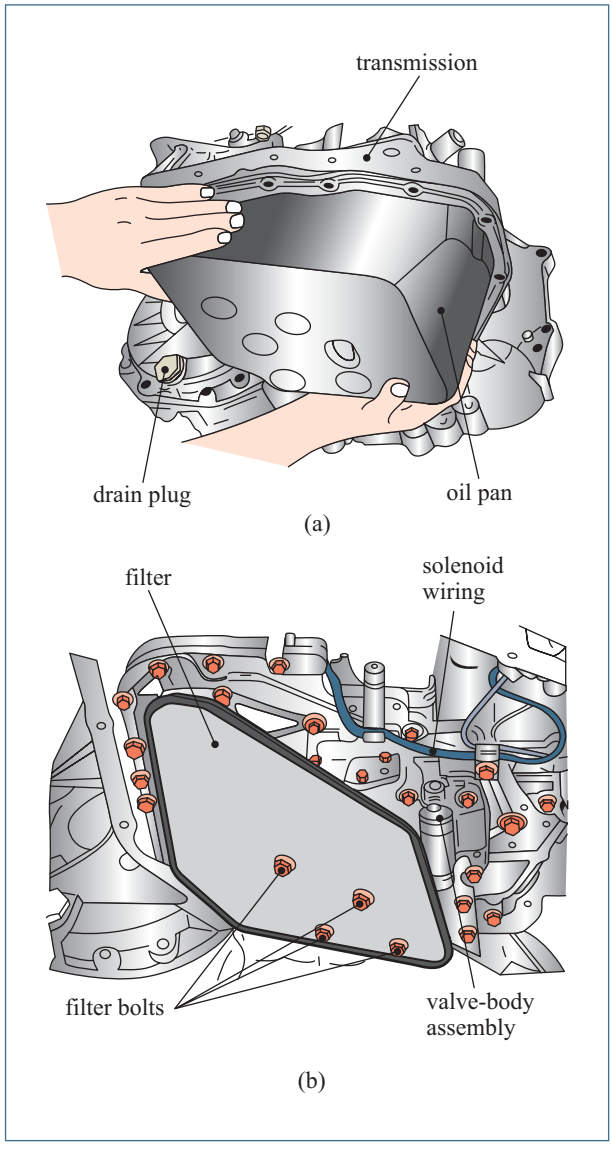


Figure 30.1 Oil pan and filter (a) removing oil pan (b) filter bolted to the valve-body assembly

transmission, particularly the bands and clutches. Most oil pans are pressed sheet steel and can distort from uneven or excessive tightening. If this has happened, straighten the oil pan sealing surface before refitting to avoid oil leaks.

Internal filter

A fluid filter is located underneath the valve-body assembly (Figure 30.1(b)). This filters all the fluid before it enters the oil pump. Some filters are discarded and a new one fitted as part of the transmission service. Other filters have a fine gauze screen which is cleaned, and the filter is then refitted.

⚠ Safety: During normal operation, the fluid in an automatic transmission can reach temperatures of around 200 °C. Take care to avoid being burnt by hot fluid that it is being drained.

External fluid filter

Some transmissions have an external fluid filter of the type fitted to the transaxle in Figure 30.3. This is similar to an engine oil filter. When carrying out a service, the filter is removed and replaced with a new filter.

30.2.4 Refilling the transmission

Figure 30.4 shows the different levels of fluid in a transmission when it is being refilled. After draining the fluid, add an initial quantity of new fluid (approximately two-thirds of the capacity) and then start the engine to allow the converter to be filled. This reduces the level in the transmission. The final fill is made with the engine idling, to bring the fluid level up to the 'full' mark.

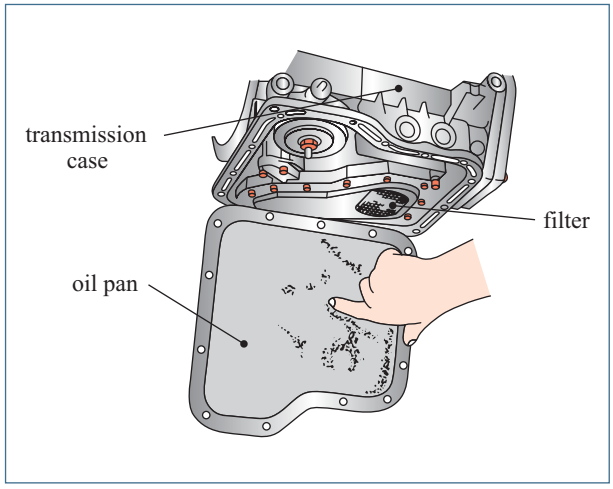


Figure 30.2 Checking for deposits after removing the oil pan GM HOLDEN LTD

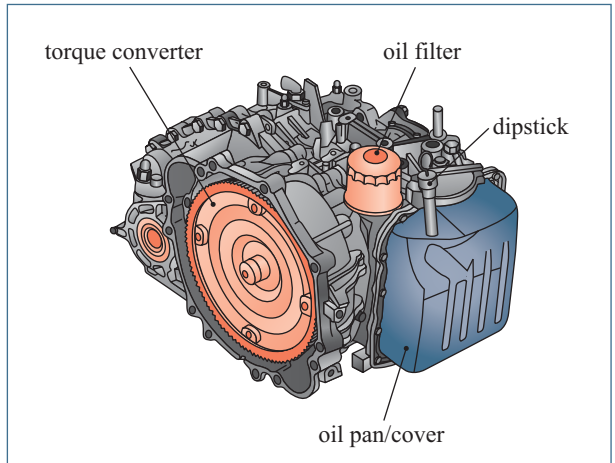


Figure 30.3 Automatic transmission with an external filter

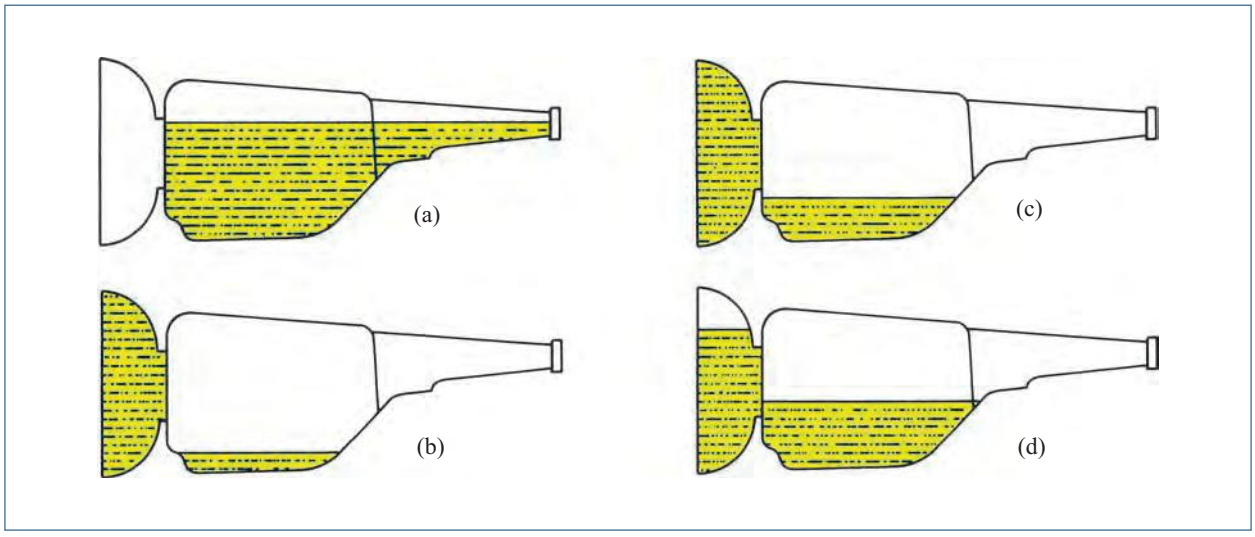


Figure 30.4 Refilling a transmission (a) initial quantity of fluid (overfull) (b) after starting (underfull) (c) after topping up and checking (correct level) (d) after engine has been stopped for a period (overfull)

30.3 Automatic transmission fluid

Automatic transmission fluid performs many functions, such as: power transmission; hydraulic control; heat transfer; lubrication of bearing surfaces; epicyclic gear lubrication; and friction control. It does this while operating at temperatures that range from very low to as high as 200°C.

30.3.1 Additives in automatic transmission fluids

To enable an automatic transmission fluid to perform the above functions, the following additives are used:

1 Anti-oxidants. Lengthen fluid life , permit high temperature tolerance and prevent formation of sludge and varnish.
2 Detergent/dispersants. Maintain contaminants in suspension and k eep hydraulic control components and filter screens clean.
3 Corrosion inhibitors. Prevent oil degradation products from corroding metal components.
4 Anti-wear additives. Prevent seizure of metal components under load and provide maximum protection against wear .
5 Seal swell additives. Provide control of swelling of the rubber seals to prevent loss of fluid. Fluid loss can lead to overheating and transmission failure .
6 Viscosity index improvers. Maintain the correct fluid viscosity over a wide temperature range .
7 Pour point depressants. Permit fluid flow at extremely low temperatures.
8 Friction modifiers. Control the friction between the clutch surfaces, enabling smooth gear changes.
9 Anti-foam additives. Ensure the rapid collapse of foam and rejection of any trapped air .

Clutch packs, convertor clutches and brake bands, which are responsible for power transmission and also for the *feel* of the gear shifts, require fluid with these additives.

Handy hint: Fluid with the correct properties is critical for ensuring smooth shifts and long clutch and band life .

30.3.2 Friction-modified fluids

Figure 30.5 shows the difference between a friction-modified automatic transmission fluid and a non-friction-modified fluid. The diagram shows that when the speed difference between the plates is close to zero (that is, when the plates are grabbing or releasing), the frictional coefficients of these two fluids are very different. The non-friction-modified oil grabs harshly and releases quickly, producing a firm shift. The friction-modified oil grabs softly and releases softly, producing a soft shift.

Manufacturers design the frictional material in their transmissions to suit the recommended oil. Therefore, if a Type F fluid is used in a transmission which has been designed for a Dexron-type fluid, it produces a bumpy or harsh shift. If a Dexron-type fluid is used in a transmission designed for a Type F fluid, a different feel of shift is expected. This would be a particularly soft shift, with possible clutch plate and band slippage under full power conditions.

Handy hint: Some transmission specifications exclude the addition of friction modifiers.

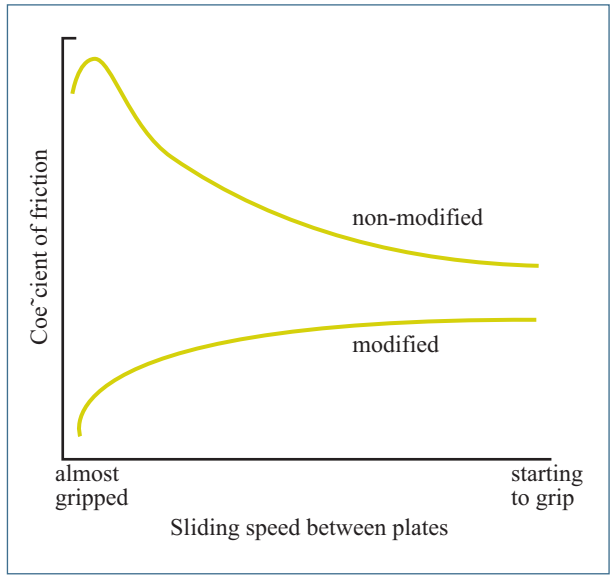


Figure 30.5 Comparison of friction-modified and non-friction-modified fluids

30.3.3 Overheating of fluid

Operating conditions in automatic transmissions are more severe than in manual transmissions, mainly due to the higher operating temperatures. For this reason, automatic transmission fluids must be able to operate over a very wide temperature range. This demands the use of a stable viscosity index improver. Since the fluid must also serve as a hydraulic control fluid, relatively low-viscosity base oils are used.

The frictional area of the transmission (mainly the bands and clutches) generates approximately 50% of the heat of the transmission fluid, the other major heat source being the torque converter. If excessive slip occurs in the bands and clutches, the transmission fluid will be subjected to greatly increased temperatures, and these will degrade the fluid.

The graph in Figure 30.6 illustrates the probable relationship between fluid operating temperature and the kilometres likely to be travelled before a transmission requires overhaul. It also shows the advantage of maintaining cool fluid in the transmission.

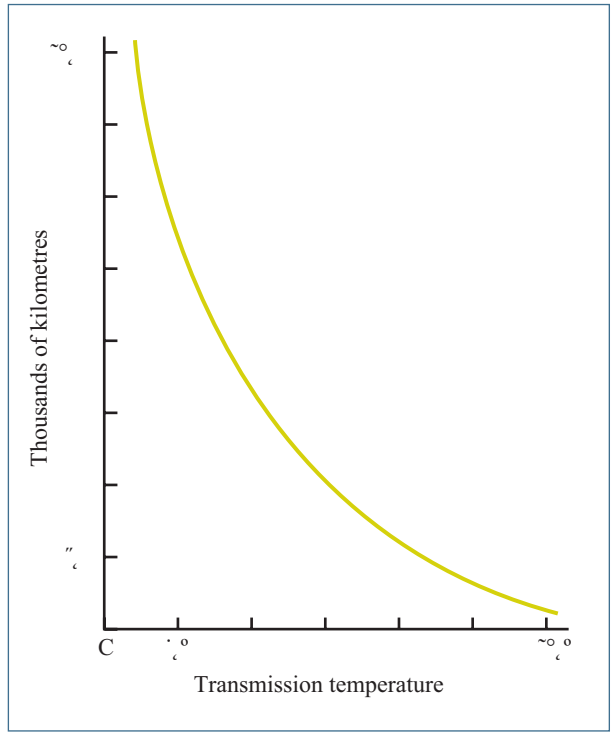


Figure 30.6 The graph shows the possible relationship between the operating temperature and the service life of an automatic transmission

30.3.4 Types of transmission fluid

There are a number of different types of transmission fluid. Some are known by brand names (such as Dexron), others by a type (such as Type F). Most transmission fluids are vehicle-specific and are identified by the vehicle's name and/or model.

For correct shift feel, and to prevent possible wear or damage to the transmission, only the recommended fluid should be used.

Handy hint: Always consult the manufacturer' s recommendations when selecting an automatic transmission fluid.

30.4 Fluid problems

Some of the possible problems associated with automatic transmissions can be related to the fluid. For this reason, the fluid should be one of the first things to be checked.

30.4.1 Low fluid level

Low fluid level can produce many symptoms that can be mistaken for more serious transmission problems. Two of the most likely causes of low fluid level are incorrect filling of the transmission during service and external leaks. Before deciding that the transmission is low on fluid, ensure that the level is being checked correctly. If the manufacturer's recommendation is not followed, a false reading can easily be obtained.

Handy hint: If a fluid level problem is suspected, make sure that the check is being done correctly and the correct dipstick is being used.

Fluid leaks

Oil seals and gaskets are possible sources of external fluid leaks. Others are the connections between the cooler pipes and the transmission, or those between the cooler pipes and the cooler. Automatic transmission fluid has a distinctive colour, enabling automatic transmission leaks to be distinguished from engine-oil leaks.

Figure 30.7 identifies the location of possible engine oil and transmission fluid leaks in the torque converter area of an automatic transmission. Some of the leaks might be cured by tightening the housing bolts; others can only be cured by renewing an oil seal, an O-ring or a gasket. To do this, the transmission might have to be removed from the vehicle.

Transaxles of most types of design could have leaks from the area of the converter or from the oil pan. Leaks are also possible from the joints between the parts of the gear casing or from the drive shaft oil seals, which seal between the drive shafts and the final-drive housing. Internal leaks are more difficult to locate, but leaks that cause problems usually result in a loss of pressure, and this affects transmission operation. Pressure tests can be carried out.

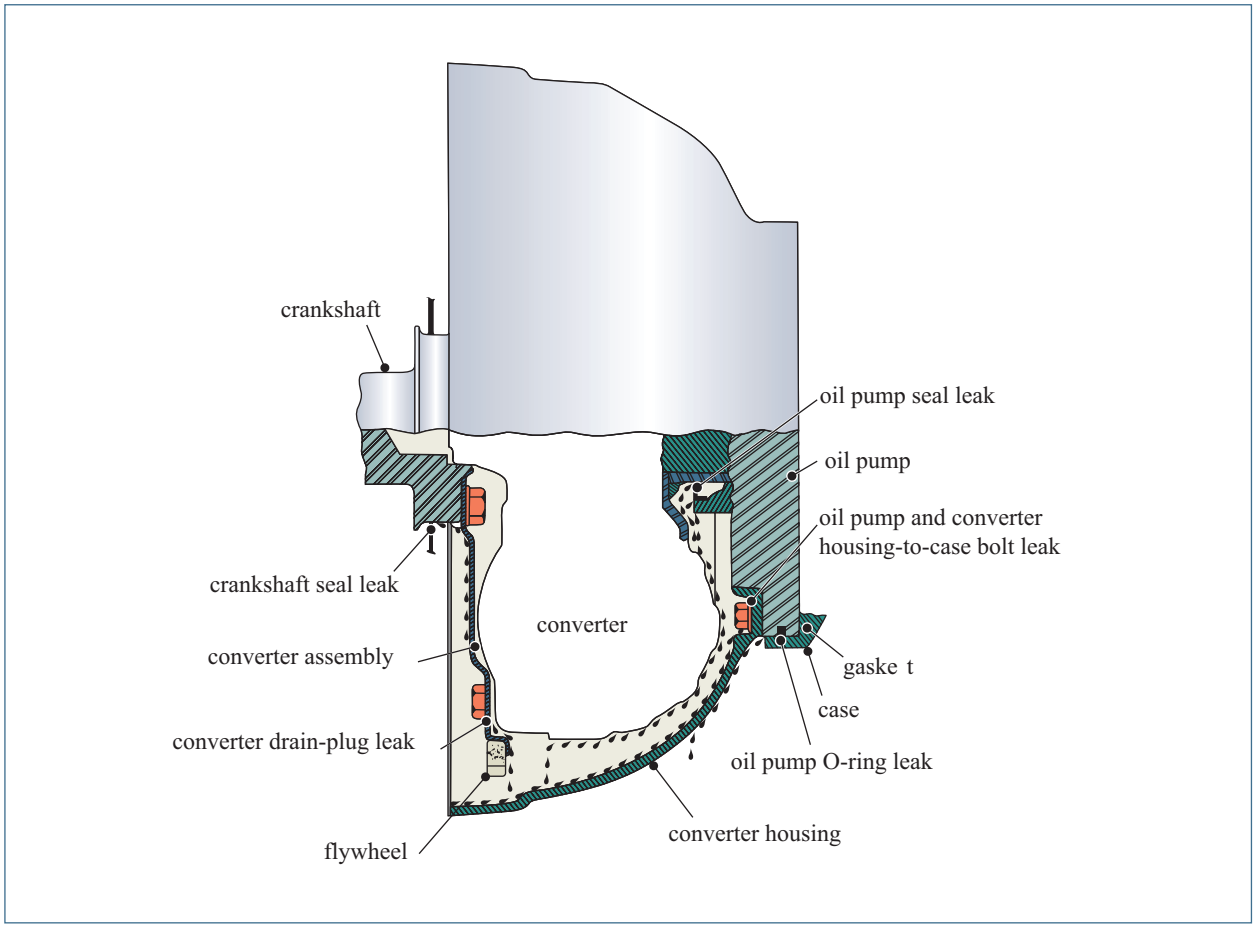


Figure 30.7 Possible sources of oil leaks in the converter area—l eaks could originate from the engine or from the automatic transmission

30.4.2 Dipstick information

As well as measuring the level of the fluid in the transmission, a dipstick can also be used to sample the fluid and provide a guide to its condition (Figure 30.8). The fluid on the dipstick is checked as follows.

Fluid colour

If the fluid has its original distinctive colour, with no discolouration, it is in good condition (discolouration indicates poor condition). Badly discoloured fluid indicates a probable transmission problem as well.

Fluid odour

If the fluid has a burnt odour, it will also be discoloured. This indicates that it has deteriorated due to overheating and should be changed. If the transmission is operating properly, the fluid level is correct and the fluid is not badly discoloured, a change of fluid could be sufficient. However, if the fluid is badly discoloured, there is probably a problem within the transmission, most likely a clutch or band slipping and causing overheating.

Particles in the fluid

Fluid that is dark in colour, has a strong burnt odour and is contaminated with small particles of foreign matter indicates problems. The particles are the result of band or clutch slip and wear. The discolouration is due to overheating and degradation of the fluid as well as the particles that it contains. A transmission with fluid in this condition probably needs an overhaul.

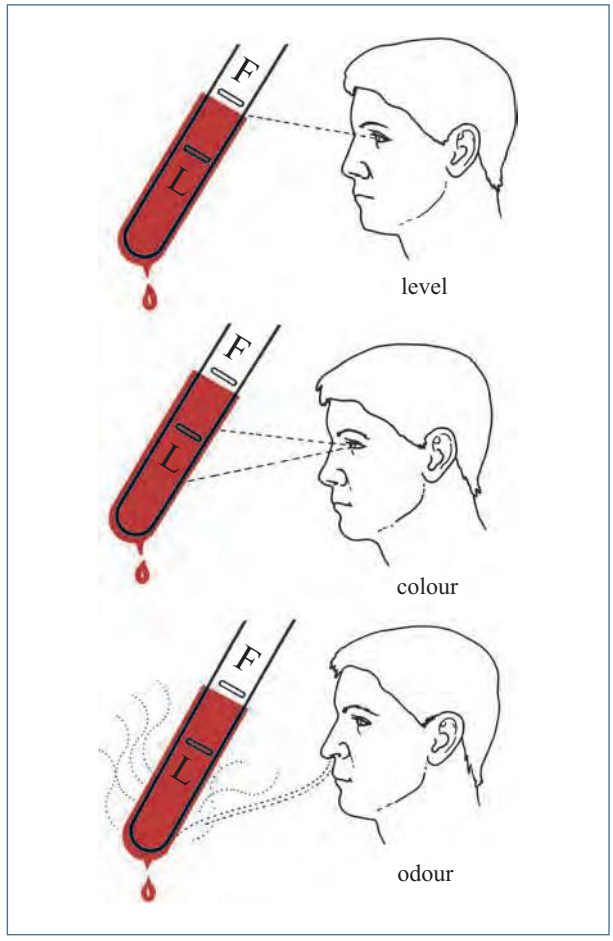


Figure 30.8 The fluid on the dipstick is checked for level, colour and odour

Water contamination

Water in the fluid will cause it to emulsify and turn a milky colour. Water contamination is not usual, but could occur from some external source or if the cooler in the radiator is faulty. The frictional material of the bands and clutch plates is attached with water-based glue. If water enters a transmission, it can dissolve the glue and cause the frictional material to become detached.

30.5 Transmission adjustments

Automatic transmissions and their controls are provided with adjustments. These vary considerably with different makes and models of vehicle. The type and method of adjustment will depend on whether the transmission has full hydraulic control or electronic control.

The variations between makes and models and the importance of correct adjustment make it essential that detailed information is obtained from the appropriate service manual before attempting any adjustment.

The importance of checking the basic settings and adjustments cannot be overstated—a transmission simply cannot function properly unless these are correct. Many service problems can be rectified by attending to the following service adjustment items:

- engine idle speed
- selector cable or linkage
- starter isolator (neutral switch) or range switch
- throttle cable or vacuum control (for hydraulic control)
- throttle-position sensor (for electronic control)
- hydraulic pressure
- brake bands.

30.5.1 Engine idle speed

Idle speed is checked with a scan tool and is not normally adjustable. Make sure the engine is at the correct operating temperature before checking. The idle speed is controlled by the car's ECU, usually in the vicinity of 800 rpm. A slight drop in engine rpm will be noticed when the selector is moved to D. This is caused by the increased load on the engine. High idle speed will cause creep; that is, the vehicle will move slowly as soon as a gear position is selected, even with the engine idling.

High idle speed could also cause a band or brake to be applied harshly when the selector lever is moved to a gear position. Low idle speed will cause the engine to stall. If the idle is incorrect check the intake manifold for any loose connections between the airflow sensor and the engine.

Safety: Engine idle or any other engine adjustments should only be carried out with the selector lever in the N or P position, with the park brak e applied.

30.5.2 Selector cable

The selector cable connects the driver's selector lever to the manual valve in the transmission, so whenever a gear position is selected, the manual valve will be moved to that position. For the selector adjustment to be correct, the selector lever indicator should be in the N position, with the manual valve also in the N position.

The two ends of a selector cable are shown in Figure 30.9. The selector lever and its end of the cable are shown in Figure 30.9(a) and the transaxle end of the cable and its lever arrangement in Figure 30.9(b). This is a push–pull cable which enables the selector lever to move the lever on the transaxle case in both directions.

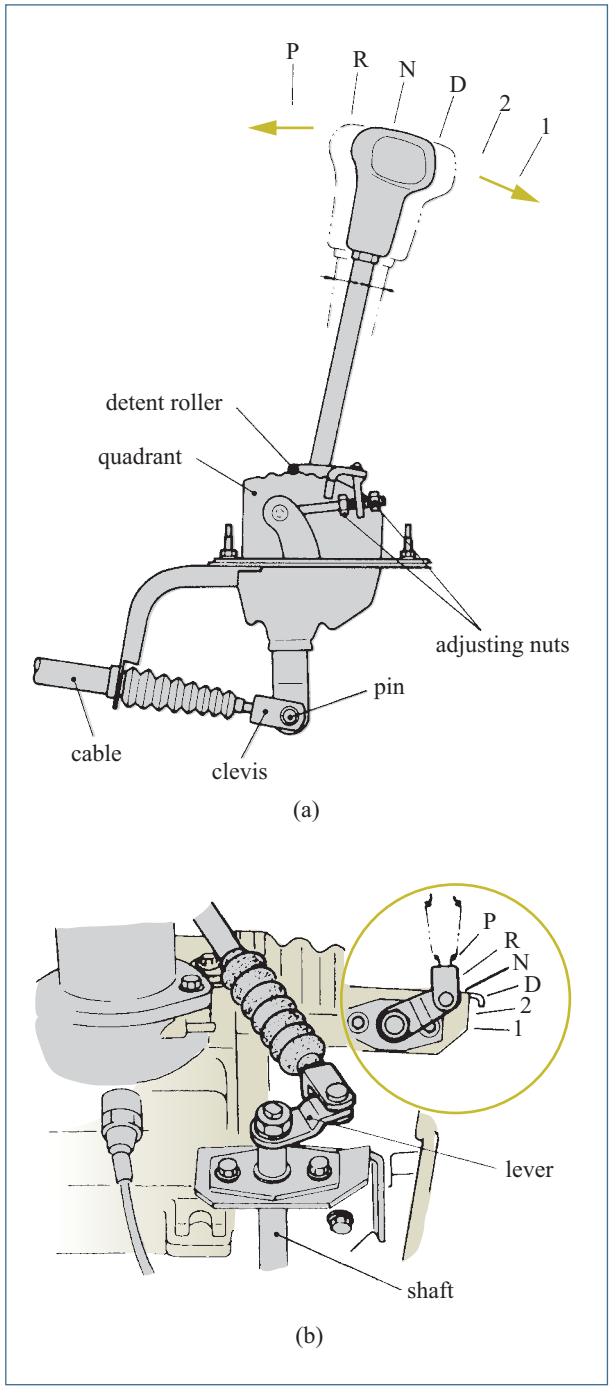


Figure 30.9 Selector lever (a) lever and selector end of cable (b) transaxle end of cable FORD

A threaded adjustment is provided at the selector lever. This is adjusted so that the selector positions at the selector lever correspond with those at the transaxle. In the design shown, a roller and quadrant locate the selector lever in the various selector positions. Inside the transaxle, a detent locates the manual valve in its correct positions. The adjustment is made with the selector lever in N and the manual valve also in N.

30.5.3 The starter isolator or neutral switch

Usually located on the transmission case (Figure 30.10), this is a safety switch that prevents the engine from starting in any gear position except N or P. Incorrect operation of the switch would allow the engine to be started with the transmission in gear, causing the vehicle to move out of the control of the driver.

The isolator switch forms part of the starter solenoid circuit. It is operated by the gear-selector mechanism to provide an open circuit in all positions except N or P. This prevents the starter from operating in any other position.

Handy hint: The isolator switch is also called the neutral switch, inhibitor switch and range selector switch.

Checking the isolator switch operation

To check that the switch isolates the starter, try to start the engine with the selector lever in all positions. The starter should operate in N and P only. Check this while moving the selector lever backwards and forwards (within the free play) from N and also from P. Note that as a safety precaution, the parking brake and foot brake should be firmly applied during the check: the vehicle could move if the switch is incorrectly adjusted.

To check the switch itself, disconnect the harness connector at the switch and use an ohmmeter to check between the terminals at the switch connector. The ohmmeter is connected between the terminals, and the switch moved to each of the gear positions.

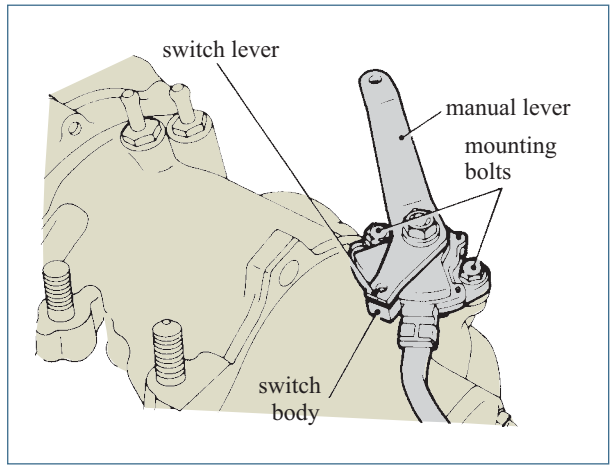


Figure 30.10 Starter isolator and position switch, rotary type MITSUBISHI

Checking the range switch operation

With electronic control, the isolator switch is also a position switch. It sends signals to the ECU to tell it which position has been selected. An example is shown in Figure 30.11. Some vehicles have the selector positions (or range positions) shown as indicators on the instrument cluster. With this arrangement, the range selector switch shows the position that is selected.

When checking the operation of the switch, the panel indicators should also be checked.

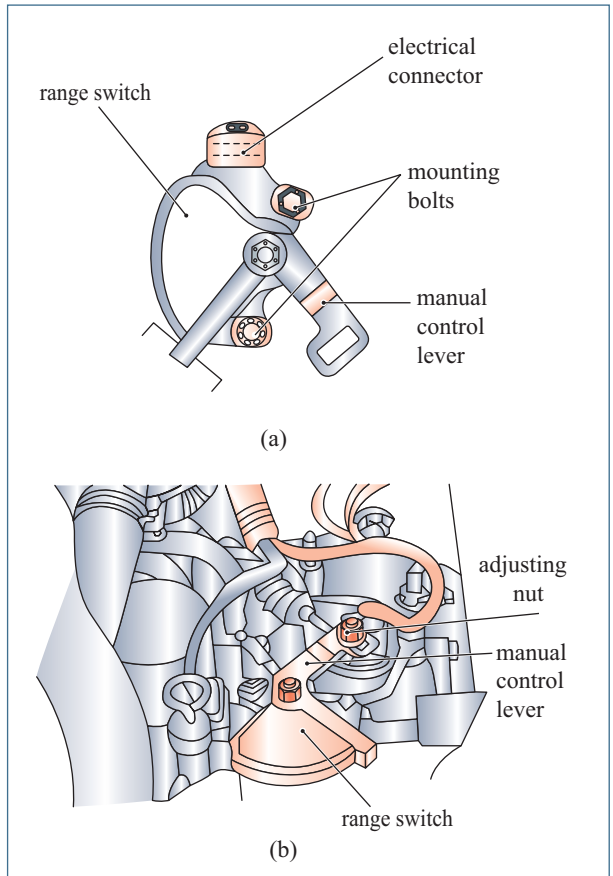


Figure 30.11 Manual control lever and range switch (a) switch assembly (b) cable adjustment

30.5.4 Throttle cable

There are two cables in the accelerator and throttle cable arrangement. One is the accelerator cable between the accelerator pedal and the throttle valve in the throttle body of the engine's air intake system. The other is the throttle-valve cable, which connects the throttle valve to the hydraulic throttle valve (TV valve) in the transmission.

To avoid confusion, the throttle valve in the air intake will be referred to simply as the *throttle valve,* while the hydraulic valve in the transmission will be referred to as the *TV valve.* An arrangement with two cables is shown schematically in Figure 30.12. When the accelerator pedal is depressed, the throttle valve is opened by the accelerator cable movement. The transmission downshift valve and the TV valve are moved by the action of the throttle cable.

Throttle linkage adjustment is correct when the accelerator pedal height, the throttle valve opening and the position of the TV valve in the transmission are in correct relationship. In general terms, the relationship of these three is as follows:

1 The pedal should be of sufficient height above the floor to allow full movement of the linkage .
2 The throttle valve should be closed (at idle position).
3 The TV valve in the transmission should be at or near its stop .

The manufacturer's method of adjustment should always be referred to as any errors will affect both the fluid pressure and the road speeds at which gear changes occur.

Handy hint: Incorrect adjustment through low line pressure could cause the transmission to slip, resulting in erratic changes and damage to bands or clutches.

Cable adjustment

The throttle valve ends of both an accelerator cable and a throttle cable are shown on Figure 30.13.

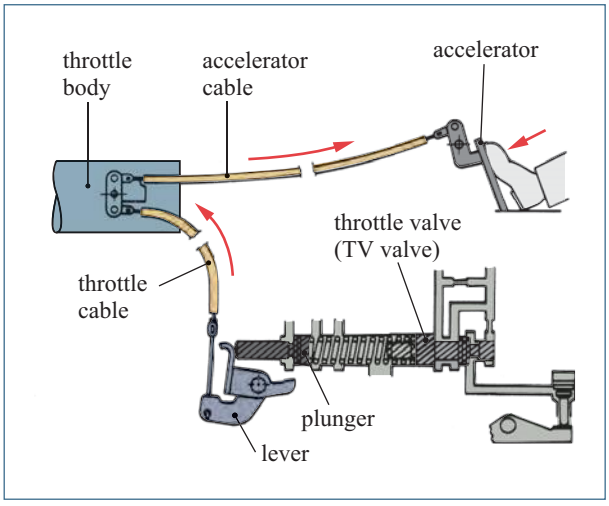


Figure 30.12 Throttle cable arrangement GM HOLDEN LTD

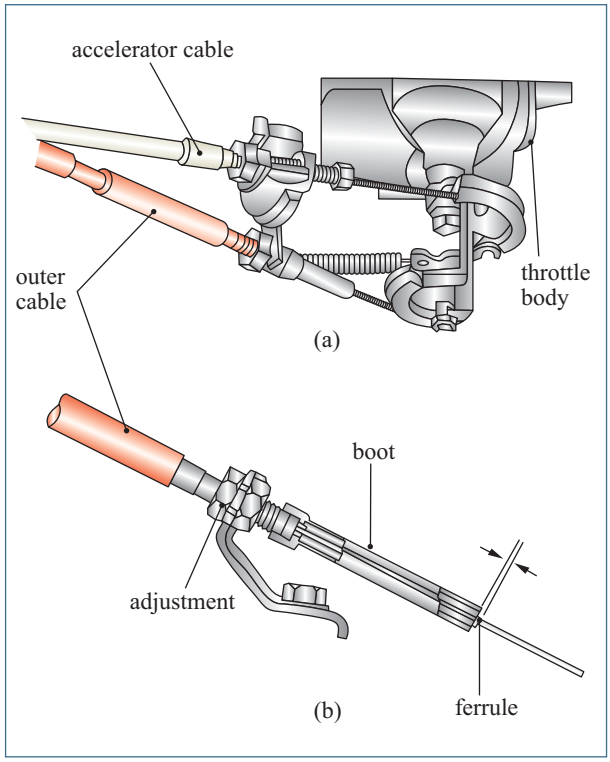


Figure 30.13 Throttle cable assembly and adjustment

Both the inner cables operate around quadrants. With this arrangement, the accelerator inner cable shortens and the TV valve inner cable lengthens when the accelerator pedal is pressed.

To check this arrangement, first check the accelerator cable: depress the accelerator pedal and check that the throttle valve is fully open. If necessary, adjust the length of the cable with the adjusting nuts until the throttle valve opens fully.

With the accelerator pedal fully depressed, check that the throttle inner cable has moved out far enough to expose a stop which is crimped to the inner cable. The stop should be about 1 mm beyond the end of the boot on the cable. If necessary, adjust the nuts on the outer cable to obtain this dimension (A in Figure 30.13(b)).

As with all transmissions with hydraulic control, the throttle cable adjustment affects throttle pressure in the transmission and throttle pressure operates on the shift valves. If the outer cable is lengthened (and the inner cable effectively shortened), throttle pressure in the transmission will increase and delay upshifts. If the outer cable is shortened, upshifts will occur earlier.

In the transmission, throttle pressure operates on the regulator valves and on the shift valves. This means that both line pressure and converter pressure can be affected by throttle cable adjustment. If line pressure is too high, the shifts will be harsh as well as late. If it is too low, upshifts will be early and clutches or bands could slip.

Vacuum control

A vacuum control unit is shown in Figure 30.14. This performs a similar function to the throttle linkage. The unit, which is mounted on the transmission case, consists of a diaphragm in a sealed

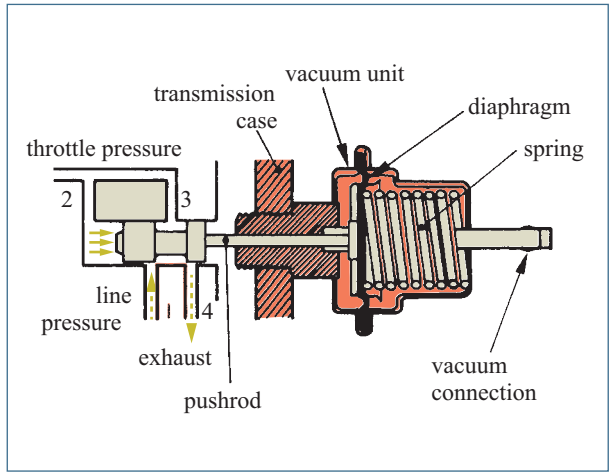


Figure 30.14 Vacuum-operated throttle valve

container connected by a pipe to the engine manifold. The diaphragm is under the influence of engine manifold vacuum and therefore is sensitive to variations in engine load.

A pushrod from the diaphragm extends into the transmission and operates the throttle valve (TV valve). Changes in throttle butterfly opening and engine load will therefore affect throttle pressure, which will determine when gearshifts occur. (Line pressure will also be affected.) Any necessary adjustment can be made either by changing the length of the pushrod between the diaphragm and the throttle valve or by turning a small screw inside the vacuum connection.

Kickdown

Where a throttle cable is used, the downshift valve is operated by the cable and no adjustment is required. Where vacuum control is used, forced downshifts are obtained via a kickdown switch operated by the accelerator linkage and a solenoid which controls a downshift valve in the transmission (Figure 30.15). When the accelerator pedal is depressed to the floor, the switch contacts are closed, the solenoid is energised and downshift pressure is provided to the shift valves to force a downshift. An adjustment is provided on the switch or the linkage, and this can be altered if the switch does not operate.

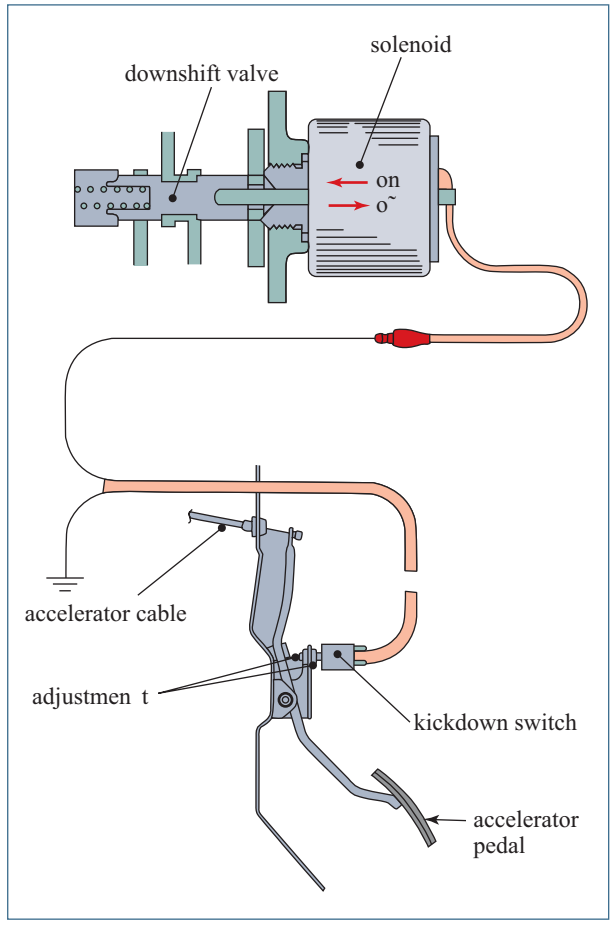


Figure 30.15 Kickdown (downshift) switch and solenoid

30.5.5 Throttle-position sensor

The throttle-position sensor, used with electronic control, is attached to the throttle body. It can usually be adjusted by loosening its screws. There are two basic types of sensors, a rheostat and a switch.

The rheostat provides a voltage signal that varies with throttle opening. It is basically a variable resistance, so can be checked with an ohmmeter (Figure 30.16). Its resistance should vary between closed-throttle and full-throttle positions. The switch-type sensor provides signals in a number of steps, being a switch with a number of contacts. For checking purposes, it can be treated in the same way as any other switch.

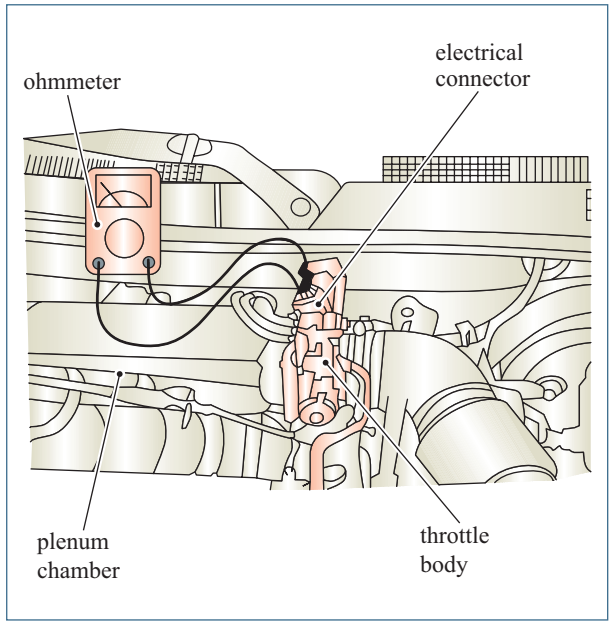


Figure 30.16 Checking the throttle-position sensor

30.6 Brake band adjustments

These are carried out to compensate for wear of the band lining. A loosely adjusted band could slip, resulting in overheating and excessive wear. A tightly adjusted band will cause binding, again resulting in overheating and wear. Correct adjustment provides a small clearance between the brake band and the drum. This enables the band to be applied smoothly and firmly, with minimum wear occurring. Some transmissions have two band adjustments, others only one. Some automatic transmissions have disc brakes instead of bands, and these have no adjustments.

Handy hint: The band adjuster may be internal or external. Internal adjustments can only be carried out after the oil pan has been removed.

30.6.1 Internal adjustment

Figure 30.17 shows a band adjustment on a transmission; in this case, the adjustment is inside the transmission. The oil pan has been removed and a small tension wrench is being used on the screw adjuster. In most transmissions, the band is adjusted by tightening the adjusting screw to a specified torque and then backing the screw off a specified number of turns. Gauge blocks are sometimes used.

30.6.2 External adjustment

The adjustment shown in Figure 30.18 is an external adjustment, which is accessible after removing the outside cover from the servo. The following is an example of the procedure to adjust a band:

1 Loosen the locknut.
2 Holding the servo piston to prevent it from turning, tighten the adjusting screw to 10 Nm and then back it off . Repeat this twice to seat the band snugly on the drum and prevent a false reading when adjusting.
3 Tighten the adjusting screw to 5 Nm and then back it off 3½ turns.
4 Tighten the locknut to 15 to 20 Nm.

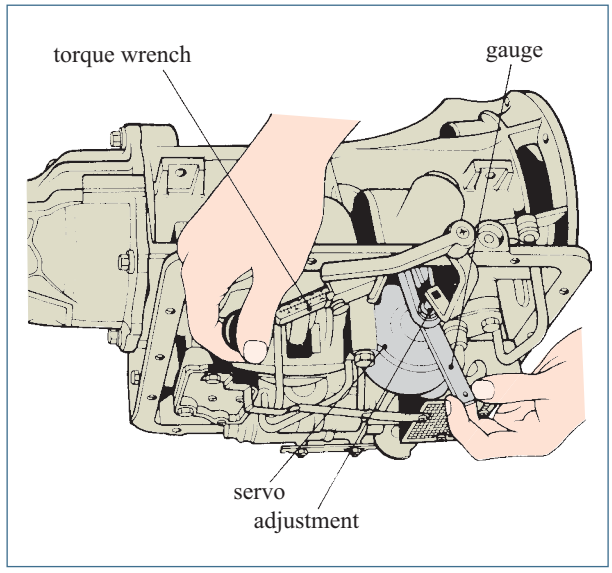


Figure 30.17 Servo and band with an internal adjustment MITSUBISHI

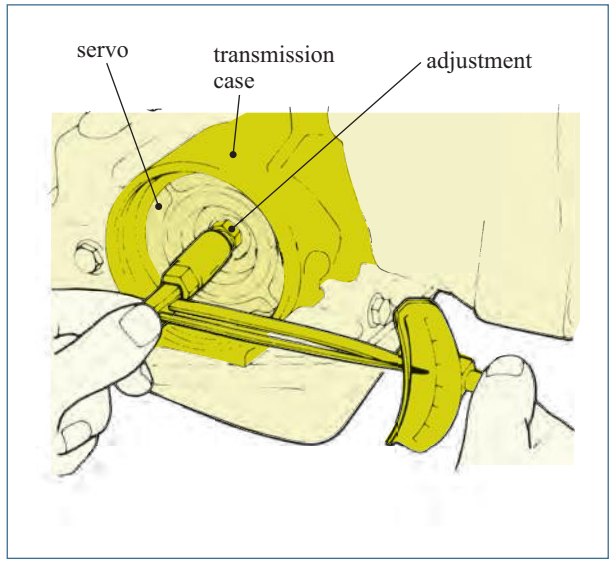


Figure 30.18 Servo and band with an external adjustment

30.7 Fault diagnosis and checks

An understanding of the construction and operation of the particular type of transmission or transaxle is necessary to carry out checks and diagnose faults.

Handy hint: Vehicle manufacturers provide diagnosis guides, and these should be referred to whenever a fault is suspected.

30.7.1 Basic checks

Where an automatic transmission has an operational problem, the following preliminary checks can be carried out:

1 Check the fluid level, top up if necessary and check for external leaks.
2 Check the fluid for deterioration and contamination.
3 Check and adjust the engine idle speed to specifications.
4 Check the throttle cable or linkage for free operation and ensure that there is no lost motion. Adjust to specifications. Check to ensure full throttle is available .
5 Check operation of selector linkage and starter neutral switch.
6 Check electronic control unit self-diagnosis for faults.
7 Check all electrical connections associated with the transmission sensors for looseness or corrosion.
8 Check both battery terminals for looseness or corrosion.

It is important to perform these as they could lead to the correction of many less serious operating problems.

Handy hint: The checks should be made and the vehicle road tested before any internal repairs are considered.

Band adjustments can also be carried out. As much diagnosis as possible should be carried out before removing the oil pan as this will enable the transmission to remain operational until the problem is identified. Dismantling, if considered necessary, can then occur. Where further diagnosis is needed, a pressure test or a stall test can be carried out. For a transmission with electronic control, test instruments would be used to extract self-diagnosis information from the ECU.

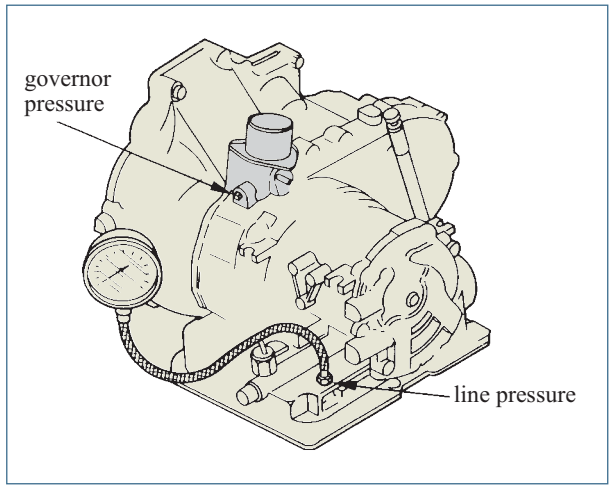


Figure 30.19 Oil pressure gauge connected to check the line pressure of a transaxle

30.7.2 Pressure check

A pressure check can help to diagnose hydraulic problems. A pressure gauge is connected to the transmission, and pressure readings are taken for different operating conditions (Figure 30.19). As an example, specifications for line pressure could be 350 kPa at idle and 700 kPa at 1000 rpm. These tests would be taken with the selector in D position. The pressure in reverse could be up to 1000 kPa.

Handy hint: Pressure readings can also be tak en during road tests.

30.7.3 Stall test

A stall test should be performed only during diagnosis. It checks the engine, the torque converter and the transmission by measuring the maximum rpm that the engine can produce with the turbine held in a stalled condition. The vehicle is held stationary with brakes and wheel chocks, the selector lever is placed in D and the throttle is opened fully for a very short period (see Figure 30.20).

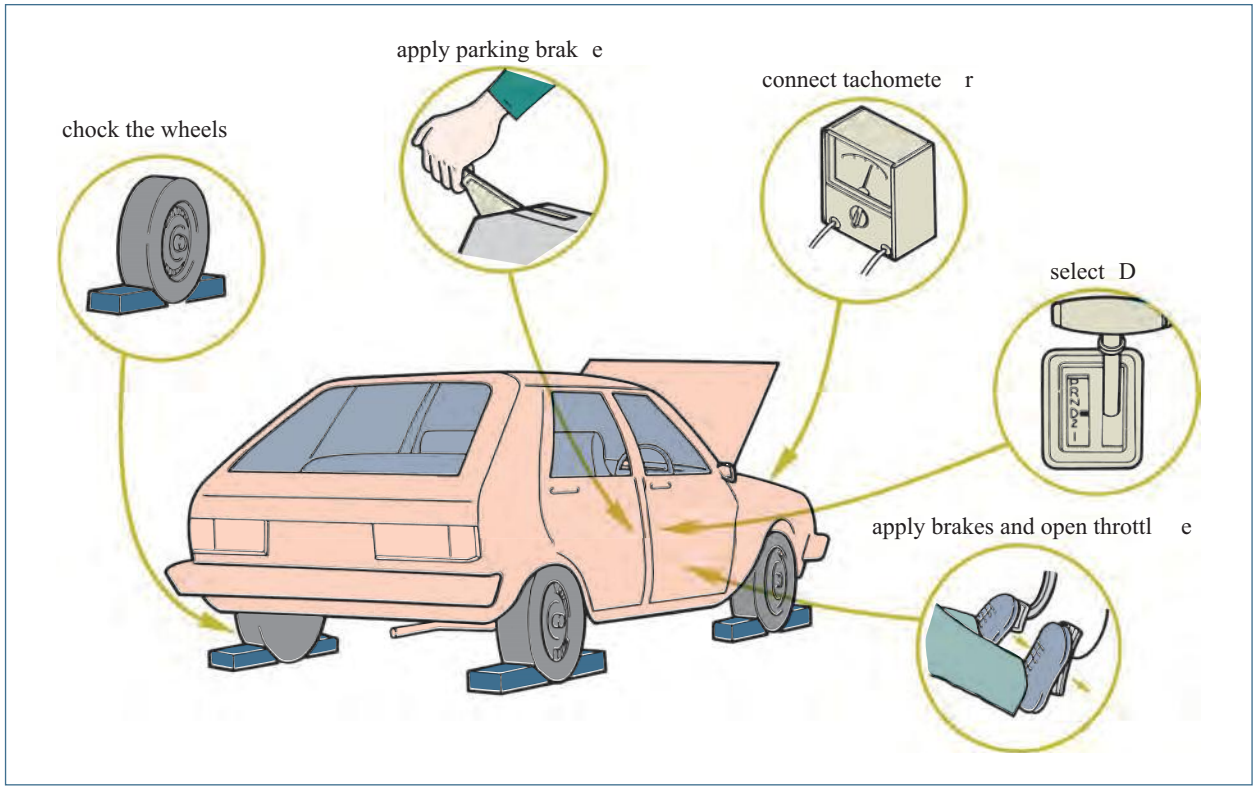


Figure 30.20 Stall testing an automatic transmission. Note that a stall test should only be carried out if allowed by the vehicle manufacturer

A tachometer connected to the engine registers the engine rpm, and this is used to interpret engine and transmission condition. Also, a pressure gauge can be connected to the transmission to check the system fluid pressure. The tachometer reading is specified by the manufacturer, with figures varying for different engines. If the reading falls within them, the transmission and converter are satisfactory.

A low rpm reading can indicate that the engine is suffering from loss of power, a clogged exhaust or a slipping stator in the converter which is placing a greater-than-normal load on the engine. A high rpm reading can be caused by slipping bands and clutches or mechanical damage in the converter. In either case, further investigation is necessary to isolate the problem.

Consult the appropriate workshop manual before doing a stall test. Stall testing generates high fluid temperatures and places severe loadings on all parts of the transmission and drive line, as well as on the engine. Some manufacturers recommend against stall testing and others allow partial stall testing only.

30.8 Road testing

When road testing a vehicle with an automatic transmission, check:

1. selector lever operation (including the isolator switch)
2. the shift pattern (road shift speeds)
3. the shift quality (engine overspeeding between shifts, or slippage)
4. noise in the transmission.

Checks are made at different throttle openings and speeds, with the selector lever in different positions.

Handy hint: Before starting a road test, check correct operating temperature , engine idle and fluid level.

30.8.1 General test procedures

The general procedure for a road test is illustrated in Figure 30.21. The following points should be observed.

Starter isolator switch

The starter should operate only in N or P positions. This is an important safety feature.

Brake switch

Check that the gear selector lever will not move until the brake pedal is applied.

Smooth engagement

The bands should be applied smoothly when the selector lever is moved through the various positions. Reverse may be a little harsher, as higher fluid pressures are often used.

Upshifts

Upshifts should be checked on a level road to determine if they occur at the correct road speeds. Check at minimum throttle, full throttle and kickdown positions. The shifts should occur at the speeds specified by the vehicle manufacturer. (See Table 30.1 for examples of shift speeds for a transmission with a hydraulic governor.)

Downshifts

Downshifts occur at lower speeds than upshifts. These can be checked at closed throttle and, where suitable conditions are available, at full or part throttle on hills to check downshifts under load. Forced downshifts (kickdown) can also be checked.

Overdrive

For transmissions with overdrive or similar switches, gearshifts can be checked with the overdrive switch both on and off. With the overdrive switch off, there should be no upshifts from third to fourth gear. When the switch is turned on at higher speeds, the transmission should shift from third to fourth.

Power and economy modes

For transmissions with electronic control that have power and economy modes of operation, the shift speeds can be checked in both modes. There may not seem to be much variation in road speeds, but the power indicator lamp should light with the power mode selected.

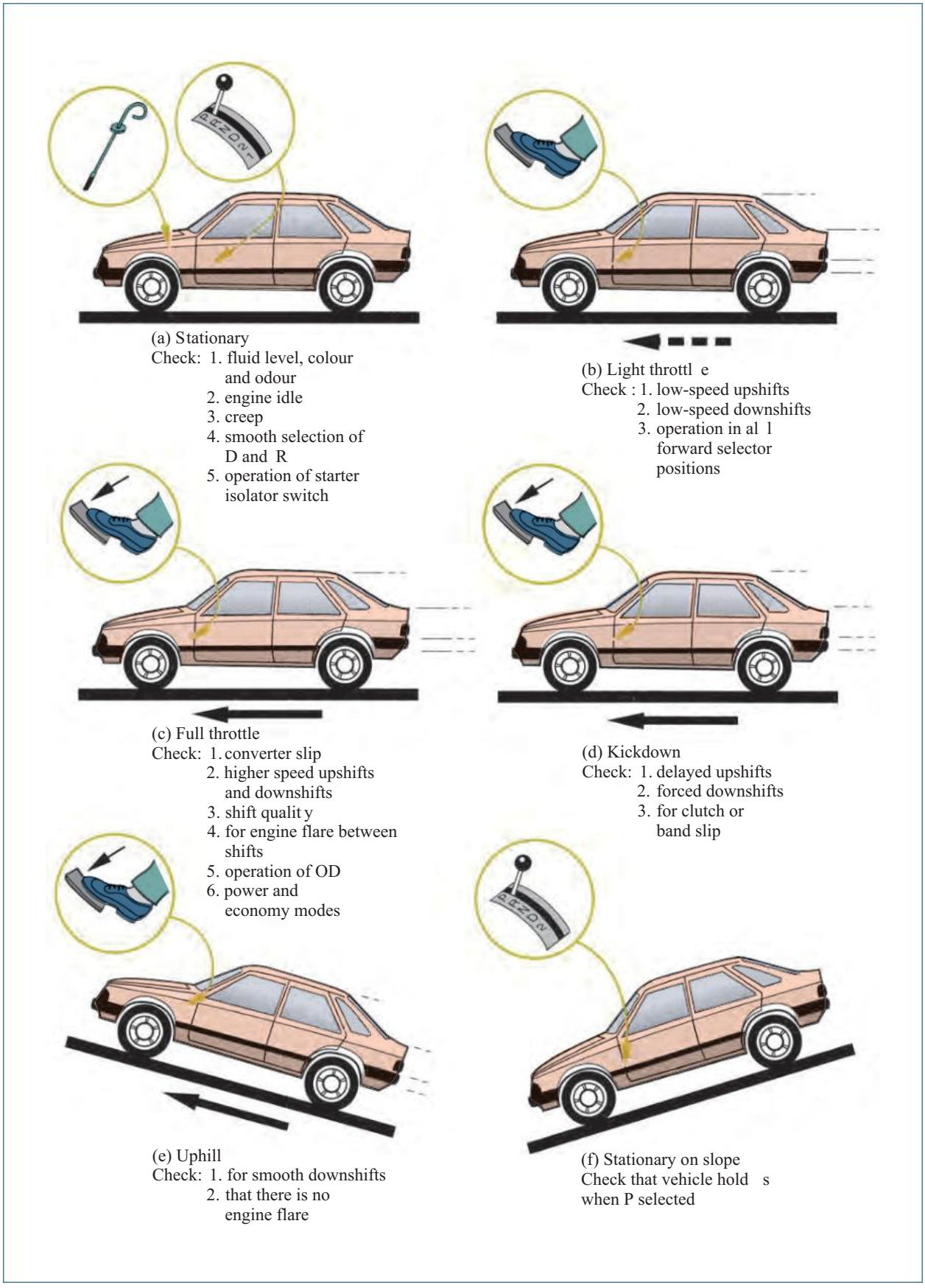


Figure 30.21 Checks that can be made during a road test of an automatic transmission or transaxle

Shift quality

Check the shifts for harshness and slip under both light- and heavy-load conditions. Checks can be made on a level road and on hills. Any tendency for the engine to overspeed during shifts can also be observed.

Low and second positions

Select 1 and check that upshifts do not occur. Do not overspeed in this gear. Position 2 can be selected with the vehicle stopped and changes observed from 1 to 2 as vehicle speed is increased.

Parking pawl

With the vehicle stopped on a hill, select P and release the brakes to check that the parking pawl holds. The brakes should be reapplied before moving the selector lever from the park position.

Table 30.1 Table of shift patterns

Throttle	Shift speeds (km/h)		
	Upshift	Upshift	Upshift
	1–2	2–3	3–4
Light	12–20	21–30	35–40
Full	40–45	60–70	80–90
Kickdown	45–55	70–90	
	Downshift	Downshift	Downshift
	2–1	3–2	4–3
Closed	5	20	25–30
Full	10	20–25	30–35
Kickdown	35	60–70	

Reverse

With the vehicle stopped, select R and check for slip and noise. Some additional gear noise is not unusual in reverse.

30.8.2 Shift patterns

The road speed at which the various gearshifts occur is determined by the governor (hydraulic control), the road-speed sensor (electronic control) and the amount that the accelerator is depressed. Road-speed checks are made at defined throttle openings. In some transmissions, three positions are checked: light throttle, full throttle and kickdown. Others have shift patterns specified for different throttle positions, such as quarter, half and full throttle. Percentage of throttle opening is also used, for example shift speeds at 5% and 80%. The shift speeds should be within the specifications for the particular transmission.

With hydraulic control, the shift speeds can be corrected by adjusting the throttle linkage or by altering the length of the pushrod where a vacuum control is fitted. With electronic control, the shift patterns are embedded in the memory of the ECU. With an electronically controlled transmission, a shift-speed problem is more likely to be related to the throttle-position sensor or road-speed sensor rather than to hydraulics.

On most transmissions, the driver can alter the shift pattern with a power/economy switch. When the transmission is in economy mode, the upshifts will generally occur earlier than they would in power mode.

30.8.3 Table of shift speeds

Table 30.1 is one example of the shift pattern for a transmission, but shift patterns can be shown in a variety of ways, including on a graph. The shift speeds listed for a transmission should be treated as approximate speeds, not as exact speeds. ‘Light throttle’ means just enough accelerator movement to cause the vehicle to increase speed. ‘Full throttle’ occurs when the accelerator is pressed almost to the floor and ‘kickdown’ is when it is fully depressed. In some vehicles, there is a resistance to movement between full throttle and kickdown. In others, kickdown operates the kickdown switch and solenoid.

30.9 Diagnosing problems

Workshop manuals provide diagnosis guides and charts which should be referred to whenever a problem arises. These guides are often very extensive, with some providing step-by-step procedures. In the event of a problem, the basic checks should be carried out, as previously discussed, so that the simpler things are checked and eliminated first. If the problem has still not been cured, the more difficult things can be investigated.

When diagnosing an automatic transmission problem, the engine, power train, hydraulic controls and electronic controls must all be considered. Table 30.2 shows these and indicates some of the things that might cause problems in the different locations. As an example, do not immediately blame the transmission for a problem that could be caused by the engine not performing properly.

A general diagnosis guide appears in Table 30.2. This is not designed for any particular transmission. However, it can be used to identify the types of problems that can occur with automatic transmissions.

Table 30.2 Diagnosis guide for an automatic transmission

Problem	Possible causes
No starter operation in N or P	8, 29, 39
Starter operates in other than N or P	8, 29
No engagement in D	18, 8, 19, 22
No engagement in any selector position	8, 19, 14, 30, 7, 18
Delayed engagement	22, 19, 9, 29, 31, 40, 41
Slip or noise on tak e off in D	18, 9, 23, 14, 13, 15, 26, 34, 35
Slip or noise on tak e off in reverse	18, 9, 19, 23, 14, 13, 15, 26, 34
Harsh engagement all positions	1, 9, 22, 23, 21, 34, 35
Poor acceleration in first	2, 4, 12, 13, 14, 15
Poor performance and overheating in third	2, 3, 28
No 1–2 shift	6, 15, 27, 34, 40, 41
Slip during 1–2 shift sometimes	18, 9, 23, 14, 15, 13, 25, 19, 34
Harsh 1–2 shift	9, 22, 23, 21, 34, 35, 30, 40
No 2–3 shift sometimes	8, 13, 25, 27, 30, 34, 40, 41
Slip during 2–3 shift	18, 9, 22, 19, 34, 40, 41
Harsh 2–3 shift	9, 22, 21, 34, 35, 40, 41
Soft shifts	19, 14, 15, 9, 34, 35, 38
No 3–4 shift	37, 30, 13, 14, 15, 27, 30, 34, 40
Shift speeds incorrect	9, 22, 26, 27, 31, 38, 40, 41
No engine braking in 1 position	14, 15, 25
Whine in N with engine running	11
Grating noise from transmission	10, 16, 17
Knocking noise from converter	4, 5, 7
Park will not hold	8, 10
Transmission overheating	28, 18, 3
No converter clutch lock -up	5, 6, 7, 22
Transmission binds	25, 14, 20, 24
Engine stalls	1, 2
Engine flare between shifts	20, 14, 15, 18, 40, 41
Vehicle has ex cessive creep	1
No forced downshift	9, 36

Key to possible causes
Engine
1. Idle speed
2. Lack of power
Torque converter
3. Stator O WC stuck
4. Stator O WC not locking
5. Converter clutch
6. Pressure low
7. Converter damage
Mechanical/power train
8. Selector cable or linkage adjustment
9. Throttle cable or linkage adjustment
10. P arking pawl or mechanism damaged
11. Oil pump worn or damaged
12. Transmission O WC not locking
13. Clutch plates worn
14. Band adjustment
15. Brak e bands or plates worn
16. Gearing worn or damaged
17. W orn bearings or thrusts
Hydraulic system/controls
18. Fluid level low
19. Low line pressure
20. Internal fluid leaks
21. High line pressure
22. Valves sticking
23. Vacuum control fault or leak
24. Clutch piston sticking
25. Servo piston
26. Governor valve sticking
27. Shift valves sticking
28. Cooler inefficient or line block ed
Electronics/electrics
29. Isolator/selector-position switch adjustment, or fault
30. Wiring or connectors
31. Throttle-position sensor adjustment, or fault
32. Speed-sensor fault
33. Oil-temperature sensor
34. Shift solenoid
35. Pressure-regulator solenoid
36. Kickdown switch or solenoid
37. OD switch fault
38. ECU fault
39. Anti-theft system armed
40. Loose or corroded battery terminal
41. Low alternator output

30.9.1 Diagnosing electronic control problems

Transmissions with electronic control have a self-diagnosis program in the ECU which can diagnose faults as they occur during operation.

If a sensor or component of the electronic control system is not functioning properly, then it will send abnormal signals to the ECU. When the ECU receives an incorrect signal, its self-diagnosis program recognises that the signal is not normal and records a fault in that part of the system. In most cases, the information will remain in the memory of the ECU until the battery is disconnected.

To obtain the codes, the vehicle must have been operated so that the fault is recorded. The test equipment is then connected into the system, usually by means of special connecting cables into a diagnosis connector provided for the purpose. The ignition switch is turned on, but the engine is not running.

Safety: During road-speed checks, k eep the speed within the legal limit. R oad testing is distracting to the driver so extra care is required.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- identify transmission service requirements, including checking the fluid level, fluid contamination and assessing the need to change it
- demonstrate how to service transmissions, including visual inspections, filter replacement and band adjustment for correct and smooth shifts through gear changes
- demonstrate road testing to check for the correct shift pattern and quality
- list and identify general problems which may occur when fluid is low or contaminated
- diagnose automatic transmission faults.

REVIEW QUESTIONS

1 How is the fluid level check ed in an automatic transmission ?
2 What precautions are needed when draining the fluid from an automatic transmission ?
3 What information can be gained from the fluid on the dipstick?
4 Why must the correct type of fluid be used?
5 What are the different types of fluids ?
6 Name some of the properties of automatic transmission fluid, and indicate why the fluid has these properties.
7 What effect does ex cess transmission fluid temperature have on the transmission ?
8 What is the effect of incorrect engine idle speed on a vehicle with automatic transmission ?
9 What are the lik ely problems if the selector linkage is not correctly adjusted?
10 What is the purpose of the isolator or neutral switch ?
11 How can the operation of the isolator switch be check ed?
12 What is the purpose of the throttle cable and what does it operate ?
13 How would incorrect adjustment of the throttle cable affect transmission operation ?
14 When is a throttle-position sensor used?
15 Generally , how is a band adjustment carried out?
16 What would be the effect of a faulty band adjustment?
17 What are some of the basic checks that should be carried out if an automatic transmission is not operating properly ?

PART 5

Petrol fuel and engine management

CHAPTER 31

EFI and petrol fuel systems

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 state the importance of the correct air–fuel ratio
2 describe the operation of carburettors
3 identify the mechanical and electric pump operation used in carburettor systems
4 state the basic operation of EFI systems
5 describe the three basic sections of EFI systems
6 state the operation of throttle body, multipoint and direct fuel injection
7 identify the input sensors and describe what they do
8 identify the outputs of an engine management system
9 describe what signals from sensors are and how to check them
10 describe the use of scan tools and oscilloscopes for diagnostics.

This chapter explains how an engine gets its power by burning a mixture of air and fuel in the combustion chamber in both carburettor and electronic fuel-injection (EFI) systems. Although both systems deliver the air–fuel mixture to the engine in a combustible form, each does it in a different way. Carburettors atomise the fuel by a venturi action, while in EFI systems an electronic fuel injector sprays the fuel under pressurised conditions either into the intake manifold or directly into the combustion chamber.

The electronic control unit (ECU) computer can be programmed to monitor almost all engine controls, a function referred to as engine management. By using electronics, engine management systems provide precise control of the ignition system, the cooling system, emissions and engine performance.

Although engine management has generally been directed towards vehicle performance and economy, manufacturers have been forced to prioritise the control of emissions to comply with strict anti-pollution regulations.

31.1 Petrol as a fuel

The most commonly used fuels in Australia today are unleaded petrol, diesel, bio fuel, liquefied petroleum gas (LPG) and natural gas. All fuels used for automotive use are hydrocarbons. Petrol is a hydrocarbon, which means that it consists mainly of hydrogen and carbon atoms. Petrol cannot be used in the engine in liquid form, and must be mixed with air to obtain oxygen to form a combustible mixture. The liquid fuel has to be *atomised* so that each little droplet can be surrounded by air with enough oxygen to completely burn the fuel (Figure 31.1).

With an ideal mixture of air and fuel and complete combustion taking place, the fuel would provide full power. The engine's exhaust would be clean, and pollution would be reduced.

31.2 Air–fuel ratio

For a petrol engine, the most suitable ratio of air to fuel is approximately 15:1, by mass—15 kg of air to 1 kg of petrol. An EFI system (or a carburettor) must supply a mixture with this ratio, although the ratio is varied for certain engine conditions, such as starting, accelerating and operating under heavy load. The air–fuel ratio for complete combustion is known as the *stoichiometric ratio*, and is actually 14.7:1 (by mass).

If there is too much fuel for the air in the engine's cylinders, there will be a *rich mixture*; combustion will not be complete and some fuel will remain unburnt. This will be exhausted into the atmosphere as gas and will cause air pollution. Black smoke from the exhaust signifies a particularly rich mixture.

If there is not enough fuel for the air in the cylinders, there will be a *lean mixture*. This could cause hard starting, poor combustion and loss of power. The chemical composition of the gases in the engine's exhaust system will vary according to how well the fuel has burnt, which can be checked with an exhaust-gas analyser, as in Figure 31.2.

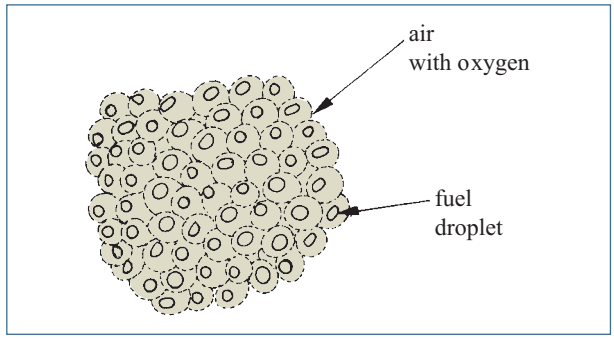


Figure 31.1 In a fuel charge, each fuel droplet is surrounded by its own supply of air with oxygen

Figure 31.2 An exhaust-gas analyser takes a sample of the exhaust gas and analyses it for emissions

Handy hint: Poor combustion might not be a fuel problem—it could be the result of poor ignition or lack of air.

Handy hint: Chapter 33 has more information on emissions.

31.3 Carburettor systems

Before EFI was developed, carburettors metered the air and fuel at the correct ratio. Figure 31.3 shows a basic fuel system with a carburettor. The system consists of:

1. Fuel tank. Stores the fuel.
2. Pump. Supplies fuel from the tank to the engine.
3. Filter. Traps foreign matter in the fuel.
4. Carburettor. Atomises the fuel and provide the correct mixture of air and fuel.
5. Engine intake manifold. Delivers the air–fuel mixture to the engine cylinders evenly.
6. Air cleaner. Supplies clean air.

The exhaust system is sometimes considered to be part of the fuel system. Figure 31.4 is a schematic diagram of a carburettor fuel system, showing the layout of the fuel tank, fuel lines and other parts in relation to the body and engine.

31.3.1 Fuel tank and fuel lines

There are three pipes (or lines) between the fuel tank at the rear of the vehicle and the components in the engine compartment in carburettor systems. The pipes connected to the fuel tank are:

1. Fuel supply line. Carries fuel from the tank to the filter and then to the fuel pump.
2. Return line. Returns surplus fuel from the pump.
3. Vapour line. Vents the fuel tank to the charcoal canister.

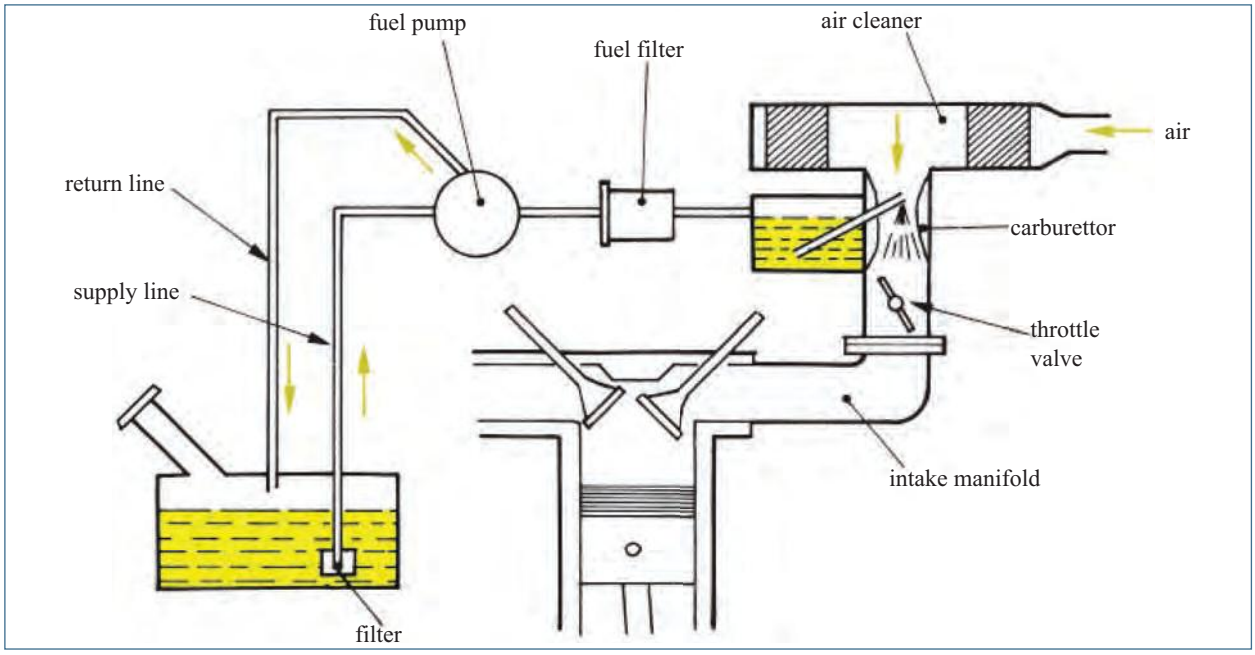


Figure 31.3 Basic fuel system with a carburettor

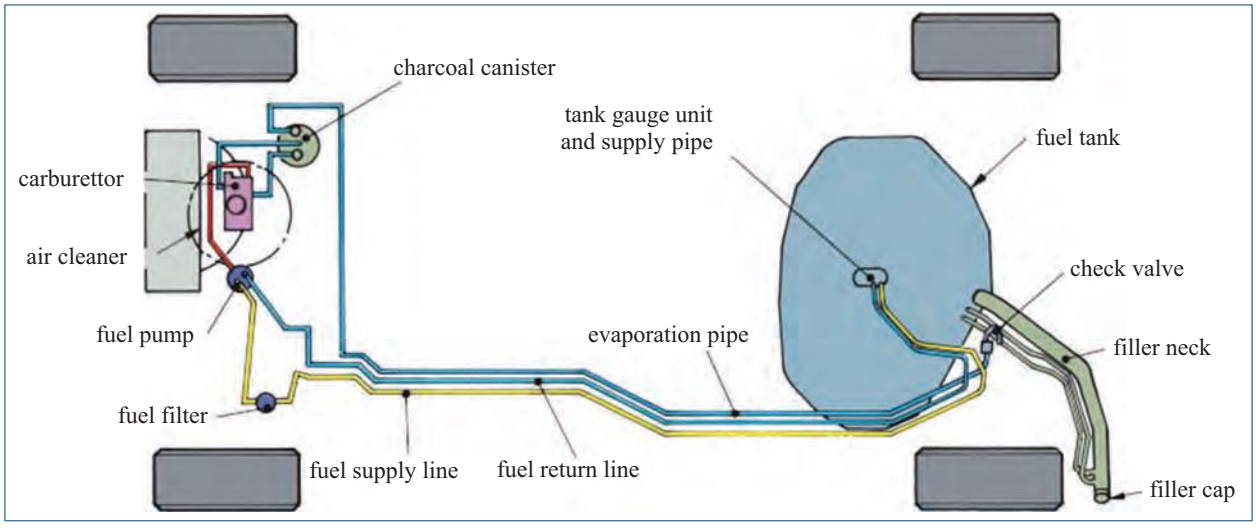


Figure 31.4 Schematic fuel system showing the fuel lines (pipes) between the fuel tank at the rear of the vehicle and the engine component FORD

Other lines connect the fuel pump to the carburettor, and the charcoal canister to the engine.

31.3.2 Fuel filters

A fine gauze filter is fitted to the suction pipe in the fuel tank, and a line filter is fitted in the supply line between the fuel tank and the fuel pump, or between the fuel pump and the carburettor (Figure 31.5). The filter traps dirt and water that may have entered the fuel tank. It is not serviceable and should be replaced periodically. The amount of dirt or water in the filter can usually be seen through the transparent plastic body. A blocked filter on the suction side of the fuel pump will restrict the fuel supply to the pump and cause a shortage of fuel at the carburettor.

Figure 31.5 Low-pressure disposable fuel filters

31.3.3 Fuel pumps

Figure 31.6 shows a simplified mechanical fuel pump. This has an inlet and an outlet valve and a flexible diaphragm that is moved up and down by the action of the rocker arm. The end of the rocker arm is operated by an eccentric on the camshaft. A spring under the diaphragm pushes it upwards, with a spring against the rocker arm ensuring that it follows the eccentric. The pump operates as follows:

1 As the camshaft rotates, the eccentric moves the rock er arm backwards and forwards.
2 This movement is transferred through the pullrod to the diaphragm.
3 As the diaphragm is pulled down, fuel is drawn through the inlet valve into the pumping chamber above the diaphragm.
4 As the diaphragm is moved up by the action of the diaphragm spring, fuel is forced from the pumping chamber through the outlet valve and into the bowl of the carburettor .

31.3.4 Fuel pump operation

The fuel pump can deliver much more fuel than is needed by the engine, and a return line takes surplus fuel back to the tank. The circulating fuel cools the fuel pump and prevents vapour locks from forming. It also keeps the fuel at a fairly uniform temperature, assisting mixture control.

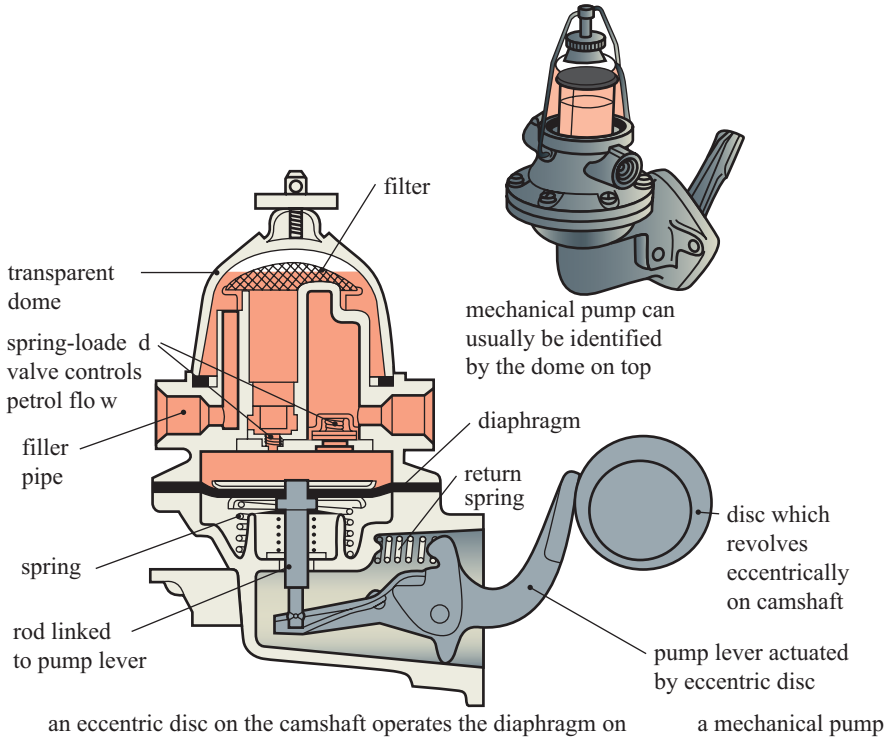


Figure 31.6 Mechanical fuel pump

The stroke of the pump is automatically adjusted to suit the volume of fuel required. When pressure builds up between the pump and the carburettor, pressure in the pumping chamber prevents the spring from forcing the diaphragm fully upwards, reducing the pumping stroke. The eccentric continues to move the rocker arm through its full movement, but the design of the pump allows free movement at the pull rod end.

31.3.5 Electric fuel pumps

Electric fuel pumps are sometimes used with carburettor systems (Figure 31.7). They are usually plunger pumps, where a small plunger in a cylinder is moved up and down electromagnetically. Some electric pumps operate continuously, and others cut out under pressure. Generally, these pumps are not repairable.

31.4 Carburettor functions

The carburettor provides a mixture of air and fuel to the engine. This mixture must be in the right proportion to suit all the different operating conditions of the engine: too much fuel for the air would be wasteful and would pollute the atmosphere; not enough would cause loss of engine power and poor performance.

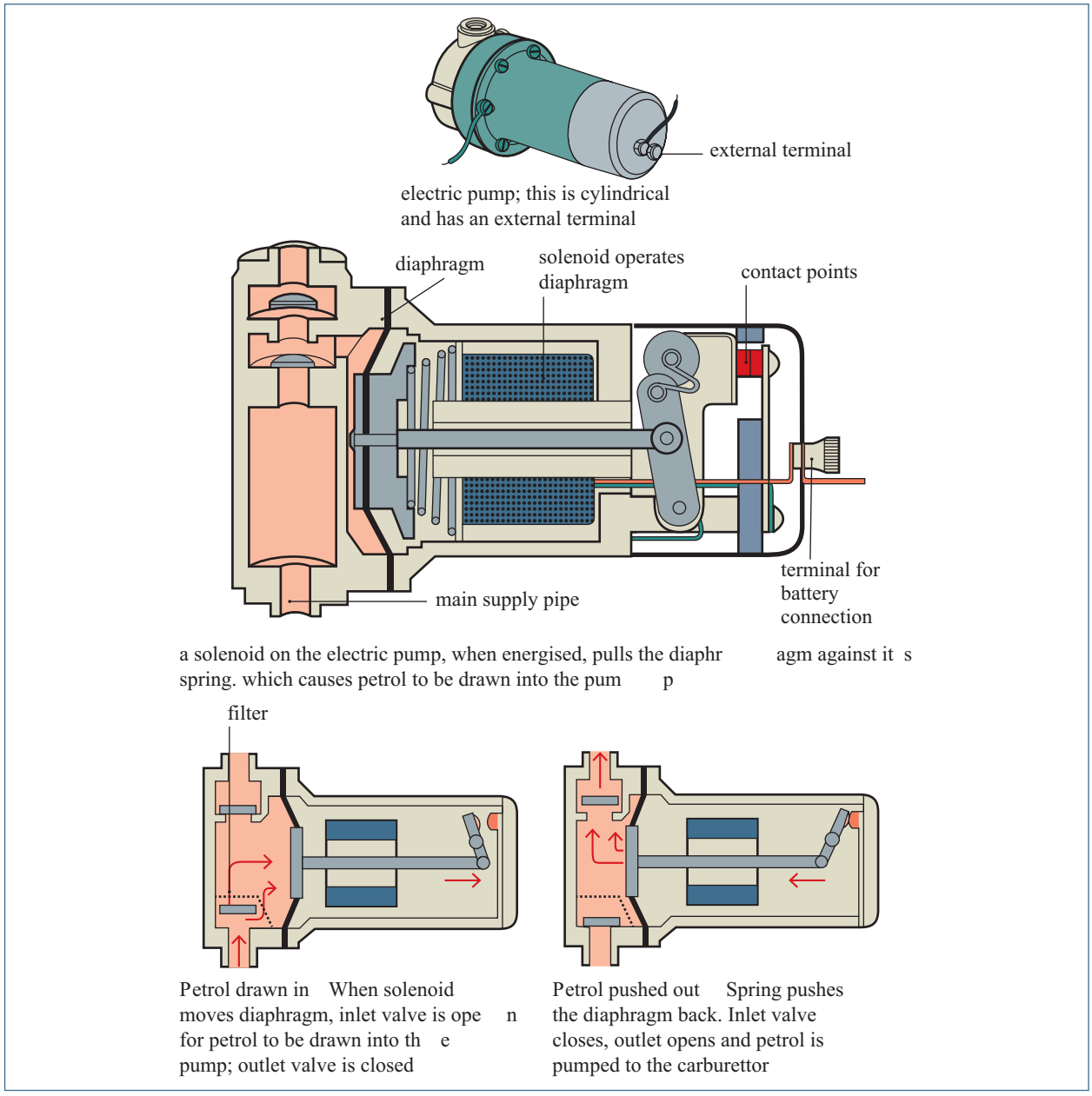


Figure 31.7 Electric fuel pump

As well as providing the correct air–fuel mixture, the carburettor controls the speed and power of the engine. The carburettor has to perform the following functions:

1 Atomise the fuel and mix it with air .
2 Provide the correct air–fuel mixture for good combustion.
3 Control the amount of air–fuel mixture delivered to the engine .

31.4.1 Atomisation

Atomisation means breaking down a liquid to a spray. Figure 31.8 shows how a carburettor does this by immersing a nozzle in a bowl of fuel. In Figure 31.8(a), the nozzle is discharging atomised fuel. Fuel from the bowl has collected air from the air bleed, and this has atomised the fuel. In Figure 31.8(b), the nozzle has no air bleed and this supplies large drops of liquid fuel.

The atomised fuel from the nozzle has less density than liquid fuel, and the flow of atomised fuel in the carburettor can be stopped, started or varied much more quickly than if the fuel was a liquid. The atomised fuel from the nozzle is further atomised by the air flowing down through the carburettor.

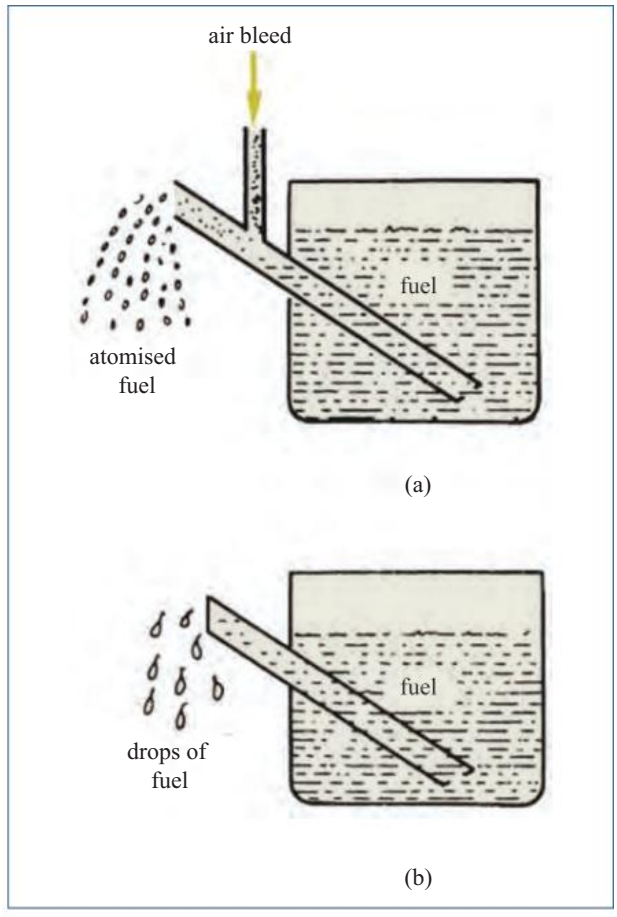


Figure 31.8 Principle of the air bleed (a) atomised fuel from the discharge nozzle (b) large drops of liquid fuel as there is no air bleed

31.4.2 Controlling the amount of air–fuel mixture

The amount of air–fuel mixture delivered by the carburettor is controlled by the carburettor throttle valve (sometimes referred to as a *butterfly valve*). Located in the throttle body at the base of the carburettor, the throttle valve is connected by a cable or linkage to the driver's accelerator pedal.

Pressing the accelerator to open the throttle valve allows more atomised fuel to pass, increasing the speed or power of the engine. Closing the throttle valve reduces the amount of atomised fuel passing from the carburettor to a minimum. This reduces engine power and, if the vehicle is stationary, allows it to idle.

31.5 Air and fuel flow in a carburettor

The simple carburettor shown in Figure 31.9 has a float bowl for the fuel, a fuel discharge nozzle, an air venturi and a throttle valve. When the engine is running, an air flow is created through the venturi from the pumping action of the pistons during the intake strokes. The venturi has a particular shape, with the inside diameter having a constriction. A low pressure is created at the constriction, and this is where the end of the nozzle protrudes into the air flow. Figure 31.9 shows fuel in the float bowl and the nozzle discharging fuel into the air stream. Atmospheric

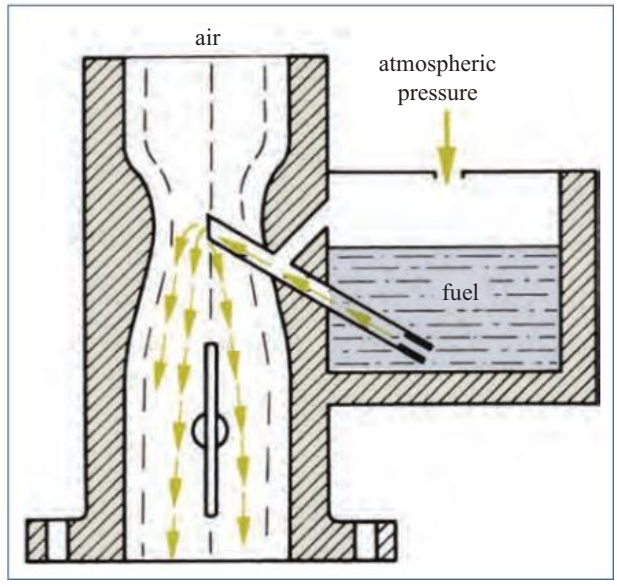


Figure 31.9 The venturi causes a low-pressure area in the air system and atmospheric pressure forces fuel from the nozzle

pressure on the fuel in the float bowl is greater than the pressure at the end of the nozzle, and this causes fuel to flow from the nozzle.

31.5.1 Venturi action

To understand venturi action, air can be considered to consist of a number of molecules. High pressure occurs when the molecules are crowded together, and low pressure occurs when they are spaced apart.

The venturi works as follows: air flows into the top of the carburettor and the molecules are moving at a certain speed. However, when they reach the constriction in the venturi, they have to speed up so that they can all pass through the narrower space. At this higher air speed, the molecules tend to separate from each other, and so a low pressure occurs where they reach their highest speed. The faster the molecules move, the lower the pressure.

31.6 Basic carburettor operation

Figure 31.10 shows a basic downdraft carburettor. In addition to the parts shown in previous figures, it has a float and needle valve in the float bowl, an idle mixture adjusting screw and a choke valve.

The diagram shows the throttle valve partly open, which would be its position with the engine running at a reasonable speed. Opening and closing the throttle would change the speed of the engine.

31.6.1 Operation at normal driving speeds

Carburettor operation for normal driving speeds, as shown in Figure 31.10, is as follows:

1. The fuel pump provides fuel to the float bowl, and the float and the needle valve control the fuel level.
2. The throttle valve is partly open to allow the air–fuel mixture from the carburettor to pass into the intake manifold.
3. Air entering the top of the carburettor flows down through the venturi to create a low pressure (below atmospheric) in the area around the end of the discharge nozzle.
4. Atmospheric pressure acting on the surface of the fuel in the float bowl forces fuel through the main jet and up the discharge nozzle into the venturi.
5. Fuel from the nozzle discharges into the air stream passing through the venturi. The fuel is atomised by the air and carried down past the throttle valve to the intake manifold and into the engine.

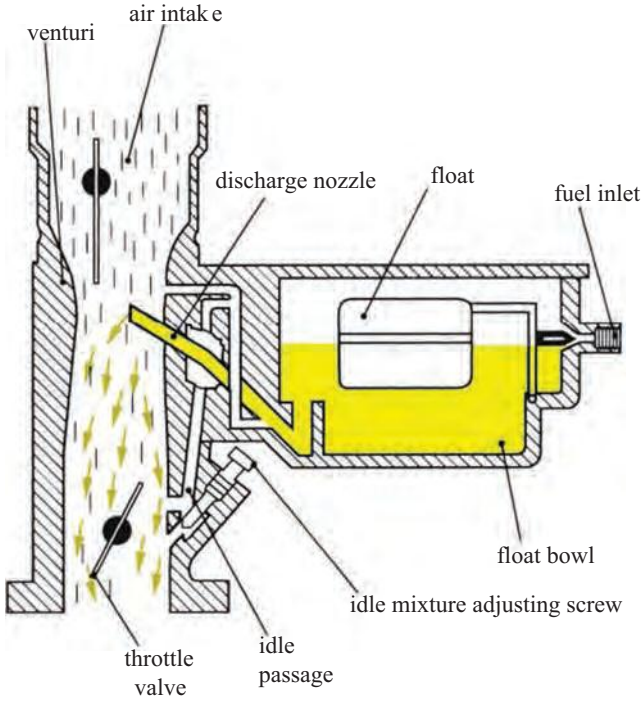


Figure 31.10 Basic downdraft carburettor at normal driving speeds—the throttle valve controls air and fuel flow

The position of the throttle valve controls the quantity of air–fuel mixture entering the engine. If the throttle is opened, more air and more fuel will be delivered to the engine, and this will increase engine power or speed. If the throttle is closed, less air–fuel mixture will enter the engine and so the engine power or speed will be reduced.

31.6.2 Operation at idle

Carburettor operation with the engine at idle, as shown in Figure 31.11, is as follows:

1. The throttle valve is closed and only a small amount of air flows through the carburettor .
2. Because the throttle valve has block ed off the main air flow , there will be no venturi action, but there will be low pressure below the throttle valve .
3. Fuel flows from the float bowl through the idle passages to be discharged through the idle port below the throttle valve .
4. The air bleed allows air to enter the at-idle fuel on its way through the passage from the float bowl. This helps to atomise the fuel before it is discharged through the idle port.
5. The idle adjustment screw adjusts the idle mixture . The screw has a tapered end which fits into the idle port. This is screwed in or out to vary the amount of fuel that passes through the idle port.
6. A small amount of air passes the throttle valve . Fuel from the idle port mix es with this to provide the air–fuel mixture for idling.

31.6.3 Operation at low speeds

Figure 31.12 shows operation at lower—but above idle—engine speeds.

1. The throttle valve is slightly open so only a small amount of air flows in through the top of the carburettor . The air flow through the venturi is too slow to provide a low pressure , so there is no fuel from the discharge nozzle.
2. The throttle valve is opened so that it is just past the low-speed port, which is located directly above the idle port.
3. Fuel, which already has some air mix ed with it from the air bleed, flows from both the idle port and the low-speed port. This mix es with the air passing the throttle valve to provide the air–fuel mixture needed for low-speed, low-power operation.

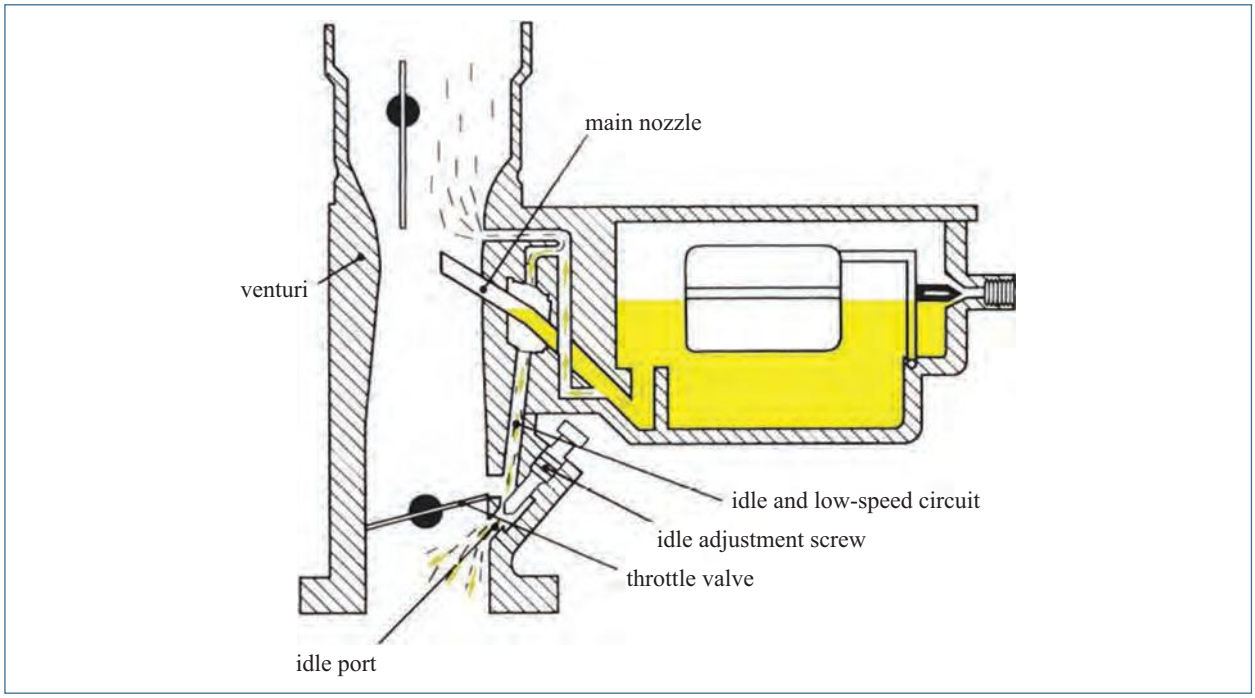


Figure 31.11 Idle system of a carburettor—the throttle valve is al most fully closed; the fuel, with some air from the air bleed above the venturi, is supplied past the idle adjustment screw

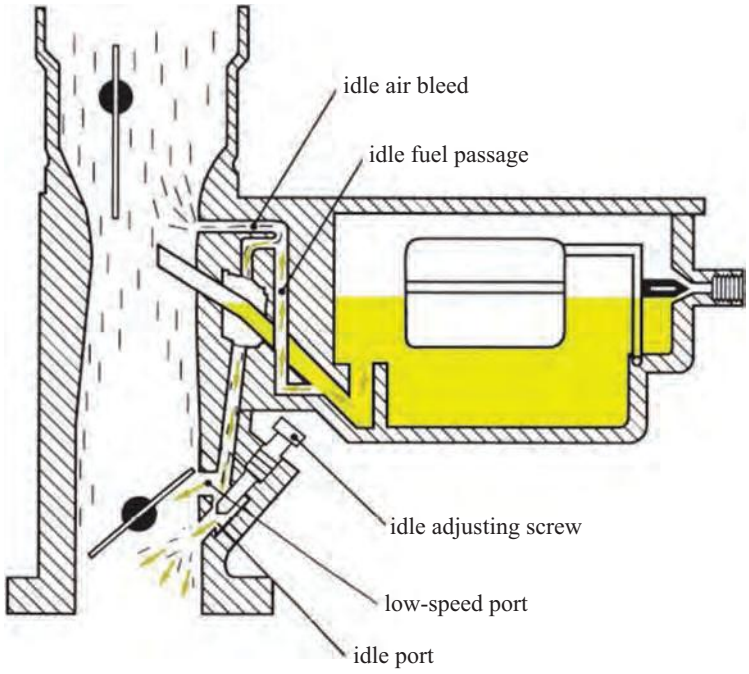


Figure 31.12 Low-speed system of a carburettor—the throttle valve is slightly open and fuel is supplied through the low-speed port and the idle port

31.6.4 Operation when starting (choke)

When the engine is being cranked for starting, there is very little air flow through the carburettor, whether the throttle valve is open or not. The choke valve is needed for cold starting, as shown in Figure 31.13.

1 With the choke valve closed, the top of the carburettor is almost closed off and there is no air flow.
2 As the engine is cranked, the pumping action of the pistons creates a low pressure in the carburettor.
3 The low pressure causes fuel to flow from the discharge nozzle and from the idle and slow-speed ports to provide a rich mixture for starting.

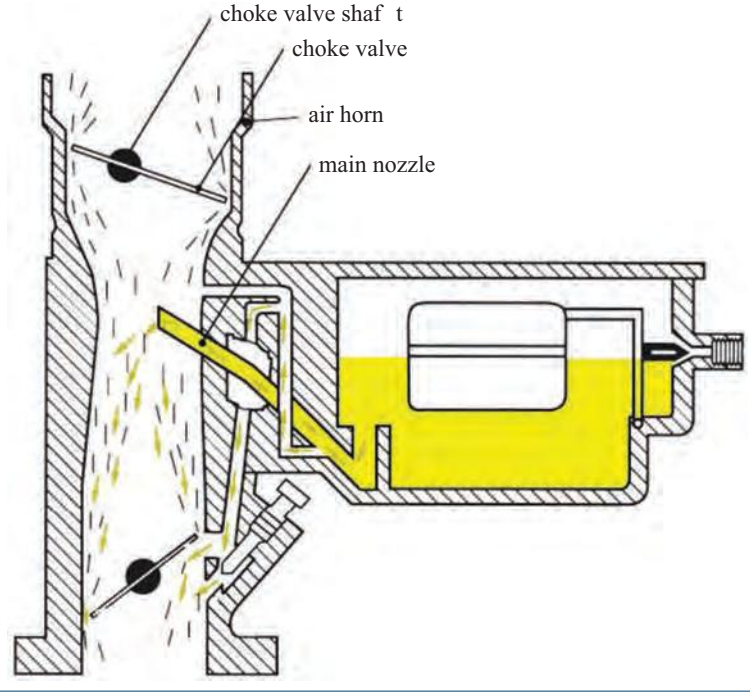


Figure 31.13 Choke operation—the choke valve has closed off the air supply to create a vacuum (negative pressure) in the carburettor, causing fuel to flow from the main nozzle and the idle ports

31.7 Carburettor systems

The carburettor has a number of different systems, also referred to as *circuits, stages* or *phases*:

- float system
- idle system
- fast-idle or low-speed system
- main or high-speed system
- chok e system
- power system
- accelerating system.

With the exception of the float, power and accelerating systems, these systems have been explained as part of the basic carburettor operation. The float system includes the float bowl and the float, as well as the needle valve and seat. Fuel from the fuel pump flows into the carburettor bowl and is maintained at a set level by the float, which opens and closes the needle valve. The power system provides extra fuel for the discharge nozzle when the engine is operating under heavy load conditions. The accelerating system squirts extra fuel into the air stream whenever the accelerator is pressed. This prevents any hesitation by the engine that could occur as a result of a temporary shortage of fuel.

31.8 Carburettor construction

Figure 31.14 is a diagrammatic view of a complete carburettor (a single-barrel downdraft carburettor). The following is a summary of its parts and their functions.

1 Venturi. Increases the air velocity to create a depression at the main discharge nozzle . There is a primary venturi and a secondary venturi, which increases the venturi efficiency .

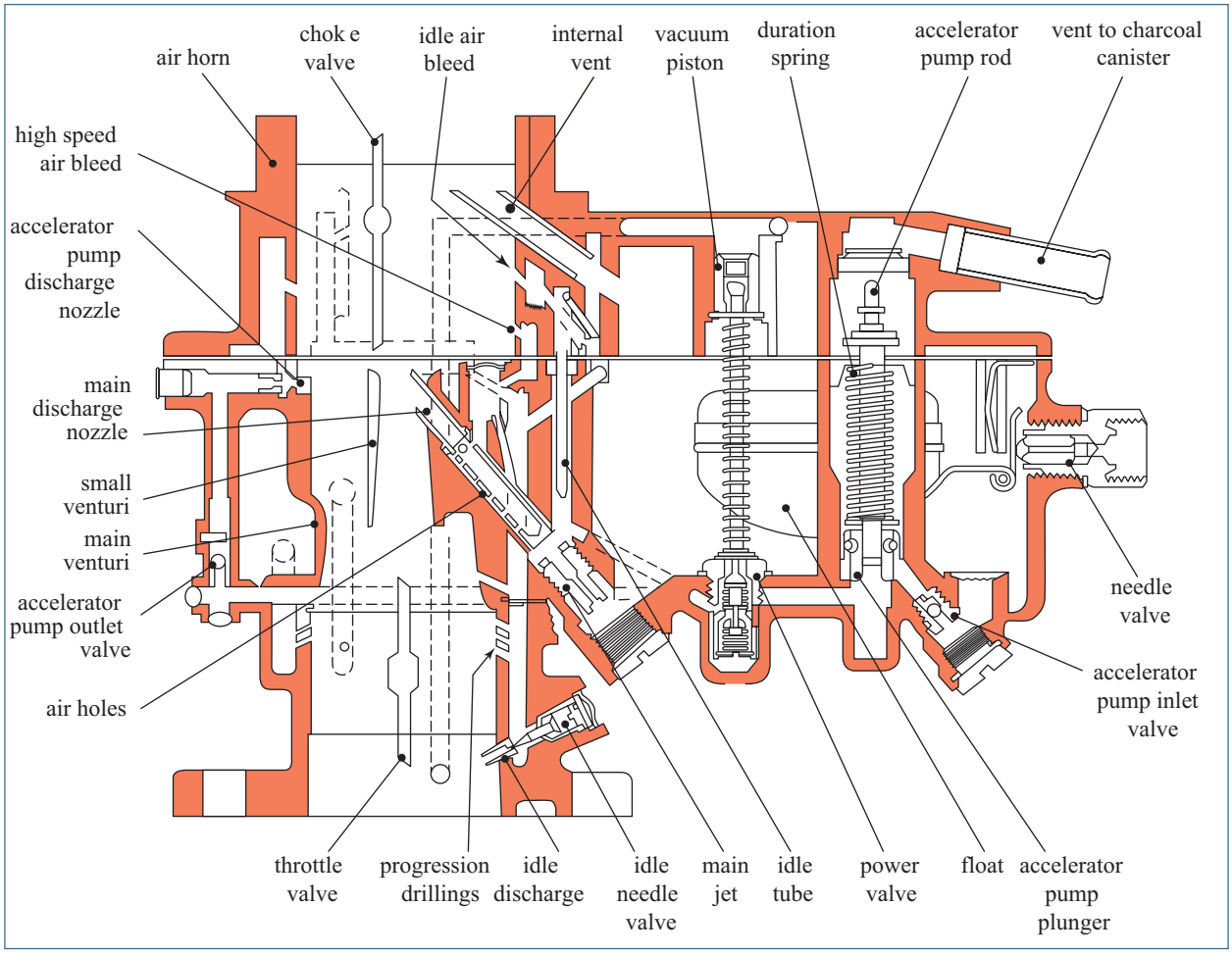


Figure 31.14 Schematic diagram of a carburettor BENDIX

2 Main discharge nozzle . Discharges atomised fuel into the air stream during normal engine operation.
3 Main metering jet. Meters the fuel that goes through the main discharge nozzle .
4 High-speed air bleed. Bleeds air into the main discharge system to atomise the fuel in the discharge nozzle .
5 Throttle valve . Controls the air flow through the carburettor and so controls the quantity of air–fuel mixture that goes to the intak e manifold.
6 Chok e valve . Restricts the air supply to provide a rich mixture during the starting and warm-up period.
7 Idle mixture adjustment screw . Adjusts the quantity of atomised fuel delivered from the idle discharge port.
8 Progression drillings. Discharge atomised fuel during the slow-speed range .
9 Idle air bleed. Located in the air horn, this bleeds air into the idle system to atomise the idle fuel.
10 Idle tube . A jet on the lower end of the tube that meters the fuel for the idle system.
11 Float and needle valve . Control the level of the fuel in the float bowl.
12 Power jet. Supplies fuel for high-speed driving or heavy load conditions. It is operated by the vacuum piston and supplements the fuel from the main jet.
13 Vacuum piston. Controlled by intak e vacuum, this automatically opens the power when the engine is operating under load at low speeds.
14 Accelerator pump . Briefly sprays fuel into the venturi area during acceleration.
15 Accelerator pump inlet valve . Opens on the pump upstrok e to admit fuel into the pump .
16 Accelerator pump bypass jet. Meters fuel being discharged from the pump . Includes pump outlet valve .
17 Accelerator pump discharge nozzle . Discharges fuel from accelerator pump when accelerator is pressed.

31.9 Types of electronic fuel injection systems

There are three main types of electronic fuel injection (EFI), the differentiating factors being the location of the injectors and their mode of injection. These three systems are:

1 Throttle-body injection. One or two injectors are used in a throttle body , which is mounted on the intak e manifold. Also called single-point injection or central fuel injection, this system was used in the change from carburettors to multipoint injection (it is rare today).
2 Multipoint injection. A separate injector is used for each cylinder , and the fuel is sprayed into the intak e ports. Also called port fuel injection, this is the most commonly manufactured type .
3 Direct fuel injection. The fuel injectors are mounted directly into the combustion chamber and high-pressure fuel is injected straight into the air charge above the piston.

31.9.1 Throttle-body injection

Figure 31.15 shows a basic throttle-body, or single-point, EFI system. This has the same type of supply system as a multipoint but runs at a lower pressure. It has a throttle body with one or two injectors. In both systems, the ECU controls the quantity of fuel delivered by the injectors.

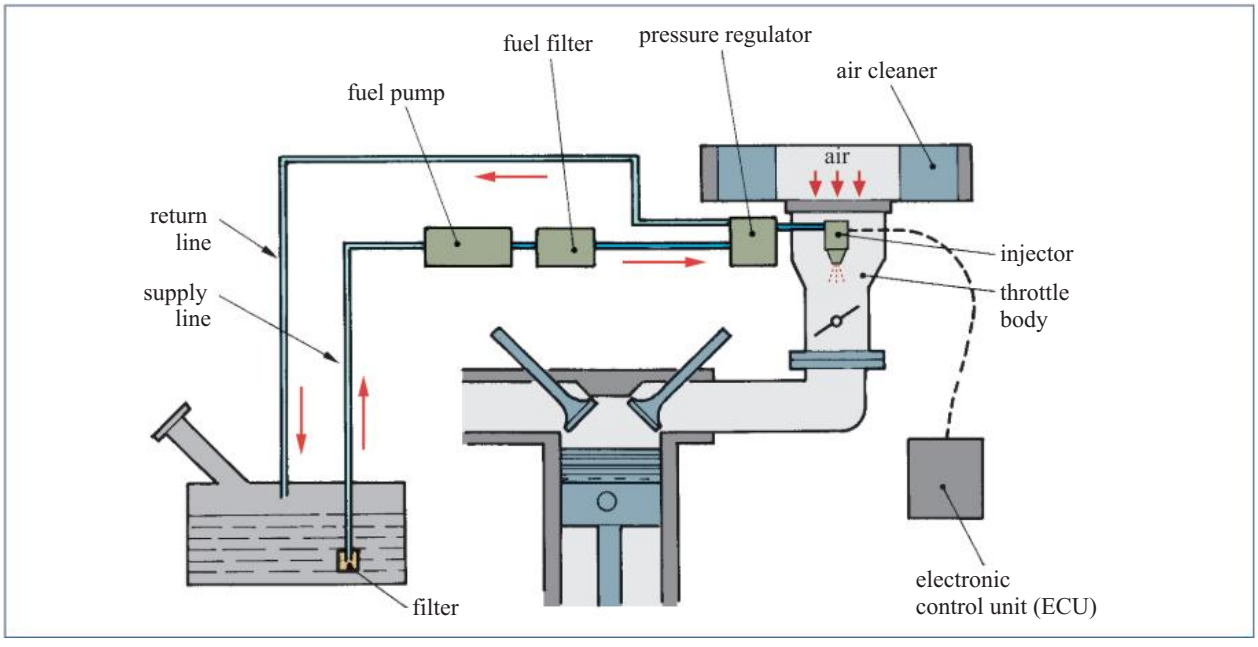


Figure 31.15 Basic throttle-body injection system

31.9.2 Multipoint injection

Figure 31.16 shows a basic multipoint EFI system. The parts are:

1 Air cleaner and ducts. Provide clean air and reduce induction noise .
2 Airflow meter (sensor). Measures the flow of air .
3 Throttle valve . Controls the flow of air into the engine .
4 Plenum chamber (surge tank or swirl chamber). Dampens the flow of air .
5 Fuel tank. Stores fuel.
6 Electric fuel pump . Provides pressure in the system.
7 Fuel filter. Protects the injectors.
8 Fuel rail. Supplies the injectors with pressure fuel.
9 Injectors. Spray measured fuel into the intak e ports.
10 Pressure regulator . Controls the pressure in the system.
11 ECU. Controls fuel injection and other engine requirements.

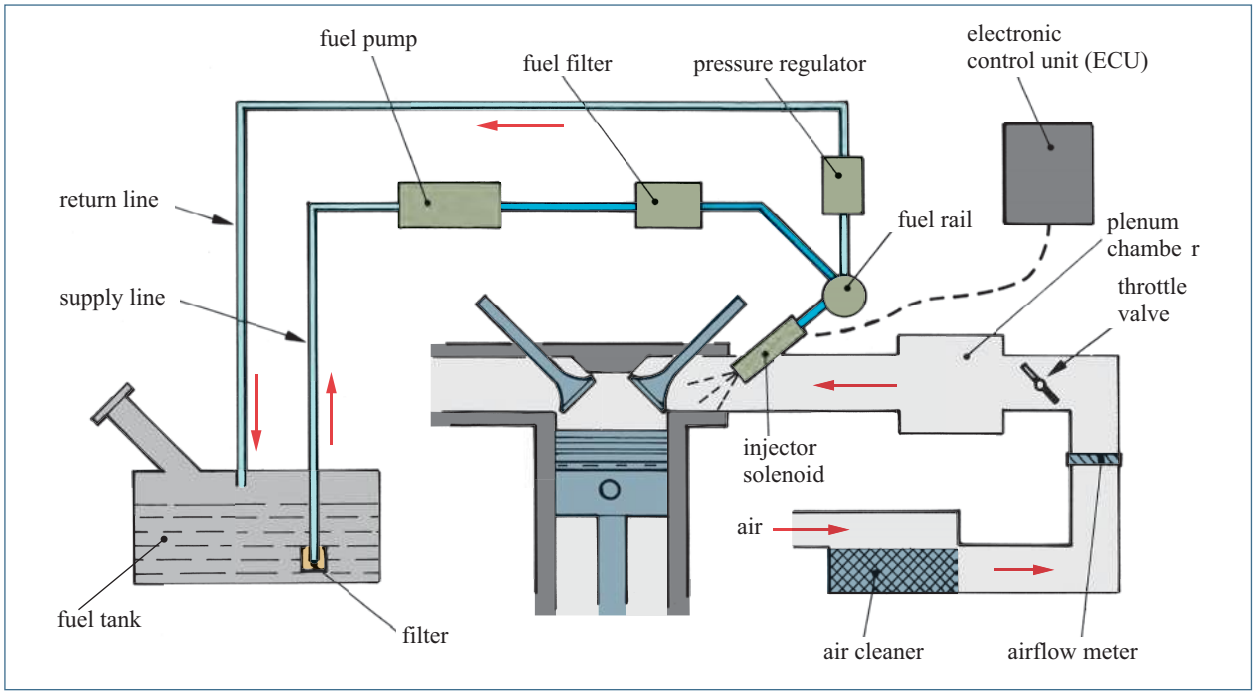


Figure 31.16 Basic multipoint EFI system

31.9.3 Direct fuel injection

Figure 31.17 shows a basic direct fuel-injection system, with the main components identified. Direct injection sprays the fuel directly into the combustion chamber and has greater control over fuel delivery and higher operating pressures than other EFI systems.

31.10 Basic principles of EFI

The basic operation of an EFI system hinges upon three sub-systems:

1 Air intake system. The air passing through the engine 's air intak e system is measured. This determines the base air–fuel ratio mixture , and is used by the ECU to determine engine load.
2 Fuel system. Consists of an electric petrol pump , electronically controlled fuel injectors and a mechanically controlled fuel pressure regulator with a fuel return line .
3 Electronic controls. An ECU collects information from various parts of the engine and controls outputs such as the fuel delivered by the injectors. The quantity of fuel delivered is almost instantaneously adjusted by the ECU to meet changes in engine conditions.

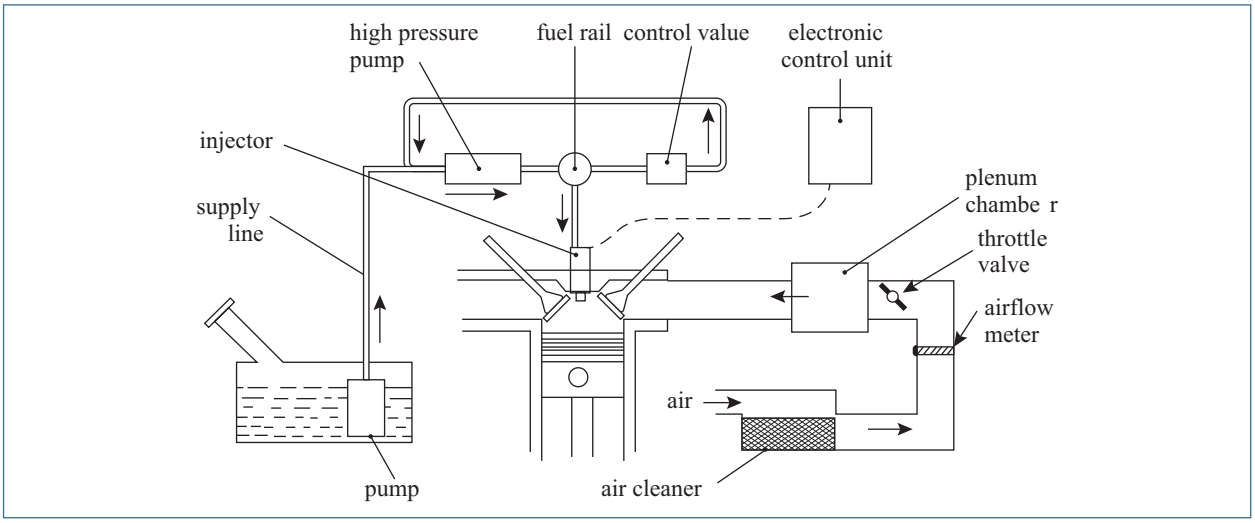


Figure 31.17 Basic petrol direct injection system

31.11 Air-intake system

In the block diagram of an air-intake system shown in Figure 31.18, the air enters at the air cleaner and flows through the system to the engine. The parts and their functions are as follows:

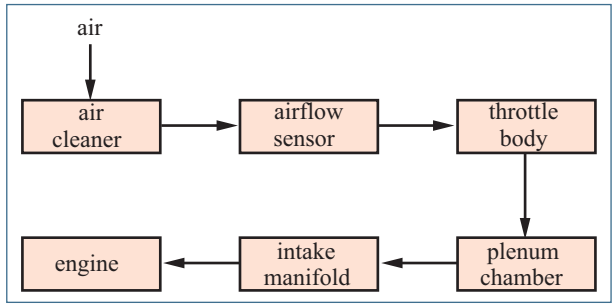


Figure 31.18 Block diagram of a basic EFI air system

1 Air cleaner . Has a cellulose fibre element that provides clean air for the system.
2 Airflow sensor . Measures the quantity of air flowing into the system so that the correct amount of fuel can be provided for the air–fuel ratio .
3 Throttle body . Has a throttle valve operated by the accelerator pedal. This controls the amount of air that enters the engine .
4 Plenum chamber . Acts as a surge tank and distributes the air evenly to the branches of the intak e manifold.
5 Intak e manifold. Its branches or pipes carry air to the cylinders and also provide a mounting for the injectors.

31.12 Fuel systems

31.12.1 Return-to-tan k fuel system

The main parts of a return-to-tank fuel system are shown in the block diagram in Figure 31.19.

1 Fuel tank. Performs the usual function of storing fuel, has a fuel supply line to the engine and a return line . In most installations, a submerged fuel pump is fitted.
2 Fuel pump (electric). The electric motor and pump are in a common housing and operate whenever the engine is running. If the fuel pump is fitted above the level of the fuel in the tank, an additional low-pressure pump is sometimes located inside the fuel tank to prime the main pump .
3 Fuel filter. A paper filter inside a metal or heavy plastic casing is fitted in the fuel line so that all the fuel is filtered before it reaches the injectors.
4 Fuel rail. Receives fuel from the filter and supplies it to the injectors. All the injectors are connected to the common fuel rail.

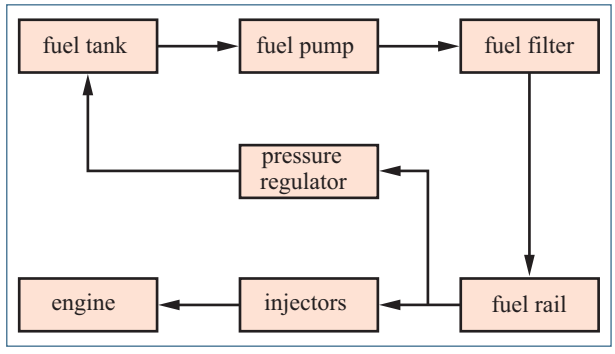


Figure 31.19 Block diagram of the fuel system for multipoint EFI return-to-tank system

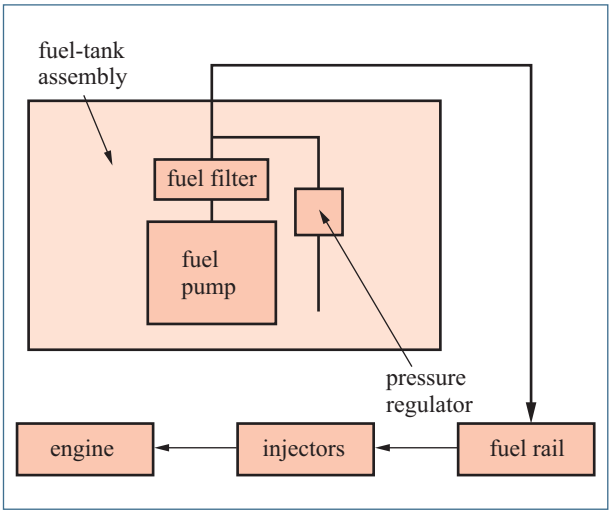


Figure 31.20 Block diagram for a returnless EFI fuel system

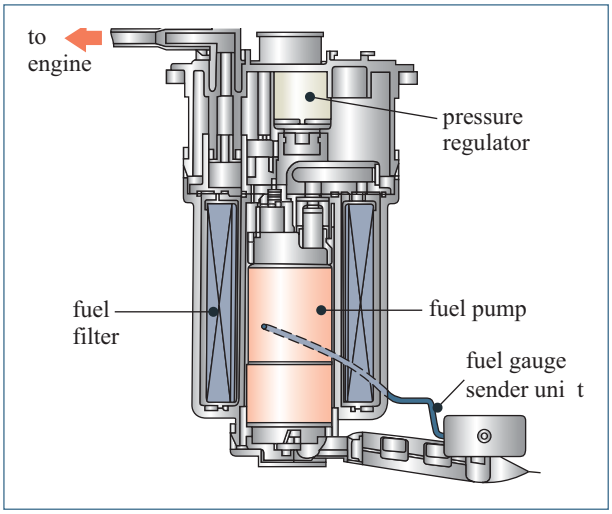


Figure 31.21 Fuel-pump assembly for a returnless fuel system located in the fuel tank

5 Injectors. Spray atomised fuel into the intake ports. For each rotation of the crankshaft in simultaneous injection systems, each injector valve opens once, regardless of whether the inlet valve is open or not. If the valve is closed, the fuel is stored in and around the inlet port until the next time the valve opens. The fuel will then be drawn into the combustion chamber. With this arrangement, only half the fuel requirements are injected each time injection occurs.

6 Pressure regulator. Fitted at the end of the fuel rail, it keeps the pressure in the system high enough for injection. It also maintains a constant pressure differential across the injector.

Handy hint: This arrangement is referred to as a return-to-tank system because it has a return fuel line from the pressure regulator in the engine compartment.

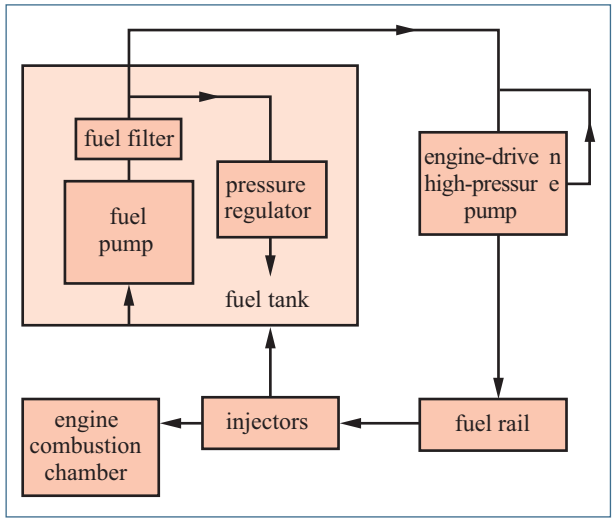


Figure 31.22 Block diagram of a direct petrol injection system

31.12.2 Returnless fuel system

Figure 31.20 shows the main parts of a *returnless* fuel system. These were developed to overcome the evaporative emission problems associated with returning hot fuel from the fuel rail back to the fuel tank. The main differentiating features between this and a return-to-tank system are:

1 Fuel tank. Also houses the fuel pump, fuel filter and pressure-regulator assembly. There is no return line from the fuel rail.
2 Fuel pump. The pump assembly contains the fuel filter, the pressure regulator valve and the fuel gauge sender unit (Figure 31.21).
3 Fuel filter. Part of the pump assembly. Mounted in the fuel tank.

31.12.3 Direct injection system

Figure 31.22 shows the arrangement of a direct petrol injection system. It has a low-pressure electric fuel pump in the fuel tank, and an external high-pressure fuel pump driven by the engine's camshaft. This pump supplies fuel to the fuel rail and regulates its pressure. The pressure regulator is part of the pump assembly fitted inside the fuel tank, as shown in the diagram. It keeps the pressure in the system high enough for injection.

31.13 Control system

The electronic control system consists of a central ECU and a number of sensors and other electronic controls. Some of these are shown in the block diagram in Figure 31.23. The sensors use various means to measure the engine conditions at their locations, and this information is then fed to the ECU. These sensors or controls are:

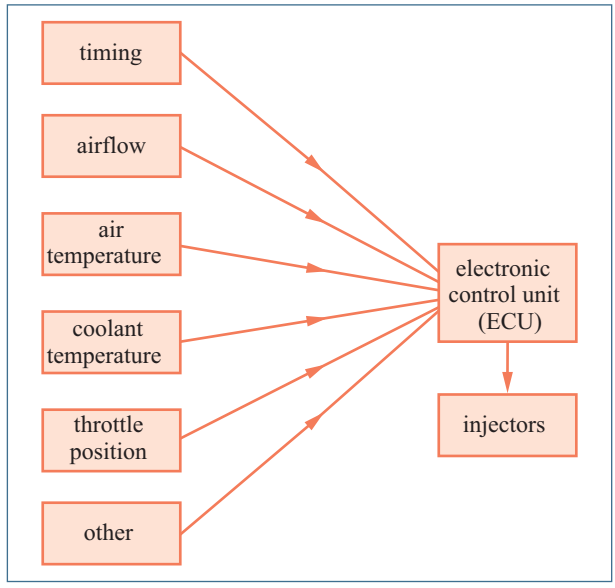


Figure 31.23 Block diagram for a control system for a basic EFI system

1 ECU. Processes the information provided by the sensors. It determines the opening period of the injectors and therefore the amount of fuel injected. It also controls the spark and ignition timing.
2 Timing sensor . Provides a signal that, after being processed by the ECU , times the injectors. Each injector could be opened once per engine revolution, or once each second engine revolution. In some early systems, this was a distributor tachometer signal; later systems used a crank -angle sensor .
3 Airflow sensor . Also referred to as a load sensor , this provides a continuous measurement of all the air being tak en into the engine . The ECU directs the injector to provide the right amount of fuel to suit the air flow.
4 Air-temperature sensor . Installed in the airflow meter or the intak e airstream to measure the temperature of the air being drawn into the system. The density of air (and the amount of o xygen that it contains) is related to its temperature . The ECU adjusts the quantity of fuel to suit the air density .
5 Coolant-temperature sensor . A sensor in the cylinder head that measures the coolant temperature . It enables a richer mixture to be provided when the engine is cold and also during the warming-up period.
6 Throttle-position sensor . Operated by the throttle-valve shaft, this transmits the throttle position to the ECU , which can then mak e adjustments. It also indicates other positions, including wide-open throttle .
7 Other sensors. Variously used for particular conditions, such as the thermo-time switch for cold starting.

The voltage of the electrical system is also taken into account by the ECU, because the state of the electrical system affects the operation of the injector solenoids.

Handy hint: The relationship between the following should be noted: the throttle valve , controlled by the driver through the accelerator , determines the amount of airflow; the airflow sensor measures the actual airflow; and the injector provides an appropriate amount of fuel. The actual airflow can vary for the same throttle opening due to engine load.

Handy hint: Some engines have a cylinder-head temperature sensor instead of , or in addition to , the coolant temperature sensor and a fuel temperature sensor .

31.14 Operation of a multipoint EFI system

Figure 31.24 shows the arrangement of an early multipoint fuel system. It contains the three sub-systems (air intake, fuel and control) previously described. Its principles have been applied to many other EFI systems, and it has been developed to include engine management functions.

31.14.1 Air-intake system

The air system provides clean air to the engine and also measures airflow and therefore engine load. It operates as follows

1 Filtered air from the air cleaner (not shown) passes into the airflow sensor .
2 The airflow sensor measures the quantity of air as it flows through, sending information to the ECU .
3 The throttle valve is used by the driver to control the flow of air into the engine . This controls its speed and power . The position of the throttle valve is relayed to the ECU by the throttle-valve switch.

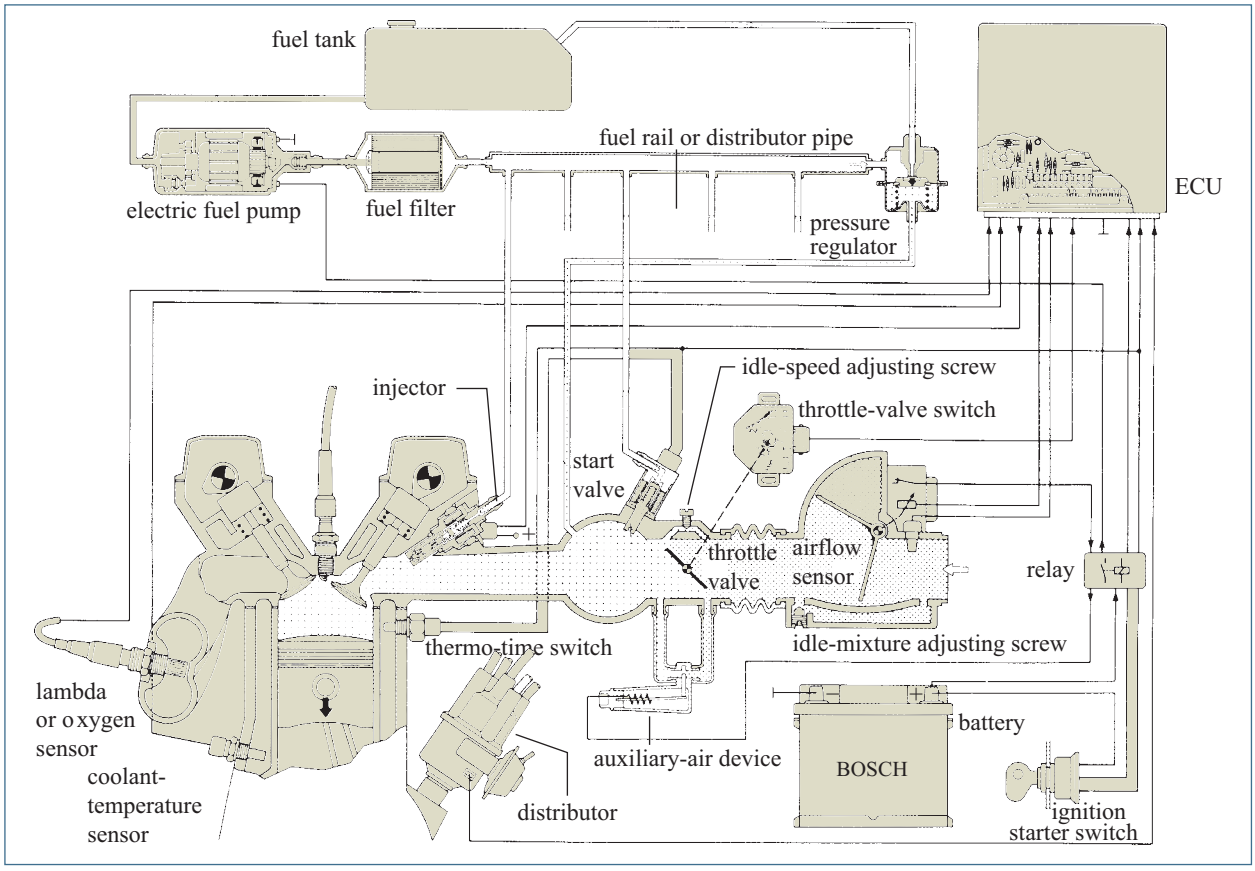


Figure 31.24 Schematic of an early multipoint EFI system BOSCH

4 Air passes through the plenum chamber and then into the intake manifold before entering the engine at the intake port.
5 The air is mixed with fuel sprayed towards the valve from the injector solenoid to form a fuel charge.
6 The auxiliary-air device allows extra air around the throttle valve when the engine is cold to speed up the engine idle. This has a similar effect to opening the throttle slightly.

Handy hint: In current systems, a separate ignition coil over each spark plug is used. This reduces the wearing of components by doing away with the ignition distributor.

31.14.2 Intake manifold design

The intake manifold used with multipoint EFI systems carries air only and not a mixture of air and fuel. This means that the manifold can be designed specifically to suit airflow. As the fuel is injected at the intake ports, the manifold requires no heating to keep the air–fuel mixture atomised. It is designed with all its pipes or branches of equal (or almost equal) length. The pipes are made of a particular length to make most use of the ram effect produced by air-intake pulsations for improved volumetric efficiency.

31.14.3 Fuel system

The fuel system pumps fuel from the fuel tank to the fuel rail and sprays it into the intake manifold by the ECU opening the injectors. It works as follows:

1 The fuel is pumped from the fuel tank by an electric pump, which maintains a flow in the system. The fuel pump contains a pressure-relief valve and a non-return check valve.
2 Fuel is filtered as it passes through the filter into the fuel rail or distributor pipe.
3 Fuel pressure is held in the fuel rail by the pressure regulator.
4 The injectors are connected to the fuel rail. They spray fuel into the intake manifold when actuated by the ECU.
5 In early systems, a start valve or cold-start injector was sometimes used for cold conditions. This supplied an additional spray of fuel for starting.

31.14.4 Electronic control system

The electronic control unit (ECU) receives input voltage signals from a number of sources. It processes them and sends out voltage pulse signals to the injectors and ignition coils. When the ignition switch is turned on, the relay is energised and the ECU is activated. The ECU can then adjust fuel injection to suit the input information that it receives. This information comes from a number of sensors. These sensors and their functions are:

1 The distributor . For engine speed and injection timing.
2 The airflow sensor . For the quantity of air (for which the right amount of fuel must be injected) and current engine load.
3 The throttle switch. For the throttle-valve opening.
4 The temperature sensor . For engine-coolant temperature .
5 The oxygen sensor . In the exhaust manifold, for fine-tuning the air–fuel mixture .
6 The thermo-time switch. For the length of time that the cold-start valve remains operative .

31.15 Components of a multipoint EFI system

The above covers the general operation of a fairly basic multipoint EFI system. The components can now be considered in more detail. Later versions of systems will have components that perform the same functions as these, but some will be of a different design.

31.15.1 Airflow sensor

The airflow sensor in this particular system (Figure 31.25) consists of a flap or vane that is deflected by the volumetric flow of air through the sensor. The flap is connected to the moving contact of a *potentiometer* so that the resistance of the potentiometer is varied according to the position of the flap. This provides a changing voltage signal that is related to airflow by volume (litres/minute). The ECU then adjusts the fuel from the injectors to suit the amount of air entering the engine.

The flap is V-shaped. One part of the flap is used as an airflow valve; the other part is a compensating flap. This operates in a damping chamber to dampen flap movement. This is a basic method of sensing airflow.

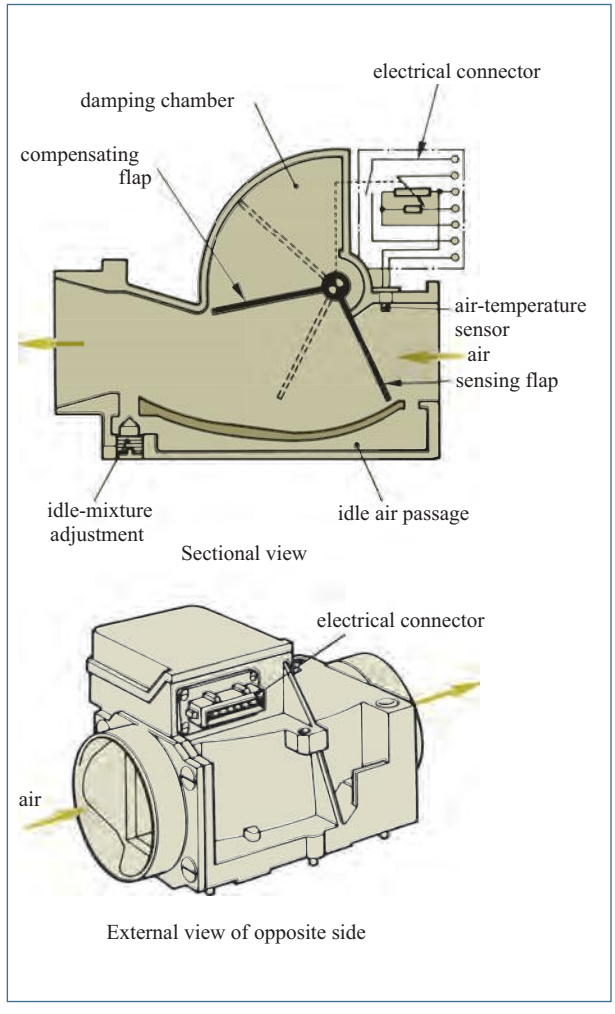


Figure 31.25 Vane-type airflow meter FORD

31.15.2 Air-temperature sensor

An inbuilt air-temperature sensor is fitted in the intake side of the airflow sensor. This measures the temperature (density) of the incoming air and signals this information to the ECU, which adjusts the fuel to suit air density.

31.15.3 Fuel pump

The fuel pump is a roller-cell electric pump (Figure 31.26). It consists of a pumping element and an electric motor in a common housing. An electric pump is used because the system must be full and pressurised before the engine can be started. The injectors need this pressure to spray starting fuel into the intake manifold.

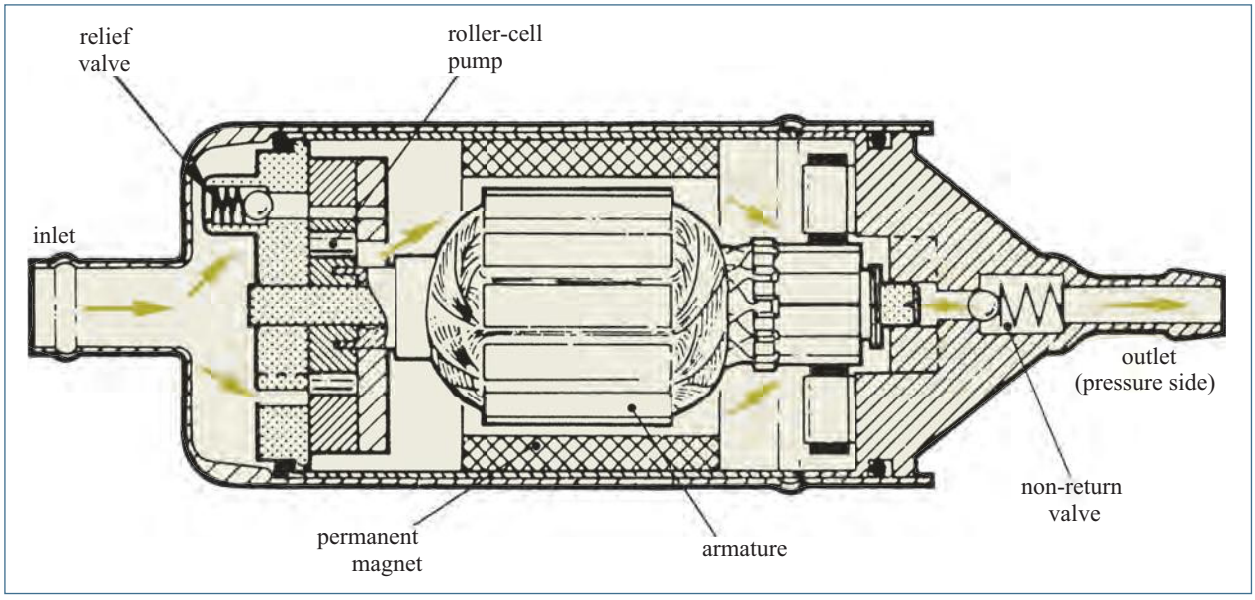


Figure 31.26 Roller-cell electric fuel pump FORD

The pump has an inlet at one end and an outlet at the other. Fuel flows straight through the pump, and this both lubricates and cools the pump motor. A permanent-magnet-type motor is used, and this drives the roller-cell pump element. The pump has a non-return valve and a pressure-relief valve.

The roller-cell pump consists of a rotor in a housing (Figure 31.27). Slots in the rotor carry the rollers. The rotor is offset in its housing to form a pumping chamber so that fuel is carried around between the rollers as the pump rotates.

Handy hint: With EFI systems, before the engine can be started, the fuel pump must be operating and the system must be pressurised.

31.15.4 Fuel filter

This is an inline filter between the pump and the regulator. It has a paper filter element as well as a screen to trap larger particles (Figure 31.28), although particles with average diameters as small as 10 µm (microns) can also be filtered out. The filters are marked in the direction of flow so that the larger filter-element surface area receives the unfiltered fuel.

31.15.5 Fuel-pressure regulator

The pressure regulator, shown in Figure 31.29, maintains a regulated pressure across the fuel injector, at a nominal 300 kPa. The regulator has a metal housing with a spring-loaded diaphragm. When fuel pressure builds up, the diaphragm lifts the regulator valve to return surplus fuel to the tank.

The chamber above the diaphragm is connected to the intake manifold, and so is subject to manifold vacuum. Changes in engine load and therefore manifold pressure vary the pressure in the fuel system. However, even though manifold depressions vary, the pressure difference across the injector valves remains constant; the

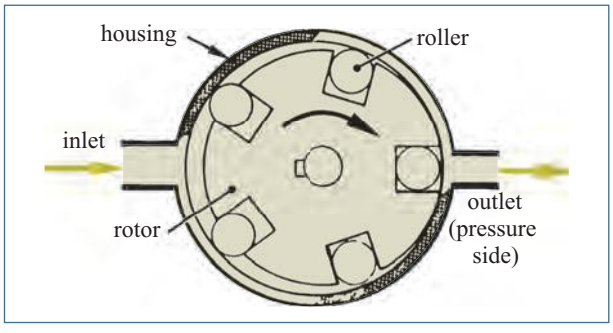


Figure 31.27 Roller-cell pumping element FORD

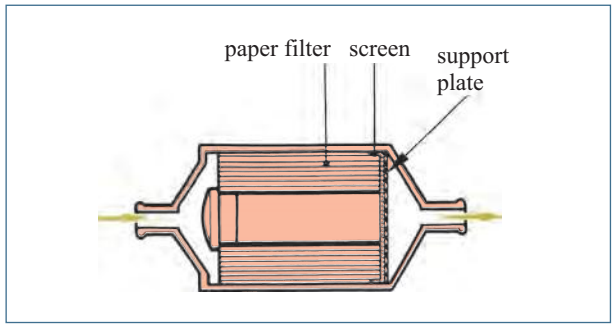


Figure 31.28 Fuel filter for an EFI system BOSCH

quantity of fuel injected is related only to the time that the injector is open. Returnless systems are now common, with the pressure regulator being housed with the fuel pump in the fuel tank.

Handy hint: This is a return-to-tank fuel system with the pressure regulator at the end of the fuel rail.

31.15.6 Fuel injectors

The injector of a multipoint system is fitted in the intake manifold so that the fuel is sprayed directly into the intake port in the cylinder head. The fuel is directed in a finely atomised form. Special fuel injectors are used in multi-valve engines so that the spray pattern suits the dual intake valve positions. The injector is fitted into the manifold in special rubber mouldings that protect it from heat transfer and vibration, and they also form a vacuum seal. The injector has an electrical connection and a fuel connection.

Figure 31.30 shows a section through an injector. Fuel is supplied through the top and is retained by the needle valve, which is held on its seat by the spring. Electrical pulses from the ECU energise the solenoid windings and attract the plunger and needle away from its seat. As a result, a spray of pressurised fuel is directed into the intake port of the engine.

Handy hint: The needle has a very small lift—only about 0.1 mm when fully open.

31.15.7 Types of injectors

Figure 31.31 shows a number of different fuel injectors, as noted below.

Pintle

Pintle-type injectors (Figure 31.31(a)) have a needle and pintle that is operated by a solenoid. The shape of the pintle end of the needle determines the fuel-injection spray pattern.

Multihole

Multihole injectors are defined by their outlet nozzle (Figure 31.31(b)). Fuel sprays from the injector through minute holes that atomise it more thoroughly than single-hole injectors. Some twin-hole injectors are used for four-valve engines.

Throttle-body injectors

Throttle-body injectors (Figure 31.31(c)) are mounted in the throttle body above the throttle valve and spray into the intake air. These injectors operate at lower pressures than other electronic types.

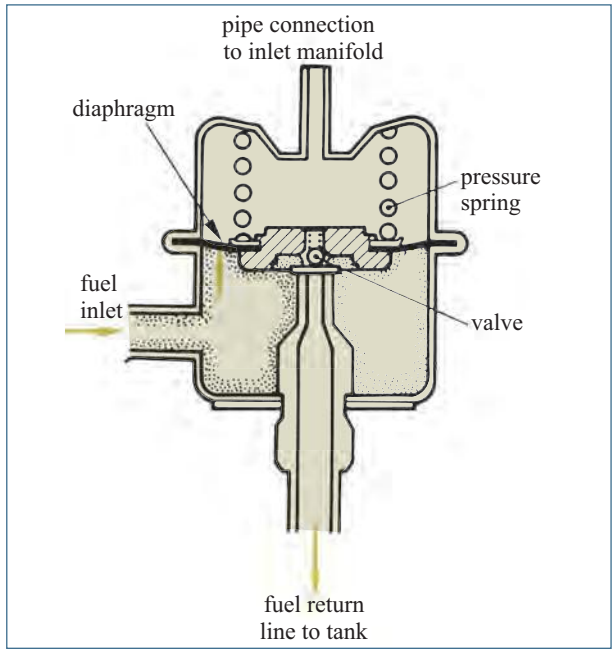


Figure 31.29 EFI fuel-pressure regulator for a return-type system FORD

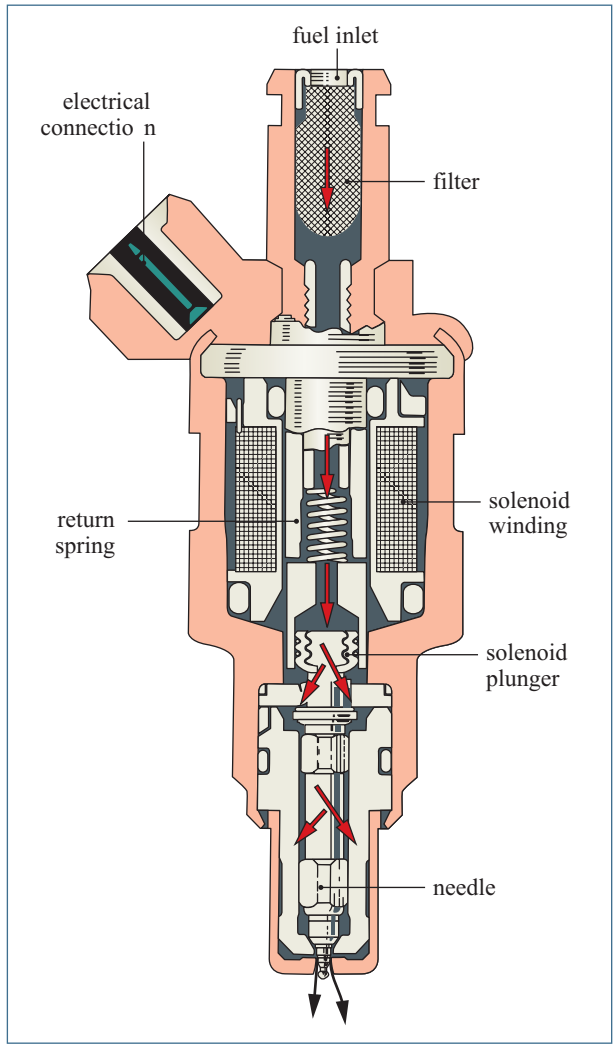


Figure 31.30 Section through a pintle fuel injector for multipoint EFI

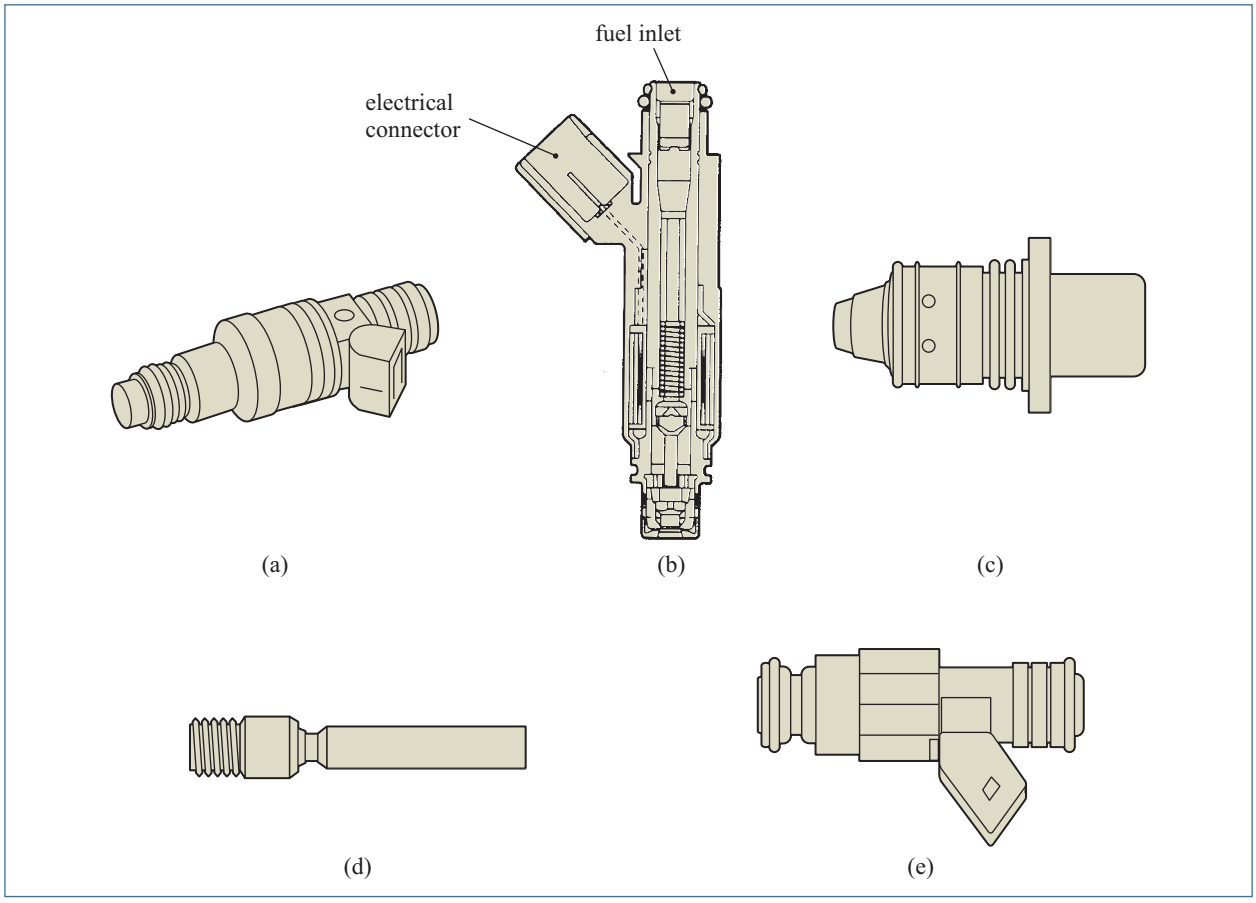


Figure 31.31 Different types of fuel injectors (a) pintle (b) multihole (c) throttle-body (d) mechanical (e) director plate

Mechanical injectors

Continuous mechanical injectors (Figure 31.31(d)) have been used in some systems. They are not electrical, but have a spring-loaded needle valve that is lifted from its seat by the action of the fuel pressure.

Director plate

A director plate injector (Figure 31.31(e)) differs from a pintle type in its use of a disc at the outlet hole instead of a needle. The disc is held in place by the injector solenoid plunger. When the ECU signals the injector, the plunger lifts off the disc. The disc vibrates, causing the fuel around it to be atomised. Director plate injectors are often multihole injectors.

31.15.8 Electronic control unit (ECU)

The two main signals that the ECU receives relate to engine speed (rpm and ignition) and the amount of air taken in by the engine (engine load). There are also a number of compensating signals, such as engine temperature and air temperature, for which the air–fuel mixture is modified. The ECU provides for a basic amount of fuel to be delivered by the injectors, and this is varied to suit different engine operating conditions.

Pulse width

The signal from the distributor measures the engine speed and the crank-angle position for injection timing. The pulse signal is passed through a pulse-shaping circuit in the ECU, which changes it from peaks into a rectangular form (Figure 31.32). The pulse then operates the injectors.

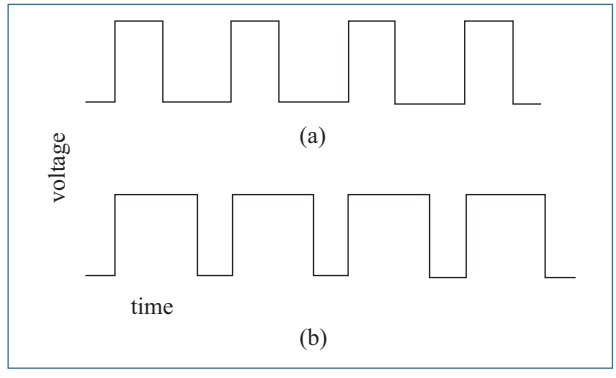


Figure 31.32 Basic pulse signal to the injectors (a) narrow pulse (b) wide pulse

In the diagram, each rectangular pulse represents the opening of an injector. The height represents the voltage, and the width represents time. The ECU changes the pulse width according to the signals that it receives. It widens the pulse for higher loads and increases the frequency of the pulse for higher engine speeds. At low engine loads, the pulse is narrow, so only a small quantity of fuel is delivered by the injectors.

Figure 31.33 illustrates how the final pulse width is calculated. The final rectangular-shaped pulse IL represents the signal to an injector. The height of the D1 and D2 pulse represents driver voltage, and the width represents time. Figure 31.34 shows the main inputs and outputs of a basic EFI control system, while the diagram in Figure 31.35 illustrates how the ECU adjusts to suit different engine operating conditions.

31.15.9 Engine-temperature sensor

A rich air–fuel ratio is needed for cold starting and for warming up, so the ECU gets a signal from the engine-coolant temperature sensor. The temperature sensor is screwed into the engine block or cylinder head, with its end extending into the coolant water-jacket. The solid end of the sensor is an NTC thermistor. The resistance of the sensor decreases as its temperature increases, the change being referred to as a *negative temperature coefficient* (NTC). The resulting analog voltage signal is used by the ECU to measure engine temperature.

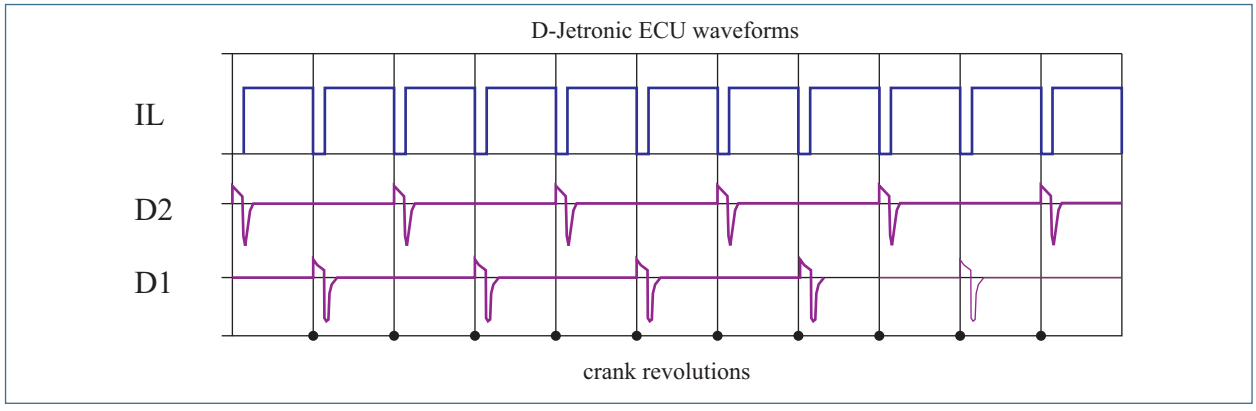


Figure 31.33 Calculation of the final injector pulse in an early EFI system

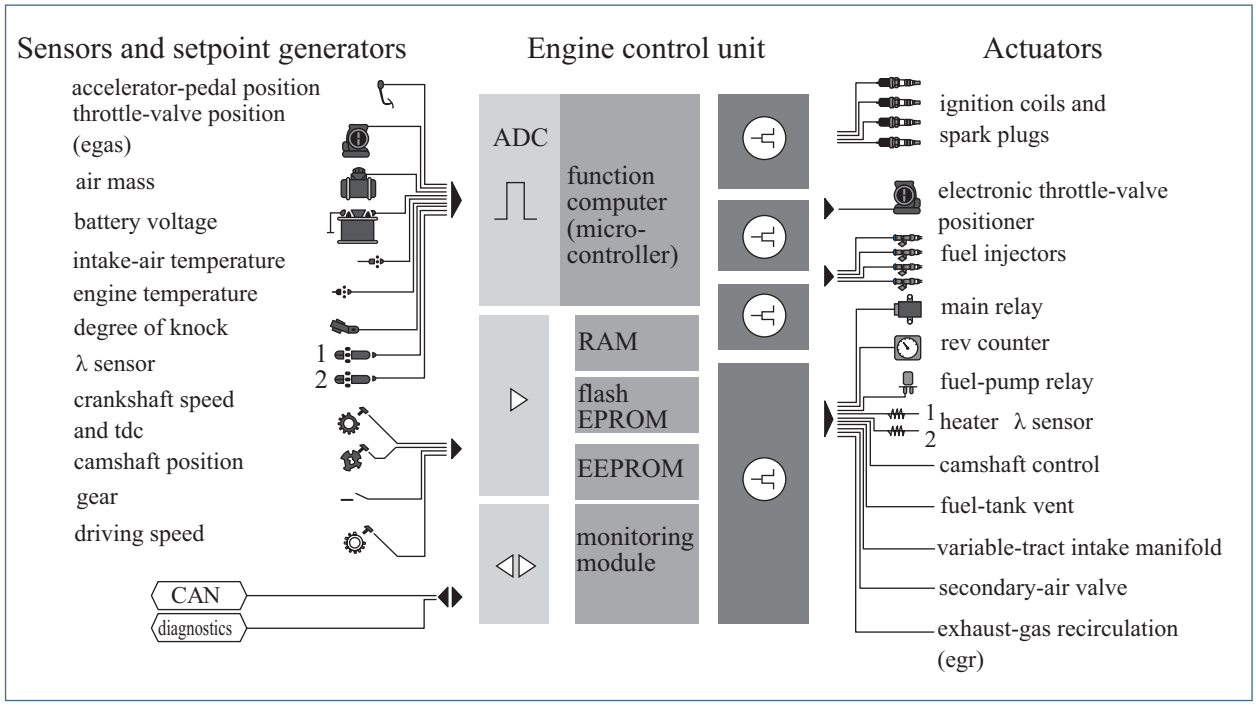


Figure 31.34 The main inputs and outputs of an EFI control system

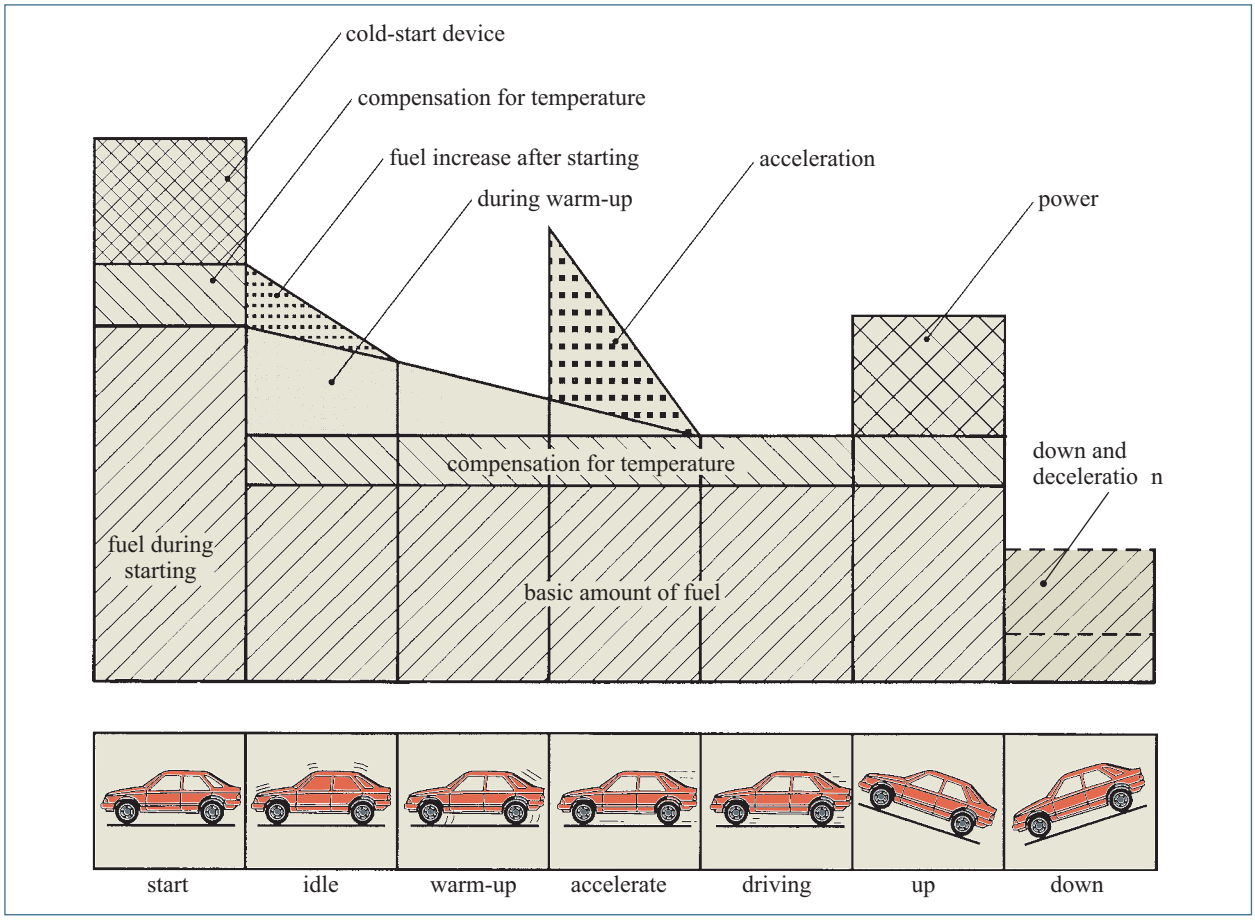


Figure 31.35 The ECU adjusts the basic amount of fuel injected to suit different engine operating conditions

31.15.10 Cold-starting devices

The cold-start injector valve on early systems is operated by a solenoid. It sprays fuel into the manifold for cold starting and is operated by the cranking signal via the thermo-time switch.

The thermo-time switch, shown in Figure 31.36, is mounted on the engine, where it is affected by engine temperature and ambient air temperature. It is a bimetal switch which has its contacts closed at lower temperatures so that extra fuel is delivered by the start valve. When hot (engine block above 40° C), the switch contacts are opened to switch off the start valve. The bimetal switch is also electrically heated, so that the contacts automatically open after a short period of operating time.

Handy hint: The cold-start injector operates only during cold cranking. The time that the switch remains on decreases as the engine-block temperature rises.

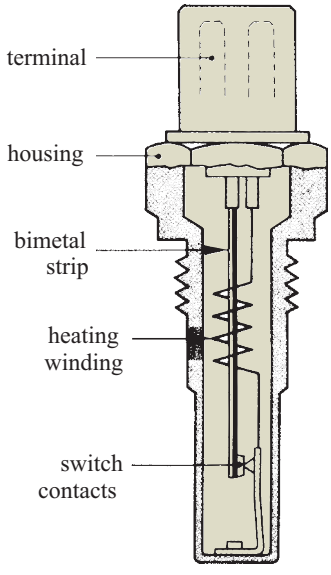


Figure 31.36 Thermo-time switch for a cold-start injector

31.15.11 Idle-speed control

Figure 31.37 shows idle-speed control in an early EFI system. Idle speed is controlled by a throttle air bypass screw. The airflow sensor has a mixture-adjusting screw, which allows air through the bypass section

that is not measured by the ECU. This unmetered air can be adjusted for idling mixture CO (carbon monoxide) content.

For cold fast idle, the auxiliary-air device allows some air to bypass the throttle valve. This air has already been measured by the air sensor and taken into account by the ECU in determining the amount of fuel to be injected. The bypass air therefore has the same effect as opening the throttle valve. The auxiliary-air valve shuts completely after five minutes of engine operation from cold. The device has an internal heater coil and is mounted on the engine block. It closes naturally and does not operate for hot starts.

31.15.12 Throttle-valve switch and sensors

The throttle-valve (or throttle-position) switch is operated by the throttle. In early systems, it had a set of contacts for both idle and full-throttle positions (Figure 31.38). The switch signals the throttle opening to the ECU, which provides mixture correction for both idle and off idle as well as full-throttle conditions. (These switches became a variable resistor potentiometer type in later systems.) The engine ECU receives an analog voltage signal that varies with throttle position (in this design, the ECU can determine the exact position of the throttle valve at any instant, as well as the *rate* of the driver's throttle application).

31.15.13 Oxygen sensor

Figure 31.39 shows the oxygen sensor in the exhaust manifold. It detects the oxygen content of the exhaust gases as they pass from the engine (which is a measure of the air–fuel ratio of the mixture entering the engine). The oxygen sensor feeds information to the ECU, which then adjusts the fuel-injection pulse width at the injectors. This is a continuous process. The oxygen sensor, also referred to as a *lambda* (λ) *sensor*, provides a closed-loop operating system.

31.16 Operation of direct petrol injection

Direct petrol-injection systems position the fuel injectors directly into the combustion chamber (Figures 31.40 and 31.17) and yield gains in pumping losses and control of the fuel charge. *Stratified* or *homogenous* mixing occurs above the piston inside the combustion chamber, rather than into the inlet ports. The fuel is injected on the start of the compression stroke for homogenous charges and later on the stroke for a stratified charge.

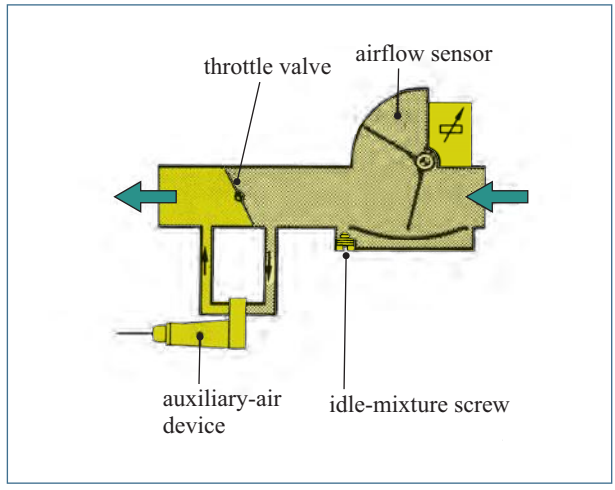


Figure 31.37 Cold idle speed control in an EFI system with an auxiliary-air valve

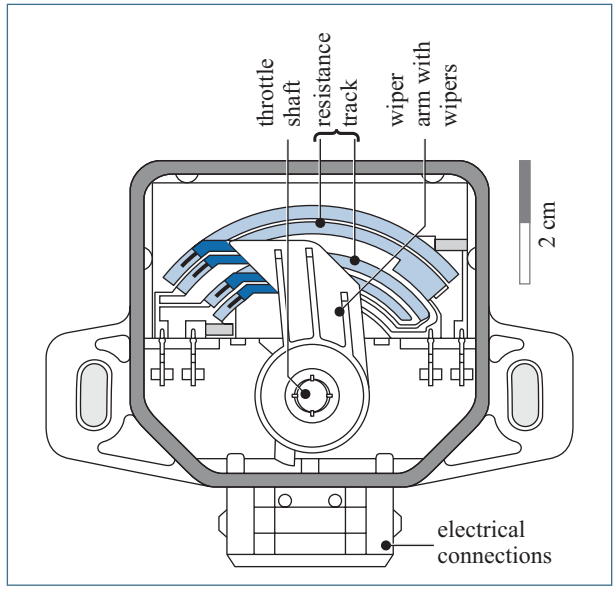


Figure 31.38 Throttle-valve sensor BOSCH

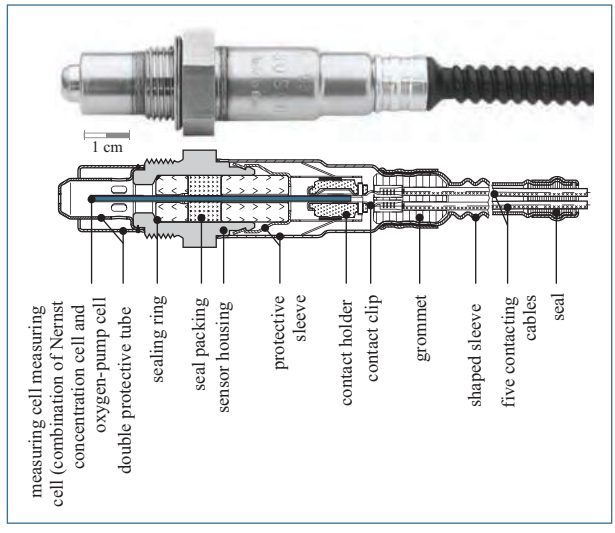


Figure 31.39 LSU4 planar wide band lambda oxygen sensor BOSCH

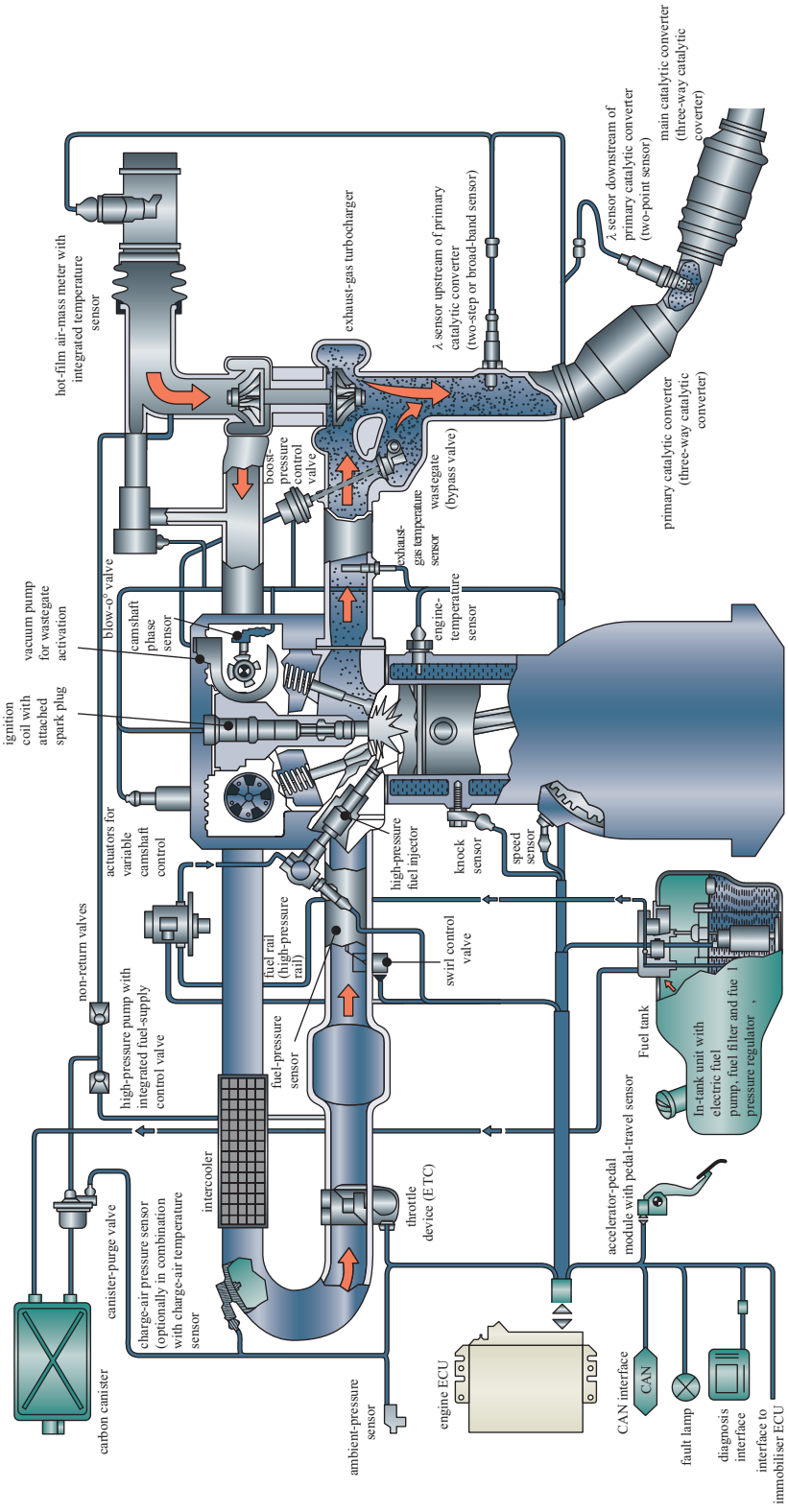


Figure 31.40 A direct petrol-injection system with the parts identified

The system can also control the *ultra-lean air–fuel* ratios required for emission-control standards. Due to the extremely high fuel-injection pressures, thorough atomisation ensures better combustion.

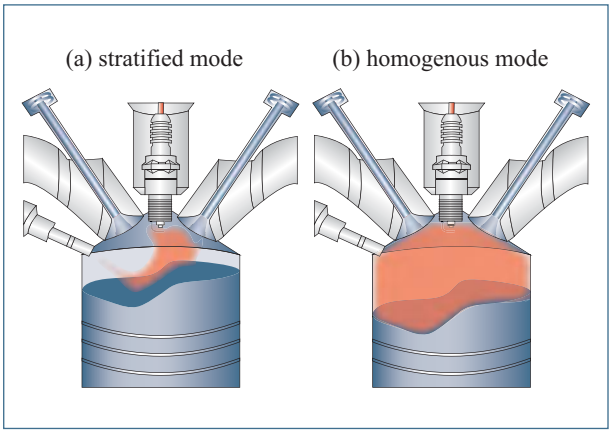


Figure 31.41 Low-speed stratified charge (a) and high-power homogenous charge (b) in a direct petrol-injection engine

31.16.1 Stratified charge

Stratified charge is used at low engine speeds with lower torque requirements. In this mode, the injector delivers the fuel late in the compression stroke. (The entire injection event is always completed before the spark plug fires, whether in homogenous or stratified modes.) The fuel charge in stratified mode is concentrated around the spark plug electrodes by the piston crown shape and air turbulence (Figure 31.41(a)).

Stratified charge describes a rich air–fuel mixture surrounding the spark plug electrode. Further out in the combustion chamber, the mixture is leaner to reduce incomplete combustion due to surface quenching.

31.16.2 Homogenous charge

Homogenous charge is gradually achieved by advancing the injection further so that it occurs earlier in the intake stroke. The mixture is then well mixed using the turbulence of the engine pumping. In homogenous charge mode, the air–fuel ratios are closer to stoichiometric (complete combustion), or slightly richer for more power (Figure 31.41 (b)).

31.16.3 Other features of direct petrol injection

In direct petrol-injection systems, the air–fuel ratio can be as lean as 55:1. The EGR systems required to control the expected increase in *oxides of nitrogen* (NO_x) are usually controlled by advancing the exhaust camshaft overlap. The ECU uses the variable camshaft position phasers for this. More exhaust/intake valve timing overlap allows exhaust gas to enter the intake stroke. This reduces combustion temperatures and therefore NO_x emissions. Complex catalytic converters are also used.

31.16.4 Benefits of direct petrol-injection systems

The injection of fuel directly into the combustion chamber has a number of advantages over other petrol-injection systems. They are as follows:

- higher compression ratios can be used
- closer control of combustion
- lower emissions
- improved fuel economy
- higher power and torque outputs.

31.16.5 Starterless starts

Direct petrol-injection systems can use *starterless starts*, a feature that uses the known camshaft and crankshaft position to inject fuel into one cylinder just after top dead-centre on the power stroke. Then a spark is provided at the spark plug. The piston is forced down the cylinder, and the engine underspeed mode is entered until the engine can run under normal speed. Starterless starting is automatically adopted by the engine ECU after the prolonged idling typical of traffic jams.

31.17 Components of direct injection

31.17.1 Fuel supply

The fuel-pump assembly in the fuel tank is a conventional electrical fuel pressure pump that is typical of multipoint or returnless injection systems. It is referred to as a *low-pressure/high-volume* or *delivery pump*. The filter, pressure regulator and gauge unit are also included in the fuel-tank assembly (Figure 31.21).

31.17.2 High-pressure fuel pump

The high-pressure fuel pump is a single-plunger camshaft-driven pump. It is flange-mounted on the cylinder head and has a separate three-lobe cam to maintain a constant fuel supply. The pump also contains a fuel-supply control valve, variable pressure attenuator and high-pressure limiting valve (Figures 31.42 and 31.43).

Pump operation

Referring to Figure 31.43, fuel enters the pump on the low-pressure side at a supply pump pressure of approximately 0.4 MPa. As the plunger moves down on the intake stroke, fuel moves past the inlet valve (not shown), filling the area above the plunger. When one of the cam lobes forces the plunger in, fuel is pressurised from 12 to 20 MPa.

The fuel-supply control valve acts as a metering device. Fuel above the plunger is not pressurised until the fuel-supply valve closes. The ECU can vary the quantity and pressure of fuel injected by closing the valve earlier or later on the pressure stroke. It operates the fuel-control valve with a *pulse width-modulated* digital signal, based on input from the fuel-rail pressure sensor.

Maximum pressure in the fuel rail is controlled by the pressure-limiting valve, with excess fuel being returned to the inlet side of the pump. The gas-filled attenuator acts like a pulsation damper to even out pressure changes in the pump. Fuel that is not required by the injectors is directed into the upper chamber, compressing the diaphragm. The attenuator assists in a rapid filling of the pump on the intake stroke when the pressure is released.

High-pressure fuel sensor

The sensor is screwed into the fuel rail and monitors the pressure for the ECU. The ECU then adjusts the pressure by changing the time the fuel-supply valve in the high-pressure pump remains closed.

31.17.3 High-pressure fuel rail

The fuel rail is manufactured from thick-walled steel to handle pressure and has fabricated injector junctions. The rail contains a large volume so that pressure fluctuations within it (due to hydraulic injector action) are dampened. The high pressure of the fuel rail is controlled electronically by a fuel-control valve that re-circulates fuel from the high-pressure pump outlet back to its inlet.

31.17.4 Fuel injector

The fuel injector atomises and meters the fuel directly into the combustion chamber. The injector must be able to cope with the high temperature and pressure of combustion, and is therefore different in construction from an indirect injector. Figure 31.44 shows a high-pressure direct petrol-fuel injector.

Figure 31.42 High-pressure pump for a direct fuel-injection system ROBERT BOSCH (AUSTRALIA) PTY LTD

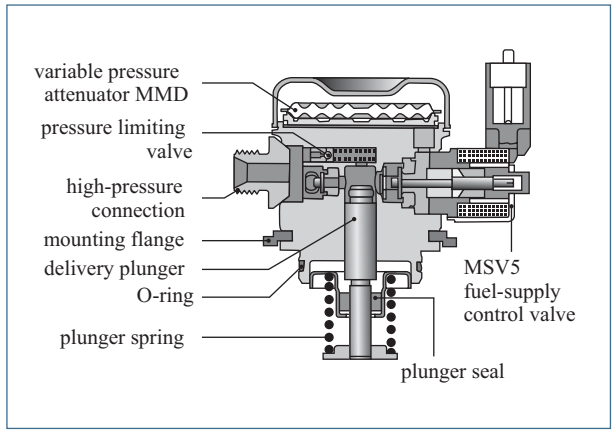


Figure 31.43 Section view of a high-pressure fuel pump ROBERT BOSCH (AUSTRALIA) PTY LTD

Operation

High-pressure fuel enters the injector through the inlet filter from the fuel rail and fills the injector. When a high-voltage signal (60 volts) is received at the input terminal from the ECU, the high-current solenoid winding is energised. This attracts the armature and plunger needle off its seat. Fuel is then sprayed out through the directional outlet hole. When the solenoid is de-energised, fuel pressure and the return spring will force the plunger back onto its seat. The quantity of fuel delivered is determined by fuel-rail pressure and the time the plunger remains open.

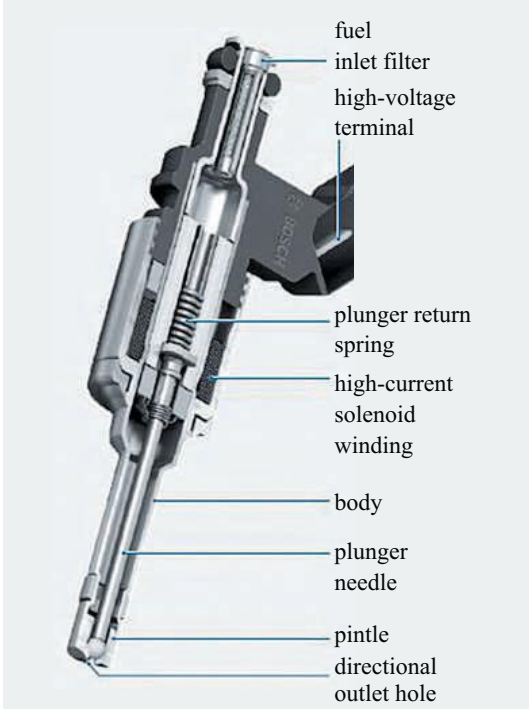


Figure 31.44 High-pressure direct petrol-fuel injector BOSCH

31.18 Engine management systems

Systems with EFI in which the ECU controls injection, ignition and engine emissions are referred to as *engine management systems*. With any engine system, the fuel system, the ignition system and the air charge system are the most important because they affect both engine performance and exhaust emissions. Data in the memory of the ECU are compared with information received from the various switches and sensors. Output signals then adjust the fuel, ignition and air charge to give optimum performance.

31.18.1 Engine management system components

Figure 31.45 shows the input and output components of one engine management system and their relationship with the ECU. Many of the ECU's functions could be performed in other ways, but electronic control has been extended beyond injection and ignition. Components such as the air conditioner and turbocharger have been included. For example, the air-conditioner compressor can be stopped at idle so that the engine idles better and produces fewer emissions.

Most vehicles with automatic transmissions also have the transmission controlled by the ECU. These control units are then referred to as *powertrain control units* or *powertrain control modules* (PCM).

Input devices

Starting from the top of Figure 31.45(a) and moving clockwise, the input devices and their functions are described briefly as follows:

1 Air-conditioning switch. Signals that the air conditioner is switched on.
2 Mass airflow meter or mass airflow sensor . Measures airflow .
3 Electrical switches. Include the headlamp switch, blower switch and electric fan switch. These affect engine load.
4 Power-steering pressure switch. Signals that the power steering is functioning.
5 Throttle valve position sensor . Senses the throttle position.
6 Coolant thermo-sensor . Senses coolant temperature .
7 Lambda o xygen sensor 1 and 2. Measures the amount of o xygen in the exhaust gases.
8 Air-intake sensor . Senses the temperature of incoming air .
9 Diagnosis connector . Checks inputs.
10 Neutral/clutch switch. Signals that the engine has no load.
11 Stop light switch. Signals braking.
12 Ignition switch. Supplies power to the ECU and signals starting.

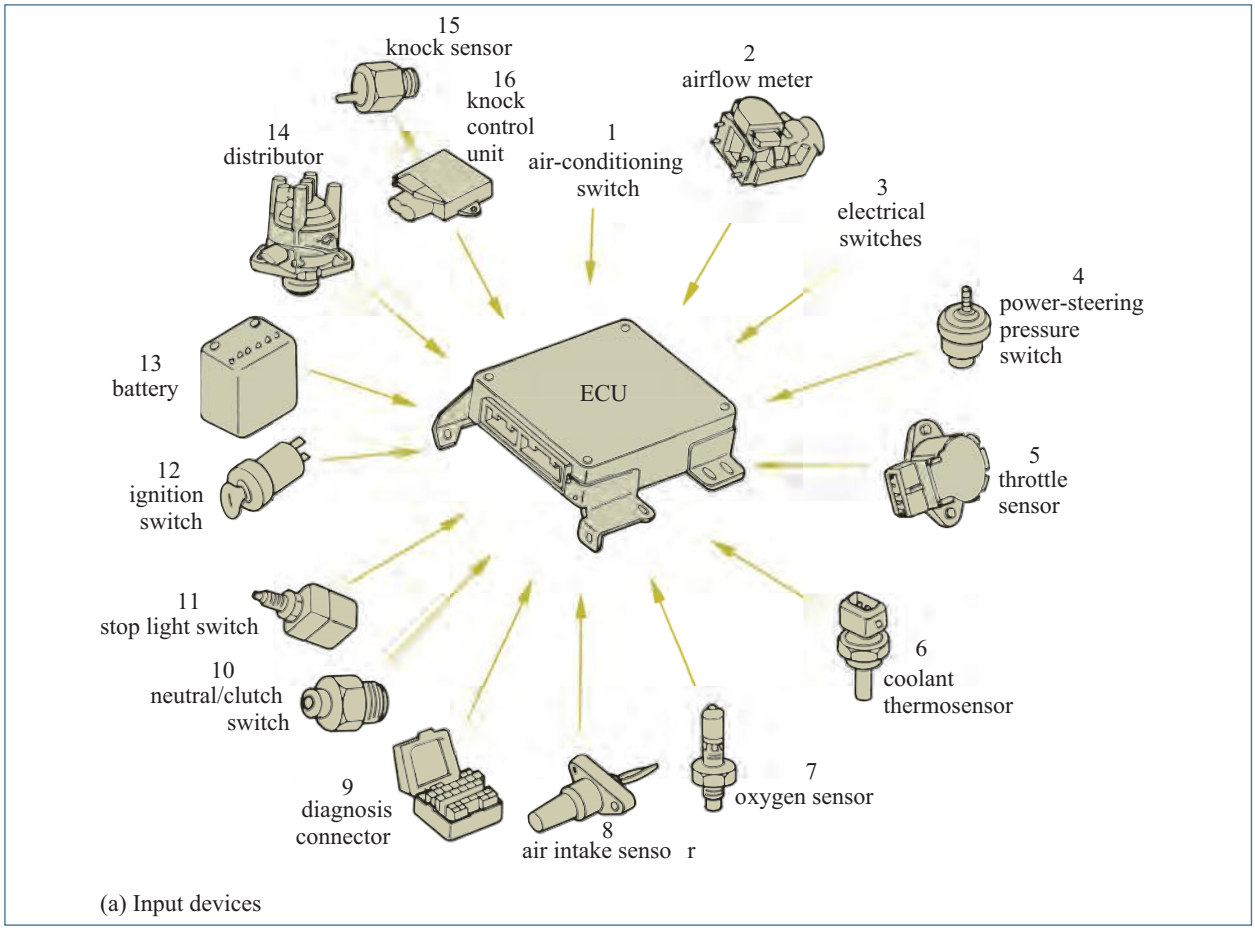


Figure 31.45a Components of an engine management system showing the devices that generate input signals for the ECU

13 Battery . This is the general power supply .
14 Distributor
15 Crank -angle sensor . Provides engine-speed signals and crank -angle signals.
16 Camshaft position sensor

The following devices are not shown but are explained later in this chapter:

- Knock sensor and knock control unit. Detects detonation and signals the need for less spark advance .
- Boost pressure sensor
- Accelerator pedal position sensor
- Vehicle speed sensor
- Fuel tank pressure sensor .

Output devices

Figure 31.45(b) shows the output devices to which the ECU sends signals. The system shown includes turbocharger devices. Starting from the top and moving clockwise, the functions of the output devices of the system are briefly described as follows:

1 Overboost warning buzzer . A signal that the turbocharger pressure is too high.
2 Air-conditioning circuit relay— Opens at idle and full throttle to stop the air-conditioning compressor and relieve the load on the engine .
3 Fuel injectors. Spray fuel as directed.
4 Diagnosis connector . Checks output signals with test equipment.
5 Solenoid valve . Used for fuel-pressure regulator control.
6 Wastegate solenoid valve . Controls the turbocharger wastegate .
7 Solenoid valve . Purges the charcoal canister (emission control).
8 Fuel pump resistor/relay . Reduces fuel pump voltage and pump speed when requirements are low .
9 Ignition coils and spark plugs
10 Air-conditioning relay . Switches the air-conditioning compressor on and off .

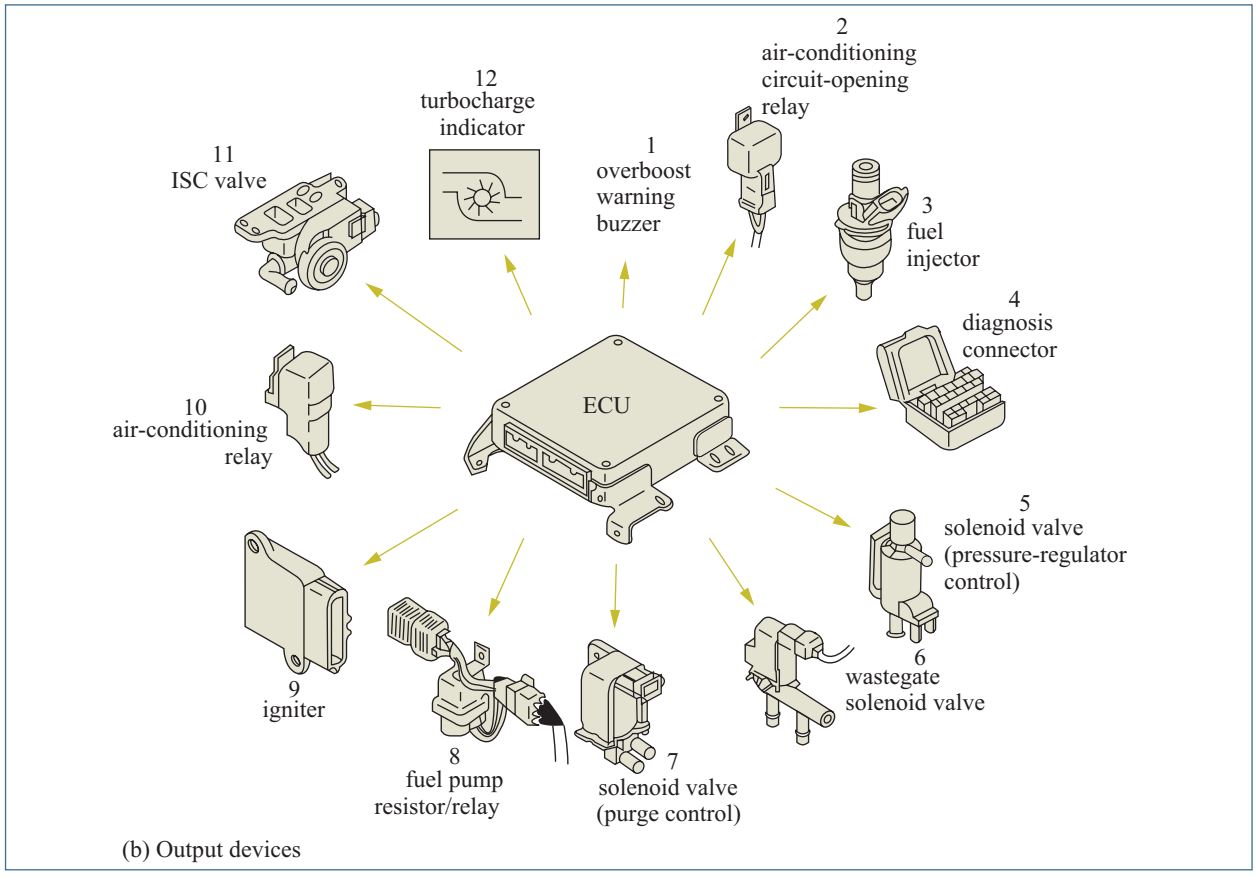


Figure 31.45b Components of an engine management system showing the devices that receive signals from the ECU

11 Idle-speed control (ISC) valve
12 Turbocharge indicator

The following devices are not shown but are explained later in this chapter:

- Exhaust gas return (EGR)
- Electric throttle valve position
- Camshaft timing control
- Engine speed counter
- Turbo charger volume control
- Variable geometry intak e manifold
- Canister purge .

31.19 Input devices

31.19.1 Throttle-position sensor (TPS)

The throttle-position sensor (TPS) is a potentiometer capable of measuring the full *sweep* (range) of throttle opening, from idle to wide-open. (A switch-type sensor can only signal a closed or wide-open throttle and nothing in between.) The engine management ECU uses voltage signal sweep to calculate the *potential* airflow into the engine. The *actual* airflow is sensed by an engine load sensor. The rate of change of the throttle valve is also noted by the control unit. The TPS signal controls areas such as:

- idle speed
- ignition timing
- transmission shifts
- air-conditioning compressor
- emissions-control devices.

Most manufacturers provide for any TPS signal testing to be carried out with the ignition on and engine off. This avoids engines being over-revved by technicians. A typical TPS signal will be around 0.5 volts at idle and 4.5 volts at wide-open throttle (WOT). These sweeping analogue signals are best tested with an oscilloscope.

31.19.2 Accelerator pedal-position sensor

Where split-second electronic control of the engine is required, electronic throttle control (*drive-by-wire*) is used. Vehicles with traction control, stability control, engine management with direct petrol injection or ECU-controlled cruise control require complete ECU-controlled throttle.

The accelerator pedal-position sensor in Figure 31.46 is basically a throttle-position sensor attached to an accelerator pedal. The operation and testing are the same as for a TPS. When an accelerator-position sensor is used, a second TPS potentiometer is required to confirm an accurate throttle position. This second signal will have a reverse-bias signal to that of the TPS. That is, it will have 4.5 volts at idle and half a volt at wide-open throttle (WOT). These two signals will mirror-image each other for *definite* throttle position readings that can be confirmed by the ECU.

Figure 31.47 shows two voltage traces on a running engine. One is the mass airflow (MAF) signal reacting to a sudden increase in incoming air (blue), and the other is the TPS trace (red). The event recorded took one-and-a-half seconds of snap acceleration.

31.19.3 Coolant-temperature sensor

An engine coolant-temperature sensor (CTS) (or a cylinder-head-temperature sensor) is usually a negative temperature coefficient thermistor that provides an analog voltage signal. This is read by the ECU and related to engine temperature for accurate changes to the fuel injection *pulse width.* Figure 31.48 shows the gradual voltage change of a CTS signal. The CTS thermistor can be tested for resistance values as directed by any workshop manual specifications. A typical resistance value chart is shown in Table 31.1.

31.19.4 Manifold air-temperature sensor (MAT)

The manifold air-temperature (MAT) sensor (Figure 31.49) has the same NTC construction as a coolant-temperature sensor. It is *not* a load sensor, but it does contribute to the base air–fuel ratio calculation by assisting the ECU to determine the density of the incoming air. These sensors can be located in the intake-air ducting to sense

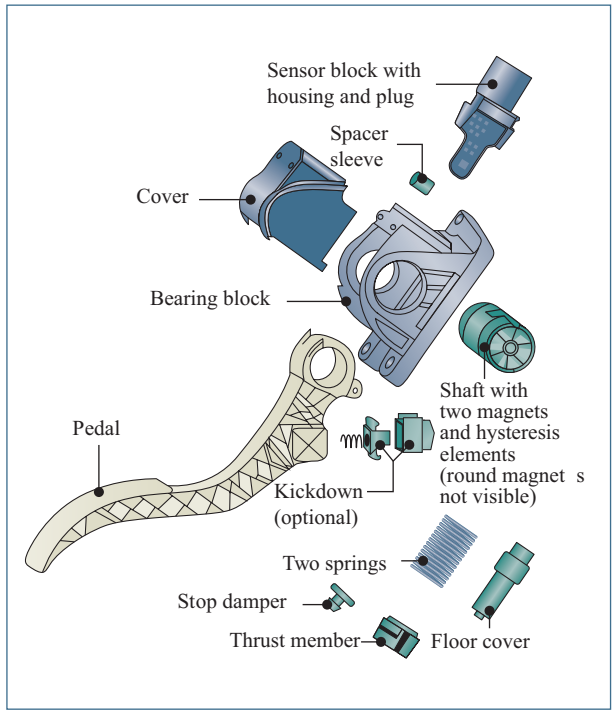


Figure 31.46 Accelerator pedal position sensor

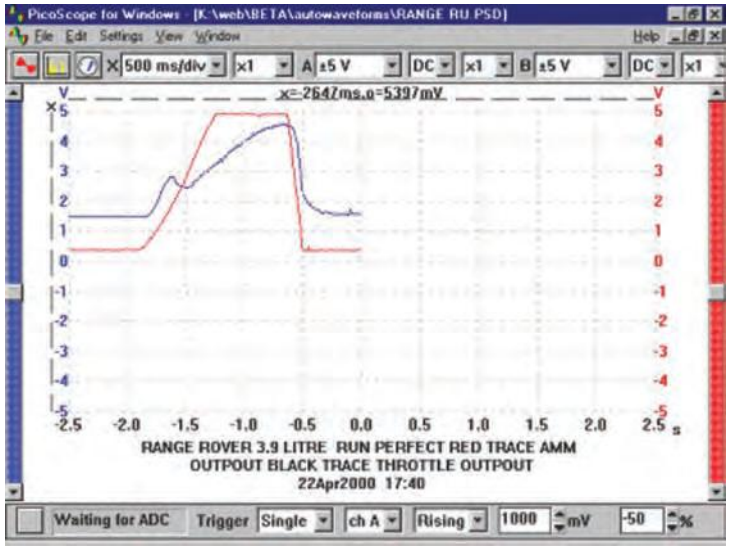


Figure 31.47 An oscilloscope trace of an MAF and a TPS analog signal PICO TECHNOLOGY

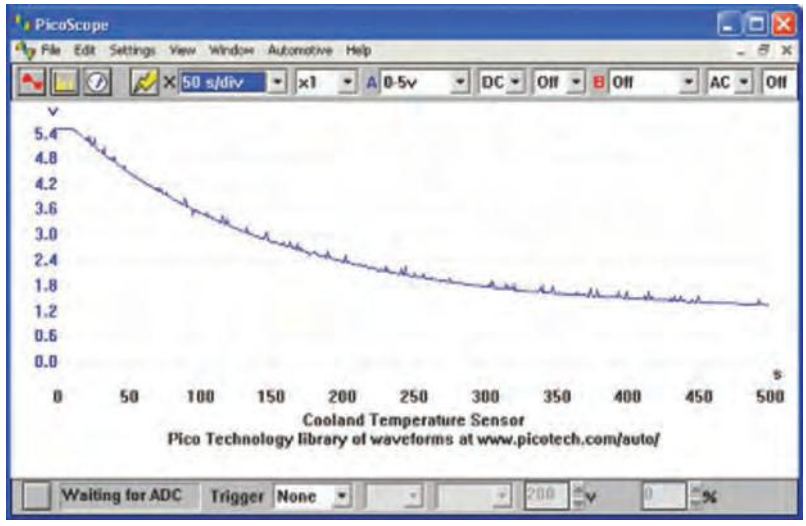


Figure 31.48 A typical coolant-temperature sensor trace tak en over an eight-minute period PICO TECHNOLOGY

the air temperature directly behind the air filter; alternatively, they can be screwed into the intake manifold. The ECU uses the intake-air temperature to calculate the final injector pulse width.

31.19.5 Oxygen sensors

The oxygen sensor measures the amount of oxygen (O_2) in the exhaust gas, allowing the ECU to determine if the mixture is rich or lean. The materials in the oxygen sensor either produce or modify a voltage signal when in contact with the exhaust gas. The operating temperature is between 310°C and 600°C.

Types of oxygen sensors

The different types of oxygen sensor can be recognised by the number of wires they have.

- Single wire . The output to the ECU is through a single wire , with earth being through the sensor body and exhaust manifold.
- Two wire . One wire is the sensor signal. A separate earth wire to the ECU overcomes earth problems from corrosion of the single-wire type .
- Three wire . Has an internal heater element to improve cold engine performance . The wires are: (1) heater positive; (2) heater negative; and (3) ECU signal. Signal earth is through the body . They come in 12- or 18-watt elements, and the correct one must be used to avoid damaging the element.
- Four wire . The most common is the zirconium dio xide-heated element (HEGO: heated exhaust gas o xygen) sensor shown in Figure 10 .39. The four wires are: (1) heating element negative; (2) positive at battery voltage; (3) ECU ground; (4) sensor signal to the ECU .
- Five wire . Known as broadband sensors because they can measure o xygen over a wider scale . A fifth wire provides a reference voltage of 0 .4 volts from the ECU . These sensors also have faster reaction times. (Figure 31.52 shows the broader-range and lambda mixture window in which these sensors can operate.)

Table 31.1 CTS resistance vs. temperature chart

Temperature (°C)	Resistance (V)
0	5800
20	2500
70	480
100	200

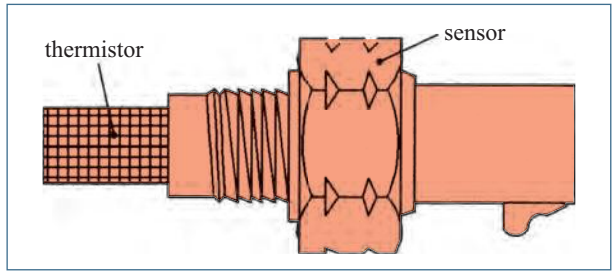


Figure 31.49 A MAT sensor is mounted in the intak e manifold to measure ambient incoming air temperature GM HOLDEN LTD

Zirconia element oxygen sensor

Figure 31.50 shows the construction of a zirconia element oxygen sensor. The body is stainless steel to resist corrosion and withstand the high temperatures of the exhaust system. It houses a sensor and heater element in a ceramic bracket. The zirconium dioxide element is coated on both sides with a thin layer of conductive platinum. The inside of the U-shaped element is in contact with the outside atmosphere oxygen levels, and the outside is in contact with exhaust gas oxygen via a porous layer.

Basic operation

When there is a greater bias of oxygen levels (that is, less oxygen in the exhaust due to a rich mixture), there is greater conductivity in the element and a higher signal voltage is generated (900 mV). When there is less fuel and more oxygen in the exhaust, the conductive bias is less and the zirconia-type oxygen sensor will generate a lower voltage (100 mV).

The engine management system ECU constantly monitors this oscillating analog signal, but will ignore it when the engine requires greater fuel demands such as a cold engine or full load. Most vehicles now have two oxygen sensors. One is mounted before the catalytic converter to measure oxygen levels and might be referred to as a fuel mixture sensor. The second one is mounted after the catalytic converter to measure the oxygen levels to ensure that the converter is working properly.

During normal operation, the engine ECU will react to this rich-and-lean signal oscillation to fine-tune a stoichiometric air–fuel ratio of 14.7 parts air by mass to one part fuel. This continuous feedback signal from the exhaust gas and the subsequent fuel-injector pulse width adjustment (both richer and then leaner) is termed *closed loop* (Figure 31.51).

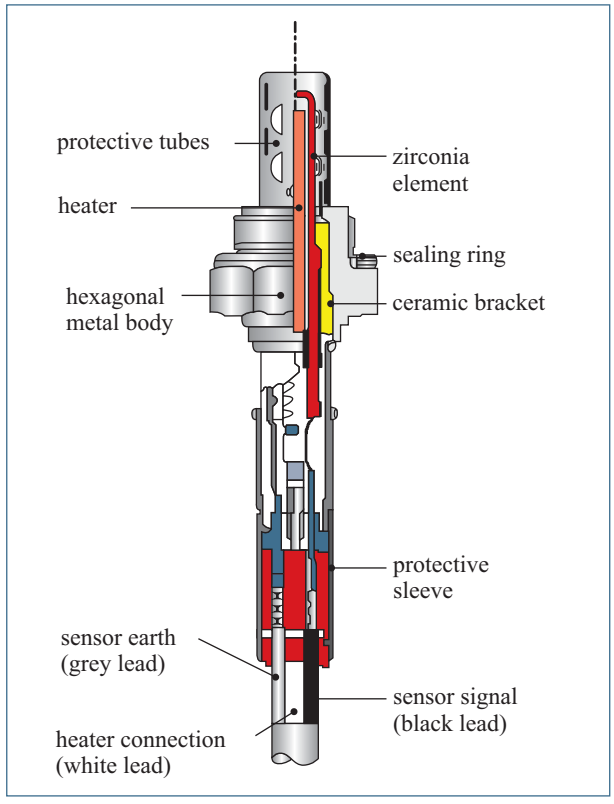


Figure 31.50 Zirconia element o xygen sensor showing construction

31.20 Lambda

Another term associated with the theoretically perfect air–fuel ratio is the *excess air factor lambda* (λ). When lambda is said to be at exactly '1.00' (no excess air and no excess fuel), the oxygen sensor sends a 450 mV signal to the ECU, confirming a perfect mixture. When lambda creeps up to 1.02, there is some *excess air* in the exhaust and therefore a leaner mixture. When lambda is 0.98, the mixture is becoming too rich.

An oxygen sensor is sometimes referred to as a *lambda sensor*, but the voltage readings are still in the 0 to 990 mV range. (Diagnostic lambda values are not actual oxygen-sensor voltage signals.) Figure 31.52 shows a typical lambda sensor sweep.

'V' engines have an oxygen sensor in each exhaust manifold bank. Later models have a second pair of sensors after the catalytic converters to monitor the catalytic operation. These can be either air–fuel ratio sensors or catalyst sensors. A catalyst sensor will have a slower and weaker voltage signal after the catalytic converter if it is functioning correctly.

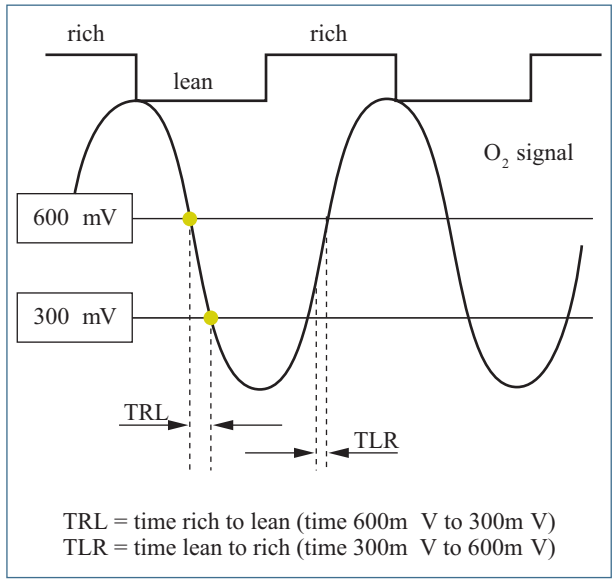


Figure 31.51 A zirconia-type o xygen-sensor signal with an after-catalyst o xygen sensor

Handy hint: Oxygen sensors have a service life and should be regularly check ed.

31.20.1 Load sensors

The engine-load sensor is the most critical sensor in the air section of the EFI. There are four types of load-sensing devices:

- mass air flow (MAF) meter , which can be hot wire or hot film
- manifold absolute pressure (MAP) sensor

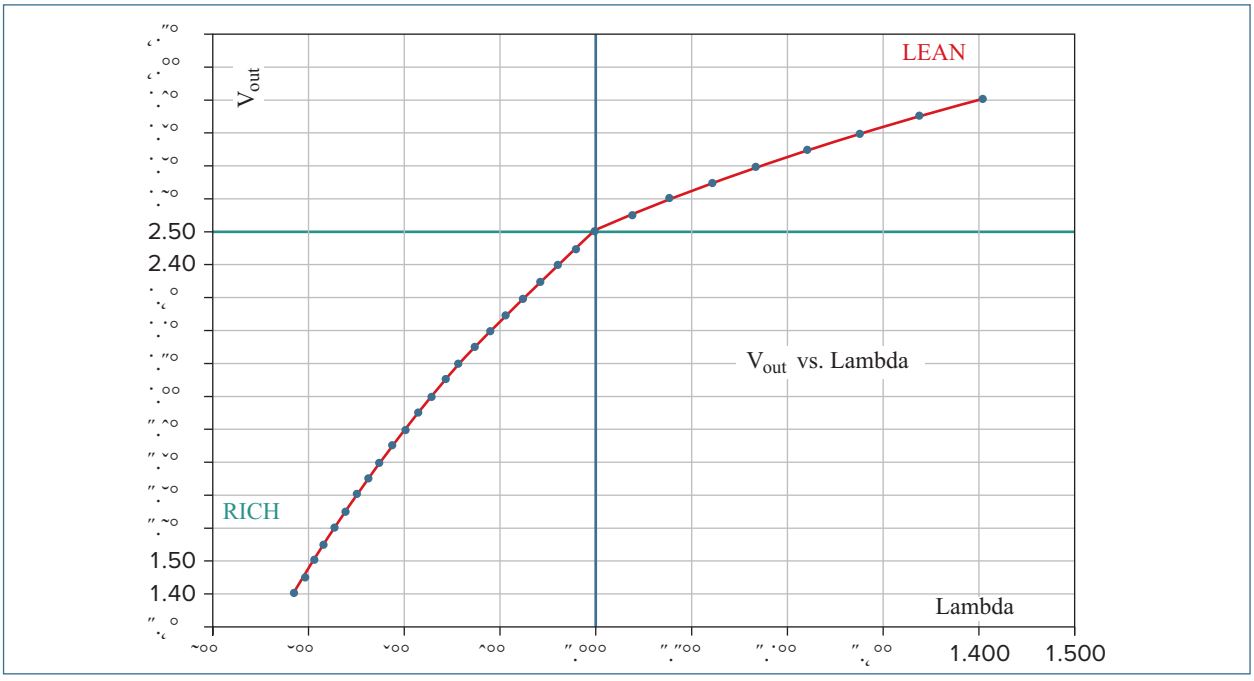


Figure 31.52 A wideband o xygen sensor performance chart

- vane airflow or airflow-controlled meter (AFC), as used in early systems
- Karman vortex sensor .

If a vehicle is cruising along a freeway at 80 km/h at 2500 rpm, the throttle opening will be small, as will the airflow. If the vehicle suddenly begins to travel uphill and the driver wants to maintain the same vehicle speed and engine rpm, the throttle will have to be opened to compensate for the extra load. So, a vehicle travelling at the same speed can have completely different throttle openings—and therefore airflow—depending on the conditions.

The ECU needs to know the mass of the air intake to calculate the fuel requirements of the engine. To calculate mass, the flow and temperature of the air must both be measured. Hot air will have less mass than colder air with the same flow rate.

Mass airflow meter

The mass airflow meter uses a hotwire sensor to measure the incoming air by mass (kg/s). The incoming air passes over a thin arrangement of tungsten wire heated to a constant 100°C. The intake airflow has a cooling effect on the sensing hot wire. The more air that flows, the more current is fed by the air-mass meter circuit to keep the wire at the pre-set constant temperature. This current change is converted to a varying voltage or frequency and signalled to the ECU as a measure of engine load (relative airflow). This type of sensor is shown in Figure 31.53.

Another type of air-mass meter uses *hot film.* The sensor contains a small side tunnel that houses a membrane with thin metal film and internal circuitry. The sensor protrudes slightly into the incoming airstream in a location ahead of the throttle valve. The operation of the hot-film sensor is similar to the hotwire sensor, but it samples a smaller quantity of incoming air.

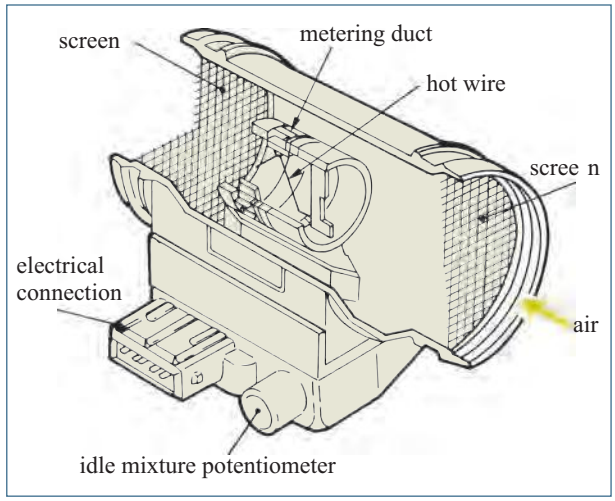


Figure 31.53 Section through a hot-wire-type air-mass sensor FORD

Manifold absolute pressure sensor (MAP)

Engine load can be determined by measuring the pressure in the intake manifold during normal operating conditions. A partial vacuum exists in the

manifold between the throttle valve and the intake valve. The vacuum is highest at idle and lowest at wide-open throttle.

MAP sensors come in two different operating formats. The capacitive type (Figure 31.54(a)) sends a digital-frequency load signal to the ECU, and the piezo-resistive type (Figure 31.54(b)) sends an analog-voltage load signal to the ECU. Both types are connected directly to an intake-manifold vacuum source.

The control unit will provide the MAP sensor with a reference voltage and a sensor ground. Signals are sent back to the ECU as a result of the internal MAP sensor circuit being deformed by variations of the manifold vacuum.

Karman vortex sensor

Figure 31.55 shows a Karman vortex sensor. It is part of the air-intake system and signals engine load. All of the air entering the system passes through the sensor. It is shaped so that it creates a vortex or swirling of the air.

A transmitter on one side of the sensor sends ultrasonic waves to a receiver on the other side, and these waves are distorted as they pass through the swirling air. The more air that flows into the engine, the greater the distortion. After the ultrasonic waves reach the receiver, they are changed to a signal related to engine intake airflow and an engine load signal is sent to the ECU.

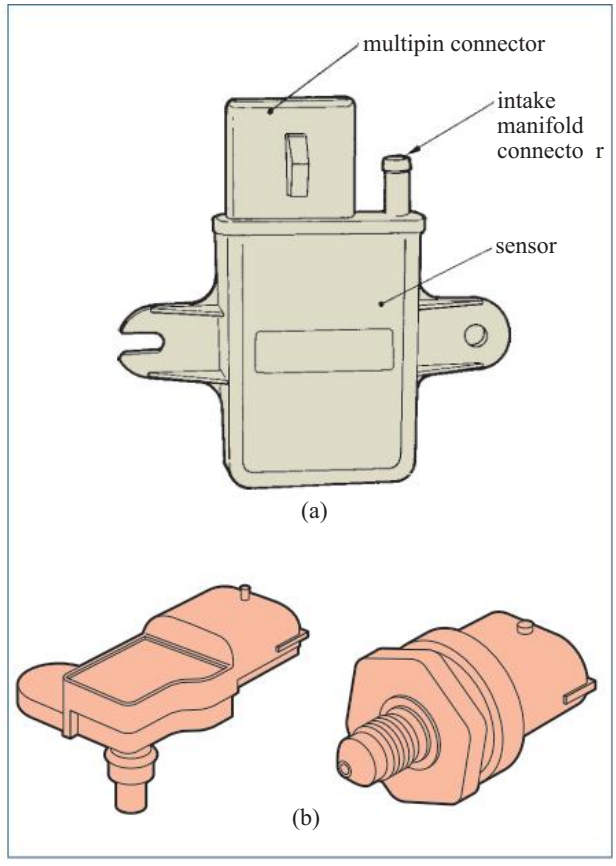


Figure 31.54 MAP sensors for signalling intak e manifold air pressure (load) (a) capacitive type (b) piezo-resistive type

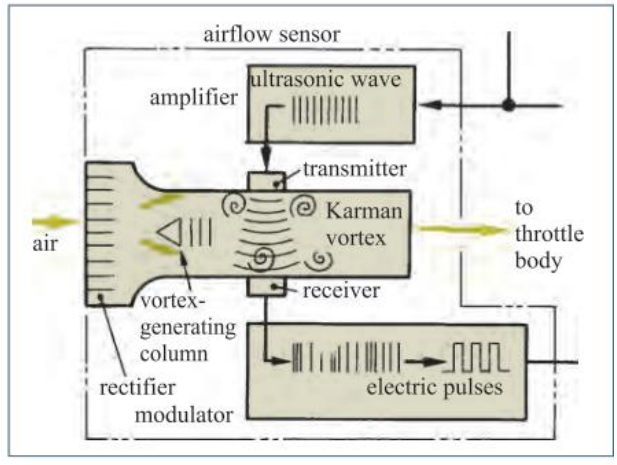


Figure 31.55 Karman vortex load sensor FORD

Handy hint: The Karman vortex sensor detects changes in air movement and uses these to measure the rate of airflow , which is then used as a measure of engine load.

31.20.2 Vehicle speed sensor

The vehicle speed sensor sends information to the engine management ECU, which translates it into vehicle road speed. The sensor is mounted either at the transmission output shaft or on the final drive. The vehicle's ABS road wheel sensors are used, with the ECU using the signal to determine vehicle operating changes such as vehicle speed limiting and gearshifts. This input is also used by the instrument cluster computer to operate the speedometer.

Handy hint: The vehicle speed sensor is a major input to several on-board computers such as transmission control, ABS and stability systems, SRS and others via the vehicle multiplexing systems.

31.20.3 Crank-angle sensor (CAS)

The engine crank-angle sensor provides the engine management ECU with information on the exact position and speed of the engine crankshaft. The ECU uses the information to control the base fuel injection and the ignition timing. Sensors can be located at various places on the engine: at the crankshaft front pulley, protruding into the engine block, at the flywheel or in a distributor-like housing.

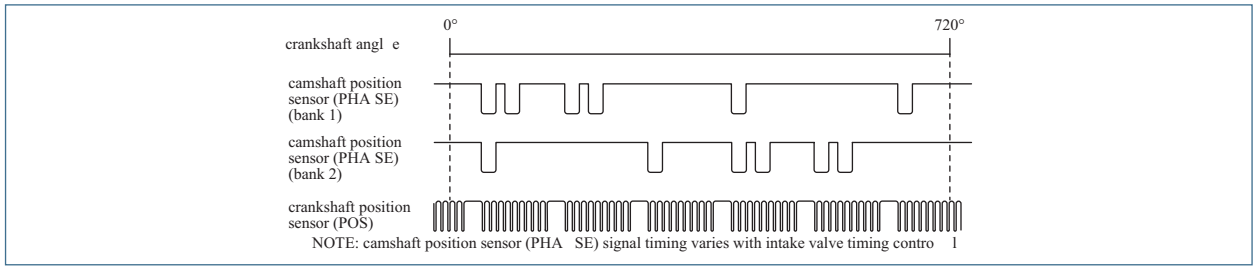


Figure 31.56 The output signals of a V6 crank angle sensor and two camshaft signals

31.20.4 Camshaft position sensor

As engine management systems developed, newer processes such as sequential fuel injection and variable camshaft timing were adopted. For these developments to operate, the engine ECU had to calculate more than just crankshaft position, and so a camshaft position sensor was needed (Figure 31.56).

For sequential fuel injection, the ECU had to know not only the crank angle, but also which stroke the piston was on. Also, with variable camshaft and valve timing, the engine ECU had to be able to read the position of the camshaft in relation to the crankshaft to determine the exact cam timing. The camshaft position sensor handles all of this. Mounted on one or more camshafts or in a camshaft-driven distributor, these sensors are usually hall-effect devices, optical triggers or inductive pickups (see Chapter 32).

31.20.5 Knock or detonation sensor

For ignition-timing control and correct combustion, an engine management system requires constant monitoring of every combustion event. For this, a piezo-electric detonation sensor is mounted close to the combustion chamber in a suitable acoustic area.

It can be a bolt-on doughnut type or can be screwed in by its own thread (Figure 31.57 shows the different designs). The sensor is tuned to respond to any sonic frequency (sound) resembling combustion detonation or *pinging*. This 'uncontrolled' combustion emits sudden vibrations in all directions throughout the solid mass of the engine. As sound travels much more efficiently through a solid than any other medium, vibrations are quickly received by the knock sensor, a signal is sent to the ECU and the ignition timing is instantly retarded.

Another way that the ECU can respond to the knock signal is to slightly increase the injector pulse width to enrich the mixture. Figure 31.58(a) shows a graphical representation of ignition timing control response and Figure 31.58 (b) shows a knock sensor signal trace.

Other inputs

There are other types of input signals critical to the management of an engine. Many signals registering an operational change or demand can be in the form of simple *switches*. Table 31.2 shows some other signal inputs to the engine ECU, briefly outlining the role played by each in the engine management system.

31.20.6 Adaptive learn

The engine management ECU can learn about the performance environment in which it is functioning. It builds a historical record of the demands placed upon it in both the short and the long term. The computer memory systems store sensor and performance data and make adjustments to adapt to the driver's driving style. Information is collected regarding the geography in which the vehicle operates, as well as transmission shifts, typical fuel

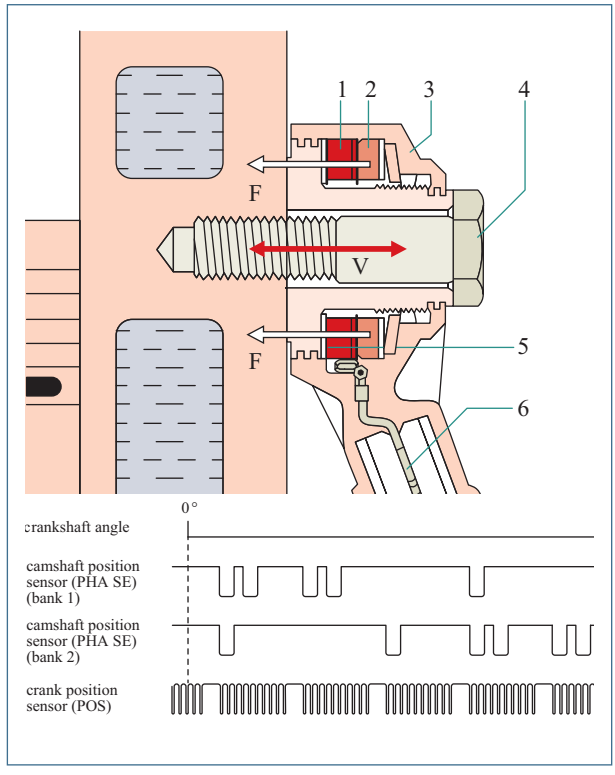
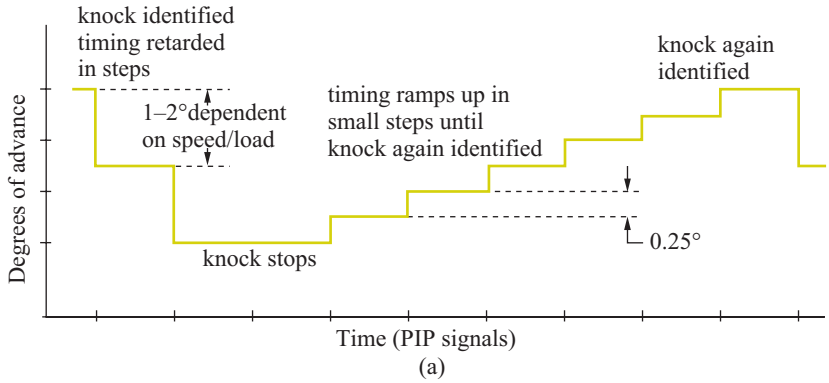
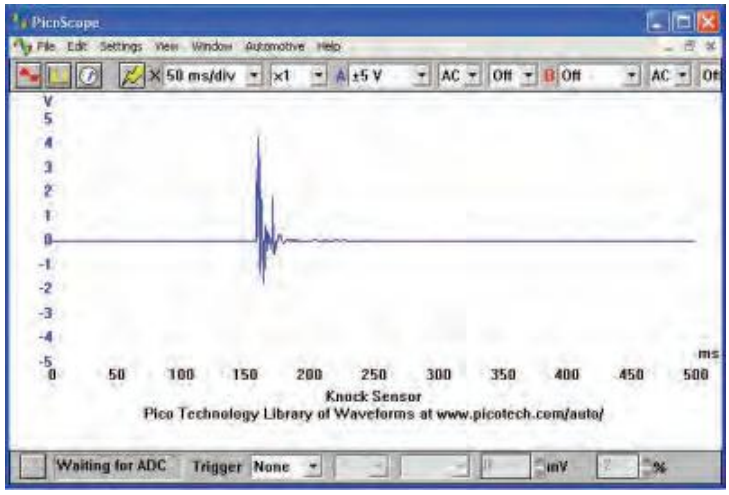


Figure 31.57 Piezo-electric detonation sensor



(a)



(b)

Figure 31.58 (a) The response of an ECU to a knock -sensor signal FORD (b) an analog A C knock -sensor signal PICO TECHNOLOGY

Table 31.2 Some other ECU input signals and their function

Input	Function
Battery voltage	Monitored for accurate operational adjustments of all electronic sy stems due to minor voltage changes. Also used for the computer' s k eep-alive memory (KAM)
Alternator load	Monitored for engine mechanical load changes due to high electr ical loads. The engine management system can also vary rotor field strength (via the regulator) to suit engine performance
Power-steering pressure switch	Monitored for engine mechanical load changes due to power-stee ring pump load, especially at idle
Ignition switch—start	Signals operation of starter relay and begins engine management operations once anti-theft system 's OK signal is also received. Also determines cranking fuel injection mode
Ignition switch—on	Provides input to ECU on k ey about engine off (K OEO) or key on engine running (KOER) conditions; used in conjunction with crank -angle sensor signal input
Ignition switch—accessories	CAN Bus communication between body electronic control comput er and engine ECU for various engine/vehicle settings.
Brake light switch	Signals engine ECU via multiplexing system that the driver is slow ing or stopping the vehicle
Transmission selector (auto) or clutch switch (manual)	Used by powertrain control ECU to determine appropriate gearsh ift points, torque maps (i.e. reverse) and idle speed loads. Prevents starter operatio n in gear
Air-conditioning request	Monitored to anticipate engine mechanical load changes due to ai r-conditioner compressor load and ECU operation of A/C compressor

Table 31.2 Continued

Input	Function
Air-conditioner pressure switch (or transducer)	Allows operation of air-conditioning system
Cruise control switches	Where cruise control is controlled by the engine ECU
Power or economy mode switch	Used by powertrain control ECU to determine appropriate torque a nd speed shift maps
CAN Bus communication	High-speed multiplexing communication between on-board vehic le computers
Immobiliser start signal	Provides coded input to engine ECU to begin fuel injection, ignitio n coil switching and starter relay operation

economy and allowances for engine wear and change. If the battery is disconnected, or the keep-alive memory (KAM) is lost, the adaptive-learnt changes will be lost and the usual driver will notice a change in the vehicle's performance. The ECU will revert to the tables originally programmed into the electrically erasable programmable read-only memory (EPROM).

31.20.7 Short-term fuel trim

Another learning capability of the engine management ECU is the monitoring of the short-term fuel trim (STFT). This feature enables the ECU to log the oxygen sensor trends (rich or lean) over the last few drive cycles. This adapts an appropriate air–fuel ratio map away from the original ECU tables and will cater for a minor engine or EFI fault in the short-term fuel metering.

31.20.8 Long-term fuel trim

Long-term fuel trim (LTFT) is the same system as STFT apart from the fact that it is an adaptation made over a much longer time-frame and can be continuous. This block learning is used for longer-term engine wear or vehicle changes. LTFT and STFT will be lost if the battery or the KAM is disconnected. Both are extremely useful for any engine management diagnosis, and their values can be accessed by any modern scan tool.

Handy hint: Output devices are sometimes referred to as actuators.

31.20.9 Assembly line diagnostic link (ALDL) or data link connector

Diagnostic trouble codes (DTC) can be sourced using a scanner at the 16-pin SAE J1850 or SAE J1962 trapezoidal shape diagnostic output link. Generally, the DTC code will be displayed in a five-digit alpha-numeric form, for example 'P0121' (see Table 31.4 later in the chapter) The code is often described in the scanner menu, but can also be deciphered using a workshop manual.

Table 31.4 Diagnostic procedure for code 'P0121' identified by a scan tool FORD

DTC application tests	Description	Possible causes	
P0121K OEO, KOER, Throttle	Throttle position sensor (TP) circuit range/ performance problem DTC P0121 is reported if the TP sensor signal is out of the self-test range .	Electrical condition Improper connection, incorrect reference voltage (VERVE), open or grounded TP sensor or signal return (SIGR TN) circuit. Sensor condition TP sensor damaged or faulty; corrosion on TP sensor brush, contaminated TP sensor brush.	Mechanical condition Binding or bent throttle linkage or cable , throttle plate below closed position, throttle plate or base idle screw maladjustment, TP sensor not properly secured; loose . Note: Idle speed is controlled by the IA C. The throttle stop screw must not be adjusted. Other condition Throttle was open during KOEO test procedure , fault or damaged PCM.

Check engine lamp

A check engine lamp (or a malfunction indicator lamp) in the instrument cluster will illuminate to alert the driver of an emissions-related engine-management system fault. If it is serious enough to interfere with the engine or system hardware, the ECU will force the vehicle into *limp-home mode*. In limp-home mode, the EFI and ignition system will switch to pre-set tables in the computer's read-only memory (ROM) to keep the vehicle mobile, but with reduced capability (see Chapter 40).

31.20.10 Sensor reference voltage and grounds

Two of the most important output signals the ECU sends are the sensor reference voltages and the sensor grounds. The reference voltage, often 5 volts, is provided to a selection of sensors as their operating voltage.

Sensors such as the throttle position, coolant temperature, camshaft- and crankshaft-position sensors and wide-band oxygen sensors will use the reference voltage to divide or switch (for a relative signal input) back to the ECU. The signal back will be a fraction or a frequency of the provided reference volts which resembles an engine condition. Many sensors share the same reference supply in a parallel circuit from the ECU. Sensor grounds or earth returns are provided to the same sensors by the ECU for reliable comparison of the returning signals (see Chapter 32).

31.21 Output devices and signals

31.21.1 Exhaust gas recirculation

To control high levels of nitrogen (NOx), combustion pressures can be reduced by introducing exhaust gas back into the intake system. This decreases combustion temperatures due to its inert characteristics. Recirculation of the gas is achieved by using an exhaust-gas recirculation (EGR) valve (Figure 31.59), which is operated by a solenoid controlled by the engine ECU.

Figure 31.59 Linear electronic type EGR valve BOSCH

31.21.2 Carbon canister purge solenoid

A carbon canister is provided in the vehicle's emission-control system. This has a connection to the engine's air-intake system. Evaporative hydrocarbon emissions can be stored in the canister charcoal pellets and later burnt by the engine. The *purge* line to the canister has a solenoid controlled by the engine ECU. Purging of the hydrocarbon vapour is permitted by the ECU only when it will not affect engine performance.

31.21.3 Automatic transmission operation

The powertrain control module (PCM) has full control over the electronic automatic transmission. It is responsible for the following:

- gearshift solenoids. To change gear at varying road speeds.
- torque converter lock -up. For 1:1 drive through without slip .
- various pressure-control solenoids. To modulate transmission line pressures.
- driveline controls. For different driving maps and adaptive learn.

31.21.4 AC compressor control

When the air conditioner is switched on, an increased mechanical load is placed on the engine. The ECU then energises the air-conditioning compressor clutch (directly or via CAN Bus), but only when engine operating conditions are suitable. The ECU might disengage the clutch during engine idle or high power output.

31.21.5 Broadband intake manifold

Inlet manifolds can be designed with dual branches. A solenoid operates a pneumatic servo, which directs the incoming air between two possible paths—a short and direct path or a longer, more curved path (Figure 31.60). An air charge entering an engine through relatively short and wide manifold runners will

provide more power due to rapid air speed. Longer and narrower runners provide greater turbulence, resulting in higher output torque.

31.21.6 Throttle motor (drive by wire)

Vehicles using drive-by-wire throttle control have no direct mechanical link between the driver's foot and the throttle valve. Instead, the ECU controls the throttle position via a throttle motor. Multiplexing signals and serial data from other control units determine the exact angle of the throttle (Figure 31.61).

31.21.7 Variable valve/camshaft timing

With variable camshaft timing, the cam pulleys are attached to the camshaft shaft via hydraulic motors. Engine oil pressure is modulated to the hydraulic actuators via ECU-controlled solenoids. The signal to the solenoid/s is *pulse-width modulated* to advance or retard the camshafts relative to the crankshaft. The camshaft overlap is then small at idle and larger at higher engine speeds.

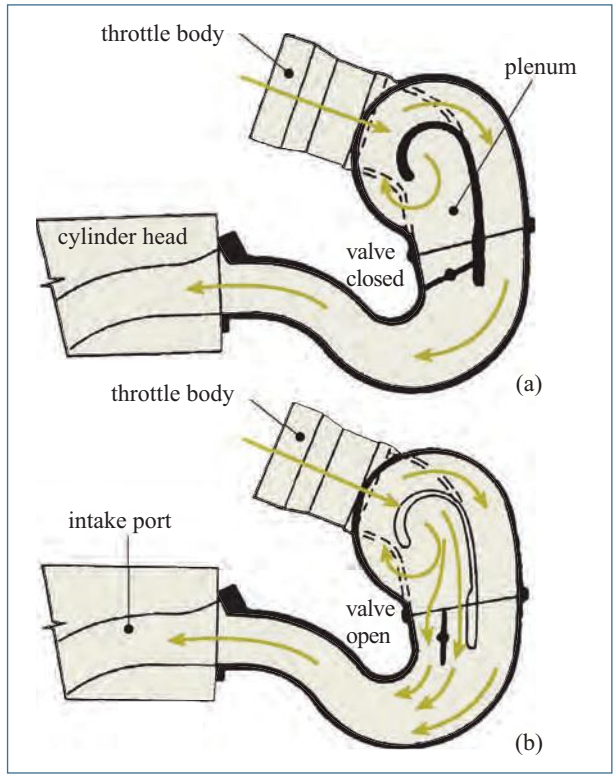


Figure 31.60 Broadband intake manifold FORD

31.21.8 Engine cooling-fan relays

The radiator and air-conditioning condenser fans are controlled by the engine ECU for greater control over engine idle and performance. The ECU operates various relays which provide the fans with different voltages for high and low speeds, giving finer control over engine temperature.

31.21.9 Idle-speed control device

The fuel for engine idle speed is provided by the injectors, the duty cycle being determined by the ECU to suit the airflow through the load sensor. The idle-speed control device can supply filtered air for a range of normal idle-speed requirements (Figure 31.62). These devices use solenoid-operated valves, rotary vanes or stepper motors to control the rate of air that bypasses the throttle valve according to a closed rpm loop with the ECU. This sends signals to the solenoid valves to increase the air supply when rpm is dropping from a pre-set ROM/PROM table and also increases the amount of fuel injected. This maintains idle speed under varying engine conditions.

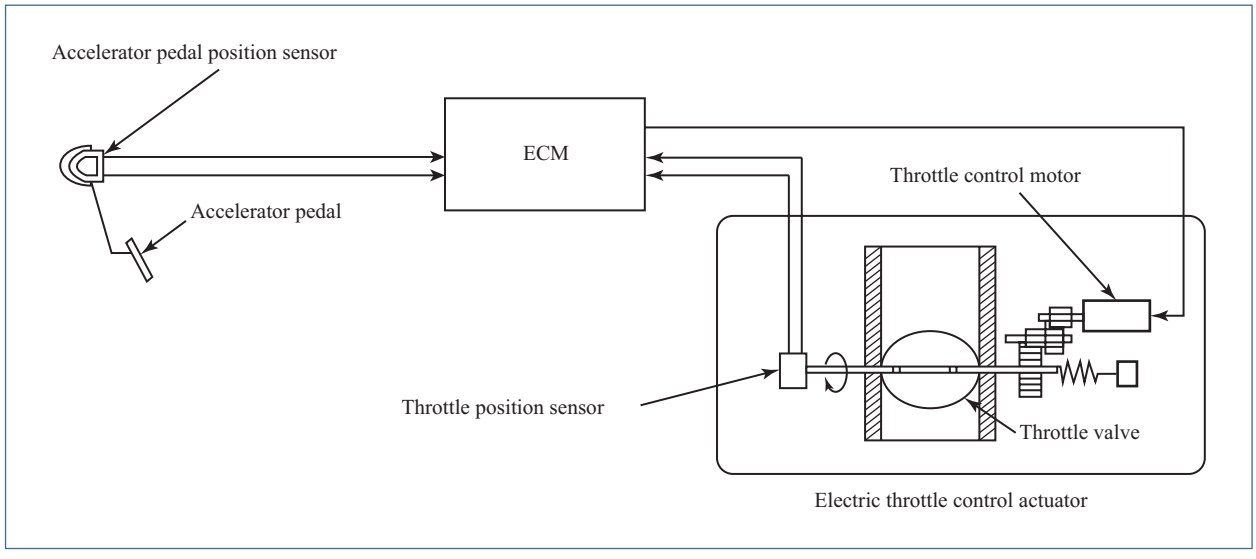


Figure 31.61 Connections between the throttle motor and the throttle position sensor

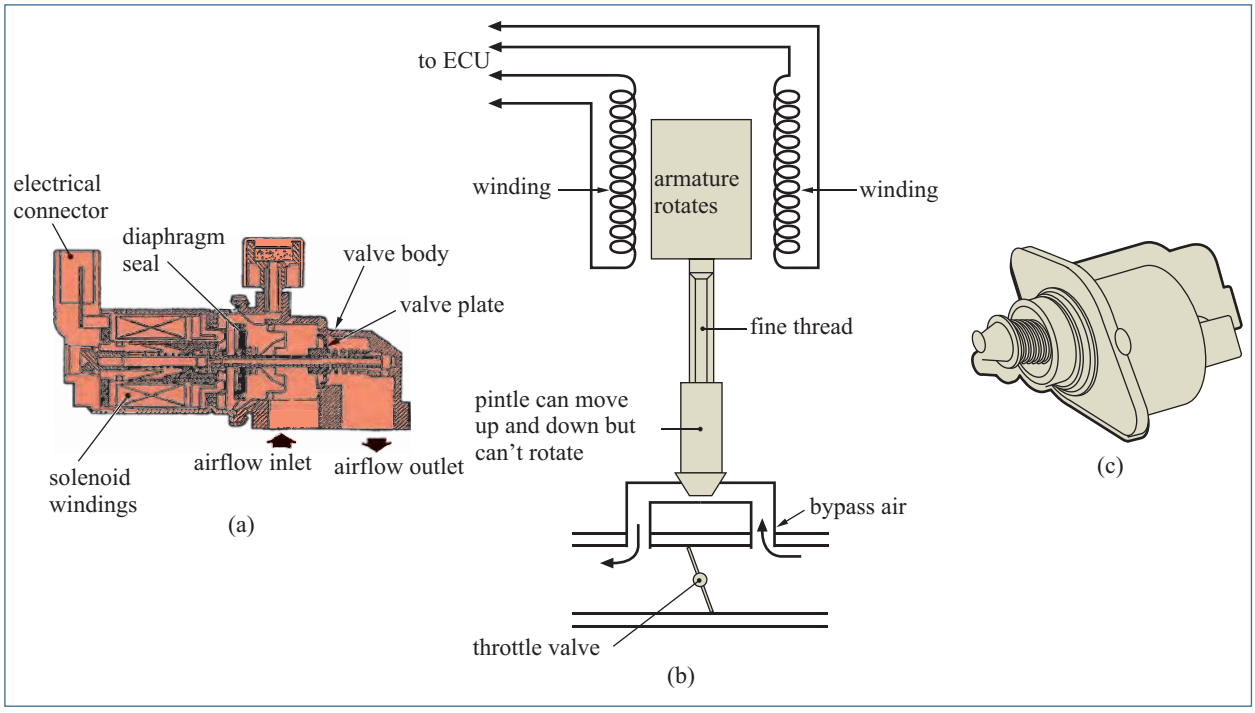


Figure 31.62 Idle control devices (a) duty solenoid type (b) rotary solenoid type (c) stepper motor type

Duty solenoid air-control valve

The operating principle of a duty-solenoid air-control valve is shown in Figure 31.62(a). A spring tries to push the valve towards one end of the bore (closed), and the solenoid tries to push it towards the other end (open). The ECU pulses the solenoid coil on and off. The higher the duty cycle of the solenoid, the stronger it becomes, and the valve opens further. As the valve opens, more air is allowed to bypass the throttle valve and the engine speed is increased.

31.21.10 Fuel pump relay

The fuel pump control is an output of the ECU, together with the ignition switch. They control the operation of the electric fuel pump, so that it operates only when needed and not continuously with the ignition switch turned on and the engine stopped.

Modern engine management systems use a dropping resistor circuit to decrease the electrical load and the actual fuel flow rate when not required. If a 'start' signal is not received by the ECU after the ignition switch is turned on, the fuel pump will operate for a short priming period only. If the engine fails to start or the ignition switch is accidentally left on, the fuel pump will be stopped. The pump continues to operate as long as the engine is running, but when the engine stops, it will automatically stop after about one second.

Safety tip: Some systems also use a roll-over switch or airbag deployment signal to switch the fuel pump off in an accident.

31.21.11 Oxygen sensor heater relay

The ECU provides an output for an oxygen sensor heater relay or supplies a wideband sensor reference voltage. The heater relay supplies battery voltage to the oxygen sensor to bring it into operating temperature as quickly as possible. The reference voltage is sent to wide-band sensors for the internal sensor circuit operation.

Handy hint: Information concerning ignition coils can be found in Chapter 32, while information on variable delivery turbocharger controllers can be found in Chapter 22.

31.22 Location of system components

Figure 31.63 shows the location of the components of a sequential multipoint fuel-injection system. The fuel and the ignition are centrally controlled, as are the variable valve timing mechanism and a number of other items. This is a total engine management system. The various parts of the air and fuel systems are shown in the illustration and are noted below:

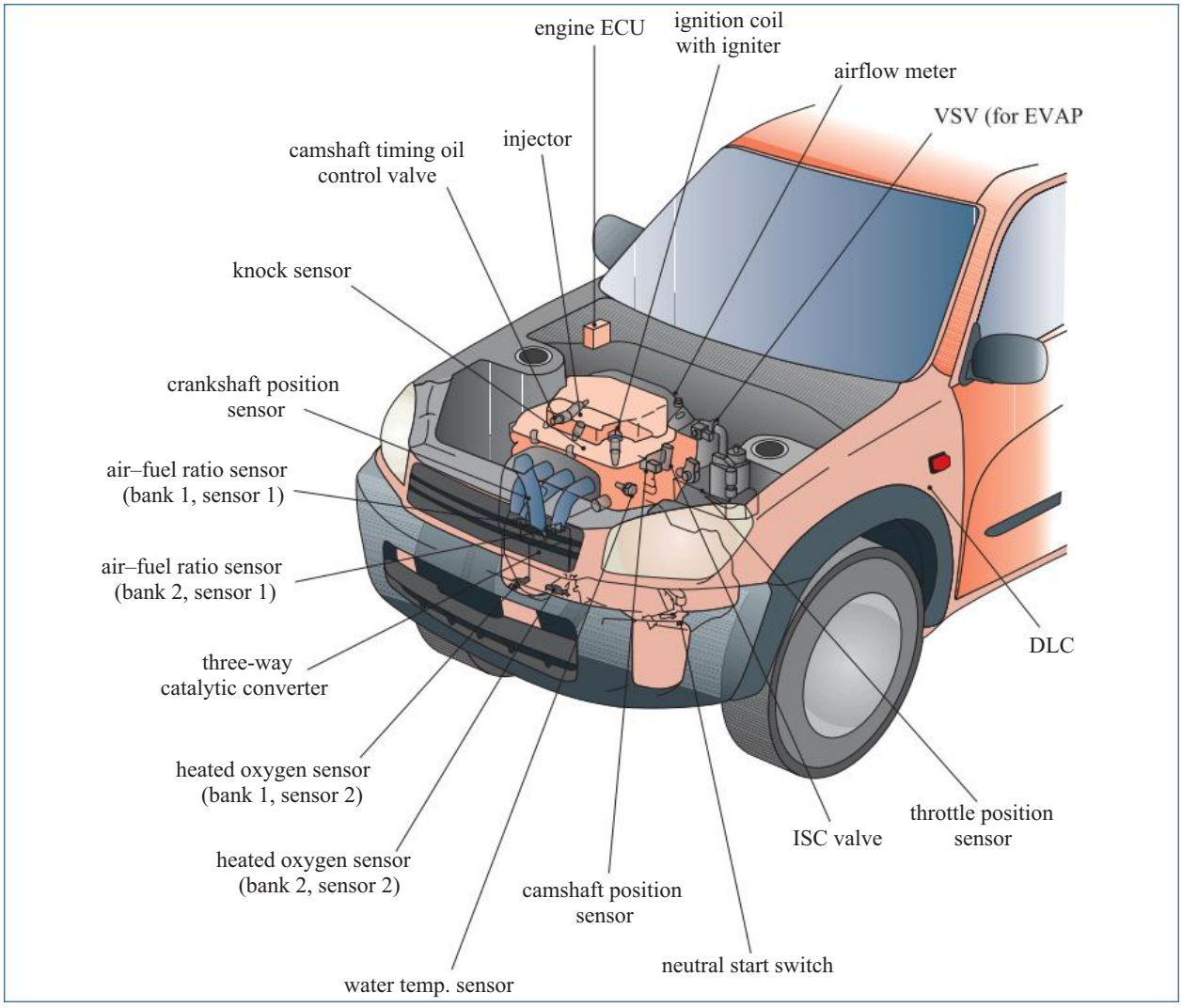


Figure 31.63 The location of the components of a returnless engi ne management system

1 Engine ECU. Reads inputs from sensors and delivers processed outputs to actuators to control the system.
2 Ignition coil with igniter. Supplies the spark for the fuel charge . This is a coil-on-plug arrangement which reduces high voltage loss.
3 Airflow meter. Provides engine load and airflow information to the ECU .
4 VSV (vacuum switching valve). An ECU-controlled evaporative emission-control device which connects the purge line of the charcoal canister to the intak e manifold.
5 DLC (data link connector). Allows multiplexing interrogation to the ECU and actuators to be check ed by providing a connection for an OBD II scan tool.
6 Throttle position sensor . Tells the ECU the position of the throttle .
7 ISC (idle-speed control) valve . Controls the idle and fast-idle speeds.
8 Neutral start switch. Tells the ECU the gear position selected.
9 Camshaft position sensor . Tells the ECU the position of the camshaft to enable coordination of ignition timing and injection timing.
10 Water temperature sensor . Provides coolant temperature information to the ECU .
11 and 12 Heated o xygen sensors. Provide post-catalytic-converter exhaust gas-o xygen information to the ECU .
13 Three-way catalytic converter . Treats carbon mono xide, hydrocarbons and o xides of nitrogen exhaust gas emissions.
14 and 15 Air–fuel ratio sensors. Provide pre-catalytic-converter exhaust gas-o xygen information to the ECU .
16 Crankshaft position sensor . Tells the ECU the exact crank angle of the crankshaft.
17 Knock sensor . Detects fuel detonation (pinging) so that the ECU can retard ignition timing to prevent piston damage while maintaining maximum ignition advance .
18 Camshaft timing oil control valve . Varies the intak e valve timing to provide optimum engine performance for various conditions.
19 Injector. Sprays atomised fuel into the inlet port.

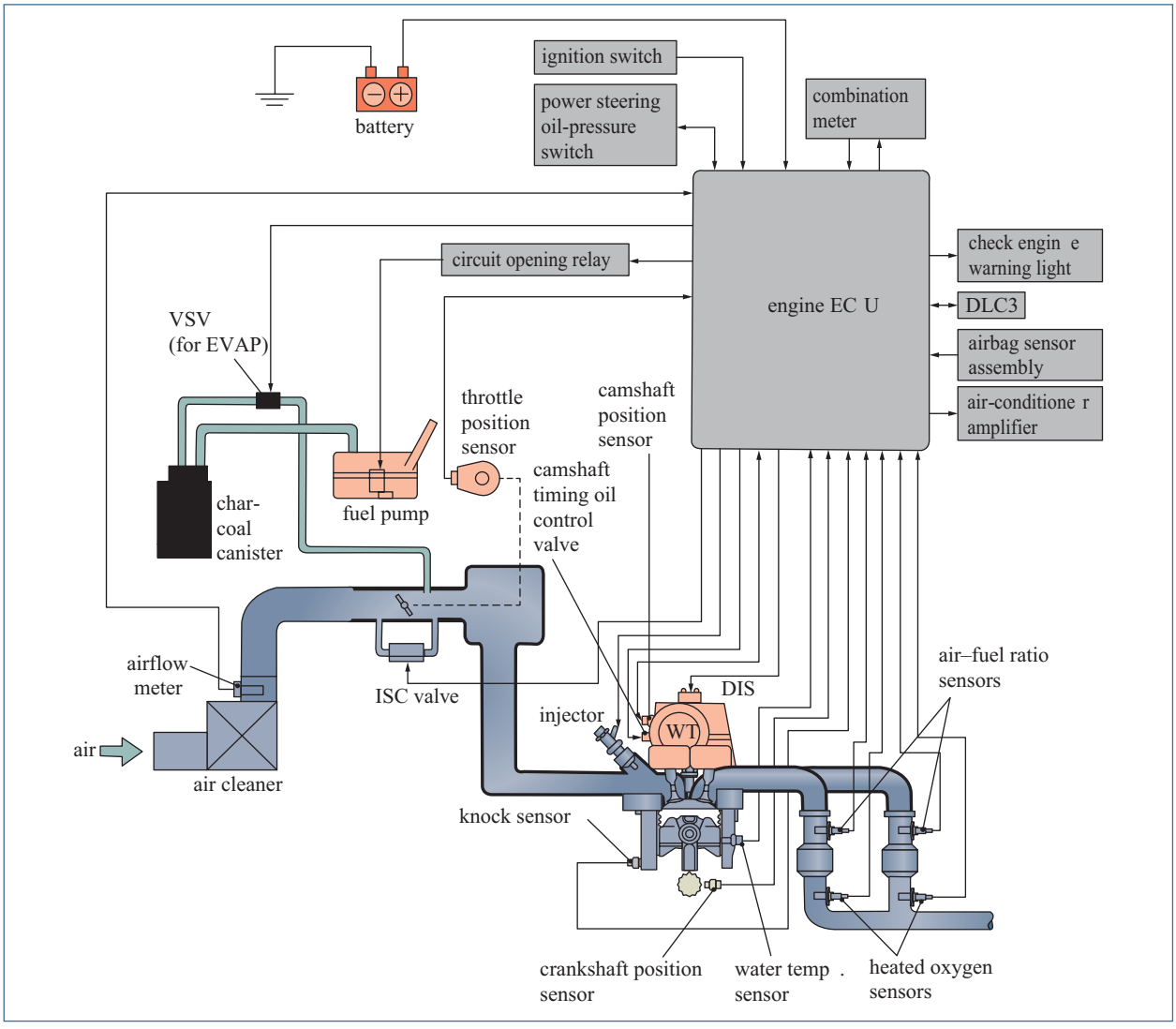


Figure 31.64 Schematic layout of a returnless fuel engine management system

31.22.1 Schematic diagram of the system

The complete system is illustrated in schematic form in Figure 31.64. Its features are described in the following paragraphs.

Air system

This is similar in operation to the air system of early electronic fuel injection, except for its use of a stepper motor idle-speed control valve (Figure 31.62(c)). This unit is operated by a series of pulses from the ECU. The ECU can turn the stepper in a forward or reverse direction by changing the polarity of the windings. The stepper moves in or out, regulating the volume of air that bypasses the throttle valve.

Fuel system

This is a returnless fuel system. The fuel pump, fuel filter and pressure regulator are designed as an assembly, as in Figure 31.63, which is mounted inside the fuel tank. The pump provides fuel to the fuel rail via a pulsation damper unit. There is no return line to the fuel tank.

31.23 Modes of fuel injection

There are four different modes of fuel injection:

1 Continuous. Injectors spray continuously and the flow rate is controlled to suit the load and speed of the engine . Usually found only on older vehicles.
2 Simultaneous. All injectors operate at the same time and inject once for each revolution of the engine .

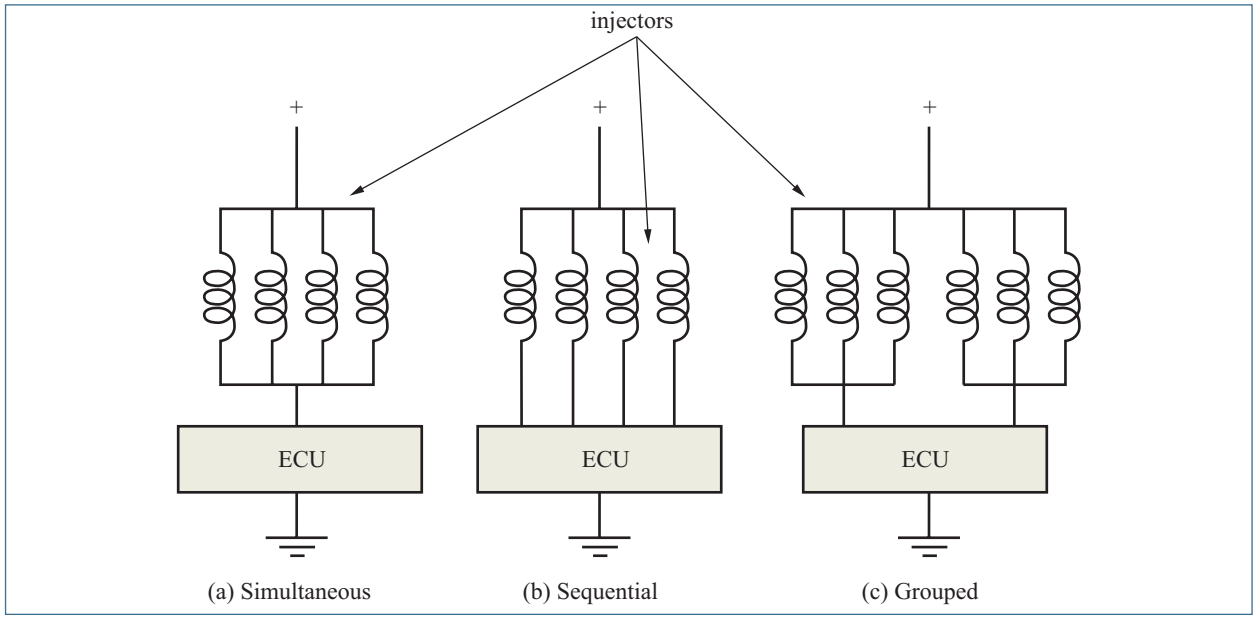


Figure 31.65 Wiring examples for different fuel-injection modes

3 Sequential. Injectors operate in a sequence that follows the firing order of the engine .
4 Grouped (bank ed). Injectors operate in groups that follow the firing order of the engine . For example , in a two-bank system for a six-cylinder engine , injectors 1, 5, 3 are grouped to operate together , followed by 6, 2 and 4.

Figure 31.65 shows the basic wiring diagrams for simultaneous, sequential and grouped modes. The ECU controls the injectors by completing the circuits to earth. For Figure 31.65(a), all the injectors will operate at once. For Figure 31.65(b), each can be operated independently, and for Figure 31.65(c), the injectors can be operated only as groups of three.

31.23.1 Synchronous and asynchronous injection

With *synchronous injection,* the operation of the injectors is synchronised to the speed of the engine. The ECU normally uses an ignition pulse, or crankshaft reference signal, to initiate injection. With *asynchronous injection,* injection is not tied to the ignition system, crankshaft speed or position. Injectors operate on a time basis, the ECU determining the time between injection pulses. Most systems are synchronous but will employ asynchronous pulses as directed by the ECU for particular conditions.

Handy hint: Asynchronous pulses could be used during acceleration, wide-open throttle and **cold starting.**

31.24 Servicing engine management systems

This section outlines general points relating to service, but for any form of adjustment or diagnosis, test equipment and a workshop or specification manual are essential. Most systems have a built in self-diagnostic facility which can check the ECU and sensors. However, to prevent damage and diagnose problems sensibly, the detailed information in the test equipment operating manual should be followed.

31.24.1 Service precautions

The following precautions should be taken when working on engines equipped with electronic control systems.

Electrical

Observe the following:

1 Always use a 12-volt battery as the vehicle power source . Do not connect batteries in any way that will give a higher voltage .
2 Do not attempt to disconnect the battery cables while the engine is running.
3 Before disconnecting the cables from any electronic component, turn the ignition switch off and disconnect the battery earth cable .
4 Use a spark tester to test spark. Do not open circuit spark plug leads as this may damage the ECU .

5 The connections to the ECU must be secure , with connectors pushed firmly into their sock ets. A poor connection can cause a high-voltage surge , which could damage electronic devices.
6 Keep the harness to the ECU away from adjacent harnesses to prevent cross-signals occurring.
7 Keep the ECU and harness dry . Avoid steam-cleaning the engine .
8 Components should not have 12 volts directly applied. In most cases, sensors operate on 5 volts, and testing must be done only with approved meters. Some tests require the use of a digital meter .
9 Do not use a multimeter on ohms function when checking Hall-effect sensors. The voltage applied by the multimeter could damage the sensor .
10 When back -probing injectors, never touch the test probes together . The resulting short circuit could destroy the output driver circuitry in the ECU .
11 Disconnect the battery terminals before connecting a battery charger .
12 Take precautions with battery jumper leads. Voltage spik es can be produced that will damage electronic components. Always use spik e-protected jumper leads.
13 Remove all computers from a vehicle prior to placing it in a paint-baking oven or carrying out arc welding.
14 Use diode-protected relays when fitting accessories.

Air system

Observe the following:

1 There should be no air leak in any part of the air-intake system as this will upset the air–fuel ratio in systems with airflow/mass meters, or give a high idle speed with MAP sensors.
2 Make sure that the air cleaner is serviced and correctly fitted.
3 Treat the airflow sensor with care to avoid damage .
4 Do not attempt to dismantle an airflow sensor .
5 Do not clean the airflow sensor with any type of detergent. Only use dedicated hotwire sensor cleaner on air mass sensors (Figure 31.66).
6 When changing the air cleaner element, look for signs of dust leaks (Figure 31.67)

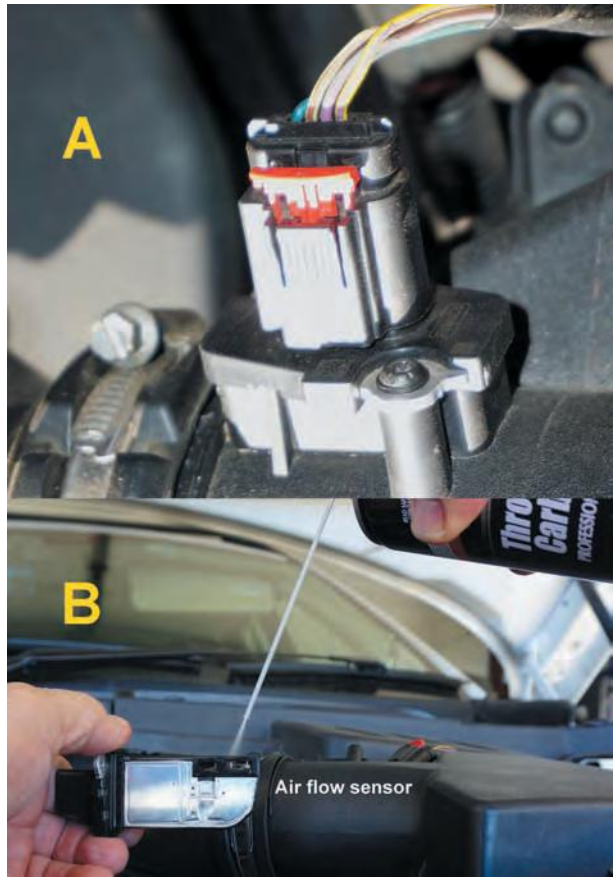


Figure 31.66 A airflow sensor location and B cleaning airflow sensor with correct cleaner

Figure 31.67 Checking for dust leaks in air intake system

Fuel system

Observe the following:

1 The fuel pump should not be operated unless there is fuel in the tank. Under normal circumstances, fuel will provide pump lubrication and cooling.
2 Always depressurise the fuel system before breaking it for service work, such as replacing a filter by removing the fuel pump fuse or relay and running the engine until it stalls.
3 Always use EFI-rated fuel hose and hose clamps for any replacements.
4 All hose connections must be tight to prevent fuel leaks.
5 Handle the fuel injectors carefully .
6 Battery voltage should not be applied directly to the injectors.

7 Always have a fire extinguisher available when working on fuel systems.
8 Take care when changing fuel filters. Many modern vehicles have the fuel filter as an integral part of the fuel pump in the tank and are not a serviceable item.

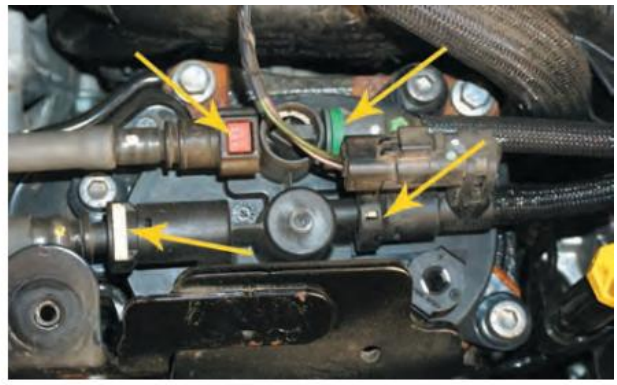


Figure 31.68 The fuel filter fitted to the vehicle and the quick clamps

Changing a fuel filter

If the vehicle has a serviceable filter and it needs to be changed, remove the fuel pump fuse or relay or disconnect the pump and run the engine until it runs out of fuel. When the engine stops, try it again to ensure all the fuel pressure has gone. This will de-pressurise the fuel system. Place a rag around the fuel filter connections to catch any fuel loss and undo the hoses. Replace the fuel filter and dispose of the old filter in the filter recycling.

To disconnect some fuel filters, hose clamps must be undone. Special retaining quick clips/clamps are used in other filters, and are increasingly common (Figure 31.68). Follow the manufacturer's procedures when disconnecting them. Figure 31.69 shows quick clamp designs.

General

Observe the following:

1 Do not speed up the engine prior to switching it off .
2 Do not depress the accelerator before starting the engine . This can cause damage by backfire through the intake manifold. Some vehicles will enter clear flood mode when attempting to start on full throttle .

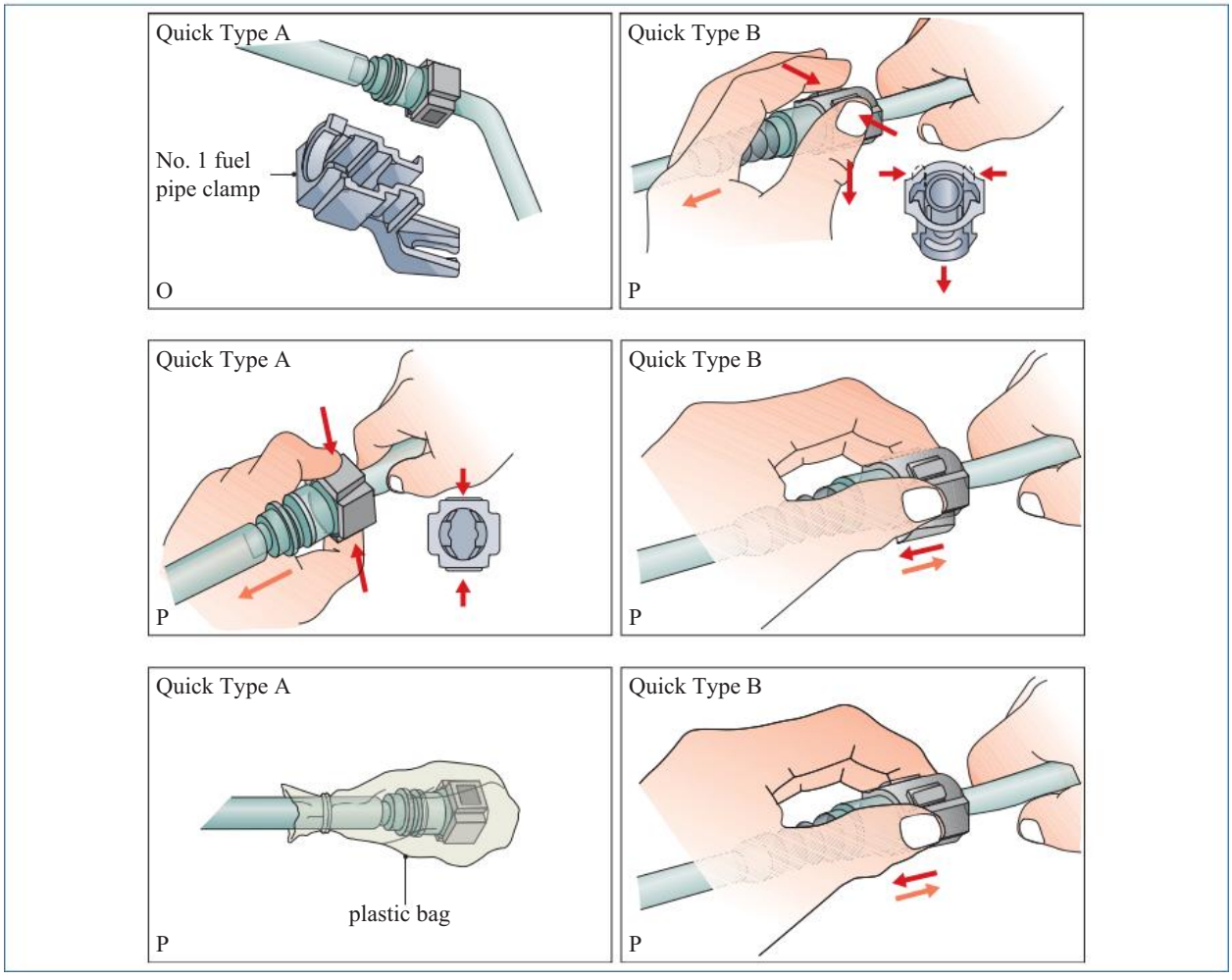


Figure 31.69 Disconnecting fuel pipe quick clamps—identify the st yle of clamp and fit new boring seals when replacing pipes

31.25 Fault finding and diagnosis

31.25.1 Locating basic faults

When checking for engine faults, start with the basics. Do not assume that the problem lies with the electronic controls. If the engine will not start, is hard to start, has unstable idling, runs 'rough' or has poor acceleration, begin by checking the following:

1. Power supply . Check the battery , battery terminals, the fusible link and the fuses.
2. Alternator output. Check for voltage output, current output and signal trace .
3. Body earths. Check for poor or loose connections that could have resistance and cause voltage loss as well as voltage spik es.
4. Fuel supply . Check the fuel lines (leaks, deterioration, tightness), the filter (leaks, service interval) and the fuel pump (noise , flow rate , output pressure).
5. Ignition system. Check the spark plugs, cables, distributor (if fitted) and connections.
6. Emission-control system. Check crank case ventilation and the EGR system, and check for vacuum leaks.
7. Others. Check ignition timing and idle speed.
8. Connectors. Problems with EFI systems are often caused by poor contact at the connections. Check all connectors and mak e sure that they are secure . Make sure connector plugs are fully clipped in and that waterproof boots are fitted correctly .

31.25.2 Star ting problems

Check the spark by using a test spark plug with the gap opened up to approximately 6 to 8 mm. Keep hands away from all parts of the ignition system—the high voltage is dangerous. Check the fuel pressure and flow by listening for the electric pump operation, or check for pulsations which can be felt in the fuel delivery and fuel return lines. A fuel pump pressure-flow test should be made by connecting a pressure-flow gauge in series into the fuel-delivery line. Figure 31.70 shows a pressure and flow tester.

Safety: Tak e care when disconnecting fuel lines, as they are under pressure whether the engine is running or not. Do not disconnect direct injection high-pressure lines without consulting the manufacturer' s procedure .

Figure 31.70 Fuel-system analyser with pressure gauge , fuel-flow-rate meter and vacuum gauge CODA PRODUCTS PTY LTD

31.25.3 Checking fuel pressure

Fuel pressure can be checked in two ways, depending on the vehicle system—with a scan tool or with a pressure gauge. When using a pressure gauge, follow the previous procedure to de-pressurise the fuel line. Insert a T-piece to place a pressure gauge in the line to check the fuel pressure. The correct pressure for the vehicle being worked on will need to be found in the workshop manual.

31.25.4 Injectors

Generally, injectors can be checked by isolating them one after the other to see the effect on the engine. Power to the injector can be checked by plugging a noid light into the injector harness, as shown in Figure 31.71. If an injector appears to be faulty, it can be removed from the engine and its tip and sleeve examined for damage and deposits by using a magnifying glass. An alternative method is to use a stethoscope or an electronic stethoscope (Figure 31.72). By placing a probe on each individual injector, it is easy to distinguish which injectors are working.

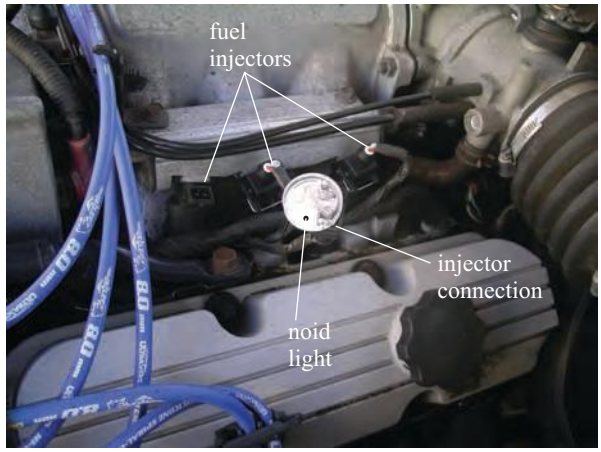


Figure 31.71 Checking power to the injector with a noid light

Equipment is available to clean injectors and test their operation, usually on a bench-testing rig, as shown in Figure 31.73. (On-the-vehicle injector cleaning is maintenance, not diagnosis.) To eliminate a failing injector, assess its *before* and *after* performance. Figure 31.74 shows some correct and incorrect spray patterns. A good injector should produce a clean, fine spray.

31.25.5 Fail-safe

Control units have an inbuilt fail-safe function (known as *limp-home mode*). This automatically comes into operation if a problem exists in the system. Should a sensor fail, the system could adopt a fail-safe mode. The sensor will either be isolated or average values substituted by the ECU for signals that it is not receiving.

Handy hint: Fail-safe functions enable a vehicle to be driven, but engine performance is affected until the problem is rectified.

31.25.6 Self-diagnosing faults

Modern systems have the ability to self-diagnose, recording faults and storing information within the ECU memory. The information can then be obtained in the form of a code via the data link cable with a scan tool. The code identifies the location of the malfunction and enables further checks to be carried out.

Self-diagnosis is carried out automatically whenever the ignition is switched on and power is supplied to the ECU. If an intermittent fault occurs in the system while the vehicle is being driven, the ECU records this and stores it in its memory. This information is available for any subsequent diagnosis check.

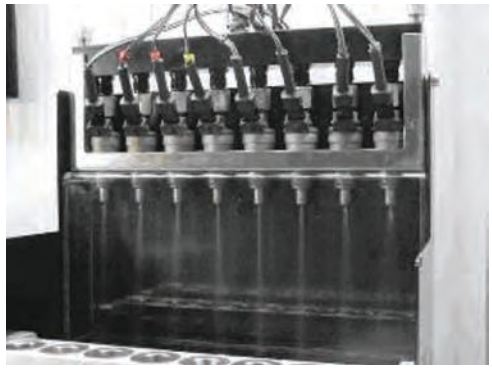
Handy hint: Disconnecting the battery will erase recorded data from the ECU .

31.25.7 Diagnosis methods

A number of methods have been used to access fault codes. In very early systems, the use of flashing light codes from LEDs in the ECU, flashing-light codes from the engine warning lamp on the instrument panel and meters that register codes by needle movement were used to evaluate DTCs. A device mentioned in a DTC should not be replaced without testing the entire circuit as well as the device in question. The codes narrow a fault down to a circuit area only and do not immediately condemn components.

Hand-held scan tools and dedicated test instruments are now exclusively used for checks and diagnosis (Figure 31.75), along with larger workshop test equipment. Most vehicle manufacturers provide an internet diagnostic service for their dealerships.

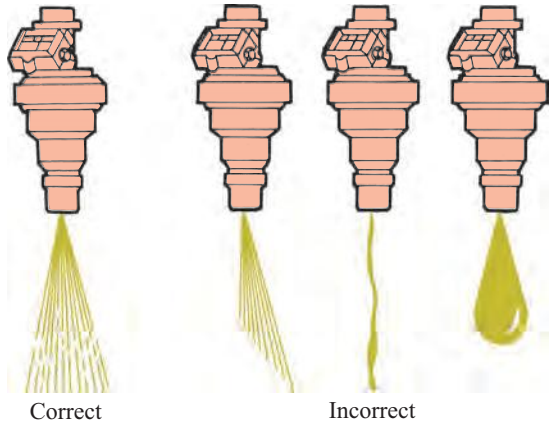
Figure 31.72 An electronic stethoscope allows the clicking noise emitted from an injector to be amplified and listened to on headphones



(a)

(b)

Figure 31.73 Off-vehicle injector testing and servicing
(a) testing flow rate , spray pattern and leakage
(b) ultrasonic cleaning bath



Correct Incorrect

Figure 31.74 Correct and incorrect injector spray patterns for a multipoint injector FORD

Figure 31.75 Wireless Bluetooth scanner ROBERT BOSCH (AUSTRALIA) PTY LTD

Diagnosis with instruments

Test instruments connected to the data link connector enable diagnostic codes and other information to be extracted from the ECU. There are various designs of instruments, and these are used in different ways. (Some of these are noted in later sections on testing and testing equipment.) For example, if a scanner gives out the code for a *coolant-temperature sensor voltage out of range,* diagnose a fault somewhere in the coolant-temperature sensor circuit. A workshop manual diagnostic flow chart advises that the next step is to test the sensor resistance.

Checking the resistance of a component

Figure 31.76 is an example of how a component's resistance—in this case a temperature sensor—might be checked. The sensor is suspended in a container of water and its resistance is checked as the temperature of the water is increased. Because the sensor is a thermistor with a negative temperature coefficient, its resistance will decrease as the temperature is increased.

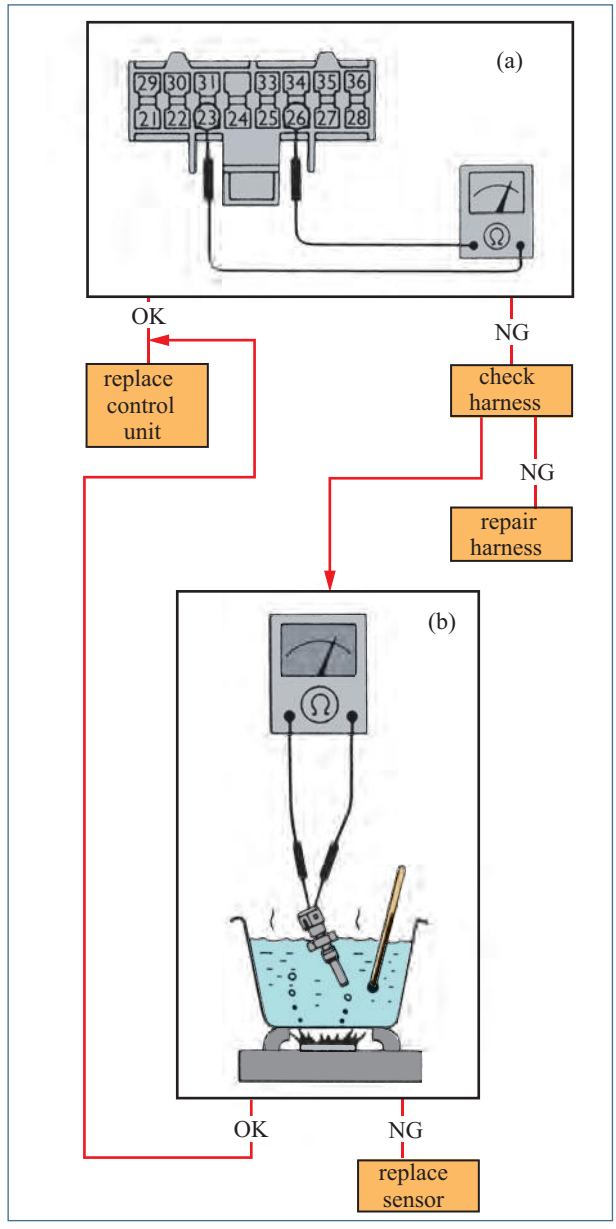


Figure 31.76 Testing a coolant-temperature sensor resistance vs. temperature

After disconnecting the connector, the harness can be checked with an ohmmeter. This measures the resistance between two particular pins. The reading is then compared with the resistance specified for the sensor. In all cases, the component being tested *must be isolated* from the rest of the electrical system. Ohmmeters can destroy sensitive electronics, and should only be used where a workshop manual suggests it. Most engine management system components are diagnosed live, using an oscilloscope.

General

Similar checks to that in the example above can be made on the other components of the system. Regardless of all the electronic controls that are fitted, the engine still needs the correct air–fuel mixture and compression in its cylinders and a spark at the spark plugs to ignite the mixture. Failure to start, or some other irregular engine operation, could still be caused by these fundamentals failing.

31.25.8 Scan tools

The scan tool shown in Figure 31.75 is a device for interrogating the electronic control system through the data link connector (DLC). When connected to the DLC, fault information can be extracted. The scanner shown only requires a *dongle* to be placed in the DLC and uses Bluetooth communication to interrogate the vehicle remotely.

The scan tool might, for example, indicate the throttle position code P0121. Relating to one particular manufacturer's system, this shows that the throttle position sensor is reporting values outside the self-test range. The workshop manual can then be consulted for possible causes.

An extract of the diagnosis chart from the service manual is shown in Table 31.4 as a further example. This shows the diagnostic trouble code (DTC) and the possible causes of faults that relate to the throttle position sensor. The code KOEO stands for 'key on, engine off' and KOER stands for 'key on, engine running'. Chapter 40 gives more information on the use of scan tools.

Data loggers

Other tools associated with the diagnostic link are *data loggers*. These are devices that record large amounts of computer data and signal exchange, their purpose being to capture an intermittent fault. The data logger is placed in the data link connector (DLC) and the vehicle driven as usual in an attempt to have the fault occur (Figure 31.77). Once the fault has been experienced or the malfunction indicator lamp has illuminated, the live data recordings can be *rewound* to observe the faulty circuit or system. The data is retrieved through a simple personal computer program. A sample data capture is shown in Figure 31.78.

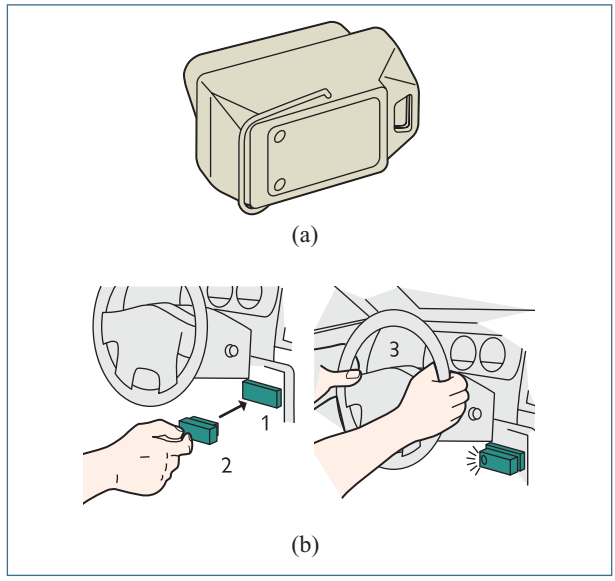


Figure 31.77 Data logger and connector (a) data logger (b) plugging into the connector and recording procedure

Handy hint: Scan tools can have a digital code readout mode—a two- or four-channel oscilloscope display , an actuator self-test function, live data display or a data logger function. There are many variations

31.25.9 Voltmeters and multimeters

A voltmeter or a digital multimeter can check the circuit voltage and, in some early systems, would read diagnosis codes. Before using a voltmeter, make sure that it is appropriate for the system on which it will be used, and also check that it will be used correctly—consult the workshop manual.

The voltmeter must have a high internal impedance (of at least 10 megaohms (MΩ)) to prevent damage to the circuitry being tested. Auto-ranging digital multimeters (DMMs) are often used. Due to the rapid operation

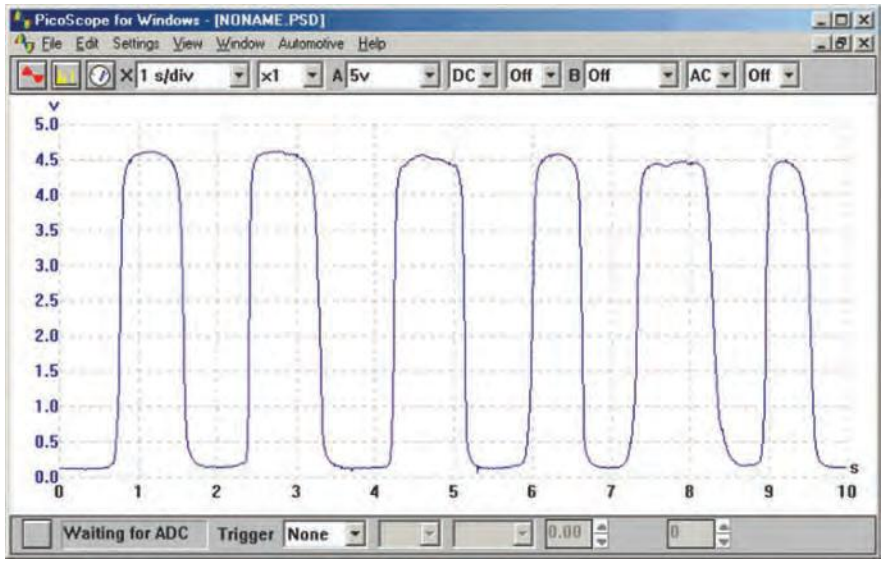


Figure 31.78 Sample data capture from a data logger , showing a freeze-frame data capture on three circuits EASE DIAGNOSTICS

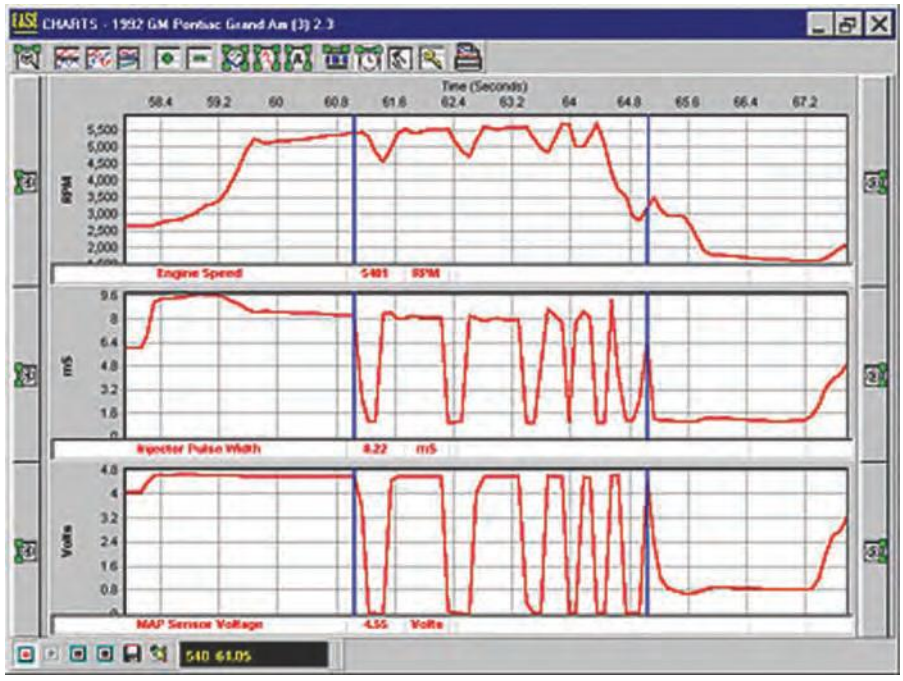


Figure 31.79 A wide-band o xygen sensor signal trace tak en by an oscilloscope PICO TECHNOLOGY

of modern engine management system devices, DMMs can no longer display results fast enough—an oscilloscope is needed to accurately capture signals.

31.25.10 Oscilloscope

An oscilloscope can check the waveform of components and signals produced by sensors. The oscilloscope and the system or component being checked are connected in parallel in exactly the same way as a voltmeter is connected to a circuit. An oscilloscope is essentially just a voltmeter, but it has many advantages over a voltmeter or digital multimeter, the clearest being its ability to log a voltage (or current) *trace* showing a signal's amplitude (height in volts), frequency (cycles or events) and brief snapshots of its immediate history.

Figure 31.80 A four-channel hand-held oscilloscope ROBERT BOSCH (AUSTRALIA) PTY LTD

Figure 31.79 is an example of a waveform from an oxygen sensor. The height of the vertical lines represents voltage, and the horizontal axis line represents frequency or time. The oscilloscope pattern obtained can be compared with a known good pattern. Some oscilloscopes can display the signals from more than one sensor. This enables the test results of different devices to be compared. A four-channel oscilloscope is shown in Figure 31.80.

Handy hint: The term frequency **is a measure of cycles per second. Frequency is measured in hertz (Hz).**

31.26 Sensor testing

All automotive computers work on voltage signals or resistance values. These signals may be constant or sweeping analog voltages, sweeping resistance values, digital stepped voltages or a combination of these. The change in voltage frequency signals may be gradual or very rapid.

Resistance readings on sensors or actuators at room temperature can lead to misdiagnosis. The most reliable diagnostic check of an engine management circuit is to check the real-time voltage or resistance values sent to or from the ECU. The quality of the ECU power and ground supply should always be confirmed using voltage drop tests. Figure 31.81 shows a simple analog sensor circuit.

31.26.1 Sample oscilloscope traces

An oscilloscope (Figure 31.82) can freeze the image and enable it to be reviewed. Figure 31.83 shows four different captured traces of sensors and actuators.

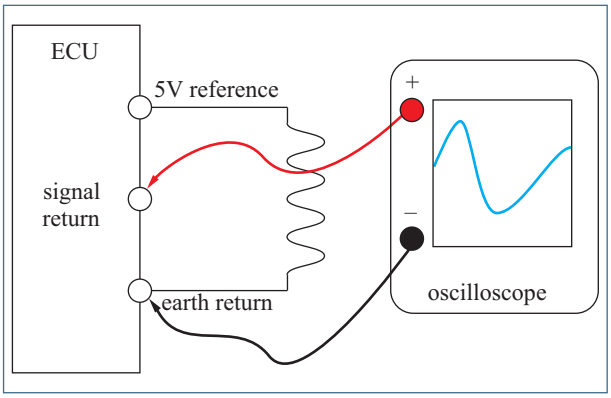
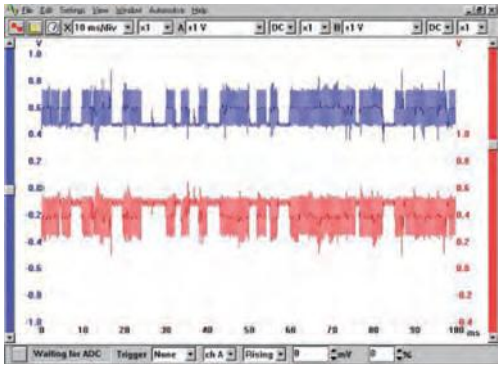
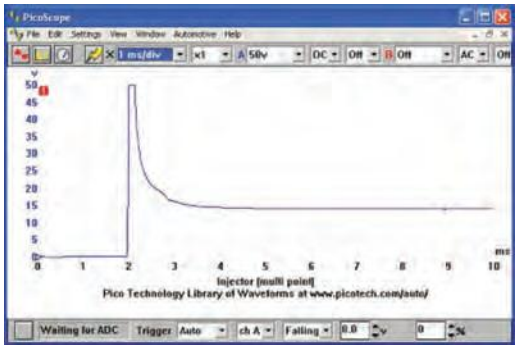


Figure 31.81 A simple analog sensor circuit being tested by an oscilloscope

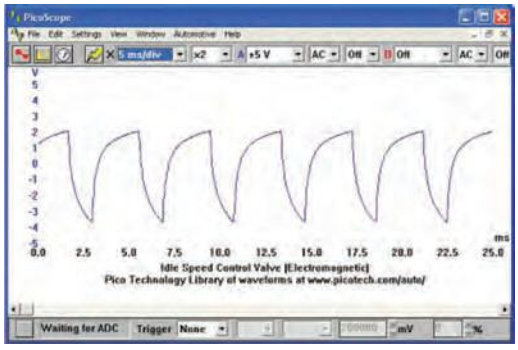
Figure 31.82 An automotive multichannel oscilloscope that couples to a personal computer PICO TECHNOLOGY LTD



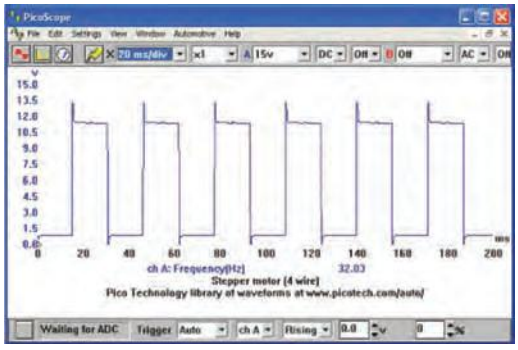
(a)



(c)



(b)



(d)

Figure 31.83 Sample oscilloscope waveforms (a) CAN Bus communication along a twisted pair (b) duty cycle-type idle solenoid (c) fuel injector (d) stepper motor-type idle control device PICO TECHNOLOGY

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- state the correct air–fuel ratio for a petrol engine
- describe the functions of a carburettor and its components

- explain the functions of a mechanical fuel pump and its components and their function when used with carburettor systems
- describe the different types of EFI systems, their components and their function
- explain the basic operation of—and systems used in—EFI systems
- describe the two types of fuel supply systems (return-to-tank and returnless)
- state the sensors relied on by the EFI system
- explain what the outputs from the ECU are and what they control
- describe the different types of injectors used in EFI systems
- explain stratified and homogenous charge
- describe the service requirements of an EFI system
- diagnose EFI system faults using scan tools, multimeters and an oscilloscope .

REVIEW QUESTIONS

1 What does EFI stand for?
2 List some reasons why EFI is used.
3 What are the two main types of EFI systems ?
4 State the main difference between the three types of EFI.
5 Identify the main parts of the injector in Figure 31.30 and indicate the function of each part.
6 Name the three subsystems of an EFI system and indicate the general purpose of each.
7 Name , in order , the parts of an EFI air-intak e system.
8 State the main parts of a basic fuel system.
9 What is the purpose of the ECU (electronic control unit)?
10 Name some of the sensors in an engine management control system.
11 Identify the main output components in the system.
12 Which three types of fuel pumps are used with EFI systems ?
13 How does a vane air sensor measure airflow?
14 Select one of the systems and indicate the provisions made for engine idle speed.
15 What is an oxygen sensor ?
16 Briefly describe the difference between an open system and a closed-loop system.
17 What is a crank -angle sensor ?
18 What is a knock (detonation) sensor ?
19 What is the purpose of the pressure regulator in a fuel system ?
20 What is a MAT sensor ?
21 What is meant by engine management ?
22 What are the three main input signals to an ECU?
23 What is meant by fail-safe or limp-home mode ?
24 State some of the precautions that should be tak en to protect electronic components.
25 Why should test lamps not be used with an engine management system ?
26 What type of voltmeter or multimeter should normally be used for checking an EFI system ?
27 What is meant by self-diagnosis ?
28 What is meant by simultaneous injection and sequential injection ?
29 What would be the lik ely effect of a vacuum air leak in the air-intak e system for:
   a. MAP sensor systems ?
   b. airflow meter systems ?
30 Briefly describe how self-diagnosis information is obtained from one system.
31 What is a scan tool ?
32 Name the parts of a carburettor fuel system
33 What is the main difference between a carburettor fuel system and an EFI fuel system ?
34 What is a venturi and how does it function ?
35 What is the purpose of a fuel jet in a carburettor?
36 What is the function of the throttle valve ?

CHAPTER 32

Ignition systems

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify different ignition systems and their components
2 describe spark plug construction
3 identify spark plug faults
4 identify testing processes of ignition systems
5 explain magneto ignition systems
6 list the ignition timing requirements of both vacuum and mechanical advance systems
7 recall firing orders for different engines
8 describe the effects of detonation and pre-ignition
9 identify the different types of ignition cables.

The ignition system provides high-intensity sparks at the spark plugs to ignite the fuel charges in the combustion chambers. The sparks must be supplied at the right time and must have sufficient energy to ignite the fuel charges for various engine-operating conditions. The energy is obtained from the battery/alternator , and the voltage is increased by the ignition coil. Magneto systems have no battery as the coil has the voltage induced into it by a moving magnetic field. The increase in energy is based on Faraday' s Law which says that if there is movement between a conductor and a magnetic field, an EMF (voltage) will be induced in th e conductor .

An ignition system has two electrical circuits: a primary or low-tension circuit, and a secondary or high-tension circuit. The primary circuit times and initiates the spark, and the secondary circuit produces the high voltage and distributes it to the spark plugs. There are a number of different ways in which this is done .

32.1 Ignition system components and their function

All ignition systems (with the exception of magneto systems) have the following components:

- battery/alternator
- low-tension section
- high-tension section
- ignition coil or coils
- spark plugs.

Figure 32.1(a) is a basic electrical circuit diagram of an ignition system that shows the arrangement of these parts, while Figure 32.1(b) is a sectioned ignition coil that shows the internal parts of the coil.

32.1.1 Battery/alternator

The battery (power source) provides the electrical energy for the ignition system during starting. Once the engine is running, the alternator supplies the electrical energy for ignition and for other electrical systems.

32.1.2 Low-tension section

The low-tension or primary section includes the power source (battery/alternator), wiring, primary winding of the ignition coil and a coil switching device. This section provides the control circuit which creates the electromagnetic field around the ignition coil's windings and core.

32.1.3 High-tension section

The secondary or high-tension section of the diagram consists of the secondary winding of the ignition coil, the spark plug, spark plug cables and connecting terminals. This section generates the high-voltage spark that jumps the spark plug gap.

In Figure 32.1(a), the sections are enclosed by borders. The part of the coil with the secondary windings belongs to the secondary section of the system. The part of the coil with the primary windings belongs with the primary section.

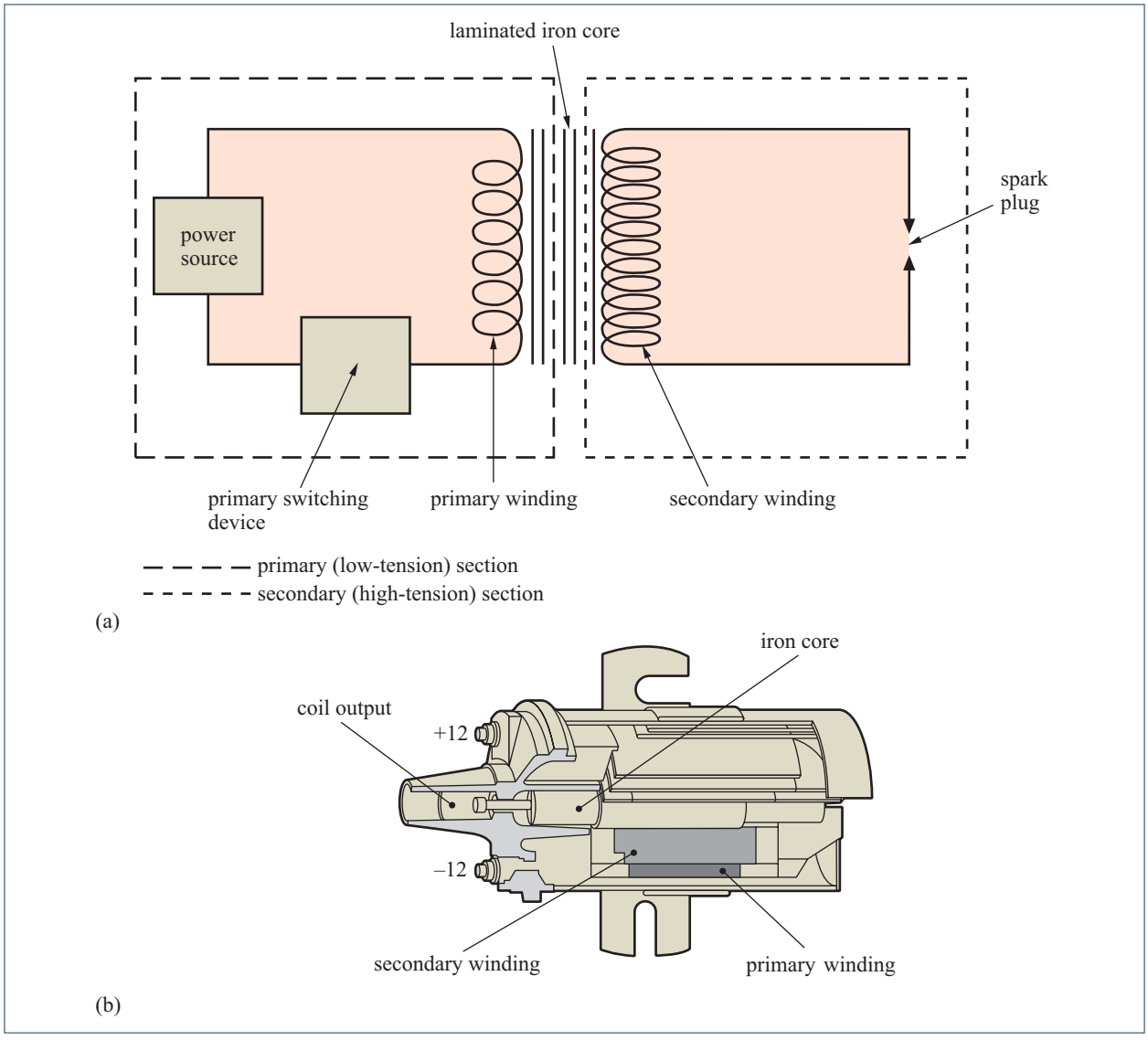


Figure 32.1 (a) Circuit of a basic ignition system, and (b) section view of an ignition coil, showing the primary and secondary windings

32.1.4 Ignition coil

Figure 32.1(b) shows an ignition coil in part section. The secondary winding consists of many turns of fine wire. The primary winding consists of far fewer turns of relatively heavy wire wound around the outside of the secondary. There is a laminated soft-iron core in the centre of the coil.

A number of ignition coils are shown in Figure 32.2. They are different shapes and sizes, but all have a primary and a secondary winding.

Electromagnetic induction in the coil

Ignition coils operate on the principle of electromagnetic induction. The nominal 12 volts of the vehicle's electrical system is stepped up to the extremely high voltage of the secondary.

With the switching device closed, and current flowing in the primary winding of the coil, the core of the coil becomes magnetised and a magnetic field builds up. The field penetrates the windings.

When the switching device opens, the current suddenly stops flowing in the primary windings. The magnetic field suddenly collapses, inducing a high voltage in the secondary winding.

With the collapse of the magnetic field, magnetic lines of force cut through the many turns of the secondary winding. This induces a small voltage into each turn. As the turns are all connected, a high voltage is produced in the secondary windings each time the switching device opens and the field collapses.

The high secondary voltage suddenly imposed on the spark plug causes a spark across the electrode gap. The time at which the spark occurs is determined by the breaking of the switching device in the primary circuit.

Handy hint: The spark must be timed so that it occurs at the correct time in relation to the position of the piston.

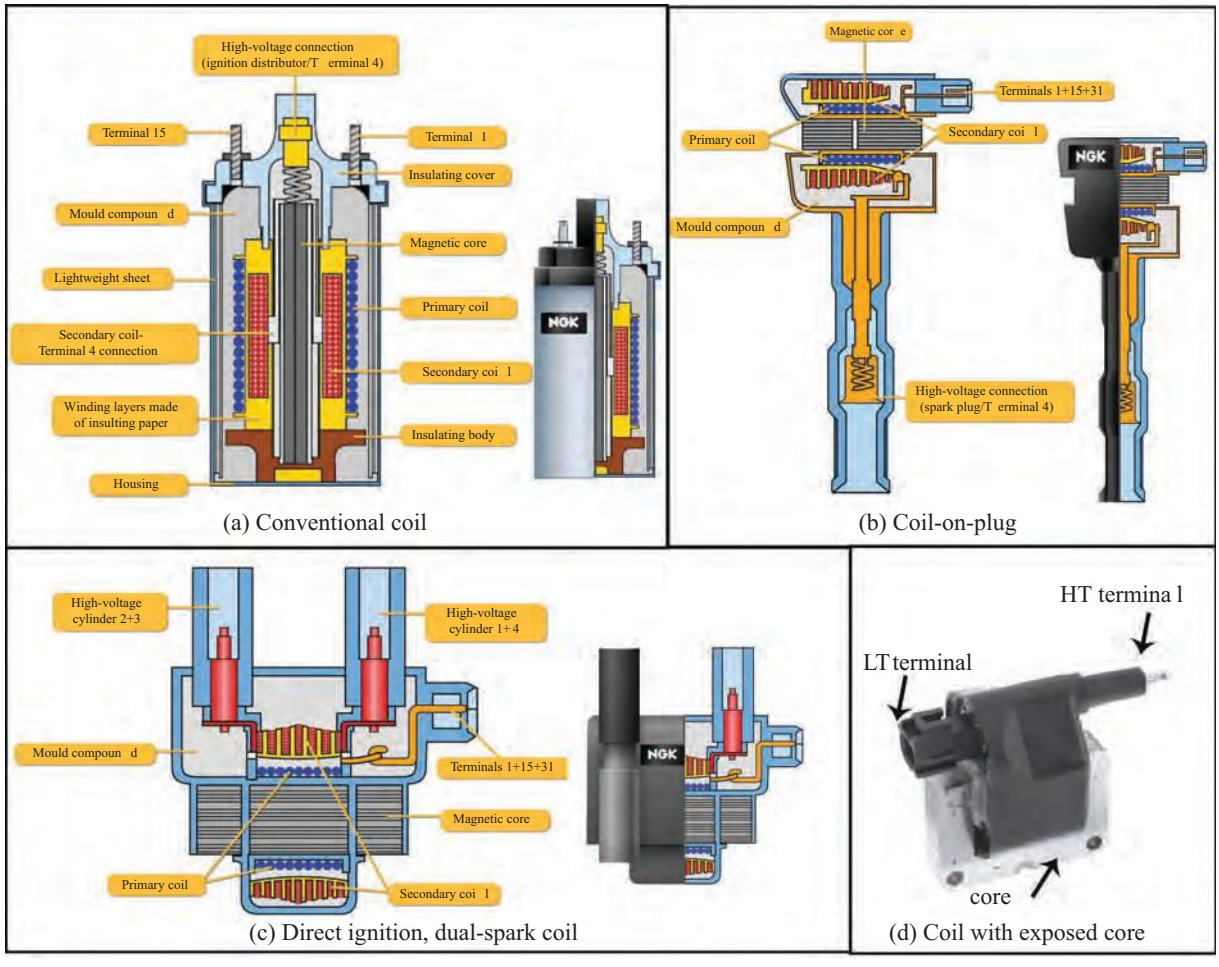


Figure 32.2 A range of ignition coils NGK SPARK PLUG EUROPE

32.1.5 Spark plugs

A simple spark plug (see Figure 32.3) consists of a metal shell with a ceramic insulator and an electrode extending through the centre of the insulator. The metal shell usually has a short earth electrode attached to one side of it which is bent in towards the centre electrode. Threads on the metal shell allow the plug to be screwed into the cylinder head with a specific reach.

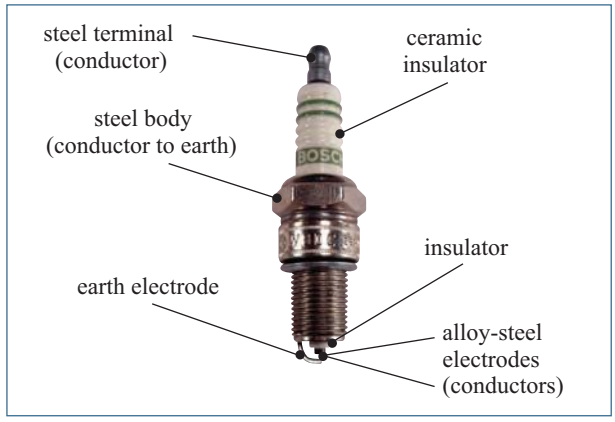


Figure 32.3 Spark plug with parts identified

The electrodes are made of special alloy wire, with a gap of up to 1.5 mm between them. The spark jumps this gap at up to 2000°C, igniting the air–fuel mixture in the combustion chamber. The seal between the metal base, porcelain and centre electrode, as well as the porcelain itself, has to withstand the high-pressure shock and the high temperatures in the combustion chamber during the power stroke.

32.2 Spark plug identification

Spark plugs are identified by their different features and part numbers. A spark plug is not suited to an engine just because its thread is the same size as the thread in the cylinder head; it must also be the correct type. For a plug to be correct for a particular make and model of engine, considerations are:

- thread size (diameter)
- reach (length of thread)
- heat range (operating temperature)
- resistance
- type and length (protrusion) of electrode tip
- number of earth electrodes
- size of spark gap .

32.2.1 Thread size

Spark plugs have metric threads of 10 mm, 12 mm, 14 mm or 18 mm diameter, the most common being 14 mm. A gasket (washer) is usually fitted between the spark plug and the cylinder head to form a seal. However, some plugs are made with a taper on both cylinder head and plug, and depend on the taper to act as a seal.

All spark plugs should be tightened carefully, but additional care should be exercised with taper-seat plugs as there is no gasket to compress. Over-tightening of the spark plug can make the plug difficult to remove and can cause the ceramic insulator to crack, as well as causing damage to the cylinder head.

32.2.2 Plug reach

The length of thread is called the *reach* of the spark plug. This can be 9 mm, 11 mm or 13 mm. A spark plug is of the correct reach when its thread is the same length as the thread in the cylinder head.

If the reach is too long, part of the spark plug will protrude into the combustion chamber. It will be prone to over-heating and may even foul the piston head or valves, causing severe mechanical damage. If the reach is too short, the end of the plug will be enclosed in a pocket, and this will affect the performance of the engine.

32.2.3 Heat range

The temperature at which a spark plug operates depends on the distance that the heat must travel from the insulator to reach the outer metal shell of the plug and enter the cylinder head. This is illustrated in Figure 32.4.

If the heat path is long, the plug will retain more heat and so run at a hotter temperature than a plug with a short heat path. Therefore, a plug that has a long internal heat path is referred to as a *hot plug,* while a plug with a short internal heat path is called a *cold plug.*

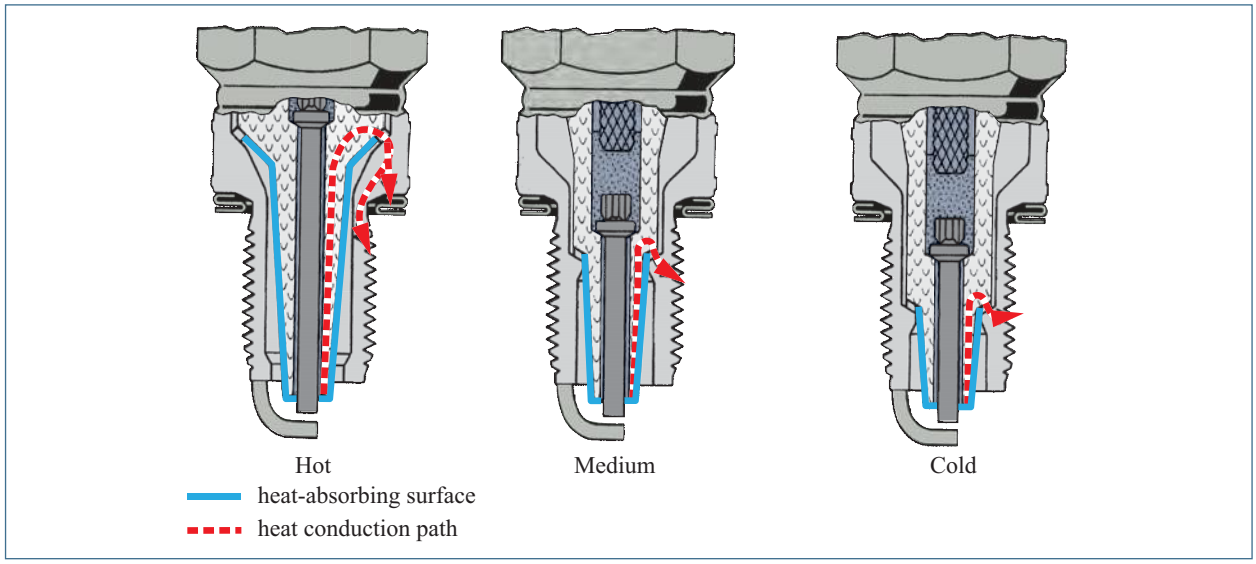


Figure 32.4 Heat range of spark plugs—the longer the heat path , the higher the temperature at which the spark plug operates BOSCH

Engines operating at a comparatively low output have low combustion temperatures. These require hot plugs to burn off excess carbon formation. Engines operating at a high output require cold plugs, which will not reach excessive operating temperatures.

Spark plugs should operate between average temperatures of 400°C and 800°C (referred to as the *heat range* of the spark plug). This is the self-cleaning temperature range and is optimal at 600°C. If the plug operates at temperatures that are too cold, it will allow carbon and soot to form, which will eventually cause plug failure. However, if the plug operates at temperatures that are too hot, it will tend to destroy itself by burning, melting the electrodes and blistering the insulator. High plug temperatures will also cause pre-ignition.

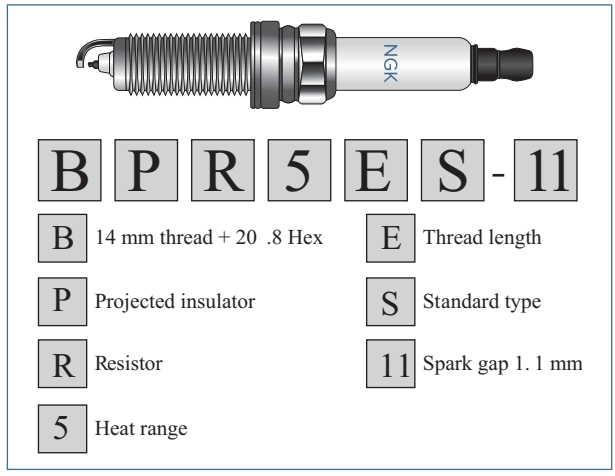


Figure 32.5 Spark plug and its identification code: prefix and suffix letters identify a special type of plug—numbers relate to thread size and heat range

Handy hint: A rule of thumb for the heat range of spark plugs is: hot engine—cold plugs; cold engine—hot plugs.

32.2.4 Resistance

Some spark plugs have an in-built resistor, usually identified by the letter R in their numbering system. This resistor helps to reduce the *radio frequency interference* (RFI) that ignition-system pulses create, which causes television and radio interference. An illustration of a spark plug with its identification numbering system is shown in Figure 32.5.

32.2.5 Type of electrode tip

Various materials are used on the tips of spark plug electrodes. These are applied to improve the ignition quality and durability of the spark plugs. Some expensive materials are used, such as iridium and platinum, as in Figure 32.6. The higher cost of these spark plugs is justified by their longer service life.

32.2.6 Number of earth electrodes

Some spark plugs have two, three or four earth electrodes (Figure 32.7). Multi-electrodes can extend the life of spark plugs, particularly those used in direct ignition systems. Direct-fire ignition systems fire

twice as many times as other systems, increasing the wear rate of the electrodes. Waste spark systems fire a spark to a *companion* cylinder on the exhaust stroke.

Handy hint: Earth electrodes are also known as ground electrodes.

32.2.7 Type of spark gap

Some engines tend to foul spark plugs. One spark plug design is the *surface-gap plug,* which has a flat insulated surface and no crevices to accumulate carbon, which could cause it to foul up. However, this has limited application in automotive engines due to poor protrusion into the stratified mixture. Figure 32.8 is an example of a surface-gap plug which has slots cut in its end to form the earth electrode. This allows good gas flow around the electrode, further reducing the possibility of fouling.

32.2.8 Spark-plug cables

As spark-plug cables and ignition-coil cables (high-tension cables) carry high voltage, they are heavily insulated. The insulation must be able to withstand the effects of high temperatures, oil and moisture. The core of the cable is made of carbon-impregnated linen or fibreglass, very fine stainless-steel wire or copper wire. Cables with a carbon core have an inbuilt resistance. If copper or steel is used, high-resistance terminals are used to connect the cable to the distributor and to the spark plug.

Resistive high-tension cables prevent the ignition system from interfering with radio and television reception. Radio interference is due to the number of large oscillations of the voltage that occur in the cable because of the collapsing coil field. Resistance cables dampen out this effect. Resistance-type spark plug cables are sometimes referred to as TVRS (television and radio suppression) cables.

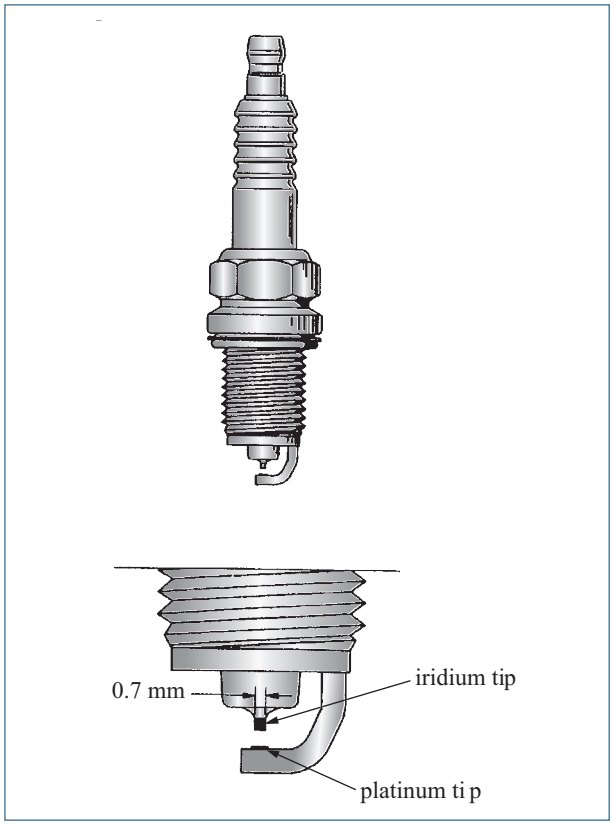


Figure 32.6 Spark plug with platinum- and iridium-tipped electrode

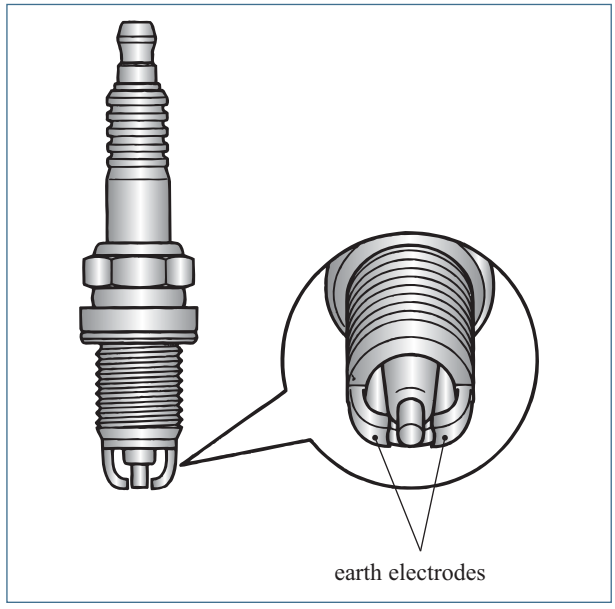


Figure 32.7 An example of a spark plug with twin earth electrodes

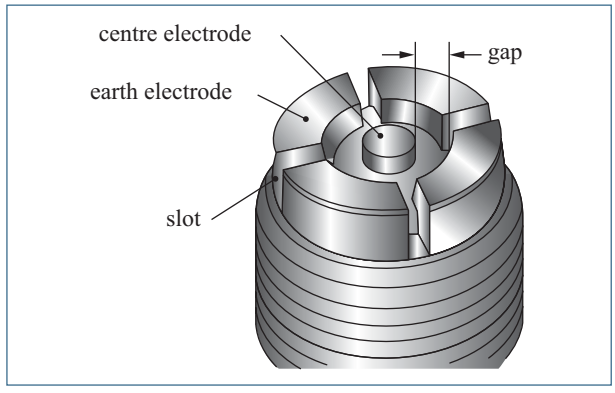


Figure 32.8 A surface-gap spark plug

32.3 Types of ignition systems

There are six general types of ignition systems:

1 Magneto ignition uses a spinning coil or magnet to create a spark.
2 Breaker ignition uses breaker points in the distributor to initiate a spark.
3 Electronic ignition uses power transistors instead of breaker points to switch the coil.
4 Direct ignition has no distributor and uses coil packs to supply the high voltage direct to the spark plugs.
5 Coil-on-plug ignition uses an ignition coil mounted on top of each spark plug.
6 Integrated ignition has the coil within the distributor.

Each of these systems is discussed below.

32.4 Magneto ignition systems

Magneto ignitions were the first ignition systems used to ignite the air–fuel mix. Rarely seen today in automotive use, they are still used in small engines and aircraft and outboard motors. The main advantage of a magneto ignition system is that it does not require a battery as the magneto itself produces the high-voltage output.

The early high-energy magneto systems had several designs, two of which were shuttle-wound and rotary inductor. Figure 32.9 shows a shuttle-wound design from 1902. The main differences between a shuttle-wound magneto and an inductor magneto are:

- The shuttle-wound magneto has the high- and low-voltage windings on the armature, which spins inside a large horseshoe-shaped magnet. This system used a condenser and a set of contact points.
- In the inductor type, the magnet, coils, condenser and points are fixed and do not rotate but a steel core is rotated, creating a magnetic flux in the core laminations of the windings.

Magneto ignition systems (Figure 32.10) used in small engines such as chainsaws, brush cutters, outboard motors and lawn mowers differ from those used in old vehicles (Figure 32.11). These magnetos have a permanent magnet as part of the flywheel and a coil mounted to the engine. There are mechanical breaker point systems, capacitor discharge ignition (CDI) systems and transistor-controlled ignitions (TCI).

Very few engines are built today with ignition points due to the need for maintenance; most use CDI or TCI. CDI systems use a capacitor to store the primary energy and a semiconductor to trigger the spark. A TCI system is an inductive system that does not use contact points but utilises diodes and transistors as the switching device.

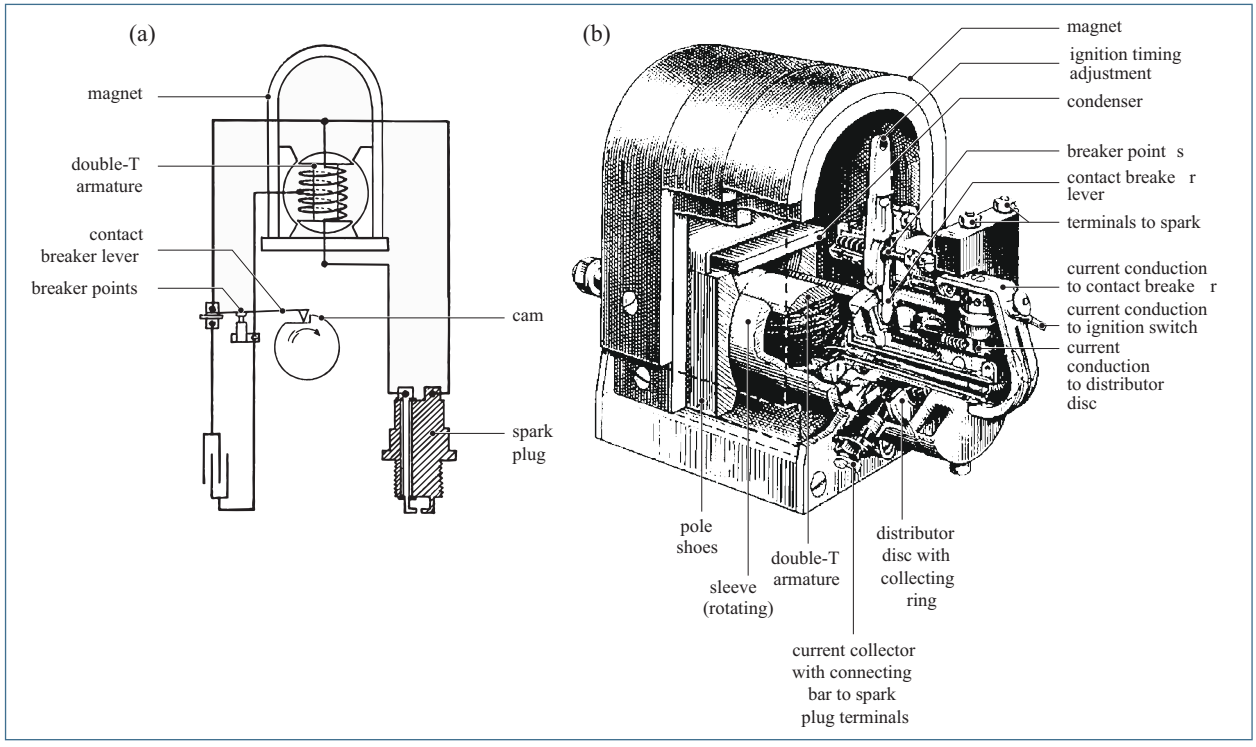


Figure 32.9 Parts of a Bosch shuttle-wound high-voltage magneto 1902 BOSCH

Figure 32.10 A magneto coil mounted on a small Honda engine

Figure 32.11 Magnetos fitted to four-cylinder tractor engines

32.5 Breaker ignition systems

An ignition system with breaker points (or contact points), also known as the Kettering ignition system or an *inductive discharge ignition system*, is shown in Figure 32.12. Although these systems are no longer used, knowing about them helps in understanding electronic systems. As previously indicated, there are two parts to an ignition system. For this system, these are:

1 the primary section, as shown in the black -and-blue colour code .
2 the secondary section, as shown in the red colour code .

Handy hint: The break er points inside the distributor are also referred to as contact points .

Action in the primary section

The primary section operates as follows:

1 With the points closed, current flows from the battery through the ignition switch, ballast resistor , ignition coil primary winding and through the points to earth.
2 A magnetic field is built up around the primary and secondary windings in the ignition coil.

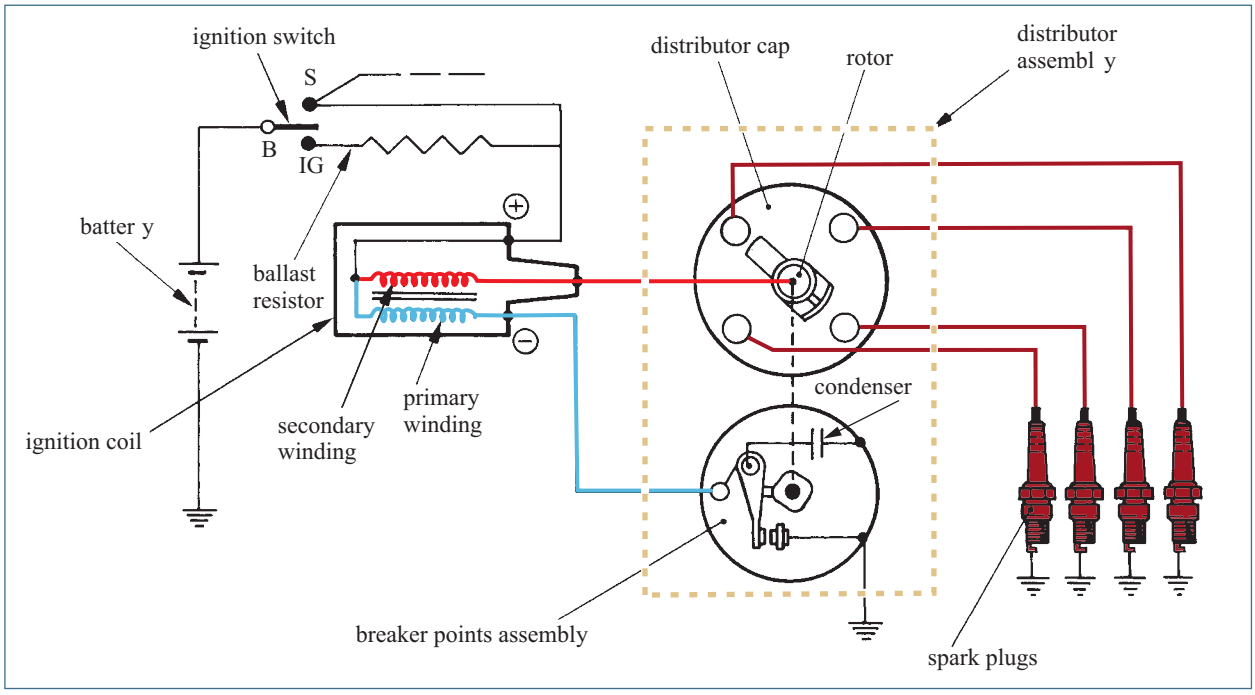


Figure 32.12 Circuit diagram of a break er ignition system

Action in the secondary section

The secondary section operates as follows:

1 When the points open, the magnetic field collapses, inducing a high voltage in the secondary winding.
2 The high voltage 'travels' almost instantaneously through the main lead to the distributor, rotor, spark-plug lead and to the spark plug and earth.
3 When the high-voltage spark jumps the spark-plug gap, a hot spark ignites the air–fuel mixture in the combustion chamber.

The capacitor

The capacitor absorbs the voltage induced into the primary winding through *self-induction* (approximately 250 volts). The capacitor has two main functions:

1 to stop arcing at the points
2 to cause a rapid collapse of the primary circuit.

Ballast resistor

A ballast resistor like that shown in Figure 32.13 limits the current and voltage in the primary circuit to extend the life of the points. During cranking, the resistor is bypassed to allow for easier starting, at which point 12 volts are supplied to a 9-volt coil; but when running, the voltage supplied via the resistor is 9 to 10 volts.

Figure 32.13 A ceramic resistor mounted next to the ignition coil

32.5.1 Ignition firing order

The firing order is the sequence in which the power strokes of the engine occur, and so it is the order in which the ignition system must provide a spark at the spark plugs. The firing order is determined by the shape of the crankshaft, the arrangement of the cam lobes on the camshaft and the ignition distributor timing. The firing order is important to ignition because the high-tension cables must be connected to the spark plugs in the correct firing order for the particular design of engine.

The cylinders of the engine are usually numbered from front to rear, although there are some variations with V-type engines. Examples of the firing order for a four-cylinder engine are 1-2-4-3 or 1-3-4-2, as shown in Figure 32.14. This can depend on the direction of distributor rotation. For a six-cylinder engine, there are a number of possibilities, but one that is commonly used is 1-5-3-6-2-4, as shown for the distributor in Figure 32.14.

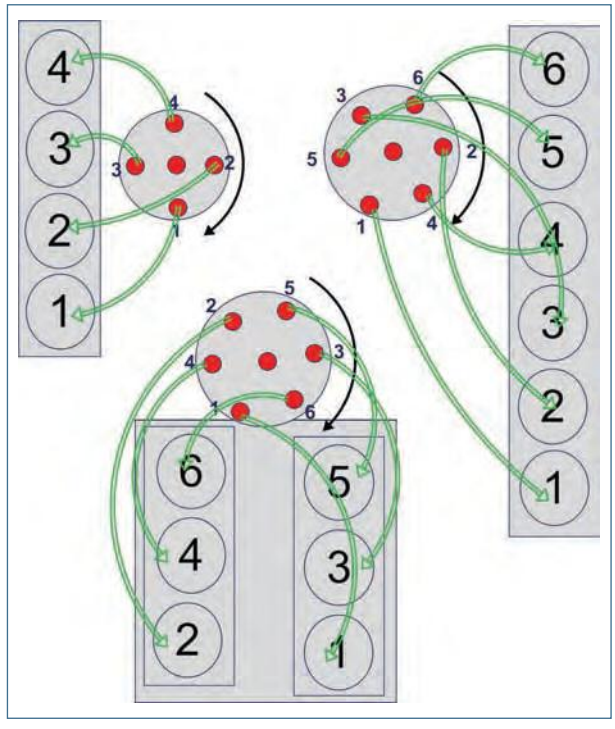


Figure 32.14 Firing order of four- and six-cylinder inline and V6 engines

32.5.2 Ignition timing

When an engine is idling, the spark is timed to occur at a specified number of degrees before top-dead-centre (TDC) of the compression stroke. This allows time for combustion to start and build pressure before the piston commences its downward power stroke. At higher engine rpm, with increased piston speeds, the spark has to occur earlier to allow the same time before the piston reaches TDC.

The spark timing has also to be adjusted to suit the load imposed on the engine. At light engine loads, it can be advanced, but for heavy engine loads less spark advance is needed and so the timing is retarded. There are three general methods of controlling spark advance: *centrifugally*, by *vacuum* and *electronically.*

Centrifugal advance

Centrifugal advance is directly related to engine speed. The advance mechanism in Figure 32.15 has two flyweights that throw outwards against spring tension as the distributor speed increases. This movement is

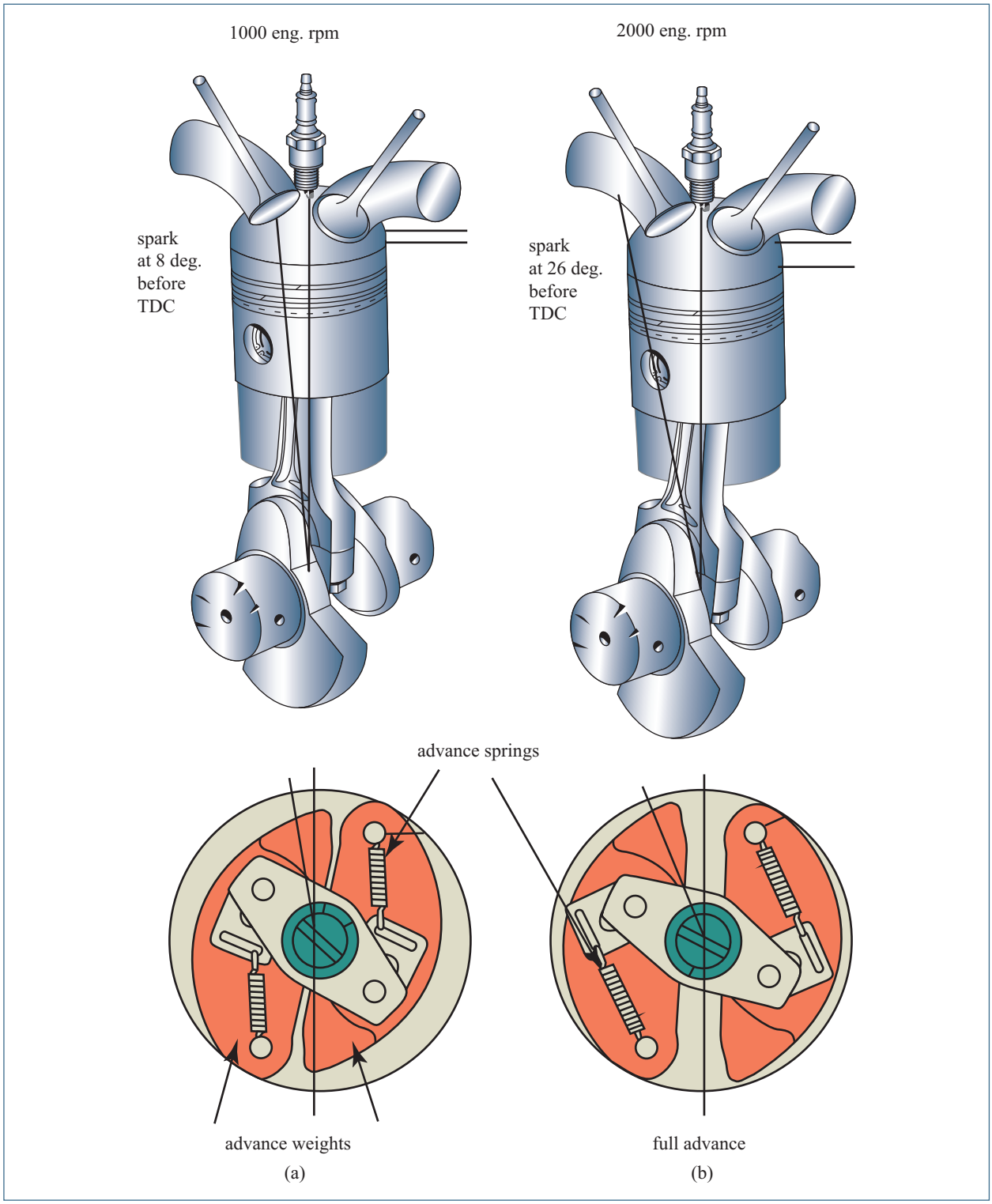


Figure 32.15 Operation of centrifugal advance (a) at 1000 rpm, advance is 8° before TDC (b) at 2000 rpm, advance is 26° before TDC

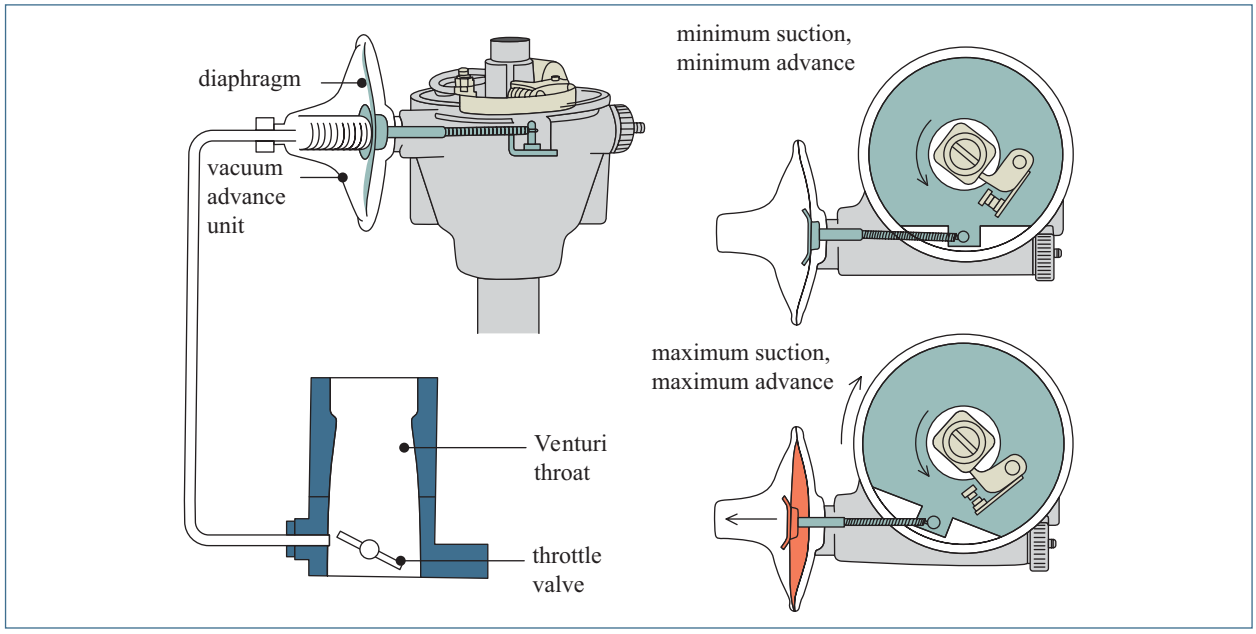


Figure 32.16 Vacuum advance arrangement

transferred through a lever arrangement to the cam. This turns the cam in relation to the distributor shaft so that the spark occurs earlier. The flyweights are restrained by two springs of different tension, allowing a progressive advance action (advance curve) that is related to the speed of the distributor shaft and engine.

Vacuum advance

Vacuum advance devices are used with earlier engines (Figure 32.16). They are operated by intake manifold vacuum via a vacuum port in the base of the carburettor. Vacuum in the throttle port varies with engine load and throttle position, so the advance provided by a vacuum advance unit is related to intake air speed and engine load.

A diaphragm in the vacuum advance unit is connected to the base plate of the distributor, which can be rotated a few degrees in relation to the distributor body. This causes the electronic sensor (or the breaker points) to advance the spark. The port to which the vacuum line is connected is usually in the carburettor or throttle body. This is located just above the throttle valve when it is in the idle position and so it receives no vacuum effect at engine idle speed. However, as soon as the throttle is opened, the vacuum port is exposed and vacuum is transmitted to the diaphragm of the advance unit. This causes the diaphragm to move against the spring to rotate the base plate and advance the spark.

The distributor illustrated has a sensor, but distributors with breaker points act in a similar way. The manifold vacuum (and the degree of vacuum advance) depend on the throttle valve opening and the engine load. Smaller throttle openings and lighter loads will produce the most vacuum effect in the intake manifold. As the throttle is opened wider, there is less vacuum effect and this means less vacuum advance.

At wide-open throttle under heavy-load conditions, there is no vacuum advance at all. The spark advance under this condition is provided entirely by the centrifugal advance mechanism.

Combined centrifugal and vacuum advance

At a particular point, there is centrifugal advance due to engine speed and vacuum advance due to engine load. An example is shown in Figure 32.17. At 60 km/h, the centrifugal advance mechanism

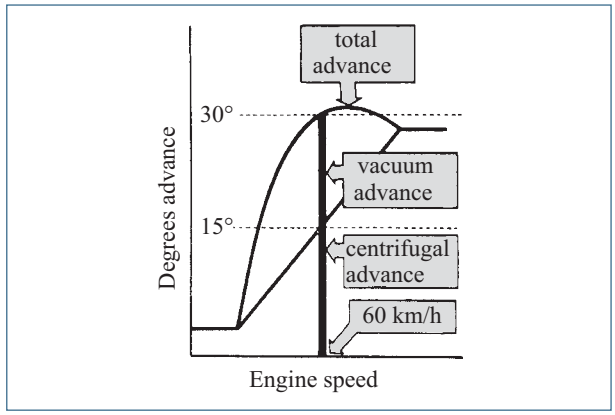


Figure 32.17 Centrifugal and vacuum advance curves for a particular speed and load

has provided 15° spark advance, and the vacuum advance has provided 15°, making a total of 30°. This would be under light-throttle, higher-speed conditions, and close to maximum total advance would be obtained. Operating together, both types of advance will automatically adjust to suit different driving conditions of speed and load.

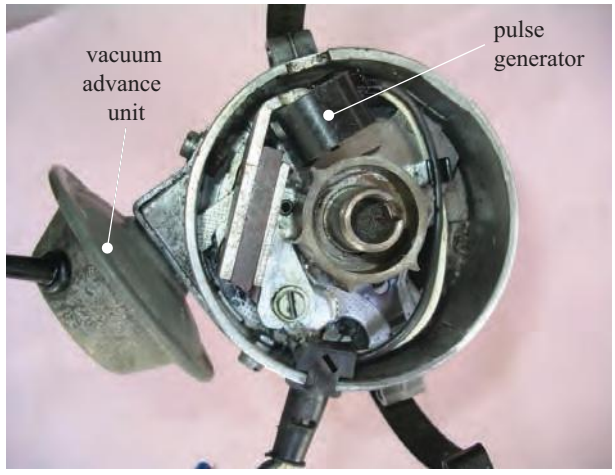


Figure 32.18 Distributor with an inductive pulse generator and a vacuum advance unit

32.6 Electronic ignition systems

Electronic ignition systems (also called *high-energy ignition* or *constant-energy* systems) use solid-state triggers and power transistors to operate the coil primary circuit. One system, an *inductive* electronic ignition system, uses a *pulse generator* in the distributor and an electronic ignition control unit to switch the primary circuit.

The magnetic pulses developed when the distributor signal rotor (reluctor) passes the pick-up coil (stator) generate an AC voltage that is used as trigger signals to the ignition control unit. The ignition module opens and closes the power transistor in the primary circuit. The pulse generator and ignition control unit work together to perform the same function as a set of breaker points.

The distributor has no points to wear or to become badly adjusted, and dwell is built into the unit so it can vary to suit the engine speed. Ignition timing is more precise, and higher-intensity sparks help to reduce exhaust emissions. A distributor of this type is shown in Figure 32.18.

Handy hint: This type of system is also referred to as break erless ignition because it has no contact points.

32.6.1 Pulse generator

A pulse generator in a distributor consists of a stator and a rotor unit. The stator consists of a permanent magnet and a small induction or pickup coil which is connected to the ignition control or *igniter* unit by two leads. The rotor, referred to as a *signal rotor* or *reluctor*, is made of soft iron and has a number of teeth—one for each cylinder of the engine. As each tooth rotates past the pickup coil, a very small AC voltage is induced into the pickup coil. This small electrical pulse is used by the igniter as a precisely timed signal to trigger the action of the power transistor.

32.6.2 Ignition control unit

The control unit, also referred to as an *ignition module*, can be mounted either inside or on the outside of the distributor. It consists of transistors, diodes and resistors. The coil-driving transistors, known as *power transistors*, are used as a switching device for the ignition-coil primary circuit. When a signal is received from the pulse generator, the ignition control unit opens the power transistor which opens the primary circuit. This causes the magnetic field of the primary windings in the ignition coil to collapse, inducing a high voltage into the secondary windings.

32.6.3 Electronic ignition circuit

A diagram of an electronic ignition system is shown in Figure 32.19. The parts of the distributor and the control unit are shown within dotted lines. The secondary parts of the system are of the same design and perform the same function as those of other distributors.

32.6.4 Breakerless distributors

An ignition system which has a distributor that does not have breaker points is referred to as *breakerless ignition.* Without points, there are different ways by which a pulse signal can be generated in a distributor. This can be done by an inductive pulse generator, a Hall-effect generator or an optical sensor. The system

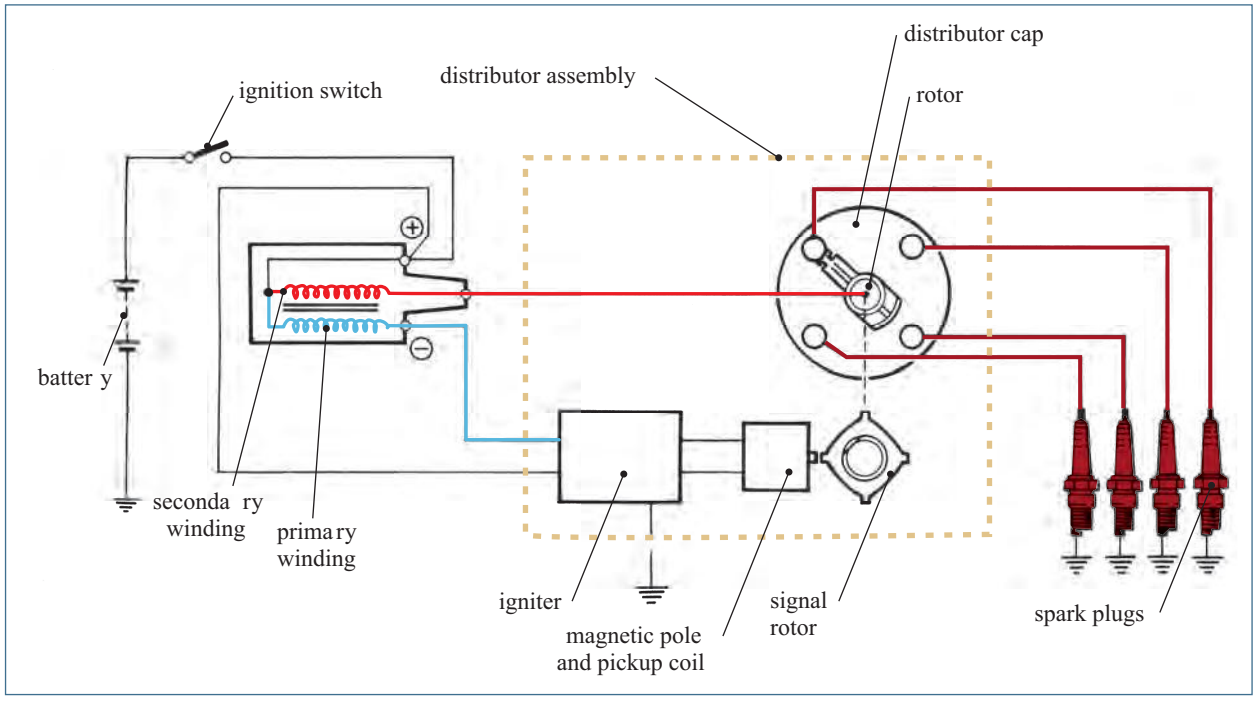


Figure 32.19 Basic electronic-ignition circuit GM HOLDEN LTD

described previously uses one type of inductive pulse generator. They all provide signals that are used in a similar way.

Some breakerless distributors used with electronic ignition have vacuum advance and centrifugal advance controls similar to those used with distributors for breaker ignition. Distributors that are used with centralised engine management control or with integrated ignition systems do not have these devices. Spark advance and other ignition settings are done by a central electronic control unit (ECU).

32.6.5 Electronic advance

With central control of the ignition system, electronic advance is determined by the ECU, which adjusts the timing signals.

Handy hint: With this type of ignition control, the ECU has an almost unlimited selection of timing options.

Three-dimensional map of electronic advance

The ECU contains a 'map' within the program that operates the ignition. It shows the engine rpm and the spark advance in degrees. However, there is not a direct relationship between engine speed and advance because of the inputs from the various sensors in the system.

In calculating the degrees of advance, the control unit has to take engine load variations, as well as engine speed variations, into account. It does this by utilising a series of two-dimensional maps to create a three-dimensional map.

A representation of a three-dimensional map is shown in Figure 32.20. Using a map of this kind, the ECU can set the timing advance close to the ideal for any combination of speed and load conditions.

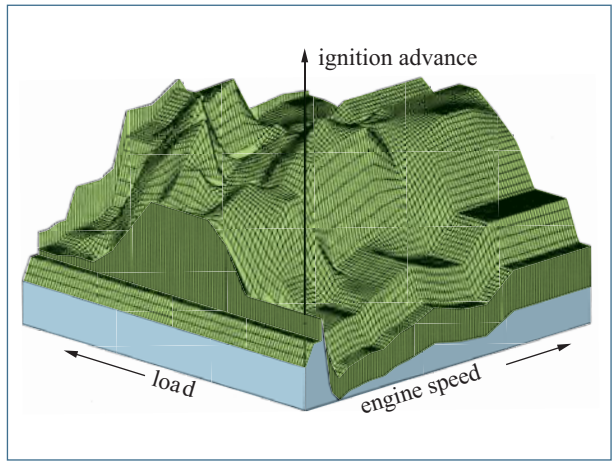


Figure 32.20 A three-dimensional ignition advance map BOSCH

32.6.6 Hall-effect generator

Figure 32.21 shows a breakerless distributor that produces a digital pulse by means of a Hall-effect generator. This distributor has a Hall-effect device in place of a stator and a rotor, using metal tabs and windows. The tabs and windows rotate between the parts of the Hall-effect device to provide a switching arrangement.

The rotor is referred to as a *profile-ignition pickup (PIP)* rotor. For a four-cylinder engine, the PIP rotor has four tabs and four windows, and for a six-cylinder engine, six tabs and six windows. As the rotor is turned by the distributor shaft, a digital square wave pulse is produced when each of the tabs passes the Hall-effect device. Figure 32.22 shows a sample Hall-effect device signal.

Operating principle

The Hall-effect device is arranged with a magnetic pole on one side of the rotor and an integrated-circuit sensor on the other.

1 As the rotor turns, first a window and then a tab pass between the magnetic pole and the sensor .
2 When a window is in the air gap between the magnetic pole and the sensor (Figure 32.22 (a)), only a weak magnetic field reaches the sensor . The device is switched off and there is no signal.
3 When a tab is passing through the air gap , it shunts the field from the Hall sensor . This influences the sensor and the device is switched on (Figure 32.22 (b)). This sends a square wave signal to the control unit.
4 When the next window passes into the air gap , the device is switched off . This switching-on-and-off cycle is repeated as long as the engine is running.

Signal wavveform

The PIP rotor has tabs and windows of equal size, so that as it rotates, the time *on* is the same as the time *off*. This produces a signal with a square waveform, as in Figure 32.22. When a tab enters the air gap, the signal voltage rises. While moving through the air gap, the voltage remains constant. On leaving the air gap, the voltage drops.

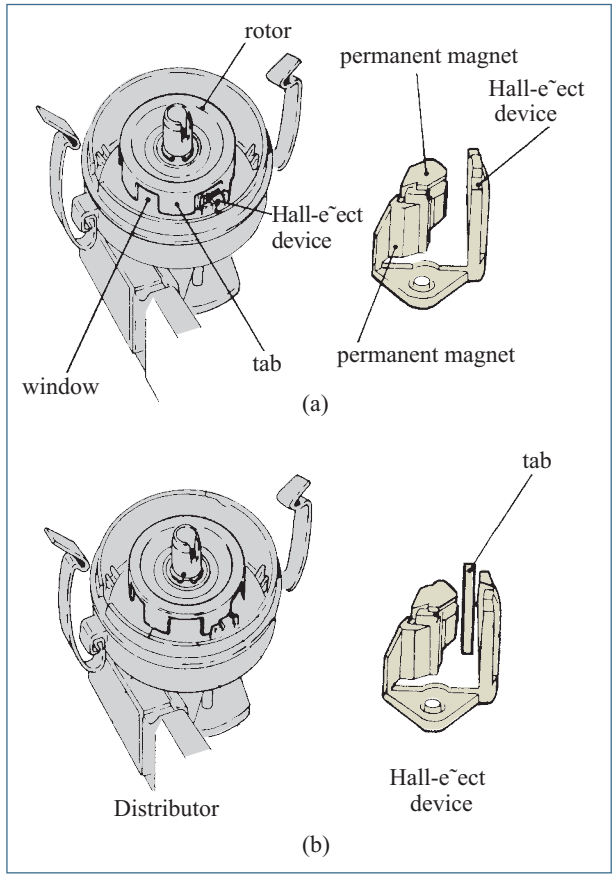


Figure 32.21 Operation of a Hall-effect triggering device FORD

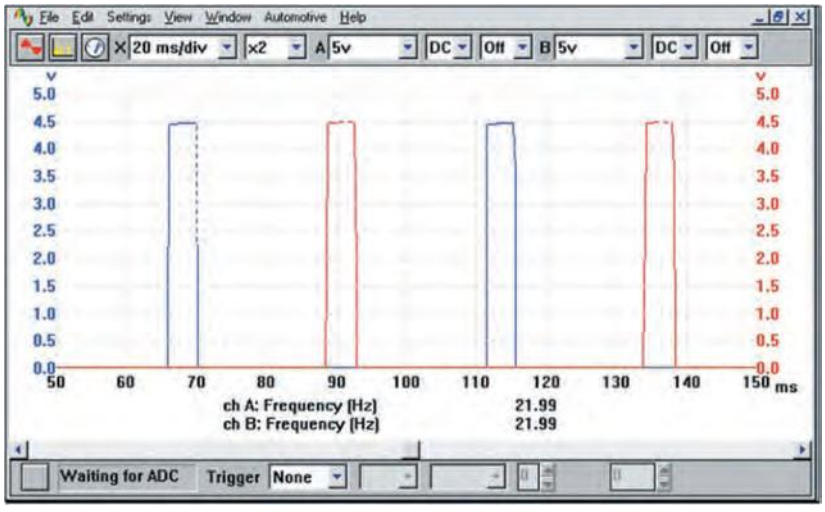


Figure 32.22 A 12-volt Hall-effect square wave trigger signal showing a larger signature window for number one cylinder identification PICO TECHNOLOGY

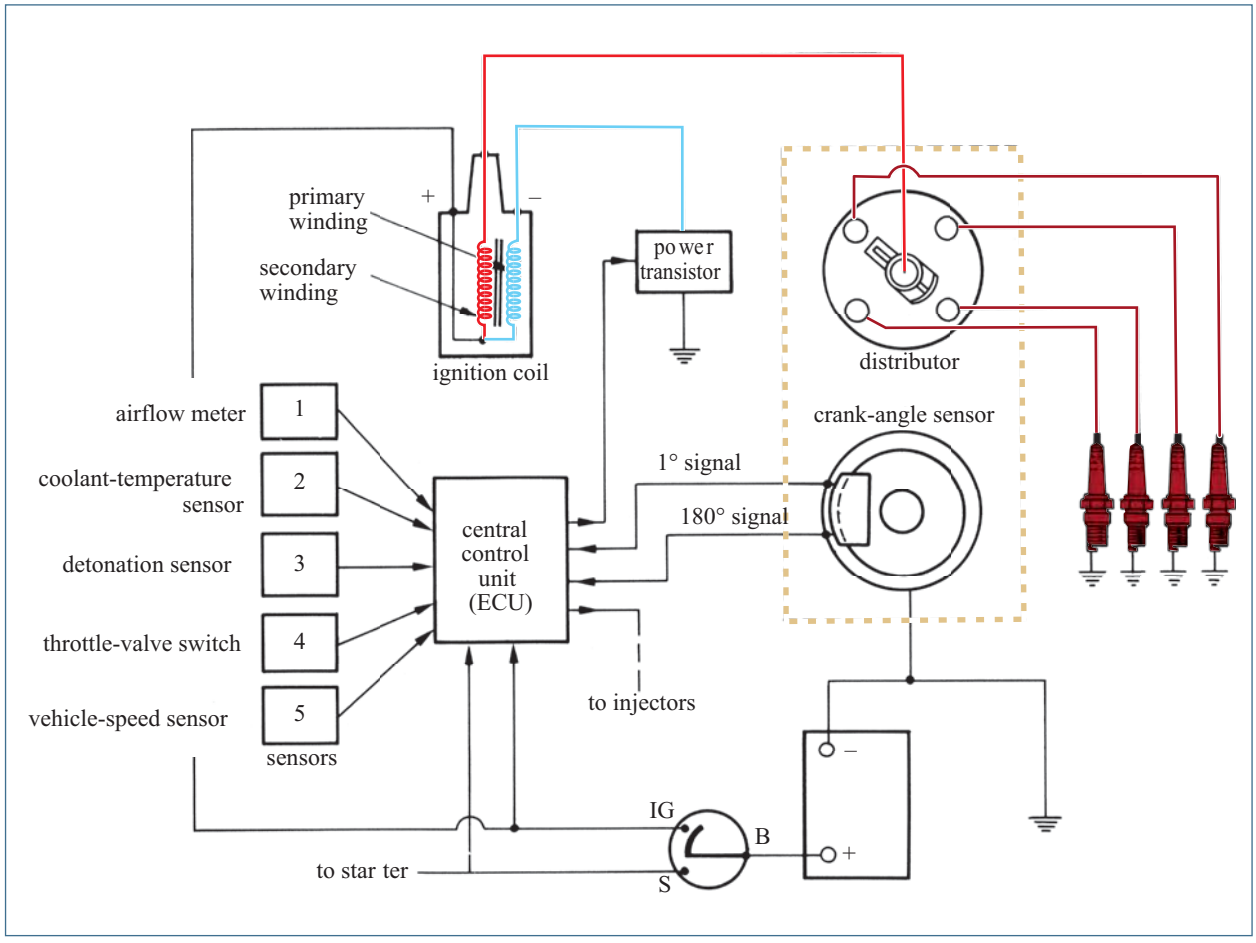


Figure 32.23 Ignition system with a central control unit and optic al crank -angle sensor

The distributor is timed so that the falling edge of the signal occurs at 10° before TDC. The electronic control unit then uses this information for a number of actions, including spark advance and electronic fuel-injection timing.

32.7 Electronic ignition central control

Figure 32.23 shows a circuit for an electronic ignition system with central engine management control. The ignition is controlled from the central ECU as part of the engine management system. The central control unit receives signals from the distributor, which has an optical sensor. Distributors with other sensors would function in a similar way.

32.7.1 Optical ignition triggers

Optical ignition uses light as an electronic trigger. The optical sensor uses a protractor disc in the distributor to rotate between two optical electronic sensors. The disc has slits or holes arranged around its perimeter. There is a light-emitting diode (LED) above the protractor disc and a photodiode beneath it (Figure 32.24). As the disc rotates, light from

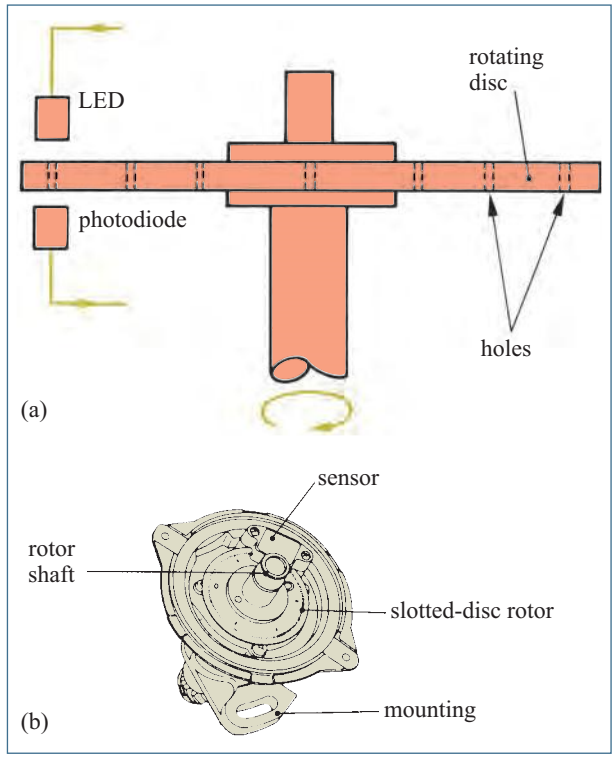


Figure 32.24 (a) Simplified optical crank -angle sensor (b) distributor with an optical sensor GM HOLDEN LTD

the LED shines through the slots in the disc to the photodiode. This forms a light-switching behaviour through the disc slots.

A photodiode reacts to light and is capable of switching a transistor when exposed in this way. The transistor switching operates a complex digital-wave-forming circuit, which produces the final square trigger signal, as shown in Figure 32.25.

The engine management system uses the distributor crank-angle trigger in the following way:

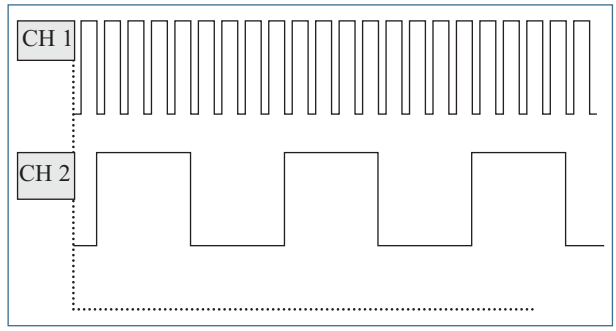


Figure 32.25 An oscilloscope trace of an optical square wave trigger signal showing 1° C AS (crank-angle sensor) position on channel 1 and cylinder trigger on channel 2

1 With the ignition switch on, the B terminal of the switch is connected to the IG terminal so that battery voltage is available to the control unit. It is also available to the primary coil winding.
2 When the power transistor is on, the primary coil windings are earthed through the power transistor and become energised. The power transistor is turned on and off by the engine management central ECU.
3 The power transistor acts as a switching device to mak e and break the primary windings of the coil, as signalled by the ECU. This produces high voltage in the secondary windings by normal coil action.
4 The timing of the spark is determined by signals from the sensor in the distributor . These , together with signals from other sensors, including the signals for engine speed, throttle opening, vehicle speed, coolant temperature and detonation, determine the spark advance setting.

Handy hint: The distributor performs two functions: it produces signals and distributes the high-tension voltage to the spark plugs in the correct firing order .

32.7.2 Distributor with two signal rotors

Some distributors used with engine management systems have two inductive pulse generators. One is used for an ignition trigger and the other for a crank-angle sensor in the same fashion as optical triggers. Figure 32.26 shows a distributor of this type. The signal rotor for ignition is in the shape of a cam and has two pickup coils. The other rotor is gear-shaped, with a number of teeth and a separate pickup coil.

32.8 Direct ignition system

Direct (or *distributorless*) ignition does not have a distributor and a single ignition coil. Instead, it uses separate ignition coil packs to provide high secondary voltage directly to the spark plugs. The coil pack includes the separate ignition coils and an ignition driver module. The number of ignition coils is exactly half the number of engine cylinders. This system is also referred to as *direct-fire ignition.*

Figure 32.27 shows the arrangement of three ignition coils for a six-cylinder V-type engine. Each coil provides a spark for two of the cylinders. This is arranged by connecting each end of the secondary winding of the coil to a different spark plug. This causes both plugs to fire at the same time—one spark is used for ignition and the other is wasted.

The pairs of cylinders that receive a spark together are referred to as *companion cylinders*, and two of these are shown in Figure 32.28. One spark plug fires with a *forward* current flow, but its companion spark plug fires with a *reverse* current flow.

A high voltage is needed for a spark plug that fires with reverse current flow, so the system is designed with a higher voltage than normal. It can produce more than 40 000 volts.

Handy hint: The spark plugs of a conventional ignition system all fire in the forward direction of **current flow**.

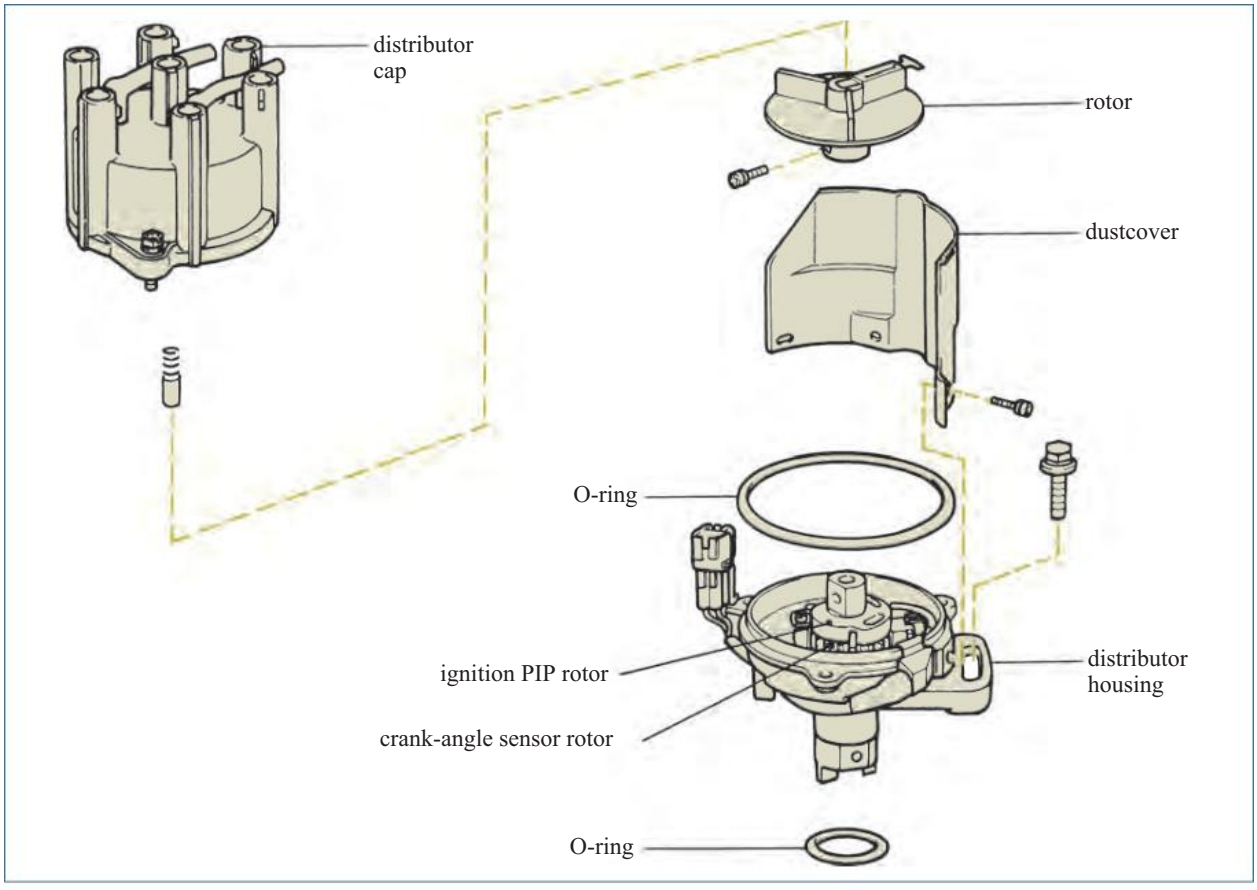


Figure 32.26 Distributor with two signal rotors

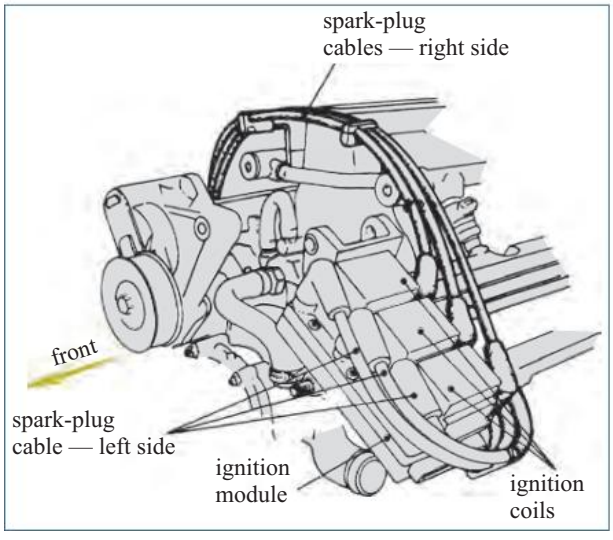


Figure 32.27 Direct-ignition system for a V-6 engine—it has three ignition coils GM HOLDEN LTD

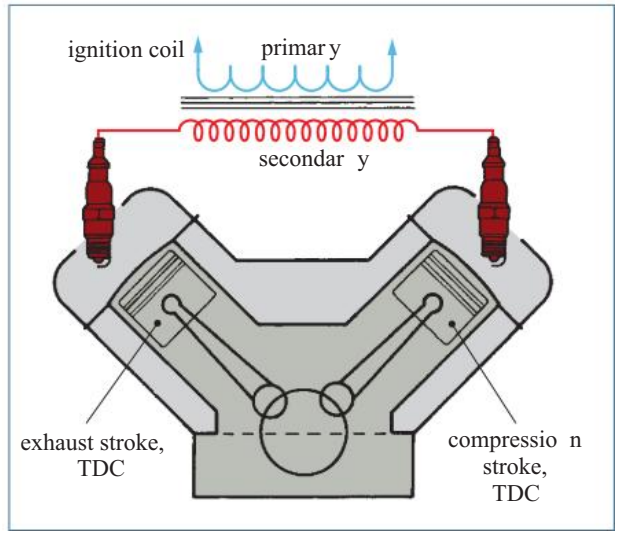


Figure 32.28 Arrangement of direct-fire ignition: a spark plug is connected to each end of the secondary winding of the ignition coil—companion cylinders are 1 and 4, 5 and 2, and 3 and 6 GM HOLDEN LTD

32.8.1 System diagrams

Figure 32.29 shows a simple schematic diagram of a direct-fire ignition system for two cylinders of an engine. In this diagram, a power transistor in the igniter opens and closes the primary circuit. The igniter is signalled by the ECU. In some systems, the power transistor is part of the ECU. The arrangement has a dual-spark ignition coil that services two spark plugs.

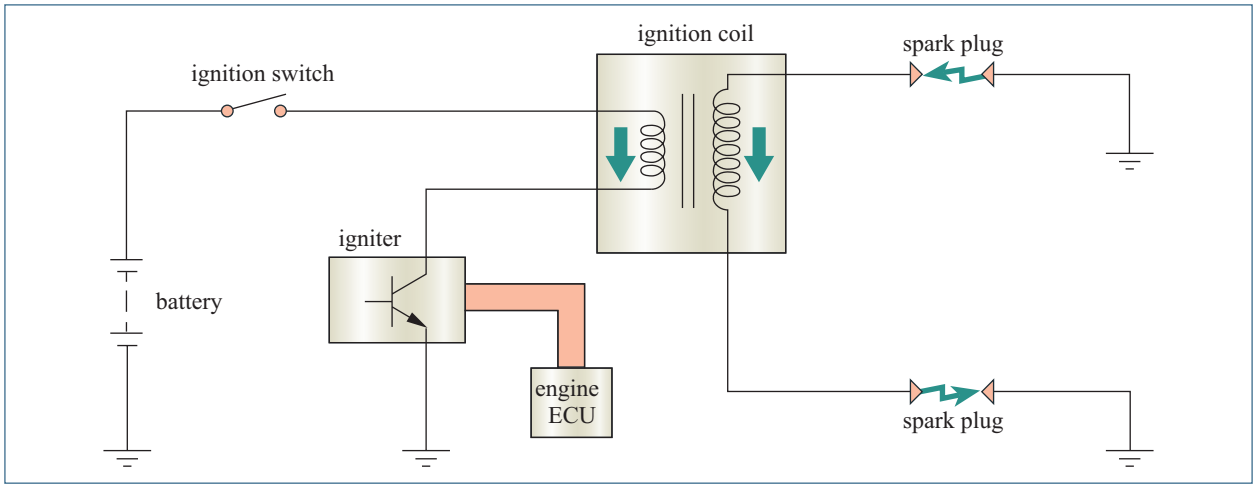


Figure 32.29 Simple schematic diagram of a direct-fire ignition system

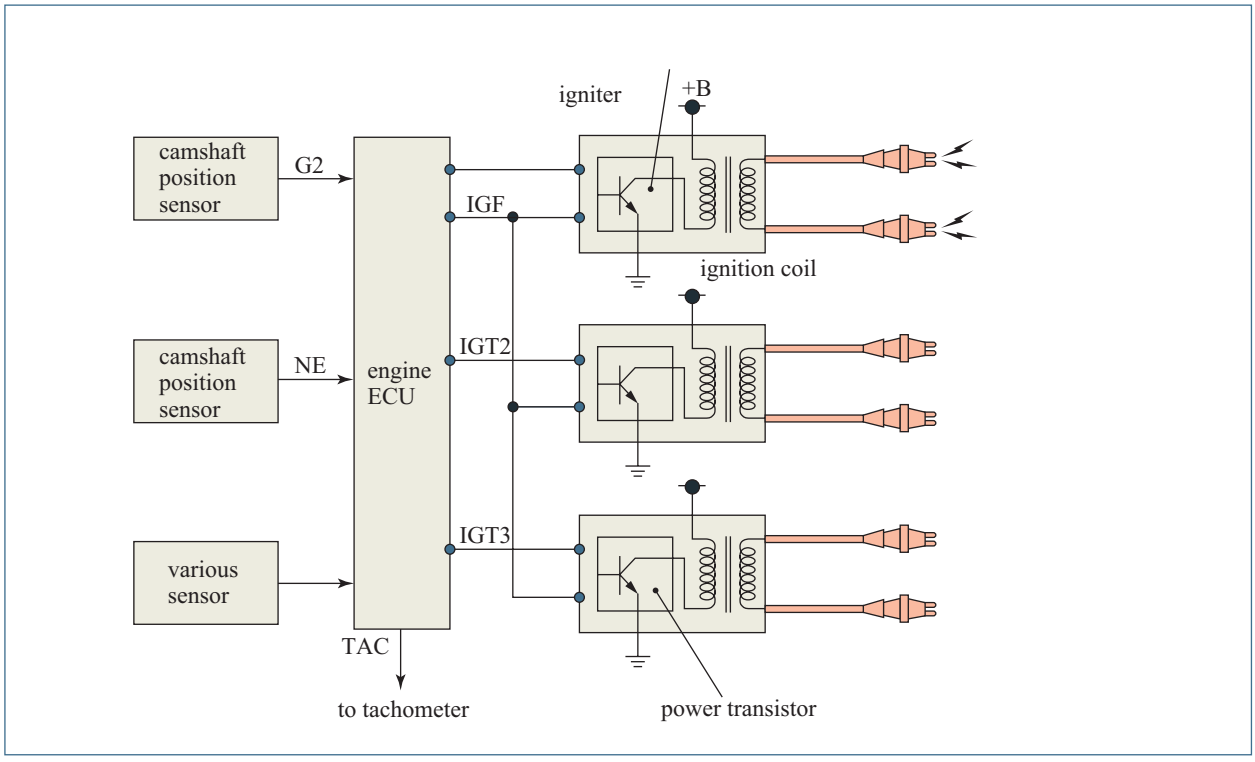


Figure 32.30 Block diagram of a direct-fire ignition system for a s ix-cylinder engine

Diagram for six cylinders

The ignition system for six cylinders is shown as a block diagram in Figure 32.30. The diagram shows the ECU, three power transistors and three ignition coils. Each coil pack has a power transistor that controls the primary current for that coil. The secondary side of the coil is connected to the spark plugs.

Each time a coil fires, the spark plugs of two cylinders produce a spark, but ignition takes place only in the cylinder that is on its compression stroke. The companion cylinder is on the exhaust stroke at that time. The ECU decides which power transistor will operate and at what time, based on information from a variety of sensors.

32.8.2 Generation of timing signal

One system has a dual-crank sensor mounted at the front of the engine, as shown in Figure 32.31. It is used in conjunction with interrupter rings on the crankshaft balancer. There are two interrupter rings on the inside of the crankshaft balancer. These rings fit into the slots (air gaps) of the sensor and rotate with the

balancer at engine speed. They have a number of blades and windows. The outer ring has 18 evenly spaced windows; the inner ring has three unevenly spaced blades and windows of different lengths (Figure 32.32). This is for a six-cylinder engine.

The sensor unit is shown in Figure 32.33. It has two Hall-effect sensors with a magnet mounted between them. These are separated by air gaps. With this arrangement, the magnetic field is interrupted by the blades of the interrupter rings as they rotate.

The interrupter ring with the 18 spaces produces 18 even *on–off* pulses for each crank shaft revolution. The interrupter ring with the three spaces produces three different-length *on–off* pulses for each crankshaft revolution. Together, the sensors provide signals to the ECU, which manages all the actions needed for ignition timing and fuel injection.

Handy hint: Depending on the system, timing is obtained by using a crank -angle sensor , a camshaft sensor or a combination of both.

32.8.3 Direct ignition—general points

The following are points of interest about direct ignition (they also apply to other systems).

1 The ignition coils are capable of very high output, in excess of 40 000 volts. Body contact with the ignition system must be avoided when the engine is running.
2 The crank -angle sensor is the critical part of the ignition system. The pulses must be generated for the engine to start and run.
3 Ignition timing is not adjustable . There are no timing marks on the balancer or timing cover .
4 Clearance of the interrupter rings in the sensors can be adjusted if dismantled, but the clearance does not affect ignition timing. There must be clearance to prevent damage .

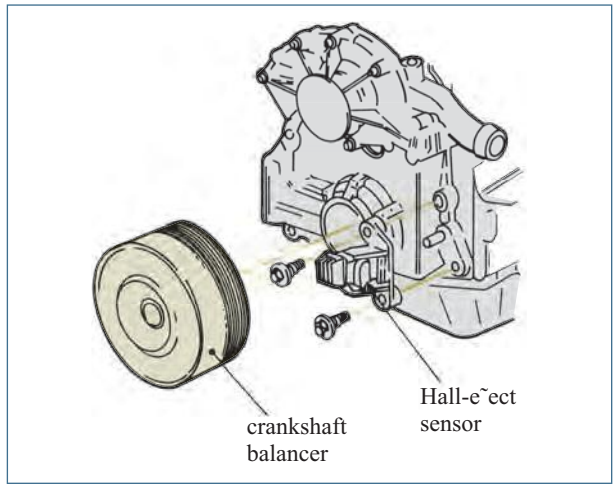


Figure 32.31 Crankshaft balancer and Hall-effect sensors GM HOLDEN LTD

Figure 32.32 Crankshaft balancer with interrupter rings

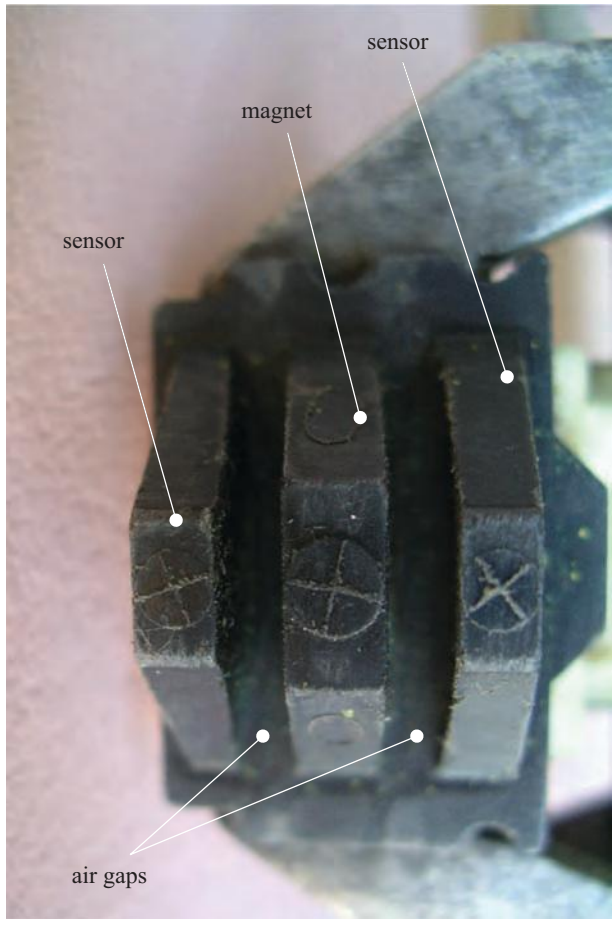


Figure 32.33 Hall-effect sensors and mounting

Safety: Due to the extremely high voltages, work on any ignition system should be done only with the ignition switched off .

32.8.4 Direct ignition for a four-cylinder engine

Figure 32.34 shows the arrangement of two coils for a direct ignition system of a four-cylinder engine. Each coil has two towers and two spark plug cables. One coil supplies high-tension voltage to the spark plugs of No. 1 and No. 4 cylinders. The other coil supplies high-tension voltage to the spark plugs of No. 2 and No. 3 cylinders. Power transistors in the ECU control the primary current to the coils.

The spark plugs of two cylinders produce a spark at the same time, but ignition takes place only in the cylinder on its compression stroke. The companion cylinder is on the exhaust stroke and the spark to it is wasted. The ECU decides which power transistor will operate and at what time.

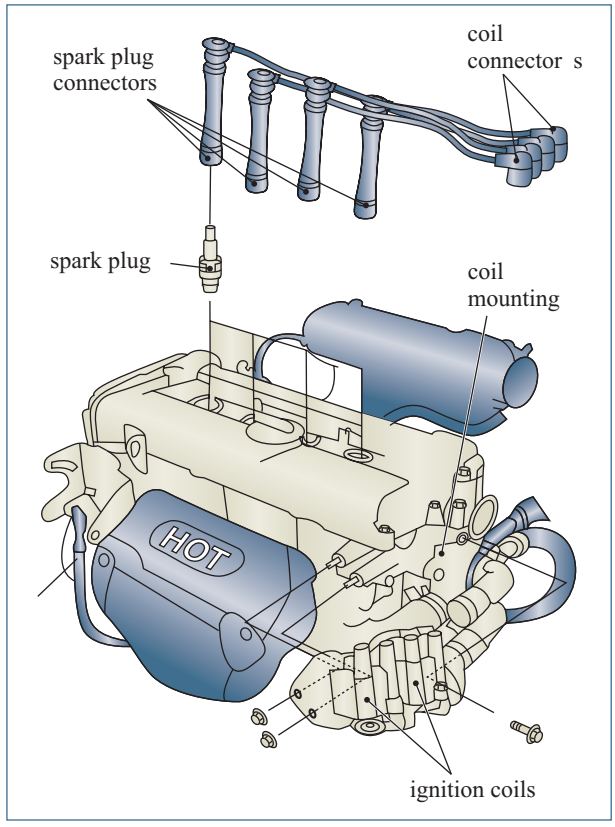


Figure 32.34 Direct ignition system for a four-cylinder engine

32.9 Coil-on-plug ignition system

This system employs a small individual coil mounted directly on the top of each spark plug. A coil of this type is shown in Figure 32.35. This arrangement with its small coil has both primary and secondary windings.

One end of the primary winding is supplied with low-tension voltage, the other end being connected to a power transistor which is switched by the ECU. The ECU controls the ignition timing and dwell for each spark plug individually by independent cylinder control of the power transistor.

The end of the secondary winding is connected directly to the terminal of the spark plug, so spark plug cables are not required. Having no cables eliminates problems that could occur with the spark plug cables of other systems. Also, because the coils operate only one cylinder each, each coil has ample *build* or *rise* time between spark events, and overheating of the coil is less likely to occur. The ECU stores ignition *maps* (see Figure 32.20) in its memory that form the basis for switching the drivers. This gives the engine management system control over ignition dwell, base timing, timing advance and knock control.

32.9.1 System arrangement

Figure 32.36 shows the arrangement of a coil-on-plug ignition system for an eight-cylinder engine. Each spark plug has its own coil assembly, which includes a single-spark ignition coil and a unitary igniter. The igniter is a power-switching diode and power transistor.

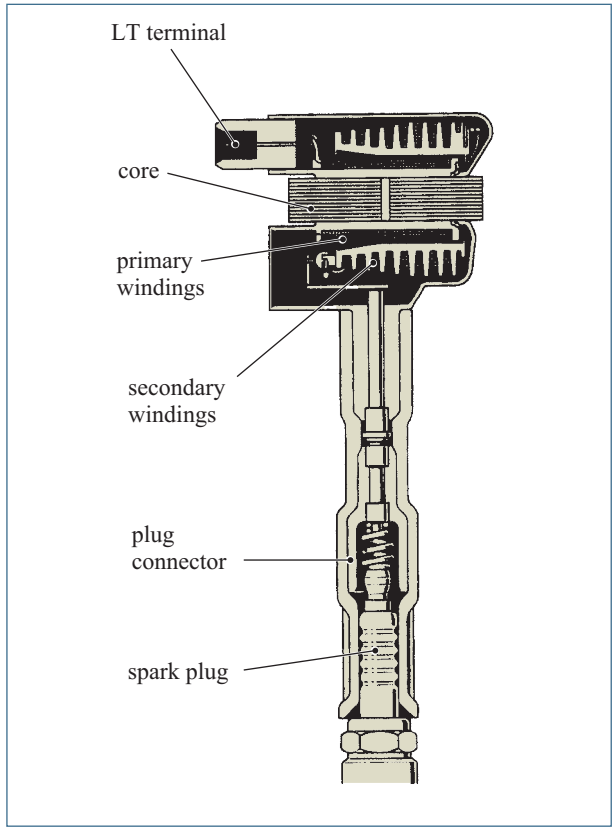


Figure 32.35 Coil-on-plug ignition in sectional view BOSCH

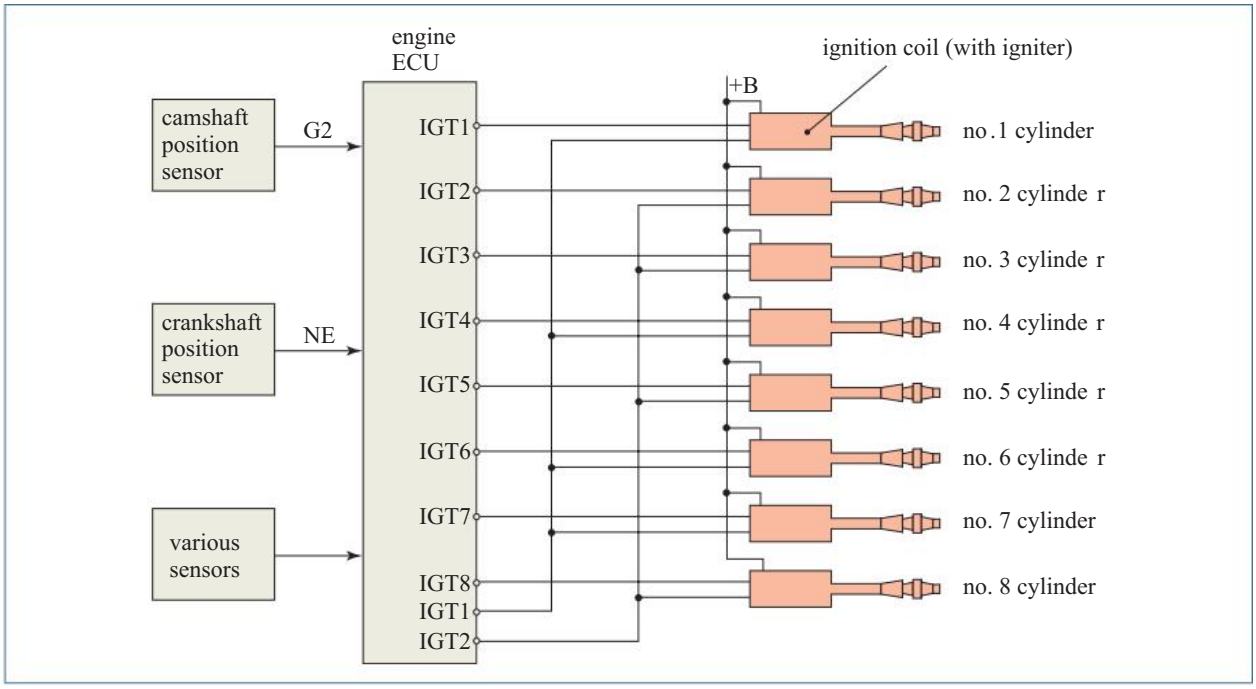


Figure 32.36 Schematic diagram of a coil-on-plug ignition system for a V -8 engine

The timing of the spark is initiated by the engine ECU. This triggers the power-switching diodes of the coils, which in turn amplify to switch the power transistor, in the correct firing order. All timing functions are conducted by the ECU, which receives inputs from a camshaft position sensor, a crankshaft position sensor and various other sources.

32.10 Integrated ignition system

An integrated ignition system is shown in Figure 32.37. With this, most of the ignition parts are contained within the distributor assembly. The distributor is usually mounted to the rear of the cylinder head and driven by the camshaft. The distributor assembly includes the igniter, the ignition coil, the distributor, two signal rotors (camshaft position and crankshaft angle) and pickup coils.

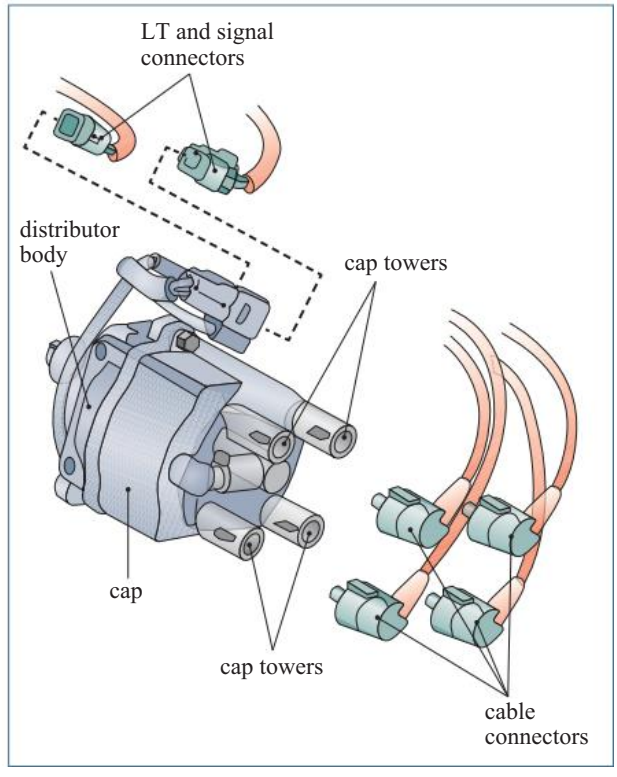


Figure 32.37 Components of an integrated ignition system—the coil is inside the distributor

32.10.1 Circuit diagram

The internal components and the circuit of the ignition system are shown in Figure 32.38. The engine ECU is programmed so that it provides optimum ignition timing under all operating conditions. It receives information from various sensors that monitor the engine functions, calculates the ignition timing and sends a signal to the igniter in the distributor assembly. The igniter triggers ignition coil action so that high voltage is produced by the secondary windings of the ignition coil and distributed through the rotor and cap to the appropriate spark plug.

The two signal rotors and pickup coils are both ignition and engine management input sensors. In the diagram, the pickup coil with the NE connections to the engine ECU detects the crank angle of the engine, while the pickup coil with the G-G connections detects the cam angle. Signals from both input sensors are provided to the ECU.

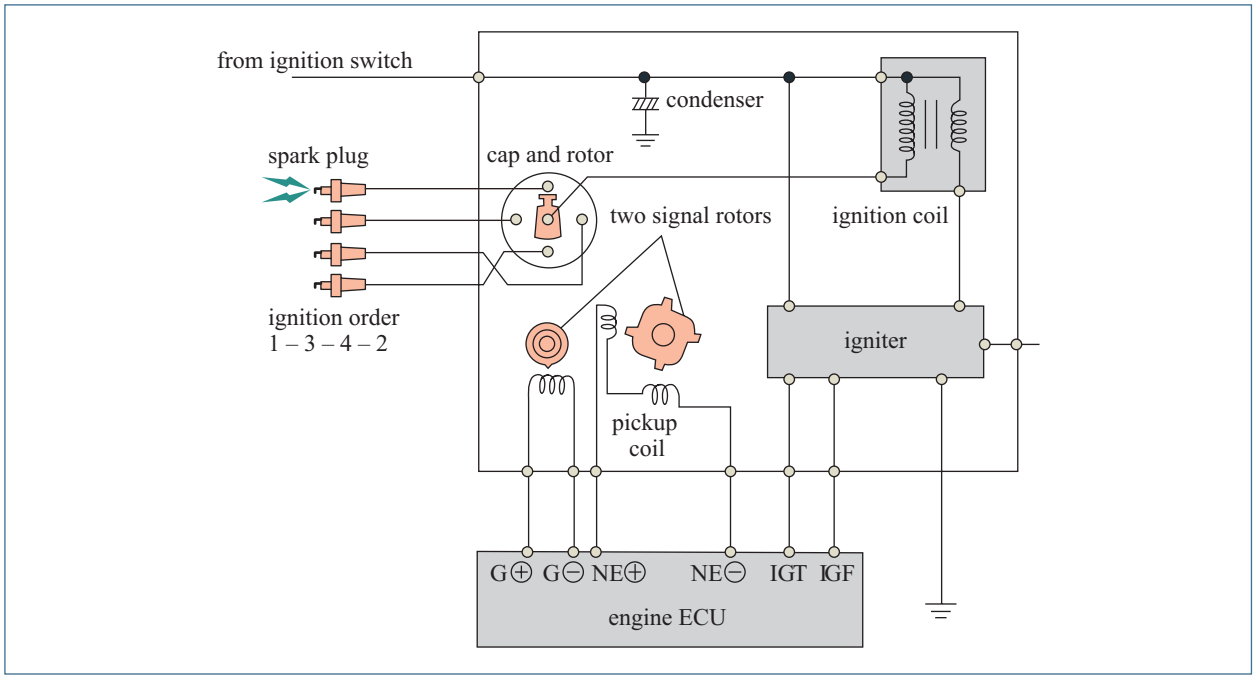


Figure 32.38 Internal electrical circuit for a distributor assembly o f an integrated ignition system

Safety: The ignition coil is enclosed within the distributor and, to prevent the coil overheating, the ignition switch should not be left on for more than a few minutes unless the engine is running.

32.11 Other ignition features

32.11.1 Knock sensors and timing

Under certain operating conditions, detonation can occur so a knock sensor is fitted to the engine. This sends a signal to the ECU when detonation occurs so that the ignition is then immediately retarded. Knock sensors, usually screwed into the cylinder block or head, contain piezo crystals that convert vibration into electrical signals. Some sophisticated coil-on-plug (COP) engine ECUs use an analysis of each coil-firing event to monitor detonation. In this way the ECU can detect knocking and reduce ignition advance so that the knocking stops. Possible causes of detonation include incorrect fuel octane rating, the spark plug being too hot, compression ratio being too high, ignition too far advanced, excess boost from a turbocharger and engine overheating.

Handy hint: There are also possible causes of detonation that are not related to the ignition system.

32.11.2 Dwell period

Dwell is the period of time that the current flows in the primary circuit and a magnetic field *dwells* around the ignition coil. During this time, the magnetic field in the coil is building to maximum strength. If the dwell period is too short, the field will not build sufficiently to generate a good spark.

When the engine is operating at slow speeds, the dwell time is relatively long, but when the engine is operating at high speed, it is greatly reduced. To compensate for this, the ECU extends the dwell for high engine speeds. For electronic ignition, it is the time in cam rotation degrees that the power transistor is switched on.

32.12 Ignition service—general

Servicing the ignition system includes items such as inspecting or replacing the spark plugs, checking the system for loose connections, cleaning away dirt and corrosion, setting the ignition timing and checking and testing various components of the system.

Many ignition systems have similar components in their secondary side. The primary side, however, varies considerably, from systems with electronic ignition to those with centralised electronic control. The service requirements for some items, such as spark plugs, cables and basic timing setting, are fairly common to many ignition systems, but each type of system has its own service procedures.

32.12.1 Precautions

Care should be taken when working on all ignition systems, particularly electronic ignition systems. The following should be observed:

1 Electronic ignition systems can produce extremely high voltages in the primary and secondary circuits, and these can be dangerous.
2 Disconnect the battery before removing a connection from, or making a connection to , any component of the ignition system. This will prevent damage to semiconductor devices.
3 Do not run the engine with a cable disconnected from the spark plug. Prolonged operation with an HT cable on open circuit will damage the ECU .
4 Connections to the system, including the battery , must be of the correct polarity . Reversal of polarity will damage the control unit.
5 The battery must be disconnected when it is being charged from an external source .
6 To prevent damage , only recommended test instruments should be connected to the system.
7 Never use an ohmmeter to check the resistance of a Hall-effect device as this will destroy the Hall integrated circuit.

Safety: **Do not work on the ignition system when it is switched on unless this is necessary during a test.**

32.13 Spark plug service

Spark plugs should be removed periodically for inspection. They can be cleaned but, apart from checking the spark gap, are not usually serviced (new ones are installed at specified intervals).

When the spark plugs are removed from the engine, they should be examined for deposits and erosion of the electrodes. If they are being re-used, the gap between the electrodes should be carefully reset by bending the outer electrode as shown in Figure 32.40(a). The centre electrode should not be bent or strained as this will crack the ceramic insulator. Iridium and platinum plugs are not normally adjusted, but the gap will require checking. Wire-type plug-gapping tools must be used on rare-metal spark plugs to avoid scoring (Figure 32.40(b)). The round section of the wire gauge also provides true gap measurement.

Handy hint: Some spark plugs are designed so the electrode gap cannot be adjusted.

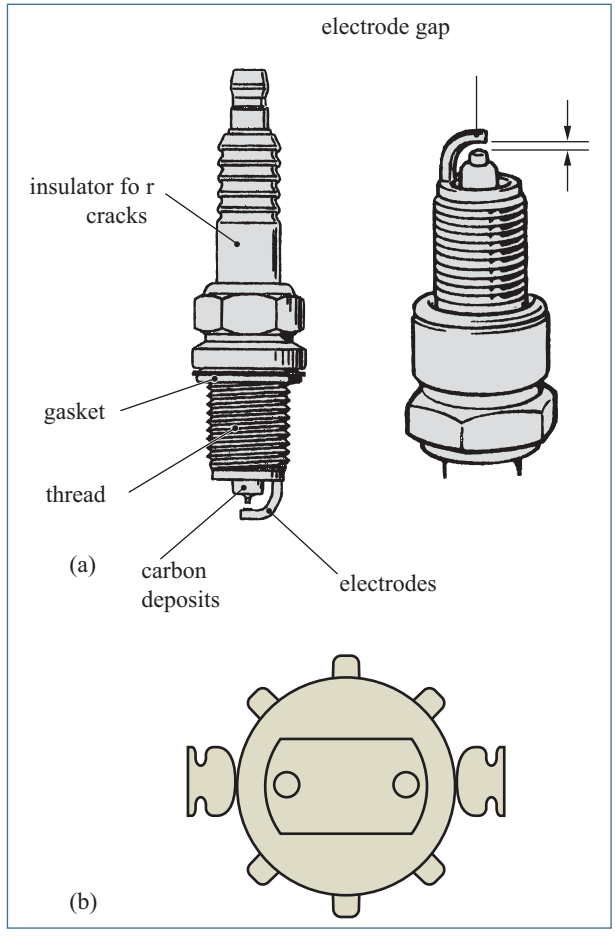


Figure 32.39 (a) Spark plug checks (b) wire-type plug gap tool

32.13.1 Installing new spark plugs

When installing new spark plugs, correct tension should be used. This will depend on the type of seal the spark plug uses and the length of thread (Table 32.1). It is important to check manufacturers' recommendations when installing new spark plugs.

32.13.2 Spark plug appearance

The appearance of the ends of the spark plugs is a guide to the operating conditions of the engine.

Table 32.1 Tension of different spark plug seals

Seal type	Spark plug with flat seat and seal				Conical seat	
Thread	10 mm	12 mm	14 mm	18 mm	14 mm	18 mm
Cast iron head	10–15 Nm	15–25 Nm	25–35 Nm	35–45 Nm	15–25 Nm	20–30 Nm
Aluminium head	10–12 Nm	15–20 Nm	25–30 Nm	35–40 Nm	10–20 Nm	20–30 Nm

A brown, tan or grey firing end is indicative of correct engine running conditions and the selection of the appropriate heat rating plug.

White deposits have accumulated from excessive amounts of oil in the combustion chamber or through the use of low-quality oil. Remove deposits or a hot spot may form.

Black sooty deposits indicate an over-rich fuel/air mixture, or a malfunctioning ignition system. If no improvement is obtained, try a one grade hotter plug.

Wet, oily carbon deposits form an electrical leakage path along the insulator nose, resulting in a misfire. The cause may be a badly worn engine or a malfunctioning ignition system.

A blistered white insulator or melted electrode indicates over-advanced ignition timing or a malfunctioning cooling system. If correction does not prove e°ective, try a colder grade plug.

A worn spark plug not only wastes fuel but also overloads the whole ignition system because the increased gap requires higher voltage to initiate the spark. This condition can also a°ect air pollution.

Figure 32.40 Appearance of used spark plugs related to causes BOSCH

When plugs are removed, they should be kept in cylinder order and the end of each plug examined: their appearance could indicate the condition of the plug or the engine cylinder.

Figure 32.40 illustrates various spark plug conditions and their causes. When the appearance indicates an unsatisfactory heat range, a hotter or colder plug can be substituted as required. The ceramic insulator should be inspected for cracks. Spark plugs with badly eroded electrodes or a burnt or cracked insulator should be renewed.

The plugs can be tested on a spark plug tester, which provides high voltage to check the spark at the electrodes. The plug is screwed into an air pressure chamber on the machine and tested under pressure. This simulates the conditions under which the spark occurs in the combustion chamber.

32.13.3 Spark plug cables

The connectors on the ends of the high-tension cables fit tightly on the spark plug terminals, so care must be taken when they are being removed. The cable itself should not be pulled because the core can become stretched, causing an excessively high resistance. The composition of cables can be seen in Figure 32.41. When removing a connector, the insulator on the connector at the end of the cable should be gripped and the connector removed with a clockwise twisting-and-pulling action (Figure 32.42).

The resistance of the cables can be checked with an ohmmeter (Figure 32.43) and should be between 3000 and 8000 ohms per 300 mm of cable length for carbon, and 200 and 1000 ohms per 300 mm for stainless wound. Copper cables will show zero resistance for the actual cable, but the plug connector is usually 5000 ohms and the distributor cap connector 1000 ohms. The rotor can also have a built-in resistor of 1000 or 5000 ohms. Always consult manufacturers' information for the exact specification.

Handy hint: Spark plug cables that have been removed from the spark plugs or distributor must be replaced correctly to keep them in the firing order.

32.14 Distributor service

Before removing a distributor, a mark can be placed on its body to indicate the position of the centre of the rotor arm. This applies to distributors that have a drive gear on the end of their shaft. If the distributor is not marked before removal, it will have to be re-timed to the engine. Some distributors have an offset drive, which determines the position of the rotor. These distributors do not require timing.

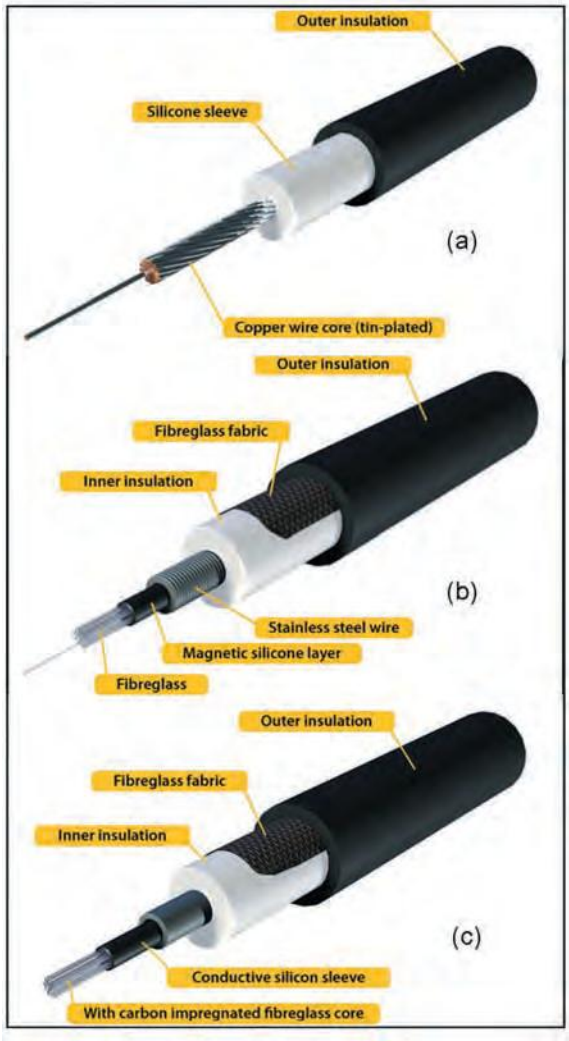


Figure 32.41 The different compositions of different spark plug (ignition) leads: (a) copper ignition cable with interference suppression; (b) ignition cable with inductive resistor; (c) carbon resistor ignition cable NGK SPARK PLUG EUROPE

32.14.1 Distributor service for electronic ignition

Distributors used with electronic ignition systems normally require no routine service. Some early high-energy ignition (HEI) distributors still retained conventional vacuum and centrifugal advance mechanisms. These require the same checking and testing procedures as breaker ignition systems. The distributor cap can be checked and cleaned externally, but there are no service adjustments.

With HEI distributors, the cap can be removed and checked internally for cleanness, and for cracks or tracking between terminals in the cap.

Figure 32.42 Cable connectors must be removed carefully to prevent damage

Figure 32.43 Checking the resistance of a spark plug cable with an ohmmeter

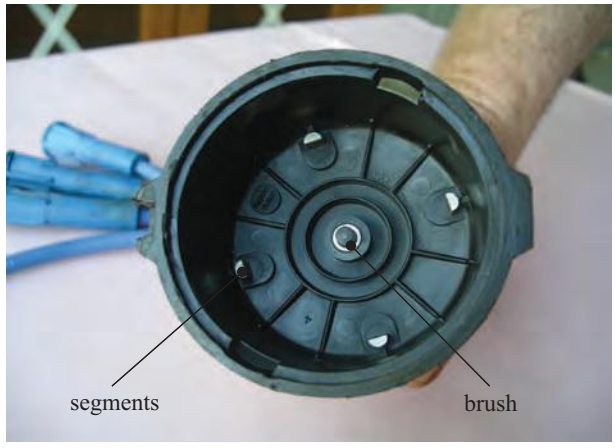


Figure 32.44 Inspection points in a distributor cap—check the segments for corrosion and deposits, and the brush for condition

The distributor cap can be checked for cleanness, corrosion of the segments and cracks or electrical tracking between the segments (Figure 32.44).

Handy hint: Dwell is designed into the control unit of electronic-type ignition systems and cannot be adjusted.

Checking advance mechanisms

Where fitted to a distributor, both the centrifugal and vacuum advance mechanisms can be checked. This applies to some electronic distributors.

The centrifugal advance can be checked by moving the rotor in relation to the distributor shaft and then releasing it (Figure 32.45(a)). The rotor should move freely and return under the action of the springs of the advance mechanism.

The vacuum advance unit can be checked by connecting a source of vacuum, such as a hand vacuum pump, to the vacuum connection on the unit (Figure 32.45(b)). Applying vacuum should move the base plate in relation to the distributor body. When the vacuum is removed, the base plate should return to its original position.

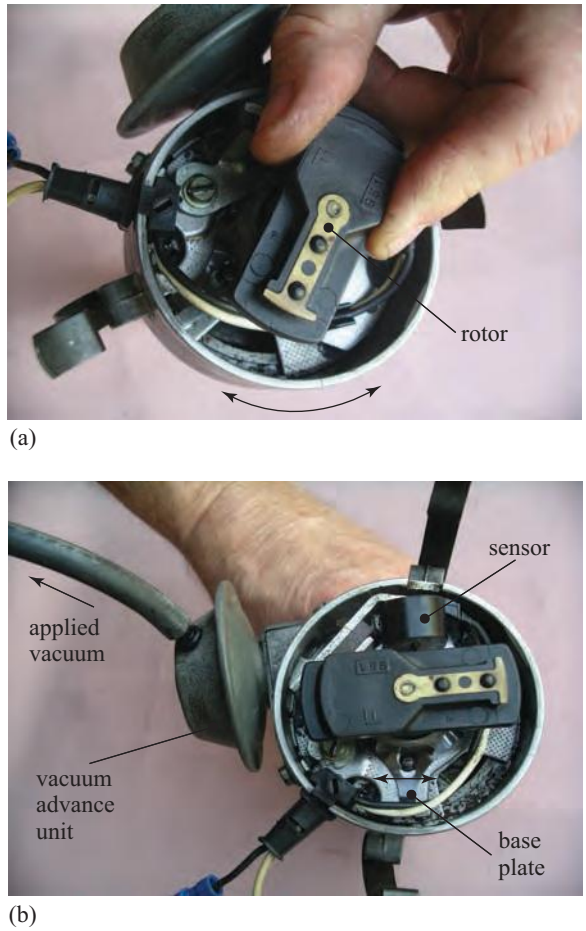


Figure 32.45 Checking the distributor advance mechanism

32.14.2 Use of a timing light

A timing light can be used for checking and setting ignition timing and for certain distributor checks. This applies mainly to distributors with centrifugal and vacuum advance.

For distributors that have adjustable timing, a timing light connected to the cable of the number one spark plug sets the ignition timing. The basic timing is set at idle speed. Whenever a spark occurs, the light will flash (Figure 32.46). If a vacuum advance unit is fitted, the vacuum line should be removed during the check.

Centrifugal and vacuum advance can also be checked for general operation. When the engine speed is increased, the timing mark on the pulley should advance in relation to the scale. With the vacuum line connected, both centrifugal and vacuum advance are checked. With the vacuum line removed, only centrifugal advance is checked.

In systems with a control unit that electronically controls spark advance, the timing light sets the position of the distributor for basic timing in a similar way to other systems.

Handy hint: For systems with electronic control, the basic setting provides an initial advance . All other timing is controlled by the electronic control unit.

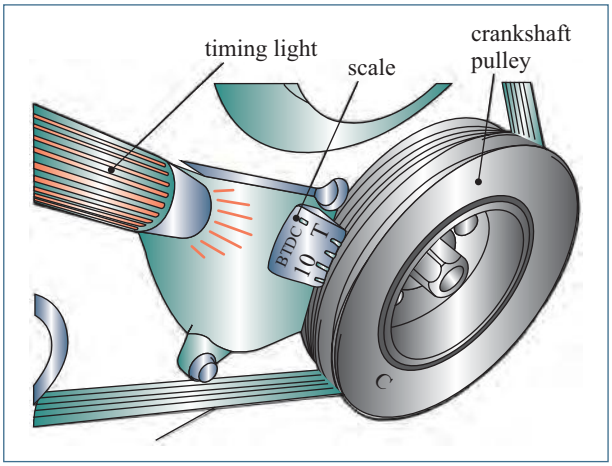


Figure 32.46 Timing light being used to check ignition timing

32.15 Fault diagnosis

Diagnosis is the process of determining the nature and cause of a problem. It should follow a logical sequence:

1 Obtain information from the regular driver of the vehicle .
2 Drive the vehicle and observe the operational symptoms.
3 Check the ECU for diagnostic data.
4 Check the obvious first.

Handy hint: Electronically stored diagnostic data can be lost if a terminal is disconnected from the battery.

32.16 Ignition problems

There are three general types of ignition problems: loss of energy in the primary circuit, loss of energy in the secondary circuit and faulty ignition timing. Each has a number of possible causes, some of which are listed in the following sections. These do not relate to any particular system, but are a combination of items relating to both breaker-type ignition systems and breakerless ignition systems.

32.16.1 Loss of energy in the primary circuit

Possible causes are:

- resistance in the primary circuit due to poor connections or a faulty ignition coil
- open circuit in the primary windings of the ignition coil, or connections to the coil
- faulty fusible link
- grounded primary circuit in the coil or wiring
- faulty pickup coil in the distributor
- faulty electronic-ignition unit.

32.16.2 Loss of energy in the secondary circuit

Possible causes are:

- spark plug fouled or defective , or spark plugs with incorrect gaps
- defective high-tension cables: faulty insulation, ex cessive resistance or induction occurring between cables
- high-tension leak age across the coil tower , distributor cap or rotor
- corroded connection in high-tension circuit
- ignition-coil secondary windings faulty
- incorrect routing of high-tension cables.

32.16.3 Faulty timing

Possible causes are:

- timing incorrectly adjusted, or distributor incorrectly installed
- vacuum advance unit defective , or vacuum line disconnected
- centrifugal advance mechanism defective
- electronic control unit malfunction
- pre-ignition due to faulty spark plugs etc
- rattle in engine causing knock sensor to actuate .

32.16.4 Ignition-coil testing

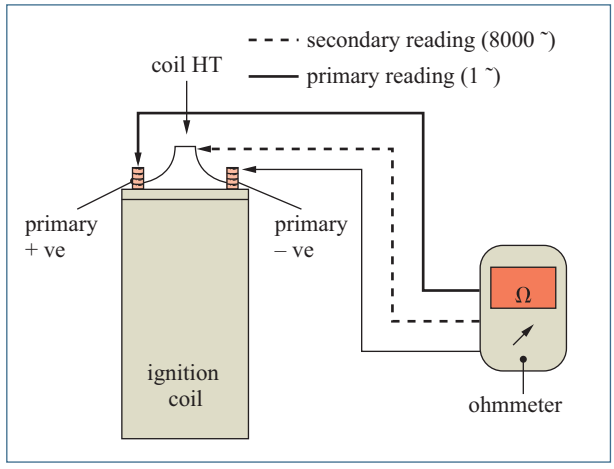


Figure 32.47 Using an ohmmeter to check the resistance of the coil windings

While coils can be tested on special coil testers or by using an ohmmeter to measure the resistance of the windings, checking the complete ignition system with an oscilloscope is the preferred method. The primary coil resistance is checked between the two low-tension primary terminals, and the secondary coil resistance is checked between one low-tension terminal and the coil high-tension terminal (Figure 32.47).

Testing coils on engines with individual coils

Follow the ignition check steps describe below and in Chapter 34 to check the ignition (see Figure 34.2):

1 Use a spare spark plug with the gap opened up to about 6 mm, or use a test plug designed for the purpose .
2 Connect a spark plug cable to the test plug erminal, and earth the body of the plug.
3 Crank the engine—a healthy blue spark should jump across the gap .

Safety: Use care with the high-tension voltage . Ignition voltages are high enough to be dangerous.

32.16.5 Capacitor testing

The capacitor for breaker ignition can be tested on a capacitor tester or the series resistance with an ammeter. A faulty condenser (capacitor) can be easily identified on an ignition check with an oscilloscope.

32.16.6 Checks for basic faults

Some of the basic checks that can be carried out could include the following:

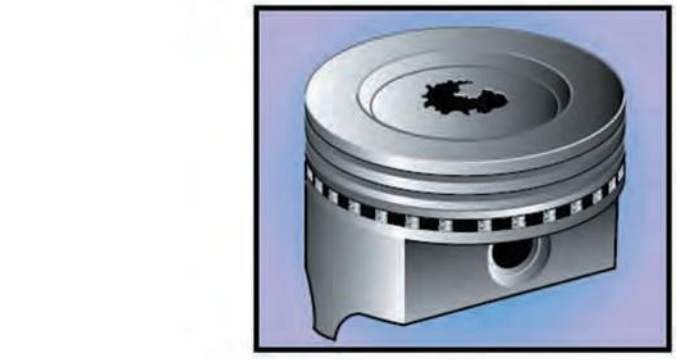
1 Battery terminals. Check for security and corrosion.
2 Battery . Check the condition and lack of capacity .
3 Alternator . Check output.
4 Wiring circuit. Check ignition wiring connectors and system earths.
5 Power supply . Check that power is supplied to the control units, sensors and actuators.

Basic checks of the general mechanical condition of the engine should also be made before assuming that a problem exists in the electronic components of the ignition system.

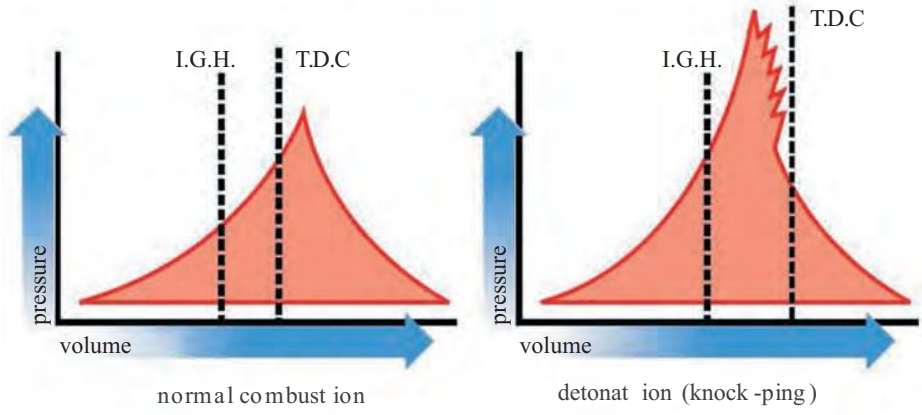
Handy hint: A symptom exhibited by the ignition system might be caused by a malfunction in another part of the vehicle .

32.16.7 Detonation

Detonation is caused by uncontrolled burning of the fuel in the combustion chamber. During the normal combustion process, the spark plug ignites the air–fuel nearest the spark plug and the flame front travels at subsonic speed across the combustion chamber (Figure 32.48). When detonation occurs, there is a secondary source of ignition somewhere in the combustion chamber. The uncontrolled burning significantly increases combustion temperatures and pressures that occur before the piston reaches TDC, causing a ‘ping’ or



damage due to detonation



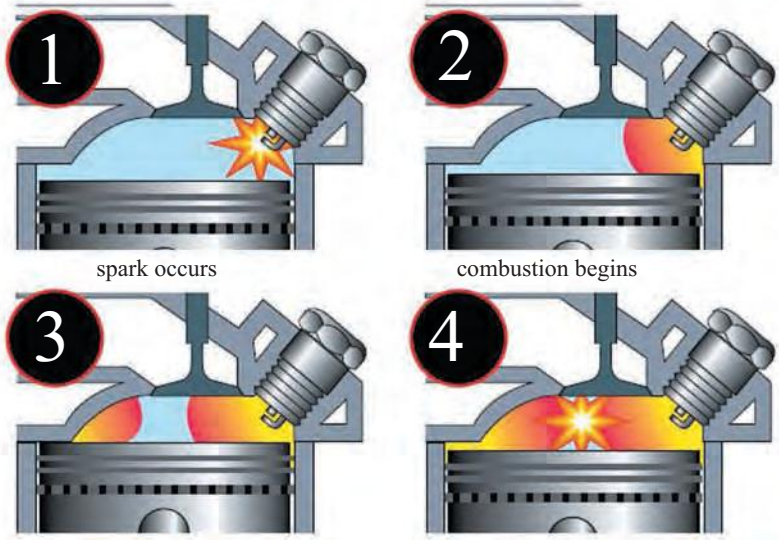


Figure 32.48 The detonation process MOTOSPECS

knocking sound. The high temperatures and pressures will burn a hole in the piston if detonation continues for long periods. This can be caused by using too low an octane fuel (low-octane fuel burns quicker than high-octane fuel).

32.16.8 Pre-ignition

Pre-ignition occurs when a part of the combustion chamber has reached sufficient temperature to ignite the air–fuel mixture prior to the spark plug firing (Figure 32.49). Typically, this might be caused by a carbon build-up in the combustion chamber or too hot a spark plug. Again, this is an uncontrolled ignition and will cause piston damage, normally near the piston edges.

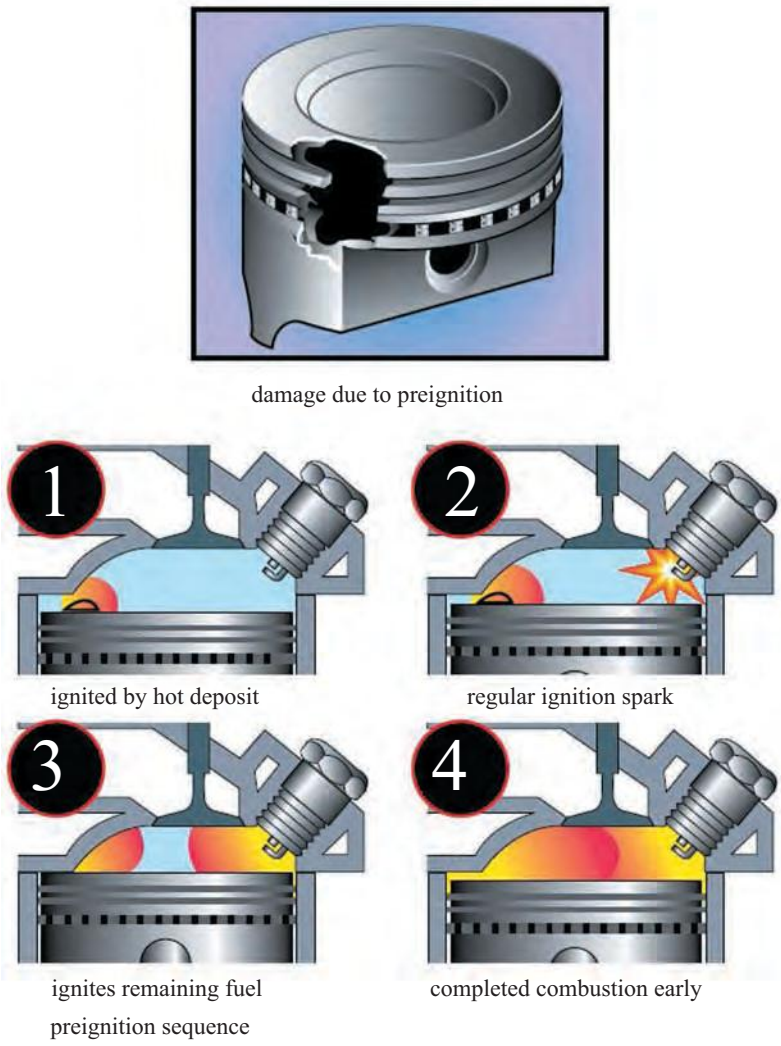


Figure 32.49 The pre-ignition process and typical resulting damag e MOTOSPECS

It is important to note the following points:

1 Continued detonation may cause pre-ignition.
2 All fuels have detonation limits, and these are determined by the type of fuel, compression ratio and mixture .
3 A damaged spark plug insulator may indicate detonation or pre-ignition.
4 When cylinders suffer from detonation or pre-ignition, the spark plug is usually destroyed.
5 The hottest cylinders will detonate or pre-ignite first. This can be seen in engines destroyed by overheating to the point when piston damage occurs.

32.17 Diagnostic equipment

The following equipment can be used for diagnosing ignition problems: digital multimeter (DMM), vacuum gauge and a scan tool, which includes an oscilloscope function. These are hand-held instruments. Larger analysers with a cathode-ray oscilloscope (CRO), or a digital monitor mounted on a console or a stand, are also used (Figure 32.50).

32.17.1 Ignition oscilloscopes

When the analyser is connected to the ignition system, it can provide a screen display of all the high-speed electrical events as they occur. The display tracks the events in the form of a graph, with ignition voltage

shown vertically (height of the pattern) and the time shown horizontally (width of the pattern). The screen can also display numerical voltage values for each cylinder, as well as the spark duration in milliseconds.

The screen can show patterns for either the primary circuit or the secondary circuit of the ignition system. Every event in the primary circuit has a corresponding event in the secondary circuit, although the patterns are quite different. Patterns for electronic ignition systems will be smoother and different from those for breaker ignition, although similar actions occur in the circuits of both types of ignition systems.

32.17.2 Secondary pattern—electronic ignition

A secondary pattern for an electronic ignition system is shown in Figure 32.51, together with the events that produced the pattern. The pattern is for one spark, but similar events will occur for all the other cylinders of the engine. The pattern shown is a basic one. It will vary for different systems and when a part of the ignition system is faulty.

The pattern shows voltage and kilovoltage vertically and time horizontally. Faults are identified by comparing the pattern shown by the system under test with a standard pattern. Technicians need to become familiar with the basic ignition primary and secondary patterns. The patterns can also be seen on most scan tools in the *scope menu.*

Figure 32.50 An engine analyser on a stand ROBERT BOSCH (AUSTRALIA) PTY LTD

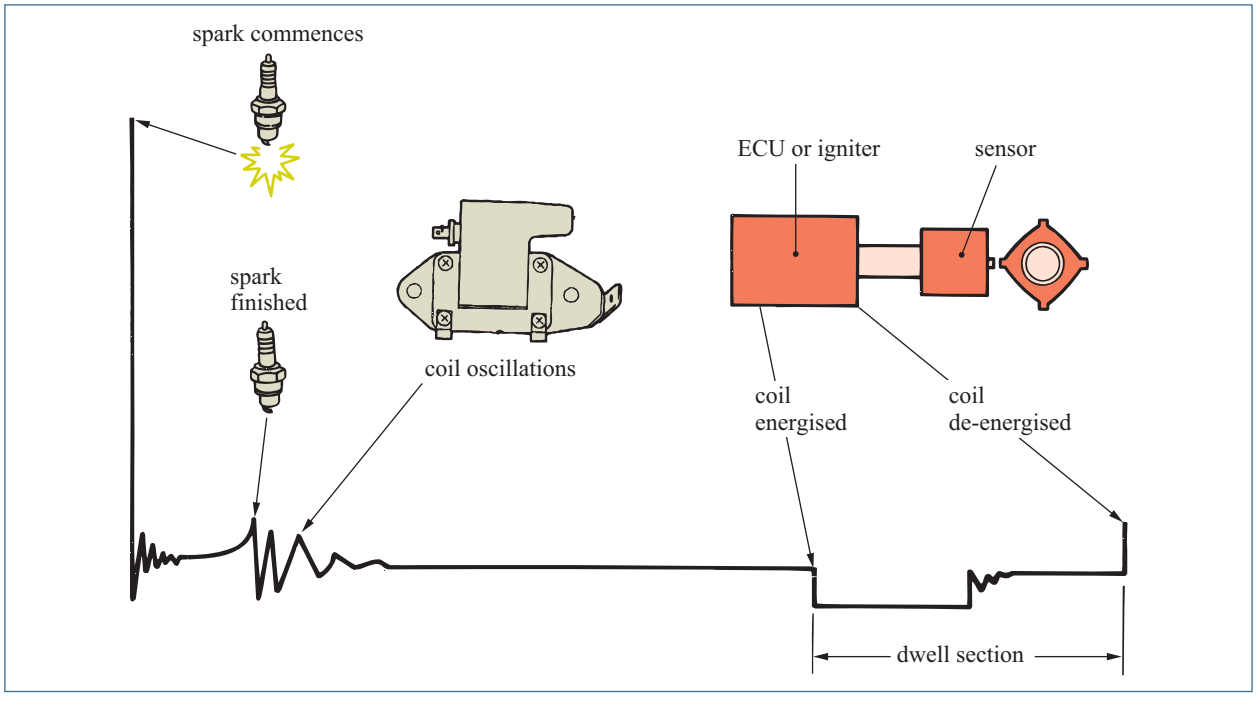


Figure 32.51 Events in an electronic ignition system that produce the secondary pattern

Figure 32.52 shows how a secondary pattern could appear on the screen of an engine analyser. The actions that occur have been identified. Ignition is initiated by the ECU. Dwell starts as soon as the ignition coil is energised and ceases when the ignition coil is suddenly de-energised. The dwell section is arranged to extend as engine speed increases.

32.17.3 Display pattern

Figure 32.53 is part of a display from an engine analyser. This shows the pattern for each of the six cylinders of an engine, in firing order. Again, the vertical axis represents voltage and the horizontal axis represents time. As well as displaying the voltage pattern for each cylinder in firing order, this instrument displays the spark-ionising voltage trace and the spark duration in milliseconds.

32.17.4 Ignition pattern display modes

Engine analysers allow the pattern of events to be displayed in four basic modes: *superimposed, single cylinder, raster* and *parade*. These are shown in Figure 32.54. In all cases, the pattern of the individual cylinders can be compared but, for particular items, one type of display may be more suitable than another. Patterns can also be expanded so that a particular part of the pattern can be more closely examined.

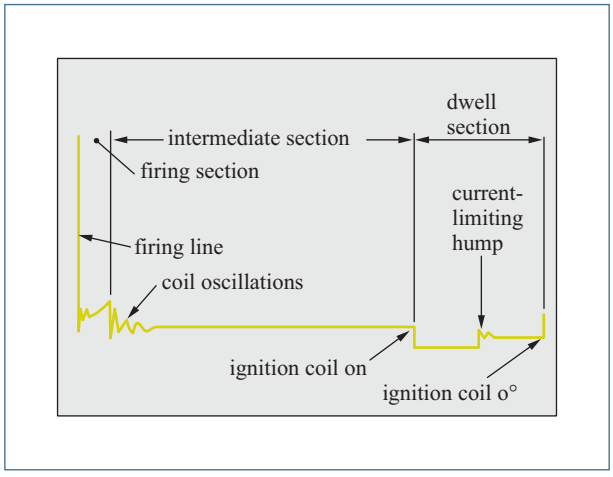


Figure 32.52 Secondary pattern for an electronic ignition system

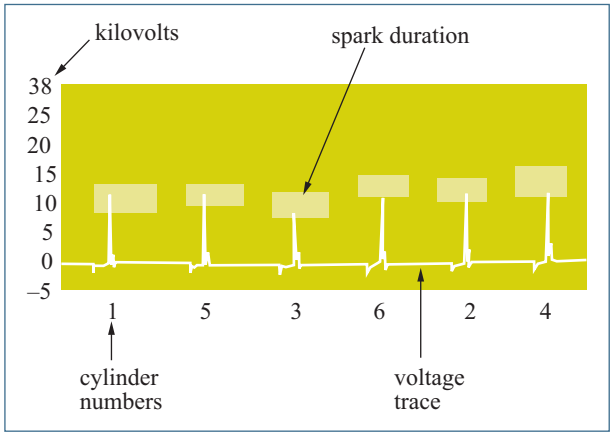


Figure 32.53 Parade display of a secondary ignition pattern showing cylinder number and firing voltage

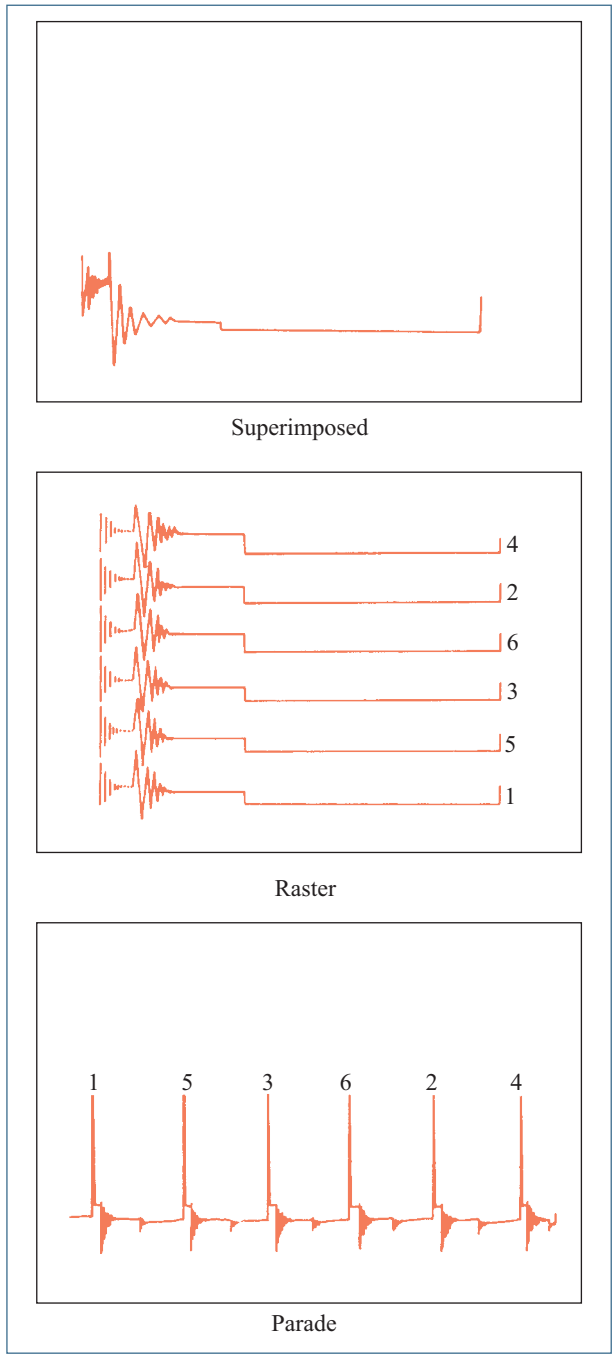


Figure 32.54 The types of ignition display patterns that can be produced on an engine analyser

Superimposed

The patterns for all the cylinders are superimposed (one on top of the other)—they appear as a single line on the screen. This enables a comparison to be made between cylinders. For example, any variations in point-closing positions can readily be seen. Superimposed view is ideal for locating the odd one out.

Single cylinder

Single patterns display primary or secondary ignition traces one cylinder at a time. This is useful for pinpointing an ignition fault to a particular cylinder. Single cylinders are shown in both the raster and parade patterns.

Raster

The patterns are stacked, or arranged one above the other, in the firing order for the vehicle, from the bottom to the top. The patterns can be checked and compared with each other. Again, this identifies a problem if one exists in a particular cylinder or for problems in the coil controlling circuitry.

Parade

Patterns of the cylinders are shown in line, with the firing order from left to right. The firing kilovoltage of all cylinders can be compared with this arrangement. This display is useful for comparing firing voltages between cylinders. Cylinders should be firing within 4 kV of each other.

32.17.5 Connecting the engine analyser to the engine

The basic connections between the engine analyser and the engine will vary with engine and ignition type. Probes that provide a pulse signal are fitted to the high-tension cables and clips are attached to the ignition-coil terminals for dwell and tacho signals. Additionally, a connection is made to battery power and the earth on the engine.

Ignition systems will usually need to be back-probed through the terminal sealing boot to access the terminals. Extreme care should be taken to prevent the sealing boot from being damaged. The connections and the way that they are made will depend on the instrument being used and on the engine system. With some engine management systems, special connectors may be needed.

Handy hint: There are many variations of vehicles, instruments and systems, so the appropriate machine instruction manual should be used.

32.17.6 Display patterns for ignition conditions

Figure 32.55 shows some general examples of ignition patterns. However, there are many variations where different types of faults exist. For particular information, the equipment operation manual should be consulted.

32.17.7 Dwell overlap

Figure 32.55(a) shows dwell overlap being checked. The four cylinders of the engine are superimposed. Overlap is measured as the difference in dwell between each cylinder. A large dwell overlap identifies a worn distributor cam in breaker ignition systems. With electronic ignition, the dwell can be checked by observing the increase in it at a specified engine rpm and the current-limiting hump near the end of the dwell line (see Figure 32.52).

32.17.8 Coil polarity

In Figure 32.55(b), the secondary pattern is superimposed or examined as a single cylinder to check the coil polarity. With correct polarity, the voltage spike is above the baseline and the oscillations are inverted and appear below the baseline.

Handy hint: This check does not apply to waste-spark systems or coil-on-plug systems.

32.17.9 Spark plug voltage

Figure 32.55(c) shows a parade display of secondary patterns, which checks the spark plug ionisation voltage. All should be of equal and acceptable kilovoltage as shown.

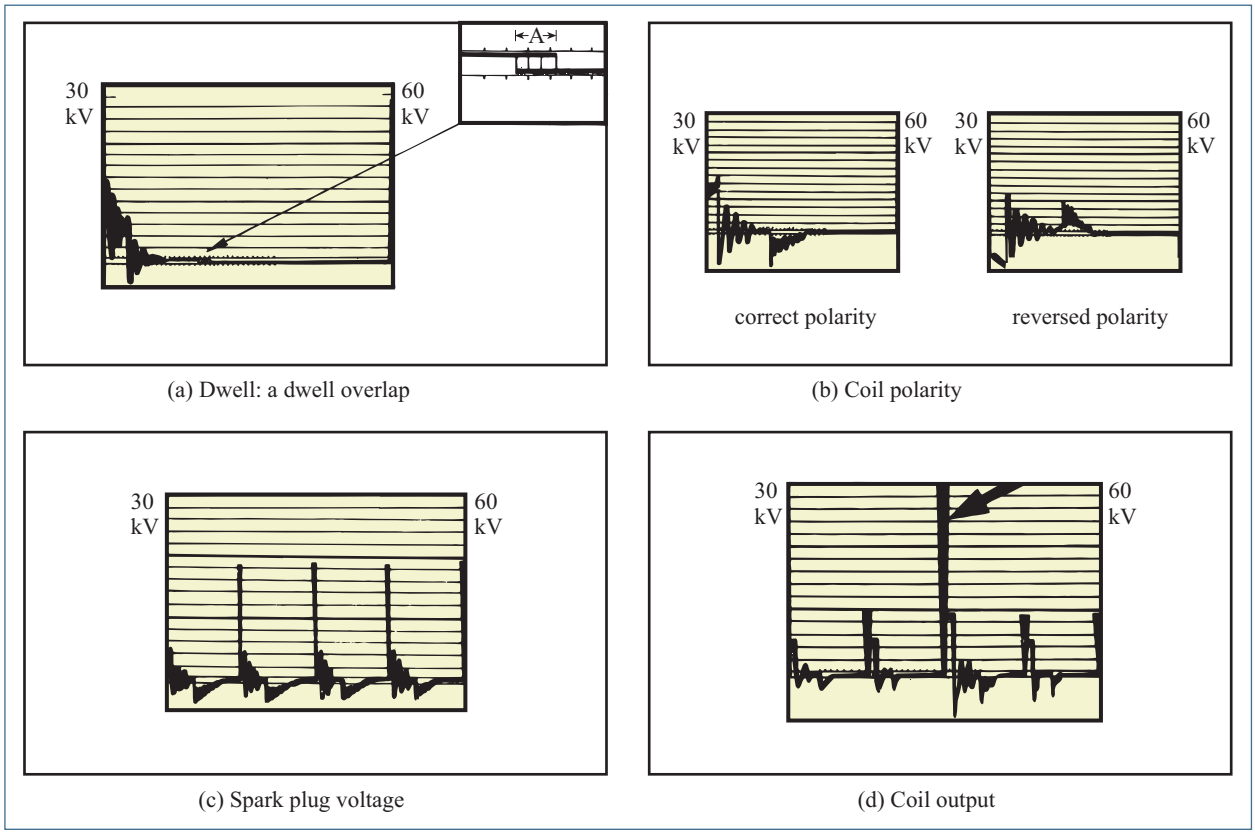


Figure 32.55 Ignition display patterns (a) superimposed, checking dwell; (b) superimposed, checking coil polarity (c) parade, checking spark plug firing voltage; (d) parade , checking coil output/reserve

The voltage can be checked under load by snapping the throttle open. On initial acceleration, the plug voltage will rise to a peak due to a sudden lean-out, but should not exceed two-thirds of maximum coil output, as previously checked. In an instant, the firing voltage will drop to less than 5 kV. This is used to observe the rotor air gap and is a check of ignition reserve.

32.17.10 Maximum coil output

Figure 32.55(d) shows the secondary patterns displayed in parade form with the maximum coil output being checked. This is done by using an appropriately earthed test plug with a 6 mm plug gap connected to one of the spark plug cables. The wide gap causes maximum voltage to build up in the coil for that cylinder. The voltage peak is much higher than for the other cylinders where the energy is being dissipated across the smaller gaps of the spark plugs.

Precautions

There are special precautions for engines with electronic ignition. They should not be run with a spark plug cable disconnected, as this could damage the electronic control unit. It could also cause problems with the catalytic converter due to raw unburnt fuel being introduced.

32.17.11 Scan tool diagnosis

The scan tool interrogates the electronic control system through the data link connector (Figure 32.56). As an example of its use, the scan tool might indicate the error code P1320 for an electronic distributorless ignition system. Reference is then made to the service

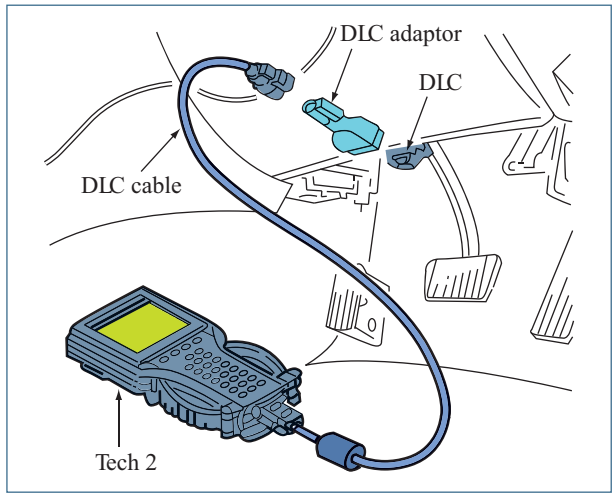


Figure 32.56 Scan tool and data link connector
GM HOLDEN LTD

Table 32.2 Flow chart for checking the crankshaft position sensor (CKP is crankshaft position)

Test step after signal has been confirmed missing/ faulty by using an oscilloscope	Result	Action to take
A1 Is the sensor fitted correctly ?	Yes ☐ No ☐	Go to A2 Rectify and retest
A2 Check sensor continuity using ohmmeter Is the reading from 300 to 400 ohm ?	Yes ☐ No ☐	Go to A3 Check sensor and wiring Rectify and retest
A3 With the sensor disconnected, measure the resistance across the connector for a possible short in EEC or wiring Does a short exist?	Yes ☐ No ☐	Rectify and retest Go to A4
A4 Measure the resistance from CKP(+ve) to ground and CKP(−ve) to ground for possible short Does a short exist?	Yes ☐ No ☐	Rectify and retest Go to A5
A5 Check wiring for open circuit Does an open circuit exist?	Yes ☐ No ☐	Rectify and retest Check sensor and tone wheel for damage Rectify and retest

literature for an interpretation of the code. For this particular system, it would be found that code P1320 indicates that the ECU has no signal from the crankshaft position sensor, or that it has an unrecognisable signal.

For fault code P1320, the crankshaft position sensor has to be checked. The diagnostic flow procedure for code P1320 from the workshop manual is shown in Table 32.2. Starting with A1, each item on the chart is followed through until the correct action to rectify the fault is found.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- explain the purpose of the ignition system and its components
- describe different types of spark plugs
- identify different types of ignition systems
- identify ignition timing and timing advance systems
- identify ignition system triggers
- identify dwell angle and knock sensor systems
- describe requirements and precautions for servicing ignition systems
- apply procedures for servicing spark plugs
- apply procedures for servicing ignition distributors
- describe detonation and pre-ignition
- apply procedures for using testing equipment.

REVIEW QUESTIONS

1 Name the main components of a break er ignition system.
2 Explain how the primary circuit of an electronic ignition system operates.
3 Name the parts of the secondary circuit of an ignition system.
4 Explain briefly how an ignition coil works.
5 In relation to coil primary operation, when does spark occur?
6 What is meant by the heat range of a spark plug ?
7 What is a hot spark plug and what is a cold spark plug ?
8 Why are special metals used on some spark plug electrodes ?
9 What is the lik ely effect if a spark plug is too hot for an engine ?
10 There are a number of different types of ignition systems. What are they ?
11 Identify the parts of the primary circuit of an inductive ignition system.
12 What are break er and break erless ignition systems ?
13 What is direct ignition ?
14 Explain how three ignition coils are used on a six-cylinder engine with direct-fire (distributorless) ignition.
15 Explain the operation of a coil-on-plug ignition system.
16 What are the advantages of electronic ignition ?
17 Why do ignition systems have spark advance mechanisms ?
18 Briefly outline the method of setting initial ignition advance .
19 What is an optical sensor ?
20 What is a Hall-effect device ?
21 Explain briefly how a Hall-effect device works.
22 Why is a pulse generator used instead of break er points ?
23 What three types of trigger sensors are used in high-energy ignition distributors ?
24 What is meant by dwell?
25 State the precautions that should be observed when working on electronic-type ignition systems.
26 Explain how a visual inspection of a spark plug can help to identify faults.
27 How should high-tension cables be removed from spark plugs ?
28 How can an ignition coil be tested?
29 List some of the faults that could cause loss of energy in the primary system.
30 What are some possible faults that could occur in the secondary system ?
31 What are the four displays for ignition patterns on an engine analyser?
32 What does CRO stand for?
33 What is a current-limiting hump and on which ignition CRO display can it be observed?
34 What are the three sections of a secondary ignition pattern ?

CHAPTER 33

Emission controls

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 explain how individual components used in emission controls work
2 identify individual components of emission control systems
3 describe the operation of catalytic converters
4 describe the operation of o xygen sensors
5 identify what pollutants are produced by the engine of a motor vehicle
6 identify the purpose of SRC systems
7 identify the testing procedure for emission control systems
8 recall the emission requirements of motor vehicles.

As emissions from motor vehicles are a major cause of air pollution, manufacturers have to control them so that their vehicles meet specified standards. Consequently , engines have been fitted with various devices to reduce emissions. Electronic fuel injection and engine management systems in particular have made engines more fuel-efficient and have reduced the number of emission devices needed.

The chemicals discharged from industrial processes and motor vehicles combine with other chemicals in the air, and some can be affected by sunlight. Under certain conditions, impurities in the air can be seen as smog. However , air pollution is a health hazard which does not have to be visible to be present.

This chapter deals with emission controls in relation to petrol engines.

33.1 Motor vehicle pollution: sources

Polluting emissions from a motor vehicle with a petrol engine come from the following sources:

1 Fuel supply . Petrol is a volatile liquid and requires very little heat to cause it to evaporate . Liquid fuel turns to vapour which enters the surrounding atmosphere .
2 Engine crank case . Gases within the crank case increase as the engine wears and the piston and rings allow more blow-by. Some unburnt fuel (hydrocarbon, HC) also finds its way down the cylinder walls.
3 Exhaust system. Chemicals enter the engine in the form of fuel and air . Most of these are changed by the process of combustion inside the engine and are then discharged through the engine 's exhaust system into the atmosphere .

Handy hint: Whenever an engine is operating, it is producing chemicals that can cause pollution.

33.1.1 Emission controls

There are three general types of emission controls that remove or reduce emissions.

1 Evaporative controls. These are fitted to prevent fuel vapour from the fuel system escaping into the atmosphere .
2 Crank case ventilation. This directs vapour from the crank case to the intak e manifold, so that the crank case is vented internally and not to the atmosphere .
3 Exhaust-emission controls. These limit the no xious gases exhausted from the vehicle by providing more efficient combustion and also by treating the by-products of combustion.

33.2 Evaporative-control system

An evaporative-control system for a petrol engine is shown in Figure 33.1. The functions of the parts are described in the following paragraphs.

33.2.1 Fuel tank assembly

A fuel tank has to be vented to allow for expansion and contraction of its contents (liquid fuel and fuel vapour). If it is vented directly to the atmosphere, the fuel vapour above the liquid fuel will be forced out of the vent during expansion. During contraction, air will be drawn back into the tank. To prevent fuel vapour from being discharged into the atmosphere, it is vented into a charcoal canister where it is stored until it can be burnt by the engine.

Handy hint: The fuel tank has to breathe , and it does this through the carbon canister .

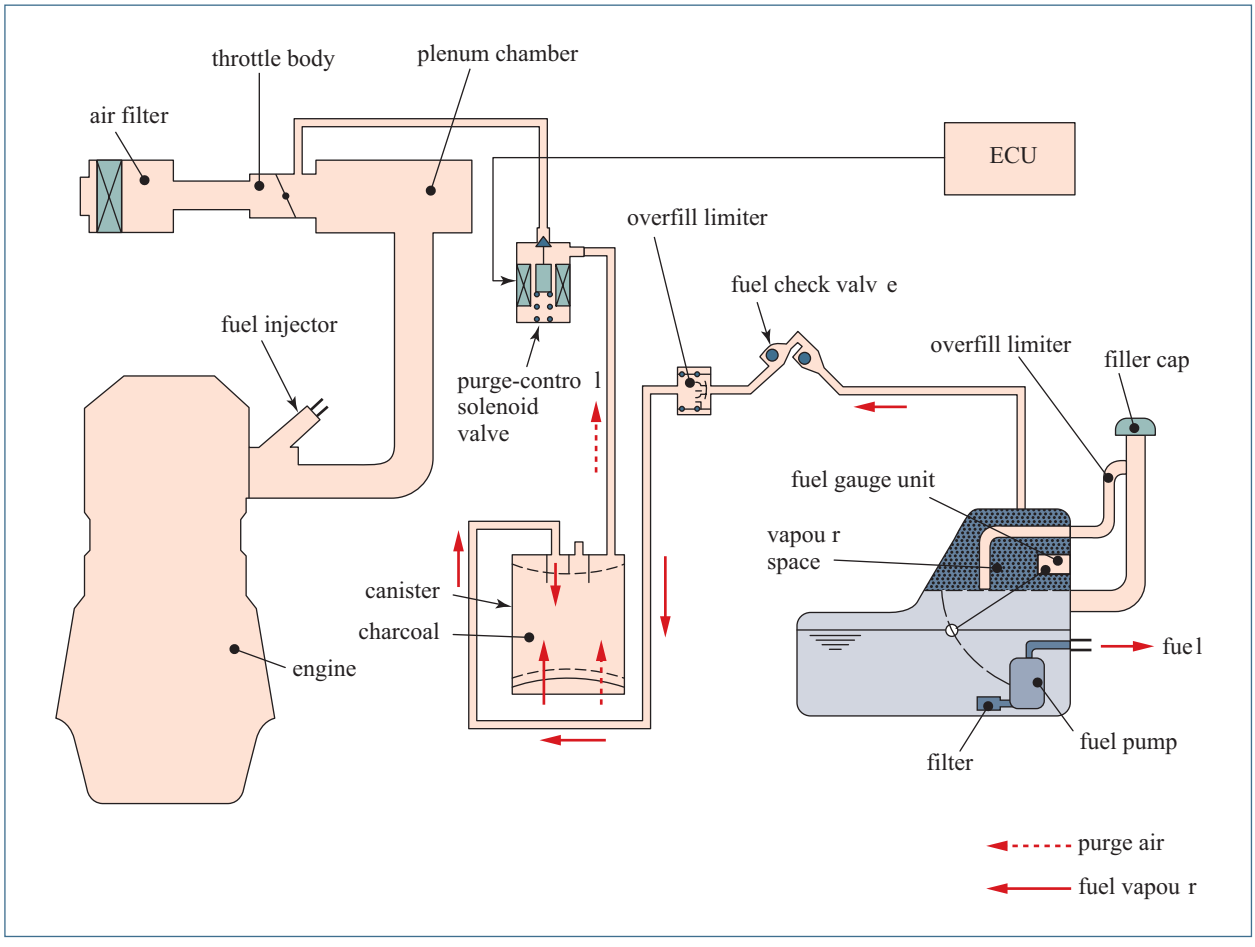


Figure 33.1 Evaporative emission control system for an EFI engin e

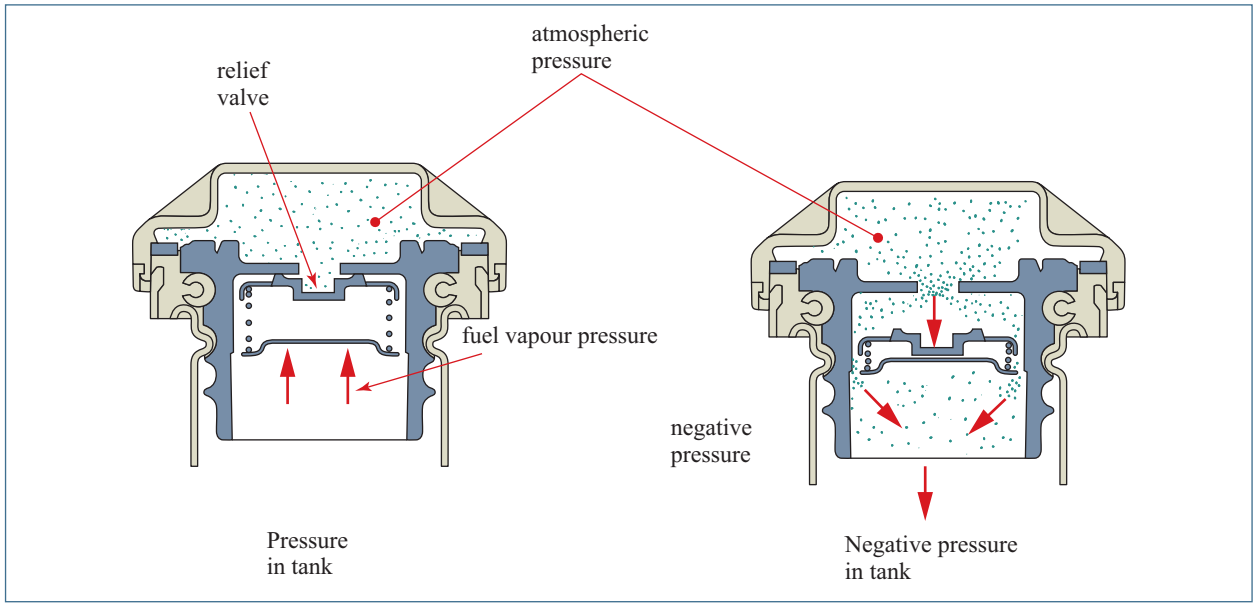


Figure 33.2 Operation of a fuel filler cap with a relief valve

Fuel tank vapour space

Space is provided in the fuel tank to store and condense the vapour rising from the surface of the fuel. The space is determined by the position of the overfill-limiting pipe, which limits the level of the fuel during the normal filling procedure. Once the fuel reaches the lower end of the pipe, air cannot escape back up the filler neck and it is difficult to add additional fuel. This limits the fuel and provides the necessary vapour space.

Fuel tank cap

The tank cap is fitted with a vacuum-relief valve. This opens when the pressure in the tank falls below atmospheric pressure, and allows air to enter the fuel tank (see Figures 33.2 and 33.3).

Handy hint: If a fuel tank cap is replaced, the new cap must be of the same design as the original.

Figure 33.3 Fuel filler cap with a relief valve

Check valve

Fuel vapour is stored in the fuel tank in the space above the fuel, but when pressure starts to build up, the check valve opens to allow vapour to pass through to the charcoal canister. Vapour can pass through the check valve, but liquid will close it and block off the vent line. This prevents liquid fuel from reaching the charcoal canister.

33.2.2 Charcoal canister

The charcoal canister, also referred to as a *carbon canister*, contains granules of activated charcoal (Figure 33.4). It has two pipe connections, one for the fuel tank vent and one for the vapour pipe to the intake manifold. There is also an atmospheric vent to admit air.

The fuel tank can breathe through the canister. Vapour enters and exits the canister as the fuel in the tank expands and contracts. The atmospheric vent in the canister allows air to enter or leave the canister. The canister shown has a solenoid-operated purge valve that is controlled by the ECU. When the engine is

running, the vapour pipe, connected to the intake manifold, purges the vapour from the canister and carries it into the intake manifold.

Purging will occur only when the engine is running at reasonable speeds. It does not occur at idle and slow speeds when it could upset the air–fuel mixture ratio.

33.2.3 Fuel tank vents

Fuel tanks can have more than one vent pipe, depending on the shape and the location of the tank in the vehicle. When there is more than one pipe, at least one pipe is above the level of the fuel, regardless of the position of the vehicle. This not only vents the tank but prevents fuel from siphoning through the vent pipe. The pipes are connected at some point above the fuel tank to a common vent pipe.

In some systems, the pipes are carried to a small container above the fuel tank, called a *condense tank* or a *liquid-vapour separator.* This acts as a trap and prevents liquid fuel from reaching the charcoal canister. A venting system of this type is illustrated in Figure 33.5. This is for a light commercial vehicle.

33.2.4 Returnless fuel system

Traditional EFI fuel systems have a fuel return line from the engine compartment to carry excess fuel from the pressure regulator in the fuel rail back to the fuel tank. The disadvantage of this arrangement is that the fuel being returned has been heated by being close to the engine. This raises the temperature of the fuel in the fuel tank and leads to unnecessarily high evaporative emissions.

A returnless system does not have a fuel return line as the fuel pump, fuel filter and pressure regulator are all housed inside the fuel tank as shown in Figure 33.6(a). With this arrangement, excess fuel from the regulator is returned to the tank without being heated. Figure 33.6(b) shows a fuel return system.

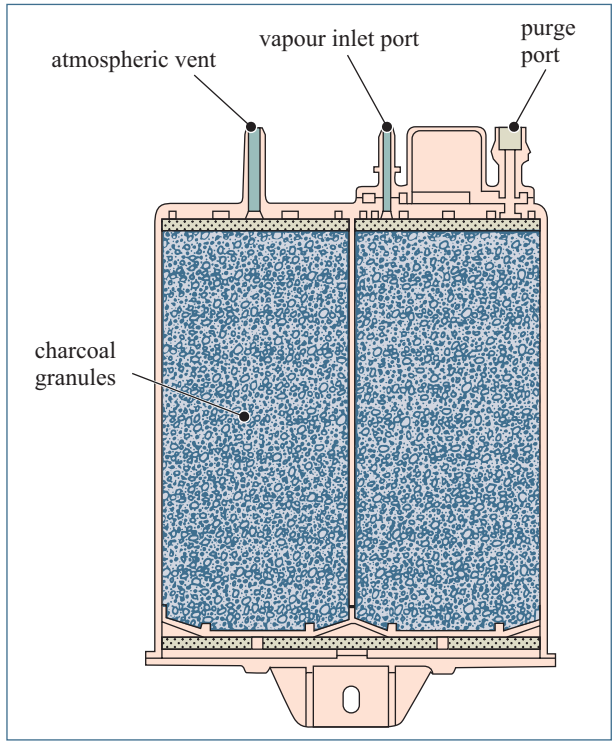


Figure 33.4 Charcoal canister

33.3 Crankcase ventilation

Positive crankcase ventilation (PCV) systems prevent pollution. They supply clean air to the crankcase

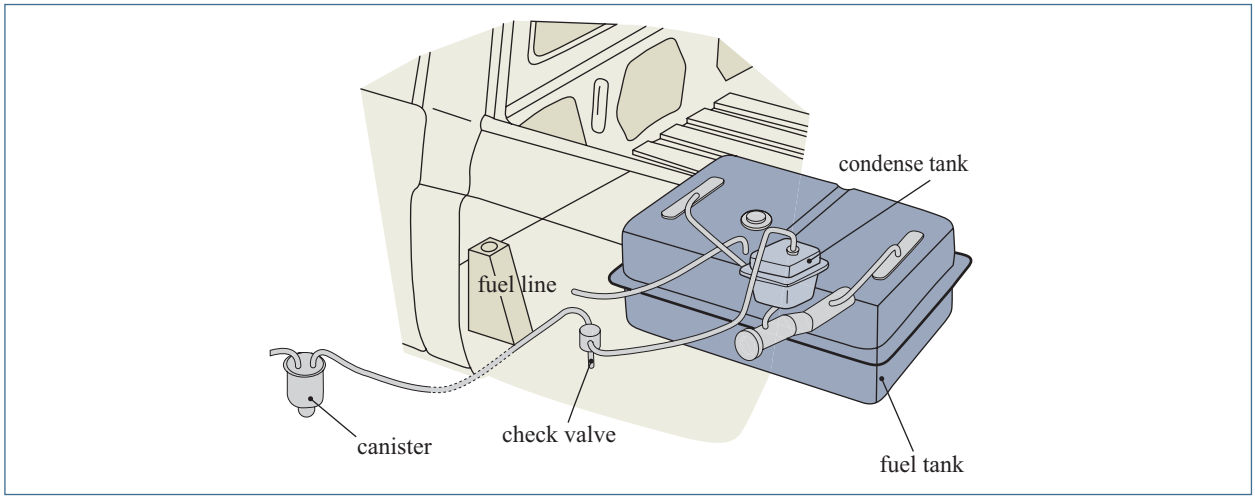


Figure 33.5 Fuel tank with condense tank and venting system

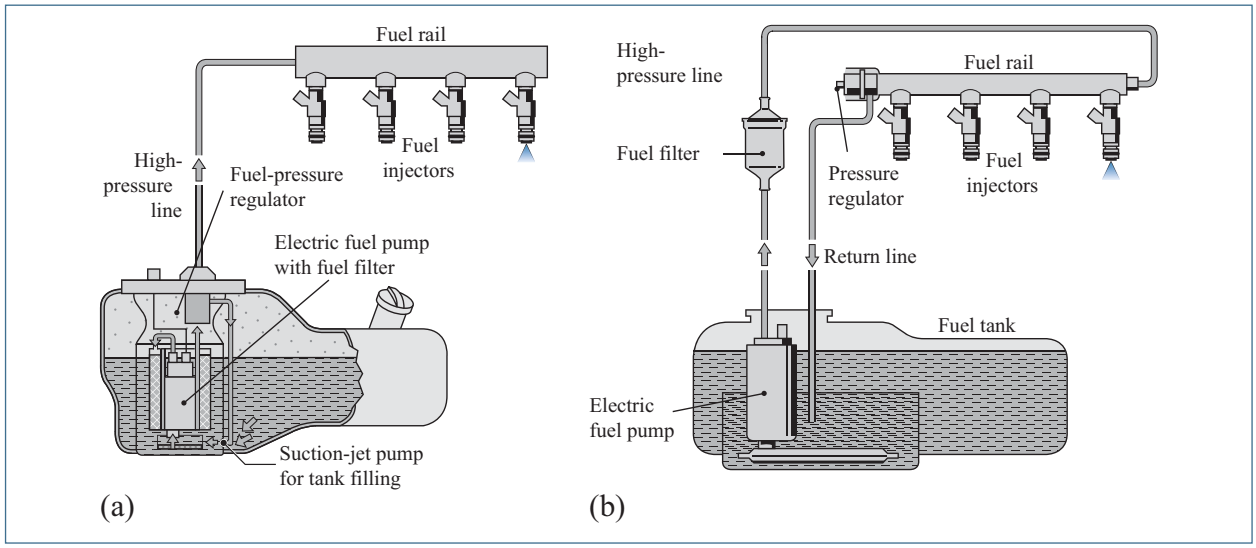


Figure 33.6 (a) Returnless fuel system (b) Fuel return system

and, at the same time, remove gases that are harmful to both the engine and the atmosphere. The gases are recycled back to the combustion chambers where the combustible elements are burnt and the remainder discharged with the exhaust gases through the exhaust system.

Figure 33.7 shows a PCV system for an inline engine. Filtered air is drawn through the valve cover and into the crankcase, where it mixes with the crankcase gases caused by blow-by. The gases are drawn from the crankcase through the positive-crankcase ventilation valve (PCV valve) and into the intake manifold. They are then burnt as part of normal combustion.

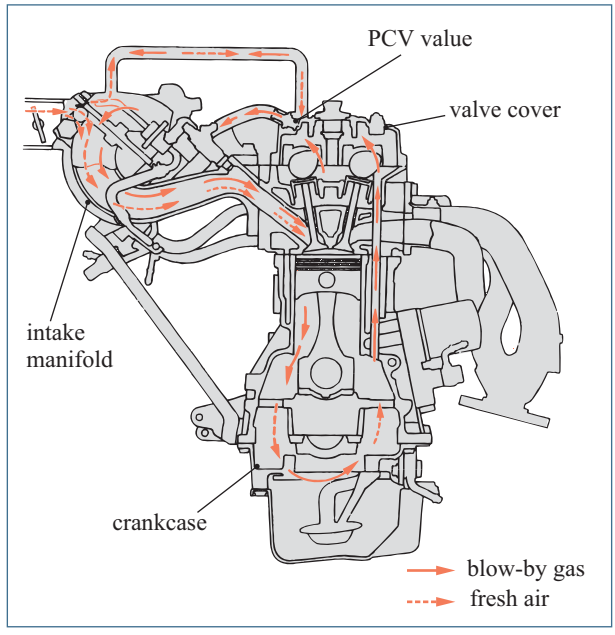


Figure 33.7 Positive crank case ventilation (PC V) system GM HOLDEN ITD

33.3.1 PCV valve operation

The PCV valve is located in the valve cover. It has a metered orifice and a stepped and tapered plunger, which also acts as a valve. These control the flow of air and crankcase gases into the intake manifold so that they will not upset engine operation. The valve is operated by the difference in pressure between the intake manifold and the crankcase. Its action is illustrated in Figure 33.8 and is as follows:

1 When the engine is not running, the plunger is held in the closed position by its spring (Figure 33.8(a)). This prevents crank case gases from entering the intak e manifold while the engine is being started.
2 At normal engine operation, the balance between the manifold vacuum and the spring holds the plunger midway in the body , allowing for normal flow (Figure 33.8(b)).
3 At idle speeds, when intak e manifold vacuum is high, the plunger is drawn to the intak e manifold end of the body (Figure 33.8(c)). This creates a small vacuum passage which results in a restricted flow.
4 During acceleration, and at higher load, the lower intak e manifold vacuum allows the plunger to move towards the other end of the body , giving maximum flow (Figure 33.8(d)).

33.3.2 Diesel engine crankcase ventilation

Diesel engine crankcase emissions are also controlled by a crankcase and an oil separator which removes the crankcase oil from the fumes. The fumes without the oil particles are then directed to the air intake via a PVC valve.

33.4 Exhaust emissions

The emissions from the exhaust system account for the bulk of the total emissions from a motor vehicle. They are more complex than evaporative emissions, and it is necessary to consider their origin within the engine in order to understand the methods of control.

33.4.1 Air–fuel mixture

The air–fuel mixture supplied to the engine consists of four main chemical elements: oxygen (O_2), nitrogen (N), hydrogen (H) and carbon (C). The oxygen and nitrogen are obtained from the air, and the hydrogen and carbon come from the fuel. The fuel is mainly hydrocarbons (HC), which are compounds of carbon and hydrogen. When the air–fuel mixture is ignited, combustion occurs and a number of chemical reactions take place.

33.4.2 Emissions from combustion

If complete combustion could occur, the oxygen in the air would combine with the hydrogen in the fuel to form H_2O (water). The oxygen in the air would also combine with the carbon in the fuel to form CO_2 (carbon dioxide), a relatively non-poisonous gas. However, ideal combustion does not occur within the engine; some hydrocarbons remain after combustion, and carbon monoxide (CO), a highly poisonous gas, is produced instead of carbon dioxide.

Safety: The carbon mono xide from the exhaust requires engines to be run in well ventilated areas.

33.4.3 Chemicals in the exhaust

Internal combustion engines produce chemical emissions in the following forms (these will be present in the exhaust system).

1 Hydrocarbons (HC). Unburnt particles of fuel.
2 Carbon mono xide (CO). A product of combustion.
3 Oxides of nitrogen (NOx). The result of high temperatures in the combustion chambers.
4 Particulates. Very small solids, such as particles of carbon and minute particles of metal.

Figure 33.9 illustrates how the main chemical elements that enter the engine combine within the combustion chamber and leave in a different form through the exhaust.

33.4.4 Methods of reducing exhaust emissions

Manufacturers have developed various ways of reducing exhaust emissions. Some are inside the engine itself; others are external modifications or devices fitted to the engine.

The purpose of most of the devices is to improve combustion so that more of the fuel charge is burnt, resulting in fewer emissions. Some devices, such as catalytic converters, do not *directly* improve combustion but treat the exhaust gases to improve their quality before they are released into the atmosphere.

Electronic fuel injection and engine management systems play a large part in reducing emissions. They have close control of the air–fuel ratio over the entire operating range of the engine, resulting in fewer emissions.

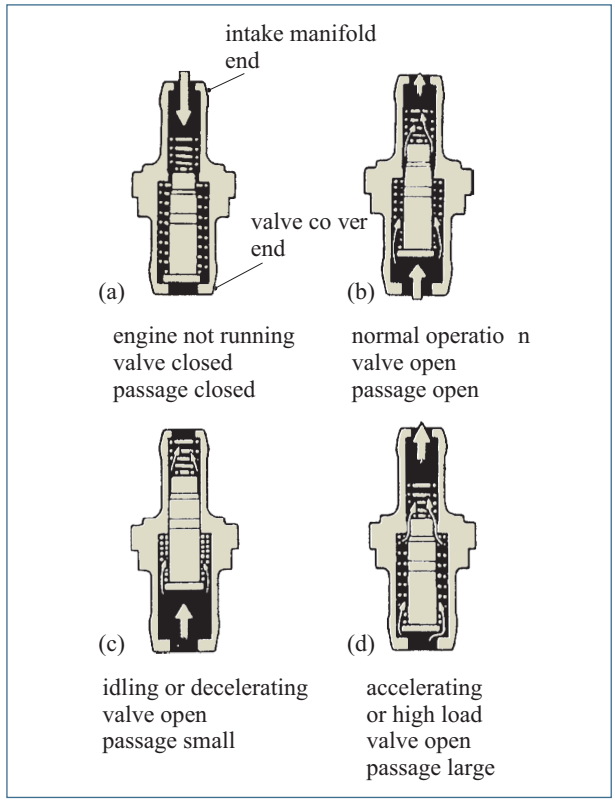


Figure 33.8 PCV valve operation GM HOLDEN LTD

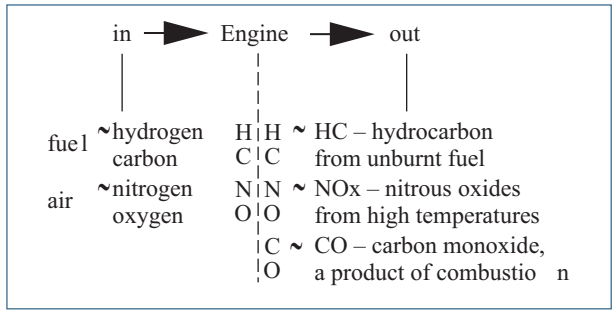


Figure 33.9 Chemical reactions of fuel and air in the engine: four elements, H, C, N and O , enter the engine—some leave in different forms

33.5 Catalytic converters

Figure 33.10(a) shows an exhaust system with a catalytic converter. With V-type engines, two catalytic converters are often used—one for each bank of cylinders. In later systems, four are used—two for each bank. Catalytic converters are basically gas reactors which reduce the amount of harmful pollutants in the exhaust gases as they pass through the exhaust system.

The construction of a catalytic converter can be seen in Figure 33.10(b). It consists of a stainless-steel shell which encloses a ceramic honeycomb core. The core has a coating of aluminium impregnated with noble metals which act as catalysts to produce chemical reactions in the exhaust gases. These reactions result in fewer harmful emissions.

A honeycomb core (approximately 160 cells per cm^2) is used because it allows a free gas flow through the converter and also provides a large surface area of contact between the catalyst and the exhaust gas. A large surface area is needed because reaction occurs on the surface of the catalyst.

Handy hint: A catalyst is a substance that promotes a chemical reaction but remains unchanged.

33.5.1 Two-way and three-way converters

Catalytic converters are referred to as *two-way* or *three-way* converters. Two-way (oxidising) converters use platinum and palladium as catalysts and convert HC and CO to H_2O and CO_2, neither of which is harmful

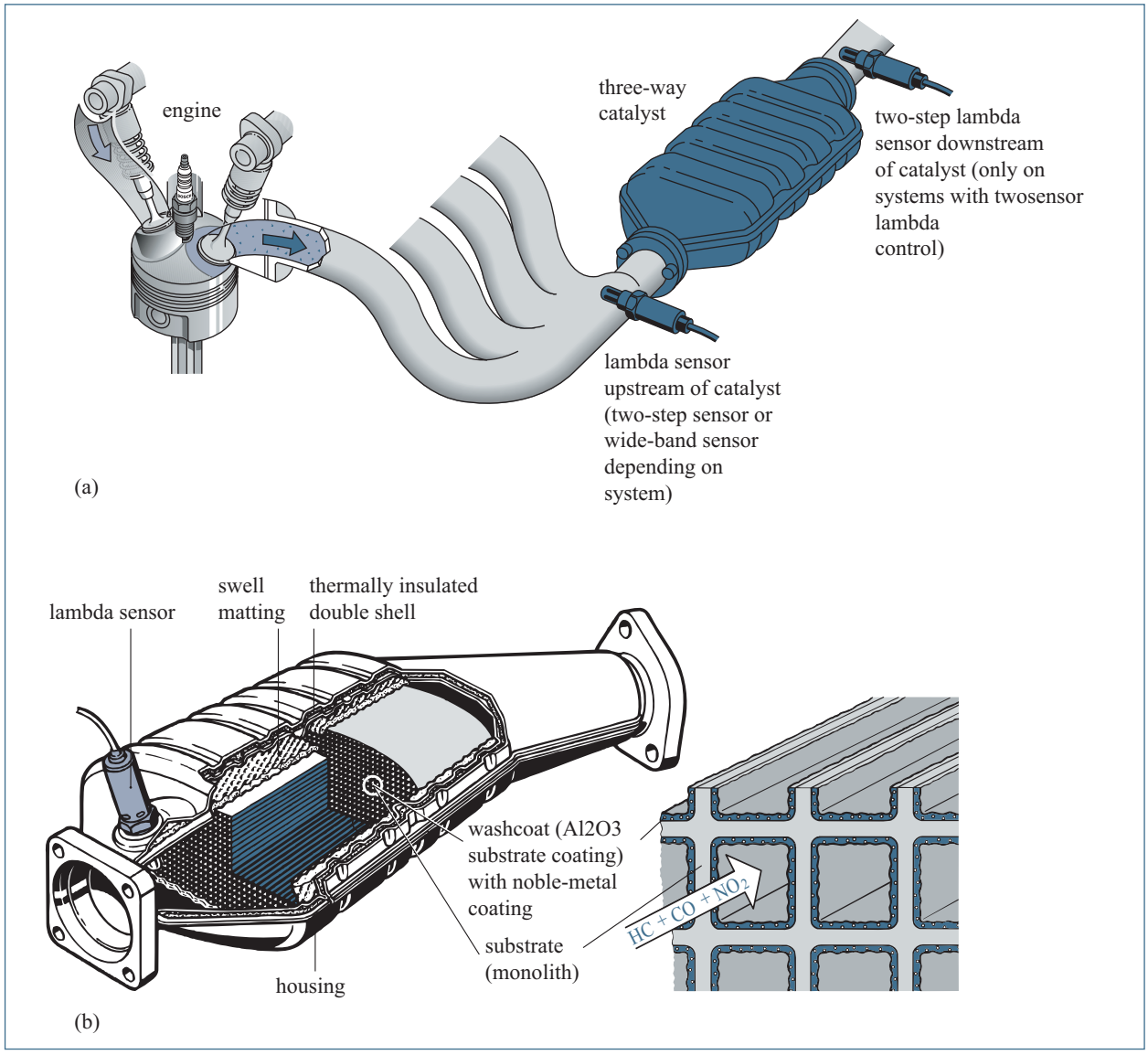


Figure 33.10 Exhaust system with catalytic converter

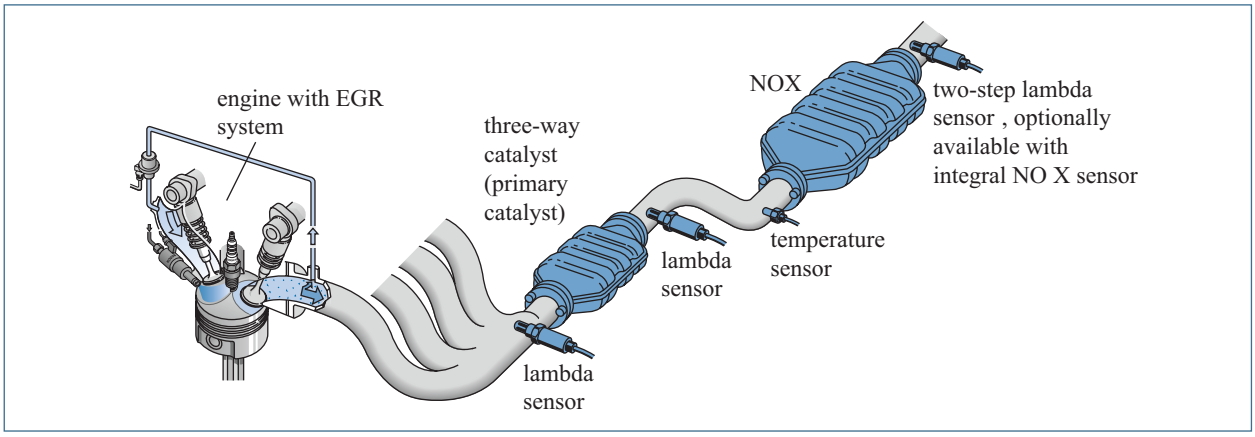


Figure 33.11 1 Engine with exhaust gas recirculation (EGR) 2 lambda sensor; 3 three-way converter; 4 temperature sensor; 5 NOx accumulator-type converter 6 two-step lambda sensor

to health. Two-way catalytic converters do not react with oxides of nitrogen (NOx), and so the engine still requires an exhaust gas recirculation (EGR) system (Figure 33.11) to control NOx emissions.

A three-way converter has an additional catalyst of rhodium which reduces the NOx in the exhaust gases to nitrogen (N_2) and oxygen (O_2).

33.5.2 Exhaust manifold catalytic converter

The catalytic converter shown in Figure 33.12 is contained in a housing attached directly to the exhaust manifold. This type of converter can be used on its own, usually with smaller engines. It can also be used with a second catalytic converter further along the exhaust system. The sensors shown are part of a closed-loop system for monitoring the exhaust gases. Signals from the sensors go to the ECU and are used for the engine management system.

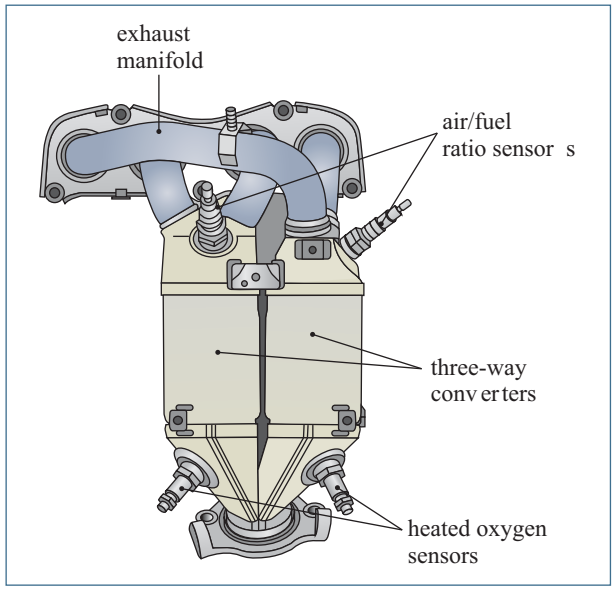


Figure 33.12 Three-way catalytic converters attached to the exhaust manifold

33.5.3 Chemical conversion path

Figure 33.13 shows the basic chemical conversions that take place in an engine and its exhaust system. These start from the point where the air and fuel are drawn into the intake manifold. This is followed by combustion and subsequent treatment processes to the stage where the end products are expelled into the atmosphere.

33.5.4 Types of catalytic converters

A two-way converter is an oxidation converter. It performs two tasks: the oxidation of carbon monoxide to carbon dioxide and the oxidation of hydrocarbons to carbon dioxide and water. This type of converter was used on petrol vehicles in early emission control and is widely used in diesel engines.

A three-way converter is used in all petrol engines in Australia and provides a reduction and an oxidisation process. It reduces nitrogen oxide to nitrogen and oxygen and performs the oxidation of carbon monoxide to carbon dioxide and the oxidation of hydrocarbons to carbon dioxide and water.

These systems run a closed loop feedback to manage fuel mixture and have more than one oxygen sensor.

33.5.5 Air injection systems

Secondary air injection systems were introduced in the early days of emission control. They are rarely used today. They incorporate an air pump to pump air into the exhaust system in front of the catalytic converter to help oxidise any remaining hydrocarbons (Figure 33.14). The air can be pumped into the exhaust

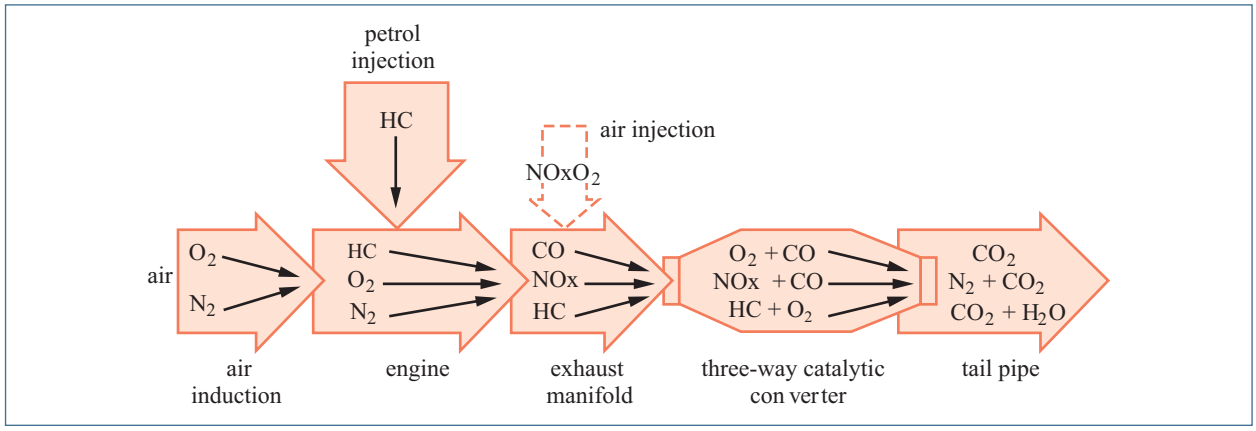


Figure 33.13 Chemical conversion path

manifold or the exhaust pipe. The pump is mounted on the engine and typically driven by a belt, similar to a power steering pump (Figure 33.15). The air is initially delivered to the exhaust manifold, but when the vehicle warms up to operating temperature an air diverter valve redirects it to the exhaust pipe in front of the catalytic converter.

33.5.6 Diesel engine SCR systems

Selective catalyst reduction (SCR) is used in commercial diesel engines (trucks). It uses an additive known in Australia as AdBlue or diesel exhaust fluid (DEF). This is aqueous urea which is injected into the exhaust system. It then becomes ammonia which reacts with NOx to reduce it to oxygen and nitrogen.

33.6 Engine management

Engine management provides a greater and more precise control of the systems and components that operate in the vehicle. Development has generally been directed towards vehicle performance and economy, but there is emphasis on the control of emissions to comply with anti-pollution regulations.

The engine management system controls the air–fuel mixture and the ignition to achieve the most complete combustion possible within the combustion chamber. Modern vehicles utilise a variety of sensors and ECU-controlled actuators to achieve a high level of control of the combustion process.

33.6.1 Electronic ignition

As the ECU controls the ignition system, it can provide the best setting for various engine conditions. Spark advance is needed to obtain the maximum benefit from the fuel charge. However, there are some conditions, such as idle and slower speeds, or when the engine is cold, where a slightly retarded spark will reduce emissions. The ECU controls the spark to provide the best ignition settings for all speeds and conditions.

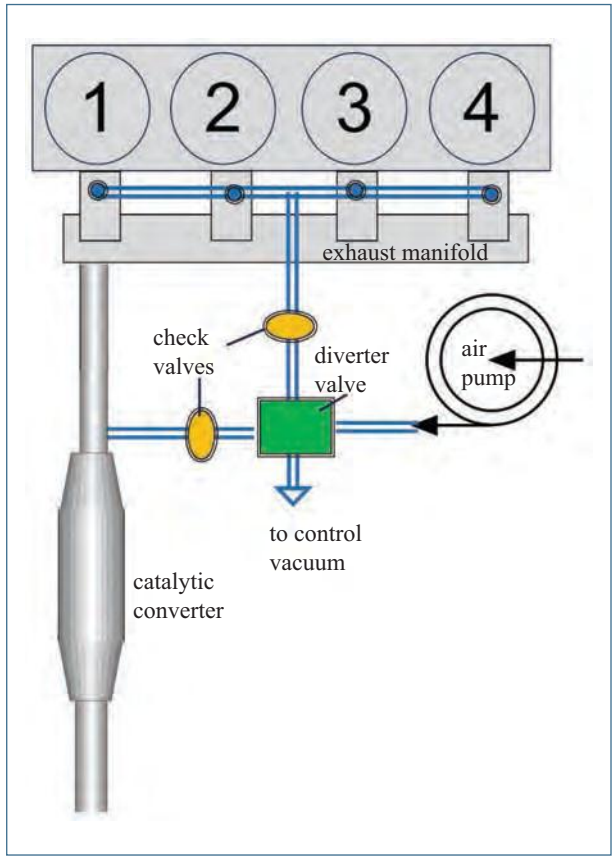


Figure 33.14 Air flow of an air pump

Figure 33.15 Air pump mounted on a Mazda RX7

Electronic ignition also helps reduce emissions because it can produce a spark that can jump the large spark plug gap required to ignite the leaner fuel mixtures that are used in more emission-compliant electronic fuel injection systems.

33.6.2 Electronic fuel injection (EFI)

Engines with electronic fuel injection and engine management systems have an electronic control unit (ECU) that can continuously adjust the injectors, enabling them to provide an accurate quantity of fuel to suit the various conditions of engine speed and load encountered by the vehicle. This gives more efficient combustion, reducing exhaust emissions.

With a closed-loop system, the oxygen sensor in the exhaust (Figure 33.16) provides continuous feedback, reporting the amount of the oxygen in the exhaust gas to the ECU. This enables combustion to be monitored at all times.

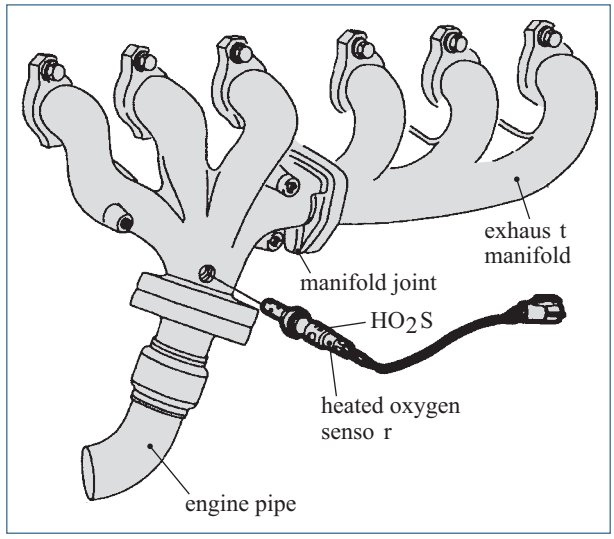


Figure 33.16 Oxygen sensor in the exhaust manifold FORD

Based on the information it receives from the oxygen sensor, the ECU varies the pulse width of the signals sent to the injectors. If the signal from the oxygen sensor indicates that the mixture is too lean, the pulse width to the injectors is increased, and vice versa. This method of control is shown in Figure 33.17.

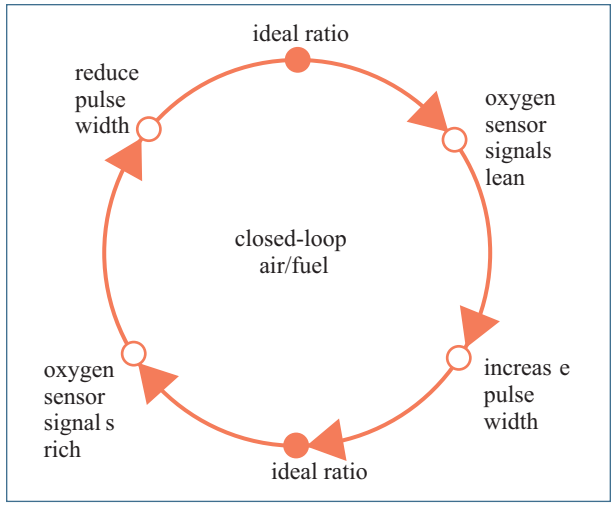


Figure 33.17 Closed-loop process for adjusting the air–fuel ratio FORD

33.7 Engine design

Engine management systems, with electronic ignition and electronic fuel injection, play a large part in emission control. The following are some other engine features that assist in the control of exhaust emissions.

33.7.1 Combustion chamber design

In the combustion chamber, burning of the air–fuel mixture starts at the spark plug and moves across the chamber, consuming the charge as it goes. Most of the particles of fuel are completely burnt, but some are not. The design of the combustion chamber can influence the amount of fuel that remains unburnt. This can be seen by comparing a wedge-shaped chamber with a hemispherical chamber. These are shown in Figure 33.18.

Wedge-shaped combustion chamber

In a wedge-shaped combustion chamber, burning starts at the spark plug at the side of the combustion chamber and moves across the chamber. A feature of this type of chamber is the *quench area*, a relatively cool section which reduces the temperature of the burning charge, preventing detonation.

However, the quench area is a disadvantage as far as emissions are concerned, because the cooler area can allow particles of unburnt fuel to collect on its surface. These are then exhausted as hydrocarbon emissions.

Hemispherical combustion chambers

A hemispherical combustion chamber has the spark plug located centrally so that burning can occur in all directions. There are no quench areas and there is less surface area. The ratio of the surface area of the combustion chamber to its volume is kept low for emission control purposes.

Hemispherical combustion chambers are designed to promote *swirl* during the intake stroke (Figure 33.19) so that the fuel will mix thoroughly and remain atomised. The location of the valve ports and the shape of the piston head also have a bearing on combustion chamber design.

Handy hint: Many cylinder heads are designed with some form of hemispherical-type combustion chamber .

33.7.2 Quench areas

All metal surfaces in the combustion space are possible quench areas on which some of the air–fuel mixture is likely to condense. These include the cylinder head, cylinder walls, pistons and piston rings. Uniform temperature of all these parts will aid combustion and reduce emissions. The engine-cooling system is designed to maintain uniform temperatures that are high enough to minimise quench areas.

33.7.3 Exhaust gas recirculation (EGR)

With EFI, hydrocarbon and carbon monoxide levels are greatly reduced. Oxides of nitrogen are produced by high combustion temperatures and so are present in an EFI engine; but they can be greatly reduced by an exhaust gas recirculation (EGR) system.

With an EGR, some of the exhaust gas is circulated back through the engine, but this is not to burn out any hydrocarbons that remain in the exhaust gas. The purpose is to add a non-combustible gas to the air–fuel charge to absorb heat. The exhaust gas, which is at a lower temperature than combustion temperature, absorbs some of the heat of combustion, reducing the temperature during the engine cycle. This in turn reduces the oxides of nitrogen (NOx) emissions that are produced as the result of high temperatures.

EGR valve

An EGR system is shown in Figure 33.20. Its operation depends on the engine load, engine speed, engine-coolant temperature and radiator-coolant temperature. The ECU has inputs from a number of sources and an output to the EGR solenoid of the vacuum switching valve (VSV).

The parts of the system function as follows:

1 EGR valve. Recirculates a portion of the exhaust gas.
2 Modulator valve . Modifies the vacuum acting on the diaphragm of the EGR valve .
3 ECU. Detects signals from the input sensors and operates the vacuum switching valve .
4 Ignition coil. Signals engine speed to the control unit.
5 Vacuum switching valve (V SV).Controls the vacuum line to the EGR valve .
6 Throttle sensor . Signals the throttle-valve opening to the ECU , so that exhaust gas does not recirculate at idle or at full throttle .
7 Coolant-temperature sensor . Signals the engine-coolant temperature to the ECU .
8 Thermo switch. Sends an off signal to the control unit when the radiator coolant is cold, and an on signal when it is warm.

Later-type EGR valves are electrically operated and electronically controlled by the engine's computer (Figure 33.21).

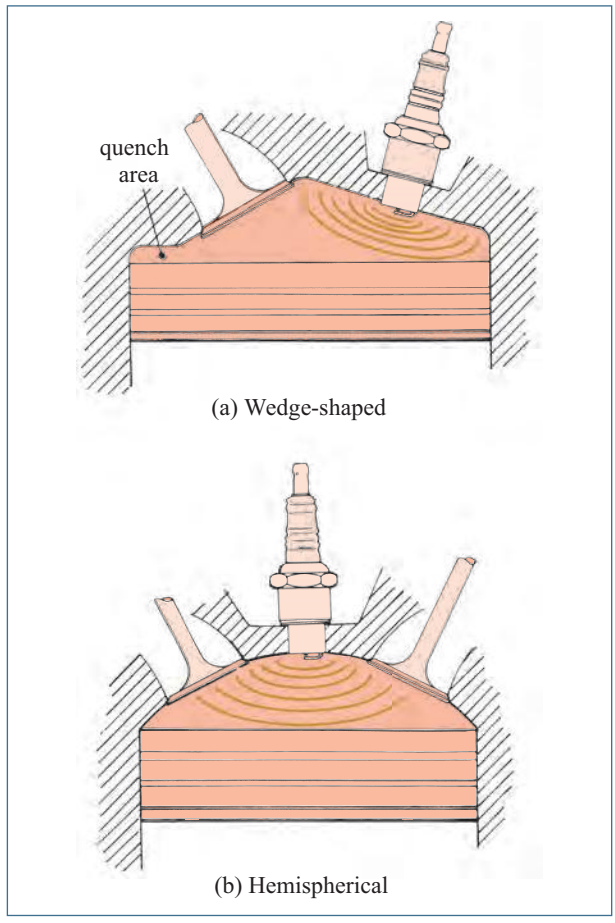


Figure 33.18 Combustion chamber designs

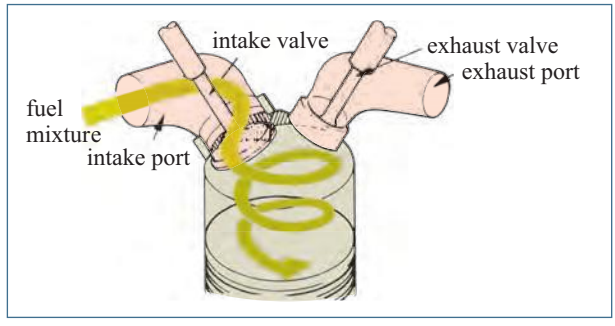


Figure 33.19 Combustion chamber designed to provide swirl FORD

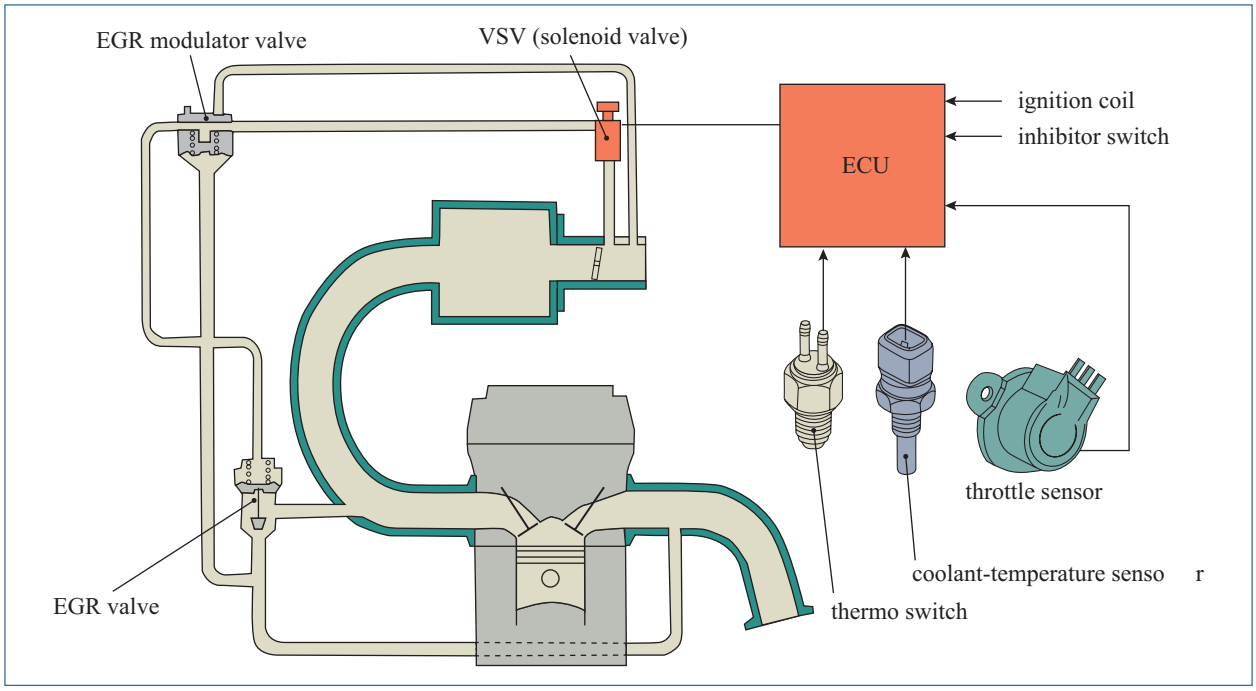


Figure 33.20 Exhaust gas recirculation system for an EFI engine

33.7.4 Valve overlap

During combustion, unburnt hydrocarbons can be trapped in the cylinder on quench areas and in crevices. These are released during the exhaust stroke as emissions, but are among the last of the exhaust gases to leave the cylinder.

The valve overlap has been changed on some engines to reduce the scavenging effect of the intake charge. This allows the unburnt hydrocarbons to remain in the engine where they can be burnt instead of being exhausted as hydrocarbon emissions.

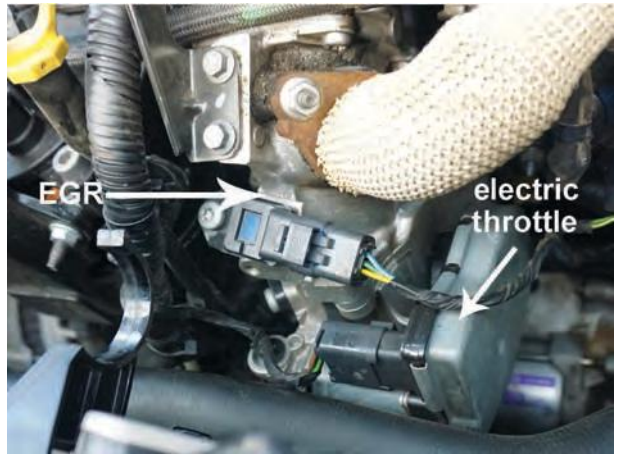


Figure 33.21 EGR valve mounted above an electric throttle control

33.7.5 Variable valve timing

Some engines with variable valve timing do not have a separate EGR system. Variable valve timing systems allow late closing of the exhaust valve, and this causes some of the burnt exhaust gas to be induced back into the cylinder. This occurs as the piston is moving on its downward (induction) stroke. In effect, some exhaust gas is being recycled. By using the ECU to control the exhaust gas recirculation via the valve timing, these engines do not need a separate EGR valve.

33.8 Other emission-system devices

There are a number of different devices used in emission control systems. Some have been mentioned already, but there are a few others, and these will now be considered. (Some of the devices could have alternative names to those used here.)

33.8.1 Coolant-temperature switch (thermo switch)

Coolant temperature can be used to operate an electrical switch, as in Figure 33.22 where the switch is screwed into the water-jacket with its end in contact with the coolant. When the coolant temperature increases, the wax element expands and closes the switch contacts.

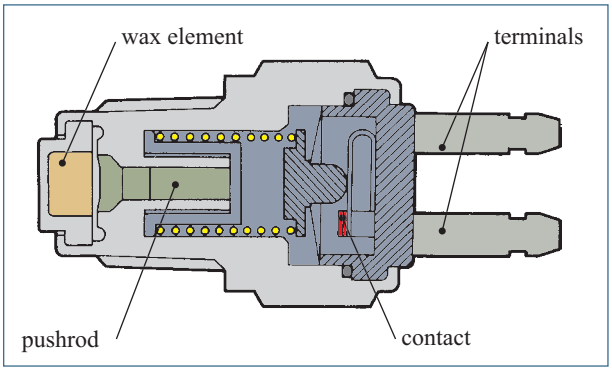


Figure 33.22 Thermo switch with a wax element

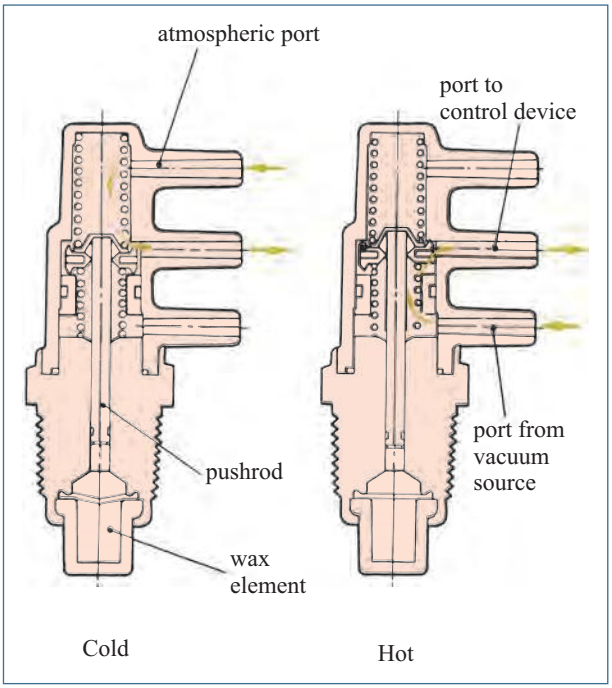


Figure 33.23 Coolant-sensitive valve , or thermo valve FORD

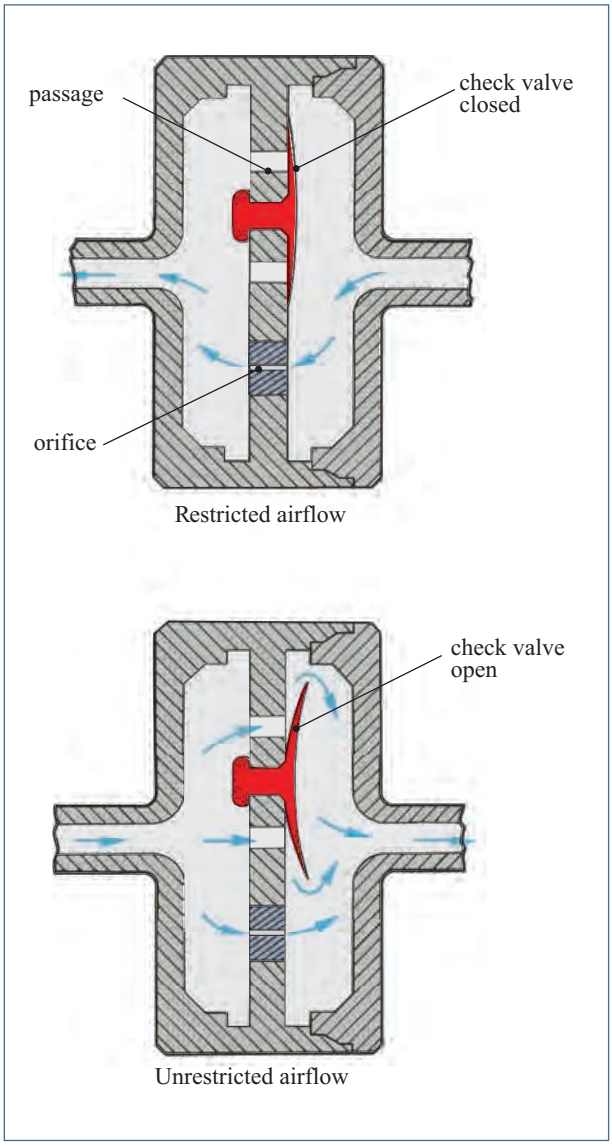


Figure 33.24 Vacuum delay valve FORD

33.8.2 Coolant-sensitive valve (thermo valve)

A coolant-sensitive (or thermo) valve is shown in Figure 33.23. Screwed into the coolant system, it has three ports and an internal valve which is operated by a wax element. The top port is open to the atmosphere, the centre port is connected to an emission control device, and the bottom port is connected to the intake manifold from which it receives vacuum.

When the engine is cold, the centre port is open to the atmospheric port and the device does not operate. When the engine warms up and the coolant temperature increases, the wax element expands. This closes the atmospheric port and opens the vacuum port to operate the control device.

33.8.3 Vacuum delay valve

A vacuum delay valve is shown in Figure 33.24. The valve is inserted into a vacuum line to delay the effect of vacuum on an emission device and has a divided chamber, with an orifice and a check valve between them. When used as a delay valve, the check valve is closed and flow is restricted to the orifice.

If the valve is reversed in the vacuum line, it becomes a sustain valve—the check valve will open and the valve will operate without restriction.

Handy hint: Valves that operate on this principle are also referred to as vacuum control valves .

33.8.4 Solenoid valves

Solenoid-operated vacuum valves are used in some systems. These can be operated by switches on the clutch or transmission. On some EFI engines, the EGR valve is operated by a solenoid which is controlled from the ECU (see Figure 33.25).

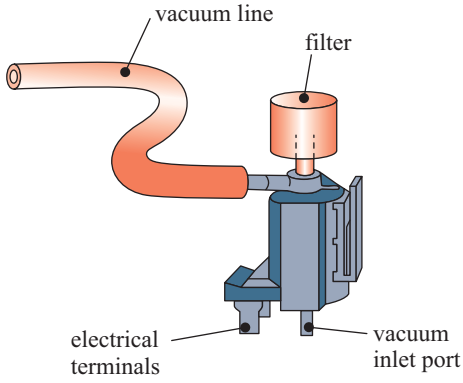


Figure 33.25 Solenoid-operated vacuum control valve

33.9 Emission standards

The standards for emission control are set out in the *Australian Design Rules* for vehicle-emission control.

The standards apply to new vehicles, including petrol and diesel cars, all goods-carrying vehicles, buses, larger motor tricycles and off-road vehicles. Smoke emission standards—known as ADR30/00—were introduced in 1976 for vehicles with four or more wheels powered by diesel engines. The requirements for heavy vehicles that run on LPG or CNG are the same as those that run on diesel. The ADR regulations are set out in Tables 33.1 and 33.2, and the emission standards in Table 33.3.

There are complex requirements for testing and collecting emissions during specified tests. The rules set out levels of emissions that must not be exceeded. For evaporative emissions (hydrocarbon fuel vapour), the levels are stated in *grams per test.* For exhaust emissions, the maximum levels for hydrocarbons, carbon monoxide and oxides of nitrogen are stated in *grams per vehicle kilometre.*

The design rules do not specify how the levels of emissions are to be achieved, so each model of engine and motor vehicle has its own modifications and systems to assure compliance. The rules require every motor vehicle to have a label fixed in a readily visible position in the engine compartment. The label must state the engine tune-up specifications and adjustments, including idle speed and ignition timing.

As emissions standard Euro 5 is current, ADR79/04 is in force for light vehicles and ADR80/03 is in force for heavy vehicles. Euro 6 for light vehicles and Euro VI for heavy vehicles were under review at time of publication.

Table 33.1 Vehicle emission standards from 2002/03 passenger vehicles

ADR Categories		ECE	ADR	02/03 Diesel	03/04 Petrol	05/06 Petrol	06/07 Diesel	07/08 Diesel	08/10 Petrol	10/11 Petrol	10/11 Diesel	13/16 All	17/18 All
GVM	Cat												
Less than 3.5t	MA MB MC	M1	ADR 79/	Euro 2	Euro 2	Euro 3	Euro 4		Euro 4			Euro 5d	Euro 6
More than 3.5t			ADR 80/	Euro 3	US 96	US 98		Euro 4		Euro 4		Euro 5d	Euro 6

The categories above are:

MA—passenger vehicle
MB—forward control passenger vehicles
MC—off-road passenger vehicles

Table 33.2 Applicable ADR regulations for light vehicles below 3.5 GVM

Euro 2/4 stage	Euro 5/6 stage
ADR79/00	ADR79/03
ADR79/01	ADR79/04
ADR79/02	ADR79/05

Table 33.3 Summary of emission requirements for new petrol passenger vehicles in Australia

Standard	Date Introduced	Exhaust emission limits				Test method
		HC[3]	CO	NOx	PM	
ADR26	1/1/72	NA	4.5% by vol	NA	NA	Idle CO test
ADR27	1/1/74	8.0–12.8 g/test	100–220 g/test & 4.5% by vol	NA	NA	ECE 'Big Bag'
ADR27A	1/1/76	2.1 g/km	24.2 g/km	1.9 g/km	NA	US '72 FTP
ADR27B	1/1/82	2.1 g/km	24.2 g/km	1.9 g/km	NA	US '72 FTP
ADR27C	1/1/83	2.1 g/km	24.2 g/km	1.9 g/km	NA	US '72 FTP
ADR37/00	1/2/86	0.93 g/km	9.3 g/km	1.93 g/km	NA	US '75 FTP
ADR37/01	1/1/97-1/1/99	0.26 g/km	2.1 g/km	0.63 g/km	NA	US '75 FTP
ADR37/00	1/1/03-1/1/04	0.25g/km	2.2 g/km	0.25g/km	NA	UN R83/04 (Euro 2)
ADR79/01	1/1/05-1/1/06	0.2 g/km	2.3 g/km	0.15 g/km	NA	UN R83/05 (Euro 3)
ADR79/02	1/7/08-1/7/10	0.1 g/km	1.0 g/km	0.08 g/km	NA	UN R83/05 (Euro 4)
ADR79/03	1/11/13	0.1 g/km 0.068 g/km (NMHC)	1.0g/km	0.06 g/km	0.0045g/km	UN R83/06 (Euro 5)
ADR79/04	1/11/16		1.0g/km	0.06 g/km	0.0045g/km	UN R83/06 (Euro 5)

Handy hint: To find out more about ADRs, go to https://www.legislation.gov.au/ Under the principal 'in force' tab, click on 'Ve' (for 'vehicle'). The ADRs will be listed on the screen and can be opened individually.

33.9.1 Workshop tests

To check the emissions output from a vehicle, a five-gas analyser is the most useful tool. It can measure:

- Hydrocarbons (HC) —parts per million (ppm).
- Carbon monoxide (CO)—percentage of total exhaust gases.
- Carbon dioxide (CO_2)—percentage of total exhaust gases.
- Oxygen (O_2)—percentage of total exhaust gases.
- Oxides of nitrogen (NOx)—parts per million (ppm).

Some analysers measure factors such as air–fuel ratio (AFR) and lambda (λ) (see Figure 33.26).

The concentration and ratios of these gases indicate how well the various systems and components in the vehicle are operating. There are two-gas analysers (HC and CO), three-gas analysers (HC, CO and CO_2), four-gas analysers (HC, CO, CO_2 and O_2) and five-gas analysers (HC, CO, CO_2, O_2 and NO).

Figure 33.26 The OPUS 40-D gas analyser © MOUNT AUTO EQUIP

Hydrocarbons (HCs) are straightforward molecules of unburnt fuel. A relatively larger amount of HCs after the combustion event suggests a misfire (where the mixture is not unignited) or the engine is over-fuelling. Carbon monoxide (CO) suggests partially burnt mixture that did not receive enough oxygen for

complete conversion into CO_2. The ideal, and theoretically perfect, combustion is an exhaust gas that only produces carbon dioxide (CO_2) and water (H_2O), so a high carbon dioxide reading is a good measure of combustion efficiency. High HC in the exhaust gases is primarily caused by ignition faults; high CO is caused by richer fuel mixtures or associated faults. A gas reading should not be examined in isolation; all the readings should be balanced. The analyser can then be used to confirm that faults have been corrected.

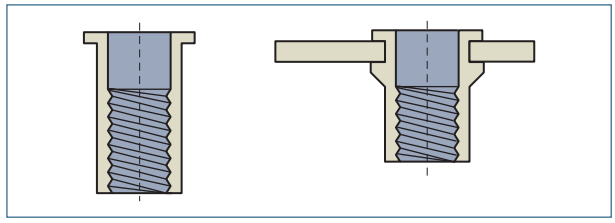


Figure 33.27 Rivnuts (a) as supplied (b) compressed into exhaust engine pipe section

The exhaust gases are sampled by means of a probe fitted into the exhaust system. If the vehicle does not have a catalytic converter, the sampling probe is inserted into the end of the tailpipe. If the vehicle does have a catalytic converter, the probe must be fitted upstream from it to obtain a true sample of the exhaust gases being discharged from the engine. (If the gas is sampled downstream from the catalytic converter, it will already have been treated by the catalyst, and only oxygen readings may be used for analysis of engine mixtures.) A *rivnut* tool (Figure 33.27) can be used to insert a small threaded sleeve into the engine pipe ahead of the catalyst, and an adaptor can connect the gas analyser probe directly to the exhaust. Care should be taken to avoid metal swarf entering the catalytic converter. High oxygen readings indicate lean mixtures, while low oxygen readings indicate rich mixtures. The normal range for oxygen readings is between 0.5% and 2%. Table 33.4 shows typical upstream exhaust gas samples for an indirect petrol-injection engine at idle, cruise and wide-open throttle (WOT).

Table 33.4 Typical exhaust gas analyser results tak en upstream of a catalytic converter

Gas	Idle	Cruise	WOT
CO	1–1.5%	0.5–1.0%	1.5–2.5%
O_2	0.5–1.5%	1–1.5%	0.5–1%
CO_2	14%	15–16%	13–14%
HC	100 ppm	<100 ppm	<200 ppm

Once the gas readings are taken and the fault is confirmed and fixed, a small bolt with anti-seize compound and a copper sealing washer are used to plug the rivnut hole.

The individual vehicle service manual will provide guidance if the emission readings do not comply with the manufacturer's specifications. Emission regulations have been introduced progressively over a number of years, each more stringent than the previous set and necessitating many changes to emission control systems.

For diesel engines, a separate smoke opacity tester is required. This measures particulate matter (PM), which consists of small particles of carbon.

33.10 Servicing emission controls

Normal tune-up services will maintain engine performance and prevent emissions that could be caused by fuel leaks, incorrect adjustments, sticky controls or incomplete combustion. However, faulty spark plugs, weak ignition, hard starting, poor idle and loss of power can all produce excessive emissions.

The self-diagnosis facility of the engine management system can be used for checking sensors, many of which are common to the EFI system and to emission control.

33.10.1 Electrical connections

Connections to sensors should be firmly attached. This is important with electronic controls, where low-voltage signals are used. Poor connections will produce problems.

33.10.2 Charcoal canister

The charcoal canister can be renewed if it appears to be ineffective, or if the purge valve is not functioning. This could upset engine idle. The purge valve can be tested with a hand-operated vacuum pump. Figure 33.28 shows a purge valve that is integral with the canister. Separate purge valves can be tested in a similar way.

A hand vacuum pump is also used to test other vacuum valves and solenoid-controlled vacuum valves.

33.10.3 PCV valve check

To check a positive crankcase variation (PCV) PCV valve, remove it from the rocker cover. With the vacuum line still connected, run the engine at idle. Check for vacuum with a finger or thumb over the end of the pipe, as shown in Figure 33.29(a).

With the valve removed and the engine stopped, check the plunger in the valve for sticking by shaking the valve. Also, carefully insert a thin rod into the end of the valve, as shown in Figure 33.29(b). If the valve is not stuck, the rod should be able to move the valve backwards and forwards against its spring.

33.10.4 EGR valve

Exhaust gas recirculation EGR valves were fitted to engines when emission controls were first introduced. After falling out of favour, they have enjoyed a renaissance due to the need to further reduce emissions. This has proved troublesome, particularly for light vehicles with diesel engines. The exhaust gas that is returned to the inlet manifold contains soot and some oil fumes as it has not passed the particulate filter. These fumes can cause a build-up in the inlet manifold and restrict the airflow on the inlet side. The best remedy is to have the inlet manifold cleaned in an ultrasonic bath. (Many products claim to clean the inlet manifolds, but they are of limited effectiveness, and the cleaned carbon and sludge material still has to pass through the engine.)

If the EGR valve is accessible on the engine, it can be checked by feel (see Figure 33.30). Alternatively, connect a vacuum hand pump (Figure 33.31). When the engine is cold, the diaphragm should not move.

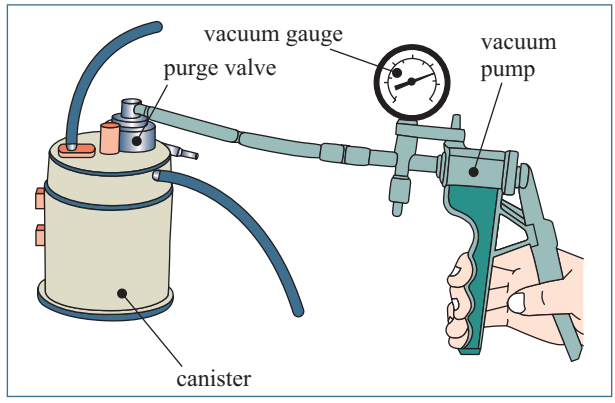


Figure 33.28 Using a hand vacuum pump to check the purge valve of a charcoal canister

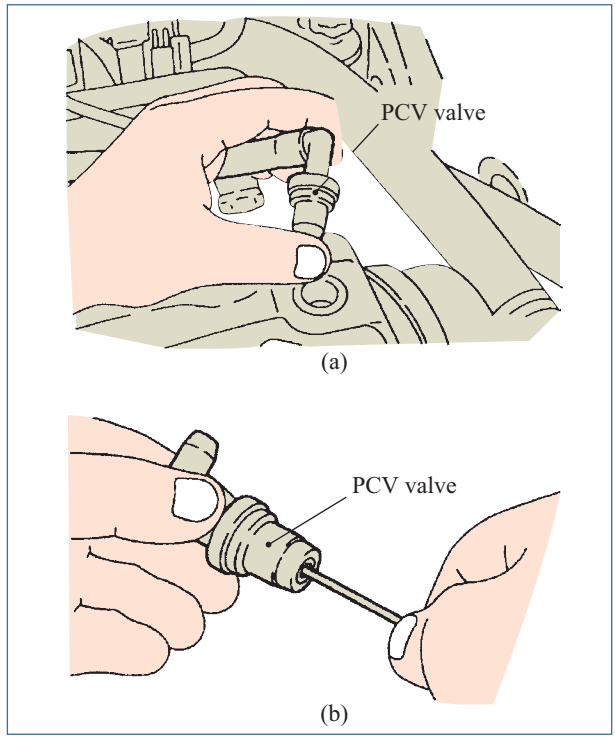


Figure 33.29 PCV valve (a) checking vacuum (b) checking the valve MITSUBISHI

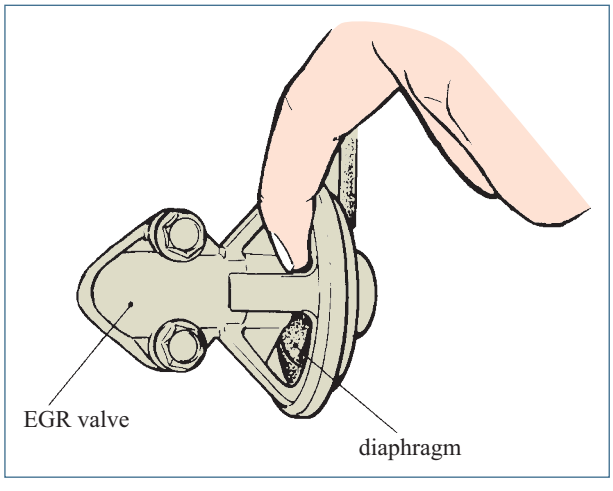


Figure 33.30 Checking the operation of an EGR valve GM HOLDEN LTD

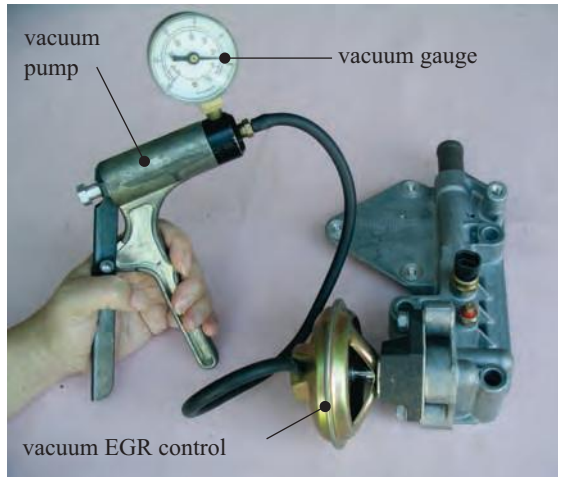


Figure 33.31 A hand vacuum pump being used to test the vacuum diaphragm on the EGR valve

When the engine is warm, the diaphragm should move away during acceleration and return during deceleration.

33.10.5 Electronically controlled EGR valve checks

The operation of electronically controlled EGR valves can be checked via a scan tool or a multimeter check at the control unit (the engine will need to be warmed to operating temperature). The control device is usually managed by a step motor, and the ECM will send pulses between 0.1 and 14 volts. To identify the correct wires, voltage and operating conditions, consult the relevant manual.

Generally, EGR valves do not operate when:

- the engine is stopped
- the engine is being started
- the coolant temperature is low or ex cessively high
- the engine speed is high
- the throttle is wide open .

33.10.6 Thermo valves

Valves and switches that are operated by coolant temperature can be immersed in a container of water and heated. Figure 33.32 shows a thermo valve that switches vacuum. With vacuum-switching valves, ports should generally be closed when cold and opened when hot. With thermo valves that include an electrical switch, the switch operation can be checked with a test lamp or ohmmeter.

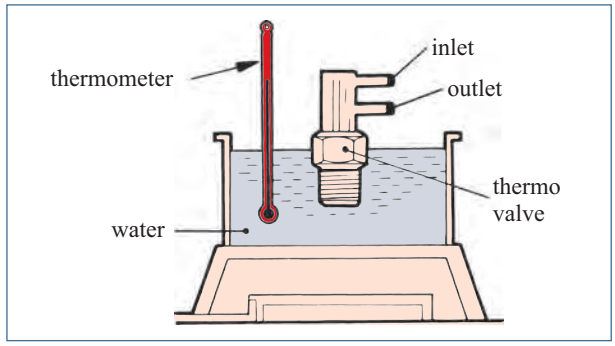


Figure 33.32 A thermo valve can be check ed by being heated in water—the outlet port should be open only when hot GM HOLDEN LTD

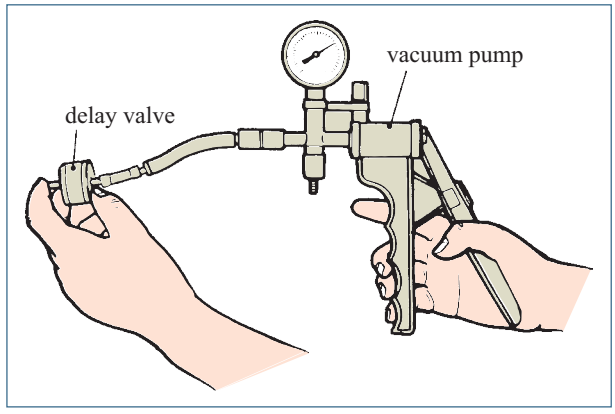


Figure 33.33 Checking the operation of a vacuum delay valve GM HOLDEN LTD

33.10.7 Vacuum valves

Vacuum delay valves and similar valves (which may have different names) can be checked by applying vacuum to the valve ports (Figure 33.33). Air should be drawn in easily when vacuum is applied to one port, but should be restricted when applied to the other port.

33.10.8 Vacuum lines

All vacuum lines should be checked for condition and leaks. Even a small leak at a connection, or one caused by faulty tubing, will upset the operation of the vacuum control.

33.10.9 Catalytic converter checks

Catalytic converters may sometimes become restricted in exhaust flow due to excess oil consumption, the wrong fuel or rich mixture caused by faulty injectors. If a catalytic converter is blocked or not performing, a fault code will be raised. The symptoms are similar to those of incorrect valve timing—poor performance, poor fuel economy, altered transmission speed changes, backfiring through the inlet manifold and stalling. Depending on the EGR valve design, it may also trick the EGR valve to recycle excessive amounts of exhaust gas.

There are two ways to test the catalytic converter for restrictions:

1 Remove the air–fuel sensor and the HO $_2$ sensor and place a pressure gauge in each (Figure 33.34). A heat-resistant line to the gauge will be needed. Run the engine at 2500 rpm and tak e a reading. There is no fixed pressure for all vehicles, but it should be lower than 20 .68 kP a or 3 psi before the converter and a bit

less after . If the converter needs to be replaced, establish the cause of the fault to avoid repeated damage . Retest after fitting a new converter and record the information for future reference .

2 Start the engine and increase its speed to appro ximately 2500 rpm, holding it there until the catalytic converter heats up , then return it to idle speed. Immediately measure the inlet and outlet temperature with an infrared temperature meter . The outlet should be 40°C hotter than the inlet. A lesser temperature difference than 40°C indicates a reduction of converter efficiency .

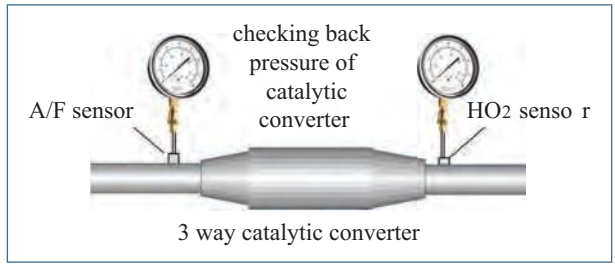


Figure 33.34 The connection of a pressure gauge to the exhaust system to check back pressure

Lambda sensors and air–fuel sensors

A lambda sensor is also referred to as an *oxygen sensor* or *O_2 sensor*. This is because it measures the oxygen in the gas flowing from the engine in comparison with that in the atmosphere, which indicates how well the fuel has burnt. The are several types of sensors and two methods of operation in the computer system: open loop and closed loop (Figure 33.35). The first sensors were manufactured in the 1960s, and three decades later the planar-style sensor became available. Relatively small, the planar was heated, giving a faster response; this was important as catalytic converters can only work effectively in a narrow range of air–fuel mix. The sensor gives a low voltage reading (200 mV, for example) if the mixture is lean as there is more oxygen in the gas. A rich mixture will give a higher voltage reading (for example, 800 mV). The voltage output fluctuates from lean to rich as the computer continually adjusts the injector output. Lambda (λ) has a value of 1, which represents stoichiometric air–fuel ratio.

In an open loop system, the ECU compares the output of the sensor in conjunction with other sensors against a map held in its program. In a closed loop system, a sensor takes a measurement before the catalytic converter and another after the main converter. This allows the ECU to provide a more accurate fuel mix before the gas enters the catalytic converter.

33.10.10 Diesel engine particulate filter testing and servicing

To check whether a particulate filter needs servicing, attach a scan tool and check for any fault codes. If the vehicle cannot clear the filter by performing a ‘burn off’, a warning message and/or a fault code will appear. If the filter is excessively blocked, it will need either to be cleaned by specialists or replaced.

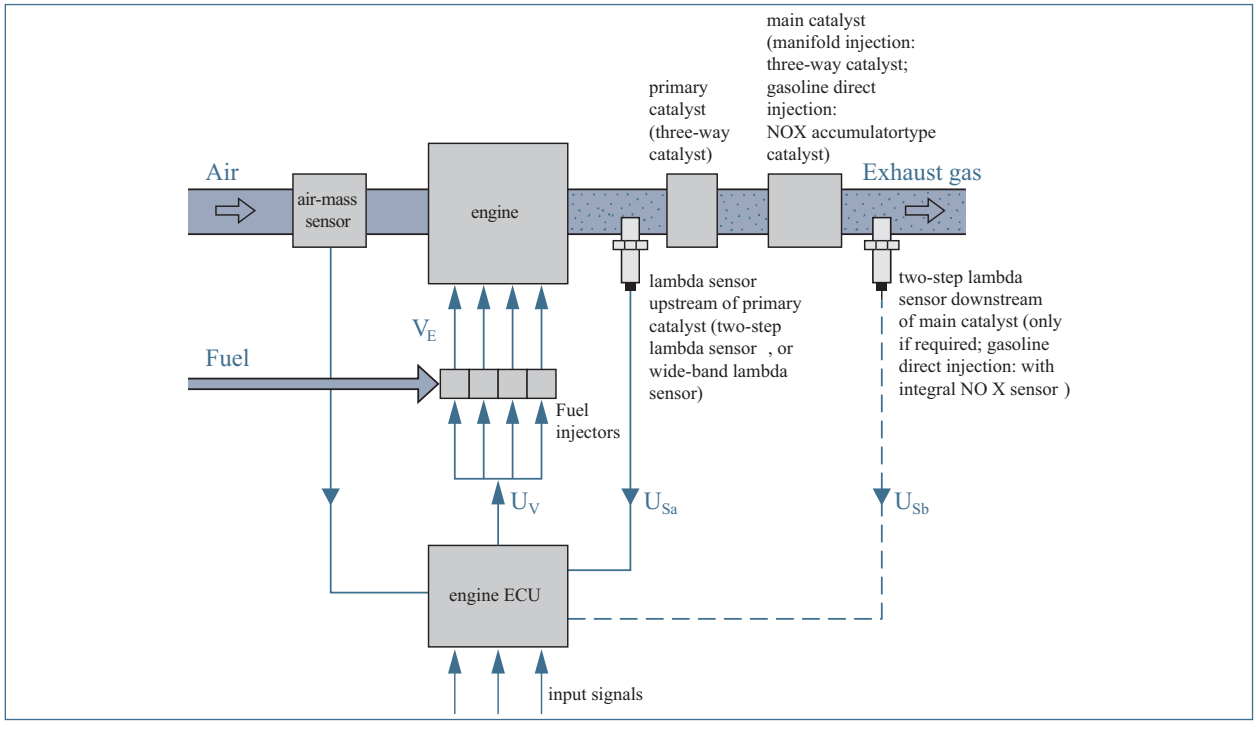


Figure 33.35 Closed loop control system

While in service, particulate filters will self-clean when exhaust temperatures reach 300°C, if the engine is performing correctly. Particulate filters (Figure 33.36) will block from excessive oil consumption, long periods of heavy throttle (excess fuel) or faulty injectors. Depending on the vehicle, the ECM can provide a *passive burn* or an *active burn*. This is possibly due to the filter being made of platinum or palladium, which acts as a catalyst, enabling a flameless burn at a lower temperature of 300°C. This allows the burn-off to happen within the operating temperatures of the exhaust system. An active burn is where fuel is injected into the filter and ignited while the vehicle is stationary. This method will raise the burn temperatures to 650°C and turn the particulate matter to soot. It is generally only fitted to commercial vehicles.

Sustainability: Never try to clean a particulate filter as the content is carcinogenic. This should only be done by specialists with the appropriate equipment.

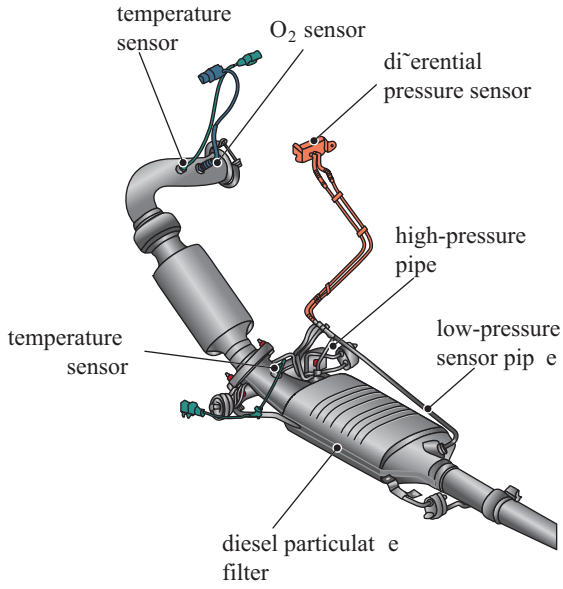


Figure 33.36 The combination of a catalytic converter and particulate filter as fitted to a diesel engine in a passenger vehicle

33.10.11 Diesel engine SCR systems

The selective catalytic reduction system (Figure 33.37) requires air sourced from a compressor and air tank reservoir to the delivery module. The delivery module also receives the AdBlue® (reducing agent) from the AdBlue tank. The delivery module contains a filter, diaphragm pump, overflow valve and pressure regulator. The AdBlue is delivered under pressure of 3.5 bar to the dosing module. Separate air pressure

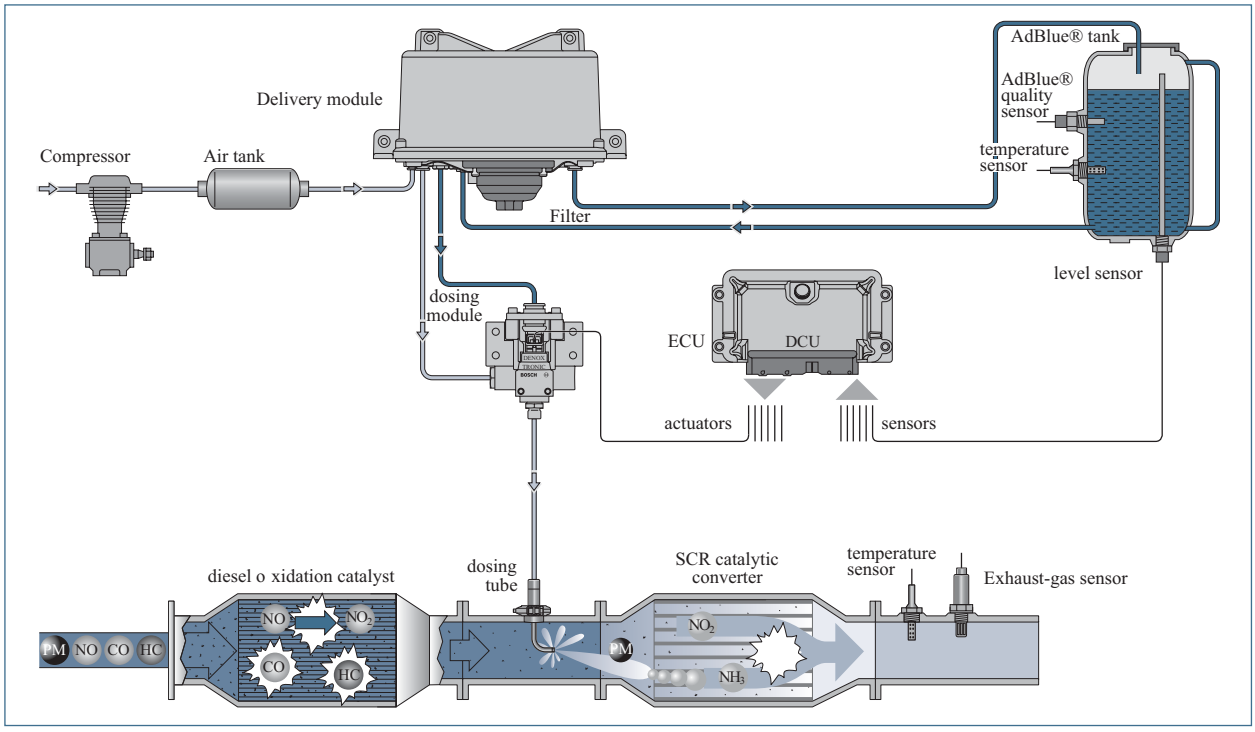


Figure 33.37 SCR system

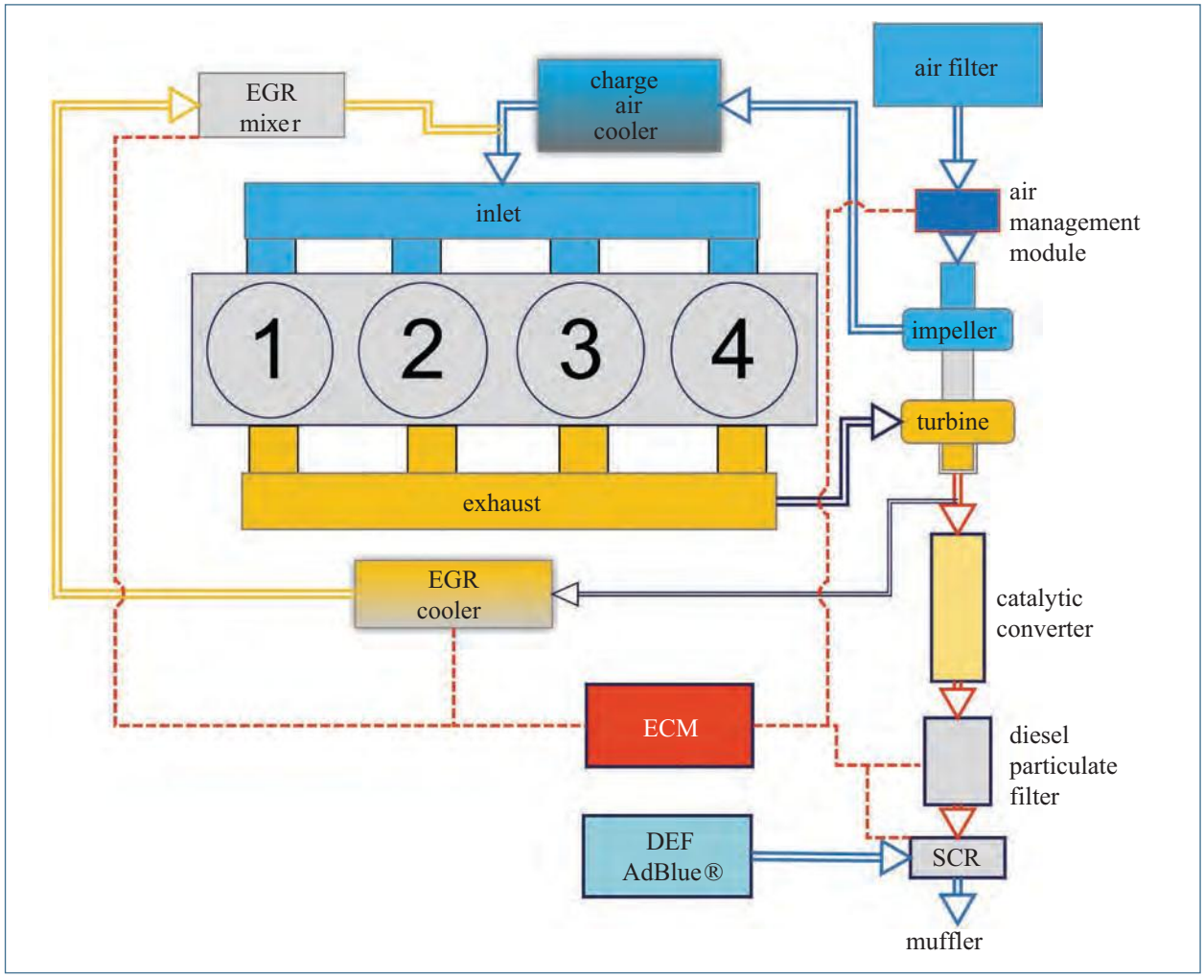


Figure 33.38 The air flow in an SCR system

is delivered to the dosing module. The urea (AdBlue)/water is metered precisely in the dosing module and mixes with compressed air through a venturi in the dosing module. The AdBlue with air forms a form of aerosol in to the dosing tube entering the exhaust system. The mix evaporates quickly reaching all parts of the exhaust tube. The (Diesel control unit) DCU monitors all functions of the engine and exhaust and operates the dosing module to deliver the correct amount of solution as required. The AdBlue acts as a catalyst to reduce exhaust emissions further.

Air flow in an SCR enters the air filter into the turbocharger impellor via an air management module (Figure 33.38). From the turbocharger impellor the air is cooled through the charge air cooler (intercooler) and enters the engine.

On the exhaust side the exhaust from the engine enters the turbo charger driving the turbine to pump the air in the intake side. From the turbine some exhaust is diverted to the EGR cooler and then to the EGR mixer. The mixer is controlled by the ECM (engine control module) or DCM (diesel control module). The main exhaust enters the catalytic converter and then the particulate filter. The particulate filter is monitored by the ECM. From the diesel particulate filter the exhaust enters the SCR (selective catalytic reduction) system which is also managed by the ECM. At the SCR system AdBlue is added to reduce the emissions further by a computer controlled dosing module.

33.10.12 Diesel engine SCR system checking

DEF systems are controlled by a dosing module and can be checked using a scan tool that has the correct software for the vehicle. An SCR system and the path of air through it are shown in Figures 33.37 and 33.38.

33.11 Diagnosis guides

As there are a number of different emission control systems and many variations of those, reference to the appropriate service manual is essential. Table 33.5 is a diagnosis guide for crankcase emissions. Table 33.6 is a general diagnosis guide for possible conditions that relate to evaporative emissions. Table 33.7 shows carbon monoxide and hydrocarbon readings, problems and possible causes for irregular readings.

Table 33.5 Diagnosis chart for crank case emission problems GM HOLDEN LTD

Condition	Probable cause	Corrective action
Rough, slow idle or stalling	PCV valve block ed Blocked or damaged ventilation hose	Clean valve or replace Clean or replace hose
Rough, fast idle or stalling	PCV valve stuck in intermediate position PCV valve leaking	Clean valve or replace Check valve ' O' ring, replace if necessary Check valve installation
Excessive sludging or diluting of oil	Engine is not being vented	Check of clogged PC V valve circuit and clogged ventilation circuit

Table 33.6 Diagnosis chart for evaporative emission problems GM HOLDEN LTD

Condition	Probable cause	Corrective action
Loss of fuel from filler cap	Unsatisfactory sealing between cap and filler neck Malfunction of filler cap relief valve	Replace filler cap Replace fuel tank if filler neck is damaged Replace filler cap
Loss of fuel from fuel lines	Loose line connection Faulty or leaking vapour separator	Secure connection Replace
Loss of fuel from canister	Fuel tank overfilled When the fuel warms up during parking or warm weather operation, ex cess fuel is discharged into the canister , flooding it Kinked hoses at filler neck and vapour separator reservoir Blocked, damaged or disconnected purge valve at canister	Avoid overfilling of tank Clean line—replace damaged line Install correctly Replace canister
Collapsed fuel tank or pressure in tank	Faulty fuel filler cap (in high temperature operating conditions some pressure may normally be encountered in the fuel tank) Kinked hoses at filler neck and vapour separator reservoir Blocked or kink ed vent line Defective canister (internally block ed) Purge solenoid valve is closed, causing canister to become overloaded	Replace filler cap Clean line—replace damaged line Replace canister Check electrical circuit Replace valve
Rough idle	Improperly routed or disconnected purge line Purge solenoid valve is open or not receiving power	Install purge line Check electrical circuit Replace valve

Table 33.7 Diagnosis chart for exhaust emission problems GM HOLDEN LTD

CO	HC	Problems	Causes
Normal	High	Rough idle	1. Faulty ignitions: incorrect timing; fouled, shorted or improperly gapped plugs; open or crossed high-tension cords; crack ed IIA cap 2. Incorrect valve clearance 3. Leaky intak e and exhaust valves 4. Leaking cylinder
Low	High	Rough idle (fluctuating HC reading)	1. Vacuum leaks: PC V hose; intak e manifold; throttle body; ISC valve; brak e booster line 2. Lean mixture causing misfire
High	High	Rough idle (black smok e from exhaust)	1. Restricted air filter 2. Faulty EFI systems: faulty pressure regulator; clogged fuel return line; defective water temp . sensor; defective air temp . sensor; faulty ECU; faulty injector; faulty throttle position sensor; defective vacuum sensor

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- describe how motor vehicles create pollution
- describe the controls used to reduce or eliminate pollution from the engine , fuel tank and exhaust in a motor vehicle
- describe engine emissions from the combustion process and how they are reduced
- explain the function of a catalytic converter
- identify two- and three-way converters
- explain how air injection, EGR and SCR systems reduce emissions
- explain how engine management helps reduce emissions
- explain how engine design and devices such as coolant temperature switches help reduce emissions
- describe emission standards
- explain how emission outputs from an engine are measured
- describe and apply servicing emission control devices
- explain what a particulate filter is and how it is tested and serviced
- explain what a lambda sensor is and its function in the management of emissions
- apply the guidelines for diagnosis of emission control systems.

REVIEW QUESTIONS

1 What are emissions ?
2 Why do emissions need to be controlled?
3 Name the three sources of pollution from a motor vehicle .
4 What is evaporative-emission control ?
5 Explain why a charcoal canister is fitted.
6 What is a purge valve and how is it used?

7 How does a returnless fuel system tend to reduce evaporative emissions ?
8 What is crank case ventilation ?
9 What are crank case emissions ?
10 Explain the system that is used to control crank case emissions.
11 What type of emissions pass through the exhaust system ?
12 State some of the ways in which exhaust emissions can be reduced.
13 What is a catalyst ?
14 Why is a catalytic converter used?
15 Briefly describe what happens in a three-way catalytic converter .
16 In a three-way catalytic converter , what are HC, CO and NOx converted to ?
17 Compare the main chemicals that enter the engine with the chemicals that are exhausted from the engine .
18 Why is exhaust gas recirculation (EGR) used?
19 How does variable valve timing recirculate exhaust gas ?
20 What are the advantages of engine management as far as emission control is concerned?
21 Generally , describe how a vacuum control device is tested.
22 What are the basic servicing requirements for an evaporative emissions control system ?
23 Explain how a PC V valve would be check ed.
24 List the possible causes of rough idle on a vehicle that has normal CO and high HC readings.

CHAPTER 34

Diagnosis: petrol engines and other vehicle systems

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 describe diagnostic processes
2 identify diagnostic tools and how they are used
3 outline methods of gathering information
4 identify the limitations of diagnostic tools
5 state the limitations of workshop manuals
6 explain the difference between symptoms and causes.

34.1 Diagnosis

Diagnosis is the process of solving problems, also called *fault finding* or *trouble shooting*. It is a skill which needs to be developed so that problems are handled in a logical way. If a problem exists, guessing is not good enough; reasoning is required.

The basis of diagnosis is to consider all possible causes of the problem, and then to decide how to remedy it. Time should be invested in thinking about the problem as well as actually fixing it. When discussing a problem with the client, always use open-ended questions to gather as much information as possible. Do not rush into dismantling a component until you are satisfied that the diagnosis is complete; a little extra thinking time could save a lot of working time.

Handy hint: Workshop manuals include diagnosis guides and charts which should be used to identify the lik ely causes of a problem.

34.1.1 Logic-based diagnosis procedure

A problem should be fully identified before any corrective action is taken, and diagnosis should follow a logical sequence, such as:

1 Obtain as much information as possible about the problem. Example below .
Customer : My car will not start sometimes.
Technician : When does this happen ? (open-ended question)
Customer : Mostly in the morning, when I try to start it for the first time .
Technician : Does the engine crank over or does it mak e any noises ?
Do any of the accessories work when this happens ?
What work has been done to the vehicle ?
Has the vehicle been in any accidents lately ?

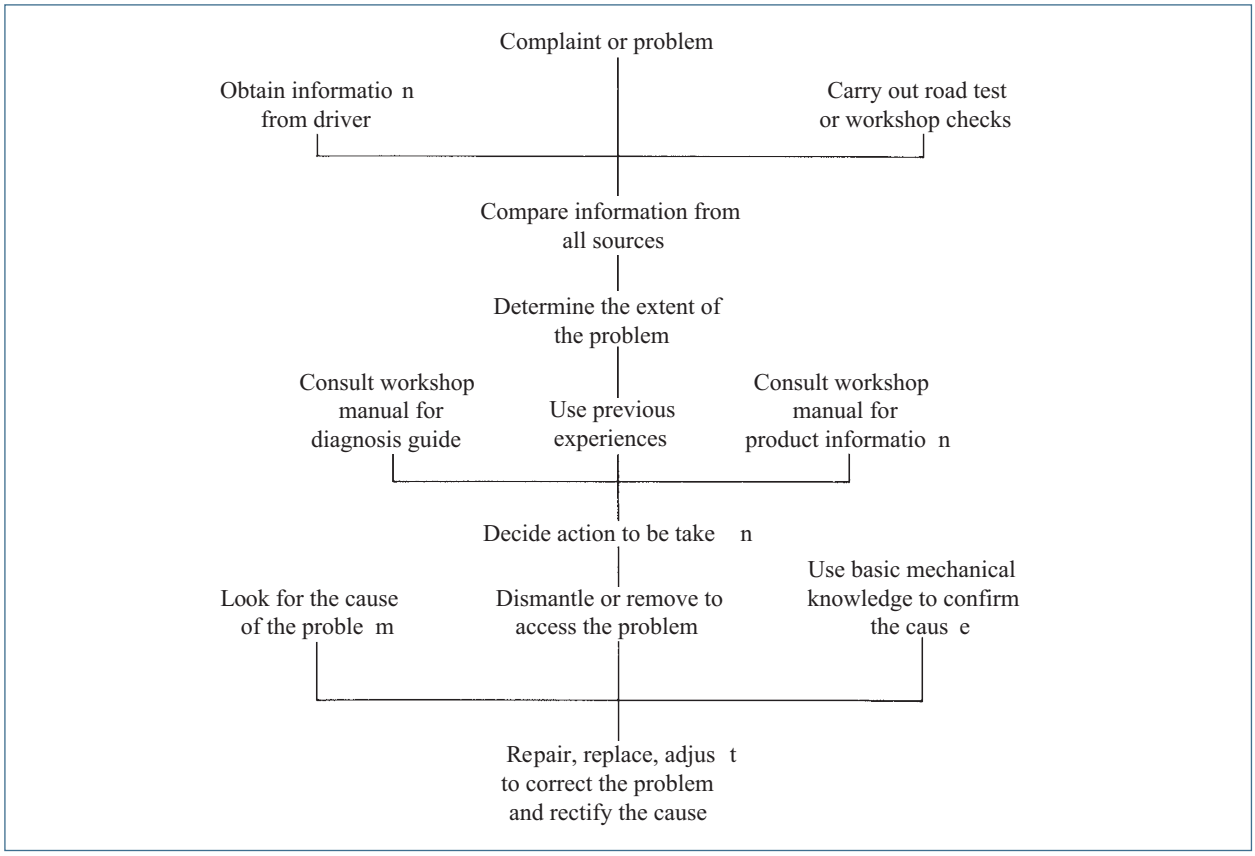


Figure 34.1 General diagnosis flow chart

2 Identify the problem
   - Look under the bonnet and examine the condition of the engine and surrounds, including wiring.
   - Check for fault codes.
   - Check the battery' s state of charge and condition.
   - Check the charging system for correct output.
   - Check the starter motor .
3 Consider all possible causes
   - Look for any obvious signs of damage under the bonnet or signs of accidents.
   - Check for current flow from the battery when the engine is not running.
4 Reduce these to the most lik ely cause or causes
   - Look at all the information that has been collected, including test results and customers ' answers.
5 Determine a probable solution

A probable solution will emerge from the information that has been collected and the testing. A problem such as the one in our example can be caused by many different faults, and testing each system (battery and connections, charging system and wiring, current drain when engine not running, etc) is more likely to find the fault.

A structured, logical sequence is set out in a simple flow chart in Figure 34.1. Item failure is often due to lack of correct maintenance or previous accidents, so include questions on these issues when obtaining information. In some cases, a client's description of a problem may not be clear due to their limited knowledge of mechanical systems.

34.2 Diagnosis chart

Workshop manuals provide diagnosis information in various ways, often in the form of a chart that can be a useful checklist. Table 34.1 is a general fault-diagnosis chart for petrol engines which lists complaints,

possible causes and checks or corrections. There are three general types of engine faults: electrical faults, fuel faults and mechanical faults. The headings that follow are the same as those in the complaint column of Table 34.1.

Table 34.1 Engine fault-diagnosis chart (petrol engines)

	Complaint	Possible cause	Check or correction
1.	Engine will not crank with starter	Dirty battery terminal Rundown battery Starting circuit open Starter motor Immobiliser	Clean terminals and posts Recharge or replace Locate and eliminate Remove for dismantling Scan and check faults
2.	Engine cranks over slowly but does not start	Rundown battery Defective starter motor Bad connections in starting circuit Also causes listed under item 3 (driver may have run battery down trying to start)	Recharge or replace Replace or repair Clean and tighten
3.	Engine cranks over at normal speed but does not start	Defective coil Ignition system defective Fuel system defective Fuel pump relay inoperative Air leaks in intak e manifold Engine faults	Replace Try spark; check timing and ignition system Check fuel pump pressure and flow , and filter Check fuse , relay and connections Tighten mounting; replace gask et as needed Check compression, valve action, timing etc
4.	Engine runs but one cylinder misfires	Defective coil/coil pack Defective spark plug Distributor cap or cable defective Stuck inlet/exhaust valve Valve adjustment Blown head gask et Faulty plug lead Faulty injector	Replace Clean or replace Replace Free valve—service stem and guide Adjust tappet Replace Replace Clean or replace
5.	Engine lacks power , acceleration or performance	Ignition defective Fuel system defective Throttle valve not opening fully Clogged exhaust Loss of compression Excessive carbon in engine Defective valve action Excessive rolling resistance from low tyres, dragging brak es, etc Engine overheats EGR defective Vapour lock Cooling system thermostat stuck Engine management sensor fault	Check timing, distributor , wiring, coil and plugs Check Injectors, air cleaner and fuel pump Clean throttle body and idle device Adjust linkage/cable Check tailpipe , catalytic converter and muffler Check compression or cylinder leakage Remove carbon, flush engine with carbon cleaner Check cylinder compression and cylinder leakage Correct the defect causing rolling resistance Check cooling system (see item 6) Clean/replace Check pump and residual fuel pressure Replace Renew
6.	Engine overheats	Lack of coolant Blocked radiator core Blocked radiator fins Corroded radiator fins Coolant leaks Loose or brok en fanbelt Defective thermostat Fan clutch faulty	Add coolant and check for leaks Clean or replace Clean Replace radiator Repair Tighten or replace Replace Repair

(continued)

Table 34.1 (continued)

	Complaint	Possible cause	Check or correction
		Electric fan inoperative	Check connections and coolant sensor
		Retarded ignition	Check ignition timing
		Clogged water-jack ets	Clean out
		Defective radiator or heater hose	Replace
		Defective water pump	Repair or replace
		Insufficient engine oil	Add oil
		Running lean	Correct fuelling problem
7.	Rough idle	Dirt in injector nozzles	Clean and bench test
		Malfunctioning crank case-ventilator valve on closed crank case system	Clean or replace
		Ignition timing	Adjust
		Air leaks at airflow sensor	Tighten—replace gask ets, seals or ducting
		Air leaks at manifold	Tighten—replace gask ets, injector seals
		Spark plug gap incorrect	Renew
		Clogged exhaust	Check exhaust system back pressure
		Vacuum leaks in emission -control devices	Check for leaks, and correct
8.	Engine backfires	Ignition timing incorrect	Adjust timing
		Spark plugs of wrong heat range	Install correct plugs
		Excessively rich or lean mixture	Repair fuel pressure regulator , clear block ed return
		Overheating of engine	See item 6
		Carbon in engine	Clean out, carbon cleaner flush
		Valves hot or sticking	Adjust, free , clean and replace
		Crack ed or dirty distributor cap	Replace cap and rotor
9.	Excessive oil consumption	External leaks	Correct seals; replace gask ets
		Burning oil in combustion chamber	Check valve-stem seals and connecting-rod bearings
		Engine wear	Check piston rings
		High-speed driving	Higher consumption possible at high speed
10.	Low oil pressure	Lubricating-system defects	Check oil lines, oil pump and relief valve
		Worn engine bearings	Replace
		Engine overheating	See item 6
		Oil dilution or foaming	Replace oil, check injectors
11.	Excessive fuel consumption	Type of operation	Check conditions
		High speed	Reduce speed
		Short-run operation	Higher consumption is normal
		Excessive fuel-pump pressure or pump leakage	Renew pressure reg.—repair return line , replace leaking pump/lines
		Clogged air cleaner	Clean or replace
		Fuel pressure reg. diaphragm puncture	Renew
		Idle too rich or too fast	Adjust
		Injector hose leaks	Replace hose; tighten clamps
		Fuel system leaks	Correct
		Faulty ignition	Check timing, plugs and sensors
		Loss of engine compression	Check compression
		Defective valve action	Check cylinder compression and cylinder leakage
		Excessive rolling resistance from low pressure tyres, dragging brak es etc	Correct defects

34.2.1 Engine will not crank with starter

If the engine will not turn over with the starter, the cause could be the battery, immobiliser, the starter or the cables. A quick check can be made by trying to start the engine with the headlamps on.

1 If the lamps stay bright, the starter is not drawing current from the battery . The starter could be at fault, or there could be an open circuit in the starter circuit.

2 If the lamps dim considerably, the starter is drawing too much current from the battery. This could be due to a fault in the starter, or the battery could be in poor condition or in a low state of charge.
3 If the lamps go out as soon as cranking is attempted, there could be a bad connection in the starter circuit (most likely a dirty battery terminal) or the battery itself could be faulty.

If the fault is not easily located after these quick checks, more detailed checks can be made. The battery can be tested for charge, the starter circuit for voltage drop and resistance and the starter for current draw. Switches and relays should also be checked. Make sure an immobiliser warning lamp is not on.

34.2.2 Engine cranks over slowly but does not start

This could be caused by low voltage at the starter, or the starter itself could be at fault. Low voltage could be caused by a battery in a low state of charge, a poor earth or resistance in the starter circuit. Make further checks (for example, starter current draw) to isolate the battery or starter.

34.2.3 Engine cranks over at normal speed but does not start

If the starter spins the engine at normal speed, the starter and battery should be satisfactory. The engine needs both fuel and ignition to fire, regardless of the type of fuel system or ignition system. After firing, the fuel and ignition systems must be functioning correctly for the engine to keep running.

Ignition check

Follow these steps to check the ignition:

1 Use a spare spark plug with the gap opened up to about 6 mm, or use a test plug designed for the purpose (Figure 34.2).
2 Connect a spark plug cable to the test plug terminal, and earth the body of the plug.
3 Crank the engine—a healthy blue spark should jump across the gap.

If the ignition appears to be in order, check the fuel system.

Safety: Take care with the high-tension voltage. Ignition voltages are high enough to be dangerous.

Fuel system checks

1 If an engine will not start because of fuel, it is fairly clear that the problem could be either too much fuel or too little fuel (or none at all).
2 If there is a shortage of fuel, the components of the system should be checked, including the pump, filter and fuel lines.
3 With some EFI systems, a quick check can be made by listening for the pump when the ignition is switched on. This indicates that the electric fuel pump is operating. The best and most thorough test is to place an ammeter across the fuel pump fuse (Figure 34.3) and insert a fuel pressure and flow tester in the regulated fuel line.
4 For vehicles that have the fuel pump and filter located in the fuel tank (returnless system), a fuel pressure and flow gauge will have to be used.
5 The air-intake system of the engine must be free of leaks to avoid upsetting the mixture. The engine might fire, but will run badly (or may not continue to run).
6 A noid light can be used to quickly check for injection pulses at the injector connector.

Safety: When disconnecting fuel lines, de-pressurise the fuel system first.

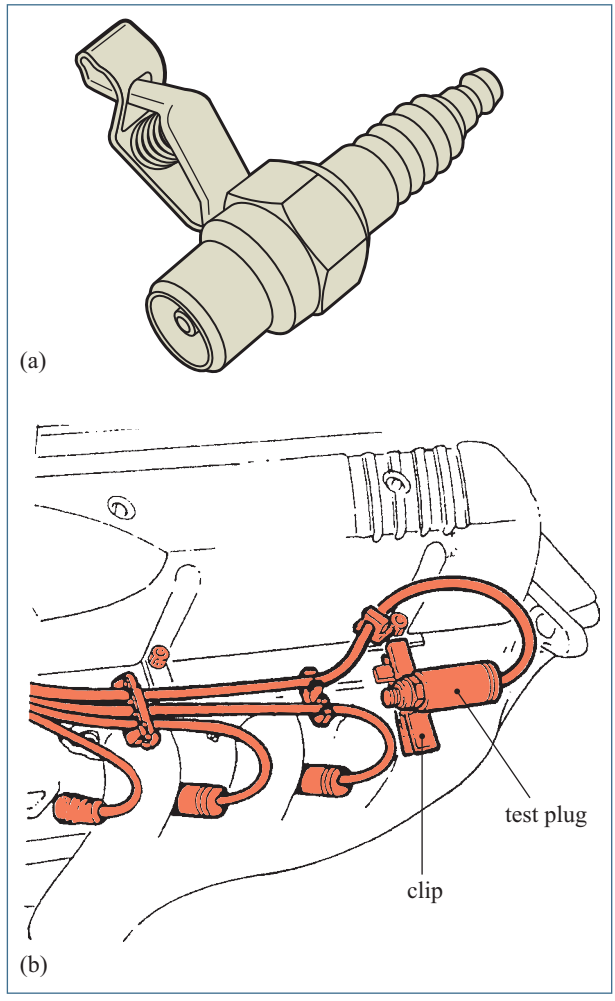


Figure 34.2 (a) A test spark plug tool (b) the same tool shown clipped to a good earth on the engine GM HOLDEN LTD

34.2.4 Engine runs but one cylinder misfires

A cylinder that is not firing, or is not producing power, can be isolated by performing a balance test. Remove an injector connector from each cylinder in turn. The cylinders that are producing power will cause a noticeable change in engine speed, while the faulty cylinder will produce no change. Once the faulty cylinder is identified, it then has to be decided whether the problem is in the ignition or the fuel injection, or whether it is mechanical.

Some engine analysers have provision for a balance test that is done without removing the spark plug cables. This is generally acceptable for electronic ignition and EFI. However, raw fuel entering a hot catalytic converter can destroy the substrate. Always check the engine service manual and the operating manual for the correct equipment required.

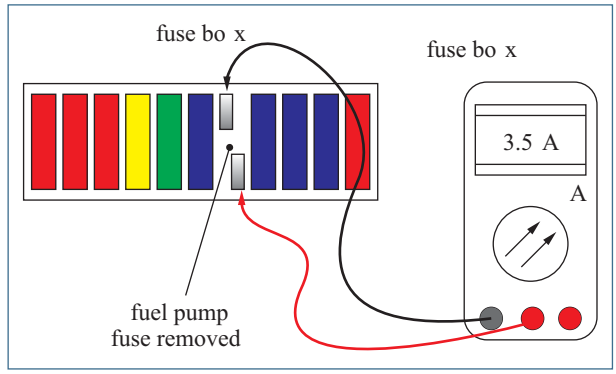


Figure 34.3 Testing fuel pump operation

34.2.5 Engine lacks power, acceleration or performance

This is a general problem that could be caused by an ignition fault, a fuel fault or a mechanical fault. An engine tune-up should correct most ignition and fuel problems. However, in some cases partially blocked injectors and carbon build-up on the throttle body may require the injectors to be serviced and the throttle body cleaned.

Loss of performance could be the result of general wear in the engine, such as worn or burnt valves and seats, carbon deposits or worn piston rings. A restricted exhaust system will create back-pressure and reduce the free flow of exhaust gases, particularly at higher speeds. Figure 34.4 shows the equipment for a test for back-pressure.

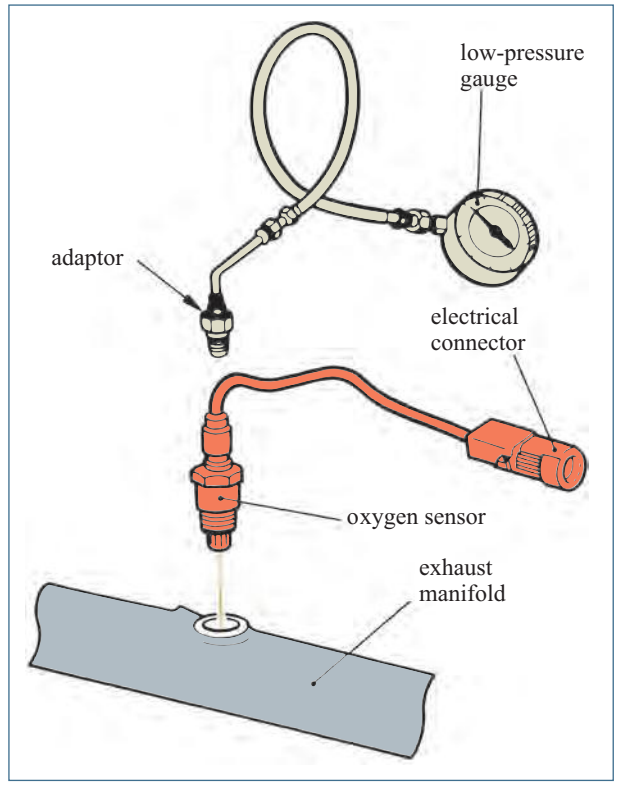


Figure 34.4 Exhaust system back -pressure check GM HOLDEN ITD

In the test shown, the oxygen sensor has been removed from the exhaust pipe and a low-reading pressure gauge will be installed in its place. As an example only, the gauge should show a back-pressure reading of less than 9 kPa at idle, or less than 20 kPa at above 2000 rpm.

There are also problems outside the engine that could affect performance, such as drag from brakes or tyres, or a faulty torque converter in the automatic transmission.

⚠ Safety: An engine should not be run with a spark plug cable open-circuited as this could damage electronic components—a test spark plug should be used

34.2.6 Engine overheats

Overheating is usually caused by problems in the cooling system, but it can also be caused by (or assisted by) retarded ignition timing. In fact, almost any fault that prevents the engine from operating normally can cause overheating. In the cooling system, checks can be made to ensure that:

1. Coolant passages in the engine are clean and unrestricted.
2. The thermostat is operating and not restricting coolant flow .
3. The radiator cap maintains the required pressure in the system.
4. The water pump impeller is operative and circulating the coolant. Check the actual coolant flow; water pump impellers can shear on the spindle shaft (especially plastic impellers).

5 Radiator hoses are in good condition and not swollen or leaking.
6 Air passages in the radiator core are clear and the fins intact and not corroded.
7 Fan and water pump drive belts are in good condition and correctly tensioned.
8 Electric fans cut in and out at specified temperatures.
9 There is not a faulty cylinder-head gasket.

Handy hint: If an electric fan does not operate, the connections, coolant sensors and fan relay should be checked.

34.2.7 Rough idle

Engine idle should be adjusted to the emission-control specifications for the particular type of engine. This is shown on a decal attached to the engine compartment of the vehicle or found easily in tuning and lubrication data manuals. Rough idle is not necessarily due to incorrect idle mixture—other possible causes, such as air leaks, vacuum leaks or the ignition should be checked.

With EFI engines, a diagnostic tester would be required as incorrect fuel pressure and flow rate will affect idle quality. Idle speed and mixture are influenced by a number of sensors, and the system could have an idle-speed control valve. Checks should be made before carrying out adjustments. EFI engines also require the use of a four- or five-gas analyser when checking and adjusting idle mixture. A dirty or partially blocked throttle body opening will cause a rough idle.

34.2.8 Engine backfires

This problem will apply mainly to a lean mixture or faulty ignition. Anything that is likely to cause ignition at the wrong time should be suspected. A backfire could occur through the intake valve into the intake manifold and ducting. The air cleaner then acts as a flame trap. A misfire can occur in the exhaust system if it becomes overloaded with unburnt fuel. Emission controls generally prevent this, but could cause it if faulty.

Handy hint: There are different procedures for the various EFI systems, and the correct information must be obtained from the workshop manual.

34.2.9 Excessive oil consumption

Oil can be lost from the engine in three ways:

1 by burning in the combustion chamber
2 by leaking externally in liquid form
3 by passing out of the crankcase through the crankcase-ventilating system in the form of a mist or vapour.

Oil can reach the combustion chamber through the valve guides and by passing the piston and rings. Worn piston rings will be unable to control the oil on the cylinder walls. Worn connecting-rod bearings, which throw an excessive amount of oil, can contribute to this problem. Incorrect oil viscosity or grade will also contribute to the oil consumption rate.

External oil leaks can be identified by inspecting the filter, oil pan, valve cover, oil-pressure switch, timing-gear housing, front crankshaft seal and rear main oil seal.

34.2.10 Low oil pressure

Low oil pressure can be caused by worn engine bearings, low oil level, an inefficient oil pump or a faulty pressure-relief valve. Diluted oil or oil that is overheated can also affect oil pressure.

34.2.11 Excessive fuel consumption

Excessive fuel consumption could be caused by ignition problems, fuel problems, the mechanical condition of the engine or the type of driving. Any complaint about fuel consumption should be checked with accurate test equipment. Complaints that too much fuel is being used are often based on the number of kilometres that are driven on a full tank, or some similar estimate. At best, this is only a guide, and is quite inaccurate as a test of fuel consumption. A thorough fuel system analysis must be carried out. In-vehicle instruments that report fuel consumption are not accurate as they calculate the consumption by using the fuel gauge sender unit to calculate fuel consumed.

Handy hint: Fuel consumption is quoted in terms of litres per 100 kilometres.

34.3 EFI system diagnosis

Electronic engine management systems have a self-diagnosis facility that enables faults in the main components to be located. These systems are covered in Chapter 31. Listed below are some basic items that should be checked. They are not electronic items, but they can affect the operation of electronic components:

1 The battery must have a reasonable state of charge.
2 Electrical connections must be firmly in place.
3 The spark plugs must be in good condition.
4 The ignition timing should be set correctly.
5 The air filter must be clean.
6 The air system should have no leaks.
7 The fuel system must supply clean, fresh fuel at the correct pressure and flow rate.
8 The injectors must be clean and must spray correctly.
9 The PCV system should not leak, and the valve should be free.
10 The EGR system should be operating correctly.

Handy hint: Check the items above before concluding that electronic components are at fault.

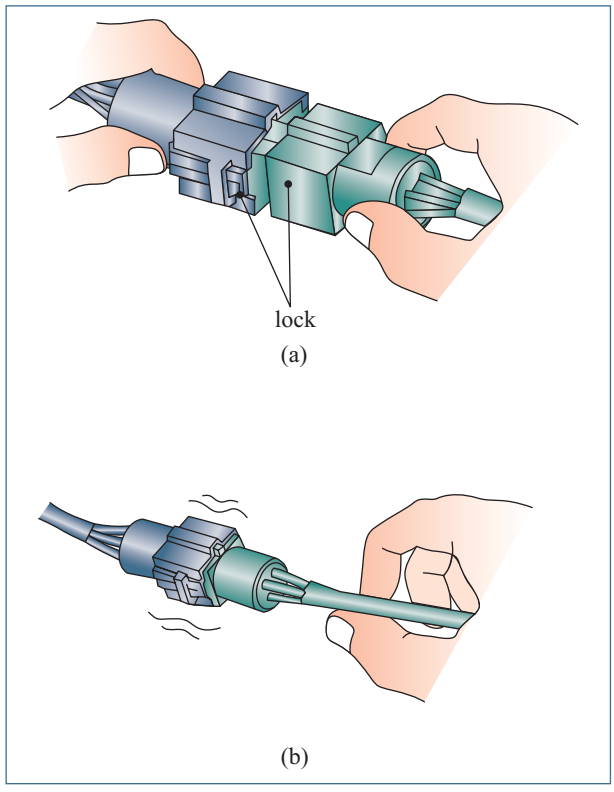


Figure 34.5 Electrical connector (a) parts must be pushed together firmly (b) checking the connector by using the 'wiggle test'

34.3.1 Engine management system electrical connections

Poor electrical connections are one of the most frequent causes of EFI problems. Check that the terminals are not bent and make sure that the connectors are pushed tightly together and locked (Figure 34.5(a)). When checking, wiggle the connector (this is known as the *wiggle test*) to see if it affects the signal or test reading (Figure 34.5(b)). Many connectors carry very low voltage, and even a small resistance from a poor connection can have an effect. Remember, the engine wiring harness can be considered to be a moving part.

34.3.2 Engine control diagnosis chart

A general diagnosis chart for EFI systems is shown in Table 34.2. This lists some EFI problems and indicates their possible causes. The chart is only an example, and more information will be needed for an individual system.

Table 34.2 EFI diagnosis chart

Problem	Possible causes
	(Numbers refer to list of possible causes)
Engine fails to start or is difficult to start	1, 2, 3, 4, 5, 10, 11, 14, 16, 17, 18, 19, 23
Engine starts but stalls	1, 2, 3, 4, 5, 11, 14, 16, 17, 18, 19, 20, 23
Engine difficult to start after standing	11, 16
Flat spot during acceleration	1, 5, 6, 8, 9, 11, 22, 23
Engine surges	1, 5, 7, 9, 10, 11, 14, 16, 23
Uneven engine idling	6, 8, 9, 15, 16, 18, 19, 20, 21, 23
Poor throttle response	5, 9, 15, 17, 19, 23
Engine misfires	1, 2, 7, 10, 11, 13, 17, 18, 19, 21, 23

Table 34.2 (continued)

Problem	Possible causes
Engine lacks power	1, 5, 9, 10, 11, 13, 14, 20, 21, 22, 23
Fuel consumption high	1, 5, 6, 7, 10, 12, 13, 14, 20, 23
CO concentration too high	5, 10, 12, 14, 16
CO concentration too low	5, 10, 14, 16

List of possible causes of problems in an EFI system

1. Fault in control unit
2. Distributor sensor faulty
3. Fuel pump relay inoperative
4. Electric fuel pump inoperative
5. Airflow sensor malfunctioning
6. Air-temperature sensor inaccurate
7. Electronic control unit defective
8. EGR device defective
9. Air-intake system leaking
10. Injectors defective
11. Fuel pressure too low or zero (regulator faulty)
12. Fuel pressure too high (regulator faulty)
13. Fuel delivery insufficient
14. Coolant-temperature sensor faulty
15. Throttle valve or control cable sticking
16. Idle adjustment incorrect
17. Components badly earthed
18. Loose electrical connections
19. Open circuit in wiring
20. Throttle switch defective
21. Contaminated fuel
22. Block ed air filter
23. Ignition system faulty

34.4 Dynamometer use

The chassis dynamometer is a common diagnostic tool (available for two- or four-wheel-drive systems) that is used for service work checks with the engine in the vehicle (Figure 34.6). The driving wheels of the vehicle are placed on rollers; the engine drives the wheels and the wheels drive the rollers. Alternatively, an axle dynamometer eliminates the frictional losses between the tyres and the rollers so the measurement is closer to actual engine output. The power delivered by the wheels/axles to the rollers or the dynanometer drive shafts is shown on a gauge or screen.

A dynamometer is an extremely useful diagnostic tool when working on performance vehicles and/or remapping a computer to improve performance. It is also useful when looking for engine problems as it allows the vehicle to be tested in laboratory conditions where instruments can be connected and information recorded in a controlled environment (Figure 34.7). This allows any changes to be recorded and compared to the original conditions in which the fault was present. The dynamometer measures torque and power but can also be used to simulate a loaded drive condition when performing diagnostics.

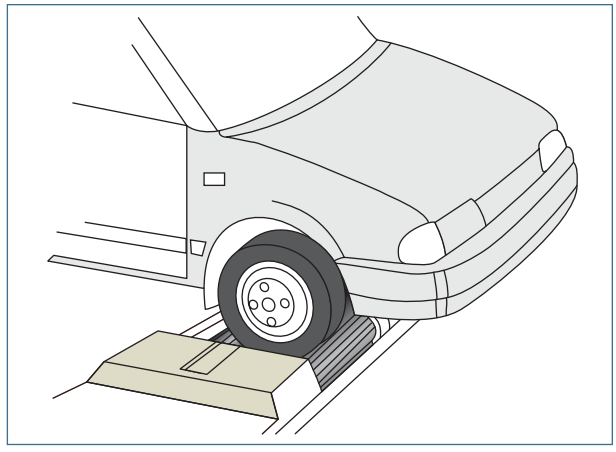


Figure 34.6 Front-wheel-drive vehicle on the rollers of a chassis dynamometer

Figure 34.7 A vehicle with the rear axle connected to a dynamometer

34.5 Engine noises

Various noises originate in the engine. Some have little significance while others may indicate trouble that requires prompt attention to prevent major damage to the engine. Characteristics of various noises and their possible causes are outlined below.

34.5.1 Detonation

Detonation is a *pinging* or rattling noise that is most noticeable when accelerating or when the engine is under load. It is the result of uncontrolled combustion and the resulting pressure shock wave. This pressure wave in the combustion chamber area can cause severe engine damage. Detonation can be caused by over-advanced ignition timing, the use of petrol with an octane rating that is too low for the engine, too high a compression ratio or high operating temperatures.

Engine management systems have a detonation or knock sensor attached to the engine block which picks up the vibrations caused by detonation. Later systems utilise coil-on-plug circuitry to monitor knock or detonation in each cylinder. The sensor signals this to the electronic control unit, which retards the ignition timing. The ECU will advance and retard the ignition timing to suit the vehicle's operating conditions.

Handy hint: Detonation could occur if the sensor is faulty .

34.5.2 Valve noise

Valve noise is caused by excessive clearance between the tip of the valve stem and the rocker arm or similar valve-operating mechanism. Excessive clearance produces a regular clicking noise that increases in frequency with the speed of the engine. Unless the mechanism is quite worn, excessive clearance can be corrected by adjustment, and the noise reduced.

Hydraulic tappets or lash adjusters prevent noise, but can become noisy themselves if they have excessive leak-down, if there is air in the system or the initial adjustment of the valve mechanism is incorrect. Hydraulic lash adjusters will collapse and become noisy with incorrect or lower-viscosity engine oil being used. In some cases, collapsed tappets will result in a no-start situation.

34.5.3 Connecting-rod noise

Noise from the lower end of the connecting rod is usually in the form of a light knock. This can become more noticeable when the engine speed is increased or decreased. The knocking occurs at engine-speed frequency and can be isolated to a particular cylinder by short circuiting each sparkplug in turn. The noise will be reduced or eliminated when the cylinder with the connecting rod that has the knock is not delivering power.

Handy hint: A knock could be caused by a worn bearing or crankpin, a misaligned connecting rod, inadequate oil supply or ex cessive bearing clearance .

34.5.4 Crankshaft knock

This is a heavy, dull, metallic knock, which is noticeable when the engine is under heavy load or during acceleration. It can be louder when the engine is cold. The knock is caused by worn main bearings, or bearings with excessive clearance.

34.5.5 Piston-pin noise

Piston-pin noise has a double knock at a frequency twice engine speed, as it occurs at both top and bottom of the piston stroke. It is caused by excessive clearance between the piston pin and the piston. Short circuiting each spark plug in turn will enable the faulty cylinder to be identified.

34.5.6 Piston slap

Piston slap originates between the piston and the cylinder wall. It is a hollow noise caused by the piston rocking in the cylinder. In most cases, the noise occurs only when the piston is cold, disappearing when the engine warms up and the piston expands. This is more a feature of piston design than an actual problem.

A light piston noise can be evident even in some low-kilometre engines or horizontally opposed engines, and is considered normal. If the noise is particularly obvious and occurs when the engine is hot as well as cold, a problem is indicated and further investigation is warranted.

34.5.7 Timing gear or chain noise

Noises can originate from timing gears or timing chains with inadequate lubrication. In some instances, a noise might originate from the timing-chain damper. Timing chain noise is not consistent with (or synchronised to) either crank or camshaft.

34.5.8 Drive-belt noise

Driving belts for water pumps and alternators slip and squeal if they are too loose. V-ribbed belts tend to flap and produce noise if they are not correctly adjusted. Timing belts are only likely to produce noise when the tensioner is out of adjustment or the belt itself is damaged or frayed. To avoid belt failure and resulting engine damage, timing belts should be renewed at specified periods. In most engines, timing-belt failure can cause the pistons to hit the valves and cause severe damage.

Handy hint: Timing belts have a specified service life and are usually renewed after 90 000 to 120 **000 kilometres of operation (individual service schedules must be referred to).**

34.5.9 Vibration

Excessive engine movement and vibration are associated with rough running of the engine. They are often most noticeable at engine idle speed. Excessive movement can also be caused by loose or worn engine, exhaust and transmission mountings or component imbalance. Sometimes a vibration may result from a mechanic not refitting a damper mass (rubber lumps or blocks that just *hang* on some engine or transmission units) that cancel out frequency resonation.

34.5.10 Miscellaneous noises

Noises can come from external components, such as the alternator, water pump or exhaust system. Other components, such as the clutch, flywheel, transmission and drive shaft can also produce various noises

34.5.11 Stethoscopes

Traditionally a stethoscope is used to locate noises in engines. Modern electronic stethoscopes (as in Figure 34.8) have the advantage of being able to amplify the sound.

Figure 34.8 An electronic stethoscope can very clearly pinpoint injector activity differences

34.6 Engine analysis and tune-up equipment

The equipment used for engine analysis and tune-up is either a portable hand-held scan tool, an oscilloscope or a laptop PC-type analyser. Engine analysers have both oscilloscope-type functions for measuring ignition events and multiscale electronic meter functions for measuring volts, amps, ohms, dwell, frequency, pulse width, duty cycle and rpm. A vacuum gauge and pressure gauge function can also be included, as well as a four-gas or five-gas exhaust analyser. A timing light is another common fixture.

Engine analysers use a computer which receives data from cables and sensors connected to various parts of the engine. They then generate on-screen outputs in the form of pictorial graphs and numerical values for all the electrical events of an engine. Some analysers also have a scanner function and can print a copy of the test results. Analysers also report important engine data such as manifold vacuum, relative compression and engine temperature.

The screen can show patterns for either the primary circuit or the secondary circuit of the ignition system. The secondary pattern is usually used for diagnosis. Every event in the primary circuit has a corresponding (but not identical) event in the secondary circuit. Patterns for electronic ignition systems will be different from those for breaker ignition, although similar actions occur in the circuits of both types of ignition systems.

34.7 Engine analyser ignition display

The use of engine analysers in relation to the ignition system is explained in Chapter 32. They can also perform several engine-management sensor and actuator tests.

34.7.1 Connecting the engine analyser

The basic connections between the engine analyser and the engine vary with engine and ignition type. Probes that provide a pulse signal are fitted to the high-tension cables, and clips are attached to the ignition-coil terminals. Additionally, a connection is made to battery power and the earth on the engine.

The oscilloscope will have more probes for the lab scope function. A probe is also required to penetrate the tailpipe for the exhaust gas analyser.

The range of connective cables and probes is shown in Figure 34.9. The connections and the way that they are made depend on the instrument being used and the engine system. With some engine management systems, special connectors may be needed. There are many variations of both instruments and systems, and reference to the appropriate instruction manual is necessary.

Figure 34.9 Connections for the engine analyser BOSCH

34.8 Engine management—oscilloscope patterns

An engine analyser can also be used to monitor the electronic components of the EFI side of the system. The *lab scope* or *special patterns* screen is selected from the analyser menu and, again, the pattern shown on the screen is a voltage-time graph. The analyser probes have to be used at the correct terminals of the control unit or sensor, information concerning which is obtained from the appropriate workshop manual or a wiring diagrams data base. Two examples of patterns of components of an EFI system are:

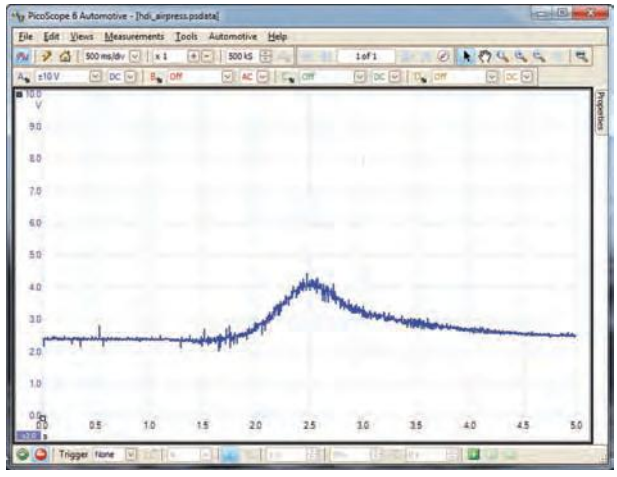


Figure 34.10 Screen pattern produced by the signal from a MAP sensor PICO TECHNOLOGY

1 MAP or load sensor . The MAP sensor in the throttle body produces a uniform pulse signal (either analog or digital), as shown in Figure 34.10. The MAP sensor measures a signal relative to intak e manifold absolute pressure (MAP) and therefore measures engine load (see Chapter 22). There are three other engine load sensors: the vane airflow meter, the hot wire or hot film air mass sensor and the K arman vortex airflow meter . The vane airflow and the piezo-resistive MAP sensors send a varying analog voltage signal while the capacitive MAP sensors and the remaining airflow/mass sensors send a digital frequency signal to the ECU.
2 Fuel injector . A fuel injector has a solenoid which operates on the normal electrical system voltage . The pattern shows the voltage and how it drops when the injector is opened (pulled to earth by a transistor in the ECU). This lower line is the pulse width. A t the end of the pulse , a voltage peak is shown when the ECU switches off the transistor and the injector nozzle closes. This is a back EMF which is induced in the injector solenoid windings as its magnetic field collapses.

Figure 34.11 is a simplified display of injector operation with the features of the pattern identified.

34.8.1 Oxygen or lambda sensor

This sensor operates in a closed loop with the ECU. The lambda sensor provides the ECU with constant feedback about small changes in air–fuel ratio either side of stoichiometric mixture or lambda (more information on lambda sensors can be found in Chapter 33).

34.8.2 Throttle position sensor

The throttle position sensor (TPS) is a simple potentiometer mounted on the throttle shaft on the throttle body. It sends an analog voltage signal to the engine management ECU that is proportional to throttle angle. Typically,

the ECU would receive an input of around half a volt at idle and up to four-and-a-half volts at wide-open throttle angle. The potentiometer sweeps smoothly and gradually without breaks or glitches using a five volts reference supply. Figure 34.12 shows an oscilloscope trace of a throttle position sensor signal.

34.8.3 Crank-angle sensor

The crank-angle sensor (CAS) is an input signal to the ECU relating the exact angular position of the crankshaft, and therefore any piston position, at any given millisecond. The ECU uses this information to calculate exact engine speed and also as a reference to begin the injection and the spark event. An engine will not start without a crank-angle sensor signal.

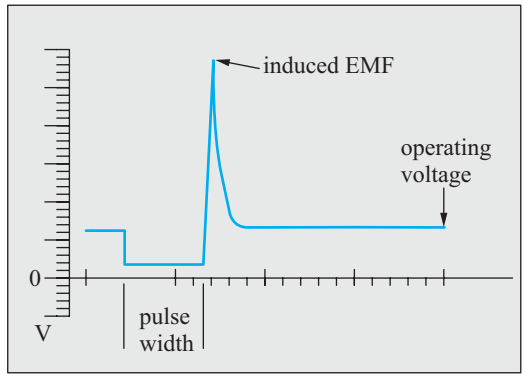


Figure 34.11 Oscilloscope pattern produced by an injector FORD

34.8.4 Camshaft position sensor

Engines featuring a camshaft position sensor can operate independent cylinder-sequential fuel injection that follows the ignition firing order of the engine. The same camshaft position input can be used for closed loop feedback and operation of variable camshaft timing devices or valve-timing phasers. The cam sensor in this instance informs the ECU of the related position of the camshafts to the crankshaft at any given moment.

The signal is best checked on a dual-trace or two-channel oscilloscope, along with the crank-angle sensor. Figure 34.13 shows a dual-channel diagnostic tool displaying an analog-inductive crank-angle sensor trace and a digital Hall-effect camshaft position sensor trace.

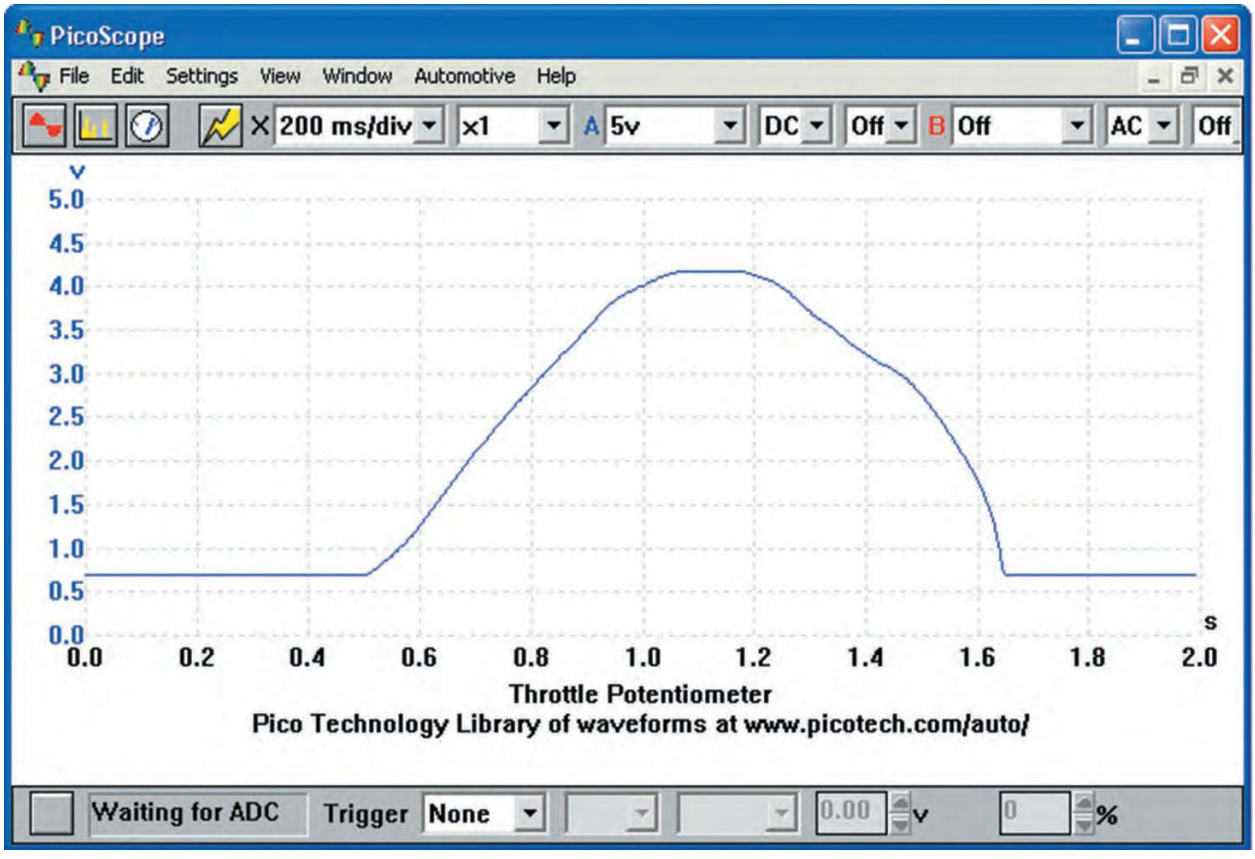


Figure 34.12 A throttle position sensor trace showing a one-seco nd smooth rev operation PICO TECHNOLOGY

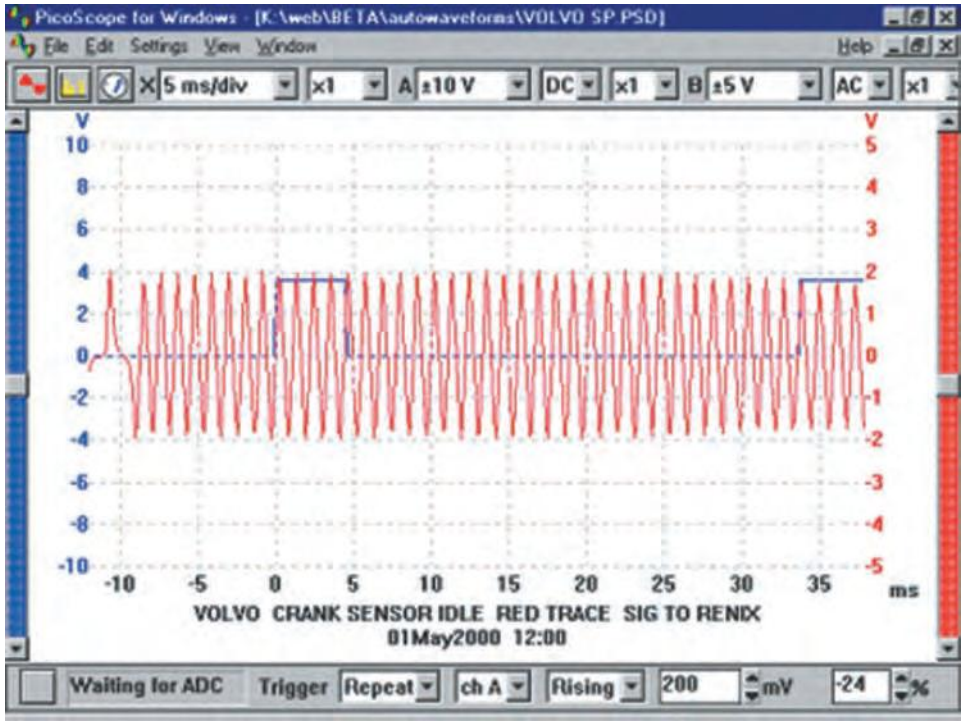


Figure 34.13 Dual-channel oscilloscope displaying an analog-inductive crank -angle sensor and a digital Hall-effect camshaft position sensor PICO TECHNOLOGY

34.9 Scan tools

Scan tools are electronic test and diagnosis instruments that can be connected to the data link connector (DLC) of the vehicle. They are essentially hand-held computers that can access real-time or stored data in the ECU and multiplexing communications systems such as detected trouble codes (DTCs). They can also test individual actuator circuits and components.

Some scanners also include *signal generators*. This type of scan tool is capable of sending signals to test a component's response. When using this feature, care should be taken that the circuit is not overloaded.

There are generic instruments that accommodate a wide range of vehicle makes and models. There are also dedicated instruments developed by individual car manufacturers to suit their range of vehicles. Figure 34.14 shows such an instrument.

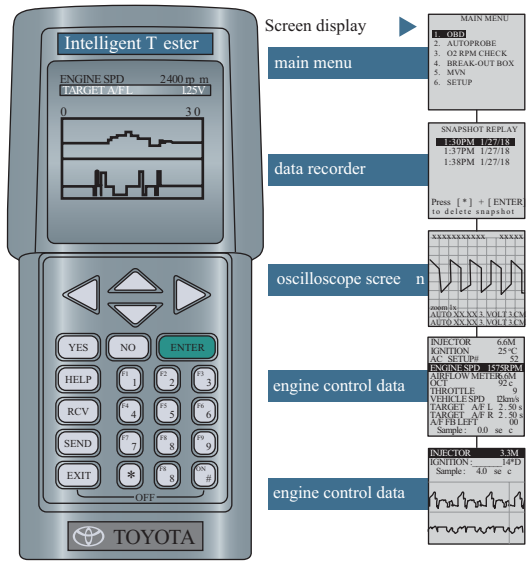


Figure 34.14 Hand-held scan tool

Scan-tool readout modes include digital, graphical, pictorial, tabular, colour-coded and oscilloscope-type displays. Scan tools allow the operation of the various components and systems in the vehicle to be monitored and tested using the live data readout function as well as the data recording function. They can also retrieve performance data, particularly diagnostic trouble codes. When a malfunction is reported in the form of a trouble code, a testing procedure is initiated.

34.9.1 Data loggers and drive recorders

Data loggers can be a dedicated tool or a function in a scan tool. In each case, they are connected to the vehicle data link connector (DLC). A data logger can store a large amount of engine and vehicle performance data.

A large sample can be taken over a twenty-four-hour period, logging data each millisecond. Alternatively, a slower sampling rate of once per second can record vehicle and engine data for up to 1000 hours of

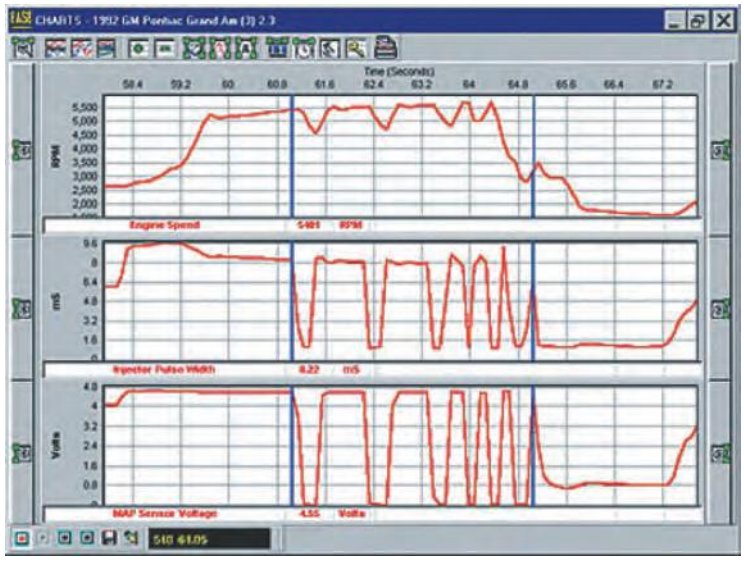


Figure 34.15 Comparisons of data tak en from a data logger EASE DIAGNOSTICS

driving. The data can be downloaded from the data logger to a laptop and compared with other data to isolate the problem (Figure 34.15).

34.9.2 Laptop with a wave form generator

For technicians with advanced skills or workshops that need to be able to perform more detailed diagnostics, a USB waveform generator oscilloscope coupled to a laptop is the best diagnostic tool for computerised system and sensor testing. Unlike a scan tool, this diagnostic equipment only tests actual signals from the sensors and not fault codes. Its main advantage is that it can look at sensor output in milliseconds in real time in great detail.

Several brands can measure information in milliseconds, and some units have sixteen channels, allowing sixteen sensors or electronic devices that have a voltage flow to be monitored at the same time. They can read from inductive clamps or from a direct connection to the device. Figures 34.16 and 34.17 show examples of sensor signals.

Figure 34.16 Pico waveform generator connected to a laptop and an engine

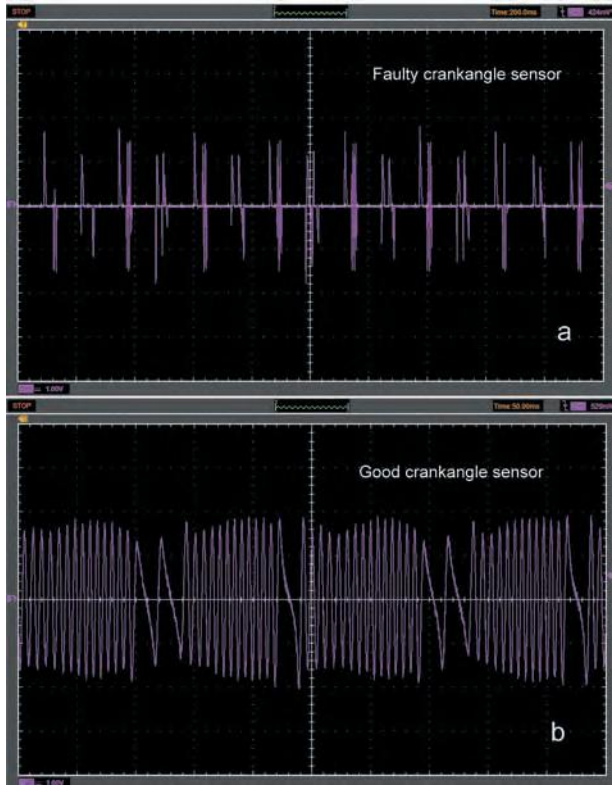


Figure 34.17 The reading tak en of a crankangle sensor before and after replacement: (a) the signal from the faulty sensor at cranking speed (b) shows the signal from a good sensor when cranking after replacement. The double and single break in the pattern tells the ECU what position the crankshaft is in TURNING POINT TECHNOLOGY

34.9.3 Symptoms and cause

Diagnosing problems in petrol engine management systems, can be very demanding. As mechatronics becomes more complex, so does locating the prime cause of faults. However, regular use of diagnostic equipment increases a technician's ability to pinpoint the causes of problems.

Figure 34.18 shows diagnostic charts of a vehicle being run on a dynamometer with a Hantek eight-channel waveform generator connected to a laptop, with the information being displayed on a TV monitor. A lot of information is displayed, the most important aspect of which is the faulty Flex fuel sensor. Note how the the ethanol sensor has affected the other readings of the sensors being monitored (Figure 34.18).

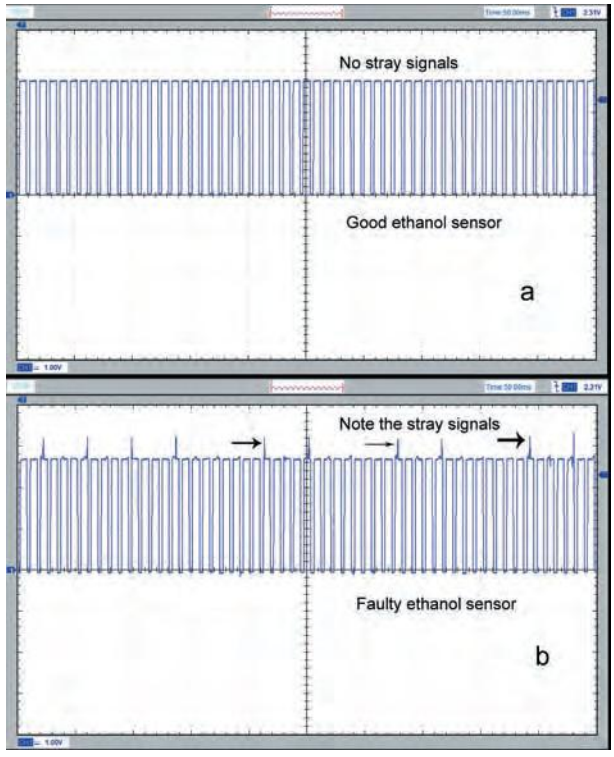


Figure 34.18 The signal from a Holden Commodore V6 Flex fuel sensor . This sensor measures fuel temperature and ethanol content by percentage: (a) shows the signal from a good sensor (b) shows the signal from a bad sensor—note the stray spik es in the top of the bad signal. A scan tool may not pick this up or log a fault code TURNING POINT TECHNODGY

Not all faulty signals produce a fault code, as exemplified by the Flex fuel sensor in Figure 34.19 and 34.20. The computer is receiving a signal so it may not see a fault. A fault may be logged, but it may not be the sensor that the fault code indicates is at fault but a mechanical failure.

Below are two more examples. Example 1 shows a fault in a sensor that is actually a mechanical failure. Example 2 shows no fault code but is a faulty operating sensor.

Example 1: a vehicle has reduced power and a MAP sensor fault is logged, but the actual problem is a crack in the intercooler or a split intercooler hose losing air pressure from the turbocharger so the throttle position and fuel delivery do not match the air going into the engine.

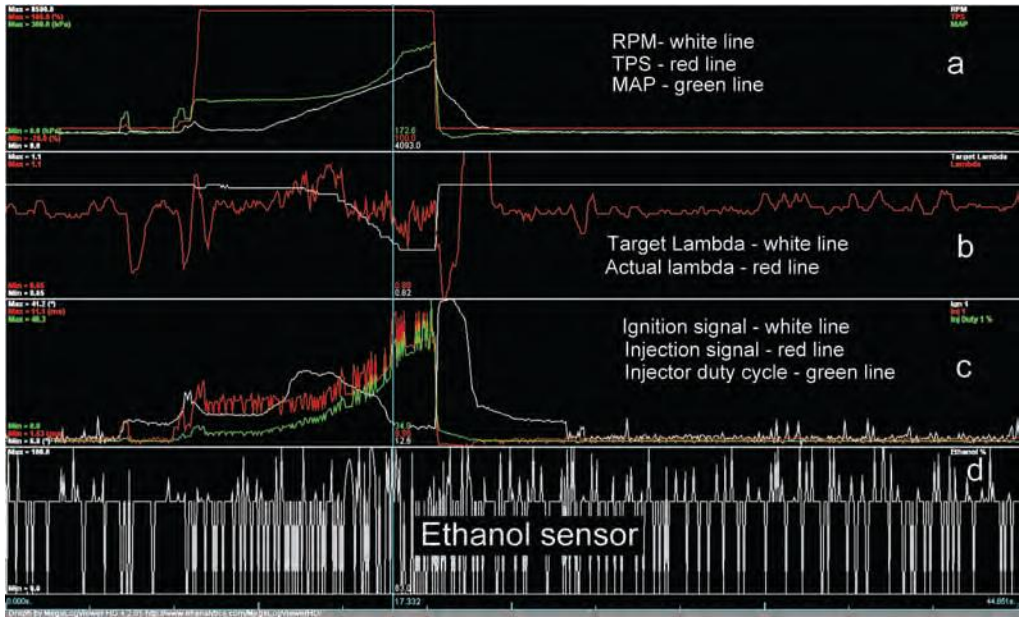


Figure 34.19 (a) RPM, TPS sensor , MAP sensor (b) the lambda target and actual (c) the ignition signal, injection signal and the injector duty cycle (d) the faulty Flex fuel/ethanol sensor signal (this should be a straight line showing a set percentage of ethanol) TURNING POINT TECHNODGY

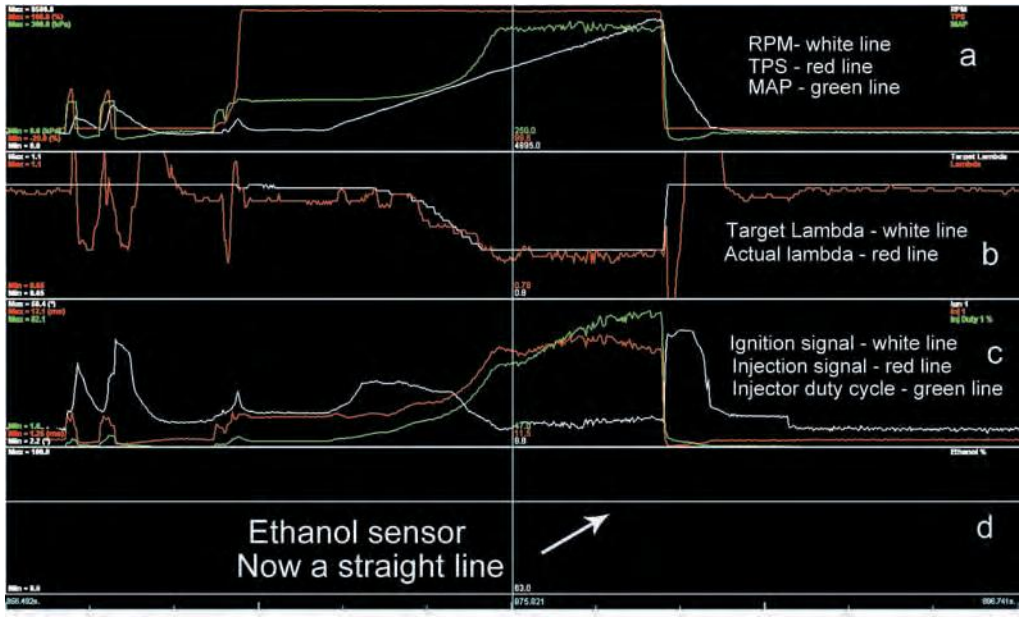


Figure 34.20 This shows the same information as Figure 34.19, but with a good Flex fuel sensor on the (d) graph. Compare the effect it has on the other readings and compare the readings with Figure 34.19 TURNING POINT TECHNOLOGY

Example 2: A petrol engine may idle poorly and perform poorly at low speed but could perform well at high speed. A search for fault codes may find none. The issue may be the airflow sensor or MAP sensor having become coated with a dirty film that affects driveability. This information is not listed as a service item in the workshop manuals, although the problem is not an uncommon one.

34.10 Meters and gauges

Various smaller meters and gauges can be used for checks and adjustments.

34.10.1 Vacuum pump

A hand-held vacuum pump of the type shown in Figure 34.21 is used to test vacuum-operated devices. These include vacuum actuators of various types, and also valves and other devices associated with emission controls. A gauge fitted to the pump enables a specified vacuum to be obtained.

34.10.2 Compression gauge

A compression gauge checks the compression of the engine cylinders with the engine warm and the throttle open so that there is no restriction to air entering the cylinder. The spark plugs are removed and an adaptor fitted to the spark-plug hole of the cylinder being tested (Figure 34.22). The engine is cranked over with the

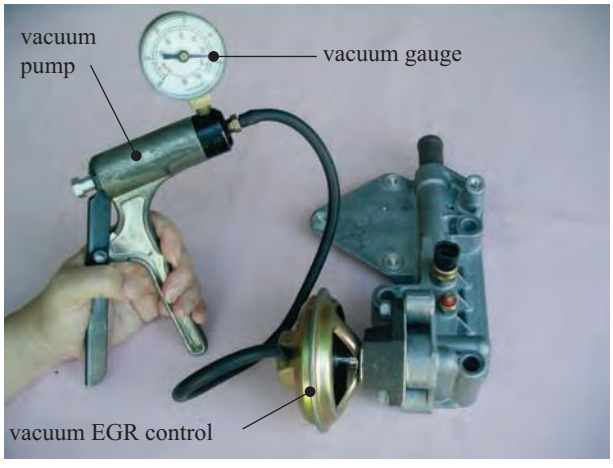


Figure 34.21 A hand-vacuum pump is used to test vacuum controls

Figure 34.22 Cylinder compression gauge—an adaptor is fitted in place of a spark plug

starter two or three times to obtain a gauge reading. The test is performed on all cylinders and the results compared. Uniform pressures should be obtained.

The injectors must be disabled during this procedure as cranking the engine for each cylinder test will fill the exhaust system with fuel vapour, which could result in an explosion and/or a catalytic converter meltdown on restarting the engine.

Interpretation of test

A cylinder that has a much lower pressure than the others could have a defective valve, or worn piston rings or cylinder. A small quantity of oil can be induced into the cylinder through the spark plug hole, the engine rotated a number of times and the compression reading taken again. An improvement will probably be due to sealing of the piston rings. If there is no improvement, a faulty valve could be the cause of the trouble.

If two adjacent cylinders have low pressure, the cylinder-head gasket between them could be blown, allowing pressure to escape from one cylinder to another. Table 34.3 shows the results of a wet and dry compression test on a vehicle that specifies a new engine compression of 950 kPa.

Table 34.3 Results of wet compression test showing lower cylind er (block) wear in cylinder 3 and upper cylinder (head) wear in cylinder 5

Cylinder	1	2	3	4	5	6
Dry (kPa)	920	925	715	940	705	915
Wet (kPa)	980	1000	990	1020	725	985

34.10.3 Cylinder leakage tester

A cylinder leakage tester is used to check cylinder condition by pressurising the cylinder. An adaptor is fitted to the spark plug hole and air pressure applied with the piston at TDC on the compression stroke. This simulates a high pressure at the top of the compression stroke. A gauge is used to read the leakage rate and comparisons are made between cylinders (Figure 34.23).

Where a definite problem exists, it may be possible to hear the air leaking through the valves into the manifolds, or possibly past the pistons and into the crankcase. A faulty cylinder-head gasket may be detected by removing the radiator cap and checking for air bubbles appearing in the coolant fluid. A leakage of more than 10% is considered unacceptable. Table 34.4 shows the five possible loss areas to check when using a cylinder leakage tester.

Figure 34.23 Cylinder leakage tool—gauge readings tak en are red = poor, yellow = fair, green = good

34.10.4 Timing light

Power timing lights are used for setting the static or initial ignition timing (see Chapter 32).

Table 34.4 The five areas to check when using a cylinder leakag e tester

Source/fault	Area on vehicle/engine to check
Burnt intak e valve	Open throttle valve and listen at throttle intak e
Crack ed head, block or head gask et to water jack et	Remove radiator cap or header tank cap and observe coolant for bubbles
Burnt exhaust valve	Listen at exhaust tailpipe
Worn piston, rings or large piston to bore clearance	Remove oil filler cap or engine oil dipstick
Head gask et blown between cylinders	Remove adjacent cylinder spark plug and observe plug hole

34.10.5 Tachometer

A tachometer is used for checking engine rpm and for setting idle speed. For EFI control systems, a tachometer connection is provided, or the information can be obtained from an analyser or a scan tool connected to the DLC. Tachometers are fitted to some instrument panels and can be used instead of a workshop instrument.

With breaker ignition, the tachometer is connected to the ignition coil low-tension negative terminal (1) and operated by ignition pulses. The meter is usually a dwell tachometer, with a dwell scale as well as an rpm scale. This enables dwell to be checked on breaker ignition systems as well as correct dwell extension on EFI systems.

34.10.6 Other testing equipment

Other small items are used for diagnosis and tune-up. These include:

1. Oil pressure gauge. This is fitted to the oil gallery in place of the oil pressure sender unit. Oil pressure is checked with the engine warm (Figure 34.24(a)).
2. Cooling system testers. This is a special fitting with a pressure gauge that is used for pressure testing the cooling system and the radiator cap (Figure 34.24(b)).
3. Coolant dye check. Hydrocarbon (HC) or carbon monoxide (CO) in the coolant indicates exhaust gases entering the cooling system (usually caused by a leaking head gasket or a cracked cylinder head or block). A tool is placed in the radiator goose-neck and a sample of vapour above the coolant line is sampled by squeezing the tool bulb. The chemical dye will change colour if carbon dioxide or hydrocarbons are present (Figure 34.25).
4. Battery testers. A hydrometer is used for testing the state of battery charge. High-discharge testers check the battery condition (see Chapter 41).
5. Coil and capacitor testers. These are used for testing ignition coils and the capacitors of breaker ignition systems. Ohmmeters and oscilloscopes are also used for coil and capacitor tests.

34.10.7 Thermal testing

A laser thermometer is invaluable when performing diagnostics: it can check the exhaust temperature of individual cylinders at the manifold or the exhaust system, including the catalytic converter, as well as the cooling system at the top and bottom of the radiator or the thermostat.

Many components in an engine system can be checked, including battery connections, as a high resistance will cause an increase in temperature.

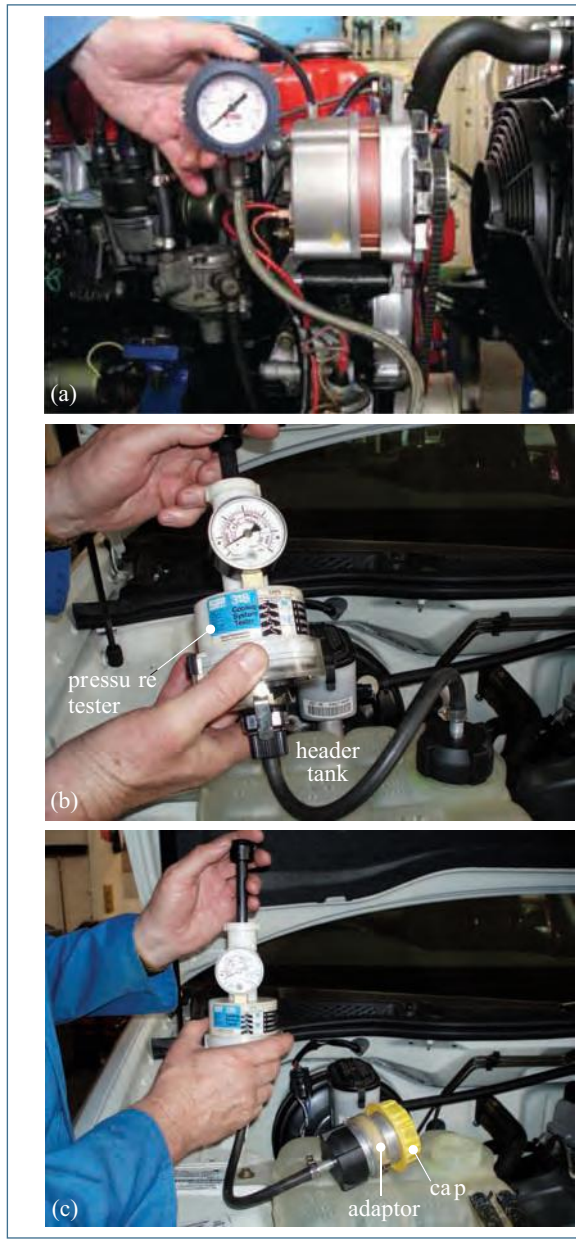


Figure 34.24 (a) Oil pressure gauge connected to the oil gallery to check the engine oil pressure (b) and (c) cooling system pressure tester

Figure 34.25 Cooling system combustion-gas analyser

Laser thermometers (Figure 34.26) can be used for other areas such a shock-absorbers, brakes and transmission parts for excessive operating temperatures.

Figure 34.26 A laser thermometer

34.11 Electrical measuring instruments

Electrical measuring instruments include ammeters, voltmeters and ohmmeters. They may be small hand-held instruments, bench instruments or part of an engine analyser. In some cases, the functions of all three instruments are built into one unit, a *multimeter*.

Multimeters have multiple scales and switches for selecting the different meters and ranges. Auto-ranging digital meters automatically adjust the range to suit the test (Figure 34.27). Multimeters used to test ECU-equipped vehicles should have an internal resistance of 10 000 ohms.

An automotive-dedicated multimeter needs many functions to work on modern engine management systems. These include:

- DC volts
- AC volts
- resistance (ohms)
- DC amps (10 A) direct
- inductive ammeter (attachment or unitary)
- tachometer (rpm)
- dwell meter
- temperature (k -type or probe)
- frequency (Hz)
- milliseconds (ms)
- duty cycle %
- continuity (audible buzzer) Ω.

Safety: As previously pointed out, only certain instruments that have a high impedance can be safely used with EFI systems.

Symbols on the selection wheel

μÃ	Microamps ac
mÃ	Milliamps ac
Ã	Amperes ac
Ā	Amperes dc
mĀ	Milliamps dc
μĀ	Microamps dc
mV	Millivolts dc
V̄	Volts dc
Ṽ	Volts ac
Ω	Resistance
Hz	Frequency
°C	Temperature

Figure 34.27 An auto-ranging digital multimeter

34.11.1 Ammeters

Ammeters are used for alternator checks and any other instance where current flow must be checked. They are often fitted with two or more scales of different ranges, which can be selected with a switch. Ammeters are connected into the circuit to measure the current that passes through the circuit (in series).

An induction ammeter, which is used to check starter motor current, is an exception in that it fits over the starter motor cable. When the starter is operated, current induced in the ammeter moves the pointer across a scale that is calibrated up to 800 amps. This enables a quick check of the starter draw to be made. The same test can be used on the alternator B+ terminal to check the charge rate (an induction ammeter is shown in Figure 38.8 in Chapter 38).

34.11.2 Voltmeters

Voltmeters are used for alternator voltage checks and for checking at any location where voltage is (or should be) present. They can be connected to a circuit without disconnecting the circuit (in parallel).

Voltmeters are also used to check voltage drop, which allows resistance in a circuit to be identified without disconnecting cables. They often have multiple scales, such as 0 to 1, 0 to 10 and 0 to 20 volts. The 0 to 1 volt scale is used to check voltage drop in a circuit.

Handy hint: A low scale is needed as the voltage drop across most circuit connections should not normally exceed 0.1 volt.

34.11.3 Ohmmeters

Ohmmeters are used to check resistance and also for continuity tests. They can be used to test a number of different components, including ignition coils, alternator windings and relays. Components must be *isolated* (removed) from a circuit to be tested with an ohmmeter. For more information on the use of electrical meters, see Chapter 38.

34.11.4 EMF radiation detection

In vehicles where electronics are used, manufacturers go to great lengths to suppress electromagnetic interference. This is to prevent stray magnetic fields from affecting other electronic devices such as sensor signals and CAN Bus communications; for example, a leaking ignition coil pack may impact on an electronic transmission shift pattern. This is not an uncommon problem, and many technicians have changed the transmission because of incorrect diagnosis when it is in fact the coil pack that should be changed. Locating this type of problem can be difficult, but an electromagnetic radiation tester (Figure 34.28) is a diagnostic tool that looks for excessive stray electromagnetic forces and electric field radiation. As with any diagnostic tool, the operator must know what is normal and what is not. Radiation fields drop off in intensity dramatically by distance or by shielding.

Figure 34.28 An electromagnetic field under the bonnet of a vehicle

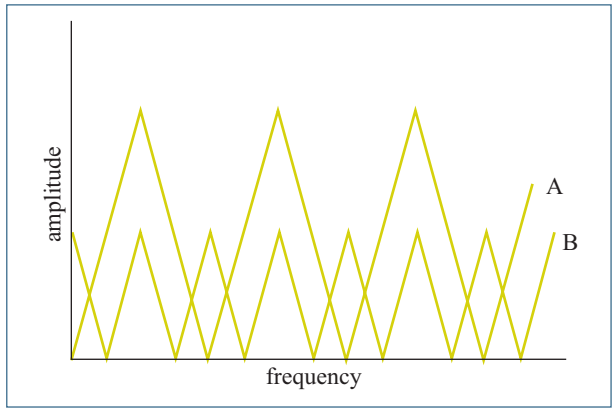


Figure 34.29 Two different vibration frequencies

34.12 Locating noise and vibration

Badly tightened bolts will allow parts to become loose on their mountings, although bolts subjected to repeated loads or shock loads may tend to come loose. Retighten the mounting bolts or nuts to the correct torque and make sure that the spring washer or other locking device is correctly in place. Also, make sure that the thread of the bolt is not damaged as this could prevent the bolt from being tightened correctly. A locking compound can be used on bolts that are likely to vibrate loose.

Some parts are more likely to become loose than others, for example the exhaust system, which is subjected to vibration and changes in temperature. Loose parts will vibrate and can produce unusual noises, and it is useful to determine whether the vibration occurs at a particular road speed or engine speed.

34.12.1 Resonance

Every part has a natural frequency of vibration, and resonance will occur when the frequency of one part matches the frequency of another. If this happens, the amplitude will increase and the noise from the natural frequency will become much more pronounced. Amplitude is the strength of vibration and the frequency is its rate of occurrence (Figure 34.29). Frequency B has peaks that occur at twice the rate of frequency A. This means that, at each second vibration, the peaks will occur at the same time, and this is when resonance occurs.

34.12.2 Sources of vibration

Vibration can come from the engine, the drive line or the wheels and tyres. Vibration dampers prevent engine vibration from being transferred to the body and chassis components. If the dampers are faulty, engine vibration could become more noticeable. Some radiators are loosely mounted on rubber that acts as a type of vibration damper.

The engine is mounted to the subframe on rubber mounts that are designed to absorb vibration. If these deteriorate or become loose or worn, vibration can be transferred from the engine through to the body. Suspension parts are mounted with rubber bushes which absorb noise and vibration. If these are worn or incorrectly fitted, noise can be transferred from the wheels and suspension to the body (Figure 34.30).

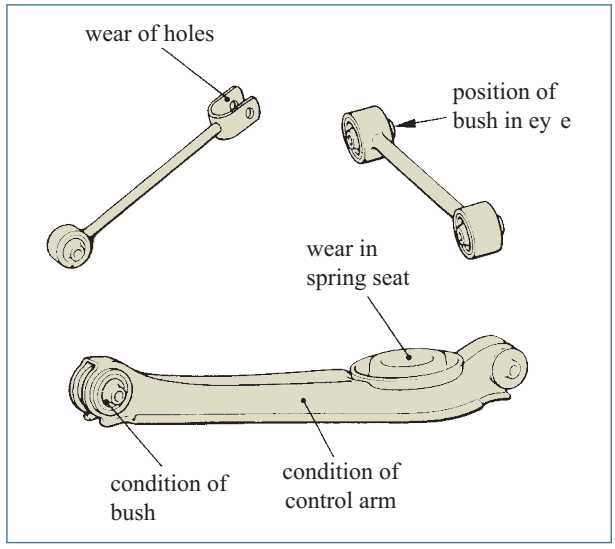


Figure 34.30 Worn or badly fitted bushes in suspension parts can cause noise

34.12.3 Rattles and other noises

The first step is to isolate the noise to a particular part of the vehicle, or to a particular component. The type of noise should indicate where to look. Noises associated with body movement are likely to come from part of the suspension, from a shock absorber, from its mountings or from the steering.

Check for such things as loose exhaust pipes or mountings, and make sure that the exhaust system is clear of the bodywork and suspension. Loose baffles in a muffler can produce loud exhaust noise and vibration.

Handy hint: When checking for rattles and noises, do not overlook loose tools or other items inside the car or boot.

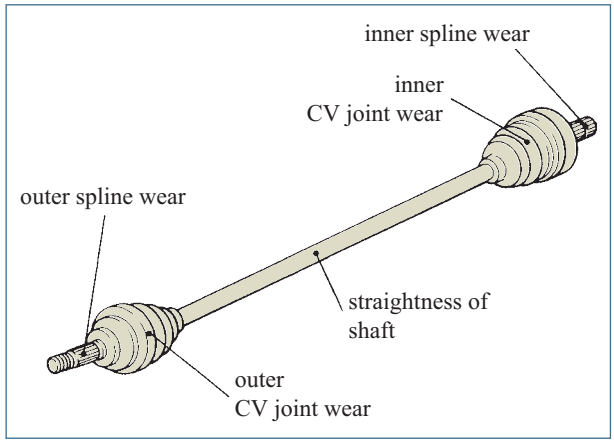


Figure 34.31 Parts of a drive shaft that could cause noise or vibration

34.12.4 Noises on the road

Noises that occur on the road can often be related to the speed. Noise at wheel speed is likely to come from a wheel or tyre. For front-wheel-drive vehicles, this is also the speed of the drive shafts, so noises from the constant-velocity (CV) joints also have to be considered. The outer constant-velocity joint, which operates at an angle during steering, might produce noise on a turn that is not noticeable during straight-ahead driving (Figure 34.31).

With rear-wheel-drive vehicles, the propeller shaft rotates faster than the wheels, and worn universal joints will produce a different type of noise. They can squeak at low speed if they are short of lubrication, and they can rattle and cause vibration at higher speeds if they are worn.

34.12.5 Intermittent noises

These are noises that come and go. Locating them often depends on obtaining a good description from the driver. However, if the noise cannot be heard, make sure that there is nothing that is likely to cause damage before allowing the vehicle to continue in operation.

34.12.6 Chassis ears

Figure 34.32 shows chassis ears, a valuable diagnostic tool when looking for noises in suspension, steering and drivetrain systems. Six microphone clamps are connected to the switchbox and the suspected areas, allowing accurate diagnosis of where noise comes from. The cables can be secured with Velcro tape,

while some kits work on Bluetooth, so no cables are needed.

Safety: Always use a driver and a diagnostic technician when using these tools.

34.13 Analysing gear problems

Gears working together can create a noise, usually called a 'whine' (although at slower speeds, misaligned gears will produce more of a 'growl'). In transmissions and final drives, noise is reduced by the lubricant between the gear teeth and the fact that the gears are enclosed in a housing. However, gears that are running out of line due to worn or defective bearings or worn shafts will produce excessive noise. With rear axles, the hypoid gears and bearings must be correctly adjusted, otherwise there will be very obvious noise.

34.13.1 Correct lubricant

The transmission or final drive must contain the correct type and amount of lubricant. Extreme-pressure lubricants are used in some transmissions. All rear axles need an extreme-pressure lubricant designed especially for hypoid gears. Those run without it would have scuffed gear teeth and would be very noisy. Limited-slip differentials and some four-wheel-drive couplings use special oils.

34.13.2 Diagnosing gear problems

When diagnosing gear problems, be aware of the forces produced by gears. A good indication of what is happening in transmissions is the oil sample. Drain the oil into a clean container and allow the sunlight to enter the oil. When high wear or damage has occurred, small metallic particles can be seen reflecting in the bright light. For tracing noises use in gearboxes and differentials, use the chassis ears mentioned earlier.

Figure 34.32 Components of a chassis ear kit (only three clamps are shown)

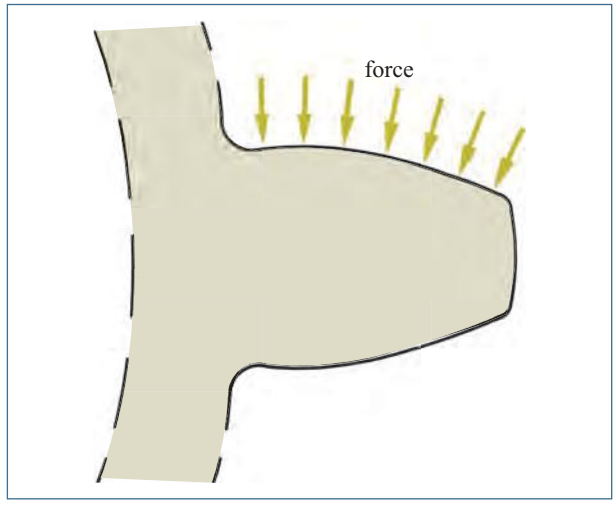


Figure 34.33 Gear tooth loading—the force moves down the tooth as the gear rotates

34.13.3 Forces produced by gears

There are three main forces that exist when two gears are in mesh and transmitting torque:

- tooth loading
- a separating force
- end thrusts.

Understanding where these forces originate and where they are applied can help when diagnosing gear problems, shaft wear, bearing noise or bearing wear.

Tooth loading

Torque is transmitted by the gears through their teeth, subjecting them to both a bending force and a shear force (Figure 34.33). These forces try to break the teeth off, but they are designed to resist this.

Separating force

Because of the somewhat-tapered shape of gear teeth, the load on the teeth tends to force gears apart, producing a separating force. This is transferred to the shafts which support the gears.

Figure 33.34 shows two meshed gears and their shafts. Any wear of the shafts will be on the inner parts. This is because these are the parts of the shafts that are taking the separating force of the gears. It is not unusual to find one 'side' of a shaft badly worn, while the opposite side (which carries no load) is almost unmarked.

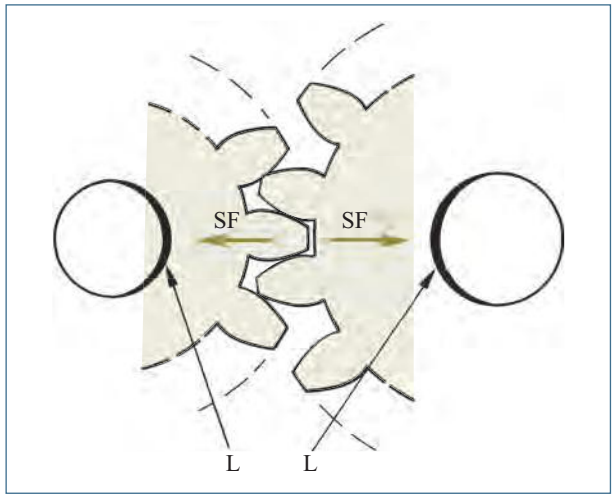


Figure 34.34 Spur gears in mesh—SF = separating force L = parts of the shafts under load

End thrusts

Because their teeth are curved, helical gears tend to wind themselves out of mesh and produce an end thrust under load. Two helical gears in mesh will produce thrusts in opposite directions, as shown in Figure 34.35. However, the direction of the thrust will change if the direction of rotation of the gears is changed.

Thrust washers are usually used to accept the thrusts from gears, although in some cases the thrust is accepted by the bearing which supports the shaft. This is what occurs with the main-shaft of a manual transmission (rear-wheel-drive vehicle). Thrust washers retain the gears in position and accept the thrust, but the main-shaft transfers the thrust to its rear bearing which is designed to take radial and thrust loads.

Early failure of the bearing could be the result of excessive thrusts caused by the way the vehicle is driven in the lower gears.

Spiral bevel gears, such as the hypoid gears in a rear axle, produce a separating force which tries to move the gears apart. They also produce a force caused by the spiral shape of the pinion. The pinion tries to wind itself out of the crown wheel and so there is a large force (thrust) along the pinion shaft which is accepted by the rear pinion bearing (Figure 34.36).

Handy hint: Plain spur gears with straight teeth have a separating force but no end thrust.

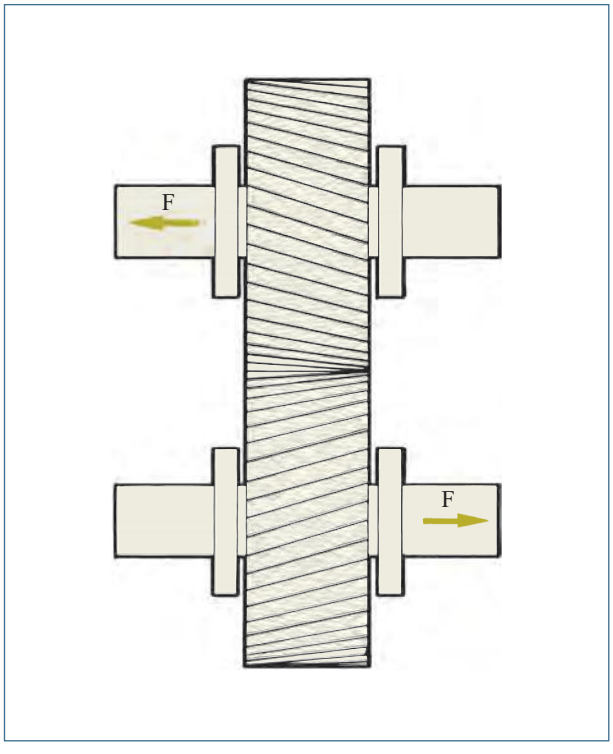


Figure 34.35 Helical gears produce end thrusts

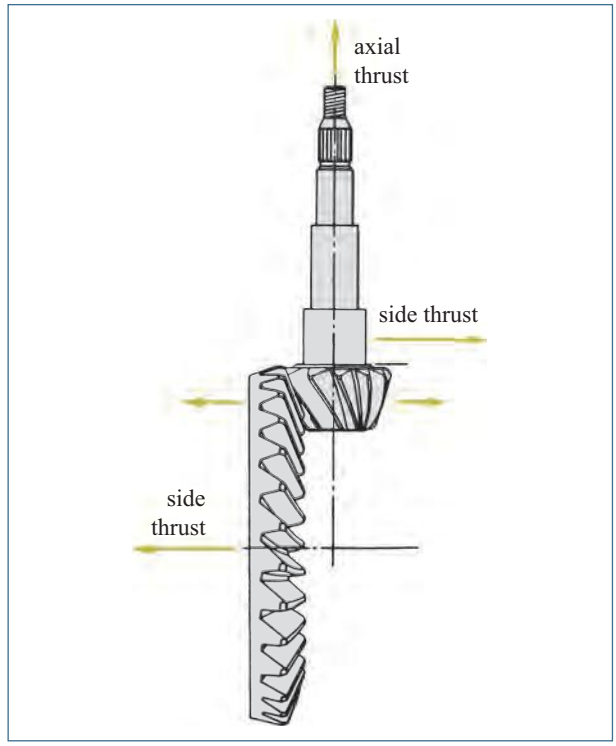


Figure 34.36 Spiral bevel gears—the load on the teeth tends to force them apart and the spiral teeth force the pinion forwards

34.14 Bearing problems

Bearings are associated with shafts and gears and so must also be considered when diagnosing shaft or gear problems. When examining ball and roller bearings for damage, consider possible causes under the following general headings:

- abrasion
- corrosion and rust
- poor lubrication
- mechanical damage .

34.14.1 Abrasion

When this occurs, the running surfaces of the bearing are a dull matt finish instead of being bright. This is due to dirt, grit or metal particles mixed with the oil, which becomes a lapping paste instead of a lubricant.

Corrosion and rust

Corrosion produces stains or light pitting on the running surfaces of the bearing. This can be caused by water entering the bearing through poor sealing or from off-road or unusual operating conditions.


Handy hint: Moisture from handling a bearing or from poor storage can cause corrosive stains.

Poor lubrication

Not enough lubricant, or the wrong type of lubricant, can cause a bearing to overheat. Discolouration of the surfaces will show if the bearing has been hot. The running surfaces could be coloured from beige to purple, depending on the temperature.

A bearing that is adjusted too tightly will overheat. With continued operation, it will cause damage in the form of light chipping or deep pitting.

Mechanical damage

This type of bearing damage could range from minor chips to broken retainers or races. The damage is fairly obvious, but the cause needs investigation. Problems such as the inner or outer race being too tight on the shaft or in the housing, faulty adjustment or poor fitting could all be possible causes. Bearings that should be preloaded but are loose can become damaged, and this will also allow misalignment of other parts.

See Chapter 6 for more information on bearings and related problems.

34.14.2 Where to find technical information and procedures

In the automotive world, knowledge is everything. Most manufactures will only allow dealerships to have access to technical information about the vehicles. This, plus the lack of printed information to copy, can make accessing information or procedures very difficult. Organisations such as the Victorian Automobile Chamber of Commerce (VACC) and Autodata can help, but this involves paying for membership to access the information. With the ever-increasing amount of content online, information may be gleaned from other people's contributions to forums and debates.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain how diagnosis requires a thorough understanding of all vehicle systems
- explain the importance in diagnosis of gathering information from the customer
- verify information provided by a customer and check potentially associated systems
- identify tools that can be used to test systems exhibiting noises and vibrations
- describe what equipment to use in the case of electrical faults
- describe what equipment to use to assist in the diagnosis of electronic faults

- explain how to use flow charts to locate or diagnose a fault
- explain the importance of testing systems after a fault is repaired and of checking associated systems that may have been affected
- explain the importance of regular and proper maintenance , correct lubricants and fluids, as recommended by the manufacturer .

REVIEW QUESTIONS

1 What is meant by diagnosis ?
2 Outline a general sequence to be followed when diagnosing a problem.
3 What are some of the possible causes if a starter motor cranks the engine but the engine does not start?
4 What are some of the lik ely causes of engine overheating ?
5 What type of problem is lik ely to be caused by an air leak at the intak e manifold?
a On an engine with a MAP sensor?
b On an engine with an airflow meter?
6 What actions should be tak en to investigate a complaint of ex cessive fuel consumption ?
7 The text notes some basic requirements for an EFI fuel system to function correctly . What are these ?
8 How can a connecting-rod noise be isolated?
9 What causes piston-pin noise ?
10 What is piston slap ?
11 What could cause drive-belt noise ?
12 What is an engine analyser ?
13 What is a scan tool ?
14 Sketch the oscilloscope display pattern you could expect from an injector .
15 What type of oscilloscope pattern could be expected from a zirconia o xygen sensor?
16 What are the three different modes in which ignition patterns can be displayed on an engine analyser screen ?
17 What type of connections are made between the analyser and the engine ?
18 What does a data logger do?
19 Describe the scanner function live data or data streaming .
20 What information can an exhaust gas analyser provide ?
21 Outline briefly how a compression gauge is used.
22 Name the three main electrical multimeter measurements, and indicate how they are connected when being used.
23 When faced with an unfamiliar problem, what should be done first?
24 What is the difference between cause and effect as far as a problem is concerned?
25 What is torsion ?
26 What is failure analysis ?
27 What is a fatigue failure ?
28 What would identify a fatigue failure of a shaft?
29 What is scuffing and scoring ?
30 What could cause seizing ?
31 Name some of the places from which noises are most lik ely to come .
32 What parts are lik ely to produce vibration ?
33 What is frequency in relation to vibration ?
34 What is an intermittent noise ?
35 What types of forces are produced by gears ?
36 How would overheating show on a bearing ?
37 How is poor lubrication lik ely to affect gears ?
38 What is the function of the road-speed sensor ?
39 State the main checks that would be made during the road test of an automatic transmission.
40 How could the parking pawl be check ed?
41 Name the different sections of an automatic transmission that would be considered when locating a fault.

PART 6

Diesel engines

CHAPTER 35

Diesel engines: features

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 list the features of diesel and petrol engines
2 describe the differences between two- and four-stroke diesel engines
3 describe the types and functions of combustion chambers used in diesel engines
4 describe the methods used to aid the starting of a diesel engine
5 describe the combustion process in a diesel engine
6 describe the operation of the diesel engine.

Although diesel engines are compression-ignition engines, they are usually referred to simply as diesels. Compression-ignition engines use very high compression ratios to produce high pressures in the combustion chambers. The high pressures, in turn, produce temperatures that are high enough to ignite the fuel charge in the combustion chambers without a spark or any other electrical device.

35.1 Comparison of diesel and petrol engines

The following points emerge from a comparison between diesel and petrol engines:

1 Diesel and petrol engines have the same mechanical parts, although diesel components are generally stronger and heavier.
2 Both engines are internal-combustion engines, but they have different fuel systems and use different fuels.
3 With a diesel, only air enters the cylinder during the intake stroke; a petrol engine has an air–fuel mixture.
4 In a diesel, the fuel is injected into the cylinder as a fine spray near the top of the compression stroke. With a petrol engine, the fuel is injected at the start of the induction stroke.
5 Ignition in a diesel occurs through the high temperature from the highly compressed air. A petrol engine needs a spark for ignition.
6 Diesel engines generally operate at lower engine rpm than petrol engines.
7 Diesel engines use distillate (commonly called diesel) for fuel, which is less volatile than petrol.
8 The design of diesel engines makes them noisier than petrol engines and they have a unique diesel knock.
9 Petrol engine fuel is measured as an octane rating, whereas diesel fuel is measured with a cetane rating. The cetane number refers to the combustion speed of diesel fuel and the compression needed for ignition. The cetane rating of fuel typically ranges from 42 to 45, while premium diesel fuel rating can be as high as 60.

Small diesel engines and petrol engines are used in passenger and light commercial vehicles. Larger diesel engines are used in all heavy commercial vehicles, earthmoving equipment and farm machinery.

35.2 Four-stroke diesel engines

Figure 35.1 shows a diesel engine of the type used in passenger and light commercial vehicles. It is a four-cylinder four-stroke engine, with an overhead camshaft driven by a toothed timing belt. Compared with an equivalent petrol engine, it has different pistons and a different cylinder head and combustion chambers. It has injectors in the cylinder head to deliver fuel and an injection pump (not shown) to supply fuel to the injectors.

Some light diesel engines have four valves per cylinder, while others have two. Some diesels have twin overhead camshafts, and others have a single camshaft operating two or four valves for each cylinder.

35.2.1 Four-stroke diesel cycle

Figure 35.2 shows a single cylinder of a four-stroke diesel engine. The cylinder head has an intake valve, an exhaust valve and an injector. The four strokes—intake, compression, power and exhaust—are completed in two revolutions of the crankshaft.

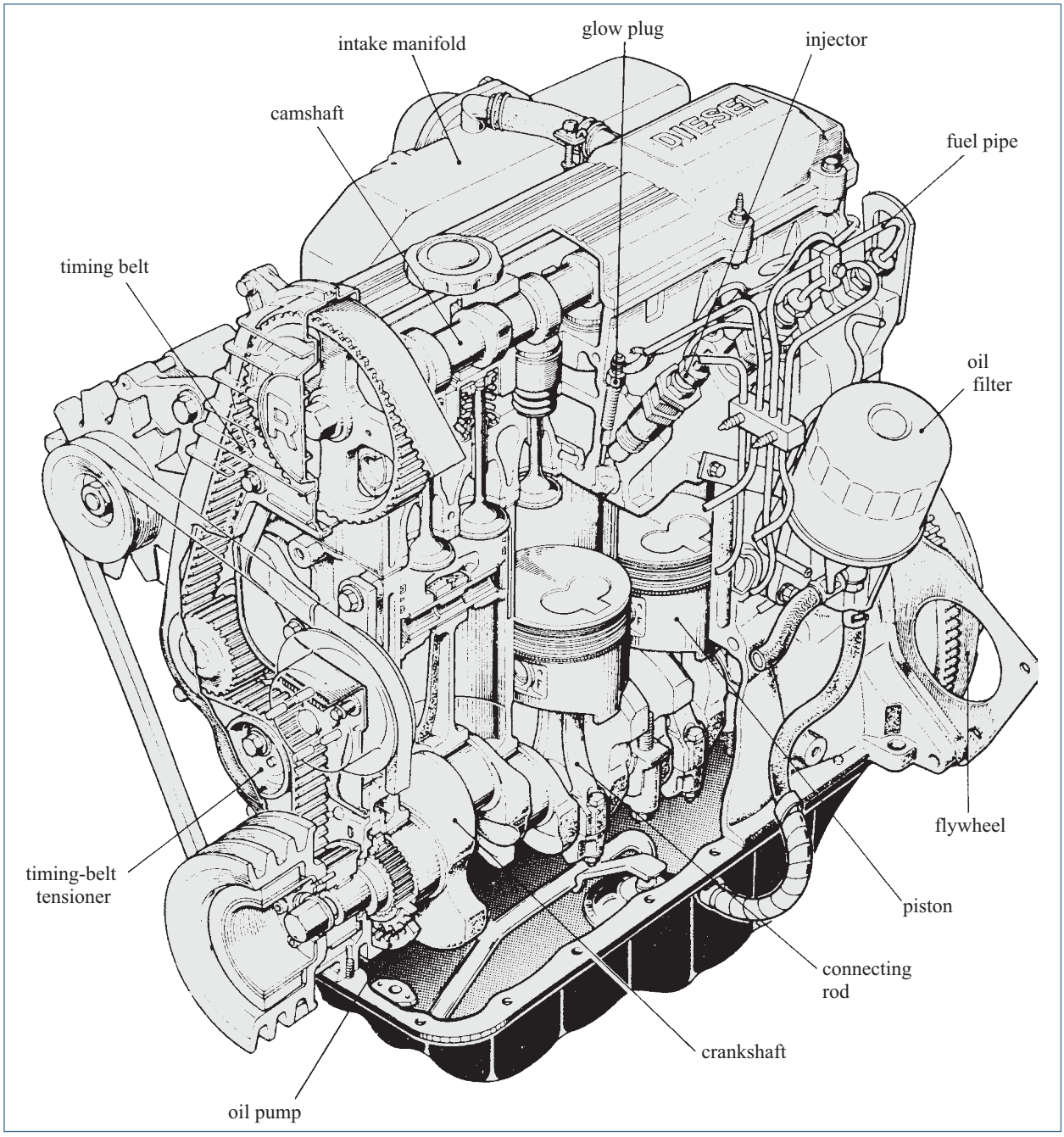


Figure 35.1 Diesel engine of the type used in passenger and ligh t commercial vehicles FORD

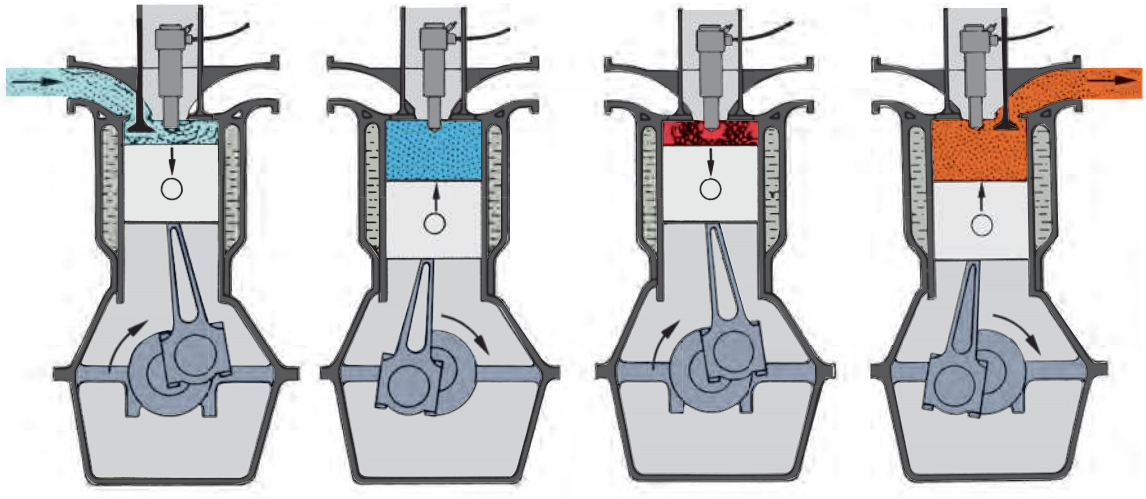


Figure 35.2 The four strokes of a diesel cycle

The sequence is as follows:

1 Intake. The piston on its downstroke takes air into the cylinder through the open intake valve.
2 Compression. Both valves are closed as the piston moves upwards to compress the air in the combustion chamber. The compression ratio is around 15:1, and this produces a high temperature.
3 Power. At the end of the compression stroke and the start of the power stroke, the injector directs a fine spray of fuel into the combustion chamber. This is ignited by the temperature of the compressed air, and the expanding gases force the piston down the cylinder.
4 Exhaust. The exhaust valve is open and the burnt gases are forced out as the piston moves up the cylinder. Once the piston reaches TDC, the cycle is completed and then recommences.

35.3 Two-stroke diesel engines

Two-stroke diesel engines are used in some heavy commercial vehicles and other heavy equipment. They are not used in passenger and light commercial vehicles. Figure 35.3 shows the operation of one cylinder of a two-stroke diesel engine.

This has an air-inlet port in the cylinder wall and an exhaust valve and an injector in the cylinder head. Unlike a two-stroke petrol engine, it does not depend on crankcase compression but has a blower driven by the engine. The blower provides air through the air-inlet port at a pressure slightly higher than that of the exhaust gases, so that it not only fills the cylinder with air but also blows the exhaust gases from the cylinder.

35.3.1 Two-stroke diesel cycle

In a two-stroke diesel cycle, all the events occur in two strokes: one upstroke and one downstroke, as shown in Figure 35.3.

1 Scavenge. The piston is at BDC. Air is being delivered from the blower through the inlet ports in the cylinder wall. This fills the cylinder with fresh air and blows out the exhaust gases through the open exhaust valve in the cylinder head.
2 Compression. The piston is moving upwards and has covered the air-inlet ports to cut off the supply of air from the blower. The exhaust valve is closed. The piston continues upwards to compress the air in the cylinder to about one-sixteenth of its original volume. This raises the temperature of the compressed air.
3 Injection. The piston is almost at TDC on the compression stroke. Atomised fuel is sprayed from the injector into the combustion chamber and is ignited by the high temperature of the compressed air. The resulting pressure forces the piston down the cylinder on the power stroke.
4 Power. The piston is moved down the cylinder on the power stroke. The exhaust valve is timed to open just before BDC to allow the exhaust gases to escape from the cylinder.

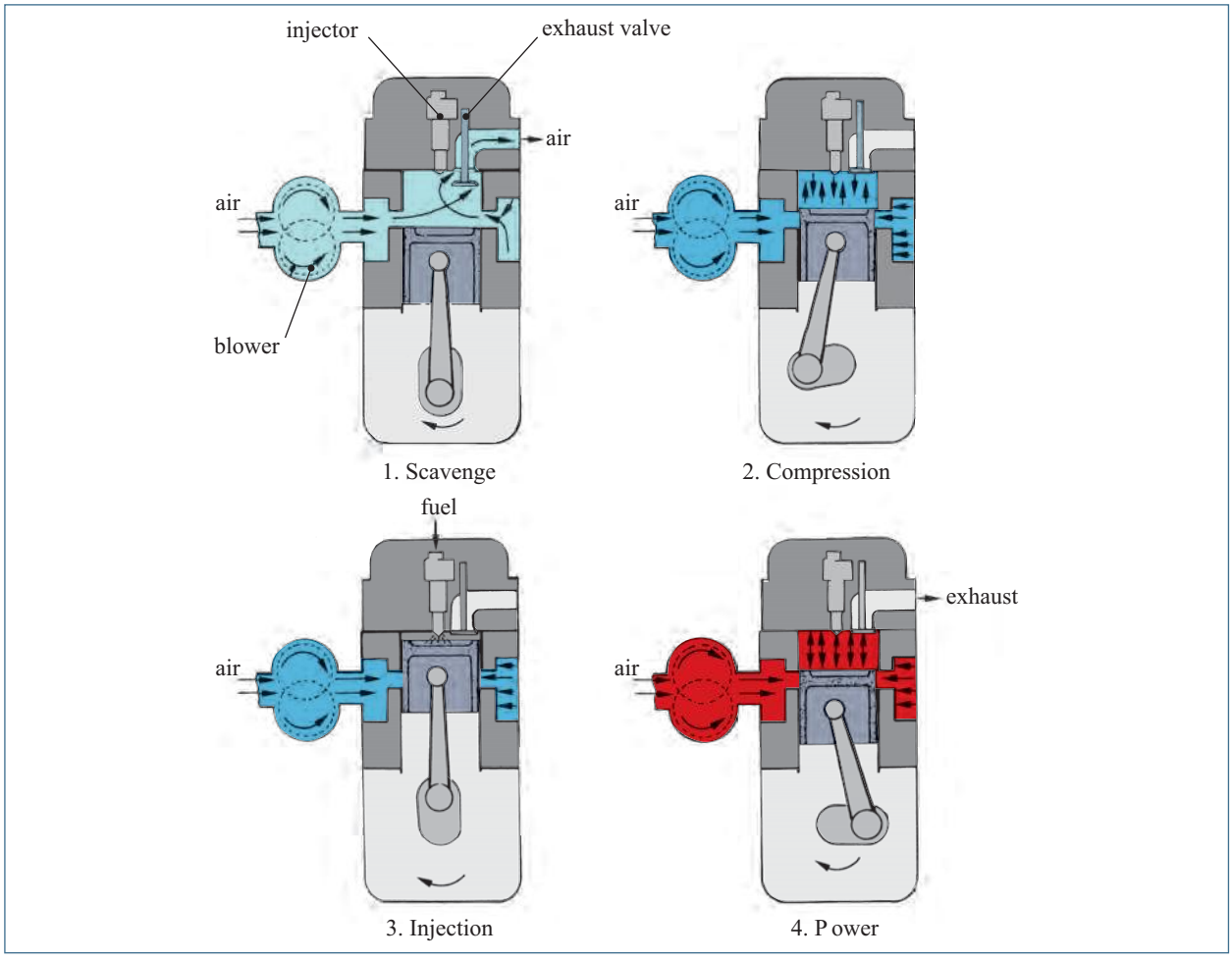


Figure 35.3 Two-strok e diesel cycle

As the crankshaft continues to rotate, the piston will reach BDC and uncover the inlet ports to admit air from the blower, and the cycle will continue as before.

Handy hint: The entire two-strok e cycle recurs with each revolution of the crankshaft.

35.4 Scavenging

Scavenging is the action of clearing the cylinder of exhaust gases. The action of incoming air also helps with this process. In a two-stroke diesel engine, scavenging occurs when air from the blower is admitted to the cylinder through the inlet ports (often referred to as *scavenge ports*, and the air from the blower as *scavenge air*). In a four-stroke engine (petrol or diesel), scavenging is arranged by combustion chamber design, and also by valve overlap; that is, having both the exhaust valve and intake valve open together for a short period of time.

35.5 Types of combustion chambers

The combustion chamber in a diesel engine is the space into which the atomised fuel is sprayed by the injector. This includes space formed in or by the piston crown as well as parts of the cylinder head.

All types of combustion chambers must be able to do two things: create the high compression pressures that are needed to produce the high temperatures for ignition and mix the injected fuel with the air in the combustion chamber to obtain complete burning and maximum power from the fuel.

Handy hint: **There are two basic types of combustion chambers (see Figure 35.4): those used with** direct injection and those used with indirect injection.

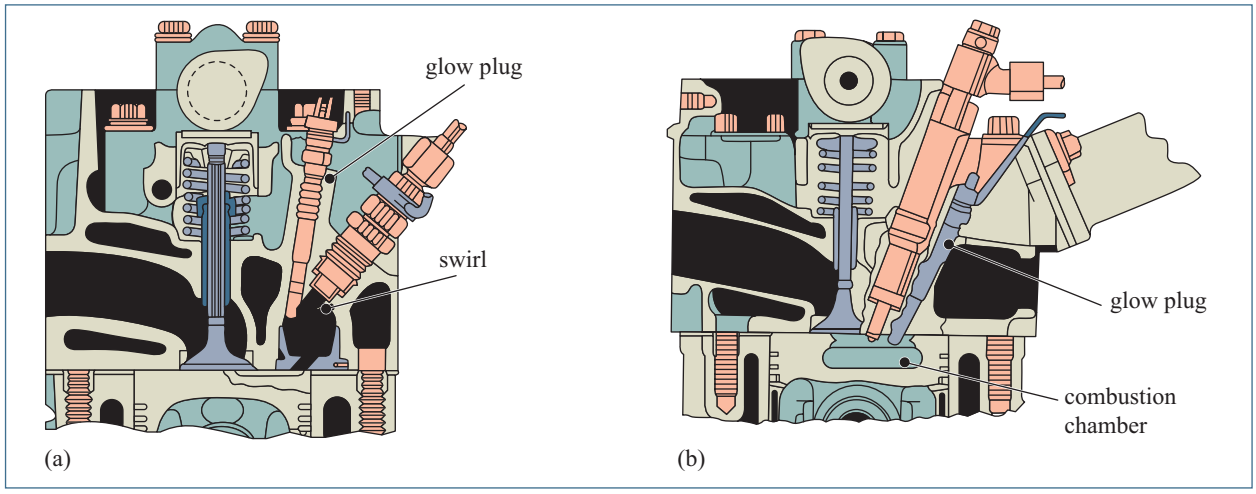


Figure 35.4 Combustion chamber design (a) swirl chamber (b) direct injection

35.5.1 Direct-injection chambers

With direct-injection engines, fuel is injected directly into the combustion chamber, which is a cavity in the piston head (Figure 35.5). There is very little clearance between the top of the piston and the cylinder head at TDC. This causes the air being compressed in the cylinder to be forced away from the outer area of the piston head towards the combustion chamber in the centre of the piston. This promotes turbulence and mixing of the air with the particles of fuel in the spray from the injector.

Direct-injection systems are also known as *open chambers*. The combustion chamber in the piston head can be cylindrical, hemispherical or toroidal (Figure 35.6). Injectors have different spray patterns to suit the shape of the combustion chambers with which they are used.

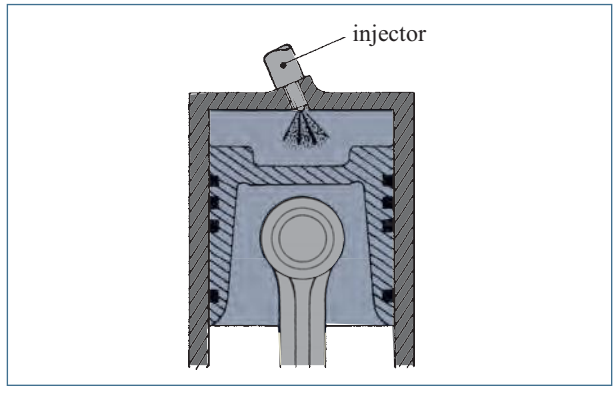


Figure 35.5 Direct injection—the combustion chamber is formed in the top of the piston

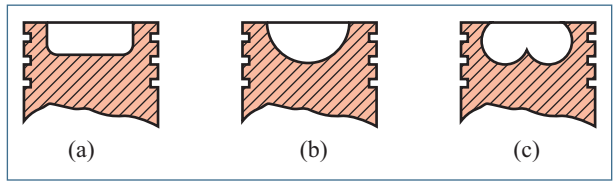


Figure 35.6 Shapes of combustion chambers in piston heads of direct-injection engines (a) cylindrical (b) hemispherical (c) toroidal

35.5.2 Indirect injection

These systems do not inject the spray of fuel directly into the main combustion space but into a small, separate chamber in which ignition occurs. The small chamber is connected to the main combustion chamber so that once combustion commences in the former, it immediately extends to the latter.

There are variations in the design of separate combustion chambers, and the names *swirl chamber*, *precombustion chamber* and *air cell* are used. Their purpose is to make sure that every tiny droplet of fuel comes into contact with air and so receives the oxygen necessary for complete combustion.

Handy hint: The function of the separate chamber is to promote combustion in the **main chamber**.

Swirl chamber

Figure 35.7 shows a swirl chamber, a spherical chamber connected to the main chamber by an

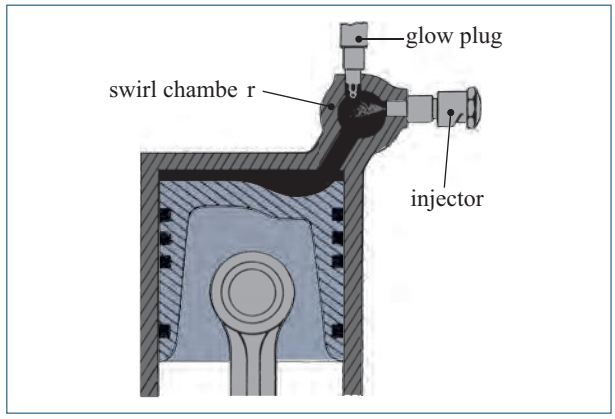


Figure 35.7 Basic swirl chamber—it has an injector and a glow plug FORD

angled passage. Air is forced into the chamber during the compression stroke and the shape of the chamber promotes rapid swirling of the air.

When the fuel is sprayed into the chamber, combustion commences, causing a very rapid expansion. The burning gases are forced out through the passage into the main combustion chamber, where combustion continues. The piston head is usually shaped to promote the swirling action.

Precombustion chamber

Figure 35.8 shows a basic precombustion chamber with an injector at its upper end. Injection occurs near the top of the compression stroke but, because of the limited amount of air in the pre-combustion chamber, only part of the fuel in the chamber will be burnt.

However, the high rise in pressure forces burning fuel from the precombustion chamber into the main combustion chamber where burning continues. Again, the rapid movement of the gases causes the fuel and air in the main chamber to mix and promote better combustion.

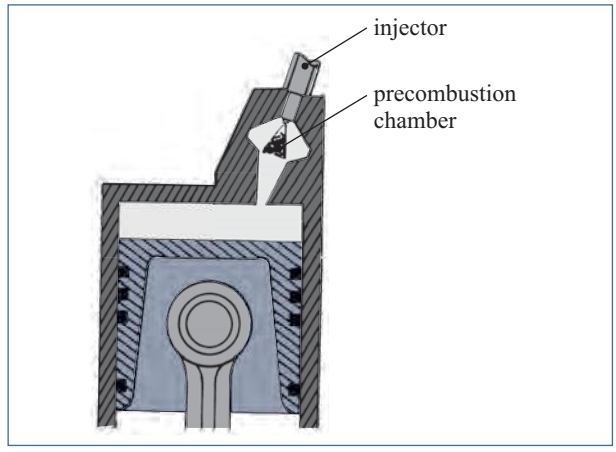


Figure 35.8 Basic precombustion chamber FORD

Air cell

Figure 35.9 illustrates an air cell, which is connected to the combustion chamber by a throat or venturi. Air is compressed in the air cell during the compression stroke. The injector is located in the throat. When injection commences, combustion pressure forces the air from the air cell, where it mixes with the spray from the injector. The resulting rush of air produces a rotary motion of the gas in the main chamber, which assists with efficient combustion.

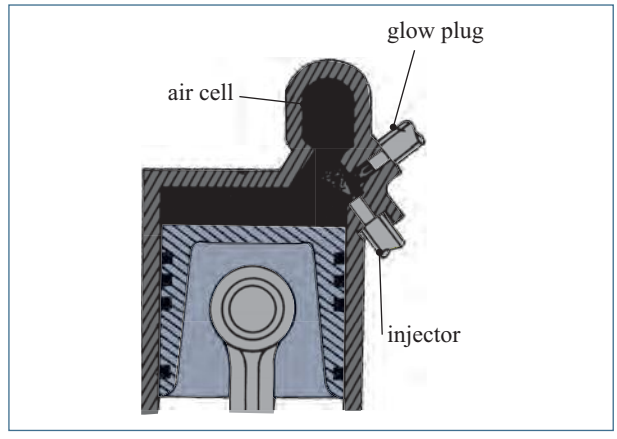


Figure 35.9 Basic air cell with a glow plug and injector FORD

35.6 Combustion chamber design

The following examples of the design of combustion chambers for four-stroke engines show how these combustion chambers are used in different engines.

35.6.1 Swirl chamber design

Figure 35.10 shows a swirl chamber in a cylinder head. The upper part of the chamber is formed in the cylinder head, in which a fitted insert forms the bottom of a spherical-shaped chamber. The injector and the glow plug are both screwed into the cylinder head. The engine in Figure 35.1 has indirect injection with swirl chambers.

Figure 35.10(b) shows the action of the swirl chamber. During compression, the air is swirled within it, as shown by the arrows. After injection, this swirling action continues as the burning gases are forced from the chamber. There is a hollow in the piston head that helps to promote turbulence. The glow plug is used to heat the air for cold starts.

35.6.2 Precombustion chamber design

Figure 35.11 shows a cylinder head with a precombustion chamber. The precombustion chamber is screwed into the cylinder head and the injector is screwed into the top of the combustion chamber. There is a diffuser ball in the upper part of the chamber and burn holes in the end of the chamber that protrudes into the main combustion chamber.

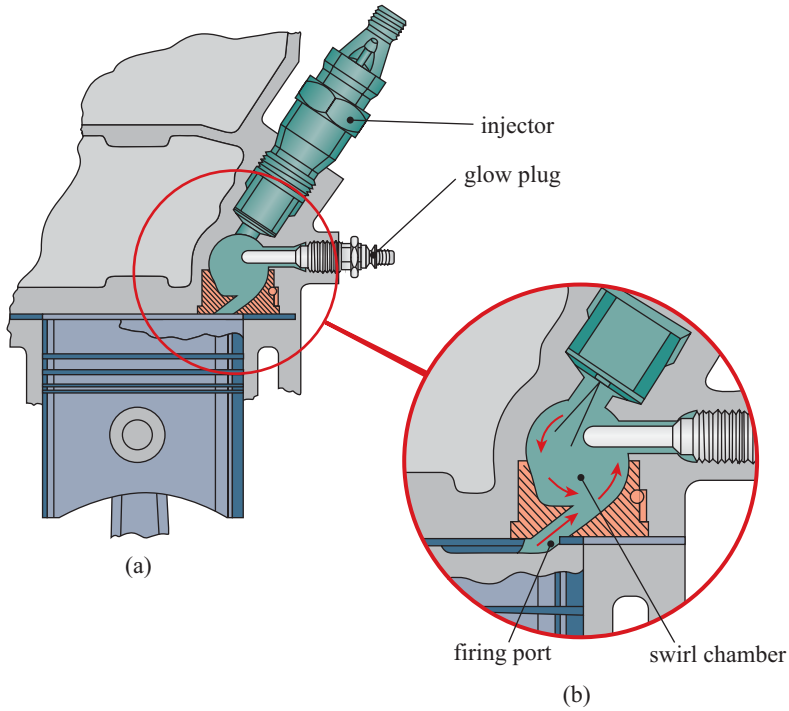


Figure 35.10 Swirl chamber (a) section of an engine with a swirl chamber , injector and glow plug (b) close-up of swirl chamber arrangement

Fuel injected into the precombustion chamber is directed at the diffuser ball, which disperses it into a mist which assists the combustion process. Burning gases then travel quickly through the burn holes in the end of the precombustion chamber into the main combustion chamber where burning continues.

The head of the piston has a pocket to provide clearance for the end of the precombustion chamber. It is also hollowed to create swirl in the main combustion chamber. This is one of the most common arrangements for automotive engines.

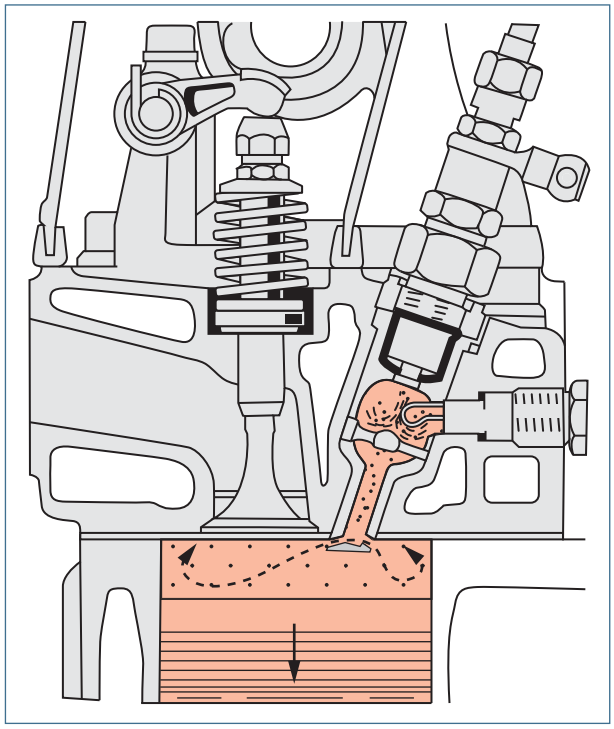


Figure 35.11 Precombustion chamber—the injector sprays fuel into a small combustion chamber in the cylinder head, which is fitted with a glow plug for starting purposes

35.6.3 Direct-injection chamber design

With direct injection, the underside of the cylinder head is flat and the whole combustion chamber is formed in the top of the piston. A typical piston for a direct-injection engine is shown in Figure 35.12. This has a doughnut-shaped, toroidal-type combustion chamber.

When the piston is at TDC on the compression stroke, there is very little clearance between its top and the cylinder head, and so the air is compressed into its cavity. Also, during the compression stroke, turbulence is created by the shape of the piston head.

The cylinder head associated with this piston is shown in Figure 35.13(a). It has four valves per cylinder, arranged so that the injector can be mounted above the centre of the piston. At TDC of the compression stroke, fuel from the injector is sprayed directly into the piston cavity.

To further assist with mixing the air and fuel, the valves are positioned as shown in Figure 35.13(b). The position of the intake valves and the shapes of the intake passages produce a swirling effect as the air enters the cylinders.

Safety: As diesel engine compression pressures can be as high as 21 bar , care should be tak en when conducting engine compression tests.

35.7 Devices to assist star ting

Various devices assist in starting diesel engines under cold conditions. Some of these provide additional fuel; others heat the air to help ignition.

35.7.1 Glow plugs

Glow plugs are the most commonly used devices. They are small electric heater plugs fitted to the small combustion chambers of indirect-injection engines (Figure 35.14). They provide heat during cold starting by increasing the temperature of the air being compressed. This replaces some of the heat that is lost from the compressed air to the colder parts of the engine.

Glow plugs are also used to ensure that there is enough heat in the combustion chamber for complete combustion after the engine has started. This reduces emissions and is controlled by the ECU. The glow plugs are connected into the starting switch and can be operated before, during or after starting. Figure 35.15 shows a basic circuit for glow plugs, with a timing device and a glow plug indicator light. Where the engine has an electronic control system, this is used instead of the timing device.

35.7.2 Excess-fuel device

Most injection pumps have a device that provides additional fuel during starting. The extra fuel makes it easier for combustion to take place.

35.7.3 Intake air heater

An electrical heating element is fitted in the air-intake system of some direct-injection engines. This provides heated air to make starting easier under cold conditions. The heater remains on for a short time after the engine starts. It is switched on and off by the engine's electronic control unit.

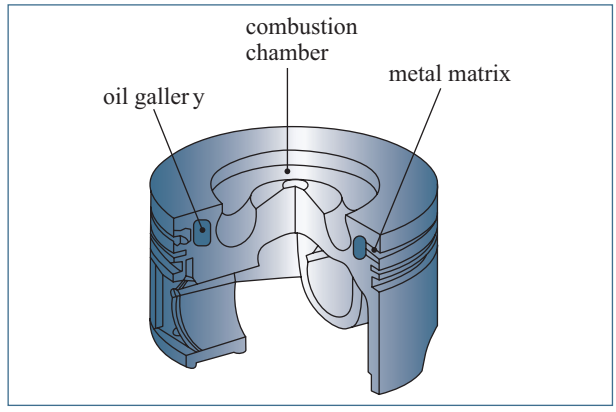


Figure 35.12 Piston with a toroidal-type combustion chamber and an oil gallery

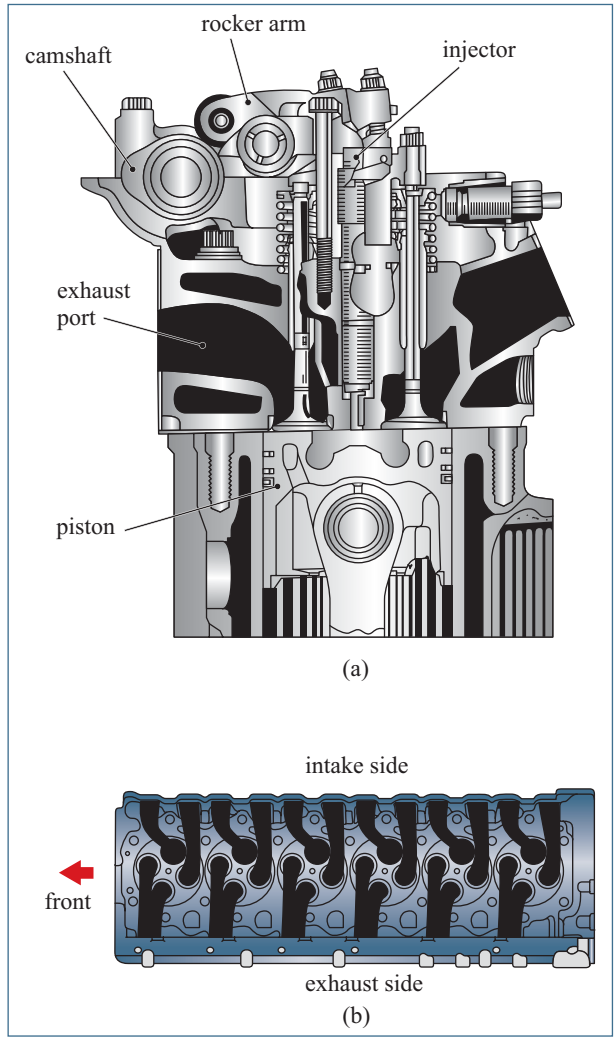


Figure 35.13 Arrangement of cylinder head with four valves per cylinder: (a) sectional view (b) arrangement of the valve ports

35.8 Combustion of fuel in the engine

A feature of diesel engines is the manner in which the fuel is burnt in the engine and the way in which power is produced. The fuel comes from an injector as a very fine spray of droplets of fuel. When these droplets are injected into the hot compressed air, they start to evaporate; when the vapour reaches the right temperature, it starts to burn.

The centre of each droplet is comparatively cool and does not burn immediately; there is a progressive burning of fuel as it turns from liquid to vapour. Once ignition is started, there is a rapid rise in both pressure and temperature, so that fuel that is still being sprayed from the injector starts to burn immediately. Burning then continues, even after injection has ceased, until all the fuel in the combustion chamber has been burnt.

Handy hint: With a diesel engine, the cylinder holds more air than is needed for the fuel that is injected. Engine operation depends on the fuel being adequately dispersed into the air in the cylinder.

35.8.1 Four phases of combustion

The combustion process in a high-speed diesel engine consists of four stages. Figure 35.16 illustrates these as a graph. It shows the increase in pressure in the cylinder compared with the rotation of the crankshaft from 90° before TDC to 90° after TDC. There are two lines on the graph:

1 The dotted line shows how the pressure in the cylinder would change if no fuel was injected. During and after the compression stroke, the rise and fall of pressure would be uniform throughout the strokes.
2 The solid line shows the change in pressure during the compression and power strokes when fuel is injected. The pressure in the cylinder increases rapidly as a result of combustion.

The four phases of combustion are indicated on the graph as follows:

1 A to B—the delay period. Injection starts at A, but combustion does not occur immediately, being delayed until the vapour surrounding the droplets from the injector spray reaches a high-enough temperature to start burning. Burning (or combustion) starts at B.
2 B to C—a phase of rapid burning. Following the start of combustion, the droplets burn rapidly, causing a sudden pressure rise until point C is reached. During this phase, burning is uncontrolled.

Figure 35.14 A glow plug provides heat during starting

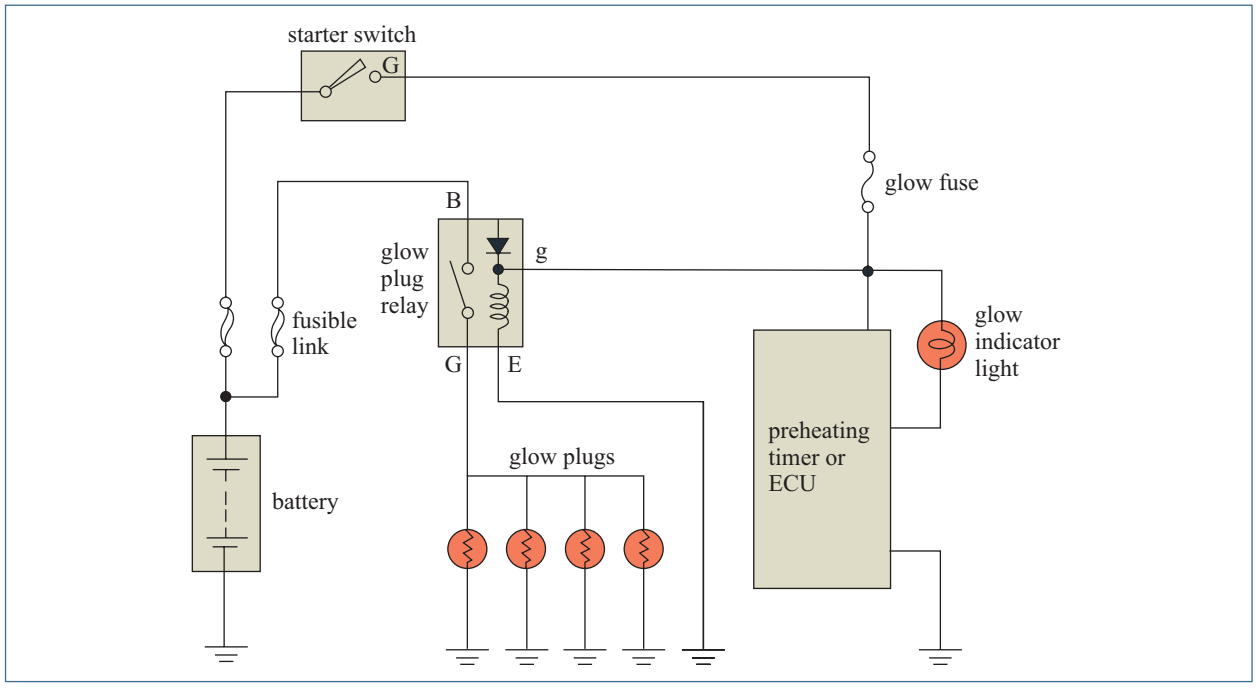


Figure 35.15 Electrical circuit for glow plugs

3 C to D—a phase of controlled burning. Fuel is burnt uniformly as it continues to be injected. Combustion is controlled by the rate of injection until point D , when injection ends.
4 D onwards—afterburning. Combustion continues until all the fuel has been burnt. There is no increase in pressure shown on the graph because the piston is now moving downwards and increasing the volume of the cylinder .

Combustion depends on a number of factors, including combustion chamber design, size and design of the injector nozzle, the fuel used and the operating conditions of the engine. If the delay period is too long, a large amount of fuel will be subjected to uncontrolled burning. This causes a sudden pressure rise that produces a knock.

35.8.2 Products of combustion

Diesel fuel is a hydrocarbon (as is petrol), and this provides the combustible elements of hydrogen and carbon. The products of combustion in a diesel engine that is operating efficiently and in good mechanical condition are:

1 water vapour (H_2O)
2 carbon dio xide (CO_2)
3 unused o xygen (O_2)
4 oxides of nitrogen (NO_x)
5 carbon mono xide (CO).

Because of the high combustion temperatures in a diesel engine, there should be little or no hydrocarbon (HC) remaining from unburnt fuel, if the fuel system is in good condition. However, during cold starting, some fuel that is not fully burnt can cause white or blue smoke to appear. Dense black smoke from the exhaust is a sign of unburnt fuel and generally indicates an injection system in poor condition.

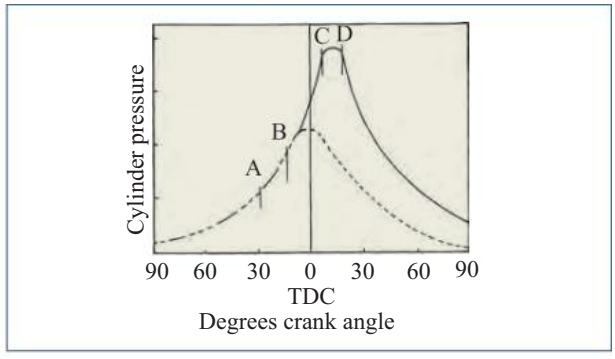


Figure 35.16 Phases of combustion in a diesel engine

Safety: Exhaust emissions can be harmful, and care should be tak en not to operate an engine in an enclosed space . Adequate ventilation must be maintained at all times.

35.9 Turbochargers and blowers

Turbochargers and blowers force air into the cylinders. This provides a greater mass of air than if only atmospheric pressure is used. The greater mass of air provides more oxygen for combustion, enabling more fuel to be burnt in the combustion chamber. The result is an increase in volumetric efficiency and a higher power output from the engine.

Blowers provide scavenge air for two-stroke diesels. This is usually at a pressure that is only slightly above atmospheric pressure and has no real supercharging effect. Engine-driven blowers of the Rootes type are used (Figure 35.17). These provide a large volume of air at a relatively low pressure.

Handy hint: The term blower is sometimes used as a common term for turbochargers, superchargers and blowers, but in this book they are considered to be different components.

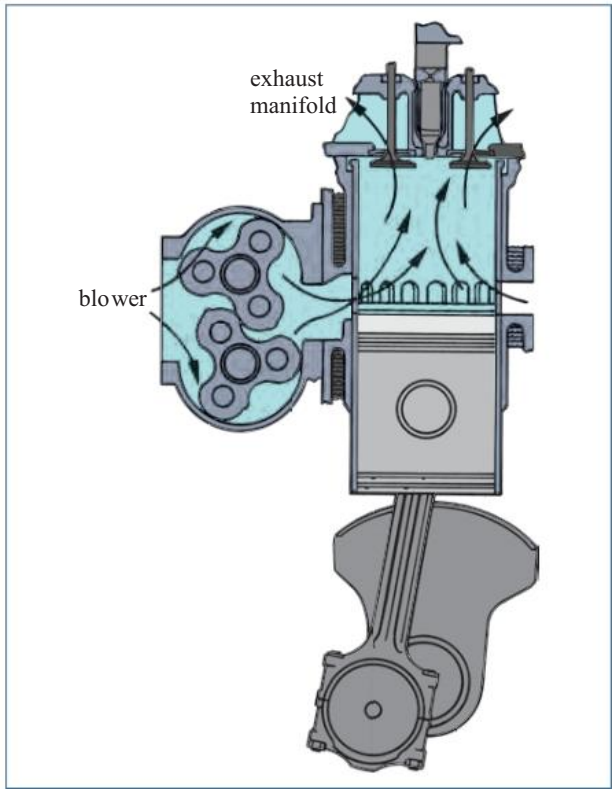


Figure 35.17 Air intake in a two-strok e diesel engine

35.9.1 Turbocharger

This consists of a compressor mounted on the same shaft as a turbine that is driven by the exhaust gas. The energy in the exhaust gas, which would otherwise go to waste, is used to increase the mass of the air charge in the cylinders. Figure 35.18 shows a basic turbocharger arrangement.

The main parts of a turbocharger are the rotor and the housing. The rotor consists of a shaft with a turbine wheel on one end and a compressor wheel or impeller on the other. The rotor is mounted in the housing to form an exhaust-driven turbine at one end and a compressor at the other. Exhaust gases directed through the turbine cause the rotor to turn at high speeds and operate the compressor.

Air enters the compressor at the centre. It is compressed as it is forced outwards by centrifugal force from the high rotational speed of the compressor wheel. In this way, a greater mass of air is forced into the cylinder.

Figure 35.19 shows the main components of a turbocharger, with the turbine on the left and the compressor on the right of the rotor. The housing has a central chamber through which engine oil is circulated to lubricate and cool the shaft and bearings. The turbine housing is arranged with vanes, which form a ring of nozzles. The exhaust gas from the engine flows around the turbine housing and is then directed inwards by the nozzle blades, so that it has a high velocity before entering the turbine wheel.

Turbochargers not only use the waste energy in the exhaust gas, but they also respond to engine demands. If more fuel is injected into the engine, the energy in the exhaust gases will increase. Turbocharger speed will increase and there will be a greater mass in the air charge entering the engine. However, turbocharger speed must be limited to prevent excessive speed and pressure, and this is done with a wastegate control.

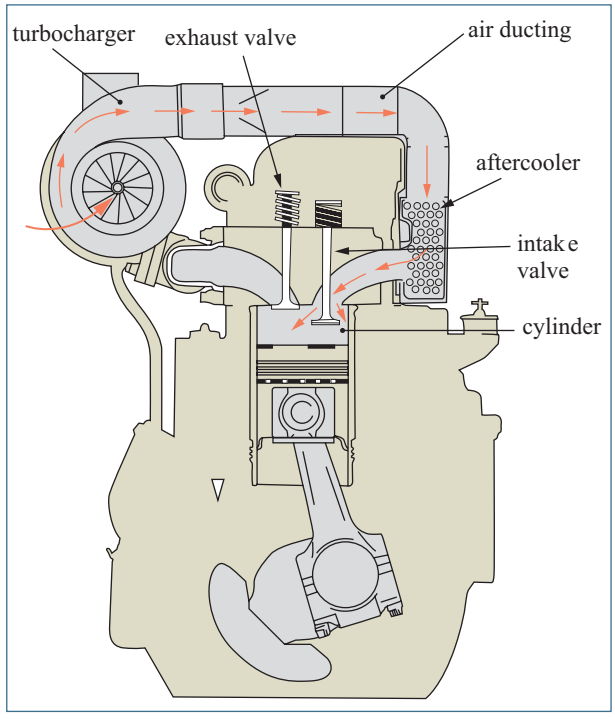


Figure 35.18 Turbocharger with aftercooler showing intake air flow

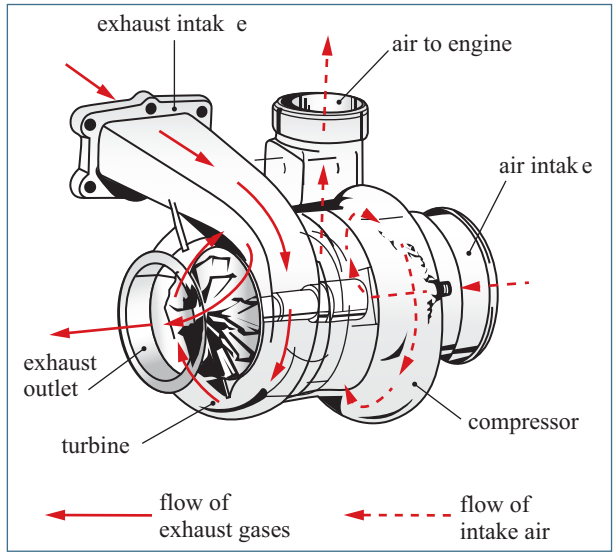


Figure 35.19 Turbocharger with parts named

35.10 Turbocharged diesel engines

Two different views of a small high-speed diesel engine with a turbocharger are shown as Figures 35.20 and 35.21. In Figure 35.20, the turbocharger is in part section, together with the wastegate control. This controls the flow of exhaust gases through the turbine, and this controls the speed of the turbocharger.

The sectional view of the engine (Figure 35.21) shows the turbocharger and the intake and exhaust systems. The injection pump, injector and glow plug are also identified. The engine has a swirl chamber in the cylinder head.

35.11 Other engine design features

The following features are found in diesel engines.

35.11.1 Oil cooler

Most diesel engines, particularly turbocharged engines, have an oil cooler. Oil is a cooling medium and it absorbs a lot of heat from the engine parts. Turbochargers are lubricated and cooled by a flow of engine oil.

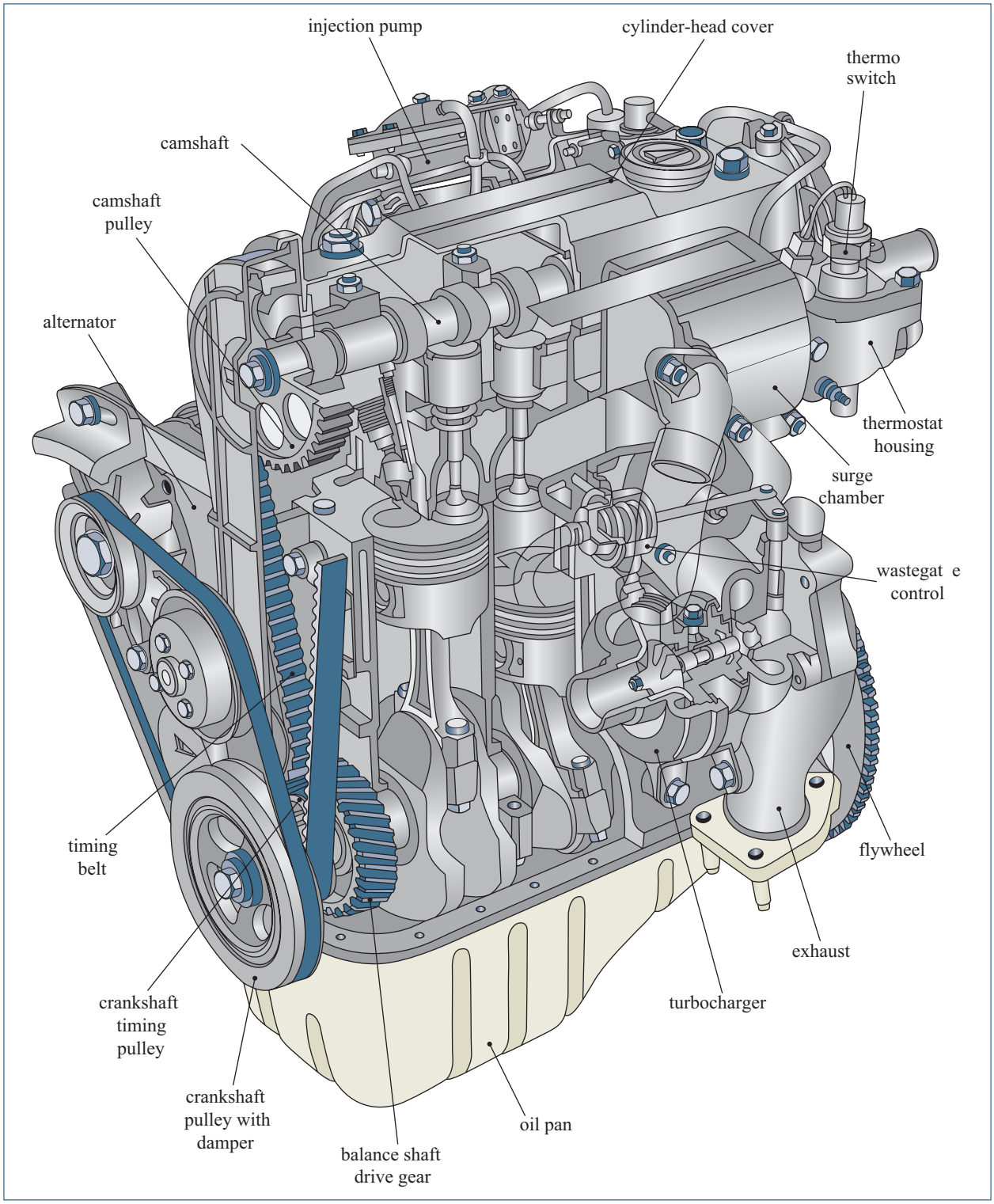


Figure 35.20 Cut-away view of a three-cylinder diesel engine show ing internal and external parts, including the turbocharger

The engine in Figure 35.21 has its oil cooler located between the oil filter and the cylinder block. Oil and coolant pass through adjacent sections of the cooler and the oil gives up its heat to the engine coolant that is at a relatively lower temperature.

35.11.2 Piston cooling

The piston (see also in Figure 35.12) is cooled by oil jets. Oil from the lubrication system is squirted up into the piston and finds it way into the oil gallery in the piston head. This is located close to the crown of the

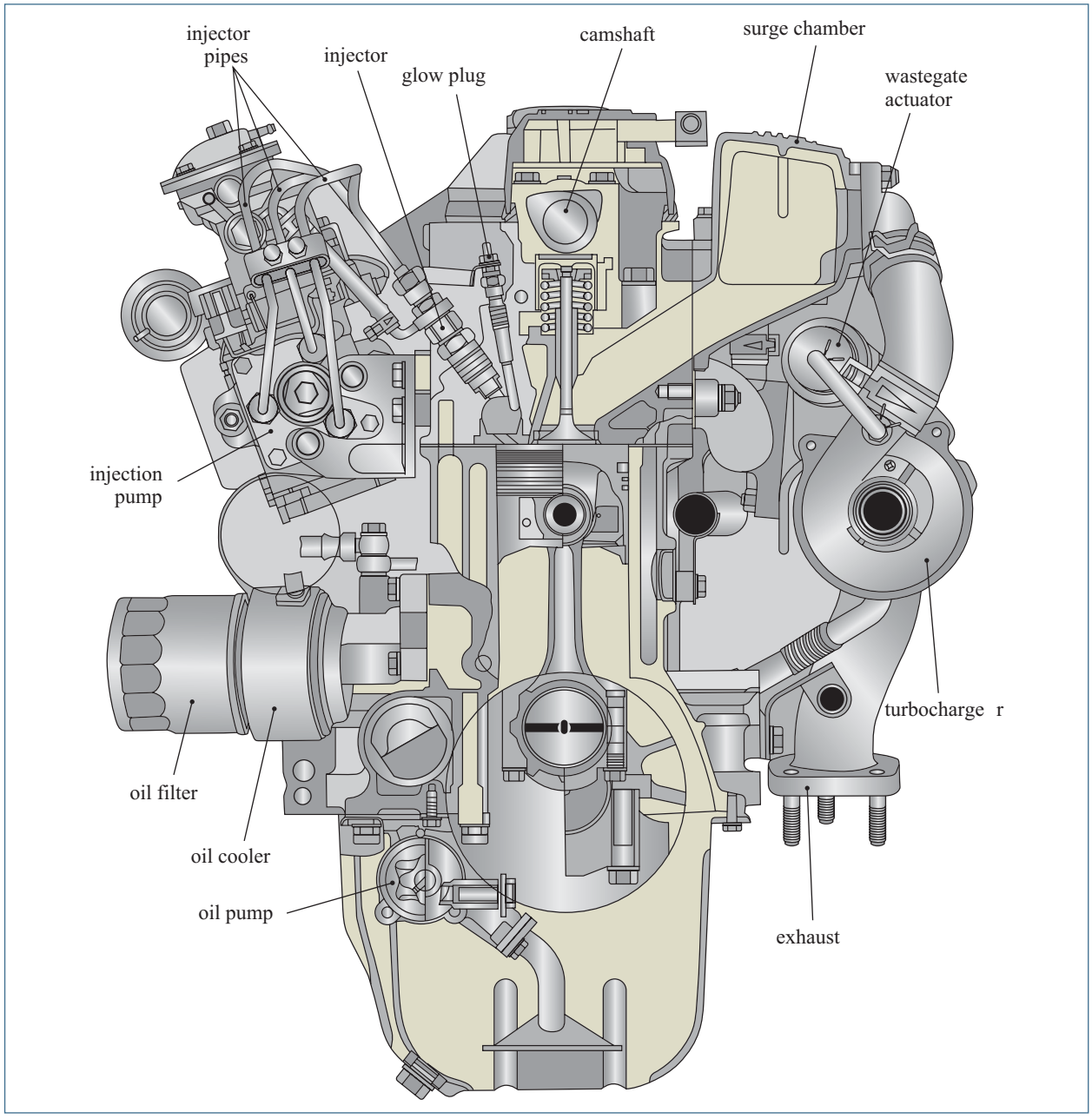


Figure 35.21 Sectional view of a three-cylinder diesel engine

piston and around the combustion chamber and is the hottest part of the piston.

35.11.3 Valve arrangements

The valves can be operated by bucket tappets, as in Figures 35.20 and 35.21, or by rocker arms. Figure 35.22 shows a different arrangement that is used in some small and large diesel engines. The cylinder head has four valves per cylinder and a single camshaft. A bridge fits over a guide pin and spans across the tips of two valve stems, enabling two valves to be operated by one cam and one rocker arm. The rocker arm is operated by the camshaft

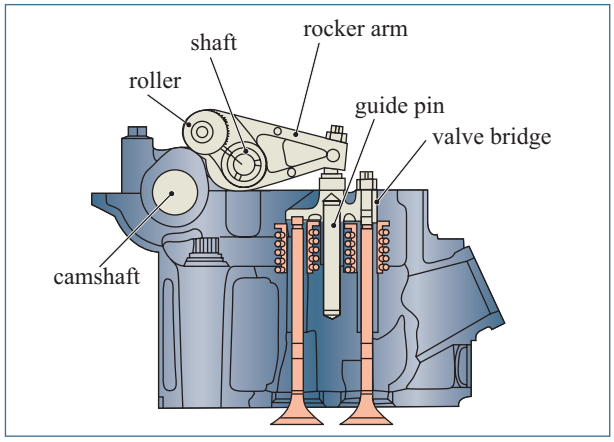


Figure 35.22 Two valves operated by a rock er shaft and a valve bridge

which, in turn, operates the bridge. The bridge moves up and down on the guide pin to open and close two valves at the same time.

Sustainability: Improved technology and design features allow the diesel to produce very low exhaust emissions. However , these can rapidly reach unacceptable levels without regular , proper servicing in accordance with state or territory legislation.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- describe the operational difference between diesel engines and petrol engines
- describe the components of a typical diesel engine and their features, function and operation
- describe the four phases of combustion in a diesel engine
- list the by-products of diesel engine combustion
- identify and explain the function of turbochargers.

REVIEW QUESTIONS

1 What is a compression-ignition engine ?
2 From where does the name diesel originate ?
3 State the sequence of events in the operating cycle of a four-strok e diesel engine .
4 State the sequence for a two-strok e diesel engine .
5 How is the high temperature obtained to ignite the charge in a diesel?
6 What is scavenging ?
7 What is direct injection ?
8 Compare direct and indirect injection.
9 Name some of the designs of combustion chambers.
10 Why are special combustion chambers used?
11 What is combustion ?
12 Describe how a droplet of fuel burns in the combustion chamber .
13 What is the lik ely cause of smok e from a diesel exhaust?
14 What are the phases of combustion ? Follow these through on the graph in Figure 35.16.
15 What is the delay period ?
16 How is the fuel delivered into the cylinder of a diesel engine ?
17 State the main differences between petrol and diesel engines.
18 Why are glow plugs used?

CHAPTER 36

Diesel fuel systems

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 describe the operation of a diesel engine and its major components
2 describe the controls used to ensure correct delivery and timing of the fuel charge
3 describe, using correct terminology, the operational systems of a common rail diesel engine
4 compare the operational differences between radial, axial and distributor-type pumps
5 outline the operation of electronic diesel engine controls.

The correct operation of a diesel engine depends on its fuel-injection system, which must supply the combustion chambers with the right amount of fuel at the right time. This chapter covers diesel fuel systems for passenger and light commercial vehicles. It provides a general understanding of the operation and function of different types of injection systems.

36.1 Diesel fuel systems: general

The locations of the parts of a diesel fuel system for a light commercial vehicle are shown in Figure 36.1. This has a fuel-supply system and an injection system. Similar systems are used in four-wheel-drive vehicles and in some passenger vehicles. A schematic diagram of the system is given in Figure 36.2. It includes the following parts, not all of which appear in the diagram.

1 Fuel tank. Holds distillate.
2 Fuel feed pump. Supplies fuel from the fuel tank to the injection pump.
3 Fuel filter. Filters minute particles from the fuel.
4 Sedimenter. Filters out water that might enter or condense in the system.
5 Injection pump. Delivers fuel at high pressure to the injectors at the right time.
6 Injector pipes. Connects the injection pump to the injectors.
7 Injectors. Sprays fuel into the combustion chambers.
8 Overflow and leak-off pipes. Returns excess fuel from the injection pump and the injectors to the tank.
9 Governor or ECV. Controls the engine speed.
10 Control lever on the governor or accelerator pedal sensor. This is connected to the driver's accelerator.
11 Air supply system. Supplies enough clean, filtered air to the engine for complete combustion.

Sustainability: All diesel fuels and components that have contained diesel fuel are hazardous to human beings and the environment. Components should be drained and the fuel gathered should be disposed of according to state or territory legislation.

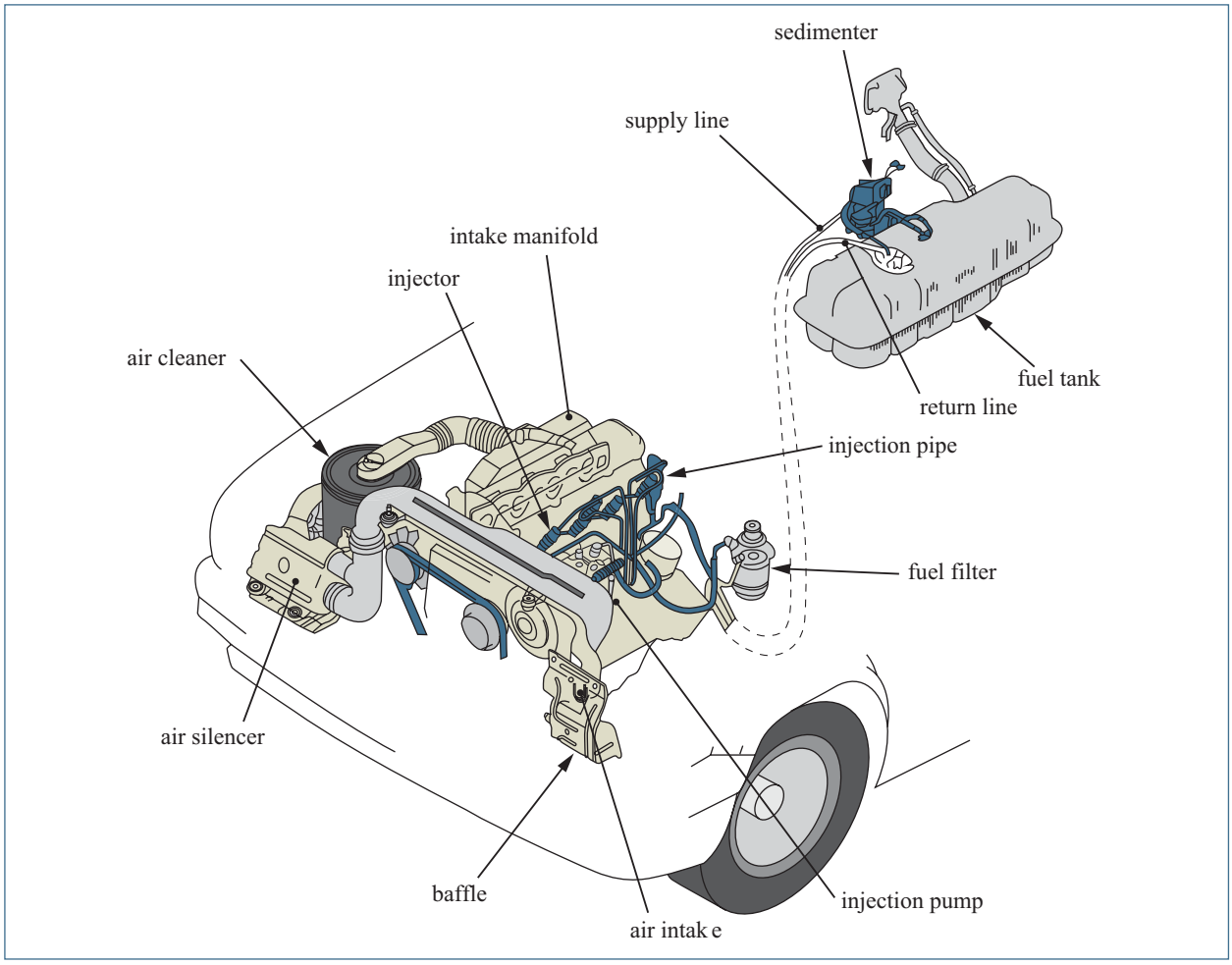


Figure 36.1 Location of the parts of a diesel fuel system in a light commercial vehicle

36.1.1 System operation

The system operates in the following way:

1. Fuel taken from the tank by the feed (supply) pump passes through the sedimenter, where water is filtered out.
2. Fuel passes from the feed pump through the fuel filter to the injection pump. The feed pump does not provide pressure, but keeps the system full. A hand-priming pump on the top of the filter is used to prime and bleed the system.
3. The injection pump has a pumping element that produces high pressure for the injectors. It also distributes high-pressure fuel to the injectors through the injector pipes.
4. The injectors are operated by the high-pressure fuel to spray fuel into the combustion chambers.
5. The injection pump has an internal vane pump (feed pump) to provide a low pressure and to keep the injection pump full. The feed pump supplies more fuel than is needed.
6. The surplus fuel is taken from the top of the pump through the overflow pipe back to the fuel tank. Circulation of the fuel cools and lubricates the injection pump, and also bleeds air from the system.
7. The leak-off pipe on the top of the injectors carries a small quantity of fuel back to the fuel tank. This is fuel that leaks up inside the injector. It lubricates and bleeds the injector before being returned to the fuel tank.
8. The engine speed and power is controlled by the accelerator and linkage, which is connected to the pump governor.
9. The fuel cut-off solenoid that is fitted to the injection pump is used to stop the engine. When the engine switch is turned off, it cuts off the fuel to the pumping element.

Handy hint: The system has two main functions—fuel supply and fuel injection. Some components are responsible for fuel supply and others are responsible for fuel injection.

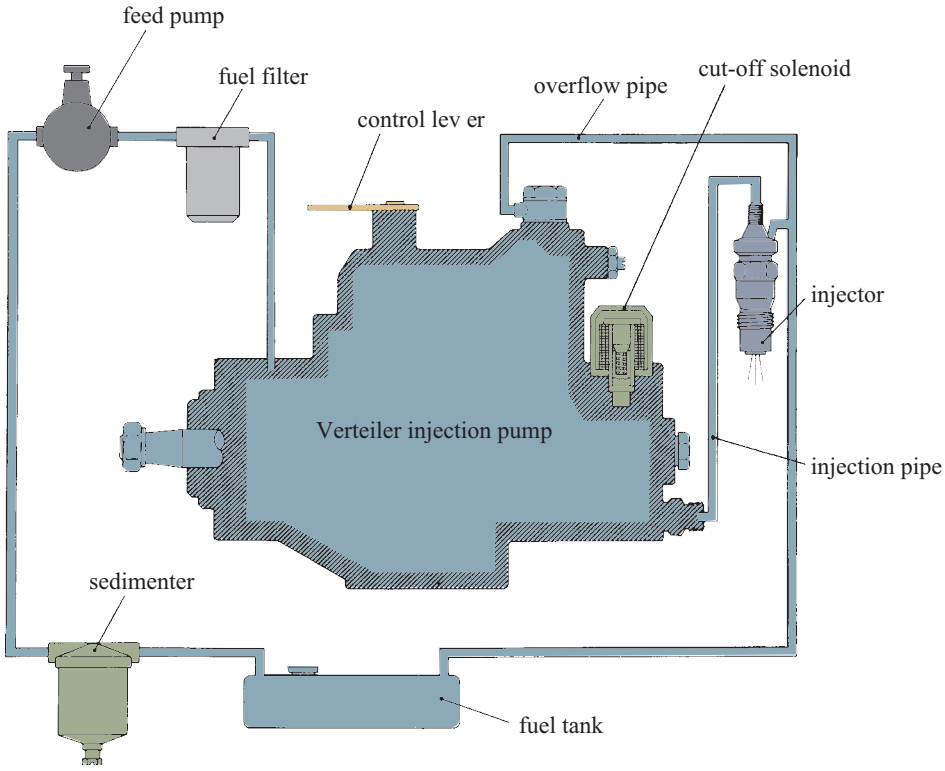


Figure 36.2 Schematic arrangement of a fuel system with a distributor-type injection pump ZEXEL

36.2 Fuel-injection systems

There are a number of different injection systems for diesel engines, the main differentiating factor being the fuel pump type (some are electronically controlled). The types of fuel-injection systems are:

1 distributor pump systems
2 common-rail, or accumulator , systems
3 inline injection pump systems
4 unit-type systems.

Distributor pump systems and common-rail systems are the most commonly used on engines in passenger and light commercial vehicles. Inline systems are now used mainly on medium-to-heavy diesel engines, and unit-type injection systems are used on heavy diesels. Those systems are not covered here.

36.2.1 Distributor pump systems

The system described above has an axial distributor pump. There are two designs of distributor pumps: *axial pumps* and *radial pumps.* These are the types that are used on most light diesel engines. Designed for engines that operate at relatively high speeds, they have a single pumping element, which, along with the distributing arrangement, are designed to suit the number of cylinders of the engine.

The main difference between these two injection pump types is the design of the high-pressure pumping element. The axial type has a pumping plunger that acts *axially,* that is backwards and forwards within the pump. The radial type has a pumping element with plungers that act *radially,* that is inwards and outwards in relation to the centreline of the pump shaft. The diagram in Figure 36.2 shows one injector only; a four-cylinder engine would have four injection pipes and four injectors.

36.2.2 Common-rail systems

The arrangement of a common-rail injection system is shown in Figure 36.3. This has a low-pressure electric pump in the fuel tank and a high-pressure fuel pump driven by the engine. The low-pressure pump delivers

fuel to the high-pressure pump, where the pressure is increased to injection pressure. A fuel line connects the pump to the common fuel rail, and injector pipes connect the common rail to the injectors.

The injectors are fitted with an electric solenoid that is controlled by an electronic control unit (ECU). Electronic control opens and closes the injectors so that they deliver a specified quantity of fuel at the right time. The system has a return line that returns surplus fuel from the top of the injectors, the high-pressure pump and the filter.

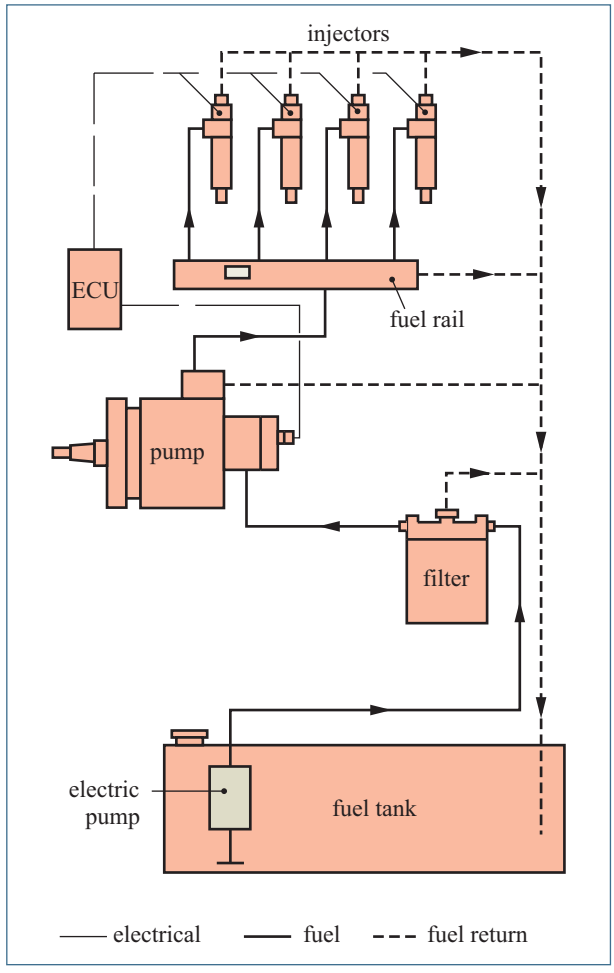


Figure 36.3 Arrangement of a common-rail fuel-injection system for a four-cylinder engine

36.3 Fuel supply pumps

All diesel fuel systems have some form of supply pump that takes fuel from the tank and delivers it to the injection pump or, in some cases, directly to the injectors. Vane pumps, diaphragm pumps, plunger pumps and gear pumps are all used, but this depends on the type of system.

Handy hint: Pumps that supply the low-pressure fuel are referred to as supply pumps, feed pumps, lift pumps or transfer pumps.

36.3.1 Vane pumps

Vane pumps are used with distributor-type injection pumps. Located inside the injection pump housing, they take fuel from the fuel tank and supply it to the high-pressure pumping element.

The vane pump is driven by the injection pump shaft (Figure 36.4). It has a rotor that is mounted off-centre in the pump housing. Slots in the rotor carry the vanes, which slide backwards and forwards as the rotor turns. Fuel taken into the pump inlet is carried around between the vanes and the body of the pump and discharged from the outlet.

Handy hint: Vane pumps used with distributor-type pumps are usually referred to as feed pumps.

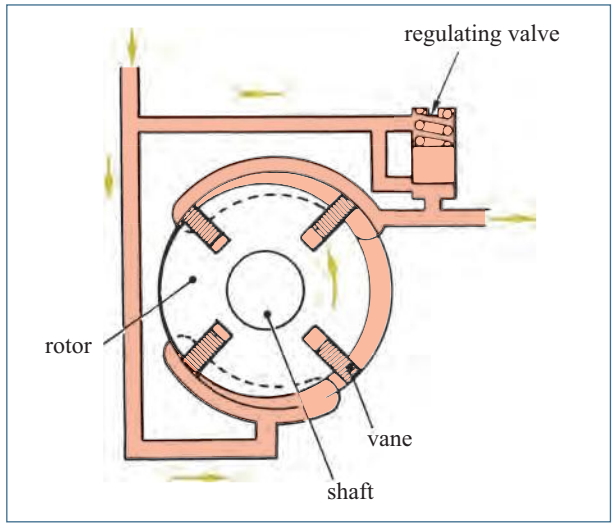


Figure 36.4 Arrangement of a vane-type feed pump, used with a distributor-type injection pump ZEXEL

36.3.2 Priming pumps

Some systems have a priming pump that is used during servicing to fill the system with fuel and to bleed air from the system. This could be a separate hand pump, or could be combined with a filter (as shown in Figure 36.7). A hand-priming pump is fitted to the top of the supply pump on inline injection systems. This is operated by unscrewing the plunger and then moving it up and down by hand. In other systems, a separate hand pump can be fitted.

36.3.3 Electric pumps

The common-rail system uses an electric fuel pump (see Figure 36.5). This is located inside the fuel tank and supplies low-pressure fuel to the main high-pressure pump. The electric pump consists of an electric motor with permanent magnet fields connected to a roller-cell pump. Fuel drawn into the pump passes

through the body of the pump before leaving the tank. A pressure limiter in the form of a spring-loaded valve opens when operating pressure is reached. It limits the pressure in the low-pressure side of the system.

36.4 Fuel filters

Filtering of diesel fuel is vital because of the very small clearances that exist between the working parts in the injection pump and the injectors. The clearance between some injection parts is as little as 2 to 4 microns. A micron is one-thousandth of a millimetre (0.001 mm).

There are a number of different designs of filters for the various fuel systems, and they can be located in different parts of the system. Filters can be fitted between the supply pump and the tank, or between the supply pump and the injection pump. Faulty sealing of a filter on the suction side of a supply pump will allow air to enter and fuel to leak, while faulty sealing on the pressure side will allow fuel to leak.

⚠ Safety: Care must be tak en so that fuel put into the tank of a vehicle is not contaminated by anything, including water .

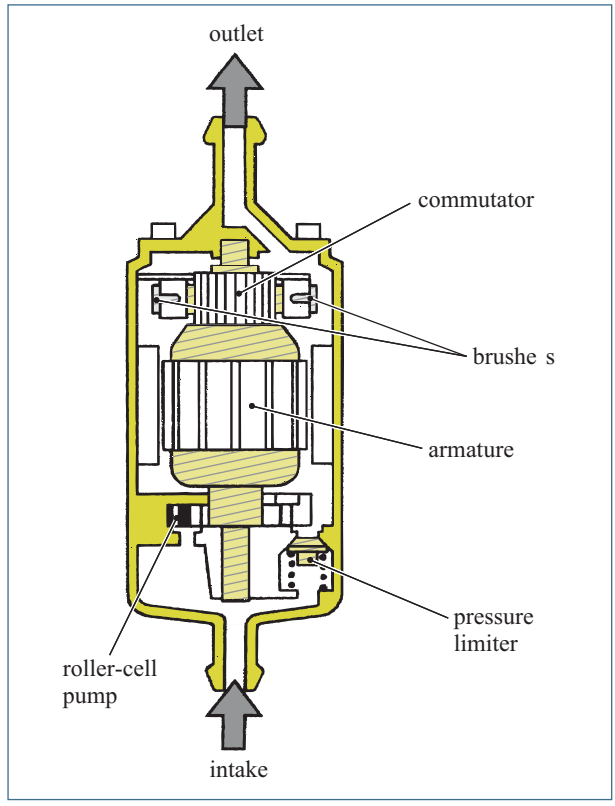


Figure 36.5 Electric fuel pump assembly for a common-rail injection system with a roller-cell pump BOSCH

36.4.1 Filters with a separate element

Figure 36.6 shows a fuel filter with a replaceable element. The filtering material is made of pleated paper, which will filter out very small particles.

36.4.2 Filters with a glass bowl

The filter in Figure 36.7(a) has a glass bowl and a filtering element. The filter can be checked for deposits or water by looking through the clear glass bowl. The bowl can be removed for cleaning.

36.4.3 Water and sediment filters

Sedimenters, or sediment filters, remove water and sediment. In Figure 36.7(b), a fuel filter and a sedimenter are used side by side. Any water in the fuel is removed by the sedimenter before it reaches the fuel filter. The sedimenter shown has a hand-priming pump.

Sedimenter

Figure 36.7(c) shows a sedimenter that has a throw-away filter. It has a filter canister similar to an engine-oil filter. The sedimenter is serviced by fitting a new canister, which also has a hand-priming pump. Water and small solid particles filtered out by the sedimenter form sediment in the bottom of the filter bowl.

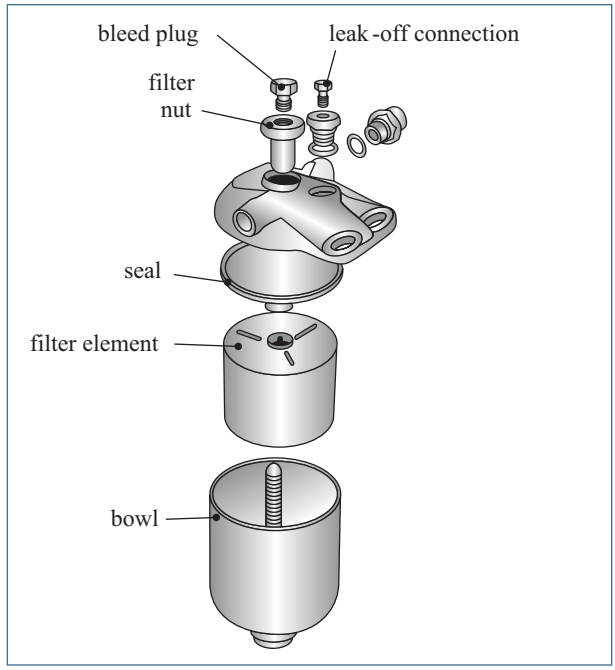


Figure 36.6 Fuel filter with replaceable element

Most sedimenters have a warning light for when the water in the filter reaches a certain level. Water in a system can block filters and will cause considerable damage if it reaches the injection pump. The sedimenter in Figure 36.8 has a water-level detector. If the water level becomes too high, the float will rise to operate the switch and light the warning indicator.

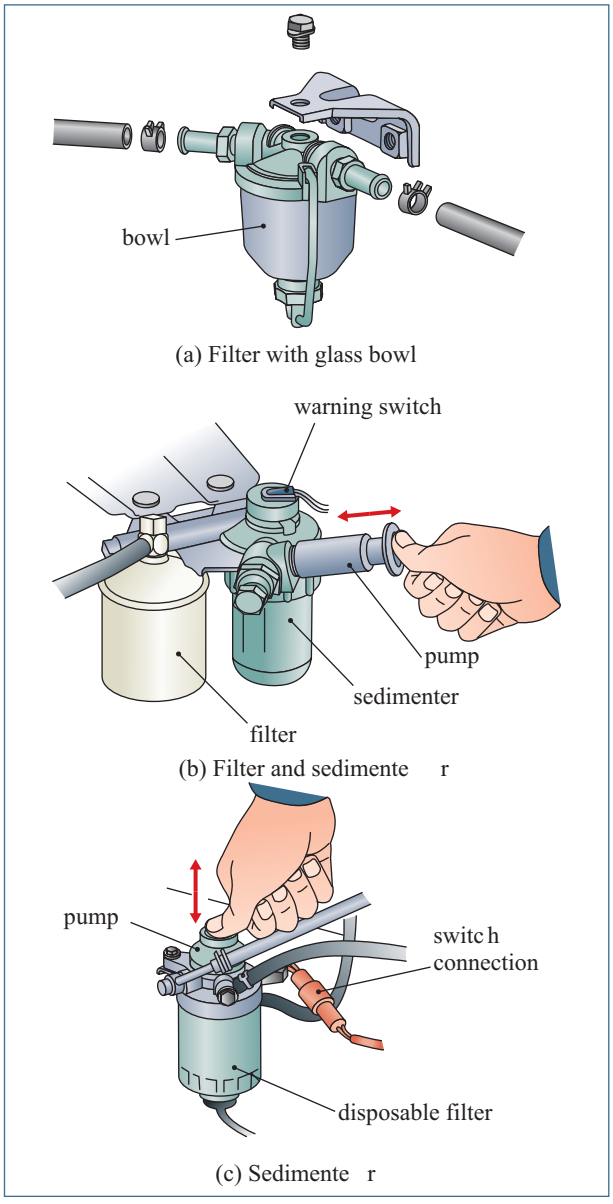


Figure 36.7 Types of diesel fuel filters

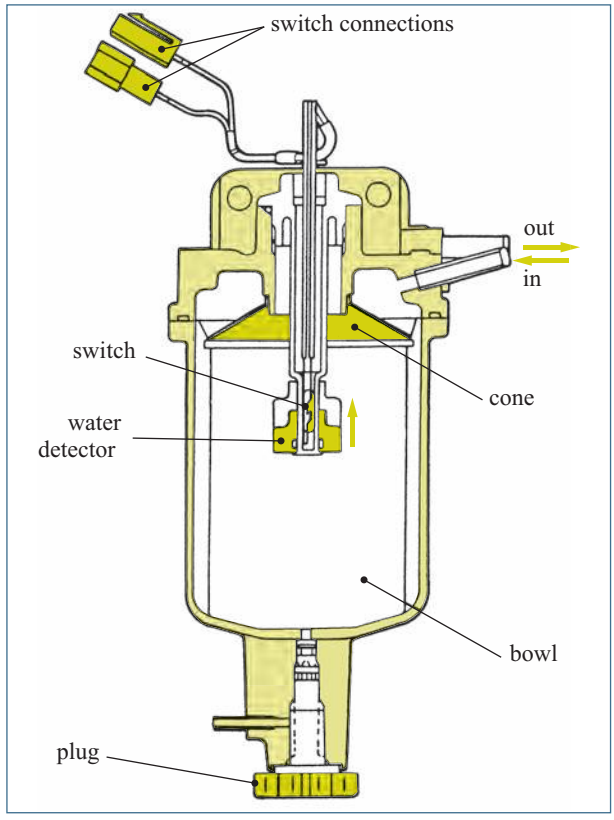


Figure 36.8 Sedimenter with water-level detector FORD

The filtering action of the sedimenter is as follows:

1 When the engine is running, fuel that enters the sedimenter flows over the top of a cone , and this acts as a diffuser to spread the fuel.
2 The fuel then passes down towards the bottom of the sedimenter , where it changes its direction and flows upwards to the outlet.
3 As the fluid changes direction, any heavy particles or water in the fuel fall to the bottom to remain as sediment, and this can be drained off .

Handy hint: Sediment is a collection of fine particles that settles at the bottom of a liquid, in this **case water**.

36.5 Injectors

Injectors come in various shapes and sizes. The connection for the injection pipe can be at the top or at the side of the injector. Injectors for engines of passenger and light commercial vehicles are either threaded and screwed into the cylinder head or secured to it with a clamp. Other injectors can have a flange bolted to the cylinder head.

The nozzle at the lower end of the injector either fits against the combustion chamber or projects slightly into it. When appropriate, the nozzle directs a fine spray of fuel into the combustion chamber. This occurs at around 200 times a minute at engine idle, and up to around 2000 times a minute at high engine speed.

Safety: Injectors can operate at pressures up to 3000 bar (300 Mpa) and high **voltages (200** V). Precautions must be tak **en to ensure safety**.

36.5.1 Injector operation

Figure 36.9 shows a simplified injector. The operating parts are the needle, the spindle and the spring. Spring force is transferred through the spindle to the needle, holding the needle on its seat and preventing fuel from

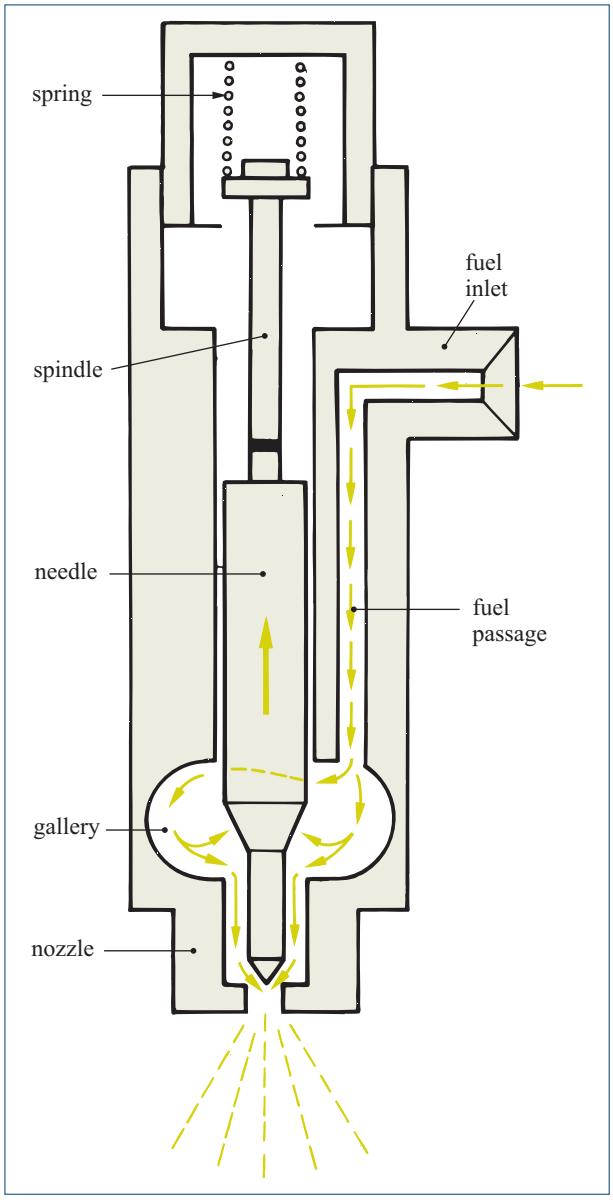


Figure 36.9 Simplified diagram showing injector action

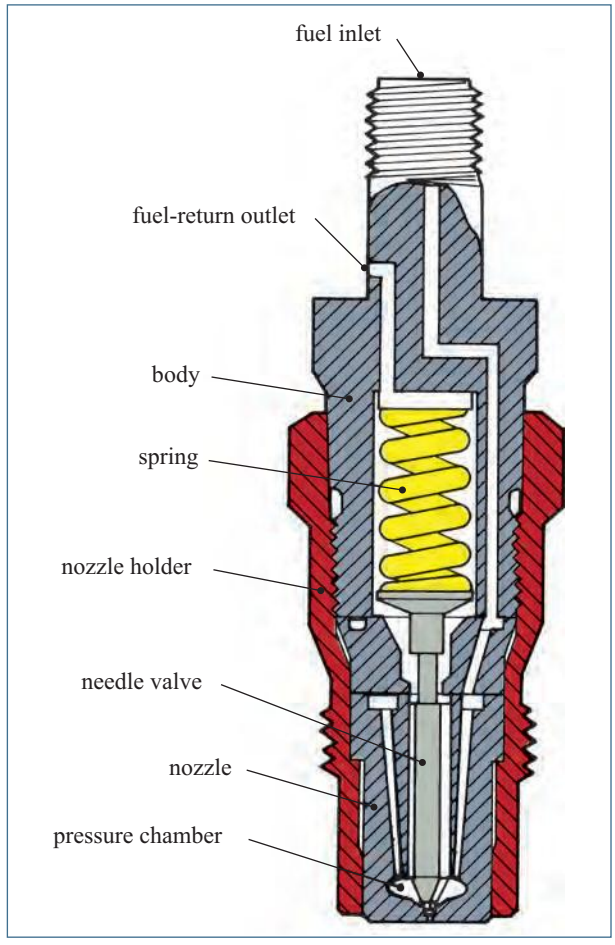


Figure 36.10 Sectional view of an injector

leaking from the end of the nozzle. With the engine stopped, the injector holds fuel but it is not under pressure. The simple injector works as follows:

1 The fuel charge from the injection pump enters the injector through the inlet connection. It passes down the drilled passage to the gallery in the nozzle near the bottom of the injector .
2 When the gallery is pressurised with fuel, pressure under the needle forces it upwards against the spring, and the high-pressure fuel in the gallery is sprayed into the combustion chamber .
3 When delivery from the injection pump ceases, the pressure in the injector drops and the spring returns the needle to its seat.
4 A small amount of fuel leaks up past the needle . This lubricates and cools the injector before passing out through the leak -off connection near the top of the injector .

The speed at which the pressure in the injector drops causes the needle to close rapidly. This gives a sharp cut-off and prevents *dribble*. The fuel has to be injected at high pressure and as a fine spray. Any fuel that dribbles into the combustion chamber will not burn properly.

Handy hint: Dribble from a faulty needle and seat will cause soot and black smok e from the exhaust.

36.6 Types of injectors

Figure 36.10 is a sectional view of the type of injector used in passenger and light commercial vehicles. It operates in the same way as the simple injector just described. These are hydraulically-operated injectors. This injector is threaded and screws into the cylinder head. It has the injector pipe connection at the top,

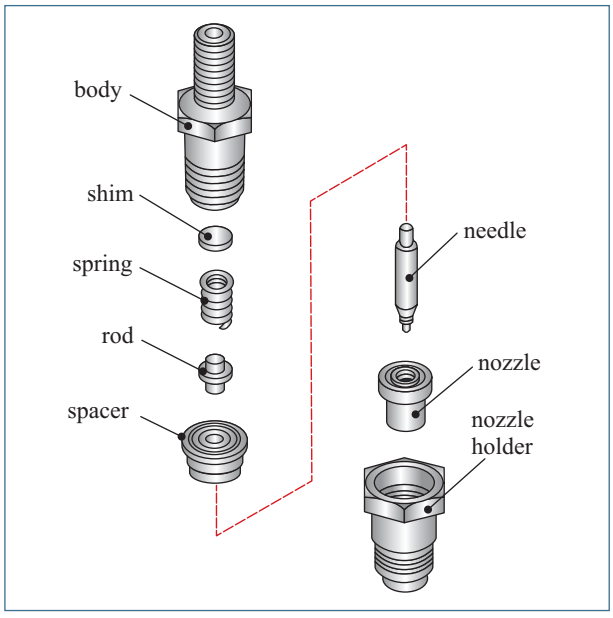


Figure 36.11 Dismantled parts of an injector

Figure 36.12 Flanged-type injector

with the leak-off pipe connection below it. The other parts of the injector are identified in the illustration. A dismantled injector is shown in Figure 36.11.

36.6.1 Flanged injectors

A flange-mounted injector is shown in Figure 36.12. When installed in the cylinder head, it is secured by two bolts. This injector is the type used with direct injection and mainly on larger engines. It has a long nozzle to reach through the cylinder head to the combustion chamber. Figure 36.13 shows its internal construction.

36.6.2 Injector nozzles

An injector nozzle injects a spray of fuel into the combustion chamber in a form which will readily burn. To achieve this, various types of nozzles have been designed. These vary in length, and in number and angle of holes. The end of the needle can be flat, tapered or conical. Various types of nozzles are shown in Figure 36.14. The fine holes in some injector nozzles are drilled mechanically. In others, a process of electrical-discharge machining is used.

Single-hole nozzles

These nozzles have a single small hole drilled through their end, its diameter being from 0.2 mm upwards. The conical-end single-hole nozzle has a single hole drilled at an angle to suit the particular engine design.

Multihole nozzles

These nozzles have two or more holes drilled in the end. The number of holes and their size and position depend on the requirements of the engine.

Long-stem nozzles

This type of nozzle has a long stem which is an extension of the underside of the nozzle. The end of the stem carries the normal holes and valve seat.

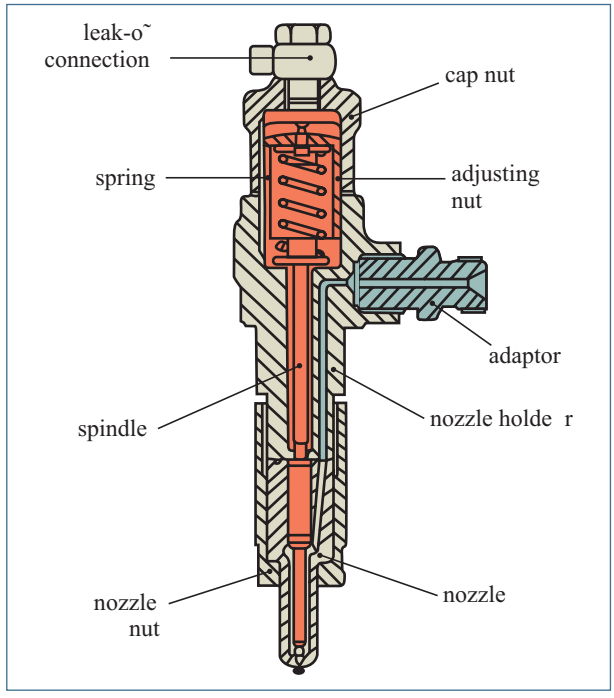


Figure 36.13 Internal construction of a flanged-type injector

The long stem enables the part of the nozzle that has fine clearances (between the needle and the nozzle) to be kept away from the combustion chamber. This enables this part of the injector to operate in a comparatively cooler area of the cylinder head.

Pintle nozzles

This type of nozzle has a much larger hole than other types, and the end of the needle is formed into a pin, or *pintle,* that protrudes through the hole. By modifying the shape and size of the pintle, injectors can produce different spray patterns. The spray can be varied from a small hollow cone to a hollow cone with an angle of 60°.

Delay nozzles are a modified pintle type whose shape reduces the rate of injection at the beginning of the delivery. This decreases the amount of fuel in the combustion chamber when combustion commences, reducing diesel knock.

Handy hint: Pintle nozzles are designed for use in engines with indirect injection; that is, those with an air cell, a swirl chamber or a precombustion chamber .

Sac-hole and seat-hole nozzles

Some nozzles have a small chamber under their tip into which holes called *sac-holes* are drilled (the nozzles are called *sac-hole nozzles*). Other nozzles have their holes drilled into their seat, and are called *seat-hole nozzles.* These two designs are shown in Figure 36.15. With seat-hole nozzles, the taper on the needle tip covers the hole so the needle is not exposed to the combustion gases.

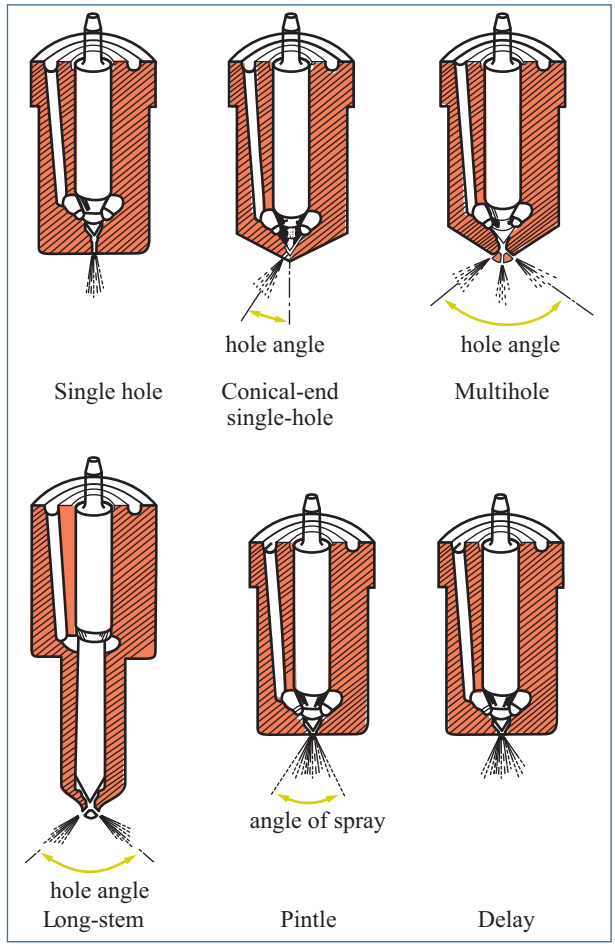


Figure 36.14 Types of injector nozzles

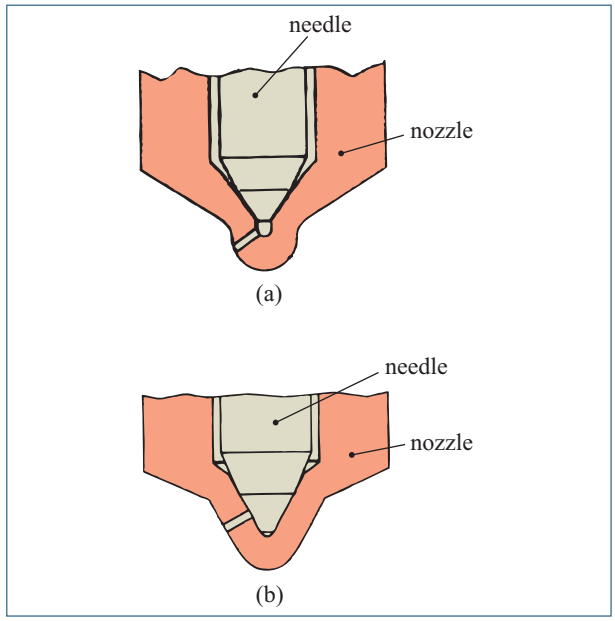


Figure 36.15 Injector nozzles (a) sac-hole nozzle (b) seat-hole nozzle BOSCH

36.6.3 Electronically-controlled injectors

The injectors used with common-rail injection systems have a solenoid or a piezo device that is electronically controlled. These are different from other injectors, and are not hydraulically operated by fuel pressure. Operation of electronically-controlled injectors is covered later in this chapter.

36.7 Distributor injection pumps: axial type

Figure 36.16 shows the external parts of a distributor-type injection pump of the kind that is fitted to the diesel engines of many passenger and light commercial vehicles. The pump is flange-mounted and driven from the engine's timing chain or timing belt. It rotates at camshaft speed.

36.7.1 Operating parts of the pump

The main operating parts of the pump, excluding the governor, are shown in Figure 36.17. These are:

1 Vane feed pump . Supplies fuel at low pressure .
2 Cam disc. Has one cam on its face for each engine cylinder .

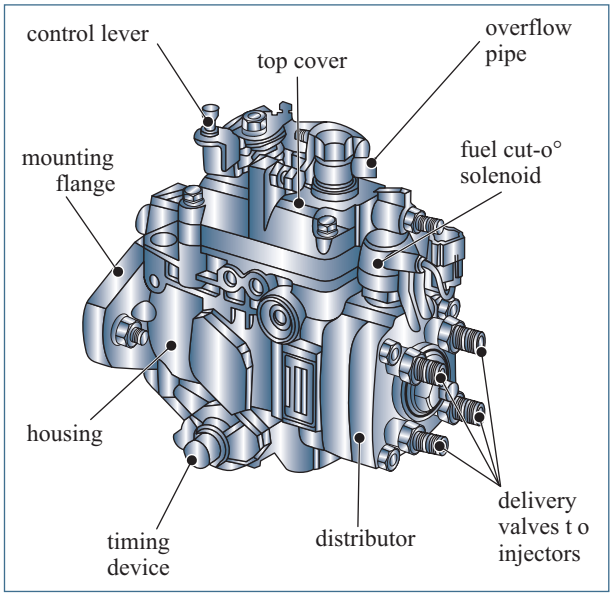


Figure 36.16 External parts of a distributor-type injection pump

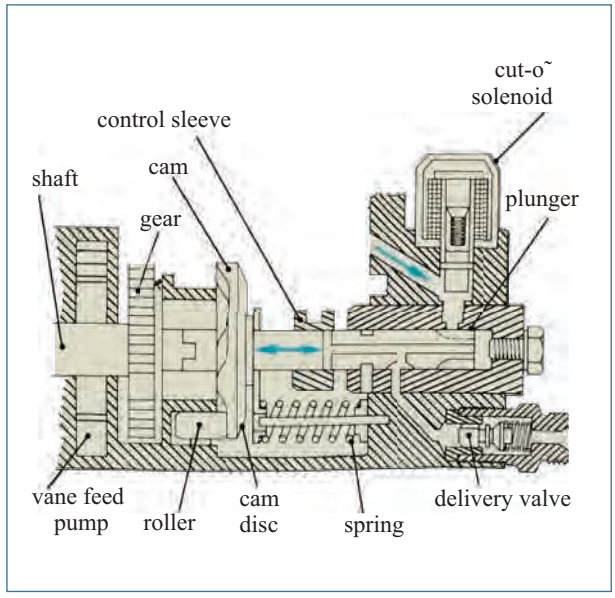


Figure 36.17 Schematic arrangement of the high-pressure pumping section of an axial distributor pump ZEXEL

3 Rollers. These are operated against by the cam disc.
4 Cam spring. Holds the cam disc against the rollers.
5 Plunger in a barrel. Produces high fuel pressure for injection.
6 Delivery valves. Deliver the fuel to the injectors.
7 Control sleeve . Controls the quantity of fuel delivered to the injectors.

The cam disc is held against the rollers by the spring. The plunger is attached to the disc and they rotate together with the pump shaft.

36.7.2 Pump operation

When the pump rotates, the cam disc and the plunger also rotate and are moved backwards and forwards by the action of the cams against the rollers. The plunger therefore slides in and out in its barrel and also rotates. The plunger has intake slits which cover and uncover the *intake port* as the plunger rotates. It also has distribution slits that cover and uncover the *distribution port* as the plunger rotates.

The motion of the plunger performs three functions:

1 It opens and closes the fuel intak e port to the pressure chamber , which is located at the end of the plunger .
2 It pressurises the fuel in the pressure chamber .
3 It distributes pressurised fuel to the correct injector at the right time .

Functions 1 and 3 are performed by the rotary motion of the plunger opening and closing ports, while function 2 is performed by its sliding motion.

Pumping action

The pumping section is shown in Figure 36.18. This is the part of the injection pump that pumps,

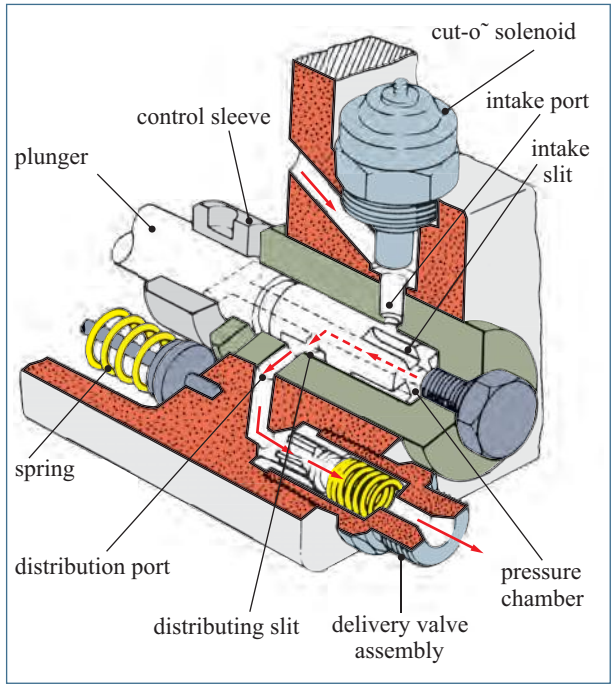


Figure 36.18 Pumping section of an axial distributor pump ZEXEL

meters and distributes high-pressure fuel to the injectors. The pumping actions are shown in the diagrams in Figure 36.19. These are as follows:

1 Intake stroke. When the intake slit comes in line with the intake port, fuel from the feed pump will flow into the pressure chamber and into the drillings in the plunger body.
2 Injection stroke. During the injection stroke, the plunger will be pushed down its barrel. The intake port will have closed and the fuel will be compressed. As the plunger rotates, its distributing slit will come into line with the distribution port. Pressurised fuel will raise the delivery valve and deliver fuel through the injector pipe to the injector (as in the illustration).
3 End of delivery. As the plunger slides to the right, its cut-off port will become exposed and pressurised fuel will spill from it. This reduces pressure, and the delivery valve will close to end delivery.

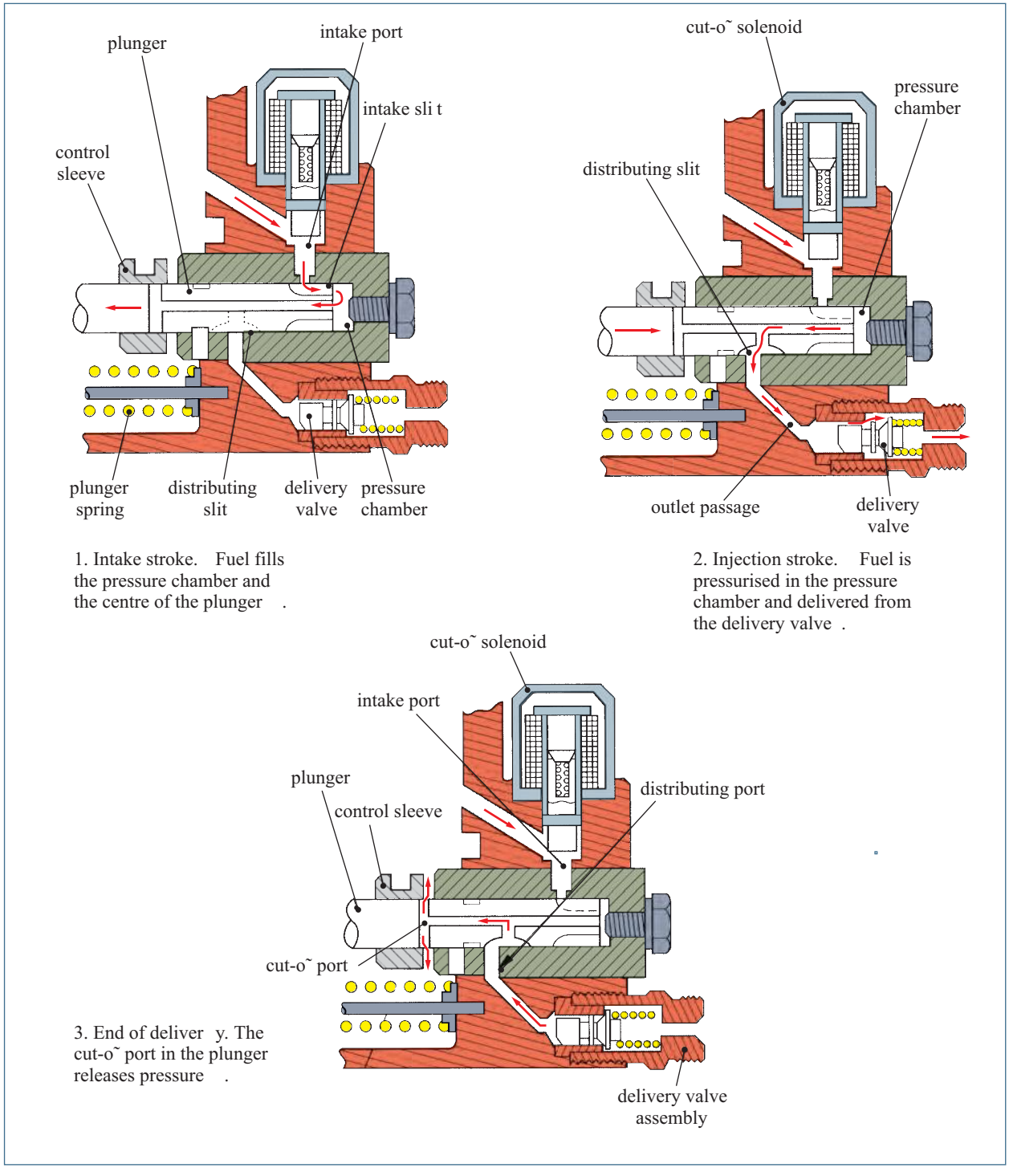


Figure 36.19 Action of the plunger of an axial distributor pump ZEXEL

Controlling the quantity of fuel

The quantity of fuel injected is metered by the control sleeve, which determines the end of delivery. If the sleeve is moved to the left, the quantity of fuel will decrease; to the right, and the quantity of fuel will increase. Sliding the sleeve along the plunger alters the effective length of the plunger stroke. When the sleeve is moved to the left, the cut-off port is exposed earlier; when the sleeve is moved to the right, the cut-off port is exposed later.

Handy hint: The start of delivery remains the same , but the point where pumping ceases is altered to suit the quantity of fuel to be injected.

Delivery valve action

The delivery valves in the distributor head of the pump are important in injector operation. The valve is lifted off its seat by the pressure of fuel from the plunger during delivery. When pumping ceases, it is forced back onto its seat by the spring. The valve has a small piston that moves down its bore as the valve closes. This reduces the volume in the delivery valve assembly so that the pressure in the injector pipe drops rapidly. This allows the needle in the injector to snap shut and give a clean cut-off of the fuel spray.

36.7.3 Timing advance

The arrangement for automatically advancing the injection is shown in Figure 36.20. The roller assembly that operates the cam disc is rotated a few degrees in a direction opposite to pump rotation. This causes the plunger action to start earlier, and so injection timing is advanced.

The movement of the roller assembly is controlled by a piston in a cylinder which is subject to feed pump pressure. As the speed of the injection pump increases, this pressure also increases to move the piston against the spring. This turns the roller assembly to advance injection.

36.7.4 Stopping the engine

The fuel cut-off solenoid stops the engine by closing off the fuel passage to the intake port (see Figure 36.19, part 3). When the engine is switched on, the solenoid is energised and its plunger is raised. This opens the fuel intake port so that fuel from the feed pump can reach the plunger. When the engine is switched off, the solenoid is de-energised and the plunger is pushed down by its spring to close off the intake port and block the supply of fuel. This stops the engine.

36.7.5 Governor for axial pumps

Figure 36.21 is a schematic arrangement of the mechanical governor for an axial distributor pump. The actual governor has three levers (a governor, a tension and a correction lever) which combine to control the idle, maximum and deceleration speed of the engine. These have been simplified and shown as a single lever to aid comprehension.

The main parts of the governor and control are as follows:

1 Control lever . Connected externally to the driver' s accelerator and internally to the governor spring.
2 Governor spring. Holds the lever against the governor sleeve . Spring tension is altered by movement of the control lever , which is moved by the accelerator .
3 Flyweights. These are rotated by the governor shaft and thrown outwards by centrifugal force .
4 Governor sleeve . This is moved against the lever by the action of the flyweights.
5 Lever . Pivots on the pivot pin. It has the governor spring at the top and a ball that fits into the control sleeve at the bottom.
6 Control sleeve . Slides on the plunger to vary the amount of fuel injected.

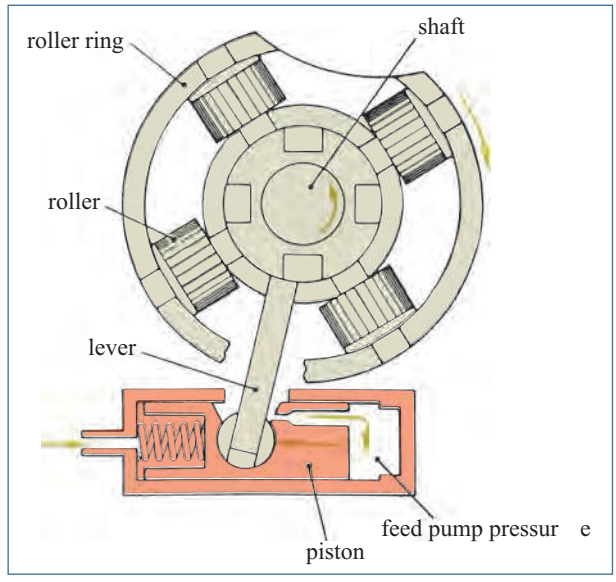


Figure 36.20 Timing device used on an axial distributor pump ZEXEL

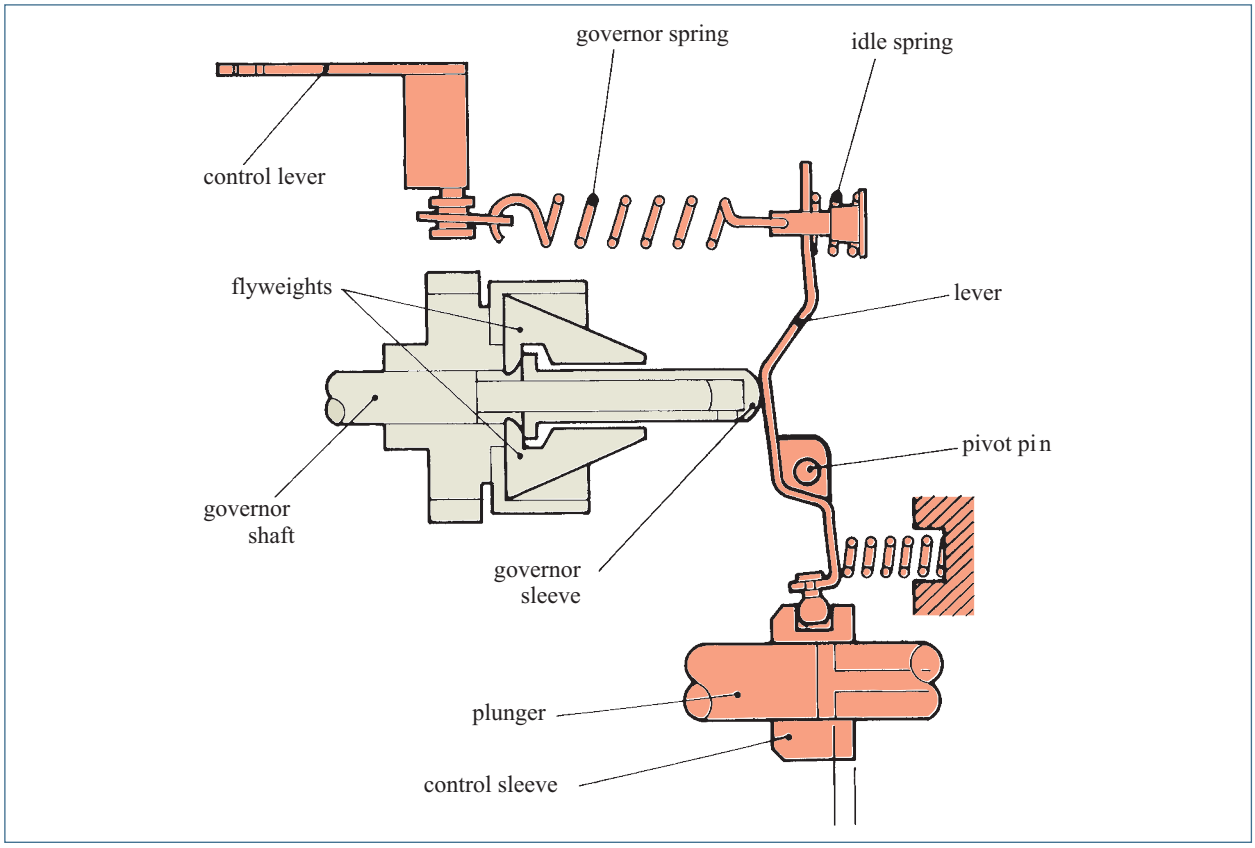


Figure 36.21 Governor arrangement for an axial distributor pump

36.7.6 Governor operation

The governor shaft and flyweights are driven by gears from the pump shaft so that they rotate faster than pump speed. When the flyweights are rotated, their ends are moved outwards by centrifugal force. This outward movement is related to rotational speed—the faster the flyweights rotate, the further out they move. Movement of the flyweights is transferred to the governor linkage and used to control the engine speed and power.

Referring to Figure 36.21, outward movement of the flyweights will move the governor sleeve along its shaft to push against the lever. Lever movement will then slide the control sleeve on the pump plunger to vary the quantity of fuel injected. This will control the speed of the engine. The governor spring opposes flyweight movement. When the tension of the spring is reduced, the flyweights are allowed to move outwards to increase engine speed. When the tension of the spring is increased, the flyweights are allowed less movement. The position of the flyweights is therefore a balance between centrifugal force and spring force.

Handy hint: This type of governor is known as a mechanical governor or a centrifugal governor . It applies the principle of centrifugal force to the flyweights.

Operation

The governor moves the control sleeve to different positions during engine operation. The spring tries to move the control sleeve to the slow position, while the flyweights try to move it to the high-speed position. When stationary and also at idle, the control sleeve is held for minimum delivery. When started, the control sleeve is moved towards maximum delivery. At any accelerator position, the governor spring will be placed under a particular tension, and this will determine the amount of movement of the flyweights and the engine speed. The governor controls starting, idle, intermediate and maximum speeds.

36.8 Complete axial distributor pump

Figure 36.22 is a complete distributor-type injection pump in part section to show almost all the internal parts. The same injection pump is shown in Figure 36.23. An illustration of an axial pump with electronic control is shown as Figure 36.35 at the end of this chapter.

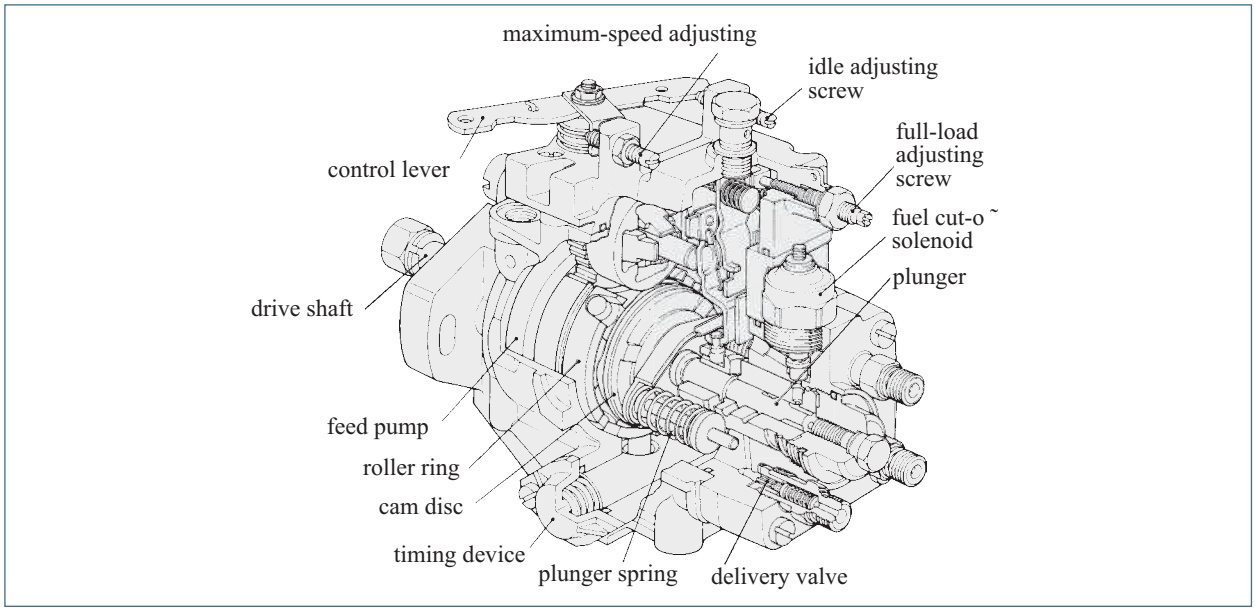


Figure 36.22 Construction of an axial distributor pump ZEXEL

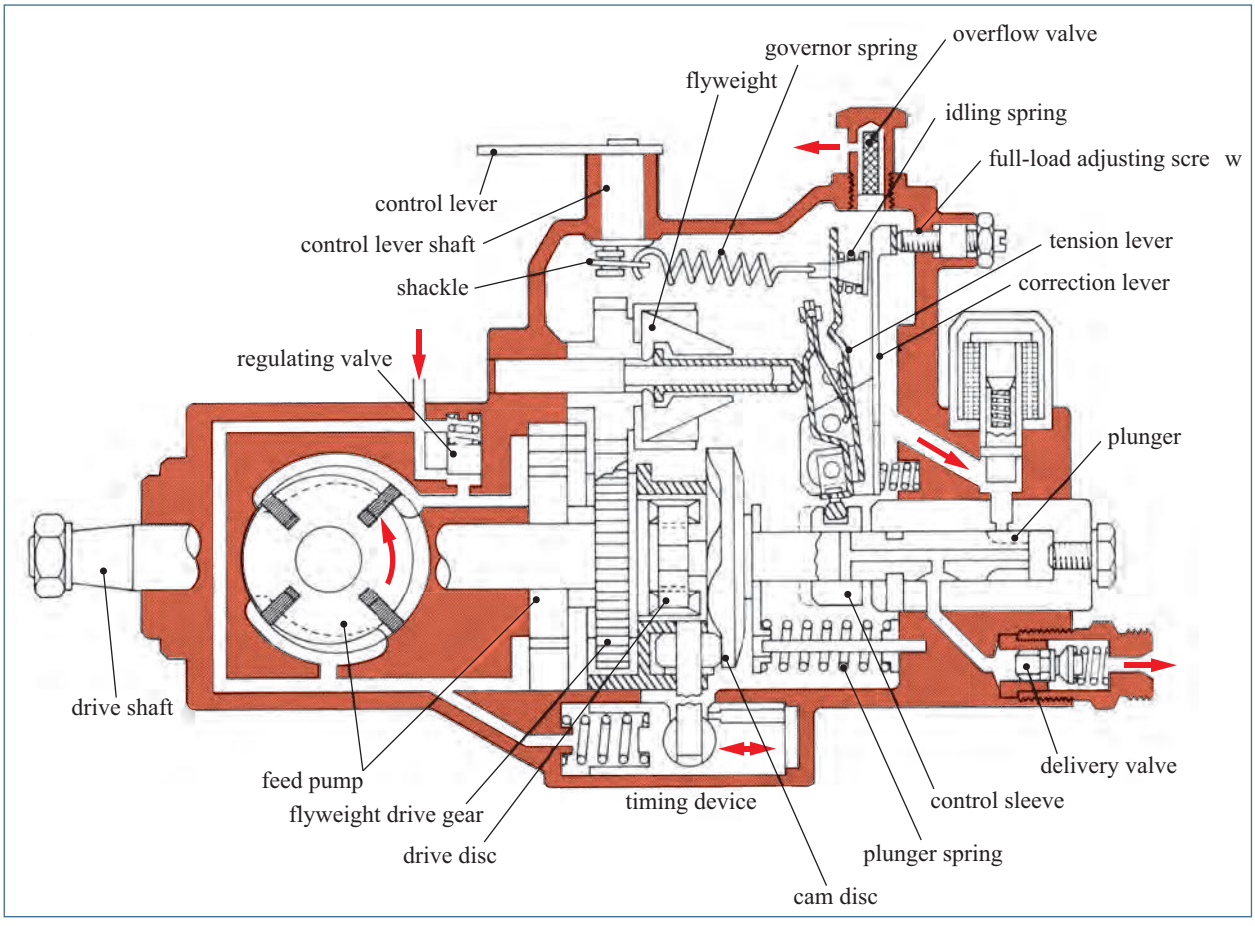


Figure 36.23 Schematic arrangement of a complete axial distributor pump ZEXEL

36.9 Distributor injection pumps: radial type

Radial distributor pumps are driven in the same way as axial distributor pumps. They have a similar vane-type supply pump, but a different high-pressure pump. A radial pump has two or more plungers that move in a radial direction in relation to the shaft, while an axial pump has a single plunger that moves axially (lengthwise) in relation to the shaft.

A simplified arrangement of the high-pressure section of a radial pump is shown in Figure 36.24. This consists of:

1 Rotor. Rotates in the barrel in the pump housing.
2 Plungers. Operate in bores in the rotor head and rotate with the rotor .
3 Cam ring. A stationary part (with internal cams) which fits over the rotor head.
4 Shoes. Operate in slots in the rotor head.
5 Rollers. These fit in the shoes in the rotor head and follow the contours of the cam ring
6 Solenoid valve . Located on the inlet to the high-pressure side of the pump .

36.9.1 Basic pump operation

Low-pressure fuel is supplied from the vane feed pump through the solenoid valve and passages to the plungers. It enters the high-pressure pump chamber between the plungers and pushes them outwards. This pushes the rollers against the inside of the stationary cam ring. As the pump rotates, it turns the rotor and the rollers follow the contour of the cam ring.

When a cam is encountered, the roller, shoe and plunger are moved inwards. The solenoid valve simultaneously closes off the fuel from the supply pump and the plungers compress the fuel in the pumping chamber. The pumping chamber is connected through timing slots in the rotor and barrel to the injectors. With high pressure in the chamber and the timing slots aligned, high-pressure fuel is delivered to an injector and injection commences; it ceases when the solenoid valve is opened to cause the pressure to drop. This cycle is repeated for each engine cylinder. The operation of the solenoid is controlled by the engine's electronic control unit (ECU), which determines when the solenoid should open or close the valve.

Handy hint: Injection commences when the solenoid valve closes and ceases when it opens.

36.9.2 Radial pump schematic: operation

Figure 36.25 shows a schematic view of a radial distributor pump. The vane-type supply pump and the high-pressure pump are both driven by the pump shaft. However, in this illustration, they have been turned

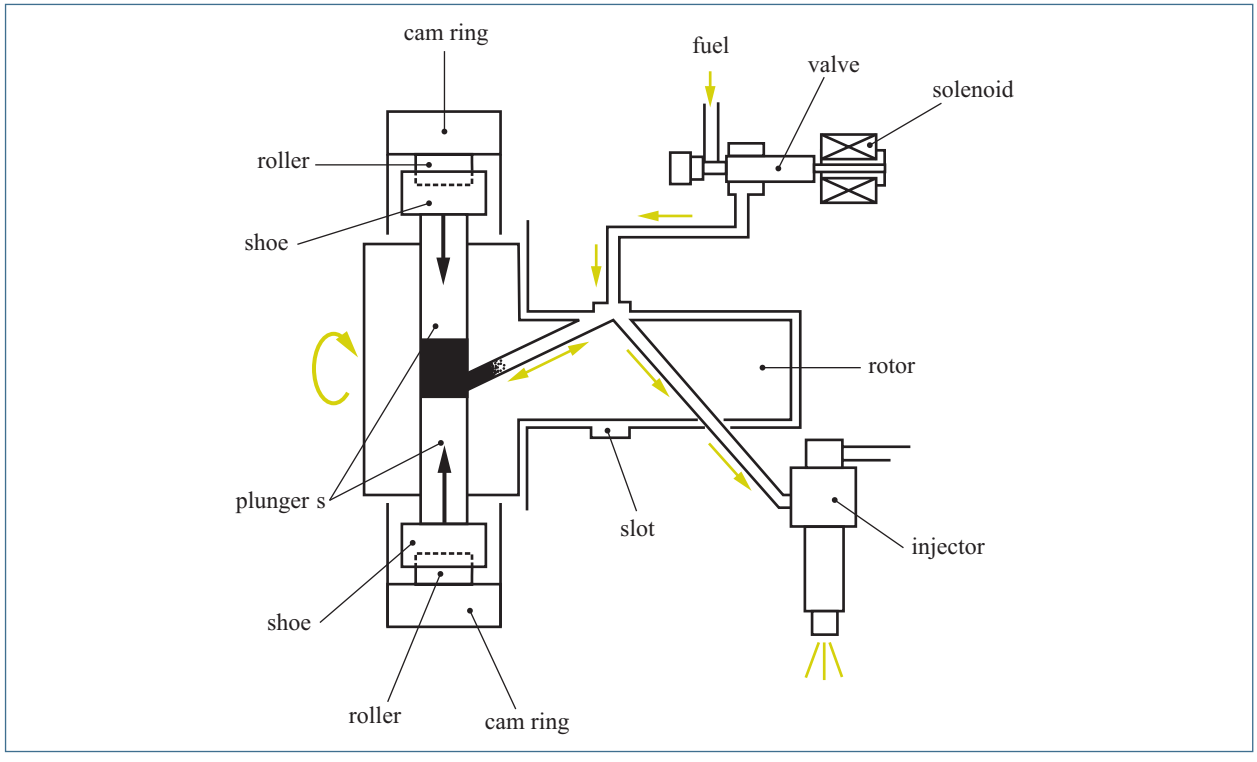


Figure 36.24 Radial pump: schematic arrangement of the high-pressure side of the pump

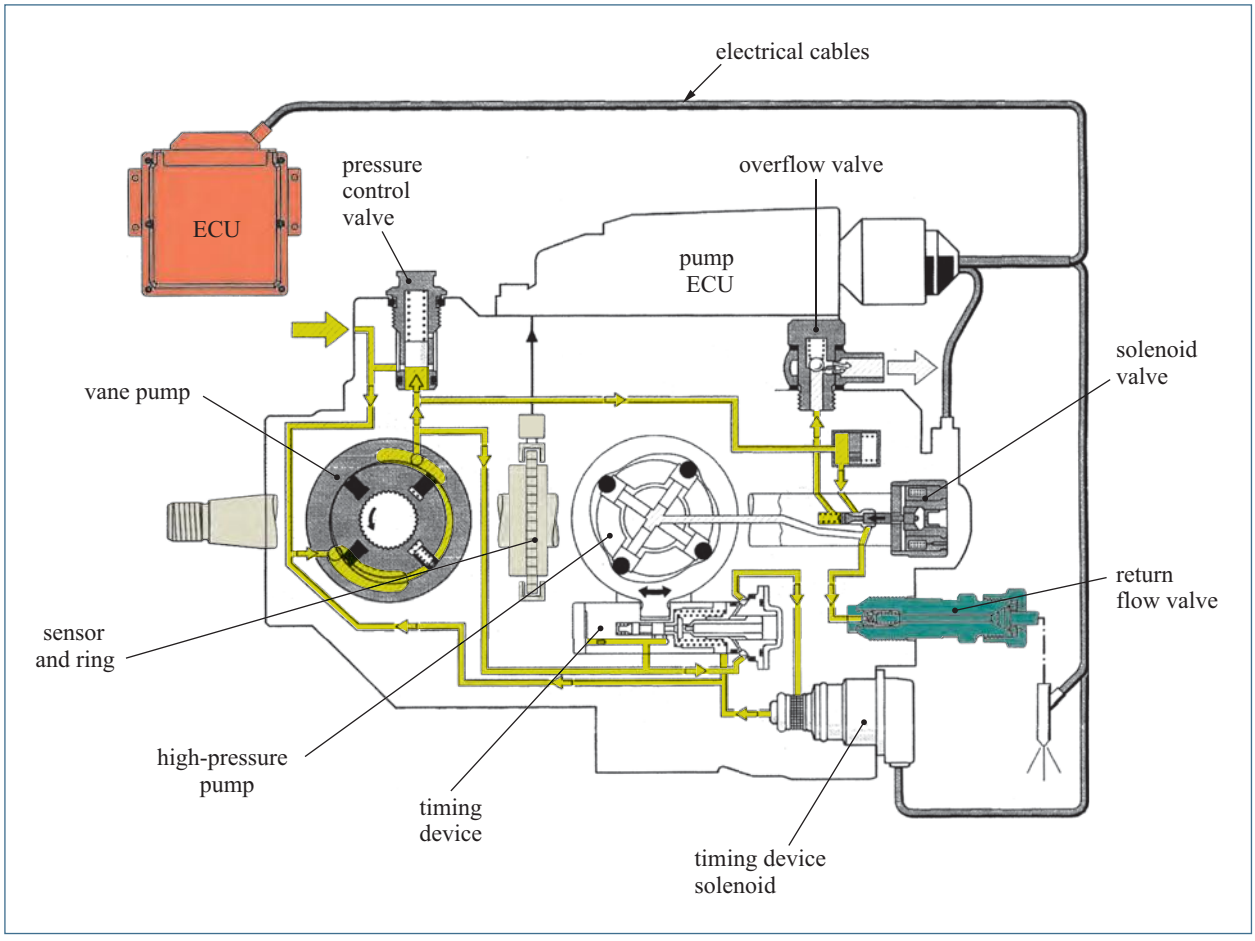


Figure 36.25 Radial distributor pump schematic with an electronic control system BOSCH

90° to show their construction. The pump has a *low-pressure stage,* a *high-pressure stage* and an electronic control system.

Low-pressure stage

Fuel is taken into the pump assembly by the vane pump. Pressure in the low-pressure side of the system is regulated by the pressure-control valve. This returns excess fuel pumped by the vane pump back to its intake side. Fuel at low pressure is delivered through internal passages of the pump through the solenoid valve to the radial high-pressure pump. Low pressure is also directed to the timing device and its solenoid valve.

High-pressure stage

The high-pressure pump in the diagram is for a four-cylinder engine and so has four plungers. The pump is driven at camshaft speed, so that two injections occur during each revolution of the engine. The fittings on the rear of the pump to which the injector pipes are connected contain a *return-flow valve.* When injection for a particular cylinder starts, the valve is lifted off its seat to allow high-pressure fuel to pass through to the injector. When injection ceases, the pressure drops suddenly and the spring forces the valve to close. The return-flow valve is designed in such a way that injection has a sharp cut-off. This prevents pressure waves that could cause the injector needle to bounce and allow dribble.

Injection timing

Because of injection lag, the injection timing has to be advanced as the engine speed is increased. This is accomplished by turning the cam ring in a direction opposite to pump rotation, as well as by varying the time of opening of the high-pressure solenoid valve. The timing arrangement is shown in Figure 36.26. The timing device is basically a piston that is moved in its bore to turn the cam ring.

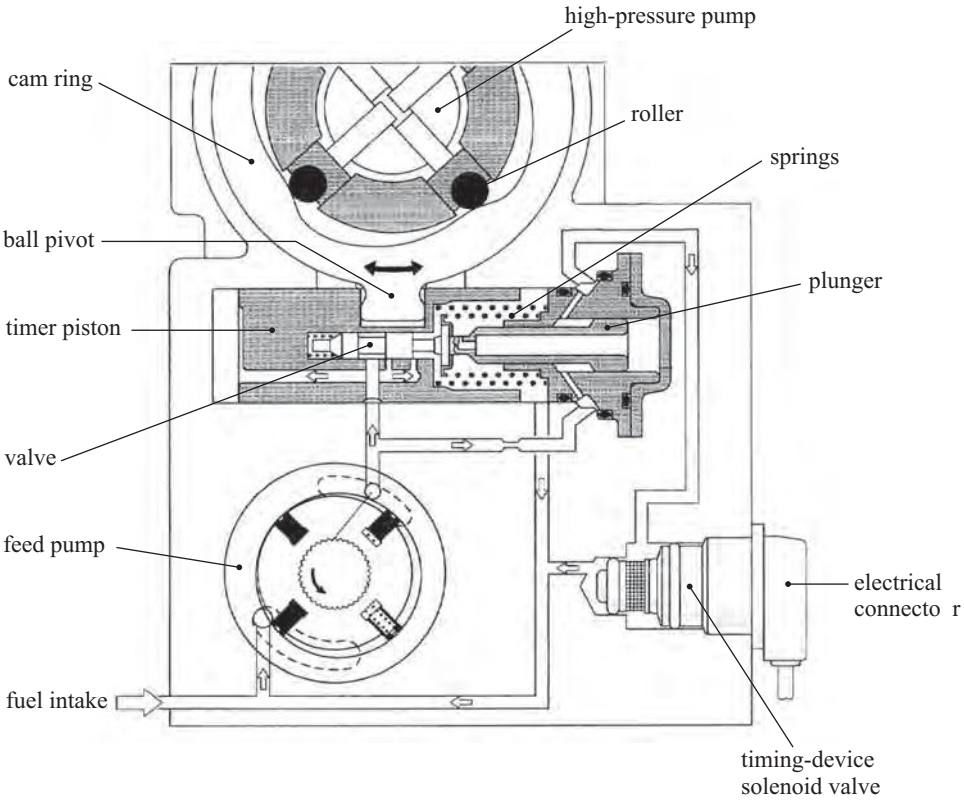


Figure 36.26 Timing device for a radial distributor pump BOSCH

With the engine stopped, the piston is held in the retard position by the springs. With the engine running, there is pressure on the left-hand end of the piston, but its position is determined by the pressure on the right-hand end. The pressure on the right-hand end can be varied by the timing-device solenoid valve, and this is controlled by the ECU. The ECU sends signals to the solenoid and so adjusts the pressure on the right-hand end of the piston and the injection timing.

Handy hint: Electronic control of this design of pump means that a mechanical governor is not required.

Electronic components

There are two electronic control units. The engine ECU is mounted on the bodywork of the vehicle, and the pump ECU is mounted on top of the pump. There are various external sensors and also an *angle-of-rotation sensor* within the pump that provides information to the ECUs. The pump ECU operates in conjunction with the engine ECU. In turn, the pump ECU signals the solenoids in the pump to control the timing of injection and the quantity of fuel being injected. It also isolates the solenoids when the engine is being shut down. A radial distributor pump with electronic control is shown at the end of this chapter as Figure 36.34.

36.10 Common-rail injection systems

The components of a common-rail injection system are shown in Figure 36.27. This includes the electronic control system as well as the fuel system. The system has a *low-pressure stage* and a *high-pressure stage*. The low-pressure stage supplies fuel to the high-pressure pump (injection pump) and the high-pressure stage delivers fuel at high pressure to the injectors. In addition, there is the ECU that controls fuel delivery, operates the injectors and adjusts injection timing.

36.10.1 Low-pressure stage

This consists of the fuel tank, an electric supply pump in the fuel tank and a filter or filter/sedimenter. There are low-pressure lines for supplying fuel to the high-pressure pump and low-pressure lines for returning fuel to the tank.

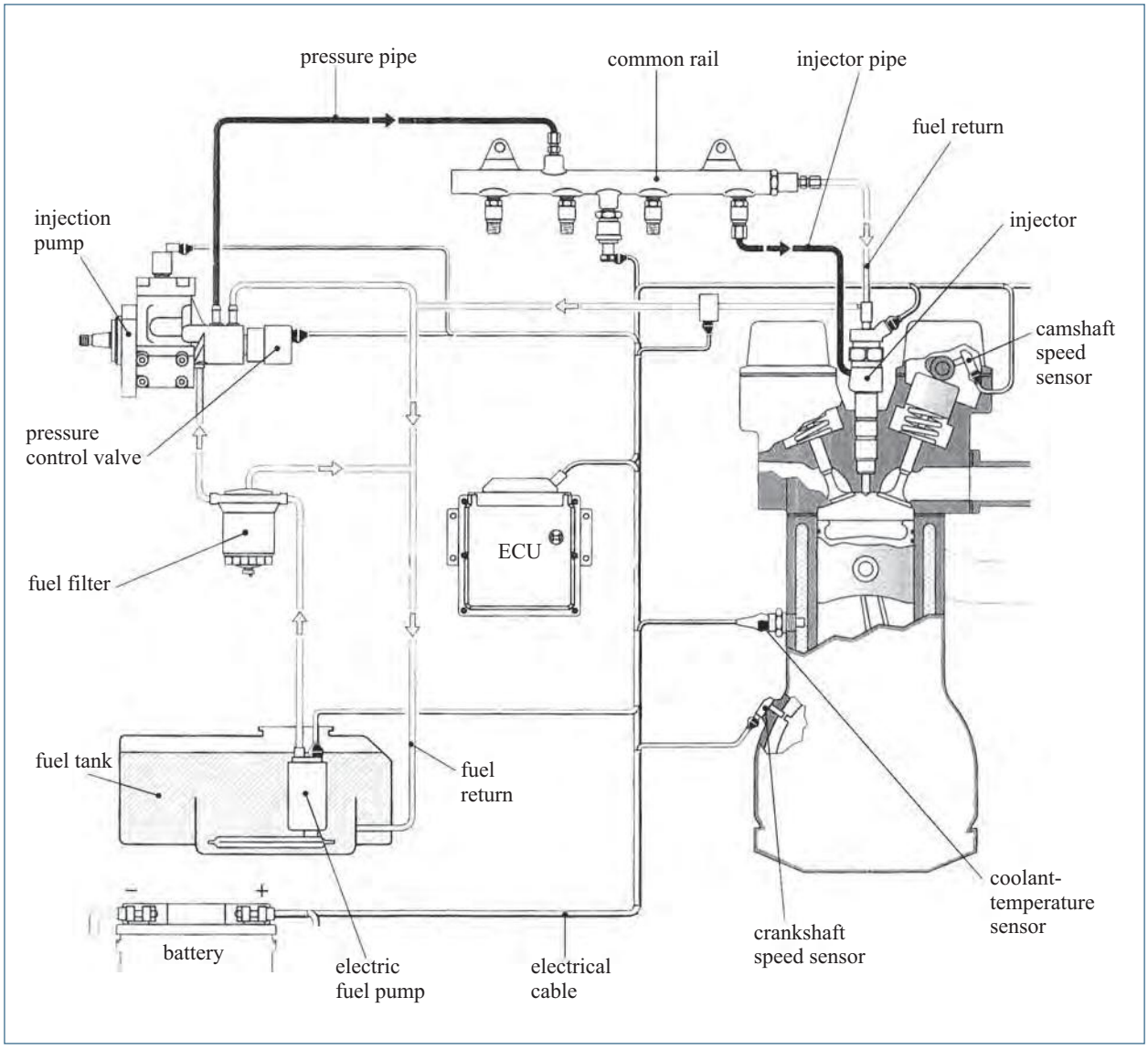


Figure 36.27 Common-rail injection system—fuel injection and e lectronic components are shown BOSCH

The low-pressure pump operates continuously to supply fuel to the high-pressure pump (up to 3 bar). It consists of a permanent-magnet electric motor driving a roller-cell pump (see Figure 36.5). Fuel flows through the pump and acts as a cooling medium. Fuel from the pump reaches the high-pressure pump after passing through the sedimenter and filter. Surplus fuel is directed back to the tank through fuel-return lines. Return lines are connected to the top of the filter, to the high-pressure pump, to the common rail and to the injectors.

36.10.2 High-pressure stage

The high-pressure stage includes the high-pressure injection pump, the common fuel rail, high-pressure fuel lines and the injectors. In this stage, the high-pressure pump generates a very high fuel pressure and delivers it to the common rail. The pump is driven by the engine's timing chain or belt at camshaft speed.

The fuel delivered from the pump to the common rail is contained by a heavy-wall tube. Individual pipes then connect the common rail to the injectors. All the components in this stage of the system carry fuel at high pressure.

Handy hint: The bar is a unit of atmospheric pressure . It is equal to appro ximately 100 kP a.

36.10.3 High-pressure injection pump

The construction of a high-pressure injection pump is shown in Figure 36.28. Its main parts are:

1 The drive shaft. This has an eccentric that operates a cam which then operates the pump pistons.
2 The pump unit. This has three pumping elements: a piston, a pumping chamber and an inlet and outlet valve. This unit produces the high fuel pressure .
3 The element shut-off . This is an electric solenoid that isolates one of the pumping elements to reduce the pump output under certain conditions when lower pressure is needed.
4 The pressure control valve . A solenoid-operated assembly that controls the pressure of the pump .

Pump operation

Low pressure fuel enters the high-pressure pump through the pump inlet and is directed through passages to the pumping elements. After being compressed, fuel is forced into the high-pressure side of the pump. It then passes from the outlet port through the high-pressure connection to the common rail.

36.10.4 Pumping elements

Figure 36.29 shows the arrangement of the high-pressure pump unit. This has three pumping elements spaced at 120°. Each element consists of a plunger (or piston) in a bore and an inlet and an outlet valve.

The pump drive shaft has an eccentric that rotates within the drive cam. As the shaft rotates, the eccentric moves the drive cam and the plungers move up and down. Each pumping element delivers fuel once during one rotation of the pump shaft. On the plunger downstroke, the inlet valve is opened by low-pressure fuel which flows into the pump chamber. On the plunger upstroke, fuel is compressed. The intake valve is closed and the outlet valve is opened by the compressed fuel that is delivered through the high-pressure side of the pump to the common rail.

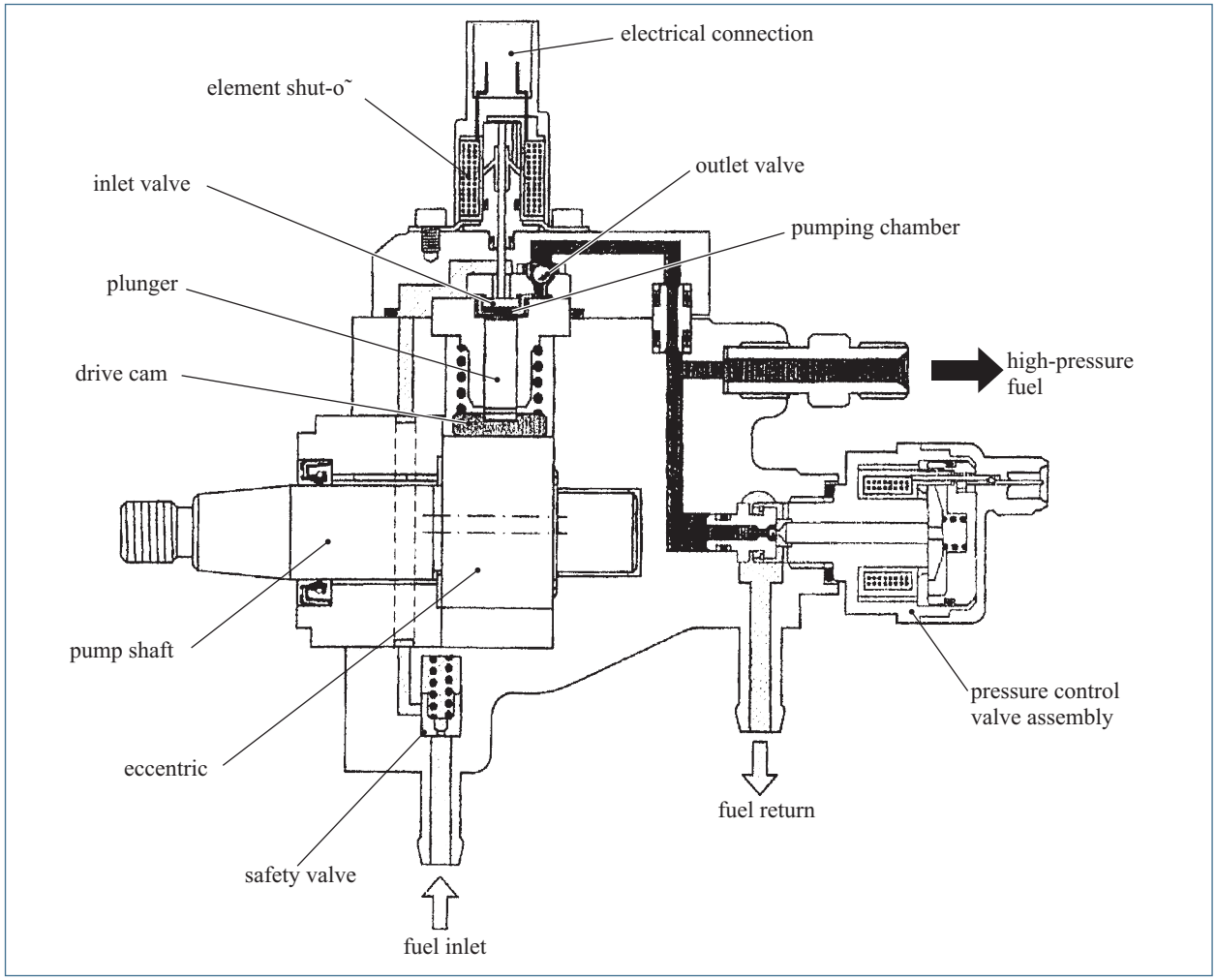


Figure 36.28 Injection pump for a common-rail injection system BOSCH

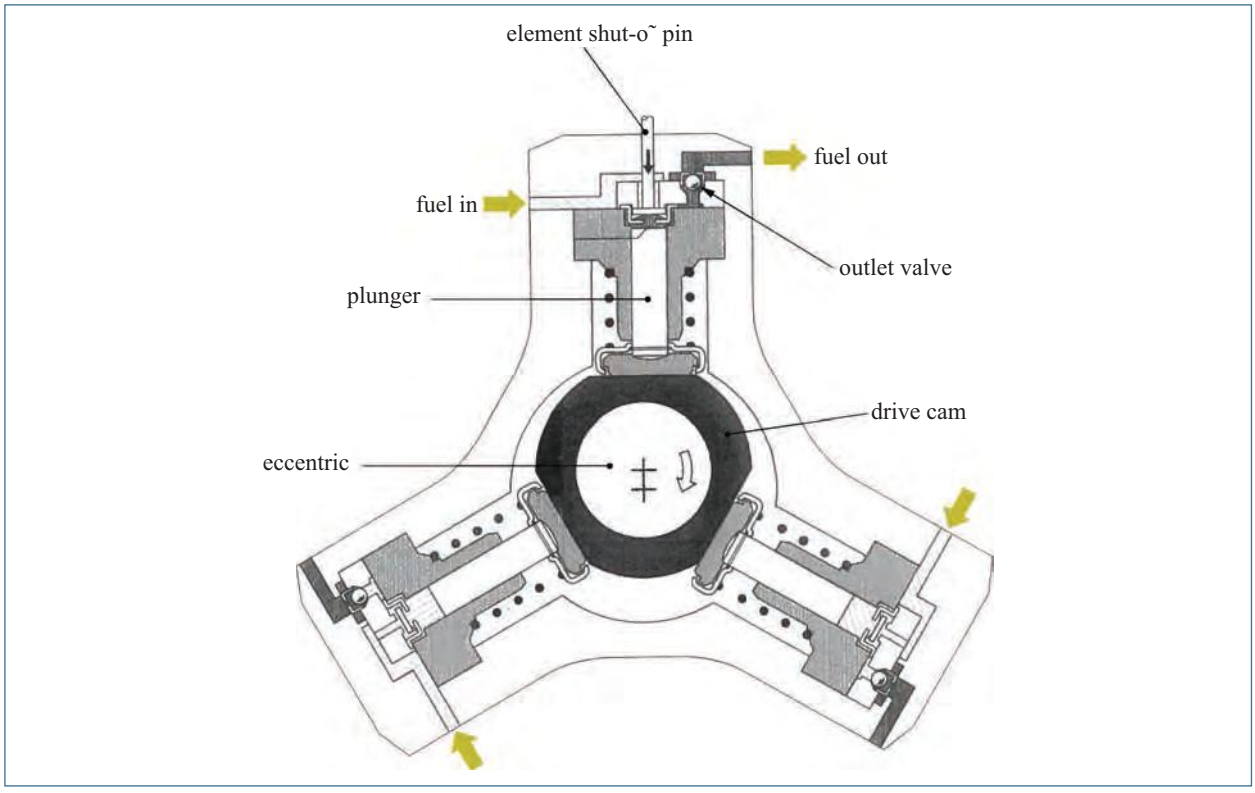


Figure 36.29 Cross-section of the high-pressure pumping elemen ts of a common-rail injection pump BOSCH

Handy hint: The drive shaft rotates—the cam does not rotate , but has an eccentric action.

Element shut-off

The pump-element shut-off is a solenoid-operated valve located on the top of the high-pressure pump. Its function is to prevent the top element from developing pressure. It does this by energising the solenoid to move a pin downward. This holds the inlet valve of the top pumping element open. The plunger continues its normal motions, but there is no pressure developed so no fuel is discharged through the outlet valve.

The element shut-off is operated by the electronic control unit, which shuts off the element at idle and lower speeds when less fuel is needed. As well as reducing the amount of fuel being pumped, it conserves engine power.

36.10.5 Pressure control valve

The pressure control valve is located on the rear of the high-pressure pump (see Figure 36.28). It sets the pressure for the fuel rail to suit the engine operating conditions. It has a spring-loaded valve that blocks off the fuel return passage until a certain pressure is reached. It then opens to allow the excess fuel that passes through the valve to be returned to the fuel tank through the return line. An electrical solenoid, operated by the ECU, controls the opening and closing of the valve to regulate the pressure.

36.10.6 Common rail (fuel rail)

The common rail (Figure 36.30) is provided with fuel by a pressure line from the high-pressure pump. It holds a quantity of fuel at high pressure, and this is provided at a constant pressure to all the injectors. It has a *pressure-limit valve* at one end with a connection to a return line. This is a spring-loaded valve that is normally closed. Should the pressure reach the valve limit, it will overcome the spring to open the valve and allow excess fuel to pass from the fuel rail through the return line to the fuel tank.

A pressure sensor on the rail is connected to the pump ECU. The ECU can control pressure in the rail through the action of the pressure relief valve on the high-pressure pump.

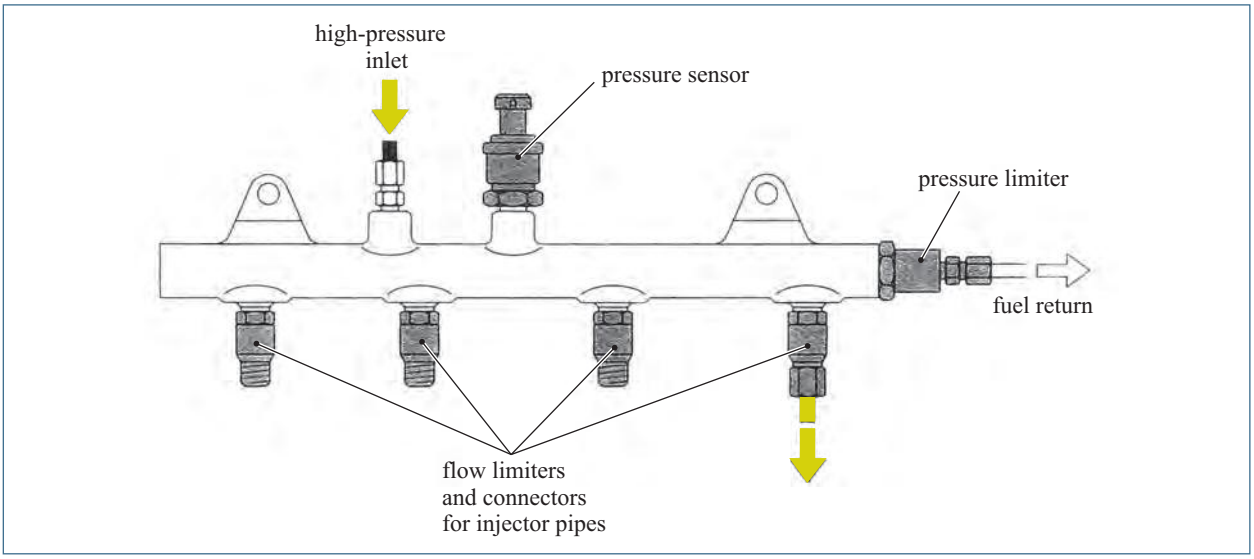


Figure 36.30 Common rail for fuel system BOSCH

Handy hint: The common rail is so named because it is a common fuel rail for all the injectors. It is also called the accumulator because it holds a quantity of fuel.

Flow limiters

These are connected between the common rail and the injector pipes. Fuel from the common rail passes through the limiters on its way to the injectors. The limiter consists of a housing with a spring-loaded valve. Under normal operating conditions, the valve is held off its seat by the spring and there is high pressure in the common rail and in the injector pipe.

If an injector was to remain open, the pressure in its injector pipe would drop. The higher fuel rail pressure would then move against the spring to close the valve. This would prevent pressure loss in the common rail and also prevent fuel dribbling from a faulty injector.

36.10.7 High-pressure fuel lines

The high-pressure fuel lines, which include the pipe from the pump to the common rail and the pipes to the injectors, carry high pressure at all times. Because of this, they are made of thicker section material than the injection pipes of other systems.

36.11 Injectors for common-rail systems

Two types of injectors are used in common-rail diesels. One is the solenoid type and the other is the piezo type.

36.11.1 Basic operation: solenoid type

The operation of a common-rail injector is similar to other injectors as far as operation of the needle in the nozzle is concerned. The main difference is that it has an electric solenoid to trigger injection. When the injector is not injecting, the needle is held down against its seat in the nozzle by spring force and by fuel pressure. When injecting, the needle is lifted from its seat by fuel pressure in the gallery in the usual way, so that fuel is sprayed from the nozzle. However, the needle cannot be raised unless the solenoid is energised. This is done by the ECU.

Handy hint: Both the timing and the amount of fuel injected are electronically controlled.

36.11.2 Operation in more detail

This is a hydroelectric device with some parts that operate electrically and others that operate hydraulically.

The main operating parts of the injector are the solenoid, the control plunger and the needle.

1 The solenoid. At the top of the injector , this has an armature that moves up or down to close or open the ball valve . The armature is normally held down by the spring and the ball valve is closed. When the solenoid is energised, the a rmature is moved up and the ball valve is opened. O pening and closing the ball valve alters the fuel pressure in the control chamber on top of the plunger .
2 The control plunger . This is moved up or down under the action of fuel pressure in the control chamber and in the gallery . With pressure in the control chamber , the plunger is moved down. Without pressure in the control chamber , the plunger moves up . In this way, it opens or closes the needle valve .
3 The needle . This is normally held closed on its seat in the nozzle by the control plunger , but is opened when fuel pressure in the gallery moves the control plunger up . This occurs when the solenoid is energised.

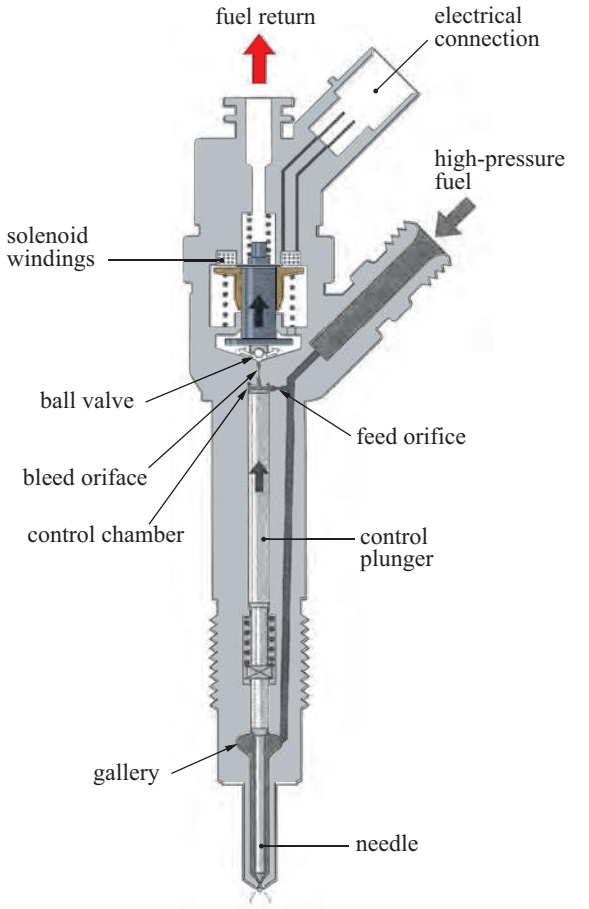


Figure 36.31 Solenoid-type injector for a common-rail system BOSCH

Three different conditions of injector operation will now be considered: *injector closed, injector open* and *injector closing*. These relate to Figure 36.31.

Condition when not injecting

1 The solenoid is not energised and its armature is held down by the spring. The ball valve closes off the bleed orifice .
2 Fuel supplied under high pressure from the pump enters through the injector inlet and passes down the feed passage to the gallery in the nozzle at the bottom of the injector . It also passes through the feed orifice to the control chamber in the upper part of the injector .
3 With the ball valve closed, fuel is prevented from flowing through the bleed orifice and out the top of the injector. This creates pressure in the control chamber .
4 The needle is held on its seat in the nozzle by the spring force and by fuel pressure in the control chamber on top of the plunger .

There is the same pressure in the control chamber and the gallery, but the downward force on the plunger is greater than the upward force. This is because the area on top of the plunger on which the pressure acts is greater than the area of the shoulder of the needle.

Condition when injecting

1 The solenoid valve is energised by a signal from the ECU , and this attracts the solenoid armature upwards.
2 The ball valve opens the bleed orifice and fluid bleeding through it relieves the pressure in the control chamber . This relieves the pressure on the top of the control plunger .
3 The pressure in the gallery , acting under the shoulder of the needle , forces the needle and the control rod upwards. This opens the nozzle holes and sprays fuel into the combustion chamber .

Condition when injector is closing

1 At the end of injection, the solenoid is de-energised and the armature is moved downwards by the spring.
2 This moves the ball valve down to close the bleed orifice . Fuel pressure quickly builds up in the control chamber and the control plunger is moved down.
3 The needle is pushed on to its seat in the nozzle and injection ceases.

Handy hint: Pressure in the control chamber closes the needle valve—no pressure in the chamber opens it.

36.11.3 Basic operation: piezo type

Piezo-type injectors are hydro-electric devices. That is, they have parts that operate hydraulically and parts that operate electrically. The main operating parts, as shown in Figure 36.32, are:

- piezo stack
- hydraulic control plunger
- control valve
- needle
- nozzle .

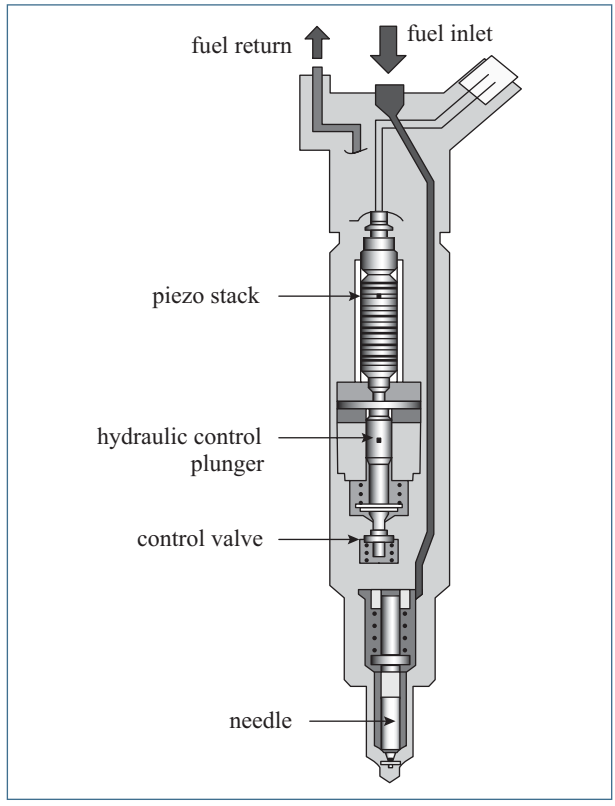


Figure 36.32 Piezo-type injector for a common-rail system

The operation of a piezo-type injector is similar to that of a solenoid-type injector, except that instead of a solenoid it has a piezo stack. This is made up of many crystal-like materials forming ceramic piezo-electric discs. The discs expand when a voltage is applied to the stack and contract when the voltage is removed. This expansion and contraction creates the movement required for the hydraulic action within the injector which, in turn, has the effect of lifting the needle from its seat.

The injector has an upper fuel chamber and a lower fuel chamber. They are separated by the control valve. Simply, this valve controls the pressure in the upper chamber. It normally holds pressure-fuel from the fuel rail in both chambers, and so the needle remains on its seat in the nozzle.

When the piezo stack is activated, hydraulic action operates the control valve, which relieves the pressure in the upper chamber and seals off the lower chamber. The pressure in the lower chamber lifts the needle from its seat and so fuel is injected into the combustion chamber of the engine.

This is a simplified description of the operation of this type of injector.

36.12 Electronic diesel control

Figure 36.33 shows the general arrangement for a distributor-type injection pump with an electronic control system. This is a radial injection pump, but an axial pump could have a similar arrangement.

There is an engine ECU and an injection pump ECU. There are also a number of sensors. These transmit signals to the ECUs, which are processed and compared with standard data or a *memory map.* Signals are then transmitted to the solenoids in the injection pump.

The solenoids open and close valves and perform other functions to control both the timing and the quantity of fuel injected. Controlling the quantity of fuel controls the speed and power of the engine.

The sensors shown are:

1 accelerator-pedal sensor
2 air-mass sensor
3 crankshaft sensor
4 coolant-temperature sensor .

Other sensors monitor fuel pump speed, fuel temperature, injection timing, and exhaust gas temperature, concentration and pressure.

The accelerator pedal is not connected directly to the injection pump but has a position sensor that is connected by an electrical cable to the pump ECU. Movement of the accelerator pedal is transmitted

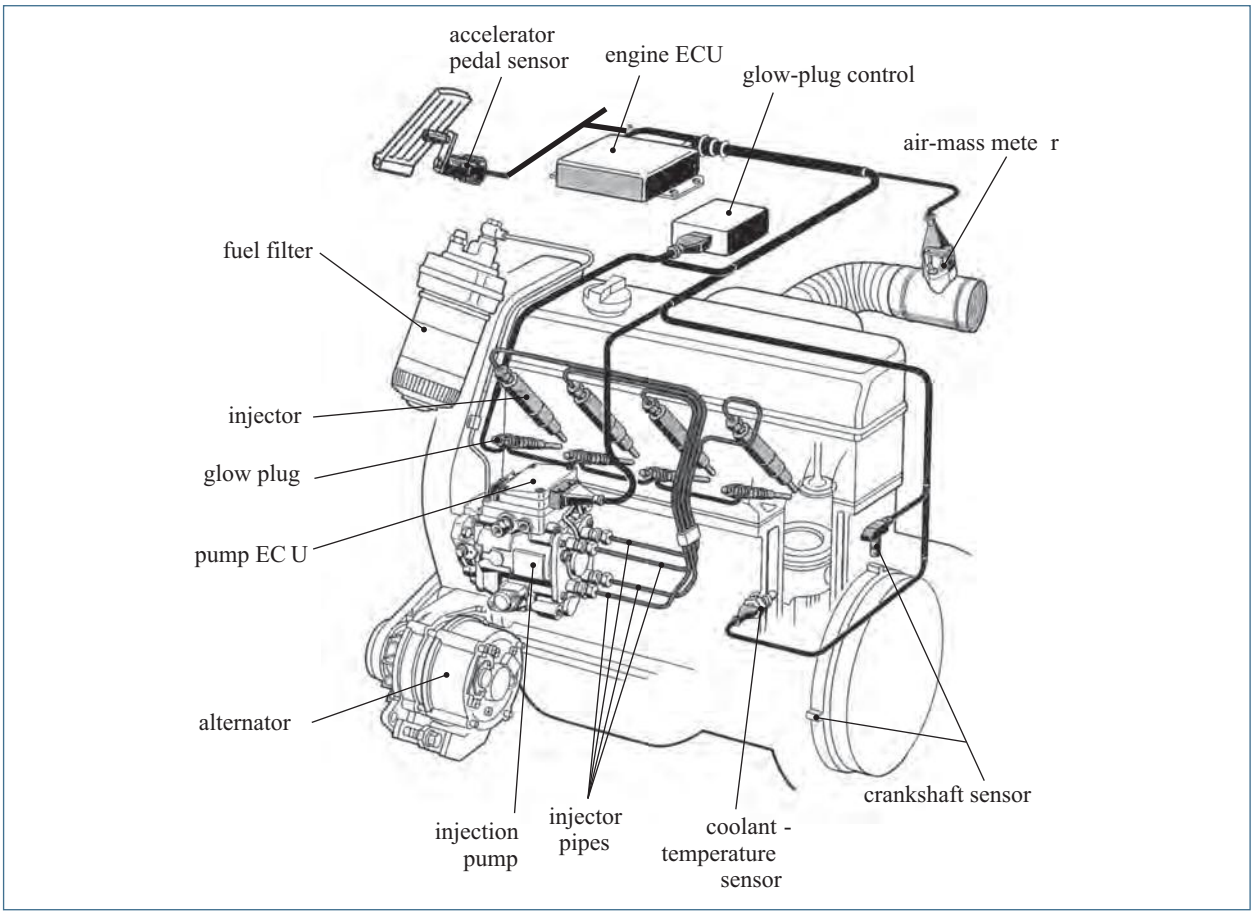


Figure 36.33 Radial injection pump with electronic control BOSCH

as a signal to the pump ECU which takes the necessary action with the pump solenoids to increase or decrease engine speed or power.

Handy hint: This arrangement, where there is no accelerator cable or linkage , is referred to as drive ***by wire***.

The main actuators are the high-pressure solenoid valve and the timing-device solenoid. The ECUs and the various sensors are interconnected by cabling with multipin connectors. This can be part of the vehicle's CAN Bus electrical system.

36.13 Injection pumps with electronic control

36.13.1 Radial pump

Figure 36.34 shows a radial injection pump in section. The various parts of the pump have been labelled and can be identified.

36.13.2 Axial pump

Figure 36.35 shows an axial injection pump. In this pump, the fuel quantity is controlled electronically and electrically by moving the control sleeve. The cut-off solenoid is electronically controlled, as is the timing device by the solenoid.

36.13.3 Common-rail system

The electronic components for this system include an ECU and electronically-controlled injectors; there are also sensors and solenoid-operated valves on the high-pressure pump, which can be seen in Figure 36.28.

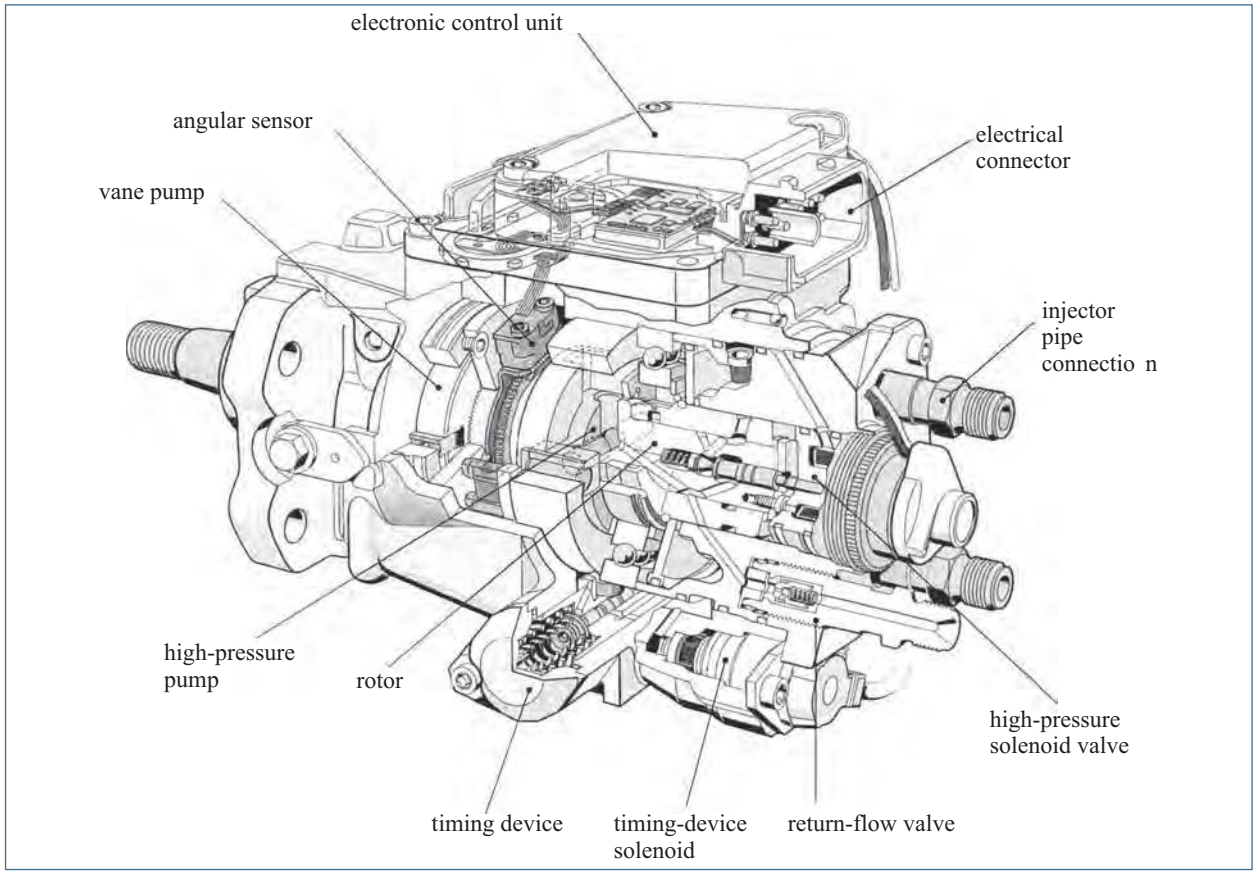


Figure 36.34 Radial injection pump with ECU BOSCH

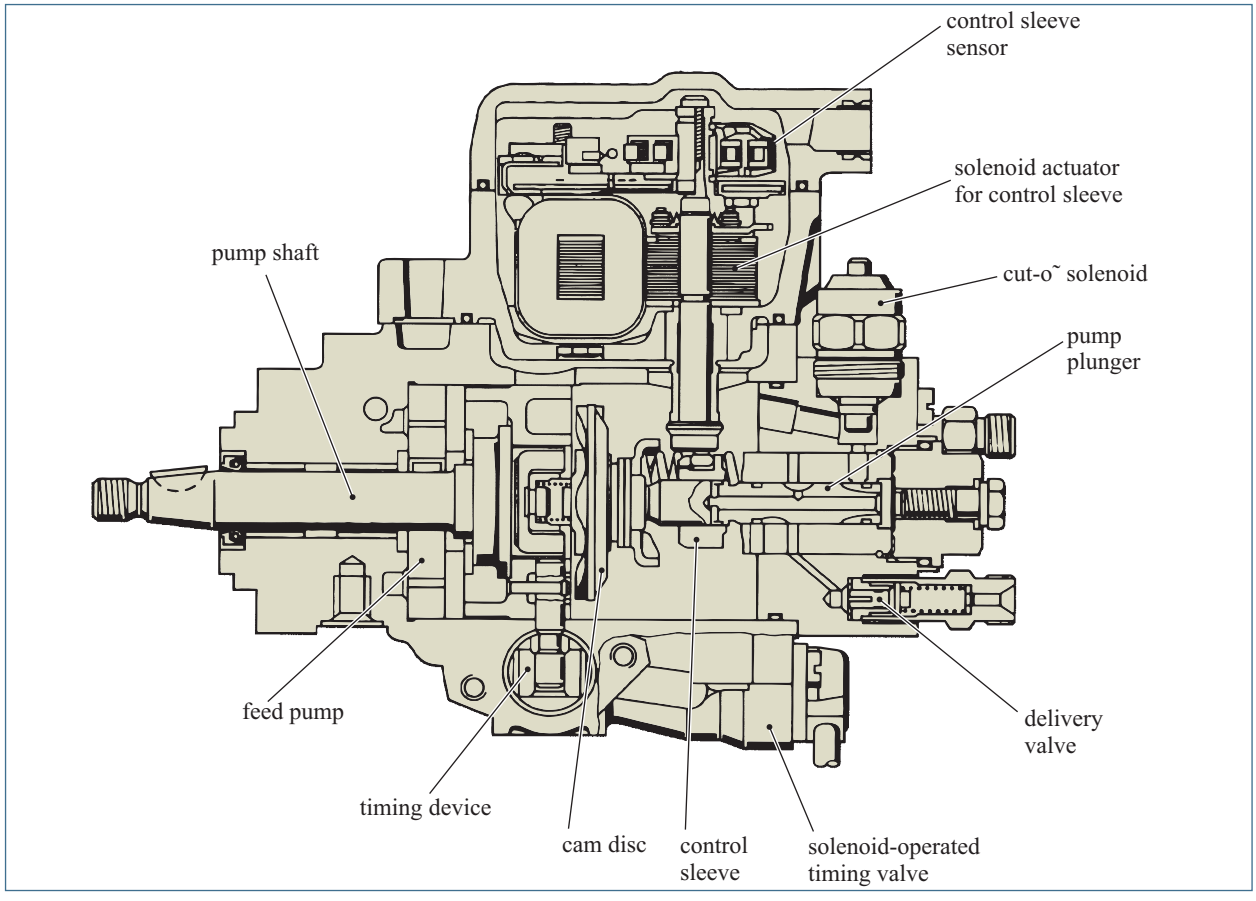


Figure 36.35 Axial distributor pump with electronic control BOSCH

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe the operation and management of diesel compression ignition (CI) engines
- explain how the correct delivery and timing of the fuel charge is determined and controlled
- explain a clean engine-stop process
- explain the operational differences between radial, axial and distributor-type fuel pumps
- compare the operational systems of common-rail injection systems with conventional mechanical CI engines
- explain how electronic diesel engine controls are used to increase fuel economy, reduce pollutants and provide better performance.

REVIEW QUESTIONS

1 Name the main parts of a diesel fuel system.
2 What is the purpose of a feed or supply pump?
3 What types of pumps are used for fuel feed or supply?
4 Why is filtration important in a diesel fuel system?
5 What types of filters are used in a diesel fuel system?
6 How is water filtered from a diesel fuel system?
7 Why is a priming pump fitted to a diesel fuel system?
8 What is a sedimenter?
9 Explain how a sedimenter works.
10 Name the main parts of an injector.
11 How are injectors secured to the cylinder head?
12 Name some of the types of injector nozzles.
13 What is an axial-type distributor injection pump?
14 Explain briefly what the plunger of an axial-type distributor pump does during a pumping stroke.
15 What produces movement of the plunger in an axial-type distributor pump?
16 How is fuel delivery controlled in one type of distributor pump? (Refer to one of the illustrations.)
17 Name the main parts of a radial-type injection pump.
18 Name the main parts of a common-rail injection pump.
19 What is the purpose of the common rail in an injection system?
20 How does the injector of a common-rail system differ from most other injectors?
21 How is electronic control used in a diesel injection system?

CHAPTER 37

Diesel fuel system service

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 list the different types of fuel filters, sedimenters and their servicing requirements
2 describe the bleeding and leak-testing procedures when servicing filters and observing all safety practices
3 describing the procedure for injector servicing
4 explain the different types of diesel problems
5 describe the methods used to check diesel engine controls.

General maintenance of a diesel engine includes ensuring the following: the engine gets clean fuel; its fuel filters are regularly serviced; its fuel connections are tight and leak-free; it is cleaned externally. Many injectors need servicing at regular intervals, but injection pumps should require very little service if the other parts of the fuel system are correctly maintained. The air cleaners and air flow sensors are an important part of the diesel engine control system and should be serviced regularly so that the engine is always supplied with clean air for use with the fuel.

This chapter outlines how fuel-injection components are serviced. However, actually carrying out the servicing is specialist work. It is important to understand and carry out the correct procedures for diagnosing and repairing diesel engine faults.

37.1 Servicing fuel filters

The very small clearances in the injection pump and the injectors necessitate keeping diesel fuel clean and free from any water or condensation. All necessary precautions should be taken when handling or storing fuel so that it does not become contaminated. Poor servicing will affect the fuel after it is put into the tank of the vehicle, and dirty fuel causes engine operating problems and damages injection components, resulting in costly repairs. The following are general points that relate to servicing fuel filters:

1 Before servicing a filter, clean all external oil and dirt from around it. Maintain clean conditions throughout the service.
2 If fitted with a drain plug, drain the filter before removing the filter bowl.
3 After removing the canister or bowl, clean inside the filter head with a lint-free cloth and diesel fuel. Also clean the bowl.
4 Inspect the sealing ring and renew it if it is not in good condition.
5 When installing, tighten the filter canister or the filter centrebolt correctly.
6 After installing or assembling the filter, prime and bleed the system and check for fuel leaks.

37.1.1 Canister fuel filters

Canister filters, or throw-away filters, are threaded onto the filter housing. When servicing the filter, the complete canister is removed and discarded. The filter can be removed with a suitable tool, but when the new filter is installed, it should be tightened by hand (Figure 37.1).

Before installation, the filter seal should be coated with fuel. During installation, the filter is hand-tightened until the seal makes contact, then tightened about an extra half-turn.

37.1.2 Sedimenters

Some sedimenters can be drained to remove water and deposits before being flushed by the hand-priming pump. Some sedimenters have a bowl that can be removed and cleaned. Others have a throw-away canister. To check the operation of a sedimenter water-level switch, remove the warning device from the top (or, in some cases, bottom) of the sedimenter and check the switch operation with an ohmmeter, as shown in Figure 37.2.

37.1.3 Filters with disposable elements

The type of filter shown in Figure 37.3 has a disposable element. The bowl is held to the top cover by a centre bolt. A plug in the bottom of the centre bolt allows the filter to be drained before the bowl is removed. After removal, the bowl is washed in clean fuel and a new filter element is installed.

37.1.4 Strainers

Strainers of fine mesh are fitted to some systems. A strainer can be used at the fuel tank, the supply pump or at a banjo connection (Figure 37.4). Strainers are serviced by being washed in fuel and blown clean.

Handy hint: Special equipment may be needed when bleeding common rail diesel fuel systems.

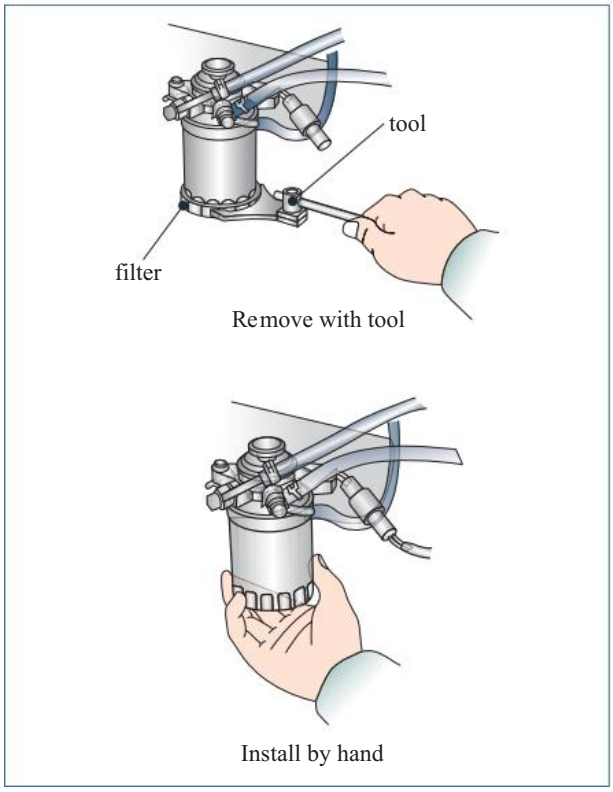


Figure 37.1 Removing and installing a canister-type fuel filter

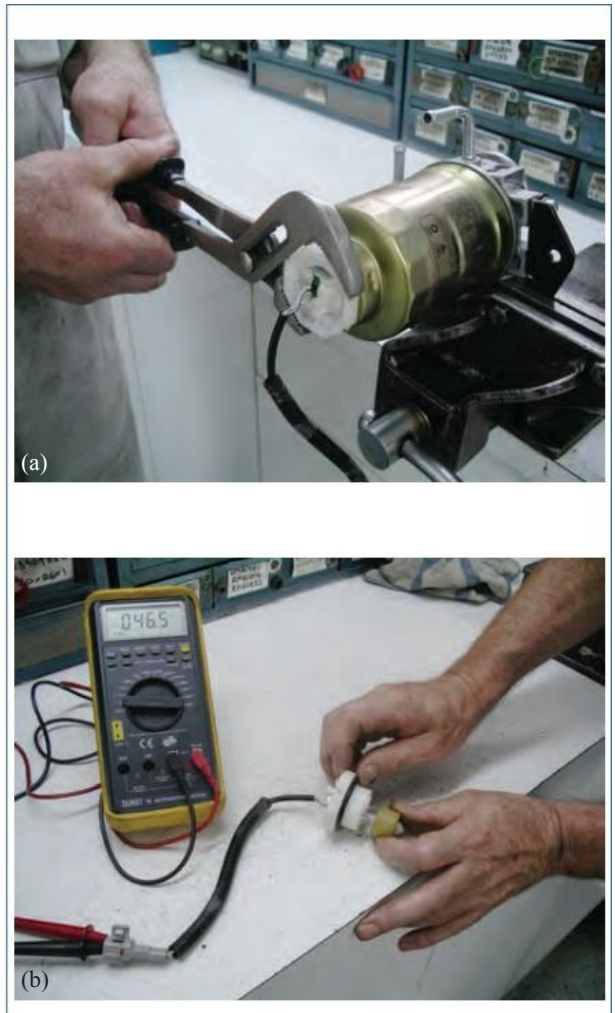


Figure 37.2 (a) Removing and (b) checking a sedimenter warning switch GEMINI DIESEL FUEL INJECTION

37.2 Bleeding and checking the fuel system

Any air that enters the system must be removed or 'bled' before starting the engine. There will not be enough fuel pressure to start the engine if air is present. Air will enter the system when filters or other parts are replaced. The following is a method that can be used to manually bleed the system on most hydraulically operated injectors.

Note. This method cannot be used on common rail or electronically controlled injectors.

1 Loosen the bleed plug on top of the filter , which is on the pressure side of the hand-priming pump .
2 Operate the hand-priming pump until fuel flows from the bleed plug. Continue until the fuel is completely free of air bubbles. Then tighten the plug.
3 If there is a second filter , perform the same bleeding operation.
4 Loosen each injector pipe at the injector (see Figure 37 .7) and crank the engine . When fuel free of air flows, tighten each injector nut and allow the engine to start and idle .

Air can be bled from the system by loosening any of the vent plugs or a fuel line connection. Bleeding should start close to the priming pump and follow through the system to the injectors. Any air in the injectors themselves will be injected into the cylinders, or will find its way to the leak-off pipe at the top of the injectors.

Safety: Diesel fuel contains harmful elements, and care must be tak en to reduce exposure to skin and eyes.

Handy hint: Any air that is trapped in the system will tend to rise to the highest point, which helps it to be bled off .

37.2.1 Checking for fuel leaks

Check the fuel filters, fuel lines and various connections for leaks with the engine running (Figure 37.5). Parts of the system that are on the suction side of an injection or a supply pump are below atmospheric pressure. With faulty sealing of these parts, air could leak into the system or fuel could leak from the system. On the other hand, parts that are on the pressure side of a supply pump could leak fuel, but should not allow entry of air.

Any leak is likely to affect the operation of the engine. Distillate is oily, so leaked fuel will soon collect dirt and dust and result in a very messy engine.

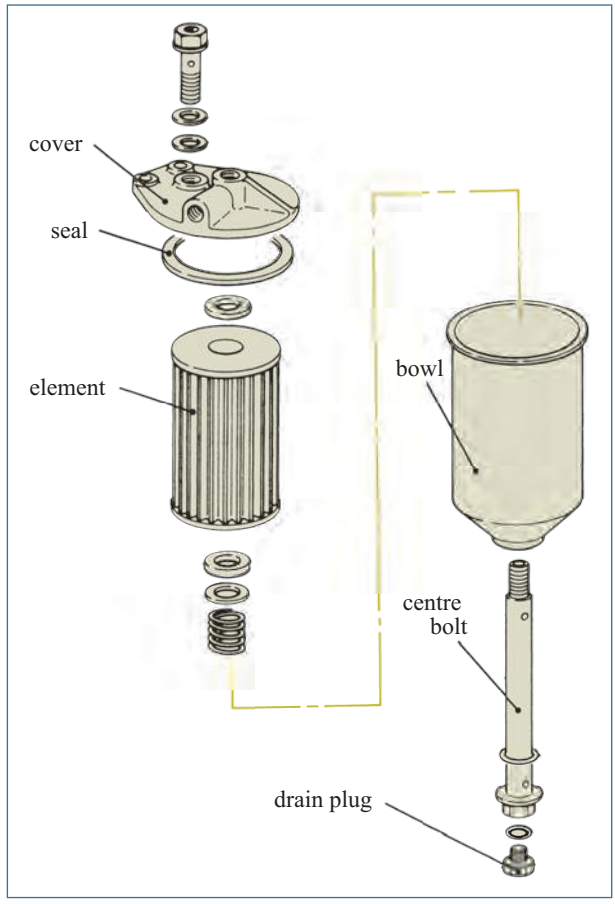


Figure 37.3 Fuel filter with a disposable element

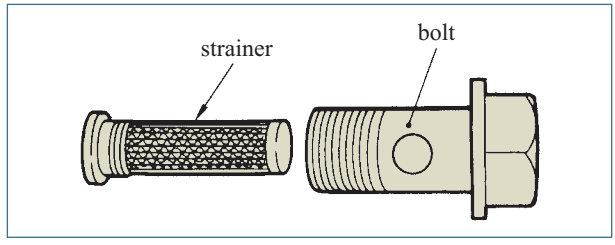


Figure 37.4 Strainer used with a banjo connection

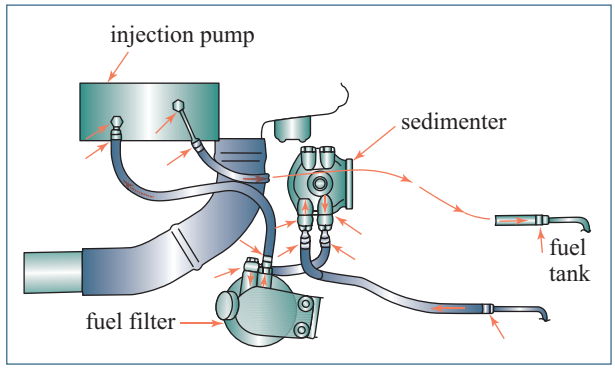


Figure 37.5 Fuel lines, connections and components are check ed for leaks with the engine running

Sustainability: Ensure that all fuel expelled during the bleeding, filter service or fuel checking processes is contained and disposed of correctly .

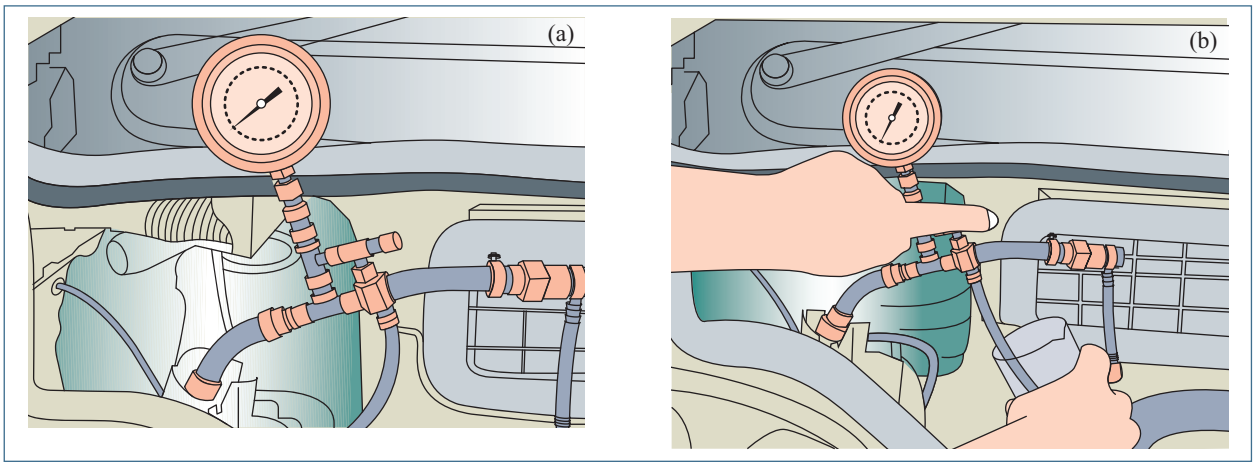


Figure 37.6 (a) Checking the fuel line pressure (b) checking fuel line flow

37.2.2 Checking low-pressure diesel fuel pumps

The many different types of low-pressure pumps used on diesel engines are all tested in a similar manner. The general procedure is:

1. Ensure the engine is off .
2. Bleed any residual fuel pressure .
3. Locate and disconnect the output hose from the pump , capturing any fuel spillage .
4. Connect a fuel pressure and flow gauge into the fuel system.
5. Start and run the engine and note the operating fuel pressure (Figure 37.6(a)) and flow (Figure 37.6(b)).
6. Compare the reading with the manufacturer' s specifications.
7. Stop the engine and remove the fuel pressure and f low gauge.
8. Reconnect the fuel pump outlet hose , again capturing any fuel spillage .

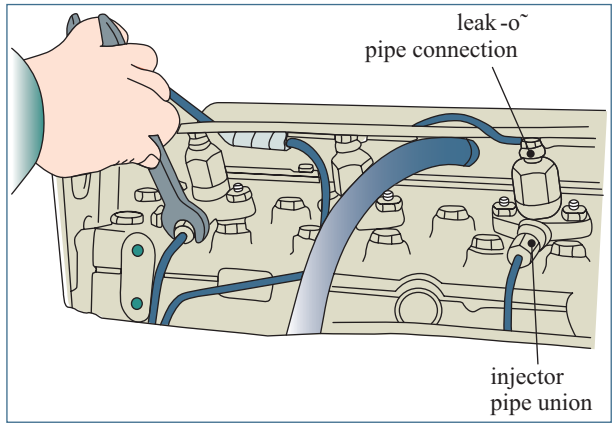


Figure 37.7 Bleeding an injector pipe by loosening a union at the injector

37.2.3 Injector service

Injectors inject a finely atomised spray of fuel into the combustion chamber. Faulty injectors can cause misfiring, engine knock, engine overheating, loss of power, smoky black exhaust or increased fuel consumption. Injectors should be removed for cleaning and testing at the recommended maintenance periods.

Safety: Injectors can operate at pressures up to 3000 bar (300 MP a; 44 000 psi), producing high voltages. Precautions must be tak en to ensure that the work environment is k ept safe .

Handy hint: The symptoms produced by faulty injectors in a diesel are similar to those produced by faulty spark plugs in a petrol engine .

37.2.4 Locating a faulty injector

There are a number of ways of locating a faulty injector. Some can be carried out on the engine while others require the injectors to be removed and tested.

Isolating an injector

Faulty injectors can be located in some earlier systems by loosening off the injector pipe at each in turn, with the engine running at fast idle (Figure 37.7). This cuts off the fuel supply to the particular injector, causing a noticeable drop in engine speed for a good injector. However, no change in speed will occur if the injector is faulty.

This is the same as the procedure used for bleeding the injector pipes. If air is in the pipes and is causing the problem, it will be bled at the same time as the injector is being checked.

Safety: This procedure does not apply to electronically controlled injectors. R efer to warning in Chapter 36.

Checking an injector spray

On some systems, an injector can be checked for operation on the engine after it has been removed from the cylinder head. The injector is fitted to its pipe, but pointing away from the engine. Loosen the union nuts of the other injectors (if they are still in place) to prevent fuel from being injected into the cylinders.

Crank the engine over with the starter so that the injector sprays into the air and its pattern can be observed. It should be a uniform fine spray, with no wetness, streaks, side sprays or dribbles (Figure 37.8). When cranking is stopped, the nozzle should cut off and not dribble.

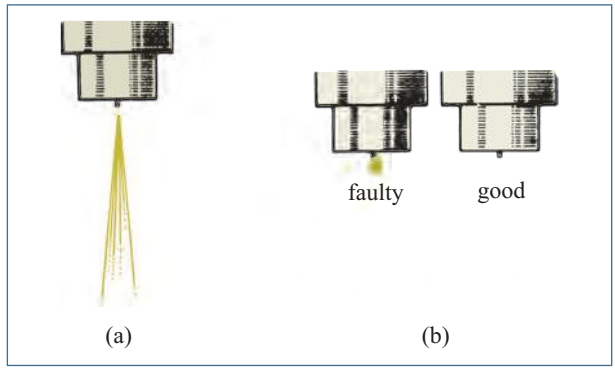


Figure 37.8 Injector operation (a) spray pattern when pressurised (b) condition when cranking stopped

Safety: Hands must be k ept clear of the injector while the engine is being crank ed.

Testing an injector

A faulty (or possibly faulty) injector should be removed from the engine and pressure-tested on an injector tester. The method is outlined in Injector Testing.

Equipment is also available for pressure testing the injection of an engine while it is running. A pressure gauge is connected between the injection pump and the injector to check the operating pressure. This information is then used to assess the condition of the injector and, to some extent, the injection pump.

Figure 37.9 Fuel injector leakage master testing equipment SP TOOLS

Testing common rail injectors

1 Slide out the wire clips that hold the electrical connectors and leakage hoses on the tops of the injectors.
2 Gently remove the connectors, being careful not to damage them (they can become brittle with age).
3 Block or clamp the fuel tank return hosepipe to prevent fuel spillage as the engine is crank ed
4 Using calibrated test bottles, connect the bottles to each injector , ensuring they are safely secured to prevent spillage and contact with hot and moving parts (Figure 37.9).
5 Crank the engine . Monitor the fill rate of each bottle . If levels are different, this indicates a problem.
6 As a general rule , less than 10% overall variation is ideal. The bottle with the greater amount indicates the injector that could be faulty .

37.3 Removing and installing injectors

When removing an injector, the injector pipe should be disconnected at both the injector and the pump end. Removing an injector with the pipe disconnected only at the injector could bend it, making it hard to reconnect.

The leak-off pipe is attached to the top of the injector by nuts or by a union. This pipe is also completely removed. Most injectors for smaller diesel engines are screwed into the cylinder head. These are removed with a special spanner that fits onto the body of the injector (Figure 37.10).

Flanged injectors are secured to the cylinder head by bolts or studs. When the bolts or nuts are removed, the injector can be loosened with a special tool or lever, and then removed from the recess in the cylinder

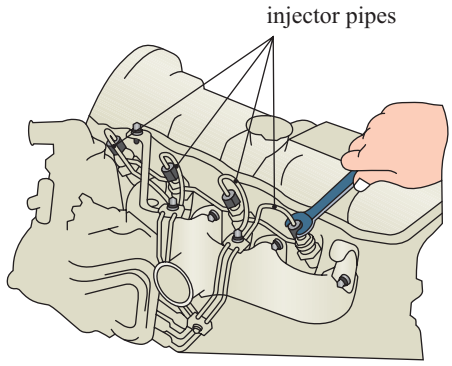
head (Figure 37.11). Common rail injectors have an electrical connection that must be removed prior to removing the injector. It is important that the battery is disconnected prior to working with these injectors.

37.3.1 Installing injectors

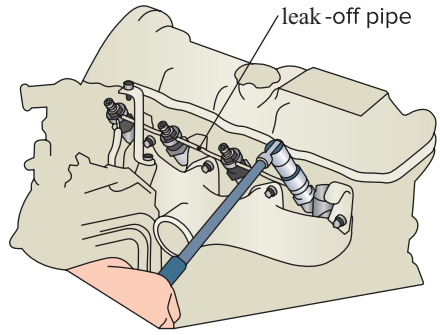
Before installing an injector, the recess in the cylinder head and the end of the injector must be clean. The washers and heat shield for the particular injector must be in place. Points relating to installing an injector are:

1 Threaded injector . Check that it screws easily into the cylinder head. A fter seating on the sealing washers and heat shield, the injector is tightened to a specified torque (Figure 37.12).
2 Flanged injector . Check that it is a free fit in the recess. Use a new copper sealing washer . Tighten the bolts or nuts evenly so that the injector is not tilted
3 Common rail injector . Check the recess and washer seating area is clean. A new sealing washer and a new fuel delivery pipe will often be required. Tighten the injector mounts and fuel delivery pipe and reconnect the electrical connector and back leakage pipe/hose .
4 Injector pipes. When being installed, the injector pipes should be check ed at both ends for a square fit before the union nuts are connected.
5 Union nuts. Tighten the union nuts at both ends of the injector pipes by hand. Then tighten them with a spanner until the pipe is firmly in position. Do not overtighten.
7 Leak -off pipes. These are installed in place on (or near) the top of the injectors and should not be overtightened.

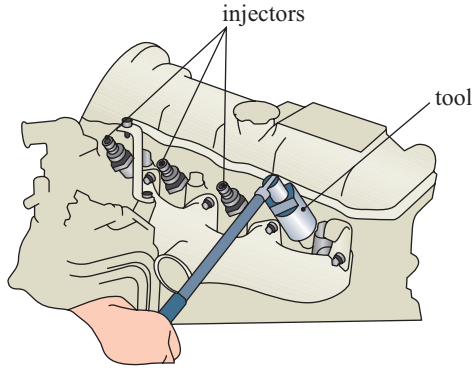
Handy hint: Overtightening could cause the nozzle to deform and the needle to stick.



(a) Disconnect injector pipes



(b) Remove nuts holding leak -o˜ pipe



(c) Remove injectors

Figure 37.10 Removing threaded injectors from the cylinder head

37.4 Injector testing

There are various designs of injector testers, but all have a high-pressure pump, a gauge, a hand valve and a method of holding the injector. An injection tester is shown in Figure 37.13. For testing and adjustment, the injector is connected to the tester and subjected to high pressure. This enables the pressure setting and spray pattern to be checked.

Safety: Keep clear of the nozzle when spraying. The spray has a very great penetrating force , and should never come into contact with the hands. Safety glasses or a face shield should be worn.

37.4.1 Injector tests

Using the injector tester, tests are carried out for opening pressure, leakage and spray. These are for the normal, hydraulic-operated injectors, not the electronic or electro-hydraulic injectors used in common rail injection systems.

Injector opening pressure

The opening pressure of an injector is checked by building up pressure with the pump lever. When nearing opening pressure, the lever is then moved slowly downwards until the needle valve opens. At this point, the injector sprays and the pointer of the pressure gauge flicks. This is the opening pressure.

The pressure gauge can be graduated in *bars* or in *kilopascals* (kPa). The opening pressure of injectors is around 15 000 to 18 000 kPa, or 145 to 175 bar. Depending on the injector design, its opening pressure is adjusted by increasing or decreasing the thickness of the shims against the injector spring. Where the injector has a threaded adjustment, the pressure is set by screwing the nut up or down to increase or decrease the force of the spring.

Handy hint: A bar is the atmospheric pressure at sea level.

Back leakage

The pressure is brought up to just below injection pressure, and the hand lever released. The time taken for the pressure to drop back is then noted. For example, a drop from 150 to 100 bar in six seconds could be acceptable. If the back leakage is faster than this, it indicates excessive clearance between the needle and the nozzle, or a possible leak between the nozzle and the nozzle holder.

Seat tightness

The tip of the nozzle should remain almost dry under a pressure of about 10 bar below the injector's opening pressure. At this pressure, there should be no tendency for a drop to form on the tip of the injector.

Spray form

With the check valve closed, the hand lever is operated smartly and the spray pattern observed. A finely atomised spray of uniform pattern should be produced. Figure 37.14 illustrates different patterns.

Handy hint: The spray form will vary for the different types of injector nozzles.

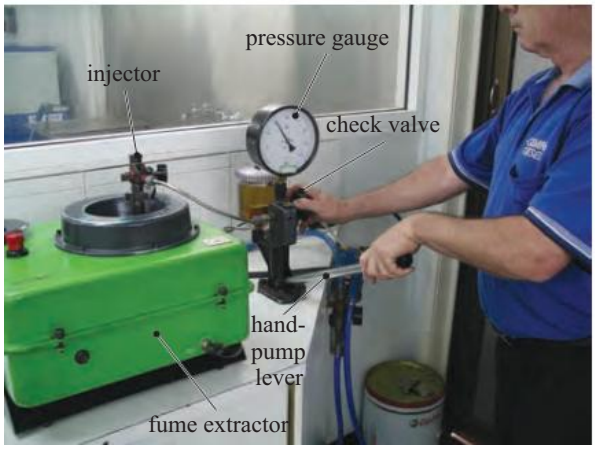


Figure 37.13 Using an injector tester with a fume extraction unit GEMINI DIESEL FUEL INJECTION

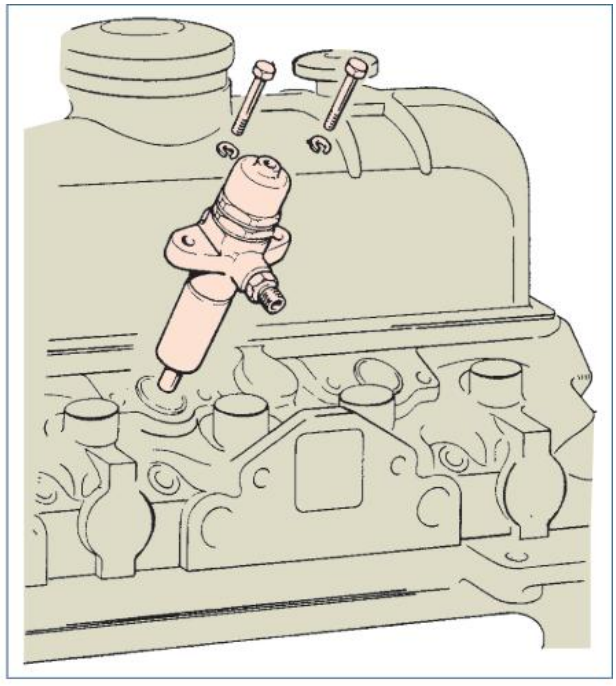


Figure 37.11 Flanged injectors are held in the cylinder head by bolts

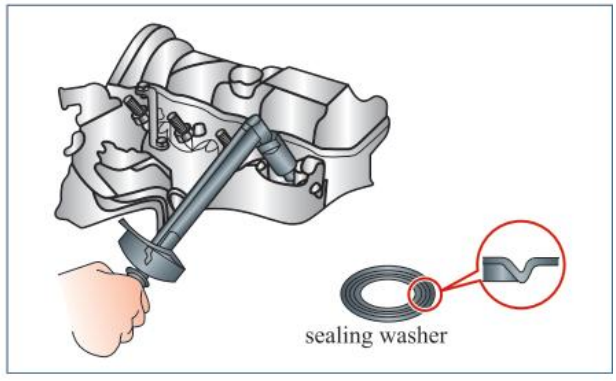


Figure 37.12 Injectors should be tightened to a specified torque—the sealing washer at the base is used

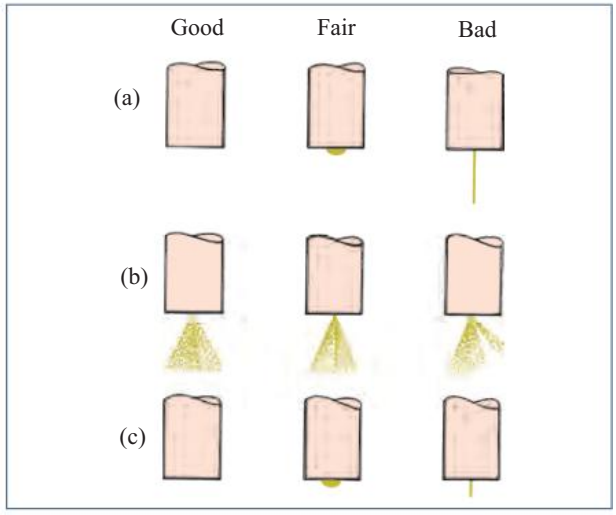


Figure 37.14 Spray from injector nozzle showing good, fair and bad conditions (a) before injection commences (b) during injection (c) after injection ceases

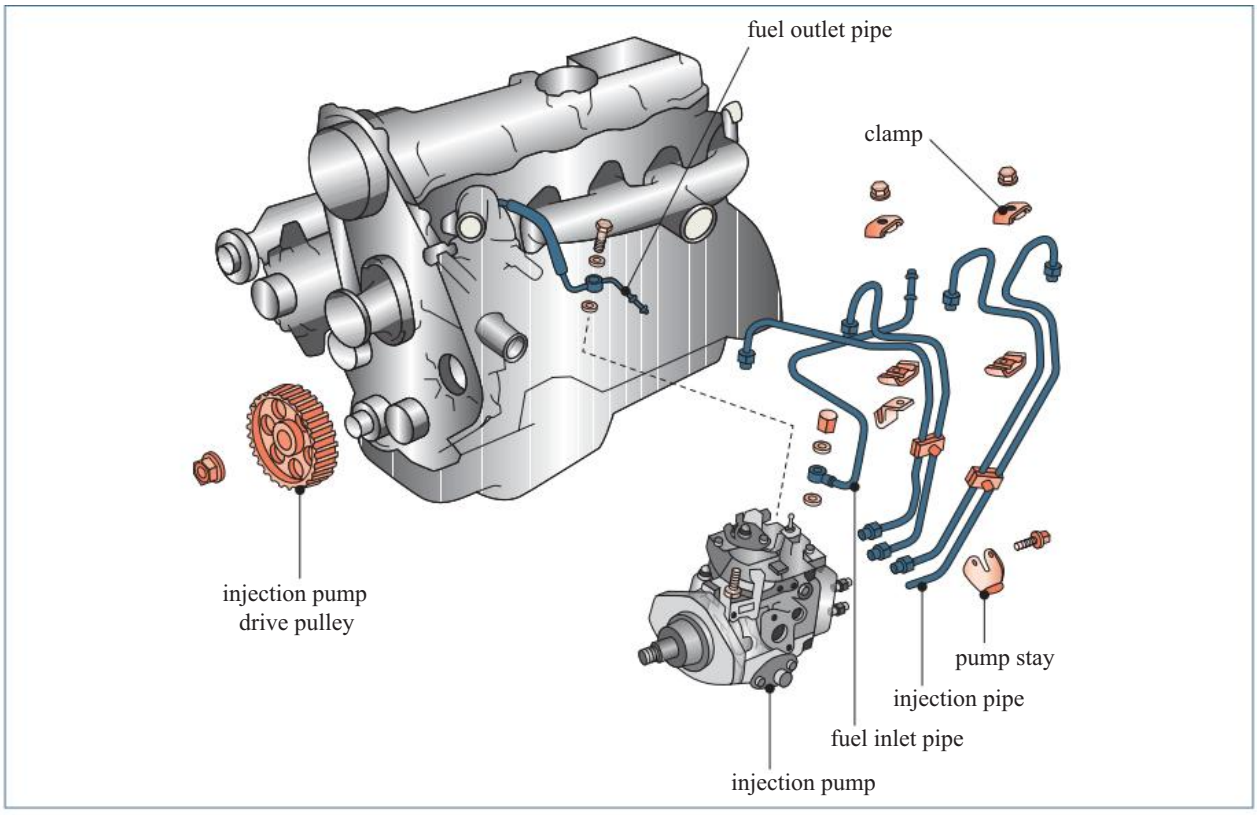


Figure 37.15 A distributor pump and associated parts removed from an engine

37.5 Removing and installing injection pumps

Injection pumps are mounted to the engine in different ways and are driven in different ways; so there is no set procedure that covers them all. Injection pumps are driven at camshaft speed and are timed to inject at a specified number of degrees before TDC on the compression stroke. An injection pump that has been removed must be reinstalled so that the injection timing is correct. Timing marks are provided for this purpose.

37.5.1 Distributor injection pump

Figure 37.15 is an example of the arrangement for a distributor-type pump. This has a toothed pulley keyed to its shaft. The pulley is driven by the timing belt. Before the pump can be removed, the injection inlet pipe, the outlet pipe (or fuel return line) and the injection pipes have to be removed. The connecting plugs also have to be removed from electronically controlled injection pumps. The pump can then be unbolted from its mounting.

Distributor-type injection pumps have a mounting flange at the front, and this is bolted to a mounting on the rear of the timing case of the engine. The bolt holes are slotted to allow the pump to be turned on its mounting for injection-timing adjustment (Figure 37.16). Before loosening the mounting nuts to remove the pump, check the flange and its mounting for timing marks. If there are none, the parts should be marked so that the injection pump can be reinstalled in its original timing position.

In the arrangement shown, the pump drive pulley has to be removed before the pump can be dismantled from the engine; so the timing belt also has to be removed, taking care that the camshaft timing is not disturbed.

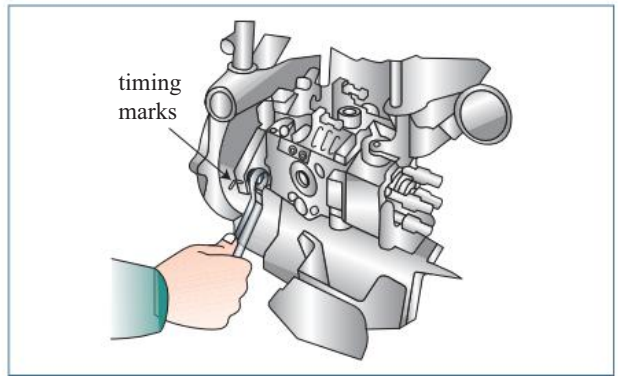


Figure 37.16 Timing marks on the engine and flange of a distributor pump

37.5.2 Timing marks

Figure 37.17 shows the timing belt with the pulleys for the crankshaft, camshaft and the injection pump. All three pulleys have timing marks and these should be aligned and checked both before the timing belt is removed and when it is reinstalled. This will

ensure correct valve timing and correct injection timing. The following are general points that relate to installing an injection pump:

1 The engine is set on the timing mark, with Number 1 piston on the compression stroke. This is the point where injection should commence.
2 The injection pump is set in the position where it is just starting to pump fuel to the injector in Number 1 cylinder. This position is identified by a mark or pointer on the pump and a corresponding mark on the pump coupling.

With both the engine and the pump set to their correct injection positions, the pump is installed on the engine. The timing marks are checked and adjustment made if necessary. The procedure for injection pump timing will vary with different engines, pumps and common or non-common rail systems.

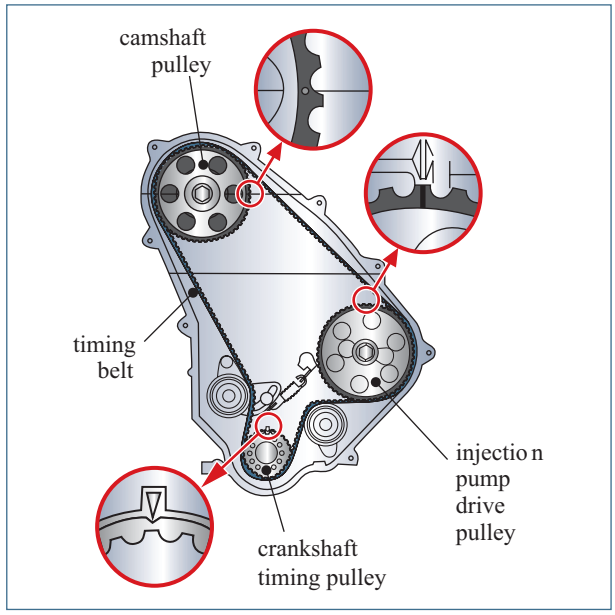


Figure 37.17 Timing belt and pulleys, including a pulley for the injection pump—the pulleys have timing marks

37.6 Injection pump servicing and testing

Any work on injection pumps that goes beyond removal and replacement or on-the-vehicle adjustments requires special facilities. These include an air-conditioned room, an injection pump testing machine and certain tools. Specifications and data related to pump adjustments, torque settings of bolts and screws, and performance figures for testing purposes are also required for each model of pump. Figure 37.18 shows a distributor pump being tested and adjusted after it has been overhauled.

Figure 37.18 A distributor injection pump being tested on a computerised pump-testing machine GEMINI DIESEL FUEL INJECTION

37.7 Diesel engine problems

Table 37.1 presents a general engine fault-finding chart. Most of the problems shown relate to the fuel-injection system, the correct operation of which is critical to diesel engine performance.

Table 37.1 Diesel engine complaints and possible causes

Complaint	Possible cause	Check or correction
Engine overheats	Faulty injector(s) Injection timing Cooling system	Test, clean and adjust Check timing Check and flush
Engine knocks	Faulty injector(s) Air in system Injection timing	Test, clean and adjust Bleed system Check timing
Black smok e from exhaust	Injectors dribbling Air cleaner block ed Injection pump timing late	Clean and adjust Clean or replace element Check timing and reset
Engine misfires	Faulty injector(s) Leaky injector pipe or union Air in system Faulty injection pump	Test, clean and adjust Tighten or replace pipe Bleed system Overhaul pump
Engine starts but will not run	Air in system Faulty supply pump Blocked filter Fuel low in tank	Bleed system Check and repair Clean or renew element Top up tank
Engine has low power	Injection timing late or early Injector(s) faulty Blocked air cleaner	Check and reset Check, clean and adjust Clean or replace element
Engine idles badly	Governor action faulty Injector(s) faulty Injection pump wear (willalso cause other faults)	Adjust where possible Check, clean and adjust Check, overhaul or replace
White smok e	Faulty or damaged injectors Incorrect injector timing Low cylinder compression	Check, overhaul or replace Check and retime Check compression pressures

37.7.1 Exhaust smoke

The smoke produced by a diesel engine can be a strong indicator of faulty engine components or operating and support systems. Black smoke from the exhaust of a diesel engine is caused by incomplete fuel combustion. Blue smoke is produced by engine lubricating oil that finds its way into the combustion chambers. White smoke is produced when the diesel engine is operating under very humid or cold conditions.

With incomplete combustion, the fuel system is at fault. Either too much fuel is being delivered to the combustion chambers, or the fuel that is being delivered is not being sprayed properly. The hydrogen in the fuel combines readily with the air and burns, but the carbon does not combine as easily, and so the carbon that is not burnt is discharged from the exhaust as black smoke.

A smokemeter (Figure 37.19) checks the exhaust gases to determine the density of the smoke coming from the exhaust pipe. A sample of the exhaust gas

Figure 37.19 Smok emeter for checking the carbon content of the exhaust gas of a diesel engine WAGER CO. INC

is obtained through a pipe connected to the engine's exhaust and the carbon that is present is collected on a filter. Smokemeters usually operate by comparing the amount of light that will pass through a sample of the exhaust gas with the amount of light that will pass through clean air.

37.7.2 Cylinder compression pressure

Good cylinder compression is essential for correct engine operation. With poor compression, air temperatures would be low and ignition difficult, risking hard starting and poor engine performance.

Compression pressures can be checked with a compression pressure gauge. This is a special gauge for diesels, which have much higher compression pressures than petrol engines. The gauge is connected to an adaptor fitted to the injector or glow-plug hole. All of the injectors or glow plugs are removed, and the test is carried out as follows:

1 Connect the compression gauge to the adaptor .
2 Ensure the fuel pump is in the 'no fuel' position or the shut-off solenoid is disconnected so fuel will not squirt out of the fuel lines. Remove the glow-plug fuse or relay .
3 Crank the engine with the starter through three or four compressions and take the highest gauge reading.
4 Repeat for all cylinders and compare the pressures.

37.8 Checking diesel electronic controls

With distributor pump systems that have electronic controls, the injectors and the mechanical parts of the injection pumps could have similar mechanical problems to those without electronic control. However, the additional electrical and electronic components have to be considered if problems arise. Fortunately, diesel electronic systems have a built-in self-diagnosis function that is similar to the facility provided for the engine management systems of petrol engines.

There are two ways to access information. One is by using a hand-held scanner or multi-tester which has programs for the particular vehicle. This is plugged into a diagnosis connector and reads fault codes. The other method uses a *check engine indicator lamp* on the instrument panel. By bridging certain terminals of the diagnosis connector, the fault codes can be read as flashes of the lamp, once the ignition is switched on.

Each engine manufacturer has procedures for undertaking engine and vehicle operating systems diagnosis. Although most systems operate using the same principles, the diagnostic procedures will vary, so following the original engine manufacturer's (OEM) procedures is essential.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- describe the different types of filters and sedimenters
- explain how to service filters and sedimenters
- describe what is meant by bleeding and explain how to check for leaks in a diesel fuel system
- explain how injectors operate, and describe their servicing and testing requirements
- apply correct procedures for removing and reinstalling injection pumps and injectors
- describe the common diesel engine problems
- check diesel engine electronic controls in accordance with original engine manufacturer's procedures.

REVIEW QUESTIONS

1 Explain why cleanliness is so important for diesel fuel systems.
2 How are sedimenters serviced?
3 How is the warning-light switch on a sedimenter checked?

4 Why is it necessary to bleed a diesel fuel system ?
5 Explain how a diesel fuel system is bled.
6 How can a faulty injector be located on an engine ?
7 What is the general procedure for removing an injector from an engine ?
8 What type of equipment is needed to service injectors ?
9 For what conditions can an injector , other than an electronic injector , be tested?
10 What safety precautions should be observed when checking the spray from an injector?
11 Compare good and bad sprays from an injector .
12 What checks are made before removing an injection pump ?
13 What checks are made before removing a timing belt?
14 What is the purpose of an injection-pump testing machine ?
15 What are the lik ely causes of black smok e from the exhaust?
16 How is a compression test carried out on a diesel engine ?
17 How are fault codes accessed on an injection system with electronic control?

PART 7

Electrical basics

CHAPTER 38

Basic electrics

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 follow electrical work health and safety procedures
2 apply electrical principles
3 identify key features of basic electrical circuits
4 recall techniques for reading and interpreting technical information
5 follow procedures for using and operating electrical test equipment
6 explain testing procedures for electrical systems.

A motor vehicle has a complete electrical system which stores electrical energy when the engine is stopped. It then generates electricity once the engine is running, distributing it to various parts of the vehicle and operating electrical and electronic devices.

38.1 Workers' health and safety

38.1.1 Using specialised tools and equipment

Modern high-quality electrical test equipment is expensive and should be used correctly, following the correct procedures. This will prevent damage to a vehicle's computer systems or to the equipment itself.

38.1.2 Controlling risks from wearing jewellery while working on electrical systems

Identifying hazards and controlling risks is covered in Chapter 2. High voltages make wearing jewellery particularly hazardous when working on electrical systems. For example, HID headlights use up to 20 000 volts, ignition systems use in excess of 40 000 volts and piezo injectors run on 140 volts. Electrical systems should be isolated and/or de-powered, and jewellery should be removed before working on them.

38.2 Electron flow

All matter is made up of minute particles called molecules. Molecules are made up of atoms, which contain three particles: electrons, protons and neutrons (Figure 38.1). Electrons have a small negative (−) electrical charge, protons have a small positive (+) electrical charge and neutrons have no charge.

38.2.1 Atoms and materials

It is the way that their electrons and protons are arranged that differentiates one atom from another, and materials are only different because of the basic structure of their atoms.

38.2.2 Electron flow

Causing electrons to move produces an effect that is usually called *electron flow*. This has practical applications in vehicles' electrical systems.

To understand electron flow, imagine that a copper wire consists of a number of atoms stretched along its length. An electron, on entering the wire from the battery, repels an electron from the outer orbit of the first atom. The electron from the battery is captured by the first atom, while the displaced electron attaches itself to the second atom, displacing another electron in order to do so. This displaced electron does the same thing to the third atom and so on throughout the length of the wire. The overall effect is a movement of electrons from atom to atom through the wire. This occurs many times to many electrons to produce a flow of electrons, as shown in Figure 38.2(a) and 38.2(b).

38.3 Electrical principles

38.3.1 Current, voltage, resistance and power

The three common units of electrical measurement are:

1 Ampere . Measures the rate of current flow (symbol A or I).
2 Volt. Measures electrical pressure (symbol V or E).
3 Ohm. Measures electrical resistance (symbol Ω or R).

38.3.2 Current

Electron flow is from negative to positive. This can be considered to be a flow of current. However, before electron flow was properly understood, it was believed that current flowed from positive to negative, that is, in the *opposite* direction to the electrons. It is helpful to use this understanding of current flow, often referred to as conventional current flow (Figure 38.2(c)), when dealing with automotive electrics. Amps (or amperes) are a measure of the rate at which current flows. When relatively few electrons flow in a conductor, the amperage is low; when many electrons flow, the amperage is high.

38.3.3 Voltage

A force is required to move electrons through a conductor. This force is provided by electrons at the terminal of an alternator or battery. When either is connected to a circuit, the concentration of electrons at the negative terminal will cause movement of the electrons in the conductor, producing a current flow. Voltage represents a difference in electrical potential, or an *electrical pressure*. Voltage is measured with a voltmeter (Figure 38.3).

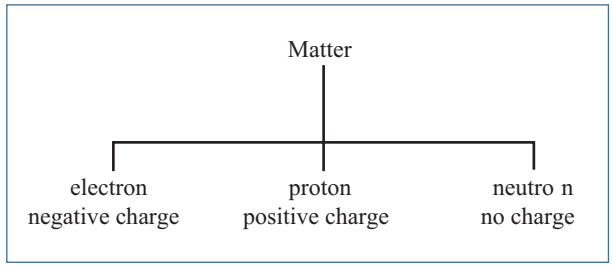


Figure 38.1 Matter divided into its constituent parts

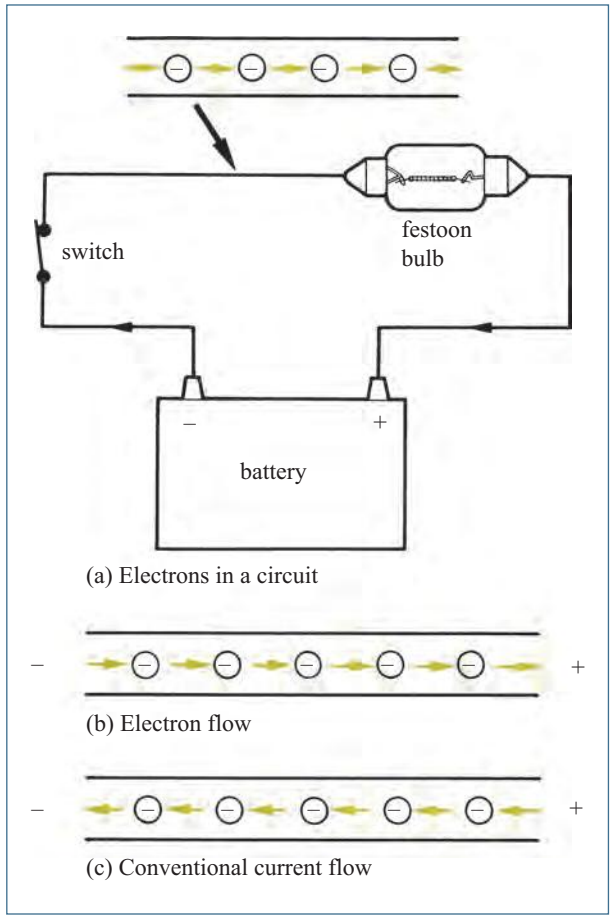


Figure 38.2 Representation of electron flow and conventional current flow

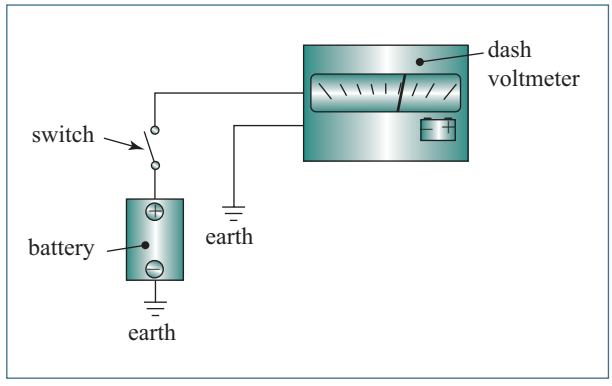


Figure 38.3 A voltmeter in an instrument panel can k eep a check of battery voltage

38.3.4 Resistance

All conductors have some resistance to the flow of electricity. The strength of this resistance is shown by resistivity (see Table 38.1). Resistivity is the opposite of conductivity, which relates to the ability of a conductor to carry current. Four factors can affect the resistance of a conductor and the current that it carries:

1 Material . Some materials have more resistance to electron flow than others.
2 Cross-sectional area. A large cross-section will have relatively many more electrons moving through it at the same time; a small cross-sectional area will allow relatively fewer .
3 Length. The longer the conductor , the higher the resistance . In a long conductor , electron movement occurs from atom to atom over a great distance , causing resistance to the electron movement. In short conductors, movement of the electrons from one end to the other is relatively easy as they have to pass through very few atoms. Short conductors, therefore , have little resistance .
4 Temperature . With many materials, the higher the temperature , the greater the resistance , so heat affects electron movement.

Table 38.1 Comparison of the resistance of some common materials

Material	Resistivity
Conductors	
Silver	1.59
Copper	1.75
Aluminium	2.9
Tungsten	5 to 6
Iron	9
Steel	12 to 14
Mercury	96
Resistors	
Carbon	4000 to 7000
Sulphuric acid	850 000
Distilled water	72 000 000

38.3.5 Ohm's law

Ohm's law describes the relationship between the three basic electrical units. It is stated as:

a pressure of one volt will cause one amp to flow through a conductor that has a resistance of one ohm.

This can be stated as a simple equation, using V for volts, I for current and R for resistance:

$$V = IR \ (1\,\text{volt} = 1\,\text{amp} \times 1\,\text{ohm})$$

or, rearranging the above, the resistance (R) will be:

$$R = \frac{V}{I} \ (1\,\text{ohm} = 1\,\text{volt} \div 1\,\text{amp})$$

and the current flow (I) will be:

$$I = \frac{V}{R} \ (1\,\text{amp} = 1\,\text{volt} \div 1\,\text{ohm})$$

An easy way to recall these is by using the diagram shown in Figure 38.4. Placing a finger over the unit required will show the other two units of the equation. For example, if you need to find the equation for current (amps), place a finger on I to give the equation:

$$I = \frac{V}{R}$$

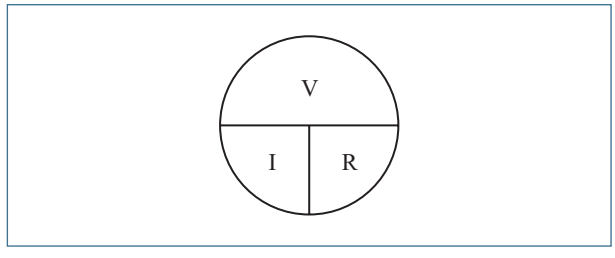


Figure 38.4 The relationship of voltage (V), current (I) and resistance (R)

38.3.6 Power

The power of any electrical component is expressed in watts, and is established by multiplying voltage with current.

The wattage of bulbs is illustrated in Figure 38.5, which shows a circuit with three different-sized bulbs connected in parallel. All the bulbs are connected to the same 12-volt battery, but because they all have a different wattage, they will draw different currents.

This is shown on the ammeter connected into the circuit for each bulb. It can be seen that:

1 The smallest bulb has a current of 1 amp and is therefore a 12-watt bulb (12 volts × 1 amp = 12 watts).
2 The middle bulb is larger and draws 2 amps from the 12-volt battery, so must have twice the wattage of the previous bulb. It is therefore a 24-watt bulb.
3 The largest bulb draws 3 amps and is therefore a 36-watt bulb.

Bulb resistance

The resistance of the bulbs can also be found by using Ohm's law (R = V/I). The small bulb which draws 1 amp has a resistance of 12 ohms, the middle-sized bulb 6 ohms and the largest bulb 4 ohms. The resistance of a bulb will change as it heats up.

Handy hint: The bulb with the lowest resistance draws the highest current and produces the brightest light.

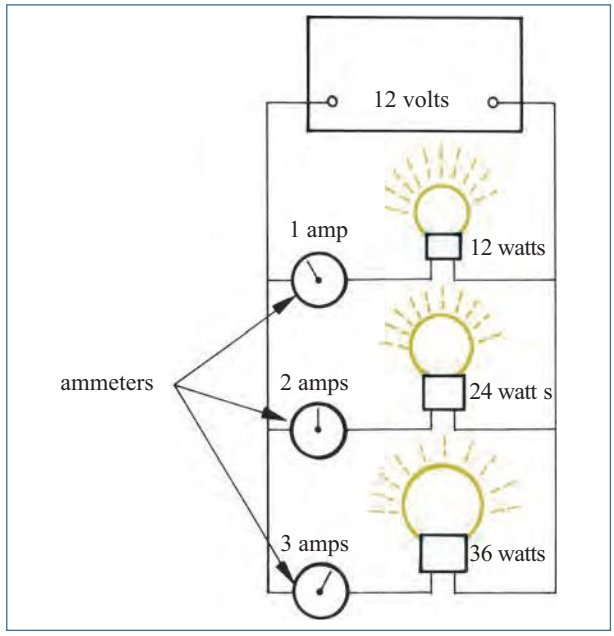


Figure 38.5 Bulbs of different wattage connected to a battery—each draws a different current

38.4 Parallel and series connections

Electrical components can be connected in series or in parallel. When connected in *series*, the components are end-on to each other. When connected in *parallel*, they are, in effect, beside each other.

Figure 38.6 shows simple electrical circuits with bulbs connected to a battery in different ways. Diagrams (a), (b) and (c) are series circuits, while (d) is a parallel circuit.

The way in which the bulbs are connected will affect the light produced by the bulbs as follows:

1 A single bulb is connected to the battery (Figure 38.6(a)). The bulb receives full battery voltage and so will glow brightly. This is a simple series circuit.
2 Two bulbs are connected in series and connected to the battery (Figure 38.6(b)). As the bulbs now have to share the battery voltage, neither of them will be bright.
3 Three bulbs are in series, so there is even less voltage for each (Figure 38.6(c)). None will receive sufficient voltage to produce light.
4 Three bulbs are connected in parallel and are connected to the battery (Figure 38.6(d)). With this circuit, all three bulbs will receive full battery voltage and all will glow brightly. If they are of the same size and type, they will all be equally bright.

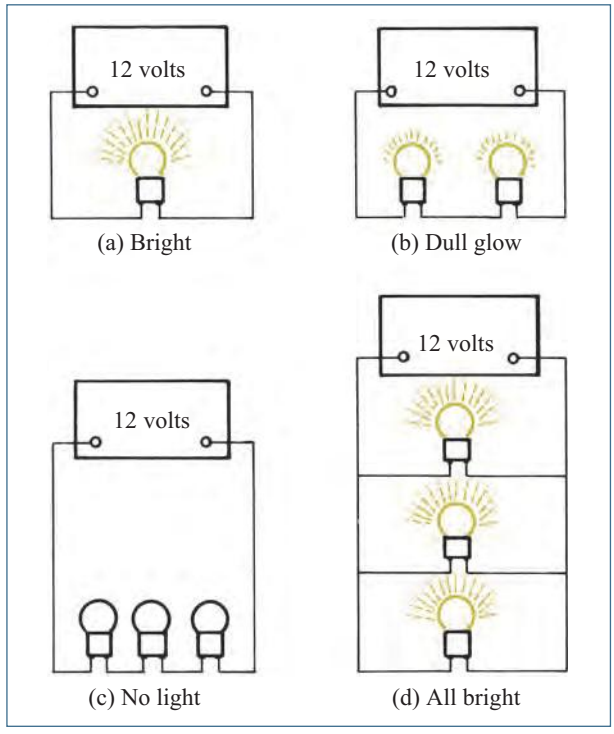


Figure 38.6 Bulbs connected in different ways (a) single bulb, (b) two bulbs in series, (c) three bulbs in series, (d) three bulbs in parallel

Any number of bulbs can be connected in parallel. They will all receive full battery voltage and so will produce their full brightness.

In a series circuit, if one bulb fails then no others will work. In a parallel circuit, if one bulb fails it will not affect the others.

Handy hint: Automotive lights have parallel circuits

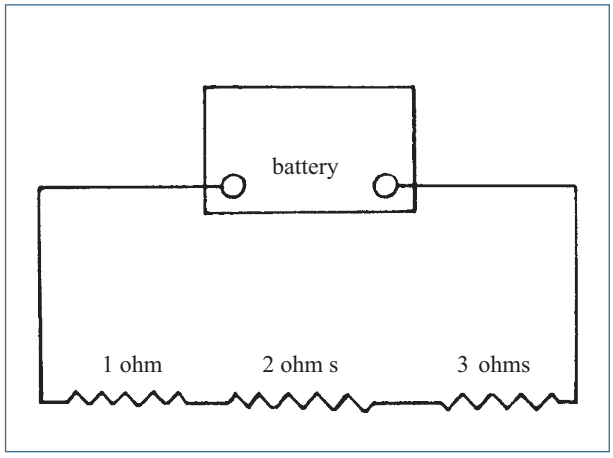


Figure 38.7 Simple series circuit—three resistors are shown connected in series to a 12-volt battery

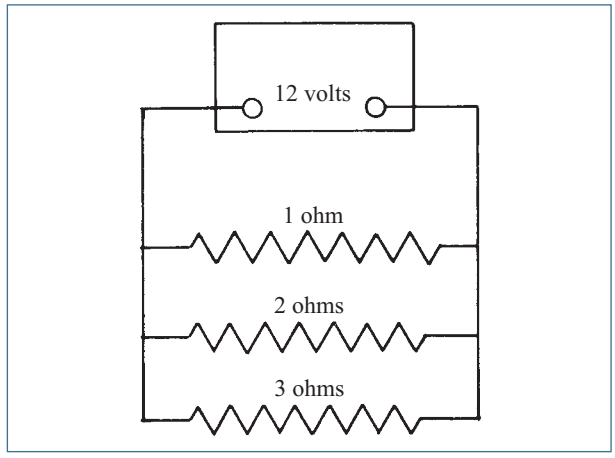


Figure 38.8 Simple parallel circuit—three resistors are shown connected in parallel

38.4.1 Series circuits

A series circuit has only one path through which current can flow, even though a number of components are connected to form the complete circuit. Figure 38.7 shows a simple series circuit with three resistors, but they could be any type of electrical component.

The resistors are connected to a 12-volt battery, end-on to each other, which helps to reduce the rate at which the current flows. They may be considered as being a single resistor, and their resistances are added together to obtain the total resistance. In Figure 38.7, the total resistance is 6 ohms and the total current flow will be 2 amps.

38.4.2 Parallel circuits

The various parts of a circuit can also be arranged parallel to each other, as in Figure 38.8 (see also the current flow in the parallel circuit in Figure 38.5).

When the connection to the battery is made, current will flow through each part of the circuit. Each resistor will operate independently and will carry its share of current from the battery.

To find the total current flowing from the battery, it is only necessary to find the current for each branch and add these together.

Using the formula ($I = V/R$) it is found that the 1 ohm branch will carry 12 amps, the 2 ohm branch (with twice the resistance) will carry only half this amount (6 amps) and the 3 ohm branch (with three times the resistance) will carry one-third of the current of the 1 ohm resistor (4 amps). The total current for the complete circuit is therefore 22 amps.

38.5 Kirchhoff's Laws

Kirchhoff developed two laws. The first, his Current Law, stated that the total current or charge entering a junction is exactly equal to the charge leaving the junction.

The second, Kirchhoff's Voltage Law, was that, in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop. Figure 38.9 illustrates this.

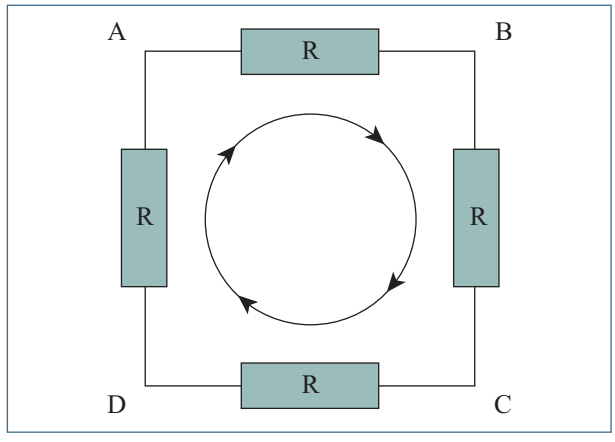


Figure 38.9 The sum of the voltage drops across each resistor = 0 volts. $V_{AD} + V_{BC} + V_{CD} + V_{DA} = 0$

38.6 Conductors, resistors and insulators

38.6.1 Conductors

Conductors are materials that contain a large number of *free electrons*. They readily allow current to flow.

In some materials, the electrons are tightly held, while in others (such as copper), they are loosely held. The materials with loosely held electrons will be good conductors, while those with tightly held electrons will be poor conductors.

38.6.2 Resistors

Poor conductors are called resistors because they resist electron movement. Generally, they are used when a reduced or limited current flow is required. Most metals are good conductors, but special metal alloys and carbon are used for resistors.

Table 38.1 shows a list of some common materials and their *resistivity*. This is a resistance value, shown for comparison. Materials with a low resistivity are classed as conductors, while those with a high resistivity are classed as resistors.

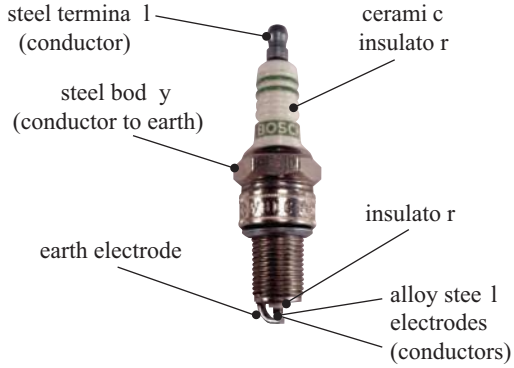


Figure 38.10 A spark plug has conductors with a ceramic insulator

38.6.3 Insulators

Another group of materials will not conduct electrons. These are referred to as insulators. They can be used to insulate (or separate) one conductor from another, for example, plastic coatings on copper wire.

This group of materials includes most common materials other than metals. For example, spark plugs use ceramic material for insulation (Figure 38.10).

Handy hint: Insulators have their electrons tightly held, so that no electron movement can occur .

38.6.4 Practical conductors

All metals are conductors, but the main—and most efficient—conductors in a motor vehicle are copper and the steel body.

Cables

Cables connect the various components of the electrical system. The conductors in these are strands of thin copper wire. Where large currents are carried, large-diameter cables are used. Battery and starter cables can be 10 mm in diameter, while lighting cables, which carry much lower currents, might be 3 mm. Battery and starter cables are kept as short as possible to avoid unnecessary resistance (Figure 38.11).

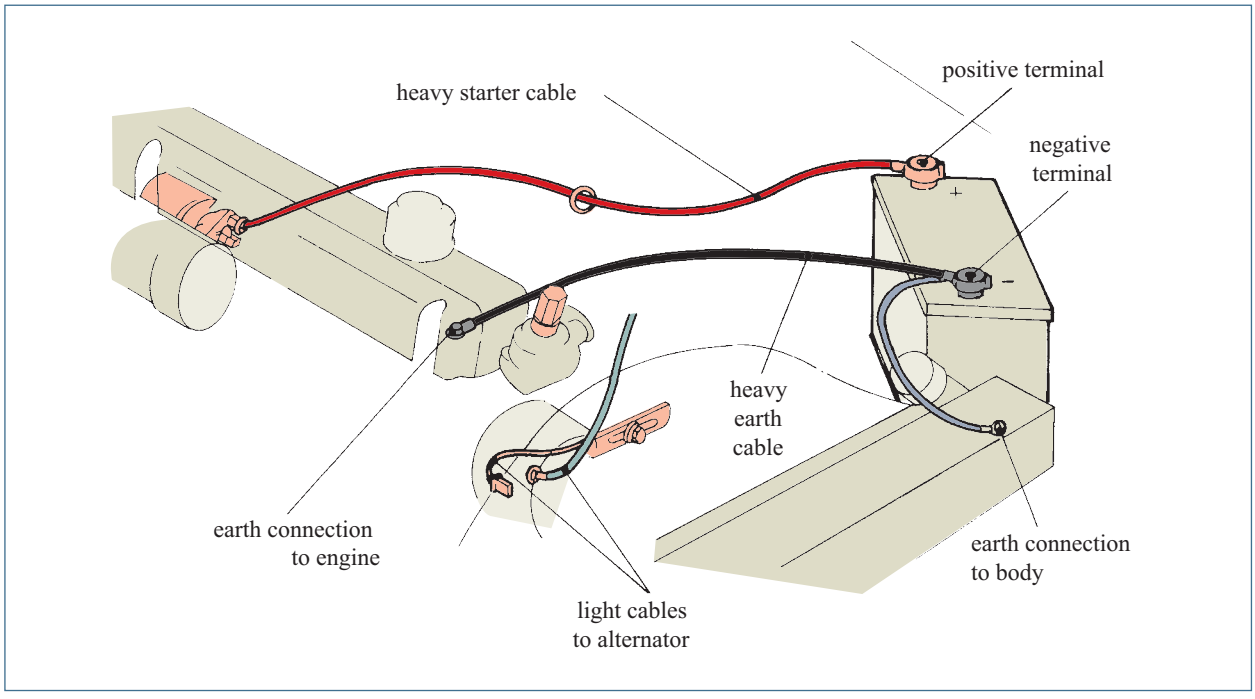


Figure 38.11 Battery and starter cables—there are earth connec tions to the body and engine

The vehicle body

The vehicle body (and its frame) are used as an earth or ground for the electrical system, and so become a common conductor for the various electrical circuits. Computer systems in vehicles will often use a separate earth made of insulated copper wire to allow monitoring of the sensor.

The metal parts of the vehicle form such a large conductor that, for practical purposes, they have no resistance. However, all the electrical connections to the body or frame (earths) must be clean and tight to prevent resistance at the connection.

Special metals

Special metals are used for particular applications. Tungsten is used for some contact points in distributors and relays where arcing could occur. Special alloy steels are used for spark plug electrodes. Some contacts used for particular purposes, such as airbag sensors, are gold plated to prevent corrosion.

Printed circuits

Printed circuits are used extensively in electronic units, as well as for vehicle instrument panels (Figure 38.12).

Printed circuits do not have separate electrical cables, but metal conductors printed on an insulating material. These are not covered with insulation, but are insulated from each other by the space between them. Small components are soldered or screened to the conductors.

The advantages of printed circuits are compactness and lower cost of production and installation.

38.6.5 Practical resistors

Wire-wound resistors

Wire-wound resistors are a number of turns of special high-resistance alloy wire wound on a former of mica or ceramic material. These are used in some alternator voltage regulators and electrical instruments. The total resistance depends on the type of material and the thickness and length of the wire.

Carbon resistors

These are a cylindrical piece of carbon with a terminal or wire attached to each end. The total resistance depends mainly on the length and diameter of the cross-section.

In the ignition system, carbon is used in spark plug cables and high-tension leads. Carbon resistors are used in some voltage regulators.

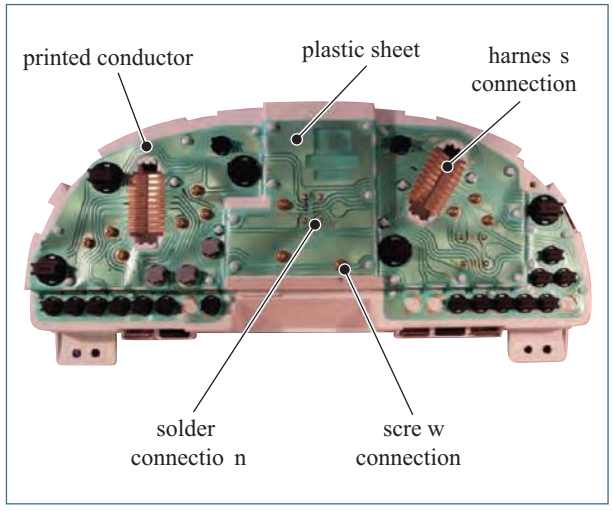


Figure 38.12 An instrument panel with printed circuit board

Rheostats

A rheostat is a variable resistor with a sliding or rotary contact that moves across a wire-wound resistor, enabling variable resistance between the end of the wire and the contact (Figure 38.13).

Rotary rheostats are used in the instrument panel light circuit. The resistance in the circuit is varied by turning a knob, so the current through the bulb can be reduced or increased. Reducing the resistance increases the brightness of the lamps and vice versa.

A sliding-type rheostat is used in the fuel tank to operate most fuel gauges (Figure 38.14).

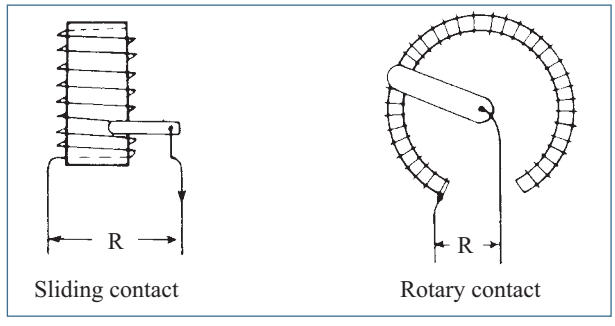


Figure 38.13 Rheostats—the resistance (R) can be varied by moving the contact across the winding

38.6.6 Practical insulators

1 Plastics. Most cables are insulated with a covering of soft plastic, with various colours identifying the different cables in a circuit.
2 Varnish. Varnish or lacquer is coated on the copper wire that is used for the windings of coils (sometimes a cotton covering is used).

3 Ceramics. Ceramic is used as the insulator for spark plugs as it can resist the high combustion temperatures to which they are subjected (Figure 38.11).
4 Glass. Glass acts as an insulator in bulbs and some fuses.
5 Fibre and nylon. These materials (and hard plastics, too) are used as washers and insulators on various electrical components. Fibreboard and fibreglass are used for printed circuit boards.

38.6.7 Electrical cables

Electrical cables are made of a number of strands of thin copper wire covered with a plastic insulating material. Cables of different sizes are usually identified by their diameter, for example 3 mm, 4 mm and so on. This measurement refers to the overall diameter of the cable, which includes the thickness of the insulation as well as the core of copper wire. The cross-sectional area of the copper wire determines the current-carrying capacity of the cable. The larger the cross-section of the wire, the greater the current it can carry. Table 38.2 gives some examples.

A cable that is the correct size will carry the current without any problems, but an undersized cable could overheat and melt the plastic insulation. An undersized cable will have a high resistance and this will produce voltage drop, particularly in a long cable, which could cause a component to malfunction.

Colour coding

For ease of identification, the cable insulation is made in various colours. Colour coding is necessary because the cables are enclosed in a harness for much of their length. Circuit diagrams have the cable colour code marked on the lines that represent the cables. For example: R for red, G for green and RG for red with a green stripe.

Figure 38.15 shows how the lines of a circuit diagram are marked with the cable code, and how this is interpreted. The cross-sectional area of the wire is also marked on the line. Other diagrams do not show this, but use numbers to identify the cables.

38.7 Circuit and circuit protection devices

38.7.1 Fuses and fusible links

Fuses are fitted to circuits to provide protection for both the circuit and for the component. Most of the fuses are contained in a fuse block inside the vehicle or in the engine compartment, but separate line fuses are sometimes used for auxiliary components.

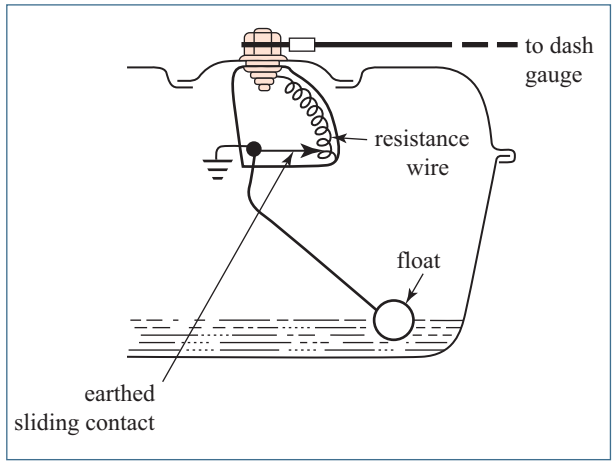


Figure 38.14 Resistance—the fuel tank engine gauge unit has a variable resistance rheostat which is operated by the float

Table 38.2 Approximate carrying capacity of automotive electrical cables (guide only)

Nominal diameter of cable (mm)	Approx. cross-section of core wire (mm^2)	Permissible current (amps)	
		At 25 °C	At 50 °C
2.5	0.85	15	10
3.0	1.25	20	12
3.0	2.00	25	15
3.5	2.50	30	20
4.0	3.00	35	25
5.0	5.00	45	30

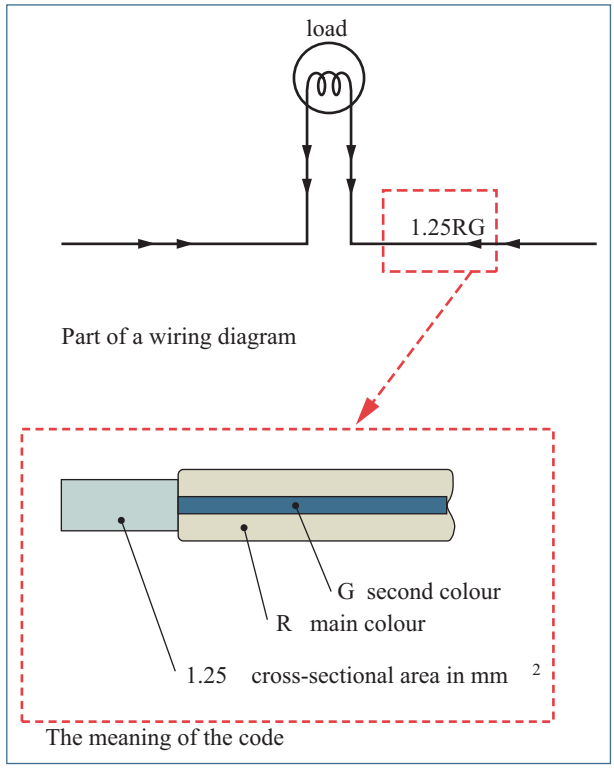


Figure 38.15 Example of a cable colour code

Fuses are rated according to their current-carrying capacity, such as 10 amps and 15 amps. Fuses range from 2 amps, used for radios, up to 60 amps, used for air conditioning or heater fans.

A fuse consists basically of an element in the form of a thin wire or strip of metal that will fuse (melt) if it is subjected to excessive current. The 'blown' fuse will open the circuit and so prevent current flow. Various arrangements are used to carry the fuse element, so there are a number of different types of fuses, and these are not interchangeable.

Three different types of fuses and a line-type fuse holder are shown in Figure 38.16. The cartridge-type fuse has its element in a small glass tube with metal contacts on each end. The ceramic type is similar, but uses a ceramic carrier with a metal strip, while the blade type has its element connected between two blades. This type of fuse is most commonly used today. Blade fuses now come in several sizes called Micro2, Micro3, Low-profile Mini-fuse, Mini fuse, Auto fuse and Maxi fuse.

Fuses do not actually protect the component. If a component is faulty due to a short circuit, then the fuse will become overheated and will melt (fuse). This will isolate the component and prevent further damage. It will also protect the circuit from overheating. Without a fuse, a fault could cause a circuit to overheat and start a fire.

Line fuse

A line fuse is carried in a separate fuse holder that is located in a circuit close to a component. Line fuses are sometimes used as part of the original system, but they are often fitted to the supply cable when an accessory is being installed. The fuse holder has a bayonet or screw fitting that allows its parts to be separated so that the fuse can be inserted or removed.

Fusible links

Fusible links in a holder are shown in Figure 38.16. These are loops of special wire, with a terminal at each end that plugs into the holder. Each link has a different current rating to suit the circuit that it protects. Fusible links are identified by colour. For example, a particular vehicle could have a black fusible link that fuses at 180 amps but has a permissible continuous carrying capacity of only 45 amps. It also has a red link that fuses at 150 amps and a green link that fuses at 100 amps. The continuous current rating in all cases is approximately one-quarter of the fusing current. Fusible links are now supplied as a type of cartridge and coloured according to the current rating.

Circuit breakers

For particular components, circuit breakers are used to protect a circuit from a temporary overload. The circuit breaker, as its name suggests, breaks the circuit to prevent damage. If a fuse was used in the same situation, it would blow and have to be replaced. A circuit breaker is a form of relay. Normally, its contacts are closed to complete the circuit and allow current flow. However, if excess current flows through the relay

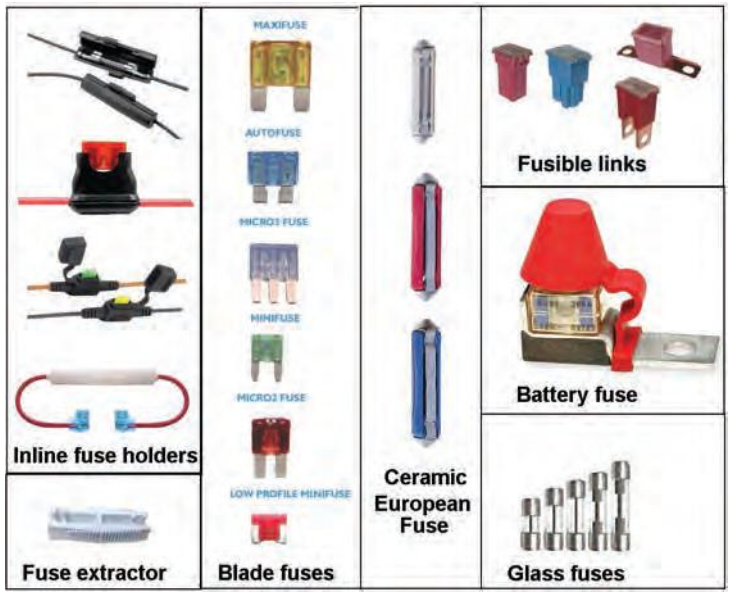


Figure 38.16 There are many types of fuses in the modern vehic le NARVA AUTOMOTIVE

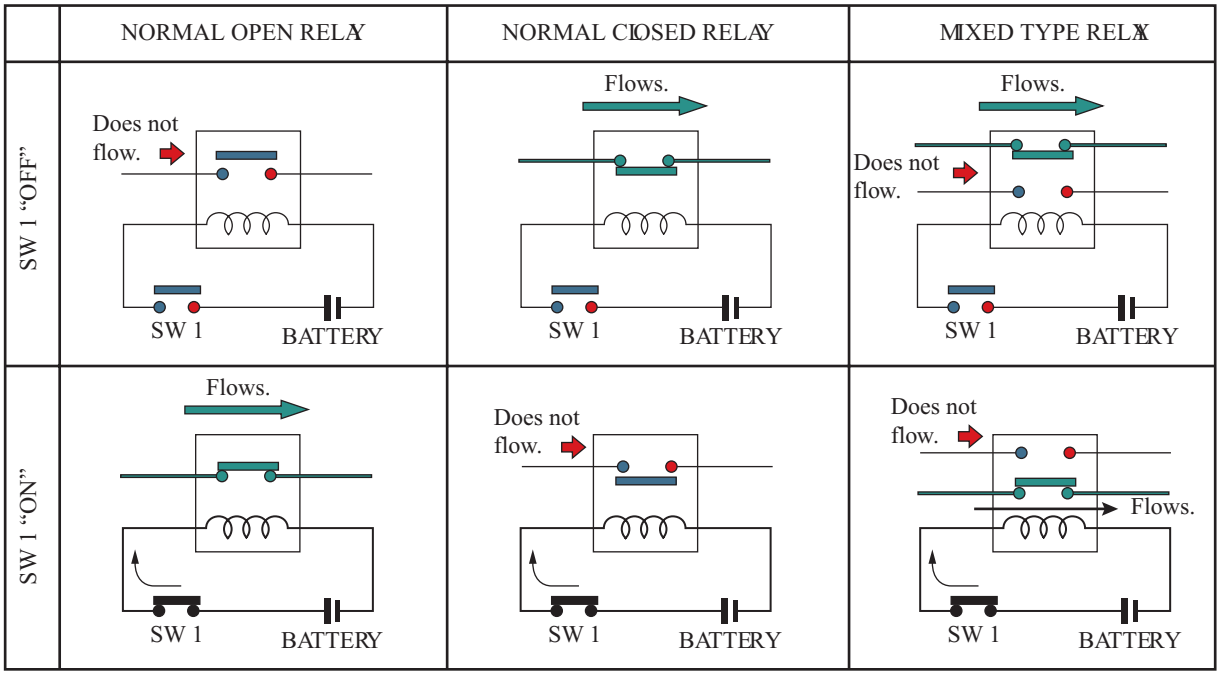


Figure 38.17 Relay schematics shows that relays can operate in a number of different ways

coil, its magnetism will increase and the contacts will be pulled open. This breaks the circuit. Some circuit breakers can be reset after they have opened; others reset themselves.

Switches

Switches are used to operate the various electrical components. Some switches are operated manually, some automatically and some by remote control. Operation of a switch closes or opens one or more sets of contacts, either to complete the circuit or to open the circuit in which the switch is installed. In many instances, switches operate a relay. The relay, in turn, acts as a switch to turn the component on or off. Some switches manage multiple functions such as the combination switch used for lights on the steering column.

Relays

Relays are fitted in various parts of the electrical system to perform some switching function. Relays are also referred to as *electromagnetic switches* or *electromechanical switches* (Figure 38.17). In some vehicles, the relays are grouped together as part of the fuse block. As shown, relays are used for lights, horn, instruments, charging system, starting system, ignition, fans and for many other purposes. There are two general types of relays, according to their basic function: relays with their contacts normally open, and relays with their contacts normally closed. When the relay windings (coils) are energised, relays that are normally open will close their contacts, while relays that are normally closed will open their contacts.

38.8 Lamps and bulbs

Traditionally, a bulb consists of a fine filament of tungsten wire that is maintained at white heat by the current passing through it: the heat of the filament produces light. The filament is enclosed in a glass envelope that is completely exhausted of air, but which contains a small quantity of inert gas. The filament must operate in an oxygen-free environment to prevent it from oxidising and rapidly burning away.

There have been many developments in bulb technology with the introduction of LED, Cree LED and Xenon Gas Discharge and HID bulbs. This changing technology has allowed for different colour temperatures in headlamp bulbs, from a yellow to a blue light. The advantage of Cree LED lamps is they draw less current but produce a very bright light. In some vehicles, this can be a problem because the body control module may be monitoring the bulbs and a drop in the current flow may signal a fault code. Figure 38.18 shows a variety of bulbs for automotive use.

Safety: There are Australian Design Rules about changing or fitting new lights to vehicles, especially bar lights. Before changing the lighting, check the regulations in your state or territory.

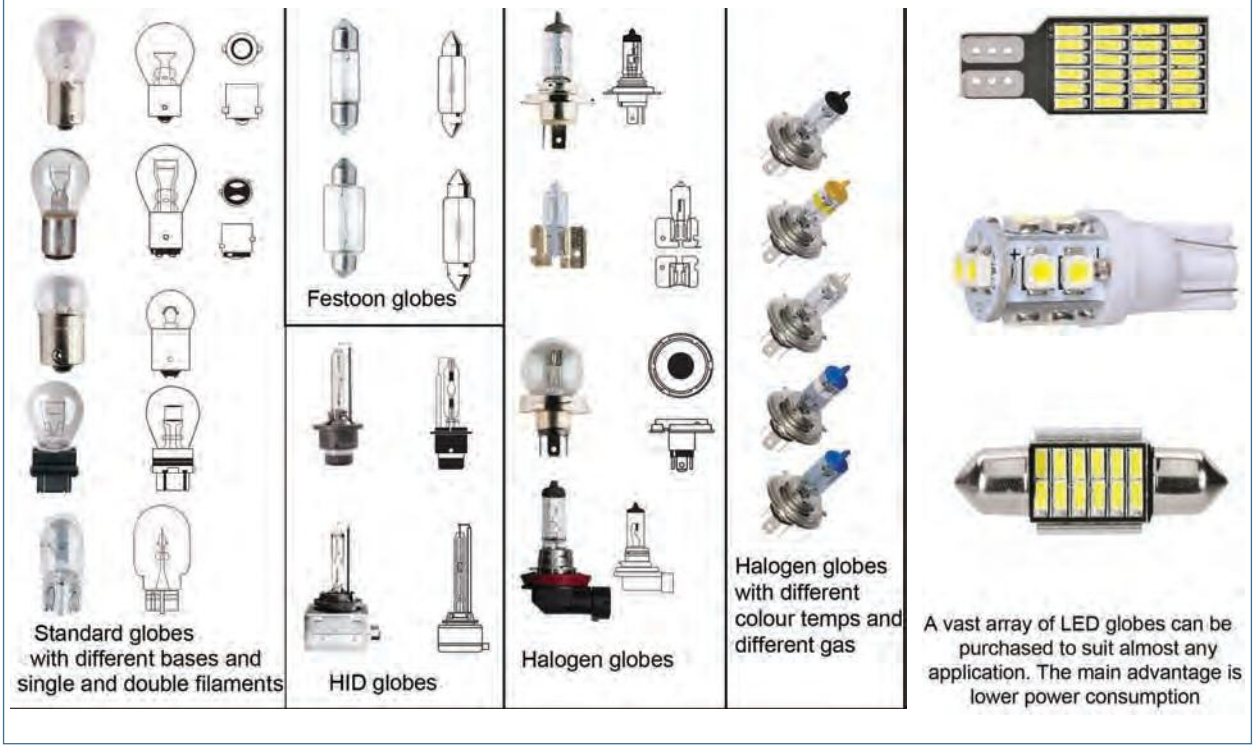


Figure 38.18 Technology has produced many different bulbs for automotive use HELLA SOUTH AFRICA/SUPERCHEAP AUTO

38.8.1 Types of bulbs

Festoon bulbs

These consist of a small glass cylinder with a filament attached to a metal cap at each end. They are used for interior lighting, number plate lamps and similar applications. They are also used in the rear lamps of caravans and trailers.

Panel bulbs

These are small bulbs used mainly for instrument illumination and in indicating lamps. Some panel bulbs have a miniature type of bayonet fitting. Others do not have a metal cap and are installed by being pushed directly into the bulb socket. Small wires on the base of the glass envelope are used as contacts.

Quartz halogen bulbs

These are used in headlamps and driving lamps. They have a small quartz or hard glass envelope, which is filled with a special gas of halogen additives. In an ordinary bulb, minute parts of the filament gradually evaporate as it is being used, and these deposit on the glass envelope as a thin black film. Evaporation also reduces the size of the filament, which eventually burns through because it can no longer carry the current. With halogen bulbs, the evaporated filament material is deposited back on to the filament of the bulb by the action of the gas. This increases the bulb's life. Higher temperatures are needed for this process and, for this reason, a quartz or hard glass envelope is used.

⚠ Safety: The filaments of quartz halogen and HID bulbs operate at temperatures of about 3000 °C in the filament and 500 °C outside the bulb glass. Any finger prints left on the glass will cause the bulb to 'blow', so never put your fingers directly on the glass. (Figure 38.19).

Correct Incorrect

Figure 38.19 Handling a quartz halogen bulb

LED and Cree LED bulbs

LED is an acronym for Light Emitting Diode and Cree is the name of the company that improved the LED by combining silicon chips that produce different colours (red, blue and green, or RGB) to

produce a white light. The new chip uses much less energy to produce about the same amount of light similar as an LED bulb. By varying how much light comes from each colour chip, the manufacturer can alter the colour temperature of the bulb. A Cree LED bulb contains many small, flat panels. This is because the silicon chip can only be made flat and light from the chip can only display in one direction. Multiple panels mean the light can be spread in multiple directions.

Safety: Excessively bright headlights that may dazzle other road users could cause accidents.

High-intensity discharge bulbs

A gas discharge headlamp system has metal halide bulbs and a control computer or ballast. The lamp consists of a base and a thin quartz tube with two electrodes (Figure 38.20). The tube contains xenon gas, mercury and metal halide. These are contained in a pea-sized envelope formed in the tube between the electrodes. When high voltage is applied this causes arcing between the electrodes and the bulb produces a high intensity blue-white light. The ballast controls the operation of the lamp. When the headlamps are switched on, the ballast generates a high-voltage pulse (around 20 000 volts). This creates the arc between the electrodes. The rise in temperature within the lamp vaporises the gases and solids so that they emit light.

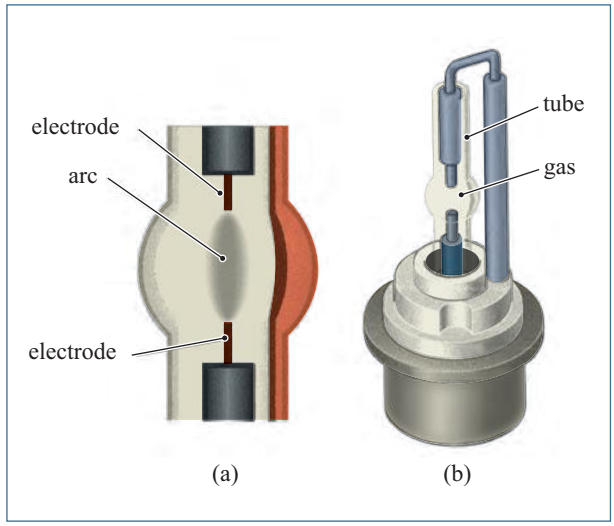


Figure 38.20 Gas discharge lamp (a) operation (b) construction

Light sources and colour temperature

Colour temperature is a measurement in degrees Kelvin that indicates the hue of a specific type of light source. Note that degrees Kelvin (°K) is a temperature scale mainly used for scientific purposes and is inidcated by the unit symbol K. Colour temperatures over 4000K are called cool colours (blueish white), while lower colour temperatures (2700 to 3000K) are called warm colours (yellowish white through red). The higher the temperature of a light source, the greater the proportion of blue and the lower the proportion of red in the colour spectrum. An incandescent light bulb has a warm white colour temperature of approximately 2700K.

38.9 Reading and interpreting electrical circuits

The wiring circuit diagram in Figure 38.21 shows a portion of the engine management section that deals with the fuel injection system. It is an example of how components and wires can be identified. Components are identified using letters and numbers and, in the case of fuel injectors, Roman numerals 1–4 (I, II, III, IV). Like components use the same letter. The following list identifies the type of component:

A—control module
B—sensor
F—fuse
K—relay
M—motor
S—switch
Y—actuator
X—external link

The number then identifies the individual component, for example K46 at the right side of the diagram is the engine control relay. This information would come from a list of components provided with the circuit diagram but not shown here.

The wiring circuits use a combination of colours, letter codes and numbers, for example a single colour wire marked *sw* is black. A multi-coloured wire marked *rt sw* is red with a black trace. The main power supply wires at the right side of the diagram use the numbers 30, 15 and 50.

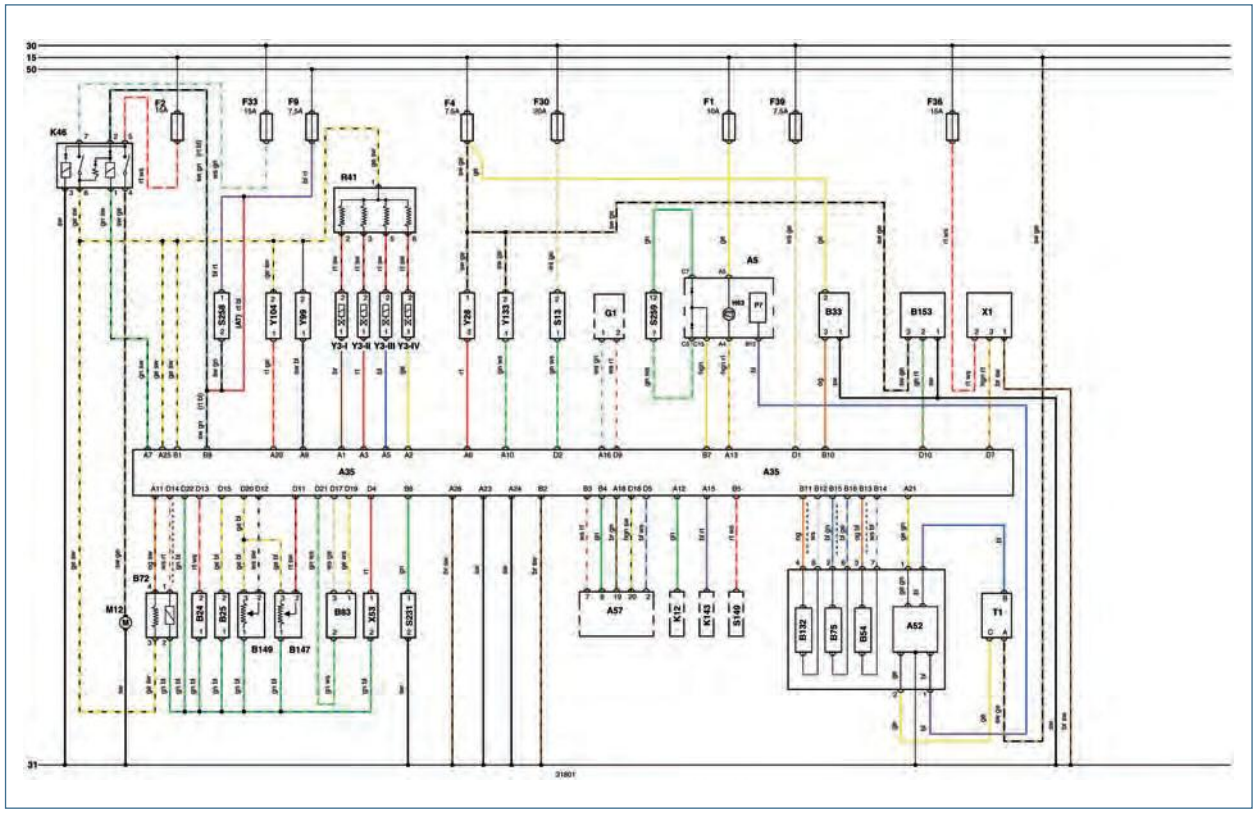


Figure 38.21 Schematic electrical circuit AUTODATA LTD

38.9.1 Using the circuit

At the centre of the circuit is the ECU A35. It receives all inputs and controls all outputs through the letter and numbered terminals. Circuits can then be traced to and from the ECU using the various wiring and component codes.

The operation of the fuel pump motor M12 can be followed: power is supplied from common live wire 15 through the fuse F2 and to the engine control relay K46 at terminal 5. When the control circuit is activated by the ECU at terminal A7, current will flow from the common live wire 50 through fuse F9 and to terminal 2 at K46, and activate the solenoid and earth through A7 at the ECU. The contacts between 5 and 4 at K46 will close, allowing current to flow through M12 and to ground through common ground 31.

It is not unusual for a modern vehicle to have 10 or more computer modules that monitor and control many of the its functions. Some even include optic fibre systems to operate audio equipment. Each manufacturer may have different codes for wiring, plugs and devices in the vehicle so it has become very important to follow the correct manual for a job. Without a wiring diagram, it would be very difficult to follow the wiring of any one component in a modern vehicle.

Figures 38.22 and 38.23 show the different approaches of two manufacturers to wiring diagrams.

Note the colour coding for the wiring of Figure 38.22 and compare it with that in Figure 38.23. Also note in Figure 38.22 the two wires going from the vehicle speed sensor to the speedo. The bottom one changes colour and the top one is thicker. The thicker wire in a manual indicates that it is sensed by the computer. The manual also tells the reader how to view the connecting plugs to select the correct wire and pin.

Figure 38.23 uses a different system to identify plugs and wires. The code on each wire next to the engine control module, (such as C0331-28, for example) indicates that the connecting plug is number 331 and the pin is number 28. The colour code for one of the wires is YG,0.35 in panel B. This indicates that the wire is 0.35 metres long and is yellow with a green trace. Note that in the grey shaded area in panel C all the wires are the same colour. This is because they are optic fibres for the speaker system. Crossed wires in a wiring diagram indicates that they are wires associated with the CAN Bus system for the computer. This is discussed further in the Electronics section.

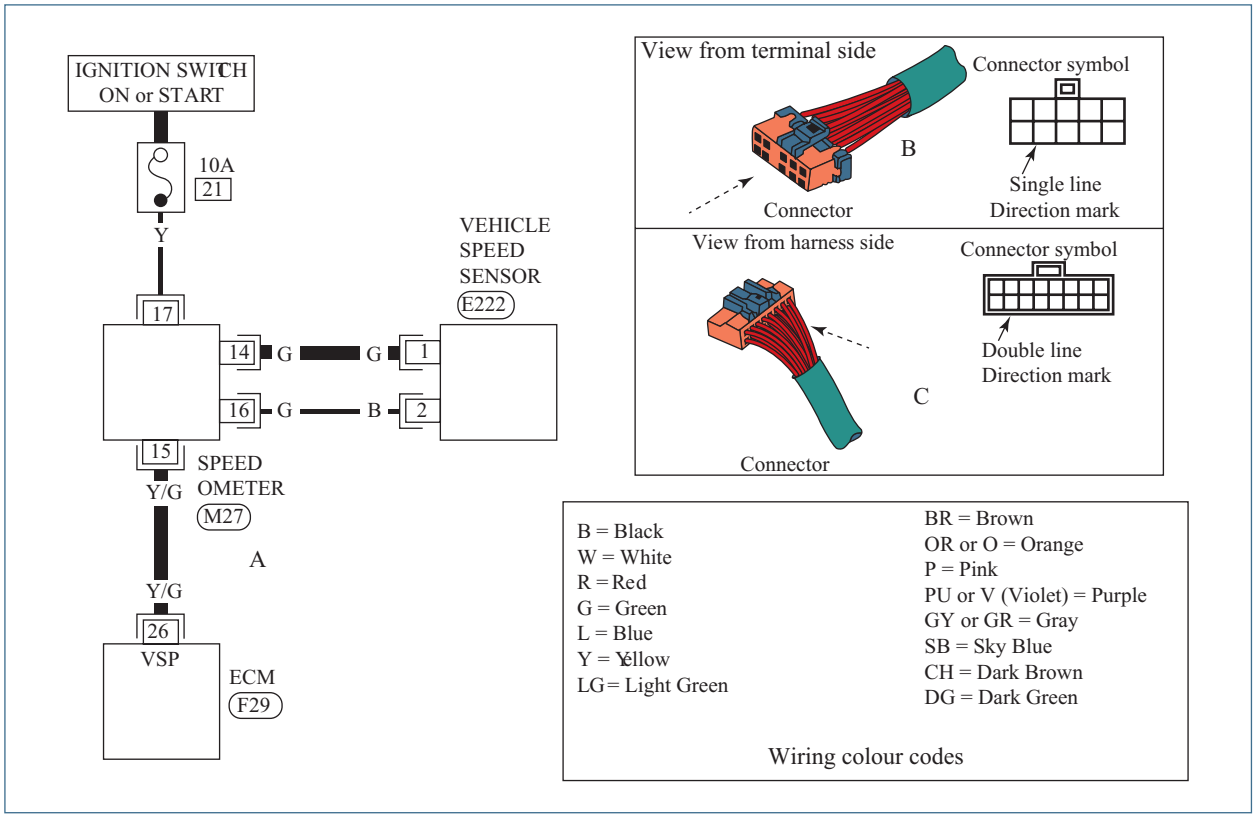


Figure 38.22 Different manufacturers will draw their wiring diagrams differently

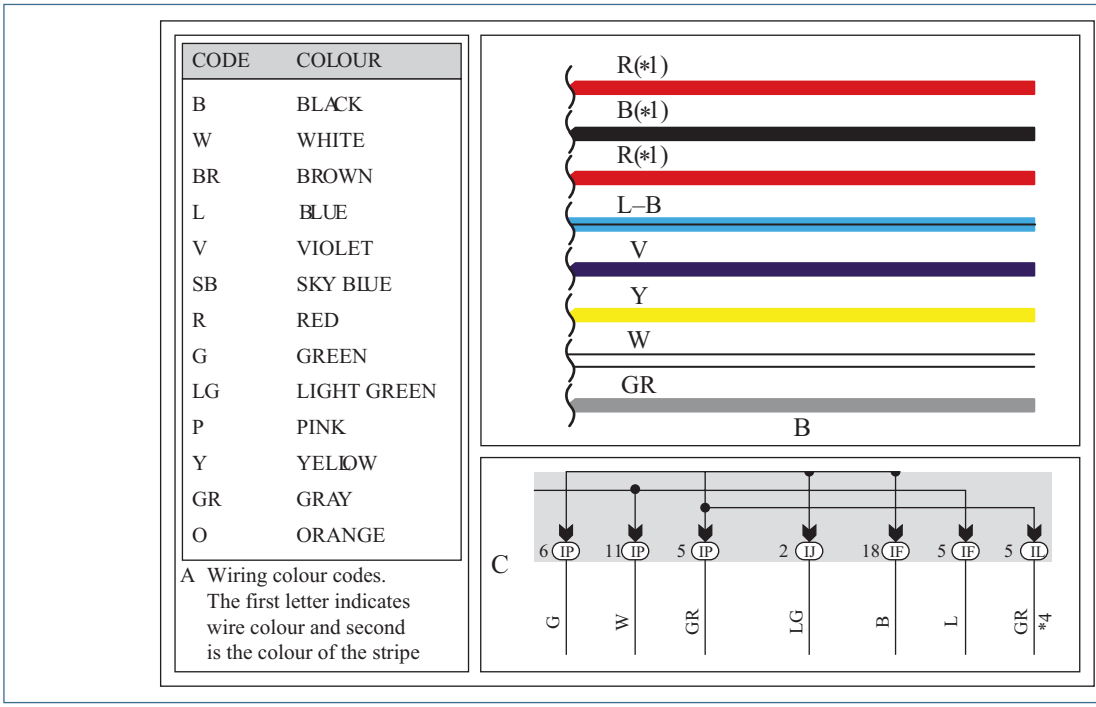


Figure 38.23 Colour coding and wiring codes may differ

38.9.2 Electrical circuit components and electrical symbols and circuits

Circuit components include cables, cable connectors, switches, fuses, bulbs, instruments, relays and motors. In addition, there are many electronic control units in the modern vehicle. There are also larger components such as the alternator, starter and ignition system components. These are considered to be part of the engine's electrical system. Figure 38.24 shows the common circuit symbol.

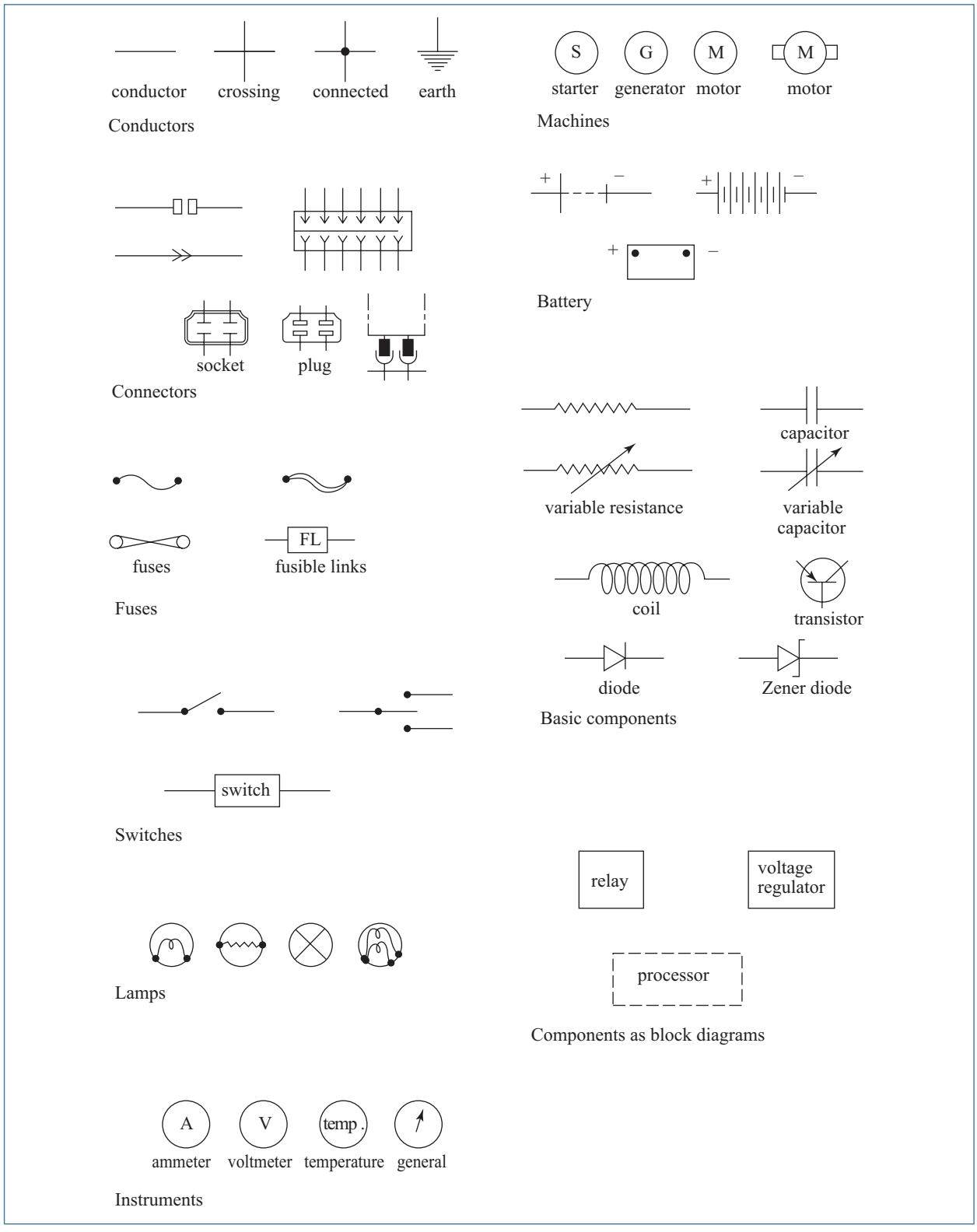


Figure 38.24 Various symbols used in automotive electrical circuit diagrams

38.10 Operating electrical test equipment

38.10.1 Digital multimeter (DMM)

The digital multimeter (or DMM) is a diagnostic tool whose usefulness is second only to that of a scan tool. A DMM can gauge the three most common measurements on an electrical circuit—amps, volts and ohms (Figure 38.25). It should have an internal resistance of 10 000 ohms, to restrict the current flow through the

meter to avoid damage to computer components. A high-quality DMM can measure AC voltage, DC voltage, DC millivolts, ohms, diode performance, milliamps and capacitance (in microfarads). Digital multimeters have an internal fuse to guard against user error.

38.10.2 Using a DMM

Readings on a DMM are displayed on a liquid crystal panel. A selector switch enables range and volts, amps or ohms to be measured.

Auto ranging meters are multimeters that can automatically select the correct range of readings to suit a particular test, as well as detect negative or positive polarity. A basic instrument of this type is shown in Figure 38.25. The meter can be used with standard leads or fused leads.

The meter in Figure 38.26 is a clamp meter, a type of multimeter that can measure high amounts of current. These meters have become a popular diagnostic tool because there is no need to disconnect any wires to check current flow. The mutimeters in Figure 38.25 can measure amps the same way using an inductive clamp. (Clamp not shown in Figure 38.25.)

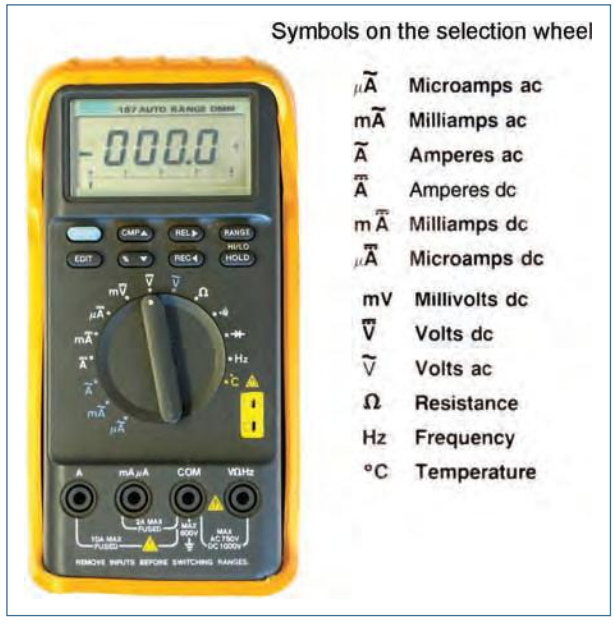


Figure 38.25 A digital multimeter with good test leads and an amp clamp is a very valuable tool when working on vehicles

38.10.3 Using a test lamp

When checking for circuit faults, a small 12-volt bulb in a socket fitted with test prods makes a useful test lamp (see Figure 38.27). A similar test lamp can be made with an LED.

An LED test lamp consists of a light-emitting diode in series with a resistor (Figure 38.28). The LED and resistor draw very little current, which protects the components being tested. This type of test light is recommended when testing vehicles fitted with computers.

Either of these test lamps can be used to locate the points in a circuit that have voltage.

Figure 38.26 Clamp-type induction meter to read amps without disrupting any connections—the test leads incorporate a fuse in the probe

38.10.4 Using a continuity tester

A continuity tester is a test lamp with a battery and a small bulb or an LED (Figure 38.29). When the test prods are touched together, the bulb or the LED will light.

A continuity tester of this type can be used between any two points of a circuit or component (other than an electronic component). If the lamp lights, there is continuity between the two points being checked. If the lamp does not light, there is a fault—an open circuit.

When using a continuity tester, the circuit must not have voltage from the vehicle's battery. Disconnect the negative battery terminal, turn off switches or disconnect the component before testing.

38.10.5 Voltage drop

Voltage drop is the loss of battery voltage in any positive supply system in the vehicle. There is a maximum voltage drop that is allowed in the system. For wiring it is 0 to 0.2 volts, for a wiring connection 0 volts,

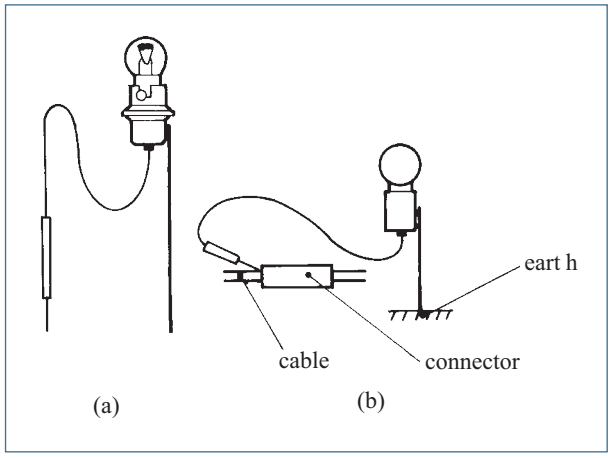


Figure 38.27 12-volt test lamp (a) construction (b) test for voltage

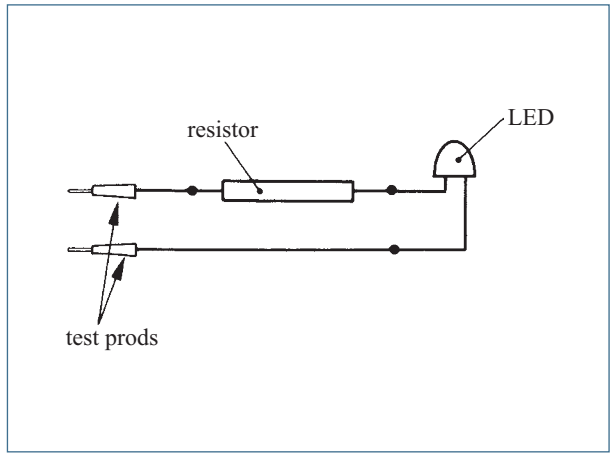


Figure 38.28 Arrangement of a test lamp with a light-emitting diode (LED)

for earth or ground connections it is approximately 0.1 volts and for switches 0.3 volts. Voltage drop can cause issues with computer systems, causing malfunctions that can be difficult to locate. Voltage drop can be checked in two ways:

1 by using the accumulated method (Figure 38.30)
2 by using the step-by-step method (see Figure 38.31). For this method, connect the DMM as shown in the image , starting from the battery and working around the circuit. A large voltage drop indicates a component that needs to be repaired or replaced.

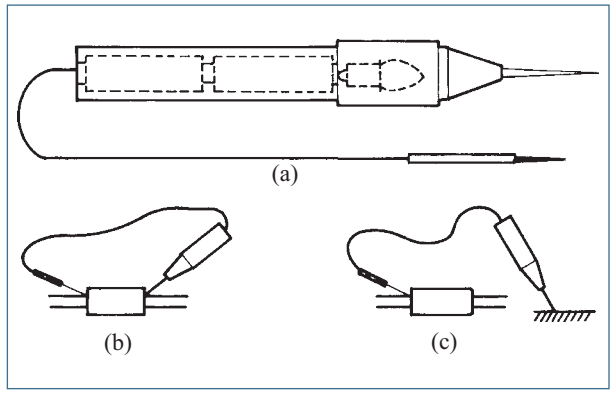


Figure 38.29 Continuity tester (a) construction (b) testing continuity of a connector (c) testing to earth

38.10.6 Use of test instruments

Table 38.3 shows a number of basic instruments that can be used for testing circuits and components. With the exception of the scan tool (item 8), they are not used for electronic equipment.

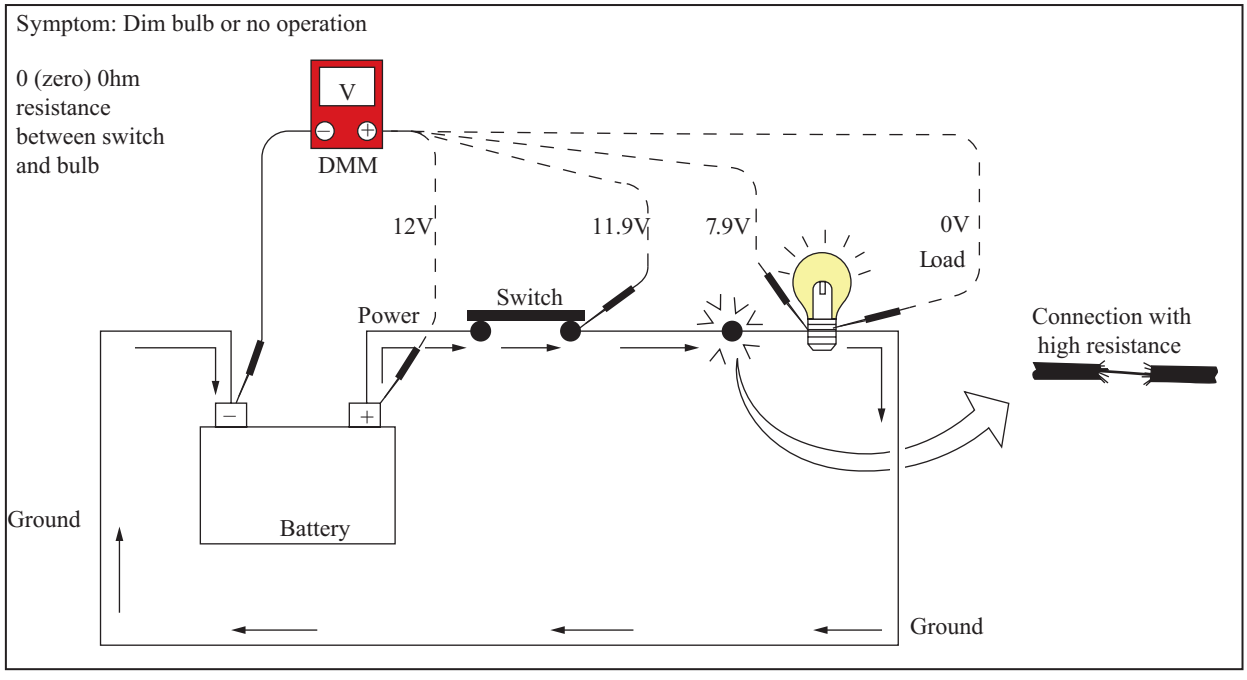


Figure 38.30 The accumulated method of measuring voltage drop

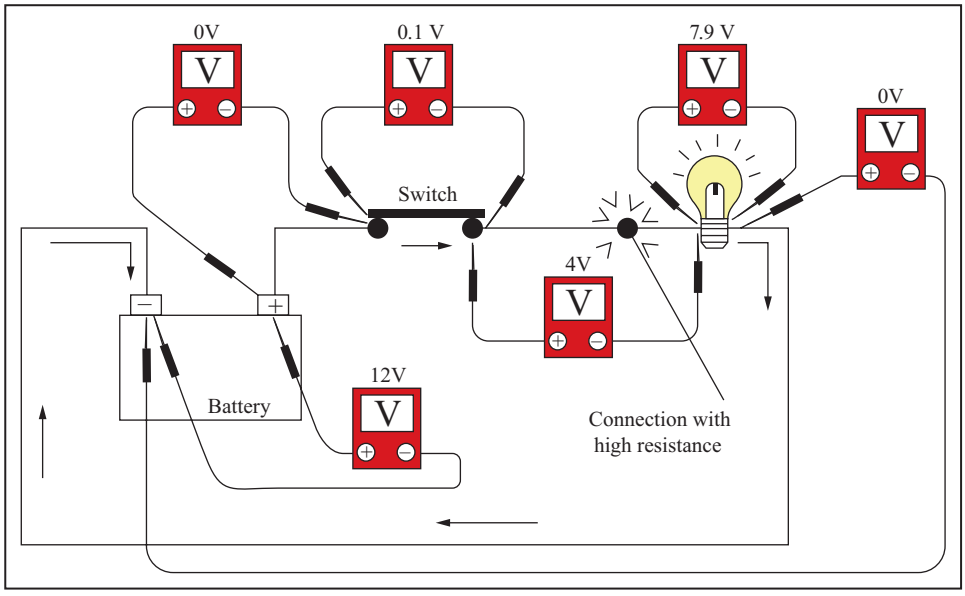


Figure 38.31 The step-by-step method of measuring voltage drop

Table 38.3 Use of basic test instruments

Tester	Test for	Effect	Test conditions
12 V test lamp	Voltage (volts)	Lamp is bright if there is normal voltage No light means no voltage Dull light means low voltage	Circuit must be energised during test Caution: not for electronics
Continuity tester	Continuity	Lamp lights for continuity No light means an open circuit	There must be no voltage in the circuit during the test, or disconnect the component Caution: not for electronics.
LED test lamp	Voltage	LED lights if voltage present	Can be used on electrical components and circuits Alternative to 12V test lamp
Voltmeter	Voltage Voltage drop	Meter reads volts at point of test Meter shows drop across a connector or component	Circuit must be energised during test Use only approved instruments for electronics
Ohmmeter	Continuity Resistance (ohms)	Meter reads zero or very low resistance for continuity , and infinity for an open circuit Meter reads actual resistance	There must be no voltage in the circuit during the test; or disconnect the component
Ammeter	Current (amps)	Meter reads current flow in a circuit	The ammeter must be connected into the circuit and the circuit energised
Multimeter (analog or digital)	Voltage Current Resistance	Reads volts, amps or ohms, as selected	As for separate instruments the correct scale and range must be selected (ex cept for an autoranging meter)
Scanner (diagnostic equipment)	Diagnostic codes and data	Various displays shown on the panel	Ignition must be on and the scanner connected to the data link connector

Safety: For electronic components and circuits, use only approved instruments.

38.10.7 Precautions with airbags and seatbelts

Extreme care must be used when working on airbags. Personal injury or damage to the vehicle could be caused if an airbag is accidentally deployed. A seatbelt pretensioner that is accidentally activated would cause similar problems. To prevent accidental deployment of an airbag, disconnect the battery and wait the required time as specified by the manufacturer. Not all vehicles have the same requirement.

38.10.8 General circuit checks

A general sequence for checking the circuit of a unit that does not operate can be shown in the form of a diagram. A logical sequence should be followed when diagnosing circuit problems. While electronic systems have built-in diagnostics, there is still a need for basic circuit checks. Follow the manufacturer's procedures as every vehicle may be different and there may be specific precautions that need to be taken.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- identify the safety issues when working on electrical and electronic systems
- explain the nature of electrons, protons and atoms and their movement
- demonstrate how to measure electricity
- explain the relationship between current, electrical power flow , voltage and resistance
- explain what electrical resistance is and how it is measured
- identify resistors, conductors and insulators
- state Ohm 's law and how to apply it to calculate power
- identify parallel and series circuits
- state Kirchhoff's laws
- explain how conductors, resistors and insulators are used in the automobile
- describe the use of circuit protection devices
- explain the application of relays and the different types of bulbs and their operation
- demonstrate how to read a circuit diagram and electrical symbols
- explain the correct operation of a multimeter , test lamps and probes
- identify wiring and terminal damage
- explain how to back probe and disconnect a connecting plug
- explain how to prevent corrosion in wiring and connections
- demonstrate how to check for and locate voltage drop .

REVIEW QUESTIONS

1 What is an electron ?
2 What is a free electron ?
3 Explain briefly how electrons move in a copper wire .
4 What is the conventional direction of current flow ?
5 What is a conductor ?
6 What is an insulator ?
7 Name some of the common insulators.
8 What is a resistor ?
9 What is the purpose of a rheostat ?
10 Explain Ohm 's law in simple terms.

11 If the voltage of a circuit is increased, what effect will this have on the current?
12 What is a series circuit?
13 Explain how three resistors can be connected in parallel.
14 If the resistors shown in Figure 38.25 were to be 2 ohms, 4 ohms and 6 ohms, what current would flow in the circuit?
15 Sketch a series circuit with an ammeter, three resistors (4, 6 and 8 ohms) and a battery.
16 If the ammeter in question 17 showed 2 amps, what would the battery voltage be?
17 What is voltage drop?
18 Provide an example of a practical application of voltage drop.
19 What function does the metal of the body perform in the vehicle's electrical system?

CHAPTER 39

Effects and applications of electric currents

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 explain the operating principles of automotive electrical systems and related components
2 identify the purpose and operation of automotive electrical systems and related components
3 perform diagnostic testing procedures for automotive electrical systems
4 recall repair procedures for automotive electrical systems
5 perform post-repair testing procedures for automotive electrical systems.

Three types of effect can be produced by an electric current, and all have automotive applications. These effects are:

1 heating
2 chemical
3 magnetic .

Handy hint: The magnetic effect is the effect of an electric current that is most extensively used in automotive electrical systems.

39.1 Heating effect of a current

Any conductor carrying an electric current will become heated as a result of its current flow. The conductors in an automotive electrical system do not normally produce enough heat to cause problems. This is because the system is designed with conductors (cables) of a suitable size. However, problems can arise if part of the system is overloaded or if connections and terminals are not clean and tight. A loose or dirty electrical connection can cause a high resistance, which will produce unwanted heat and voltage drop. Figure 39.1 shows a number of cables. Where large currents are used, such as in starter motor circuits, large cables are required. These prevent excessive voltage drop and are able to carry the starter current without overheating. In other circuits, which have much lower currents, small cables are adequate.

39.1.1 Applications of the heating effect

The applications of the heating effect of a current for lamps, fuses, glow plugs and switches are outlined below.

Lamps

The heating effect of an electric current is used in light bulbs. Current passing through the bulb filament causes it to become white hot, producing light.

Fuses

Excess current passing through a fuse will cause it to overheat to the extent that it 'blows' by melting the fuse wire. Fuses and fusible links are used as protective devices to prevent overheating of circuits. (See Chapter 38 for the various designs of fuses.)

Glow plugs

In some diesel engines, glow plugs and heater plugs are used as starting aids. These contain elements that are electrically heated by passing a current through them. In turn, they heat the air or fuel mixture around them.

Switches

Heat-operated controls and switches function via the heating effect of the current that they carry. The switches have one of their contacts mounted on a bimetal blade, which normally holds the contacts closed (Figure 39.2). The contacts are opened by the heating effect of the current passing through the blade, which causes it to distort. As the blade cools, it resumes its normal shape and this closes the contacts.

Switches and controls of this type, which are sensitive to heat and current flow, are used as circuit breakers to protect circuits from excessive current. The principle is also used in some flasher lights where an intermittent current is required.

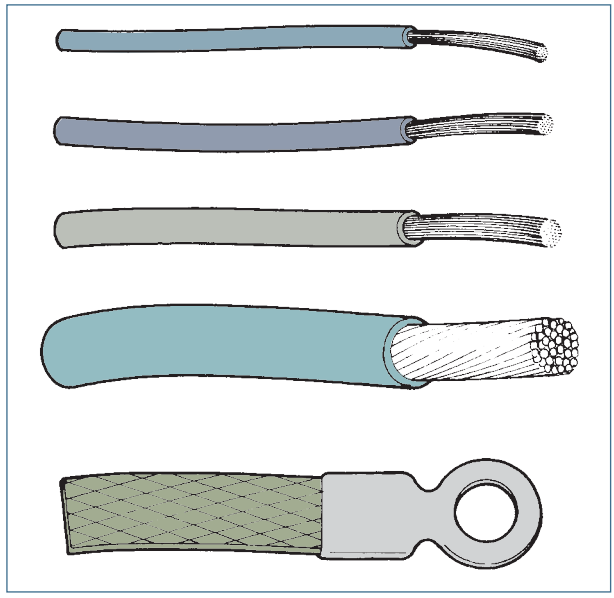


Figure 39.1 A range of electrical cables—heavy cables are used for high currents to prevent overheating and voltage drop

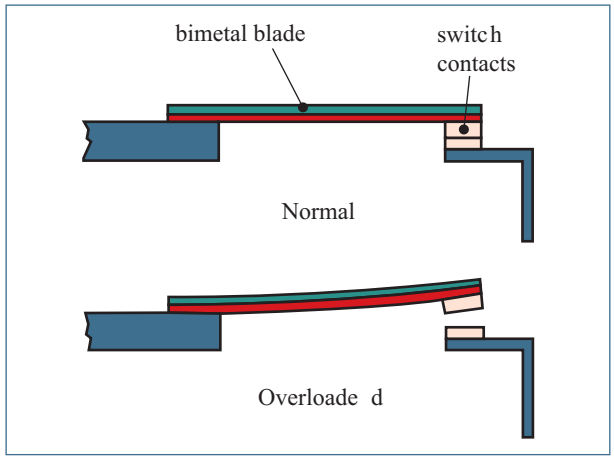


Figure 39.2 Thermal switch with a bimetal arm

39.2 Chemical effect of a current

39.2.1 Batteries

The chemical effect of current flow can also be related to batteries. Automotive batteries consist of a number of cells, which are called lead-acid cells as they consist of lead plates immersed in an acid solution (electrolyte). The cells store electrical energy in chemical form.

When current is flowing from the battery, chemical energy is converted to electrical energy. When current is supplied to the battery, the battery is being charged and electrical energy is being converted to chemical energy. See Chapter 41 for more information on batteries.

39.3 Magnetic effects of a current

Current flowing in any conductor produces a magnetic effect. This has many uses in automotive components. Some of the electrical components whose operation involves magnetism are the starter motor, alternator, ignition, horn, windscreen wipers and instruments. Knowing the principles of magnetism is essential to understand the operation of many of the electrical devices which are fitted to motor vehicles.

39.3.1 Magnets

A permanent magnet is a piece of special alloy steel that attracts other magnetic materials. The most common magnet shapes are bar magnets and horseshoe magnets (Figure 39.3).

(a) (b)

Figure 39.3 The poles at the ends of the magnets attract iron filin gs (a) bar magnet (b) horseshoe magnet

Handy hint: Magnetic materials are those containing iron. Metals such as aluminium and copper are non-magnetic.

39.3.2 Magnetic polarity

The compass needle is a familiar example of a magnet. This is a small permanent magnet, lightly suspended on a pivot, which always locates itself in a direction N and S on account of the earth's magnetic north pole.

39.3.3 Attraction and repulsion

Magnets not only attract other magnetic materials, but they also attract and repel other magnets. If two magnets are placed with their unlike poles opposite (N facing S), they will be attracted to each other as shown in Figure 39.4 When magnets are placed with like poles opposite (N facing N, or S facing S), they will repel each other.

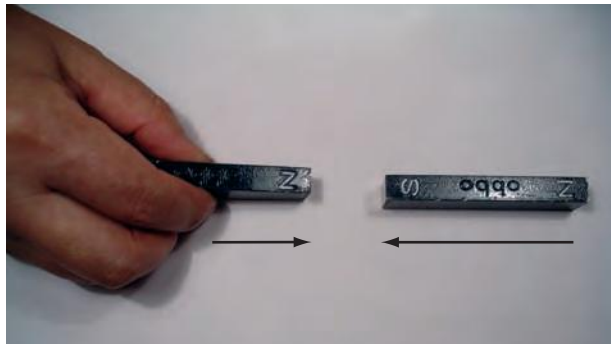


Figure 39.4 Unlike poles of a magnet attract each other whereas lik e poles repel

39.4 Theory of magnetism

Every magnet is made up of a number of minute magnetic particles. In an unmagnetised piece of iron or steel, these particles are arranged in such a way that their poles form closed magnetic loops, thereby neutralising one another so that no magnetic effect is evident (Figure 39.5). When a piece of steel is magnetised, the magnetic particles are rearranged so that their poles are all aligned in the same direction to produce the effect of N and S poles at the ends of the bar, which becomes a magnet. Iron and soft steel are easy to magnetise, while hard steel is difficult to magnetise.

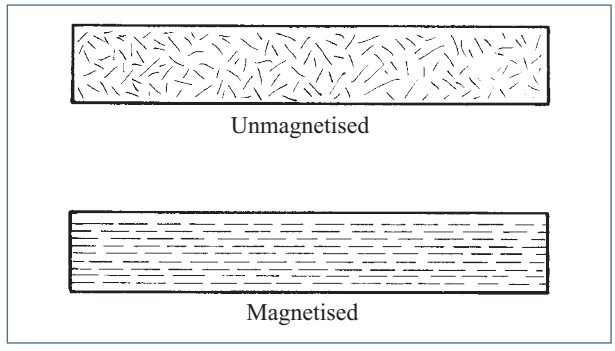


Figure 39.5 Arrangement of magnetic particles in a steel bar

39.4.1 Magnetic induction

Magnetism can be *induced* from a magnet into an unmagnetised piece of soft iron to make a temporary magnet. This is called *magnetic induction* (Figure 39.6). When a piece of soft

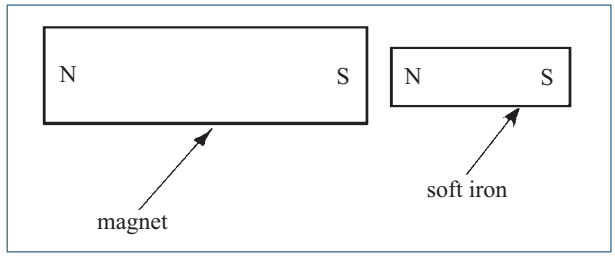


Figure 39.6 Magnetic induction—a piece of soft iron becomes an induced magnet only while it is within the magnetic field of the permanent magnet

iron or steel is removed from the influence of the magnet, it becomes demagnetised, but a very weak magnetic effect called *residual magnetism* remains. Almost every magnetic material has some degree of residual magnetism.

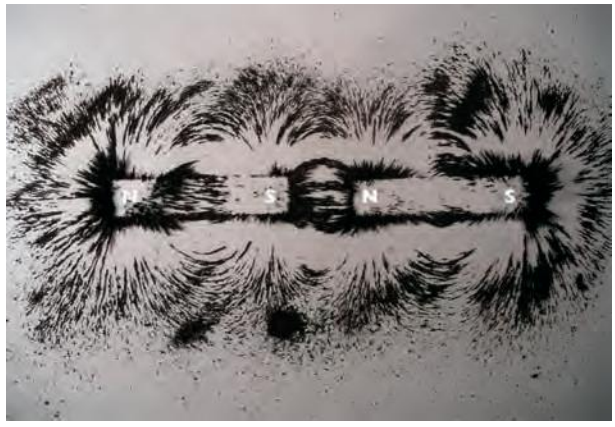
39.4.2 Magnetic field

The magnetic field is the space surrounding the magnet in which a magnetic force may be detected. It is considered to be made up of a number of magnetic lines of force which represent the field by showing the direction in which a north pole would move if it were free to do so (Figure 39.7).

The magnetic lines of force have the following properties:

1. They go from north to south outside the magnet, and from south to north within it.
2. They repel each other sideways, and do not cross.
3. They tend to crowd through magnetic materials placed in the field.
4. They are not affected if non-magnetic materials are placed in the field.

Handy hint: Magnetic flux is a term that can be used instead of lines of force . It represents all the lines of force in a magnetic field.



(a)

(b)

Figure 39.7 Magnetic fields of a bar magnet (a) unlike poles attract (b) like poles repel

39.5 Electromagnetism, interference and radiation

Whenever current flows in a conductor, a magnetic field is set up around it, an effect known as *electromagnetism.*

This means that any wire, or conductor of any type, will have a magnetic field if current is flowing through it (Figure 39.8). In most cases, this is only a weak field and is unimportant; but when a strong magnetic field is required, the wire can be wound into a coil with many turns to concentrate the effect and produce a very strong magnetic field. The magnetic field that is created by the flow of electricity can influence other components or signals that travel through wiring such as the CAN Bus lines that computers use. To overcome the magnetic field interference, a shield or foil is wrapped around the CAN Bus line and the wires twisted together. Other areas of interference may be detected in the radio signal or video cables, such as those used in revering cameras.

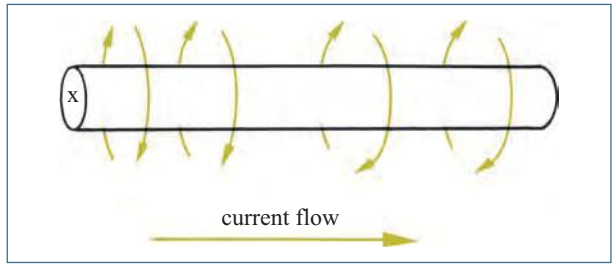


Figure 39.8 Magnetic lines of force around a conductor

39.5.1 Magnetic field of a coil

The strength of a magnetic field around a conductor can be concentrated by winding the conductor into a coil, as in Figure 39.9 The strength of the field depends on:

1. the type of conductor
2. the number of turns of the coil
3. the current flowing in the coil.

Coils are used in many electrical components, such as electric motors, alternators, relays, solenoids and door locks.

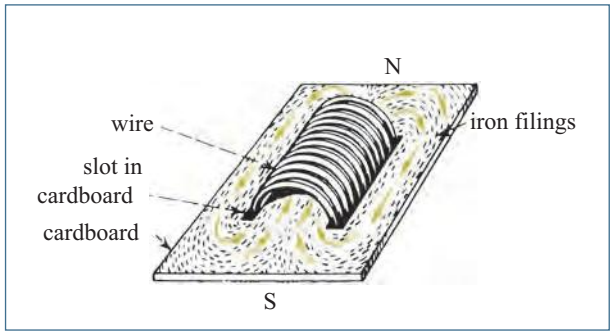


Figure 39.9 Field of a coil shown with iron filings—this is similar to the field of a bar magnet

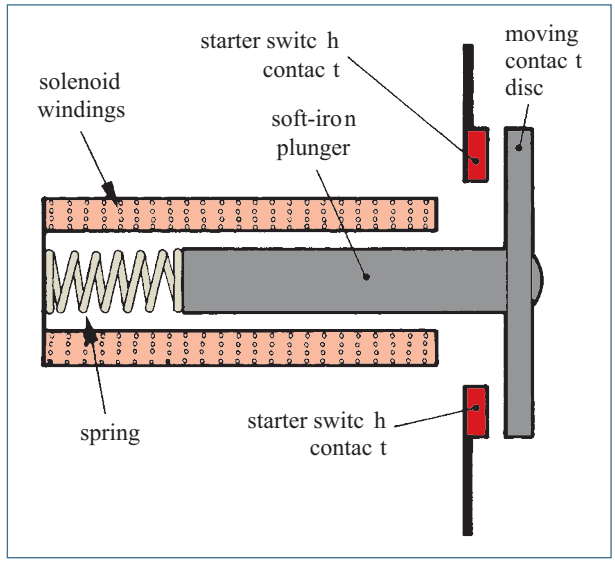


Figure 39.11 Principle of a solenoid switch

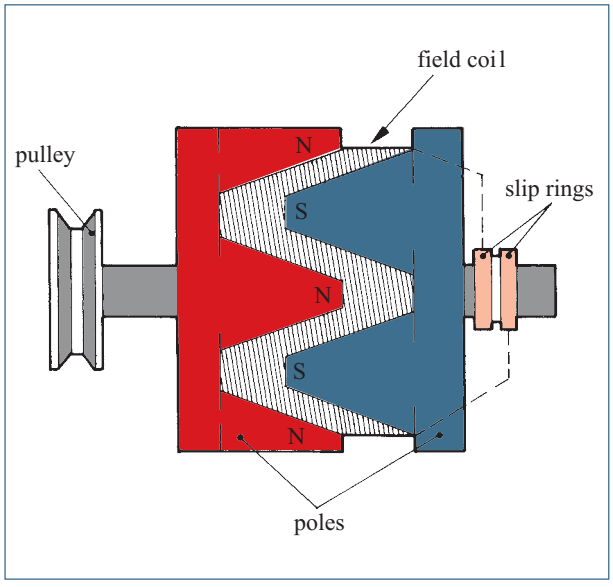


Figure 39.10 Simplified alternator rotor—the field coil is an electromagnet which magnetises the field poles

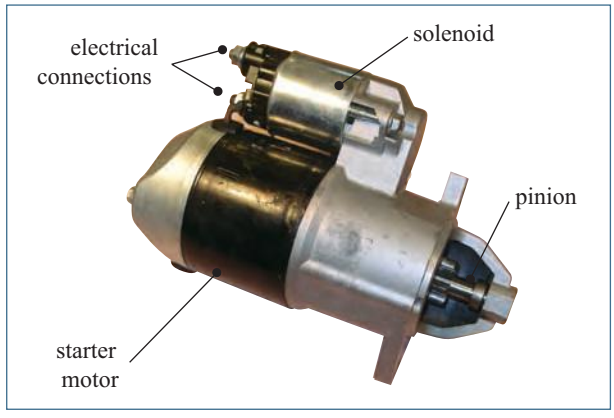


Figure 39.12 The starter solenoid is mounted on top of the starter motor , where it acts as a switch and also moves the pinion into mesh

39.5.2 Electromagnets

The strength of an electromagnet can be increased by wrapping the conductor around a soft iron core or encasing it in soft iron. When current flows through the windings, the soft iron becomes a magnet. When the current stops, the magnetic field collapses and the magnetic effect also stops.

An application of an encased winding is shown in Figure 39.10. It is an alternator rotor with the field winding encased by two iron claws or field poles. When current flows through the field winding, a strong magnetic field is built up around it. That field induces a magnetic effect into the claws to become N and S poles as shown.

39.5.3 Solenoids

A solenoid is a coil of insulated wire wrapped around an insulated cylinder of non-magnetic material. The cylinder in Figure 39.11 is hollow to form part of a solenoid switch. Here, the switch is being used as a starter solenoid.

When the ignition switch is in the start position, the solenoid windings are energised. This creates a magnetic field, pulling the soft-iron plunger into the windings against the spring. The disc closes the starter contacts and spins the starter motor. The solenoid is mounted on the starter motor and also engages the starter pinion, as shown in Figure 39.12.

39.6 Electromagnetic switches (relays)

Figure 39.13 illustrates the principle of an electromagnetic switch (also referred to as an electromechanical switch, but usually called a *relay*). A relay consists of an electromagnet, with a soft-iron armature pivoted

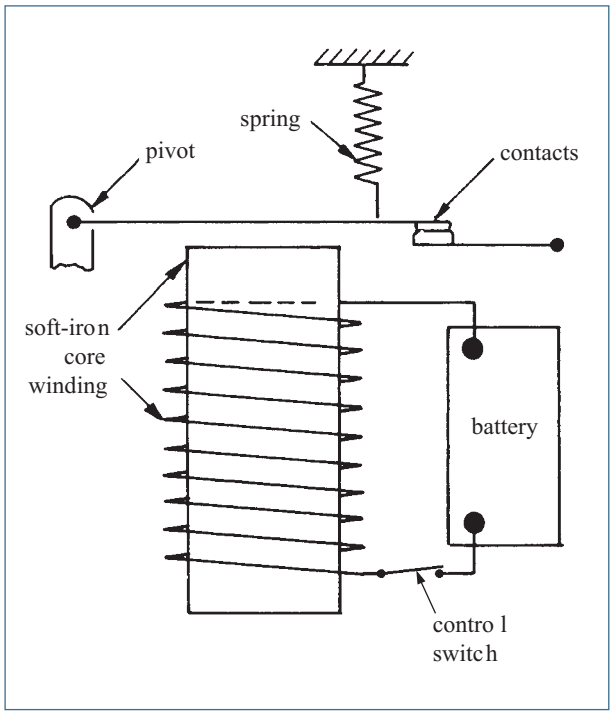


Figure 39.13 Diagram of an electromagnetic switch or relay

Figure 39.14 Example of a relay for a lighting circuit TRIDON

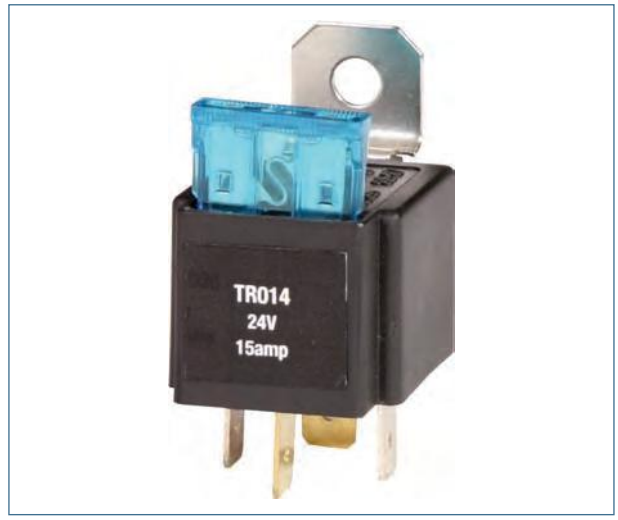


Figure 39.15 Example of a relay for a fan circuit TRIDON

to open and close a set of contact points. When a control switch is closed to connect the battery to the coil, current energises the coil windings. The magnetised core attracts the armature and the contact points close. When the control switch is open, the coil is no longer energised and the contact points are opened by the spring.

This arrangement could be used to operate the headlamps. The contact points are used to connect the headlamp to the battery by a much more direct circuit than through the headlamp switch on the steering column. The relay is mounted close to the headlamps, with heavier and shorter wire, which reduces voltage drop. The headlamp switch is used only to control a low current to operate the relay.

There are many relays used on a motor vehicle. They are used in the circuits for horns, lights, fans and many other components. The relay shown in Figure 39.14 would be suitable for a lighting circuit, while the relay in Figure 39.15 has its own fuse and could be used in a fan circuit.

Handy hint: Some relays are designed to close their points when energised; others are designed to open their points when energised.

39.7 Electromagnetic induction

Electricity can be induced into a conductor by means of magnetism. Known as *electromagnetic induction,* this is an important principle as it applies to the operation of alternators and ignition coils. Electromagnetic induction is the reverse of electromagnetism, with magnetism being used to produce electricity.

The principle of electromagnetic induction is summarised by Faraday's Law, which states:

Whenever a conductor is moved to cut a magnetic field, an emf (voltage) is induced into the conductor.

Handy hint: Simply, this means that a force is produced in the conductor to cause the electrons to move . Emf is an electromotive (or electron-moving) force .

There are three main requirements for electromagnetic induction:

1 a magnetic field
2 a conductor or conductors
3 movement between the conductor and the field (either can move) .

39.7.1 Inducing voltage

A simple example of electromagnetic induction is shown in Figure 39.16. The field of a magnet is being cut by a conductor, which is being moved at right angles to the lines of force. As a result, a reading will be obtained on the sensitive meter that is attached to the conductor. This shows that a small voltage has been induced into the conductor.

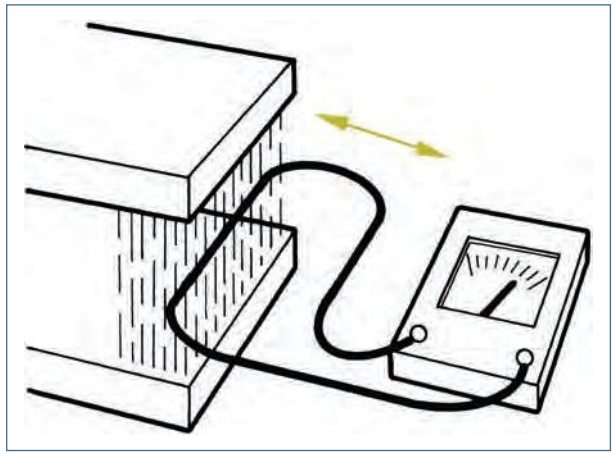


Figure 39.16 Electromagnetic induction—an emf is induced into the conductor as it is moved back and forth between the poles of the magnet

Handy hint: The conductor must be moved across the lines of force , or the lines of force moved across the conductor , to have any effect. If the conductor is moved with the lines of force , there is little effect.

39.7.2 Alternator and generation

In an alternator, the magnet or magnetic lines of force are moved and the conductor is stationary. This is shown simply in Figure 39.17, where a permanent magnet rotates between two parts of a conductor. As the magnet rotates, the magnetic field cuts the conductor and induces a small voltage into it.

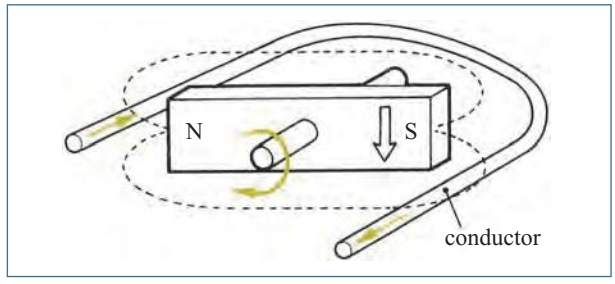


Figure 39.17 A rotating magnet has a rotating field that cuts the conductor and induces an emf

The illustration shows the basic principles of generation, but to obtain voltages that are high enough for practical use, automotive alternators need to have a number of conductors, a stronger field and increased speed of movement between the two.

39.7.3 Sensors

Not all electromagnetism is concerned with strong magnetic fields and high voltages. Sensors, which are used with electronic controls, operate on very low voltages (millivolts).

Figure 39.18 shows the principle of one type of sensor. This consists of a coil around a permanent magnet. The arrangement can be used to sense engine speed, road speed for an automatic transmission or wheel speed for antilock brakes. It can also be used for ignition-timing purposes.

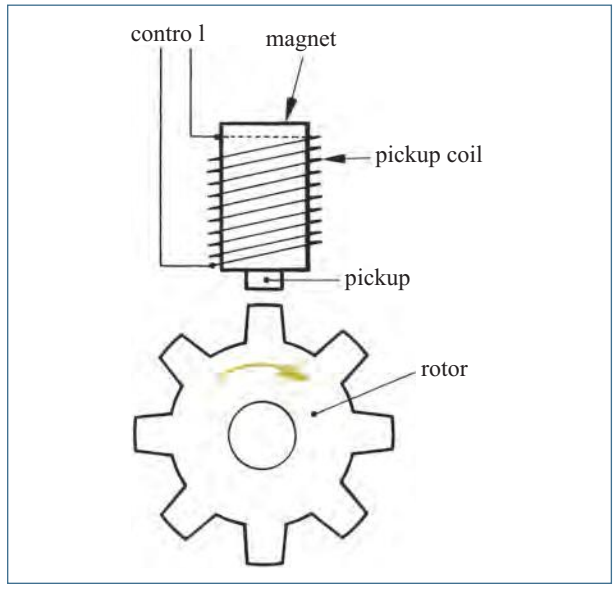


Figure 39.18 Arrangement of a rotor and a sensor for speed or timing

As the rotor turns, low-voltage impulses are produced in the pickup coil, and these are sent as signals to an electronic control. An impulse occurs each time a tooth of the rotor moves past the pickup. This happens because the tooth disturbs the magnetic field of the permanent magnet. Its lines of force cut the wires of the pickup coil and induce the voltage signal in them. When checking some sensors, extreme care should be taken as the attached connecting wires can be extremely fine and easily become damaged.

Handy hint: The three requirements for magnetic induction are again present: magnetic field, conductors and movement.

39.8 Application of automotive electrical systems

In the modern vehicle, most systems are controlled by body control modules (BCM) or body electronic module (BEM). The advantage of this is the ability to activate items automatically, such as wipers with rain sensors or headlights with light sensors. Advances in electronics have added many automatic convenience features and warning systems (see Figure 38.1 in Chapter 38).

39.8.1 Wiper motors

Figure 39.19 shows a dismantled windscreen wiper motor. This is a permanent-magnet-type electric motor. It does not have field windings, but has a permanent magnet in the yoke that provides the magnetic field. The armature carries a number of windings on a laminated core. It fits inside the yoke, with one end of its shaft supported in a bearing in the back of the yoke and the other end supported in the gear housing. The front end of the shaft has a worm that meshes with a gear in the gear housing. The shaft of the gear carries the crank arm, the end of which is connected to the wiper linkage.

The motor has three brushes that are in contact with the commutator on the armature. These brushes carry the current that causes the armature to rotate and operate the wiper mechanism. A parking switch is incorporated with the gear mechanism, only allowing the motor to stop when the wiper arms are in the correct parking position at the bottom of the windscreen.

39.8.2 Wiper motor circuits

Figure 39.20 shows a simplified circuit diagram for a windscreen wiper and washer. The wiper motor has a high speed and a low speed. It also has a parking switch which keeps it running after the wiper switch has been turned off until the wiper blades are in the correct position to park. If the vehicle has a BEM, this will also influence wiper operation. The connections to the wiper motor are shown as follows:

- A—accessory
- L—lowspeed
- H—high speed
- P—park
- E—earth.

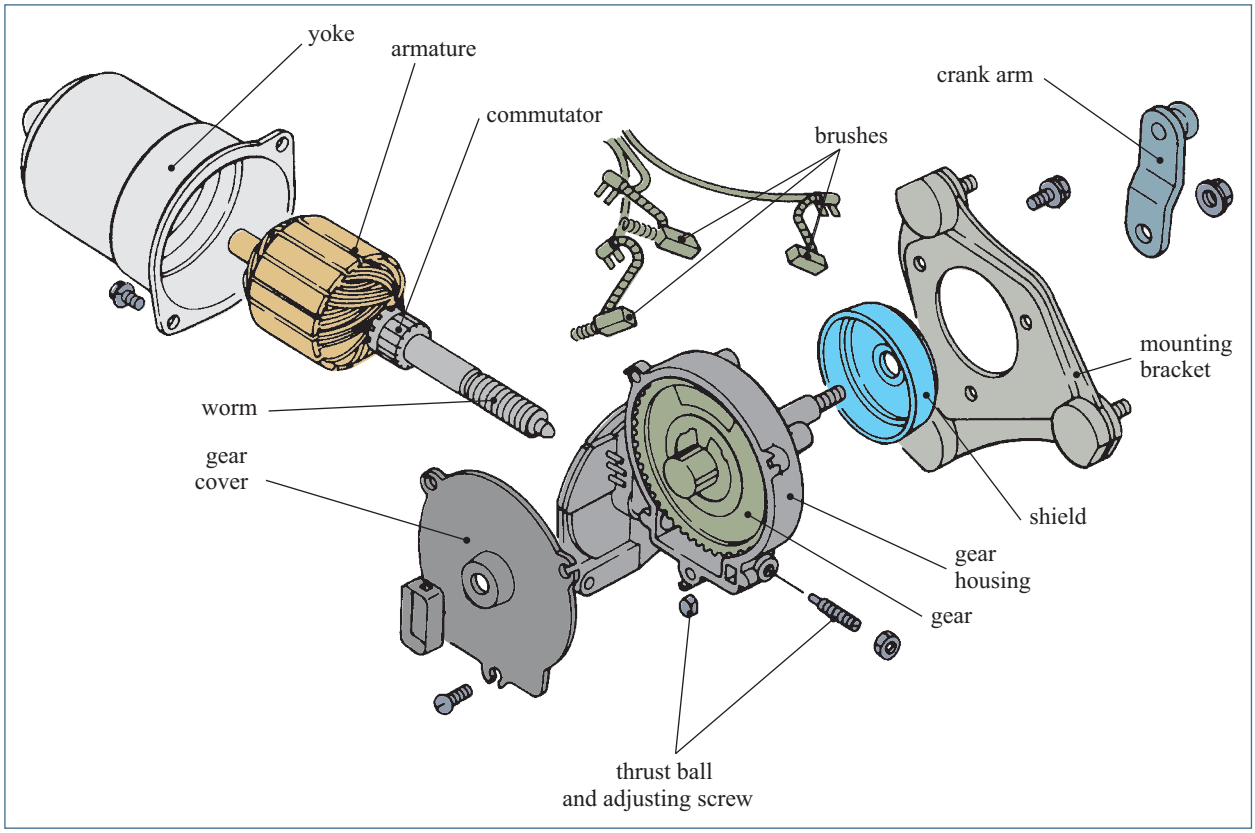


Figure 39.19 Dismantled windscreen wiper motor assembly GM HOLDEN LTD

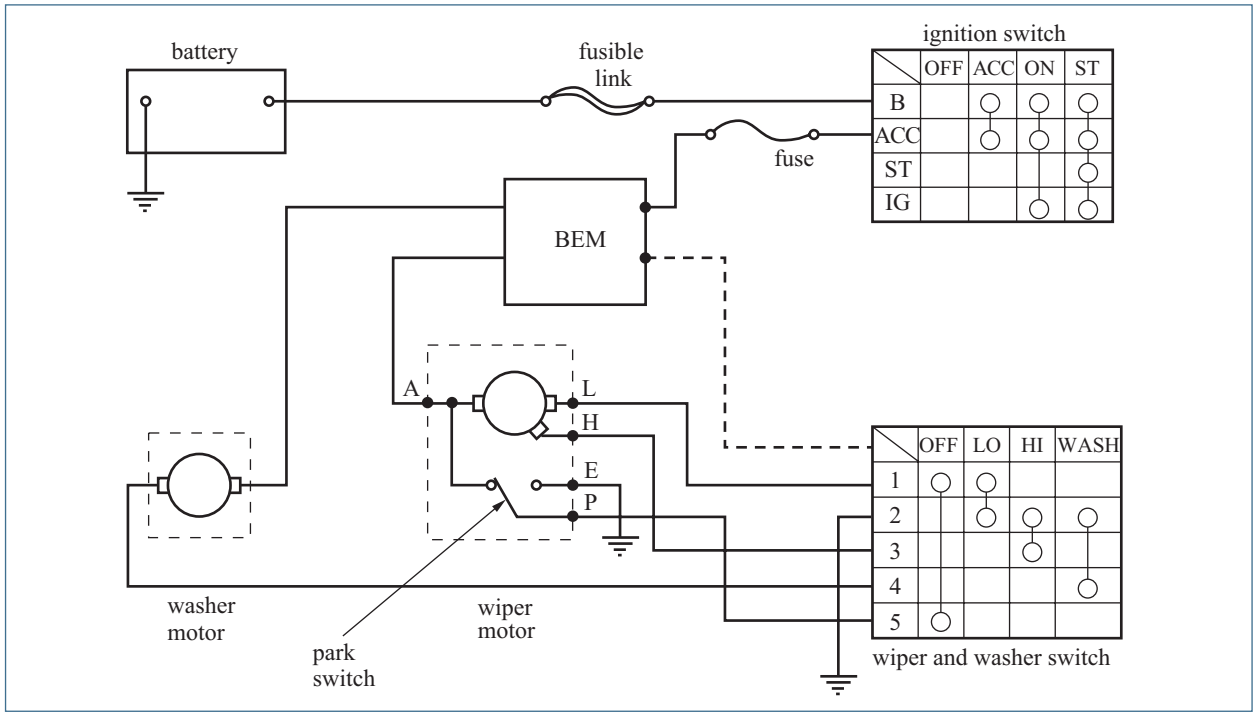


Figure 39.20 Basic circuit diagram of a windscreen wiper motor and washer

A is connected to the ignition switch. L, H and P are terminals that are joined by a multipin connector to the wiper switch. E is a connection to earth at the wiper motor. The washer motor has two terminals, one of which is connected to the ignition switch and the other to the washer terminal of the wiper switch.

The wiper and washer switch is shown as a block diagram. The connections made by the contacts inside the switch are shown for the various switch positions.

39.8.3 Circuit operation

With the ignition switch in either the ACC or ON position, the positive battery terminal is connected to the positive terminal A of the wiper motor through the fusible link, the ignition switch and the fuse. The wiper motor is operated by the wiper switch (when it is switched to the appropriate position), connecting either terminal L or H to earth. The BEM provides certain functions when required.

1 Low speed. The wiper switch is moved to the L O position to connect terminals 1 and 2. This completes the circuit from the motor L terminal to earth. The motor runs at low speed.
2 High speed. The wiper switch is moved to the HI position to connect terminals 3 and 2. This completes the circuit from the motor H terminal to earth. The motor runs at high speed.
3 Parking. When the wiper switch is moved to the OFF position, terminals 1 and 5 are connected. This connects the motor L terminal to the P terminal of the parking switch. This allows the motor to run until the blades reach their park position.

39.8.4 BEM and wiper operation

When a vehicle has a BEM, it can be part of the wiper and washer electrical circuit. With intermittent wiper operation, the BEM controls the delay period between wipes which, in some vehicles, can be adjusted by the driver. Another function of the BEM is to automatically adjust the intermittent wiping speed to suit the speed of the vehicle. The wipers will have a long delay period when the vehicle is stopped, but the BEM will shorten it as the road speed is increased.

Automatic operation

Sensors on the windscreen can be used to signal the BEM for automatic wiper operation. An optical sensor, normally located in front of the rear-view mirror, senses the change in refracted light caused when water hits the windscreen. It works on the principle that a clean, dry windscreen will reflect all of the light emitted from an LED back to a light sensor, as in Figure 39.21(a). Figure 39.21(b) shows rain on a windscreen causing some of the light to be *refracted* or allowed to pass through the windscreen. The photo diode collects this information for the micro-processor to determine the wiper speed.

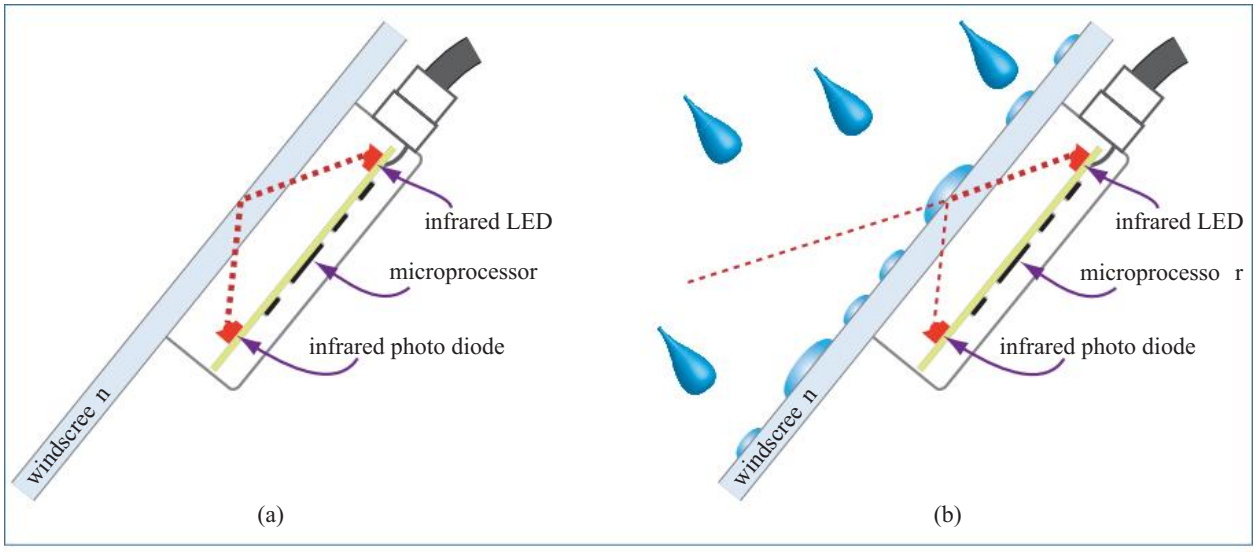


Figure 39.21 (a) Dry windscreen, light from the LEDs is reflected back onto the photo diode (b) wet windscreen, some light passes through the water on the screen, reducing the a mount of light reflected VACC TECH TALK MAGAZINE

The sensitivity is normally adjusted by a combination switch replacing the intermittent wiper switch.

39.8.5 Power windows

Power windows have an electric motor in each door to operate the window-regulator mechanism. There is a switch at each door and a cluster of master switches in the driver's armrest or in the centre console beside the driver (Figure 39.22). The switches have *up, down* and *neutral* positions.

Operating the switches will raise or lower the window fully or allow it to be stopped in any position. The lock switch can be used to override the rear-door switches. Figure 39.23 shows one arrangement of a window regulator and its electric motor. The electric motor is reversible. Current supplied in one direction causes the motor to rotate and wind the window up. When the current is reversed, the motor rotates in the opposite direction to wind the window down. All the switches are double-pole switches which enable the rotation of the motors to be reversed. The system has a circuit breaker which opens if the circuit is overloaded.

Figure 39.22 One arrangement of the master switches for power windows SHUTTERSTOCK

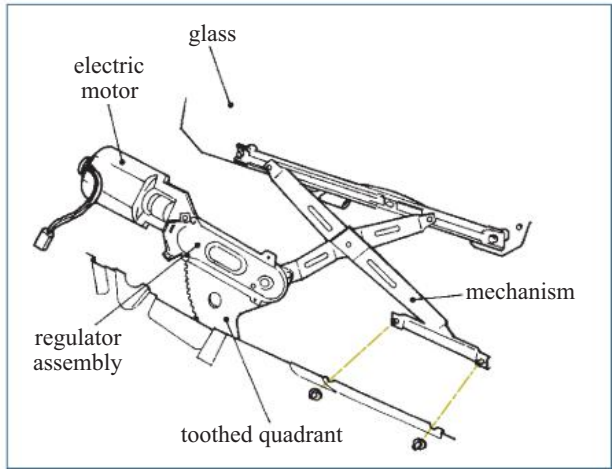


Figure 39.23 Electric motor and window-regulator mechanism FORD

Power-window circuit

A basic circuit diagram for power windows is shown in Figure 39.24. For simplicity's sake, only the motors for one front door and one rear door are shown. However, the other doors have similar circuits. A BEM has not been included in this simplified circuit, although it would perform some functions for a locking system.

Circuit components

Before considering how the circuit operates, its various parts should be identified (as follows):

1 The master switches and the rear-door switch are enclosed with dotted lines.
2 The battery provides voltage to the up and down contacts of both switches. The other fix ed contacts (E) are connected to earth.

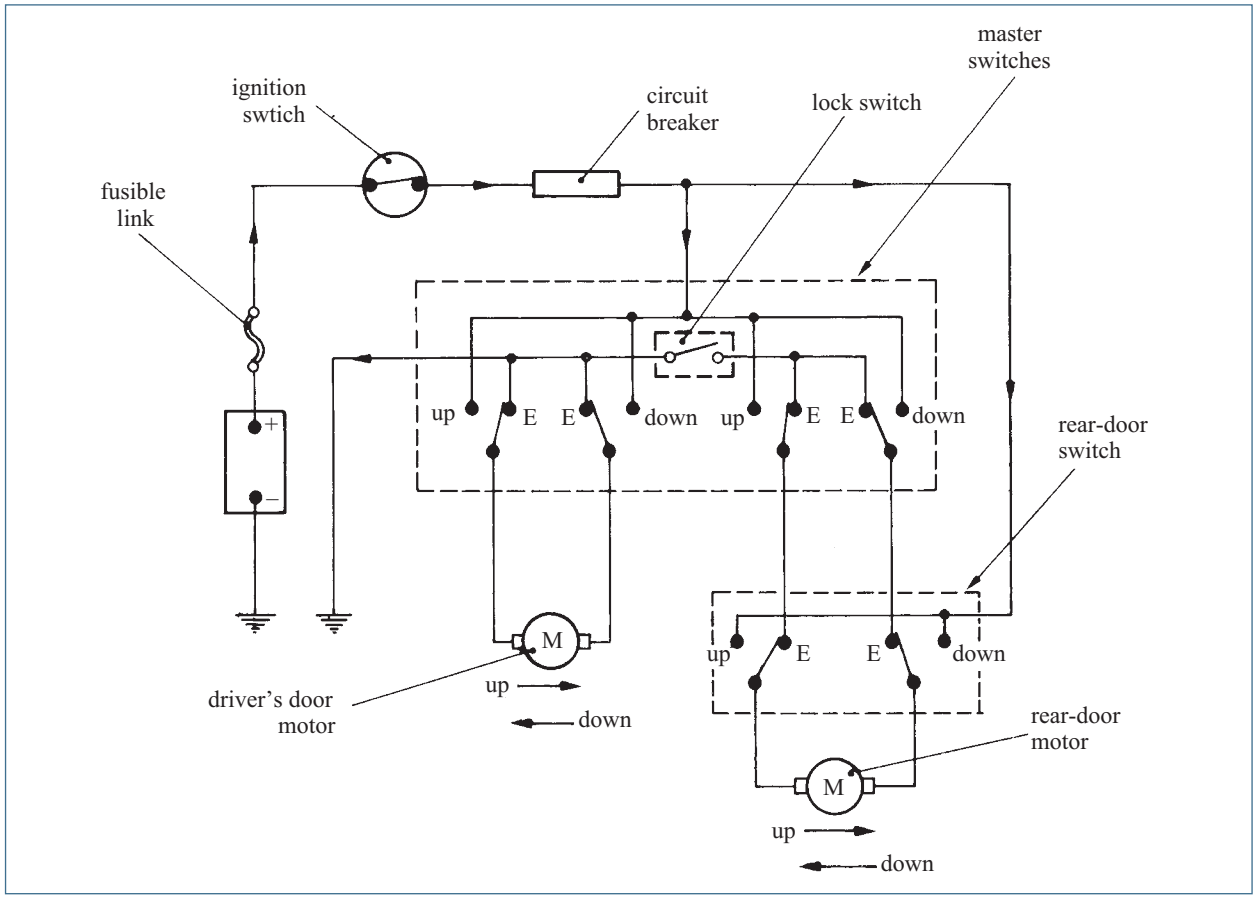


Figure 39.24 Simplified circuit diagram for power windows—the circuits for one front door and one rear door are shown

3 The motor for the driver's front door is connected directly to the moving contacts of the master switch for the front door.
4 The motor for the rear door is connected to the moving contacts of the rear-door switch. The fixed contacts of the switch are connected in parallel with the master switch for the rear door.
5 The lock switch, located in the master-switch panel, is used to open the earth circuit and prevent the rear motor from operating.

Front-window operation

To move the front window up, the master switch is moved to the *up* position, connecting voltage to the motor. Current will flow from the battery through the fusible link, ignition switch, circuit breaker and the master switch, to the motor. The circuit is completed from the motor through the *down* side of the master switch to earth. To move the window down, the master switch is moved to the *down* position. Current now flows from the master switch to the motor in the opposite direction, so that its rotation is reversed and the window moves down.

Rear-window operation

The operation of the rear-door switch is the same as that described for the master switch, except that it controls the motor in the rear door. The rear-door switch can be used independently of the master switch as long as the lock switch is turned on (contacts closed). With the lock-switch contacts open, as in the circuit illustration, the earth circuit of the rear-door motor is *open* and so the motor is isolated and cannot be operated. With the lock-switch contacts closed, the earth circuit is completed to earth, and either the master switch or the rear-door switch can be used to move the window up or down.

39.8.6 Central door locking

With central door locking, solenoids are located in the doors of the vehicle (Figure 39.25). These are used to operate the locking mechanism on the door locks. The solenoids are controlled by a central switch on

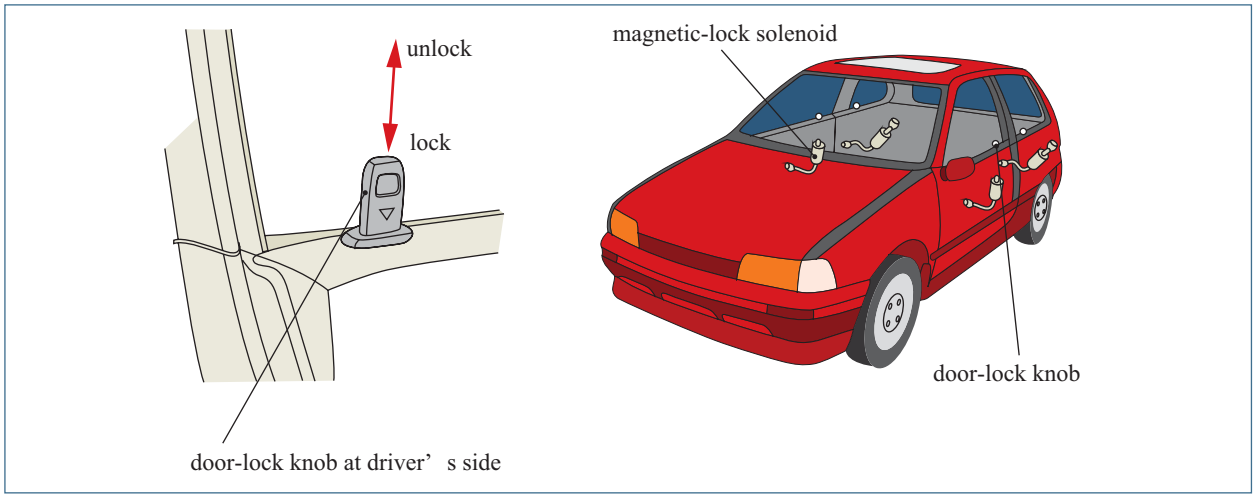


Figure 39.25 Electric door locks—solenoids in the doors operate the door-lock mechanisms

the driver's door. All the doors can be locked or unlocked by moving the button or knob of the driver's door lock *up* to unlock or *down* to lock. The button operates a switch, which then operates the solenoids. Locking of all doors can also be done by the key in the door lock. In some vehicles, all the doors can be locked from either the driver's front door or the passenger's front door. With remote door locking, the doors can be locked and unlocked without inserting the key in the lock by pressing a button on the keypad.

Double-acting solenoids are used on some door locks (Figure 39.26). These consist of electromagnetic coils and a plunger. When the switch on the door is operated, the coils of the solenoid are energised and the plunger is moved. The plunger is connected to the locking mechanism of the door lock, which it locks or unlocks, depending on which way it moves. To enable the plunger to move in both directions, it has a permanent magnet to give it polarity. One end of the plunger is a north pole, the other a south pole. The direction of movement of the plunger is changed by reversing the energising current in the coils. The door-locking circuit includes a relay that provides current to the solenoids when the switch is operated. This has a timer that switches the solenoid off after about 15 seconds so that it does not remain energised.

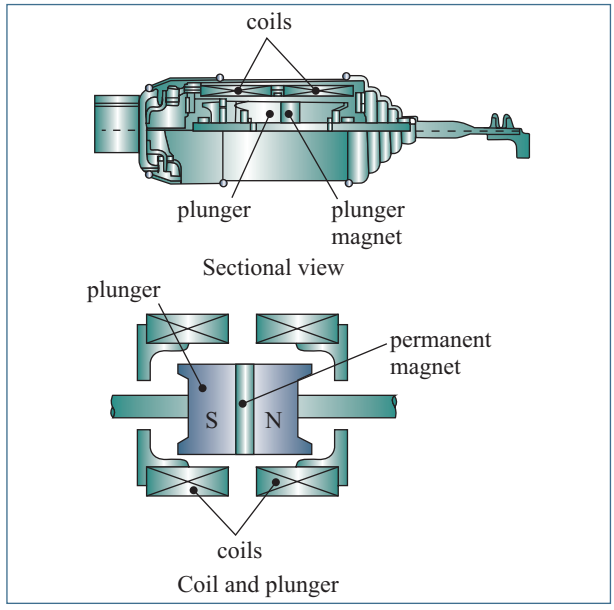


Figure 39.26 Construction of a door-locking solenoid

39.8.7 Horns

Horns produce sound by the action of a vibrating metal diaphragm. Its intensity is increased by a resonance plate, and also by the shape and size of the horn. The internal arrangement is shown in Figure 39.27.

To produce sound, the diaphragm is vibrated by an electromagnet which is operated by a set of contacts. When the horn button is pressed, current

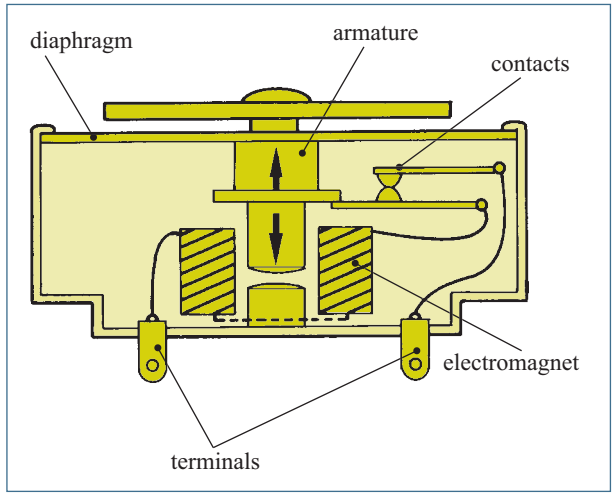


Figure 39.27 Internal arrangement of a horn

passes through the contacts, then through the coil of the electromagnet, which is energised to attract the diaphragm. A metal armature in the centre of the diaphragm strikes against the core of the electromagnet and the impact produces a sound. Downward movement of the armature opens the contacts, de-energising the electromagnet and allowing the diaphragm to return to its original position. As long as the horn button is pressed, this cycle continues at a rapid frequency to produce the sound.

The horn outlined above is known as an impact-type horn because it produces its basic sound by impact.

Horns with a musical tone also have a vibrating diaphragm, but this is used to oscillate a column of air in a tube which is shaped and acts like a trumpet. High and low notes are produced by varying the shape of the tube and the frequency of the oscillations.

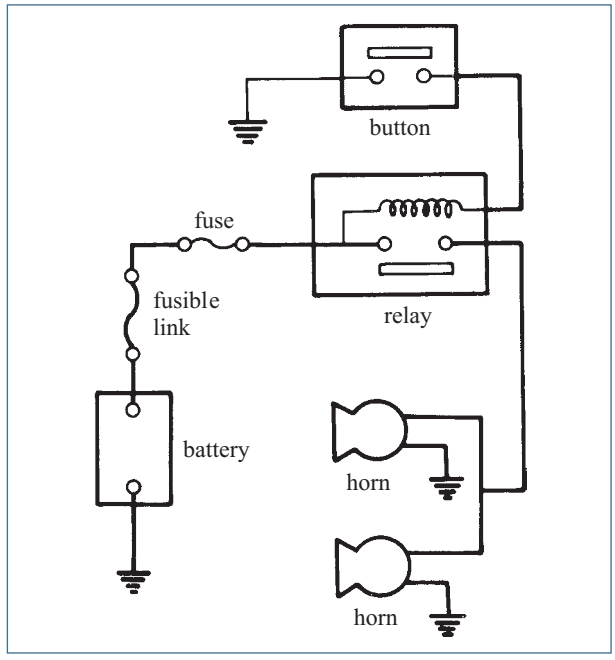


Figure 39.28 Simple horn circuit diagram

Horn circuit

A simple circuit for dual horns is shown in Figure 39.28. This includes a horn relay. The horn button or pad on the steering wheel energises the relay coil, closing the relay contacts.

39.8.8 Electric radio aerials

The use of electric radio aerials has been declining, with new vehicles having the antenna now built into the glass windscreen, rear window or roof. Some vehicles have automatic antennas that go up and down with the ignition on and off, while others need to be manually raised. The best idea is to follow the relevant manufacturer's manual.

39.9 Diagnostic of automotive electrical systems

Having a good 'eye' and sense of smell is vital when diagnosing electrical problems. Many modern connecting plugs have small male and female pins recessed into connector plug assemblies, making problems difficult to spot. The following is a range of different faults that may be found when working on electrical systems.

39.9.1 Component damage and wear

Modern vehicles are crammed with wiring looms and many different connecting plugs and devices. Their electrical systems use weatherproof/waterproof plugs, generally on exterior wiring. If kept in good condition, connections can be trouble-free for many years, but they do fail as a result of accidents or bad workmanship. Failures happen most commonly with components that are external to the vehicle cabin and are thus exposed to the elements. These include trailer-plugs, electric window motors, electric locking systems and transmission modules.

In the modern vehicle, most body components (such as lighting, wipers, door locks, electric windows and seating) are monitored by the body control module. Any fault will be displayed in the dash by the MIL malfunction indicator light. Generally, a scan tool is used to find the fault code, which indicates the area of the fault (though most manufacturers have a procedure for accessing the code without a scan tool). There is a misconception that the scan tool shows what is wrong or what component is faulty; usually the tool only shows which area is logging a fault.

⚠ Safety: Always disconnect the battery before removing or replacing any electrical component.

39.9.2 Component or connector corrosion

When water, in particular salt water, enters electrical connections, it reacts with the copper to cause the formation of copper oxide, which is commonly called corrosion (Figures 39.29 to 39.30). This can happen

Figure 39.29 Connector corrosion

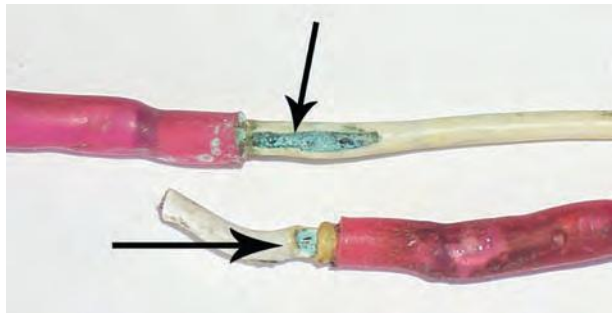


Figure 39.30 When insulation is damaged, corrosion runs up underneath it and destroys the loom

to vehicles in a salty or acidic environment such as those found in rural areas. As soil, which is acidic, splashes onto the vehicle, it will leave an acid residue. It could also occur when salt is used to stop roads becoming icy (Figures 39.31 to 39.33).

39.9.3 Component water or moisture ingress

The process of locating a moisture-related fault (Figure 39.31) can be assisted by using a hose to pour water onto the outside of a suspect area. The most effective way of initially removing moisture from components is through compressed air and then some warmth, such as the gentle application of a heat gun, hair dryer or sunshine. Where moisture ingress is pervasive, silicon may be used as a sealant. Other products such as electrical contact grease called dielectric grease can be used to prevent corrosion or oxidisation.

39.9.4 Damaged insulation

Insulation on electrical wiring, plugs and components can fail if exposed to too much sunlight, solvents, heat or vermin. Typically, the insulation on electrical wiring may become brittle before cracking starts. The only remedy for cracked and brittle insulation in a wiring loom is to replace the loom (Figure 39.32). When vermin are attracted to the warmth of an engine compartment, wiring can be chewed, damaging the electrical systems.

39.9.5 Frayed wires

Wire can become frayed if its supporting insulation has broken, been removed or perished (Figure 39.33). This exposes the wire, leading to its strands fraying out and the resulting likelihood of a short, arcing or a fire. Frayed wires should be repaired immediately with shrink wrap or electrical plastic tape. If the frayed section of the electrical cable is at one of its ends, the best solution is to solder it to hold the wires together to prevent further fraying. It is worth considering completely replacing frayed wires.

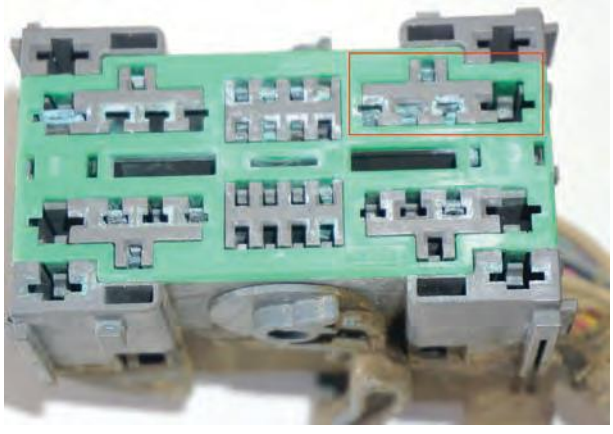


Figure 39.31 Component showing signs of water damage

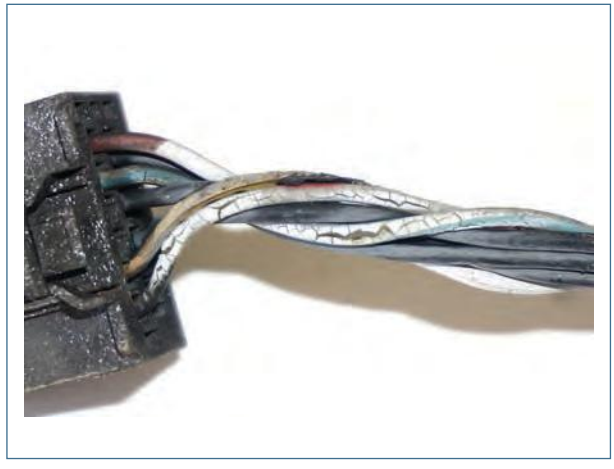


Figure 39.32 Deterioration of insulation in a wiring loom

Figure 39.33 Frayed wires caused by the loss of insulation

Figure 39.34 Burnt wiring can be detected by smell

Figure 39.35 Damage to small terminals can be hard to see . If unsure , dismantle and check each pin, or back probe each connecting pin to check for a bad connection.

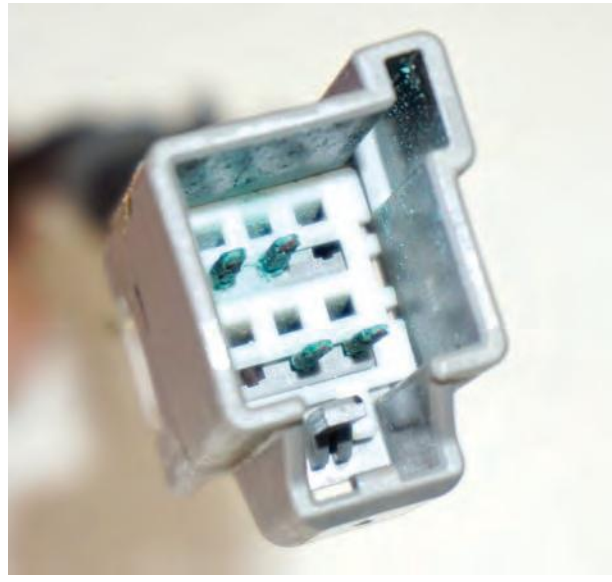


Figure 39.36 Some damage can be easily seen and will require terminal replacement

39.9.6 Burnt wiring

Burnt wiring is usually the result of a short or high resistance causing heat to be generated (Figure 39.34). It is important to diagnose the cause and rectify it to prevent further damage. Burnt wiring necessitates the complete replacement of damaged areas, including the connecting plugs.

39.9.7 Connector damage

Connector damage can occur as a result of accident, fire or poor workmanship during replacement or circuit testing (Figure 39.35). Using the wrong tools to test electrical connections in connector plugs may damage the waterproof seals. Constant insertion and extraction of trailer plugs often damages them, especially when they are left to drag on the road surface. Boat trailer plugs are particularly susceptible to corrosion through salt damage. If a connector plug becomes damaged, it should be replaced to secure the connection.

39.9.8 Terminal damage

The terminals in the connectors are often small and can easily be stretched if care is not taken when disconnecting and re-connecting them. It can be difficult to see if the female pin has been stretched, causing a high resistance connection. Other ways terminals may become damaged are through corrosion or arcing, which is caused by high current draw through the connection. If a terminal connecting pin becomes blackened, arcing is the probable cause. Any terminal that has been subjected to arcing damage should be replaced using the correct pin release tools. If terminals are susceptible to corrosion (Figure 39.36), use dielectric grease on them.

Sustainability: Old and discarded electrical wiring and looms and electrical components containing copper should be stored for recycling the copper .

39.9.9 Voltage-drop

Damage to wiring connectors from corrosion is not always visible. When a fault arises in a loom or wiring system, check the terminals in wiring connectors for voltage drop. (See Chapter 38, Figures 38.35 and 38.36, for details on the checking procedure.)

39.10 Using diagnostic flow charts

Most major manufacturers now supply information to dealerships only on line. Dealerships no longer buy books, CDs, DVDs or microfiche to access information. This allows manufacturers to update technical information at a low cost to themselves and to dealers, but makes technical information hard to access for others. When performing diagnostics and using workshop/technical manuals, having a flow chart helps working in a systematic way.

Every diagnostic work process should start with collecting information from the client and then verifying it. Figure 39.37 is an example of a generic chart, but they may vary from manufacturer to manufacturer.

39.11 Post-repair testing

39.11.1 Checking for electrical connector mating

When checking electrical connectors for mating, make sure that the retaining device has latched properly so that the connector cannot come apart. If there is any doubt that the connecting pins are making proper connection, carry out a resistance test by back-probing the plug from each side while wriggling the connector plug to check for poor fitting pins.

Many electrical faults are caused by bad earth connections. Technical manuals will show the location of earth connections on a particular vehicle. Earth connections to the body are not generally waterproof and thus can cause a fault through rust or corrosion.

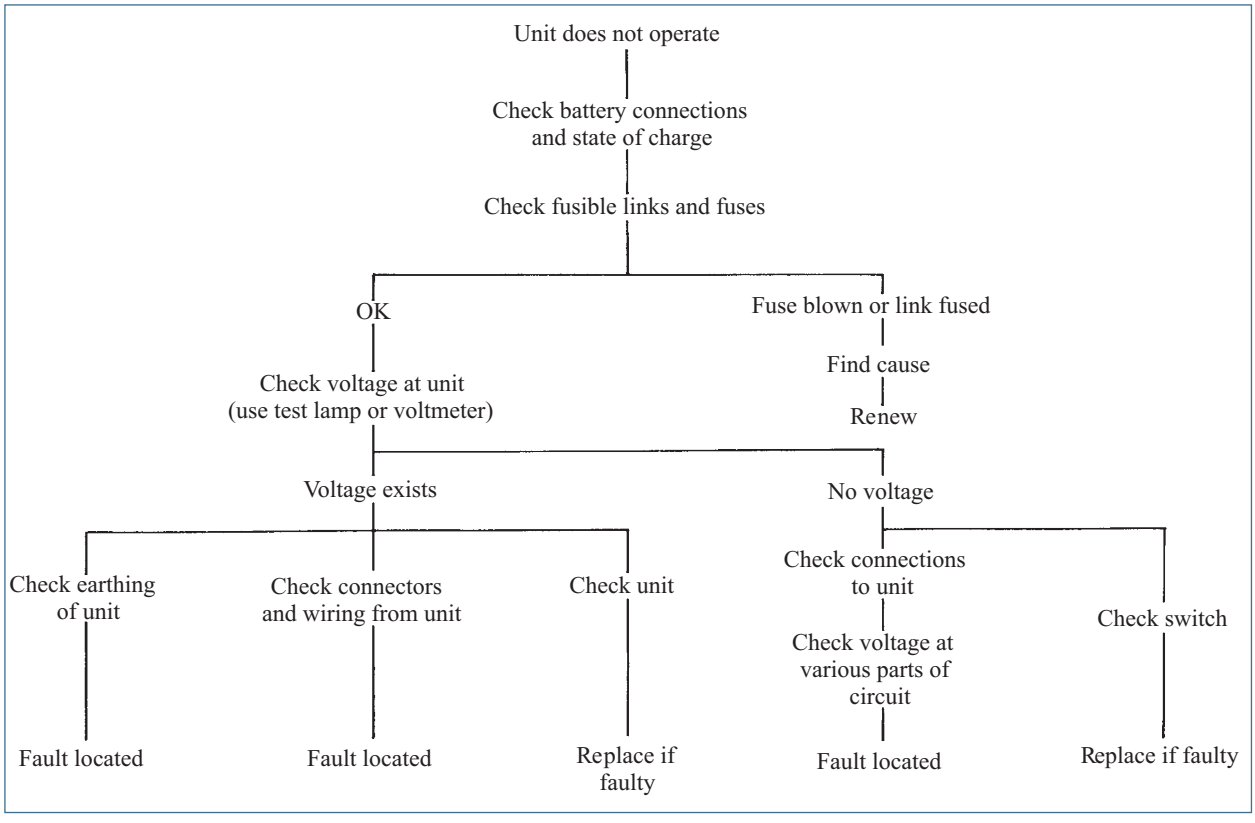


Figure 39.37 General circuit checks

39.11.2 Static and dynamic performance tests of automotive electrical systems

A static test is testing the electrical system with the vehicle in a stationary situation. To test the system under these conditions, check for resistance or voltage and current flow with the correct meters. Generally, a multimeter will do the required tests.

For a dynamic test, the vehicle will be on and running, as will the system that you are checking. It is important that the conditions under which the fault occurred are replicated.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- explain the three different effects of electricity
- describe the application of electricity to create heating effects in lamps, fuses, glow plugs and switches
- explain Faraday's Law
- demonstrate the use of electricity to create a chemical effect in batteries
- demonstrate the use of electricity to create a magnetic effect
- demonstrate the use of magnetic induction and magnetic field to operate components
- demonstrate the use of the effect of electromagnetism and interference of magnetism to operate components such as sensors and motors
- demonstrate the use of magnetism to produce electricity in an alternator
- explain how computer CAN connections prevent interference from radiation and magnetic fields
- demonstrate the use of a magnetic field to operate solenoids and relays
- diagnose automotive electric wiring and component damage
- demonstrate the use of diagnostic flow charts
- explain the importance of post-repair testing of electrical systems.

REVIEW QUESTIONS

1 What is corrosion?
2 How could corrosion affect parts of a motor vehicle?
3 What is a magnet?
4 What is a magnetic field?
5 What would occur if two magnets were placed with their north poles end to end?
6 Sketch the field of a bar magnet.
7 What is magnetic induction?
8 What are the effects of current flowing in a conductor?
9 What is an electromagnet?
10 Name some of the parts of a motor vehicle that operate as the result of electromagnetism.
11 What is a solenoid?
12 Where is a solenoid used on a motor vehicle?
13 What is a relay?
14 What is meant by electromagnetic induction?
15 Where is the principle of electromagnetic induction used?
16 What three things are needed to produce an emf or voltage?

CHAPTER 40

Basic electronics and mechatronics

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 define mechatronics
2 explain how diodes and transistors work
3 explain what a semiconductor is and how it is used in electronic components
4 describe the actions of transistors and explain how transistors create a code
5 describe what binary code is and how it is used
6 identify sensors and explain what they do
7 explain how computers activate actuators and where they are used
8 explain what analog and digital signals are
9 describe the function of a smart sensor
10 summarise the components of a micro-processor or computer
11 describe the activity of master and slave units in computer systems
12 list the different types of topology in computer systems
13 explain what C AN Bus, LIN Bus and MOS T protocols are
14 explain what a gateway module does
15 describe the diagnostic plug and pin assignment and how to test the system
16 describe the mak e-up of diagnostic codes
17 explain the uses and limitations of scan/diagnostic tools
18 list the advantages of using oscilloscopes for diagnostic work.

40.1 Mechatronics

Mechatronics is a relatively new field of engineering that includes electronics, mechanics, computer engineering, control systems and communication systems. It is used to describe the evolution of systems in motor vehicles.

40.2 Electronics

Electronics deals with the behaviour of electrons. However, the term *electronics* has been applied generally to units and systems whose components use semiconductor materials in so-called solid-state devices such as diodes and transistors.

Electronic components are used in, for example, radios, television sets, computers and industrial control systems. Automotive applications include engine management, body control systems, electronic instruments and electronic testing equipment.

The expansion of electronics is explained by the development of semiconductor materials and the manufacture of the silicon chip, which is the basis of most electronic units. Figure 40.1 shows some small electronic components. The following sections outline the use of diodes and transistors, the two most common electronic components.

40.2.1 Diode action

A diode has two external connections. When used in a circuit, it acts as a one-way valve by allowing current to flow in one direction only. Figure 40.2 shows a diode in a simple circuit, where the diode and a bulb

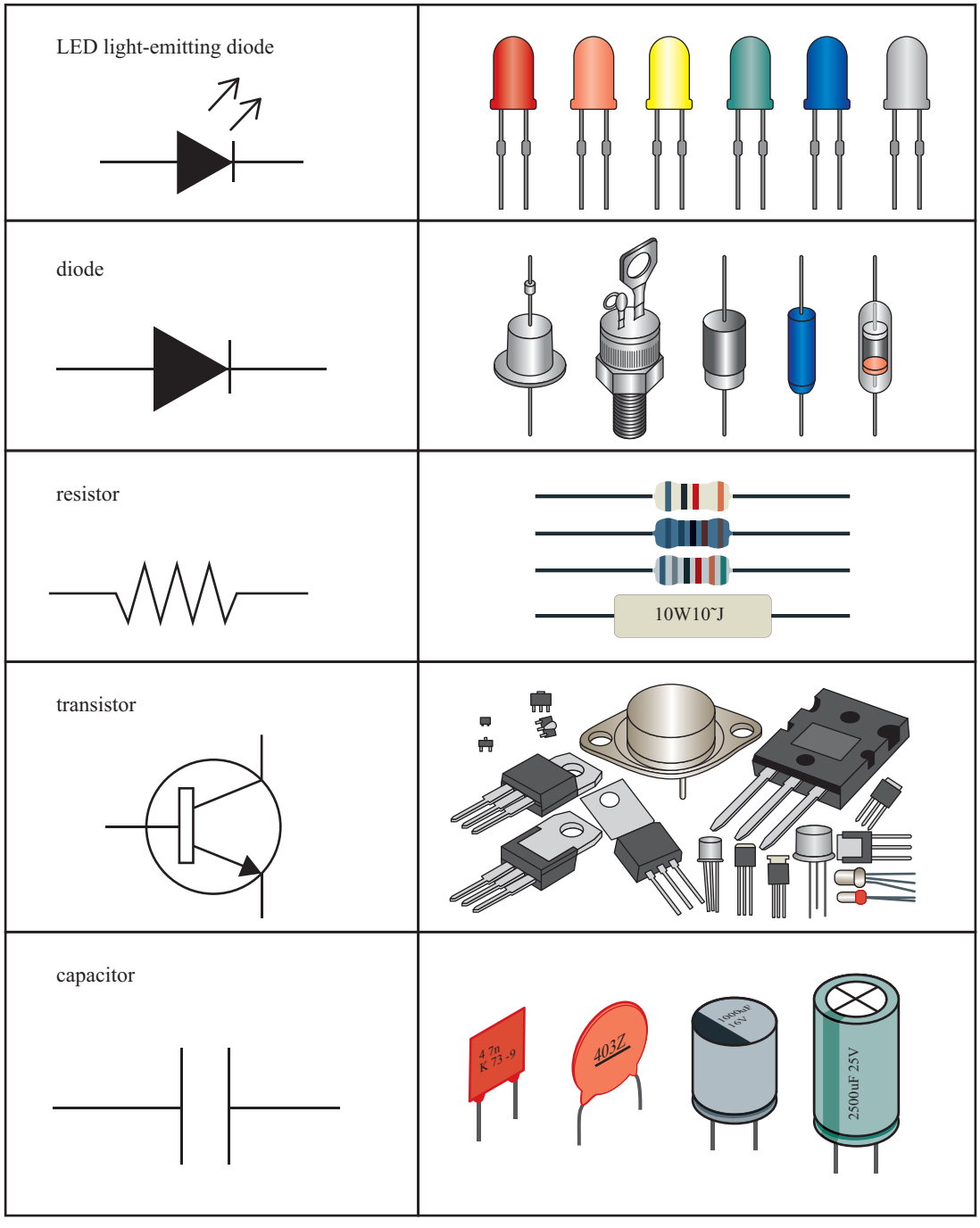


Figure 40.1 Small semiconductor components and circuit symbols

are connected in series to a battery. In the circuit (Figure 40.2(a)), the diode is conducting to allow current to flow and the bulb to light. In the circuit (Figure 40.2(b)), the diode has been reversed and is now non-conducting to prevent current flow and so the bulb does not light.

The circuit arrangement has a practical application. Diodes that are used in alternators can be connected to a bulb and battery as shown to check their operation, although an ohmmeter would usually be used.

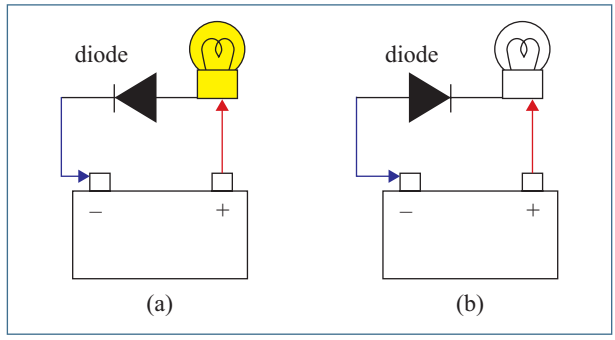


Figure 40.2 Action of a diode (a) current passes through the diode to light the bulb (b) the diode blocks current flow

40.2.2 Transistor action

Transistors are used as electronic switching devices. In a circuit, they act in the same way as an electromagnetic relay, but are comparatively small and can be operated by very low currents. Transistors have three external connections, known as the base (B), collector (C) and emitter (E).

Figure 40.3 shows the basic action of a transistor being used as a switching device for a lamp. With the manual switch SW closed, a small current from the battery passes through the resistance R to the base B. This triggers the action of the transistor, which becomes a conductor and completes the lamp circuit to the battery and so lights the bulb (Figure 40.3(a)). With the switch SW open, the transistor is non-conducting and the bulb does not light (Figure 40.3(b)).

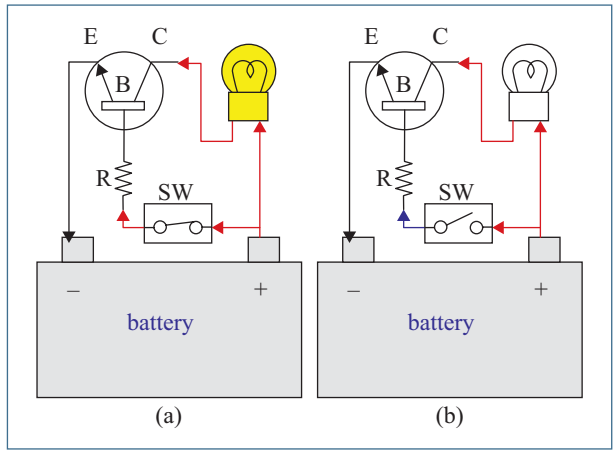


Figure 40.3 Action of a transistor—a small current operates the transistor as a switch

40.3 Electronic semiconductors

Semiconductors can be categorised as between conductors and insulators. They act as conductors under some conditions, but do not conduct under others. Electronic semiconductors are formed by *doping*. The basic material, which is usually silicon but can be germanium, is doped by adding a small quantity of other material to it. Both n-type and p-type electronic semiconductors can be produced by different types of doping. These are shown in Figure 40.4, with electrons being shown as dashes and protons shown as holes.

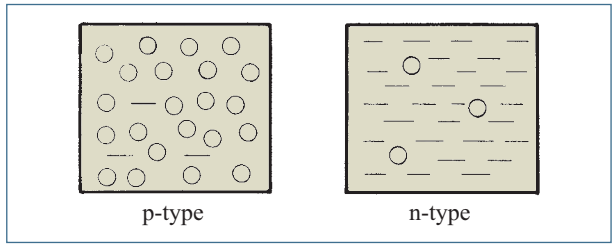


Figure 40.4 Electronic semiconductors—p-type has a predominance of holes, n-type a predominance of electrons

Handy hint: In simple terms, one of these materials is a negative-charge conductor and the other is a positive-charge conductor .

40.3.1 n-type semiconductors

When silicon is doped with certain chemicals, there will be a predominance of electrons (negative charges), and an n-type semiconductor will result. Conductivity in this type of semiconductor is based on movement of electrons in a somewhat similar way to the movement of electrons in a normal conductor. When voltage is applied, the electrons move towards the positive pole of the voltage source.

40.3.2 p-type semiconductors

When silicon is doped with different materials, the electrons which carry a charge are reduced and *holes* remain. These holes represent a shortage of electrons, and can be considered equivalent to a *positive* charge.

Conductivity in this type of semiconductor is based on movement of the positive holes. When voltage is applied to a p-type semiconductor, the holes will move towards the negative pole of the voltage source so that, simply, a flow of positive charges will result.

Charge carriers

From the above, it can be seen that both electrons and holes act as charge carriers, with the electrons being negative-charge carriers and the holes being positive-charge carriers. Electrons in semiconductor materials behave according to the electron theory of current flow, and the holes behave according to the conventional theory of current flow. So, when a semiconductor is connected to a source of voltage (such as a battery), the electrons in the semiconductor tend to move towards the positive pole (from negative to positive), and the positive holes tend to move towards the negative pole (from positive to negative).

The electrons will carry a negative charge with them; the holes will carry a positive charge. Because a flow of both negative and positive charges occurs, semiconductors are referred to as being *bipolar,* as distinct from current flow in metals, where only the electrons move.

The next step is to consider how semiconductor components function.

40.3.3 p–n junction

The semiconductor components that are used in electronic circuits consist of a combination of n-type and p-type semiconductors. This combination leads to the formation of an *n-region* and a *p-region* at what is referred to as the *pn junction.* This junction is important in the operation of semiconductor components.

When the two types of semiconductor materials are joined, electrons move away from the junction into the n-region; the holes move away from the junction into the p-region. This leaves an area around the pn junction that is depleted of both electrons and holes and that, as a result, has no charges that are effective. The pn junction therefore forms a layer, known as the *depletion layer,* which is free of charges and acts as an insulator between the two regions of the semiconductor component (Figure 40.5).

Handy hint: Both n-type and p-type conductors are used in almost all electronic components, and these mak e use of one or more p—n junctions.

40.4 Electronic components—diodes and transistors

A number of electronic components use semiconductor material of doped silicon. These include diodes, transistors, integrated circuits and forms of electronic resistors. Diodes and transistors are the two most commonly used basic components. The diode is the simplest, and forms the basis of many other components.

40.4.1 Diodes

A diode consists of an n-region and a p-region, with a single p—n junction. If the diode is connected to a source of voltage, with the p-region connected to the negative and the n-region connected to positive, as shown in Figure 40.6, the holes will move away from the p—n junction towards the negative pole, and the electrons will move away from the junction towards the positive pole.

This increases the width of the depletion layer at the p—n junction, and a more effective barrier is set up to prevent movement of the charge carriers across the junction. Under these conditions, the diode acts as a non-conductor.

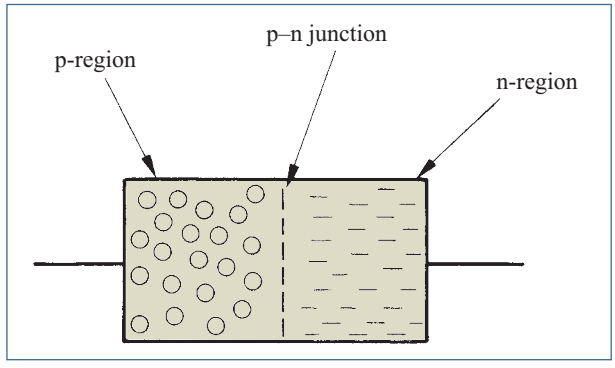


Figure 40.5 Diode—p-type and n-type semiconductors joined to form a diode

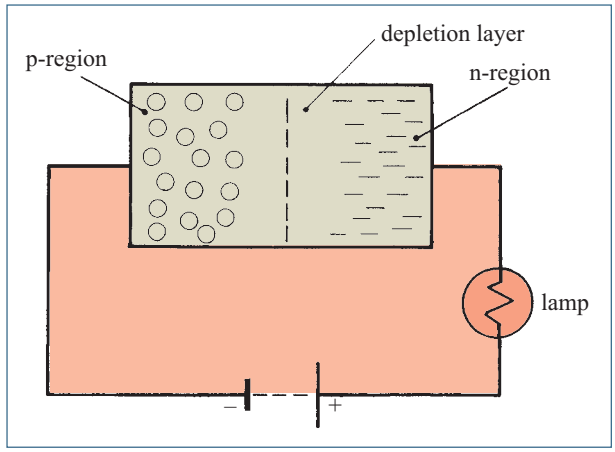


Figure 40.6 Battery connected to a diode in the reverse direction increasing the width of the depletion layer at the p—n junction

If the polarity of the battery is reversed, as in Figure 40.7, the charge carriers will move. The electrons will travel from the n-region towards the positive pole and the holes will travel from the p-region towards the negative pole. The p—n junction will become flooded with charge carriers and the depletion layer at the junction will disappear. Under these changed conditions, the diode acts as a conductor and carries current.

Handy hint: Current flow in this instance consists of movement of both positive charges (holes) and negative charges (electrons).

Bias of diodes

With the polarity of the voltage source connected so that the diode conducts, the diode is said to be *forward-biased*. If the polarity is such that the diode does not conduct, it is *reverse-biased* (Figure 40.8). The diode, as a one-way valve, is used in rectifying circuits where current is required to flow in a particular direction.

In the charging system, alternating current produced by the alternator is changed to direct current (rectified) by the action of diodes. The diodes conduct when forward-biased, but do not conduct when reverse-biased.

Diode symbol

The symbol used to represent a diode in circuit diagrams is also shown in Figure 40.8. This consists of a bar and an arrow. In a circuit, it can be considered that current can flow in the direction of the arrow, but not in the opposite direction as it is blocked by the bar.

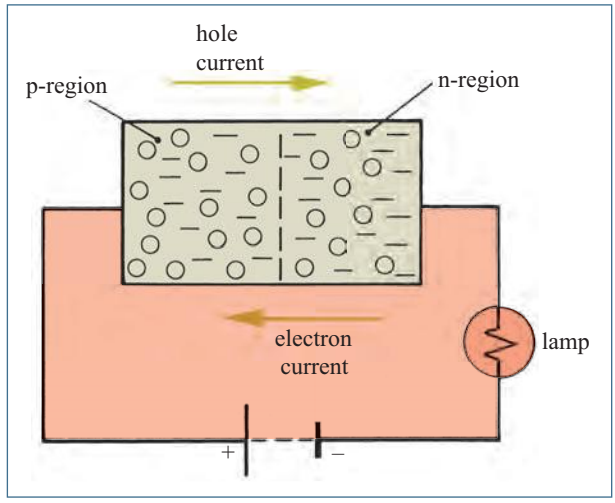


Figure 40.7 A battery connected to a diode in the forward direction causes both holes and electrons to move

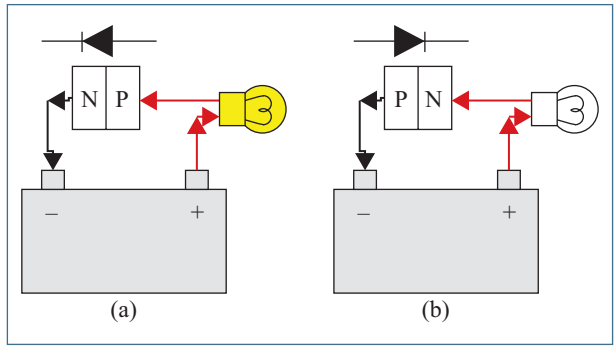


Figure 40.8 Bias of diodes (a) the diode is forward-biased and conducting (b) the diode is reverse-biased and non-conducting

40.4.2 Zener diodes

A Zener diode, also referred to as a *unidirectional breakdown diode*, is doped differently from a normal diode. It resists current flow (when it is reverse-biased) like a normal diode, but only up to a certain voltage—the *breakdown voltage*. When this is reached, the resistance of the Zener diode breaks down, enabling current to flow through it.

A diode of this type can therefore be used as a voltage-related switch. This has an application in transistorised voltage regulators, which are fitted to alternators. The Zener diode is used as a device to limit the alternator output.

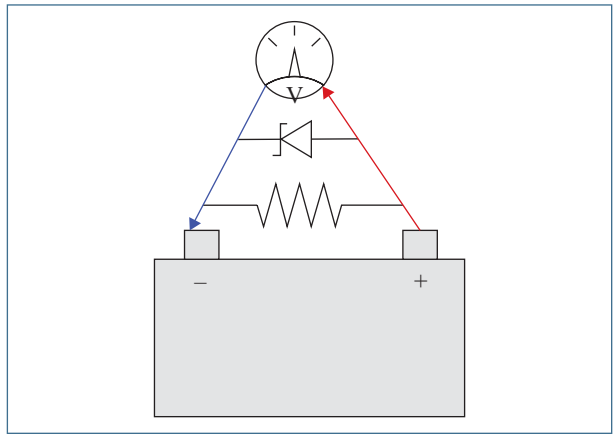


Figure 40.9 A Zener diode in parallel with a voltmeter used as a protective device

Zener diode as protection

An example of how a Zener diode can be used as a protective device is shown in Figure 40.9. It is wired in parallel with an electrical instrument and arranged to break down at the maximum safe voltage that the instrument can stand.

Normally, the Zener diode would be non-conducting but, if breakdown voltage was reached, it would act as a shunt and carry current. This would decrease the current through the instrument and protect it

from overload damage. Should the voltage drop, the Zener diode will again become non-conducting, and the meter will operate normally.

40.4.3 Transistor operation

A transistor is similar to two diodes connected together; it has three semiconductor regions and two p—n junctions. There are two general types of transistors: n—p—n transistors and p—n—p transistors. Both types operate in the same way, except that the current flows in different directions.

Diagrams and symbols for these are shown in Figure 40.10. The arrow on the emitter indicates the direction of forward current flow. (These have been shown for conventional current flow.) An n—p—n transistor has a wafer of p-type semiconductor material between two layers of n-type semiconductor material; a p—n—p transistor has a wafer of n-type material between two layers of p-type material.

There are three external connections, one for each region. The centre one is the base B, one side is the collector C and the other side is the emitter E. Put simply, in operation C collects charges, E emits charges and B operates the transistor.

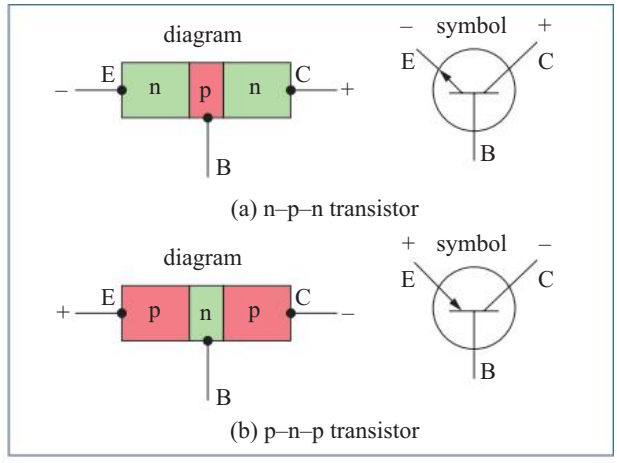


Figure 40.10 Transistor diagrams and symbols E emitter , C collector , B base

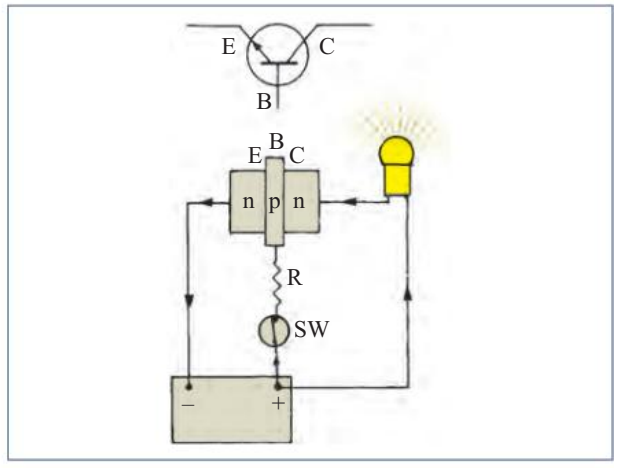


Figure 40.11 Action of an n—p—n transistor—the transistor symbol is shown at the top of the diagram

40.4.4 n–p–n transistor action

In Figure 40.11, an n—p—n transistor is used as the switching device for a lamp. With the manual switch SW off, the p—n junctions in the transistor prevent current from flowing through the transistor and the lamp does not light. When the manual switch is closed, a low voltage is applied across the p—n junction between B and E. The voltage is low because there is a voltage drop across the resistor R.

This makes this part of the transistor conductive. A small current flows from the positive pole of the battery, through the transistor from B to E, to the negative pole. The wafer of p-type material is very thin, and the voltage applied between B and E will also influence the p—n junction between B and C. So, this part of the transistor also becomes conductive. Current can now flow from the positive battery terminal, through the lamp and right through the transistor from C to E, to reach the negative terminal. As a result, the lamp will light.

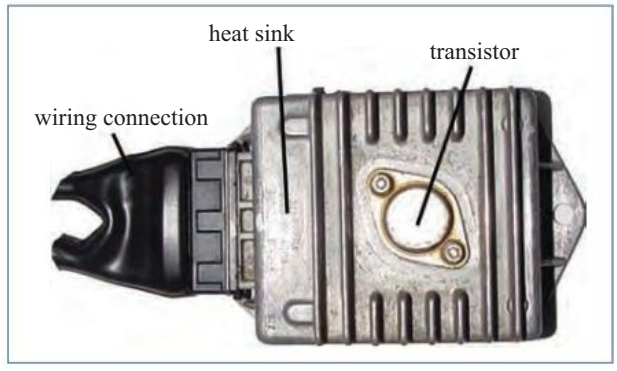


Figure 40.12 A large transistor mounted in the heat sink of an electronic control unit MITSUBISHI

While most transistors are small, larger ones are sometimes used. A large transistor is shown in Figure 40.12. This is part of an electronic-ignition control unit and is used as a switching device. It is attached to a metal container that encloses other parts, but the metal also acts as a heat sink. The transistor generates heat that could cause damage and this is shed into the heat sink.

Handy hint: A heat sink has a relatively large metal surface that is often provided with fins. Heat from its surface area is dispersed into the surrounding air .

40.5 Other electronic components

There are a number of other electronic components with semiconductor materials. Some are outlined under the following headings.

40.5.1 Darlington pair

This is a name given to two transistors that are connected to form a single component. It has three external connections, E, C and B, just like a single transistor. However, its superior switching and amplification characteristics make it suitable for use in electronic timing circuits. One of these units forms part of the circuit of an electronic voltage regulator.

40.5.2 Resistors

Resistors are diodes whose semiconductor materials have been arranged to retard the movement of holes and electrons. They act as a resistance to provide a voltage drop or to reduce the flow of current in a circuit.

40.5.3 Capacitors

A capacitor is a form of diode that has its semiconductor material doped so that electrons and holes are able to accumulate. They are used in parallel with other components to act as a buffer and absorb voltage pulses. The simplest way to think of a capacitor is as a small reservoir for electric charges. These charges are temporarily stored and then fed back into the system.

Handy hint: Most large capacitors used in electrical circuits do not have semiconductor materials but are made of insulated metal foil.

40.5.4 Integrated circuits

An integrated circuit is a composite electronic component made up of a number of semiconductor devices. It can include diodes and transistors, resistors and capacitors. The various devices are formed on a single silicon chip to create a completely integrated circuit. Its small size makes it ideal for use in the micro-circuits that are used in electronics.

The alternative to an integrated circuit is a printed circuit board with a number of components attached to it. Obviously, this would be much larger than an integrated circuit.

40.5.5 Thermistors

The name *thermistor* is an abbreviation of 'thermally sensitive resistor'. Thermistors are semiconductor resistors whose resistance varies in relation to their temperature. Some thermistors have more resistance when hot than when cold, and so are better conductors at lower temperatures. They are known as *ptc resistors* (positive temperature coefficient resistors).

Other thermistors are designed to have less resistance when hot, and are known as *ntc resistors* (negative temperature coefficient resistors). These types of semiconductor devices have applications in temperature control, where they can be used to sense changes in temperature, for example, in the cooling system of the engine.

Figure 40.13 shows how a temperature sensor for a cooling system operates. It consists of a thermistor in a housing that is screwed into the water-jacket of the engine. This senses the temperature of the coolant. The sensor in the illustration is connected to an ohmmeter to check its resistance while it is being heated in a container of water. The sensor should have less resistance when hot than when cold. If the sensor is operating correctly, the pointer of the ohmmeter will move down the scale as the temperature of the water increases to demonstrate this.

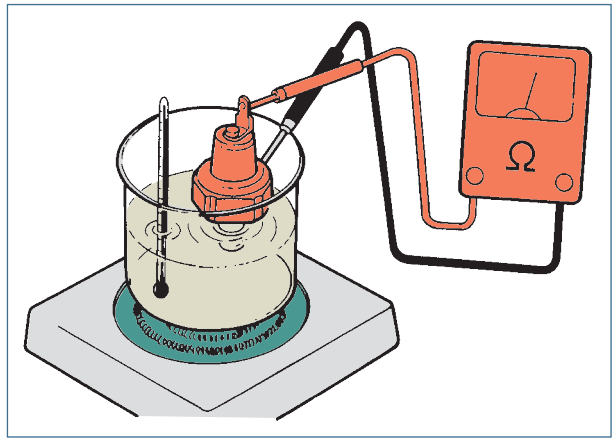


Figure 40.13 The sensor for a temperature gauge of a cooling system has less resistance when hot than when cold GM HOLDEN LTD

40.5.6 Thyristors

A thyristor is another form of transistor. It has four semiconductor regions and is a switching device that can be operated by an electric pulse. It also has rectifying properties.

40.5.7 Varistors

Voltage-dependent resistors have a high resistance at low voltage, but this rapidly decreases as the voltage increases. They can be used for voltage-overload protection and other forms of voltage control. Varistors are voltage-dependent resistors (VDRs), similar to diodes. At low voltage, they have a high resistance (which decreases as the voltage increases).

40.5.8 Photoresistor

Photoresistors (light-dependent resistors) are made of semiconductor material that is sensitive to light. The conductivity will increase (and the resistance decrease) as the resistor is exposed to brighter light.

Figure 40.14 Digital letters and numbers are made up of segments formed by light-emitting diodes or liquid crystals

40.5.9 Light-emitting diode

A light-emitting diode (LED) is made so that light is emitted from its p—n junction when a current is passing through it. Transparent material enables the light to be seen as a small red or green light. Light-emitting diodes are used singly as an indicator or warning light. Alternatively, a number of them can be arranged to form numerals or letters.

40.5.10 Liquid-crystal display

The liquid-crystal display (LCD) uses a liquid crystal that can polarise light. Numerals on the instrument face are arranged in segments (as for an LED), and these are made visible by the polarised light. During polarisation, certain light rays are reflected onto the face of the instrument, and these are used to illuminate segments and so form the numbers or letters required. Voltage applied to different parts of the crystal produces the different displays.

Figure 40.14 shows how digital letters consist of a number of segments. Altering the segments that are illuminated enables different numbers or letters to be displayed.

40.5.11 Vacuum fluorescent display

A vacuum fluorescent display uses electrons to bombard a small phosphorus-coated glass screen. As the electrons strike the screen, they emit a green light. The segments of the display are controlled by an electronic switching arrangement. This operates so that the appropriate segment is illuminated and a number or other symbol is displayed.

Handy hint: This display is produced in a similar way to the image in a television picture tube .

40.6 Sensors and actuators

A sensor is a device that produces a small electrical current or a resistance value, which is referred to as a signal (Table 40.1).

Table 40.1 Examples of sensors

Pressure sensor	Boost pressure sensors	Air mass sensors	Knock sensor
Atmospheric pressure	High pressure sensors	Speed sensor	Angle of rotation sensors
Tank pressure sensors	Accelerator pedal sensor	Yaw rate sensor	Steering wheel angle sensor
Air quality sensors	Humidity/ temp sensor	Rain sensor	Lamba o xygen sensor
Tilt sensor	Torque sensor	Distance sensor	Ranging radar
Crash sensors	G force sensors	Motion detection	Ride height sensors
Flow meters	Imaging sensors	Gas sensors	Position sensors
Axle sensors	I bolt sensors	Hall phase sensors	Transmission speed sensor

The signals from sensors can be categorised into three types, digital, analog and pulse. Analog signals can be determined by current/voltage output and resistance output. A pulse signal is an on or off voltage supply. The output signal will depend on the type of sensor used. A digital signal is one that is either on or off, and nothing in between. It may just stay on or off, or it may pulse on and off.

Because computers only communicate in on/ off language, analog sensors signals need to be converted to digital signals and possibly amplified. This will be discussed in the processors and computers section later in this chapter.

Signals from sensors can be as fast as 3 milliseconds and can only be measured with an oscilloscope. An oscilloscope is the best way to determine the quality of an output signal.

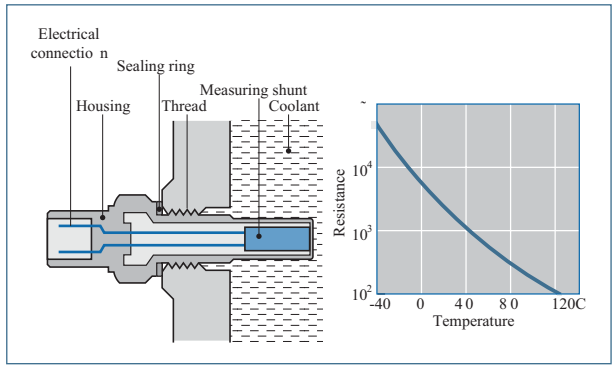


Figure 40.15 Temperature gauge , a variable resistor-type sensor whose analog signal is converted to a digital signal in the computer BOSCH

40.6.1 Sensor signal behaviour

Temperature sensor

A temperature sensor creates an analog signal of a variable resistance value. This will be converted to a digital signal in the analog-to-digital converter in the computer (Figure 40.15).

Knock sensor

A knock sensor produces an analog signal that needs to be converted to a digital signal and amplified (Figure 40.16).

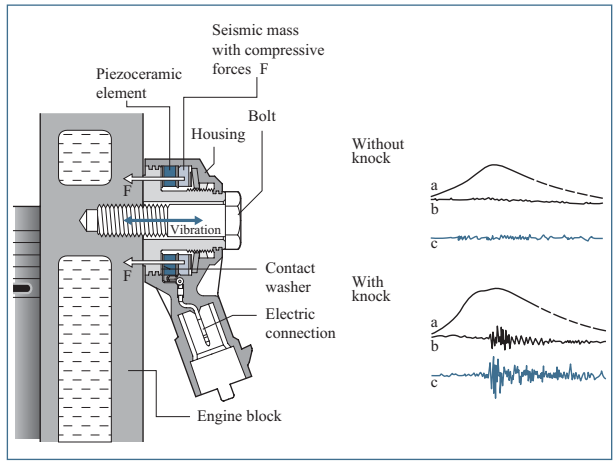


Figure 40.16 A knock sensor fitted to an engine , and the signal it produces BOSCH

Wheel speed

Wheel speed sensors (also referred to as ABS sensors) are used to help manage several different systems. These systems include ABS, speedometer, stability control, adaptive cruise control and four-wheel drive. The signal from a wheel sensor may look like a continuous line on a graph; but magnifying it many times would show that it is not a continuous line (Figure 40.17). Some scan tools can measure signals in milliseconds and read detailed signals.

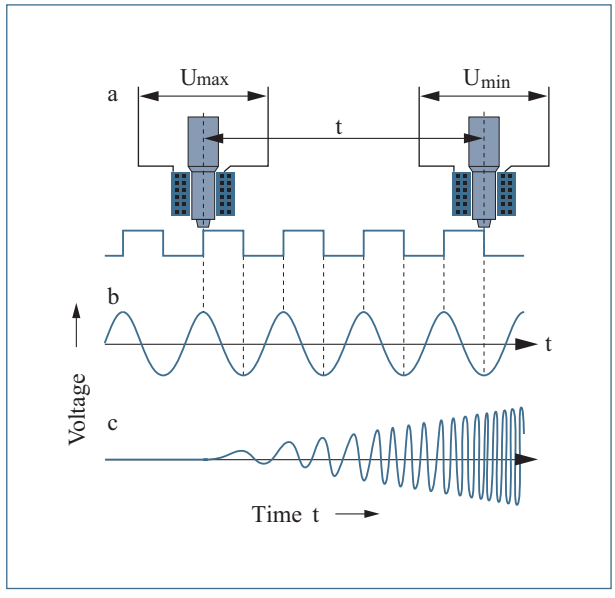


Figure 40.17 Image of a wheel speed sensor analog signal output: a passive wheel speed sensor b sensor signal at constant speed c sensor signal at increasing speed BOSCH

Smart sensor

With smart sensors, the supply voltage, the earth and the sensing wires can all be monitored by the computer. This is due to the fact that they connect through the computer (Figure 40.18). For example, when a scan tool displays a code such as C0020-01 and C0020-71, the 'C0020' indicates that the ABS pump motor control is faulty. The '01' indicates a general failure, and the '71' indicates that the actuator is stuck. When all three wires are monitored, the computer can analyse what is actually happening in the circuit, including shorts and open circuits. The reference voltage supplied to a smart sensor is 5 volts. The signal wire will have a range of 0.5 V to 4.5 V. If the voltage is outside these parameters, the computer will sense a fault.

40.6.2 Actuators

Actuators receive signals from the processor or micro-computer and, as a result, perform a required function. There are many actuators in the modern vehicle (Table 40.2). They can be relays, solenoids, modulating valves, switches or motors, and examples include fuel pumps, door locks, ABS and the horn.

Actuators convert electrical energy to mechanical action, hence the use of the word *mechatronics*.

Many actuators, such as injectors or door locks, are turned on or off, but some systems used in automatic, electronically-controlled transmissions require a pulse wave modulation. This is done by turning the current flow on and off at different speeds and duty cycles. Typically, these would operate between 30 and 100 Hz to modulate a hydraulic/electrical solenoid valve to control oil pressure or the flow of oil.

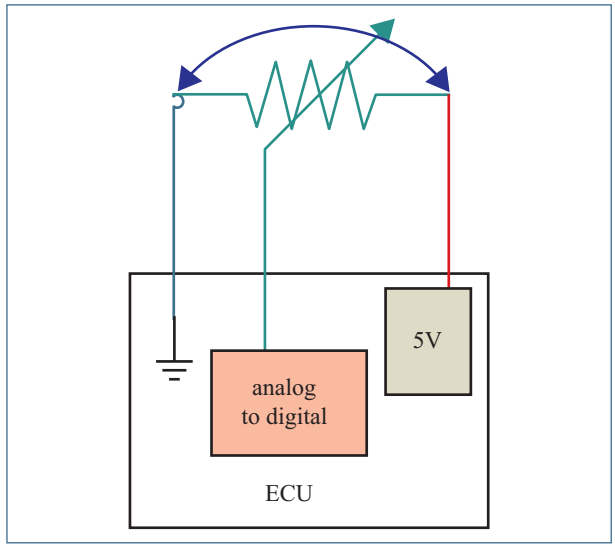


Figure 40.18 Smart sensor connections

Table 40.2 Examples of actuators

Injectors	Door locks	Turbo charger control	Air control inlet manifold
Fuel pump	Ignition timing	Valve timing control	Fuel pressure regulator
Electric steering	ABS	Transmission control	Horn
Power windows	Power mirrors	Lockup torque converter	Electric seat position
Heated seating	Air conditioning clutch	Auto temperature control	Air directional flap control
Fuel lid opener	Sun roof control	Active head lamp control	Voltage regulator

40.7 Computers and components

An outline of the engine control unit is shown in Figure 40.19, illustrating how components are connected in the Bus system.

40.7.1 Signal processing

The signal processor is designed to receive an input signal from one or more sensors. The sensor may provide only a weak signal and, in this case, the processor boosts the signal in the amplifier (amp) stage.

Some signals are analog, such as a resistance value or a variable supply of electrical current, and others may be a pulse. These will need to be converted to a digital signal for the computer to use the information. The processor might also be designed to change the signal in some way to make it more suitable.

RAM

Random access memory (RAM) is used by the computer to store, add or remove information. It is a place for temporary information that may be erased when the ignition is turned off.

ROM

Read-only memory (ROM) information cannot be erased, even if the computer is disconnected from the battery. This is where programmed information is stored for the computer to constantly check values against its inputs from sensors.

PROM

Programmable read-only memory (PROM) is different from ROM in that it stores the information specific to the vehicle model and is a ‘plug-in’ memory that can be changed or updated.

EPROM

Erasable programmable read-only memory (EPROM) is similar to ROM; but unlike ROM, it can have its information re-programmed or erased. To erase the information, it is subjected to UV light, after which it can be reprogrammed.

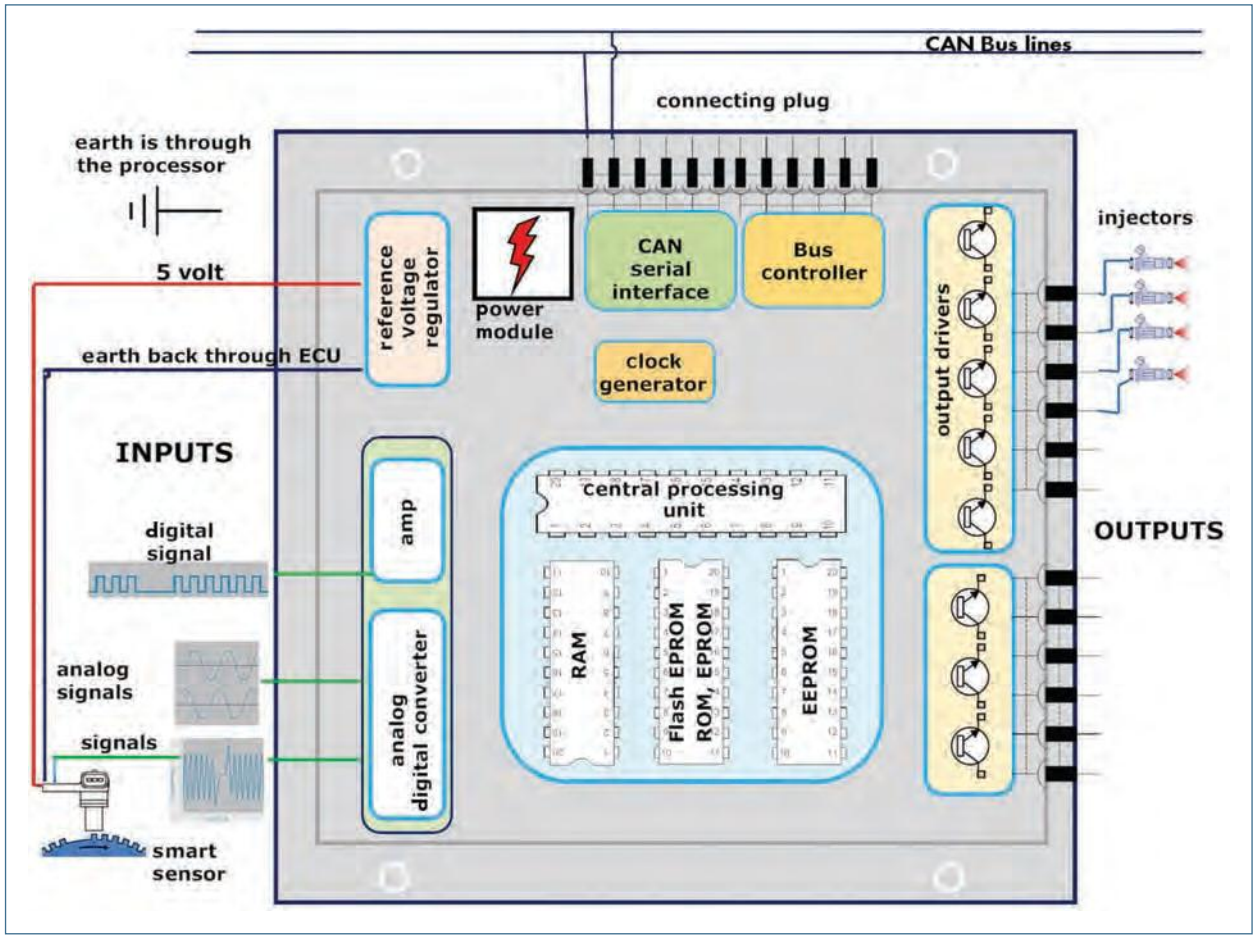


Figure 40.19 ECU components connected in the Bus system

EEPROM

With electrically erasable programmable read-only memory (EEPROM), the chip can have its program changed electrically. This is where information such as distance travelled, vehicle ID and other information is stored. If a computer module is disconnected from the battery, this memory may be erased.

⚠ Safety: When using an ECM module , follow the manufacturer' s instructions to avoid unnecessary memory loss or damage .

40.7.2 Clock generator

Also called an oscillator, a clock generator ensures that all operations in the micro-controller take place within a defined timing pattern.

40.8 Computer communication

40.8.1 Binary code

A type of high-speed Morse code can be created by the use of multiple transistors switching on and off, resulting in a 'language' that allows computers to communicate with each other. The language is called binary code. Computers only recognise power on or power off, and in binary code '0' is for off and '1' is for (Table 40.3 and Figure 40.20).

Table 40.3 The numbers 1 to 20 in binary code

Binary code	Standard decimal digits
0000 0000	0
0000 0001	1
0000 0010	2
0000 0011	3
0000 0100	4
0000 0101	5
0000 0110	6
0000 0111	7
0000 1000	8
0000 1001	9
0000 1010	10
0001 0100	20

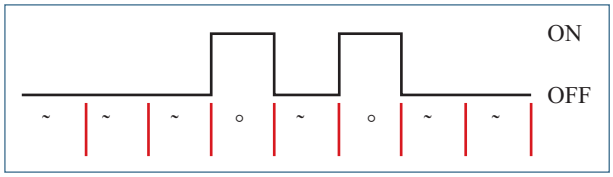


Figure 40.20 The number 20 as a binary code

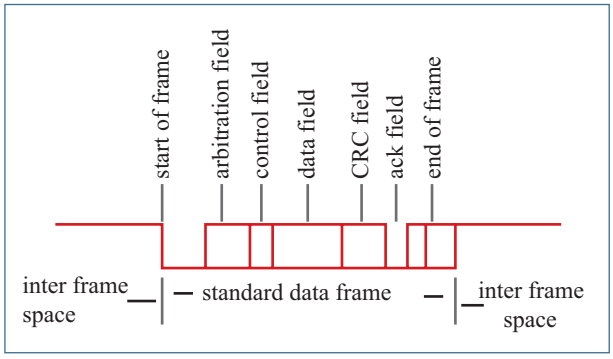


Figure 40.21 A CAN message showing a standard data frame

40.8.2 Message format

When computers talk to each other using the binary code, they send and receive the information as a data 'frame'. A data frame will contain certain elements, and these are identified in Figure 40.21. A screenshot of a typical message is displayed, (Figure 40.22). The data frame elements include:

- start of message
- arbitration field
- control field
- data field
- CRC field
- ack field
- end of frame .

40.8.3 Computer topology

Topology (electrical and network circuits) is a diagram that shows what connections there are between components. It does not show the actual connection of each wire to each unit or computer. There are many computers and computer-managed systems in modern vehicles, and these need to be connected and interconnected. For example, cruise control needs information from the ABS, and transmissions need information from the engine management. The computers or processors can be connected in several ways to facilitate the connections.

Examples of topologies used in vehicles today are:

- Bus topology (linear) (*Figure 40.23*)
- star topology (*Figure 40.24*)
- ring topology (*Figure 40.25*)

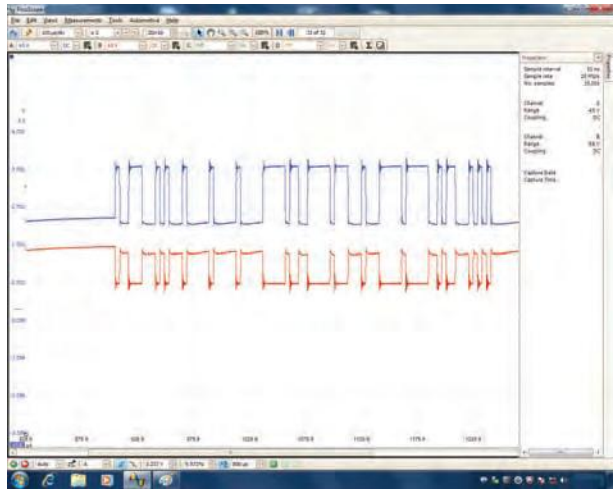


Figure 40.22 Freeze-frame of a C AN Bus message captured by a PicoScope , the graphs showing the CAN-H and C AN-L voltages

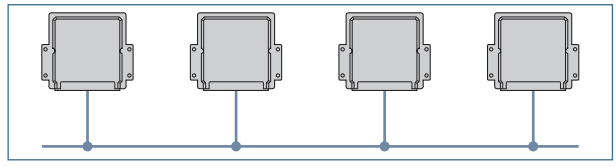


Figure 40.23 Linear Bus topology BOSCH

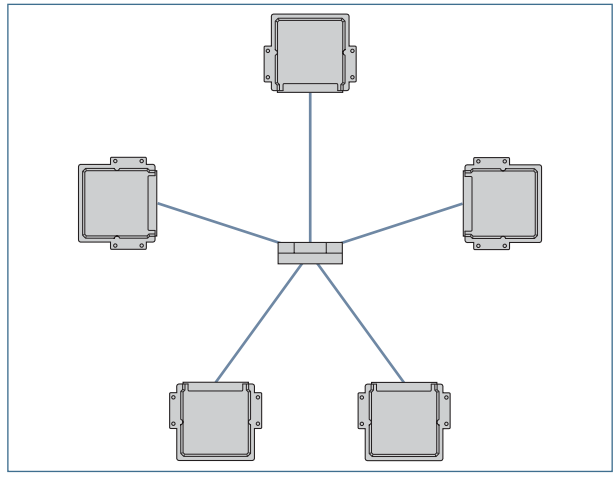


Figure 40.24 Star topology BOSCH

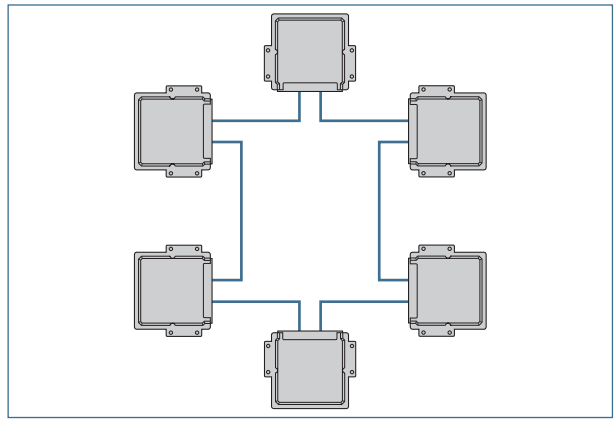


Figure 40.25 Ring topology BOSCH

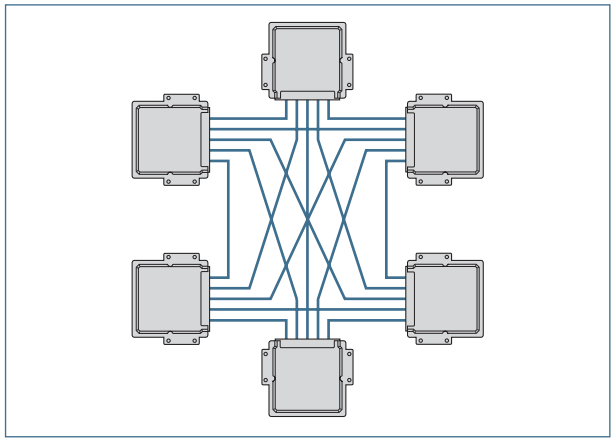


Figure 40.26 Mesh topology BOSCH

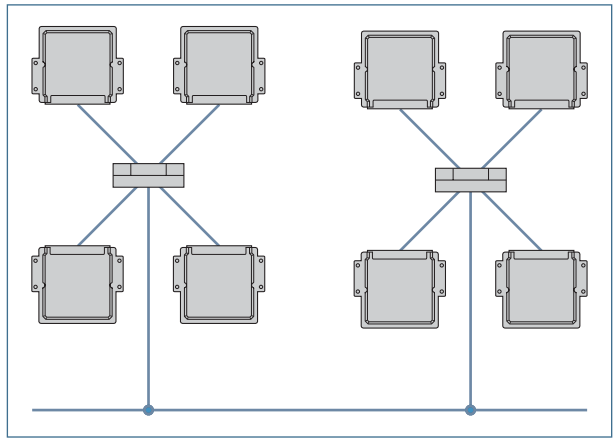


Figure 40.27 Star and Bus topology BOSCH

- mesh topology (*Figure 40.26*)
- Star and Bus topology (Figure 40 .27)
- master and slave topology (*Figure 40.28*).

40.9 Computer data protocols

Computers in motor vehicles communicate with each other in several protocols. Vehicles use CAN Bus systems, Bluetooth, LIN Bus and MOST systems. The topology for communications between computers will depend on the level of equipment, cost and the engineers' choice for the type of vehicle. The systems need to be robust, to be able to work in a range of temperatures and vibrations and to cater for the volume and complexity of the information. They also need to resist electromagnetic interference from other systems such as high-voltage ignition systems. Electromagnetic interference can cause the frames to become corrupt. Other considerations will include fault tolerance.

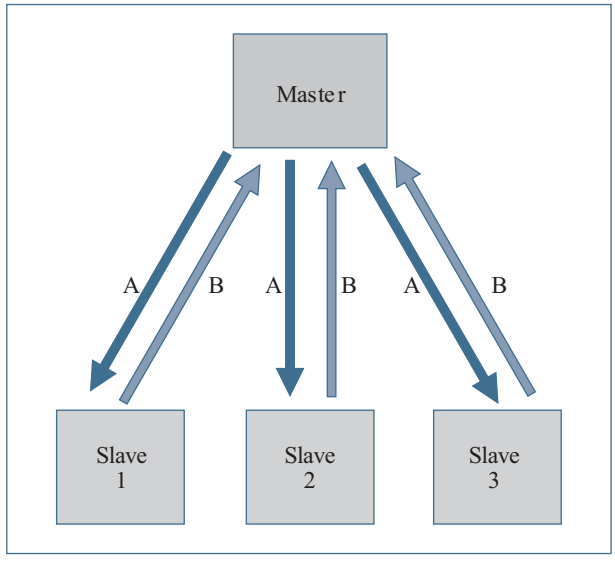


Figure 40.28 Master and slave topology BOSCH

40.9.1 High-speed CAN

High-speed CAN (Class C) is defined by ISO 1198 and operates at 125k to 1 megabits per second. This speed can meet the demands of transmission, engine management, vehicle stabilisation and the instrument panel. Generally, it runs at 8 bytes of data in a frame. (Note: 8 bits make 1 byte.) High-speed CAN systems can handle up to 10 nodes on a single Bus line. The system uses two wires that are twisted together to prevent noise or electrical interference. These wires may be shielded to further prevent electromagnetic interference which could corrupt the frame. The CAN Bus protocol uses two signals that are a perfect mirror of each other, one on CAN Low (or −) and one on CAN High (or +) (see Figure 40.22). This helps the computer to filter any electromagnetic interference out of the frame being sent. This process is shown in Figure 40.30.

40.9.2 Low-speed CAN

Low-speed CAN (Class B) is defined by IOS 11519-2 and can operate at 5 to 125 Kbit/s (thousand bits per second). Low speed CAN will handle up to 24 nodes on a single Bus line and is often referred to as *medium-speed* CAN. It is suitable for air conditioning, seat controls, power windows, lighting and similar, less important items. This system needs a twisted pair of wires to communicate in the same fashion as high-speed CAN, but does not normally need shielding.

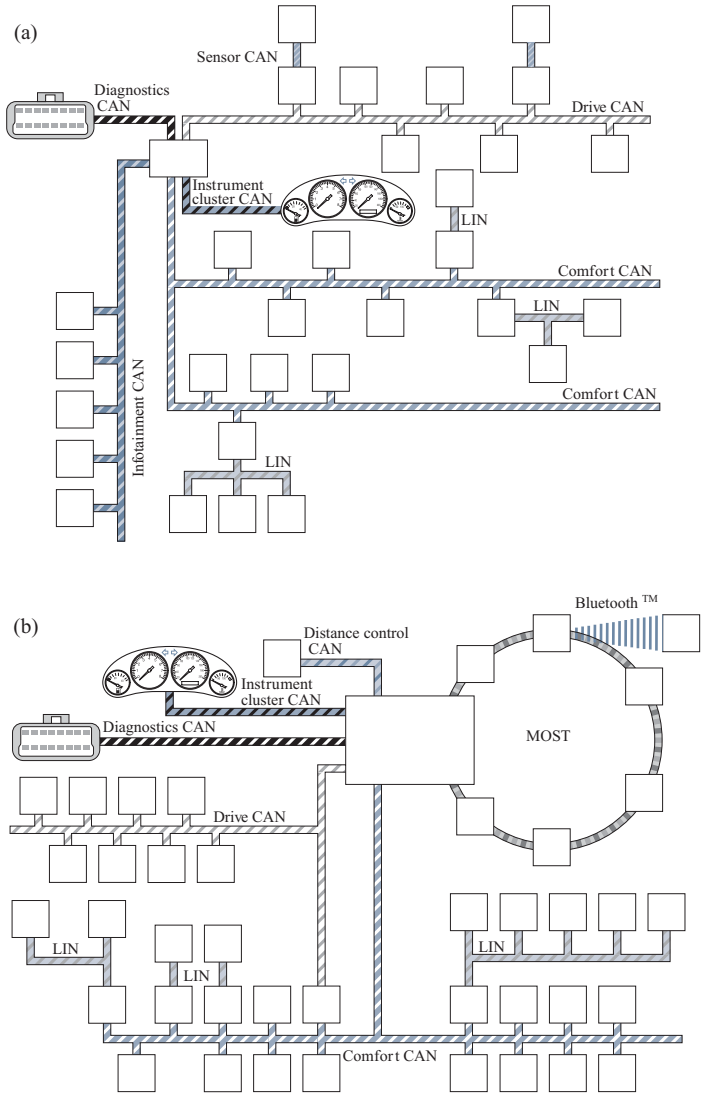


Figure 40.29 Vehicles now use multiple topology systems to connect—topology (a) would be for a lower-cost vehicle and topology (b) would be used on a luxury vehicle BOSCH

40.9.3 CAN FD

CAN FD (flexible data rate) was designed to improve the accuracy of data in real time. It can hold 64 bytes of data in a single frame (Figure 40.31). CAN FD is seen as an upgrade of the basic CAN system and will be economical for vehicles to upgrade to.

40.9.4 CAN FlexRay

FlexRay was designed to handle the requirements of 'drive by wire', 'steer by wire' and 'brake by wire'. As a failure of these systems would be catastrophic, a newer, more fault-tolerant and higher bandwidth has been introduced. FlexRay can be transmitted on copper wire or on an optical Bus system at speeds of 10 to 20 megabits per second. It is not a replacement for the CAN Bus or LIN Bus systems, but is an addition to specific systems. FlexRay can run on one or two pairs of twisted wires unshielded.

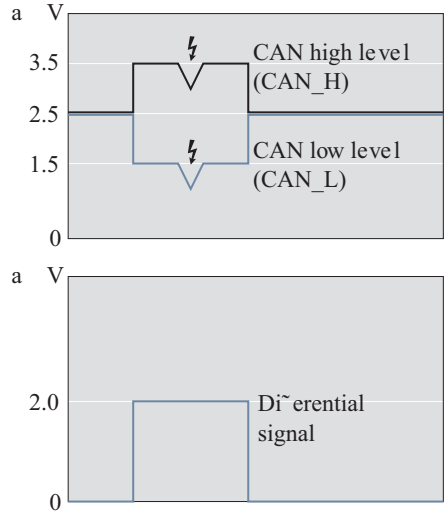


Figure 40.30 Interference filtered out on the C AN Bus

40.9.5 LIN Bus

LIN Bus systems (Class A) (LIN Consortium) require only a single wire to communicate (Figure 40.32). A single LIN Bus wire can handle up to 16 slave nodes and the topology is in a linear Bus format (Figure 40.33). The maximum data speed is 20 kbit/s, and the system has the advantage of being relatively cheap to expand. With a single wire system, only one frame can be sent at one time from a master or central ECU to the slave nodes. The master decides which messages have priority and when the line is free to send the message.

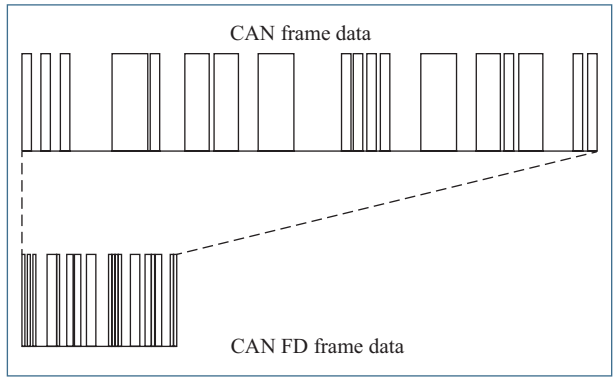


Figure 40.31 A comparison of FD and C AN frame data

40.9.6 MOST

Generally used in luxury vehicles, MOST is an acronym of media oriented systems transport. With data transfer rates of 22.5 Mbits/s, MOST works on a plastic optic fibre and is used for multimedia and

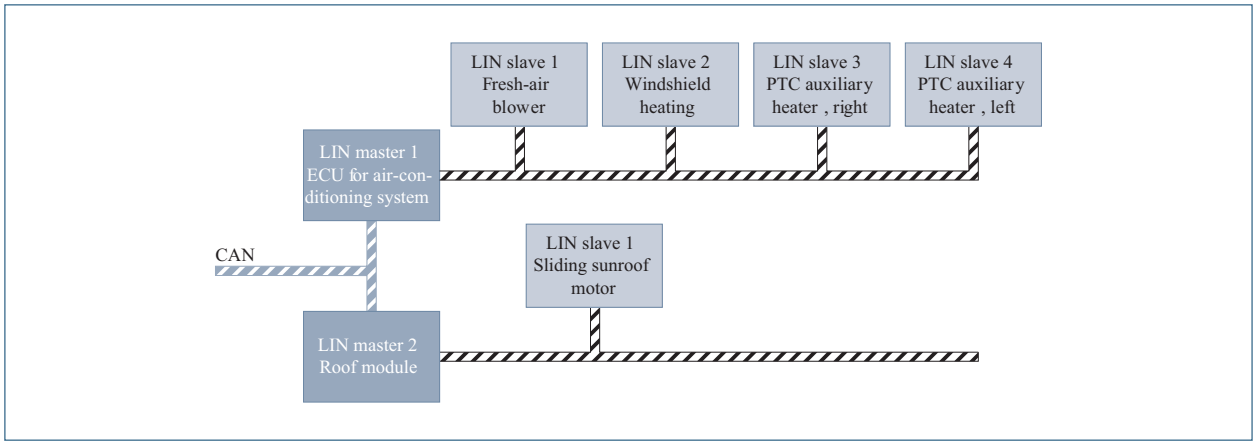


Figure 40.32 LIN Bus systems need a master for the slaves BOSCH

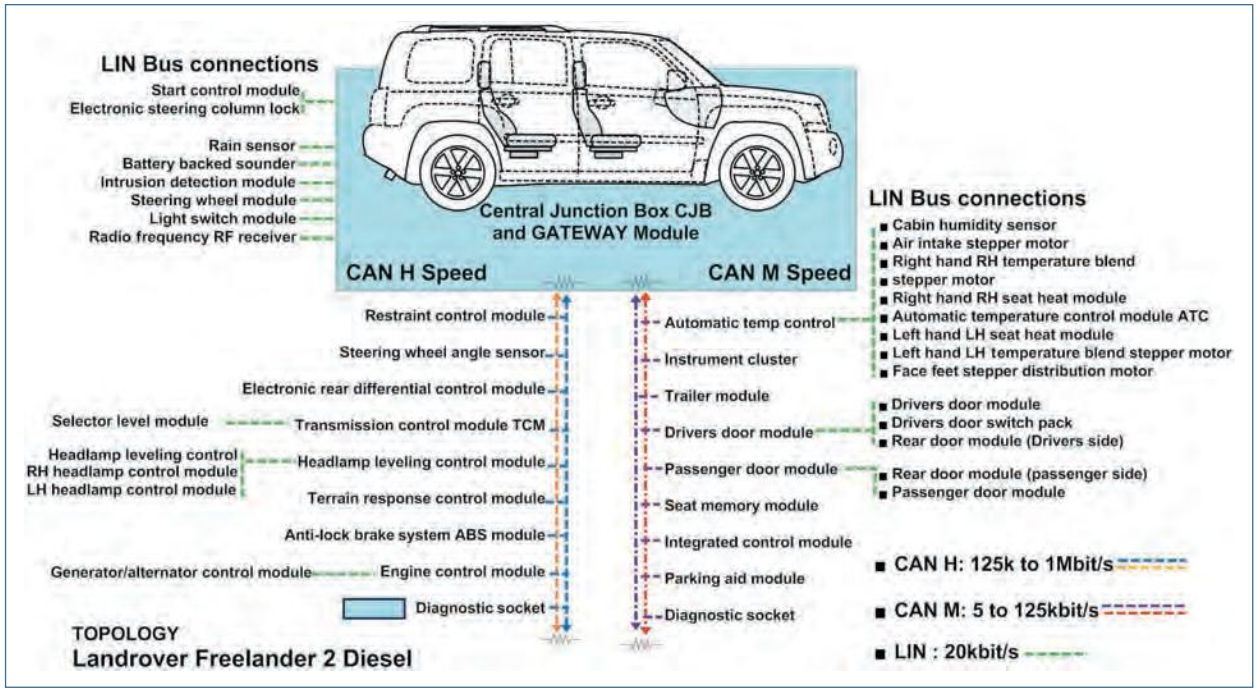


Figure 40.33 The devices connected via a LIN system

infotainment systems. MOST topology is used in a ring structure and can run up to 64 nodes. Only one message can be sent at any one time.

40.9.7 Gateway modules

Gateway modules are used where different applications come together such as CAN C, CAN B, MOST and LIN. Because they have different network protocols, the data cannot be exchanged without an interpreting device. The gateway module interprets the different systems information and passes it on so that the information can be shared across the different protocols.

40.9.8 Message delivery

With the proliferation of nodes and ECMs monitoring and acting on signals in a CAN Bus system, there will be collisions of data being transmitted. There are several methods used to avoid corrupt messages being received due to these collisions. The ECM sending a message also calculates a parity bit that is transmitted with the message. The parity bit is simply a count of how many instances of '1' are in the message. The receiving ECM or node can check the parity bit against the message to ensure it is all there and correct. If the message is corrupt, the receiving ECM will send a message back to ask for the message to be resent.

Another method is the checksum, which is a small datum that is derived from a block of digital data for the purpose of detecting errors. The transmitter calculates the value of the sent message using a predefined formula and sends this with the message. The receiver checks the checksum against the message to ensure it is correct. If it is not correct, the receiver requests that it is sent again.

Messages sent must comply with time constrains to meet real-time requirements. Non-critical equipment such as door locks will have 'soft timeframes' to work within, requiring a slower speed of 100 milliseconds. Critical equipment such as ABS will have 'hard timeframes' of two or three milliseconds. This is also managed by the ECU based on a priority system.

40.10 Diagnostic testing

Diagnostic testing of computer-managed systems is done via a vehicle data logic connector (DLC) (Figure 40.34).

The standard connector plug (ISO 15031-3:2016, used only for diagnostic) is usually located close to the fuse box or near the steering wheel column. The plug has 16 pins which have set pin allocations, and some spares for different manufacturers' specific use. The connections are:

- Pin 1. May be used by OEM for their own specific task.
- Pin 2. J1850 Bus +ve.
- Pin 3. A discretionary circuit. Has been used by Ford for diagnostics.
- Pin 4. Chassis ground.
- Pin 5. Sensor ground. Important to note that all sensors ground at the same point as the ECM.
- Pin 6. CAN High—ISO 15765-4.
- Pin 7. K-line (used for diagnostics ISO 9141). For the scan tool to use pre-C AN Bus protocols.
- Pin 8. A discretionary circuit. Manufacturer specific.
- Pin 9. A discretionary circuit. A vailable for OEM.
- Pin 10. J1850 Bus -ve .
- Pin 11.A discretionary circuit. Has been used by Ford for diagnostics.
- Pin 12. A discretionary circuit.
- Pin 13. A discretionary circuit. Has been used by Toyota for diagnostics.
- Pin 14. CAN Low—ISO 15765-4.
- Pin 15. L-line diagnostic. ISO 9141. Used pre-C AN Bus communications.
- Pin 16. Battery +. This is live at all times and is not switched.

As previously discussed, CAN Bus has different bit rates, but the digital loop carrier (DLC) is usually connected to the faster CAN Bus rate of CAN C (high speed up to 1 Mbits/s).

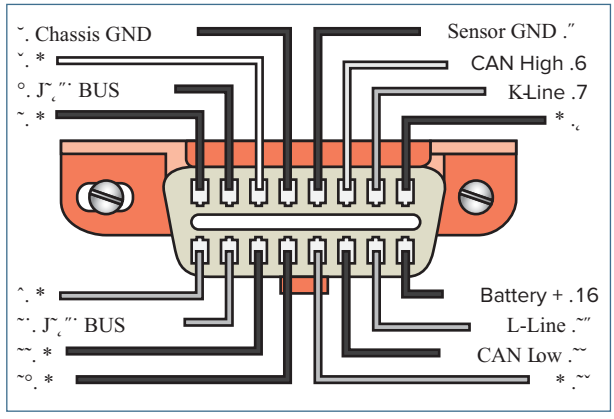


Figure 40.34 DLC plug for connection to a scan/ diagnostic tool

When a diagnostic tool is connected to the DLC, it requests information via specific protocols from the data Bus system. Before CAN Bus systems were used widely, the diagnostic tool would use L line to send a message to the ECM and the data would come via the K line.

40.10.1 CAN Bus circuit testing

Resistance testing

1 Disconnect the battery earth.
2 Check the resistance between pins 6 and 14—it should be 60 ohms. Less than 60 indicates a short circuit and 120 ohms will indicate an open circuit. Only one resistor is being measured.

Voltage testing

This should be done with the battery connected. A multimeter cannot measure the signal because of its high speed, but it can measure the average voltage. Check between:

- *Pin 4 and Pin 6 = 3 volts normal*
- *Pin 4 and Pin 14 = 2 volts normal*
- *Pin 6 and Pin 14 = 1 volt normal.*

Safety: Only use a high-quality multimeter with an internal resistance of 10 K ohms to prevent damaging an ECM.

40.11 Diagnostic codes

There are many diagnostic codes used in OBD2. Some are generic and are used by most manufacturers, while others are manufacturer specific. The code is made up of set parameters. The basic code consists of a letter followed by four numbers or letters, such as P0445. Each alpha-numeric part of the code has set parameters which are shown in Table 40.4. Actual examples of fault codes are shown in Table 40.5.

A scan tool shows different fault codes with P, B and U codes. Letters used in the fourth and fifth positions are manufacturer specific.

Table 40.4 Parameters for alphanumeric codes

First letter	B C P U	Body Chassis Power train (engine and transmission) User network (Bus wiring)
Second	0 1 2 3	Generic OBD Vehicle manufacturer specific Manufacturer defined SAE defined
Third	1 2 3 4 5 6 7, 8, 9 A, B, C D, E, F	Fuel and air Fuel and air metering Ignition systems or misfire Auxiliary emission controls Vehicle speed control and idle control Computer output circuit Transmission (gearbox) Hybrid propulsion Future allocation
Fourth and fifth		More specific fault description
Sixth and seventh		Manufacturer specific (not always used); this area will give more information that relates to the fourth and fifth item such as open circuit

Table 40.5 Examples of fault codes

DTCs	Description	Status
P0460	Fuel level sensor A circuit	Intermittent
P1346	Fuel level sensor B circuit	Intermittent
B100A	Fuel pump authorisation	Permanent
B1026	Steering column lock	Historic
B10AD	Rain sensor	Intermittent
B10D7	Passive anti-theft system k ey	Historic
B112A	Ignition on relay B	Historic
B1D13	Interior lamps 1 circuit	Historic
B1D21	Remote control switch	Historic
U0423	Invalid data received from the instrument panel control module	Historic

40.11.1 Scan/d iagnostic tool

Scan tools are an essential diagnostic tool that every technician needs access to in the workshop. The CAN Bus systems in motor vehicles monitor most of the vehicle's functions. The malfunction indicator light (MIL) or engine check light will illuminate if there is an engine fault, to alert the driver. However, there are many faults that can occur that will not alert the driver. For this reason, it is good practice to check every vehicle with a scan tool at each service, as there may be faults awaiting attention in the background. If faults are found, they should be recorded (take a freeze-frame snap shot of all fault codes listed). This will be invaluable when discussing the situation with the vehicle owner. Investigate each fault code and take a freeze-frame of each item or system in action (Figure 40.35). Most good scan tools will offer a graph layout and show the actual performance of the component that is being checked. Some monitored items may only record an on or off state and not offer a performance graph.

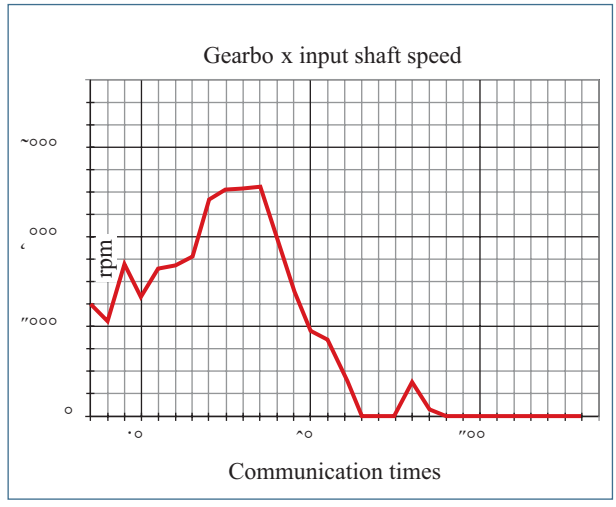


Figure 40.35 Freeze-frame of a performance graph in a scan tool

Technicians should always remember that when a scan tool shows a fault in a given circuit, it does not always mean that the fault is to be found in that particular item. It only indicates that something is not right. It may be that something external is causing the fault. Some faults in vehicles do not give fault codes because the item is still working within its programmed parameters.

A vehicle with an incorrect auto transmission shift pattern may come up with no codes. The fault may be caused by stray electromagnetic interference from the ignition coil pack. This can upset the data sent to the transmission module and cause unusual shift patterns, but there will be no fault code found.

40.12 Oscilloscope

An oscilloscope will give good-quality information about the performance of any given sensor. When an instrument measures the actions of a sensor, it does so over a period of time. If those actions occur in milliseconds (μs), some scan tools or multimeters may not be able to capture the event over such a small interval but an oscilloscope can. The high degree of accuracy they offer allows for much more exacting diagnosis; an oscilloscope is so accurate that it will inform the technician of any likely future faults.

A comparison between the freeze-frame record of a crankshaft sensor from a scan tool in Figure 40.36 with Figure 40.37, which was taken with an oscilloscope, demonstrates the difference. The scan tool in Figure 40.36 has given the number of counts on the bottom row, but the oscilloscope has recorded the events over 40 milliseconds. The gap in the pattern in Figure 40.37 is the reference point for top-dead-centre of piston number one.

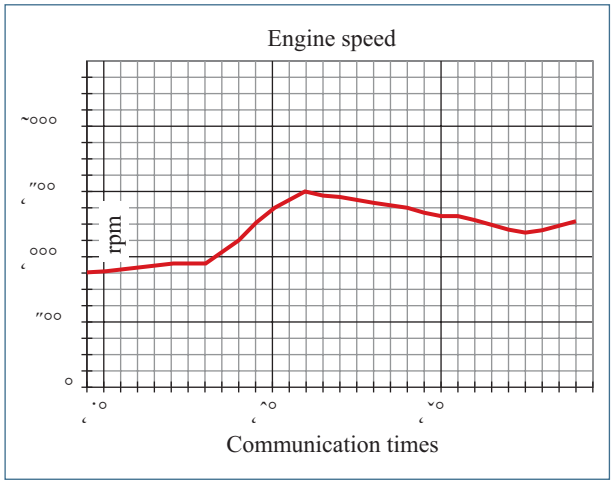


Figure 40.36 Graph tak en from a scan tool freeze-frame showing engine speed but not the actual signal from the sensor

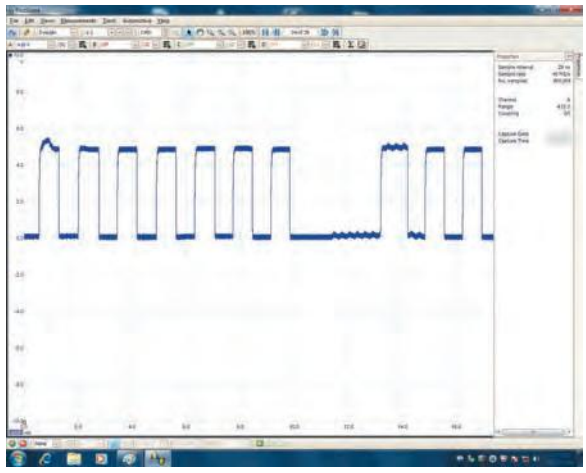


Figure 40.37 A freeze-frame of the actual signal from the crankshaft sensor captured with an oscilloscope

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain the function of diodes in relation to current flow
- explain that a transistor' s function is to act as a type of switch or relay
- describe how resistors limit current flow
- explain the uses of semiconductors
- describe the functions and applications of sensors in motor vehicles
- explain what an actuator is and how it is controlled
- describe the components of an electronic control unit and their functions
- define binary codes
- define data frames
- describe the topology used by computer networks
- describe gateway modules and Bus systems
- describe pin designations in the diagnostic links connection
- define diagnostic codes
- describe the functions and applications of scan tools and oscilloscopes.

REVIEW QUESTIONS

1 What are electronics ?
2 What is a semiconductor ?
3 What is an n-type conductor ?
4 What is a diode ?

5 What is a p–n junction ?
6 Indicate how a diode operates in a simple circuit. Use one of the illustrations if necessary .
7 What is a Zener diode ?
8 What is an integrated circuit ?
9 What is a thermistor ?
10 Name three electronic components.
11 What is meant by the bias of diodes ?
12 Name some of the places where electronics are used on a motor vehicle .
13 What are power diodes ?
14 What are light-emitting diodes ?
15 Why are some diodes provided with a heat sink?
16 Give a simple explanation of how a transistor can be used
17 What is a sensor ?
18 Where are some sensors used on a motor vehicle ?
19 What is an actuator ?
20 What does RAMstand for?
21 What is the name of the language that computers use ?
22 Computer messages (frame) consist of seven areas. What are the seven fields of a standard data frame ?
23 Computer topology refers to the way computers are connected. Name three topologies used in motor vehicles.
24 How does LIN Bus differ from C AN Bus?
25 What is a gateway module ?
26 When testing sensor signals, which tools provide accurate information ?

CHAPTER 41

The battery

LEARNING OBJECTIVES

On completing this chapter , you will will be able to:

1 list the work health and safety procedures when working with batteries
2 describe the environmental requirements for working with batteries
3 identify the location and content of manufacturers ' specifications
4 describe the types, application and operation of batteries
5 identify battery connection methods for 6, 12, 24 and 48 volts
6 list the battery classifications
7 apply battery testing procedures
8 apply battery charging procedures
9 identify battery faults
10 apply battery replacement procedures
11 apply battery jump-start procedures.

The battery supplies current for the operation of the starter motor and for the ignition and fuel systems when the engine is being crank ed for starting. It also supplies current for the lights, audio systems, instruments, security and other accessories that are used when the engine is not running. Once the engine is started, the alternator supplies all the power requirements for the various electrical systems, including recharging the battery . However , the battery continues to have a stabilising effect on the electrical system.

41.1 Work health and safety

Batteries contain gases that can explode when they are being connected to, or disconnected from, a charger. Lead acid batteries are hazardous because of their potential for causing:

- burns to skin
- eye damage
- injury from manual handling (batteries can be heavy)
- toxic fumes
- fires and explosions .

Do not operate battery testing and charging equipment unless you have read the manufacturer's safety information or have been trained in the correct procedures. The same applies to battery replacement and any other battery-related work.

Safety: Assess the risks before carrying out any work on battery systems in motor vehicles.

41.2 Environmental requirements

Safety data sheets (SDS) for all dangerous goods should be available in every workplace. Discarded batteries should be stored in a safe location in a container for recycling. Ninety-nine per cent of the material in a car battery can be recycled.

41.3 Lead acid battery construction

The lead acid battery has evolved to meet the requirements of the modern vehicle. As emission standards become more stringent, manufacturers have to set engines to idle stop start (ISS). This is a system where the engine cuts out when vehicle movement stops and starts again automatically when the throttle is depressed. This places extreme demands on the battery.

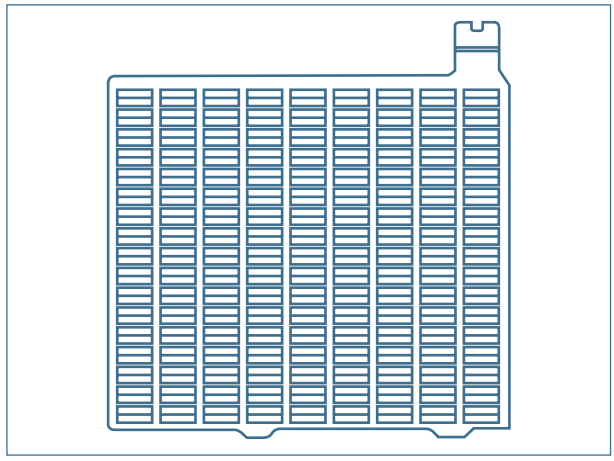


Figure 41.1 A battery plate grid

The introduction of electric vehicles (EV) and hybrid electric vehicles (HEV) has put pressure on the battery industry to develop higher-performance batteries. Many newer batteries are still based on the lead acid battery, with the exception of lithium battery technology that is used mainly in electric vehicles.

41.3.1 Lead acid battery materials

The main materials used in the battery are *spongy lead* (a solid), *lead oxide* (a solid) and *sulphuric acid* (a liquid). These are brought together in such a way that they can react chemically to produce a flow of current. The lead oxide and spongy lead are held in plate grids to form positive and negative plates. Sulphuric acid is diluted with water to become the *electrolyte*.

The plate grid (Figure 41.1) consists of a framework of lead alloy with horizontal and vertical bars. Plate grids are formed by the application of lead oxide pastes, which harden. The horizontal and vertical bars hold the hardened pastes in the plates. After the plates are assembled into the battery, it is given an initial forming charge. This changes the lead oxide in the negative plate to spongy lead and the lead oxide in the positive plate to lead peroxide.

41.3.2 Battery assembly

When the battery is being manufactured, several plates are spaced and welded to a strap to form a plate group. Plates of two different types are used: one for the positive plate group, the other for the negative plate group. A positive plate group is nested with a negative plate group, with separators placed between the plates to form an element (Figure 41.2).

Separators are made from various materials including plastic, rubber and fibreglass. They are designed to hold the plates apart but must be porous

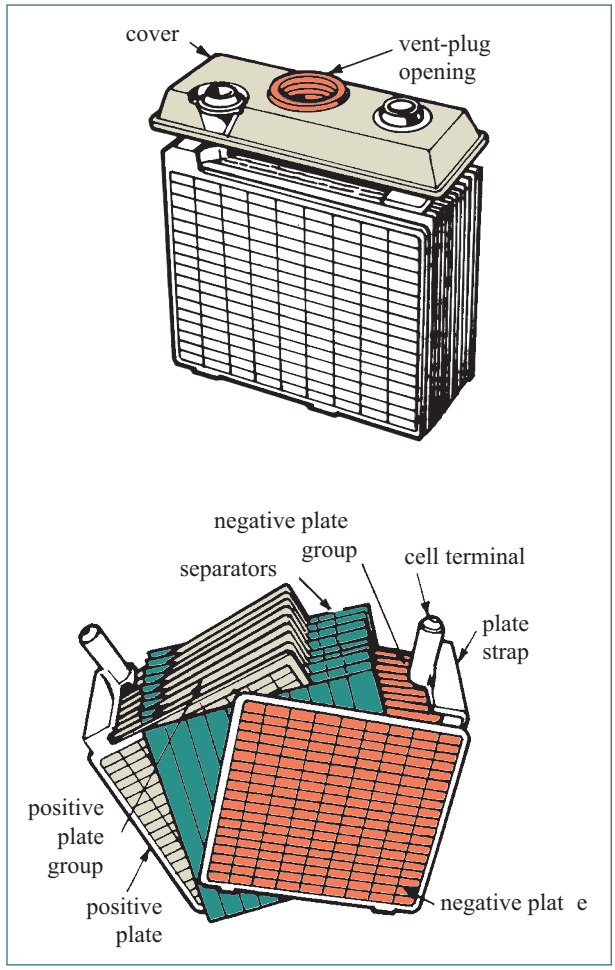


Figure 41.2 The groups of positive and negative plates are assembled with separators to form an element—this becomes one cell when assembled into the battery case

enough to allow the electrolyte to circulate between them. During manufacture, the elements are placed in compartments in the battery case, which is made of either hard rubber or polypropylene. Each of the compartments forms a cell. The top of the case is enclosed by a cover which is sealed to the case.

Each cell is a separate part of the battery, with its own electrolyte. However, the cells are electrically connected in series inside the battery, with the positive terminal of a cell connected to the negative terminal of its adjacent cell. The end cells carry the main battery terminals, or posts. With series connections, the voltages of the cells are added. There are six cells in a 12-volt battery; the cell connections for 12 volts are shown in Figure 41.3.

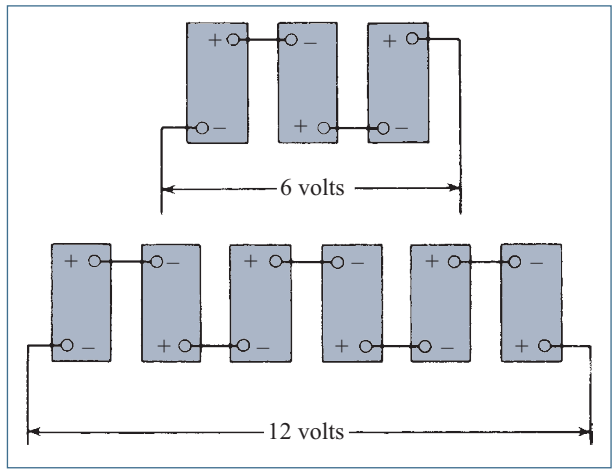


Figure 41.3 Battery cell connections—2-volt cells connected in series can provide 6 volts or 12 volts

41.3.3 Battery terminals

The battery terminals, or posts, extend through the cover, with the positive terminal located at one end of the battery and the negative terminal at the other. The terminals can be in the form of posts, lugs or both (Figure 41.4), and it is important to know their polarity so the battery can be correctly installed in the vehicle. For this reason, the terminals are made identifiable via a plastic washer coloured blue for negative and red for positive at the base of the lug; alternatively, the terminals and battery cover may be identified (+) or (−). Where the battery has round terminal posts, the positive post is larger than the negative post.

Fewer batteries today have removable filler plugs as most are of a low-maintenance or maintenance-free construction. (Heavy-duty batteries for trucks are an exception.) A complete battery is shown in Figure 41.5. One end is cut away so that the internal construction can be seen.

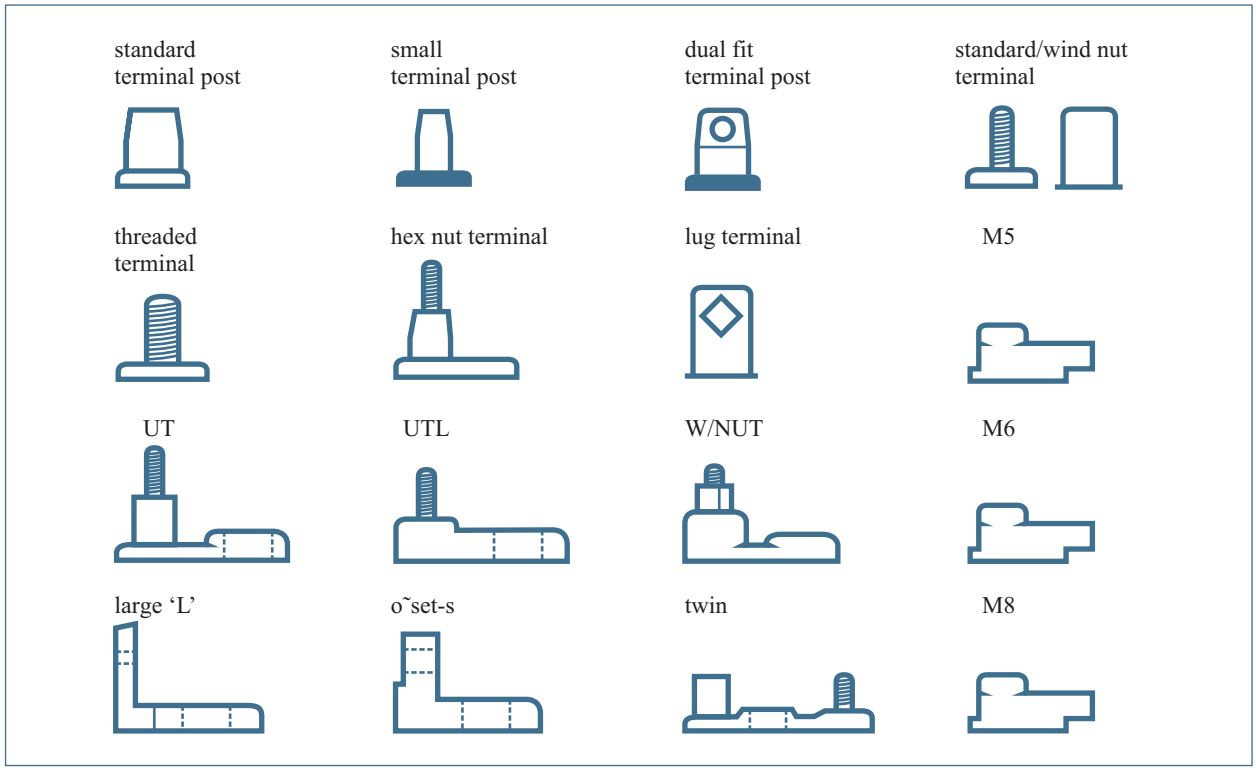


Figure 41.4 Batteries may have several different terminals, and some will have dual connections

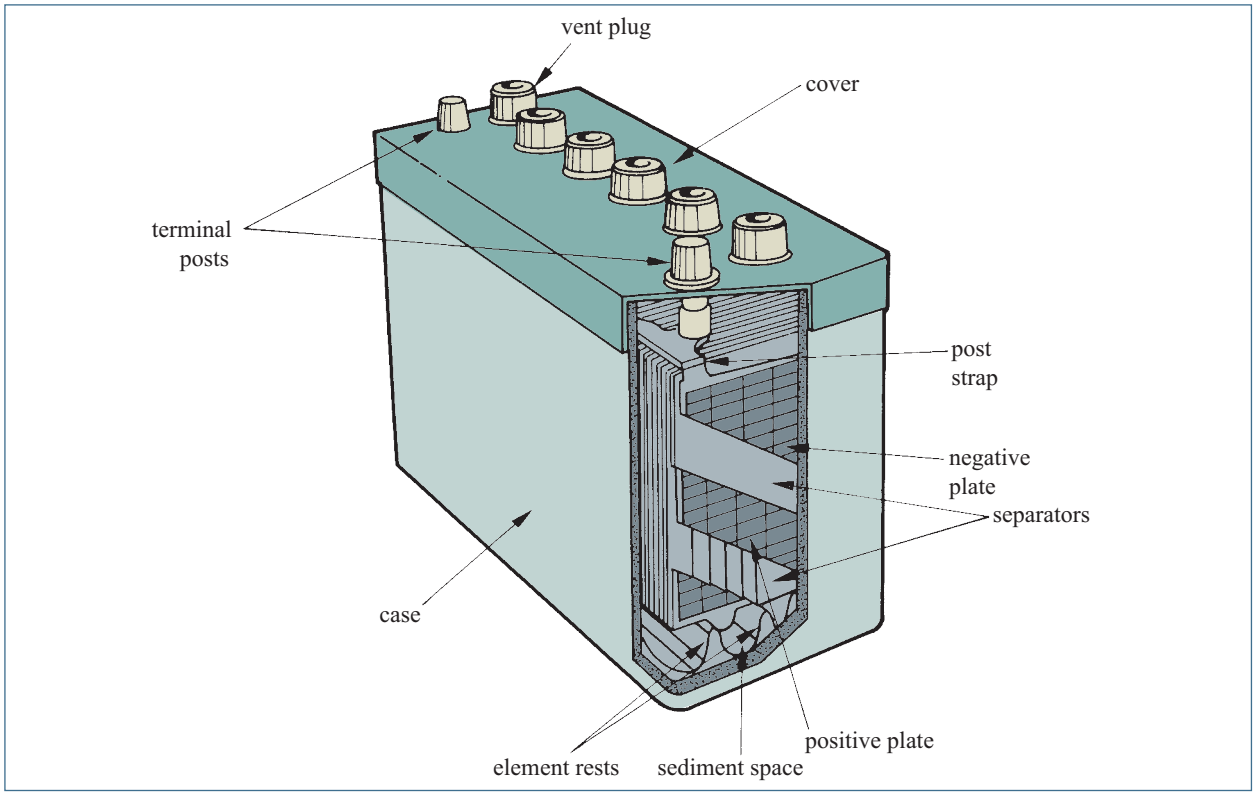


Figure 41.5 Construction of a 12-volt battery

41.4 Chemical action in the battery

The electrolyte in the battery is made up of about 40 per cent sulphuric acid and 60 per cent water. When the plates are given a charge, chemical actions remove electrons from one group of plates and mass them at the other. This transfer of electrons is carried on until there is a nominal 2-volt potential between the two groups of plates.

41.4.1 Action on discharge

When a circuit with a load is connected to the battery, the acid in the electrolyte starts to combine with the active material on the plates to form lead sulphate. This process continues until the active material on both the positive and negative plates has been converted to lead sulphate. This reduces the quantity of sulphuric acid in the electrolyte, reducing its density. At this point, the battery is discharged.

41.4.2 Action on charge

The battery can be recharged by current from the alternator or a battery charger, which passes current through it in a reverse direction, reversing the chemical activity. The plates are now converted back to lead peroxide (positive plates) and spongy lead (negative plates). The sulphuric acid is removed from them during charging to combine with the electrolyte and so increase its density. The density of the electrolyte is related to the state of charge of the battery—high when the battery is charged, low when it is discharged.

These conditions are illustrated in Figure 41.6, where the electrolyte is being checked with a

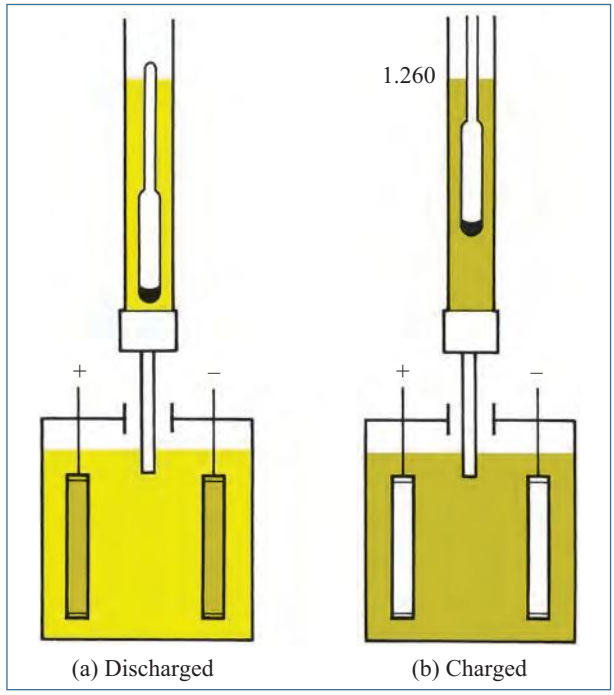


Figure 41.6 Battery action (a) when discharged, the density of the electrolyte is reduced and the float in the hydrometer does not rise (b) when charged, the density of the electrolyte is increased and the float rises

hydrometer. The float does not rise when the battery is flat but floats quite high when the battery is charged.

41.4.3 Battery voltage

Passenger cars and light commercial vehicles have 12-volt batteries. This is the combined voltage of all the cells of the battery. Heavier vehicles, particularly those with diesel engines, have 24-volt electrical systems. These use two 12-volt batteries or, in some instances, four 6-volt batteries.

Where more than one battery is used, they are connected in series to provide the higher voltage. While the battery cell has a nominal voltage of 2 volts, a fully charged battery will give a reading of 2.1 volts per cell when checked without any load. This is referred to as the *open-circuit* voltage. A 12-volt battery will therefore have an open-circuit voltage of 12.6 volts or more when fully charged.

Battery voltage can vary under different operating conditions:

Figure 41.7 The voltmeter connected to the battery shows the voltage readings

1. Open circuit. When tested without any load, a fully charged battery should have a voltmeter reading of 12.6 volts or more (Figure 41.7).
2. Starter operating. Under a heavy load and with the starter motor operating, the battery voltage could drop to 9.5 volts or less.
3. Headlights on. Under a lighter load (as when the headlamps are switched on) battery voltage could be as low as 11 volts or less.
4. Alternator operating. With the engine running and the alternator operating, the battery voltage could rise as high as almost 15 volts. This will depend on the type of battery and whether it has a smart charging system.

Handy hint: The alternator regulator limits the voltage during charging so that the system voltage **does not become too high. For the correct voltage figures for a battery during operation, check the** service manual.

41.5 Other types of batteries

41.5.1 Gel batteries

Gel batteries, also referred to as *gel cells*, are classified as deep cycle batteries. Gel batteries have the same basic construction as a lead acid battery but the electrolyte is made of silica gel mixed with sulphuric acid. These batteries use recombination reaction to prevent the escape of hydrogen and oxygen gases. They are sealed and so can sit at any angle without spillage. Gel batteries incorporate a valve-regulated venting system called sealed valve regulated (SVR) or valve regulated lead acid (VRLA) in case of excess pressure. The combination of the gel and being sealed means there is no vaporisation of the electrolyte or spillage causing corrosion. Gel batteries are also resistant to extreme temperatures and shock. Ideal for aircraft, boats and automobiles, they can be mounted at any angle (but not upside down).

The main advantages of gel batteries are that they:

- can be mounted on their side
- are long-lasting due to their ability to transfer heat to the outside
- perform at a high level until the end of their life (performance drops rapidly thereafter)
- are completely maintenance free.

41.5.2 Absorbed glass mat batteries

Absorbed glass mat (AGM) batteries (Figure 41.8) have low internal resistance and low self-discharge rates, enabling faster recharge and a longer shelf life. When fully charged, they can be stored for extended periods of time and conveniently recharged using a range of AGM-compatible chargers.

AGM batteries contain a sponge-like material that suspends loose electrolyte within highly porous glass-fibre mat separators. This eliminates the hazards associated with acid spills or leaks, while the sealed,

maintenance-free design avoids the need for regular topping-up of electrolyte. AGM batteries use special pressure valves to keep them sealed, because any oxygen entering them will cause damage.

The advantages of AGM batteries are that they:

- function at comparatively high and low temperatures (including Arctic conditions)
- are tolerant to vibration
- are lighter in weight than equivalent lead acid batteries
- experience almost no heating due to low internal resistance
- are completely maintenance free .

The main disadvantage of AGM batteries is that they need to be charged after every use. If this is not done, they experience sulphation and are rendered useless.

Figure 41.8 Cut-away of an absorbed glass mat (AGM) battery OPTIMA BATTERIES

41.5.3 Valve-regulated lead acid batteries

Valve-regulated lead acid (VRLA) is used in gel and AGM batteries to seal them, the valve allowing excess pressure to escape. These batteries must not be vented as any oxygen entering them will destroy them. Figure 41.9 shows details of a VRLA valve.

41.5.4 Calcium batteries

Calcium batteries are a type of lead acid battery. Increasingly fitted to modern vehicles, their newer technology incorporates calcium to the grid plates, giving them more strength.

The advantages of calcium batteries are that they:

- give longer service life and higher starting power
- are resistant to corrosion
- have no ex cessive gassing (production of gas from an electrode)
- are more resilient to high temperatures .

However, calcium batteries require a higher charging voltage (14.4 to 14.8 volts) and may not be suitable for older vehicles (newer vehicles have battery management systems (BMS) to manage the higher voltage). Calcium batteries also require a specialised charger and tester.

41.5.5 Lithium-ion batteries

Lithium-ion (Li-ion) batteries are mostly used in plug-in hybrid electric vehicles (PHEV), hybrid electric vehicles (HEV), electric vehicles (EV) and smaller applications such as mobile phones. Different manufacturers

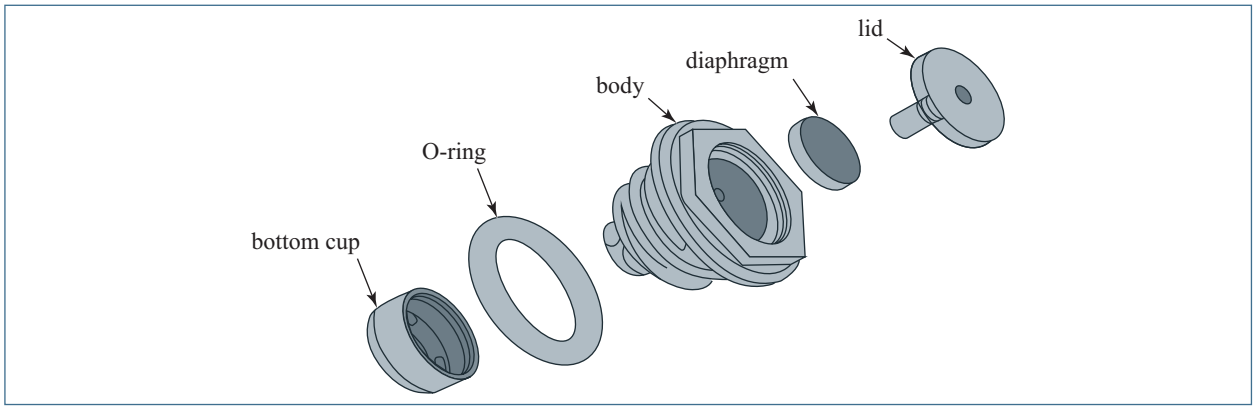


Figure 41.9 Details of a VRLA valve fitted to batteries

have selected different chemistries to suit the needs of their EVs. Many of the new jump starter packs are manufactured using lithium polymer ion. The anode and cathode are the same as previous versions of Li-ion batteries but the electrolyte is a gel/polymer compound.

Lithium iron phosphate batteries

Lithium iron phosphate ($LiFePO_4$) or lithium ferro phosphate (LFP) batteries are safer than other lithium-ion and lithium polymer batteries. They do not suffer from the memory effect of other lithium batteries and can operate safely in a wider range of temperatures due to the added iron. LFP batteries are more widely used in large electric vehicles, electric bicycles, golf carts, battery cars, forklifts, clean cars, electric wheelchairs, power tools, solar and wind power storage equipment, emergency lights, warning lights and miners' lamps.

The advantages of lithium iron phosphate batteries are that they:

- allow full power until they are almost fully discharged
- need less voltage regulation
- have a long life cycle
- are more tolerant of abuse .

41.6 Battery connections

Batteries may be connected in various layouts. When they are connected to form a larger pack of 6-volt, 12-volt, 24-volt and 48-volt application, care must be taken that they are of a similar condition and capacity. If an older battery is left among a pack of new batteries, it may have a higher resistance or capacitance than the rest of the pack. This may cause charging and starting problems (Figures 41.10, 41.11 and 41.12).

41.7 Battery classification

Batteries are benchmarked to the following three standards. The standard they adhere to will depend on their manufacturer.

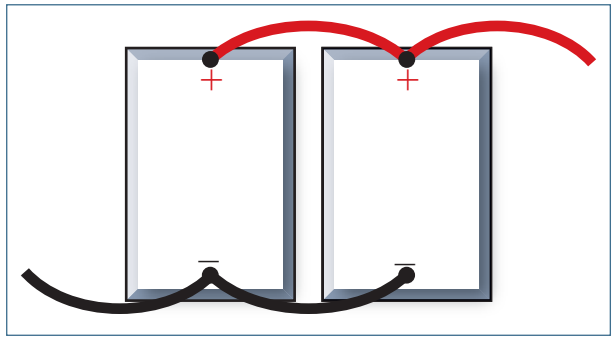


Figure 41.10 Two 6-volt batteries connected in parallel will result in 6 volts but double the amp hours

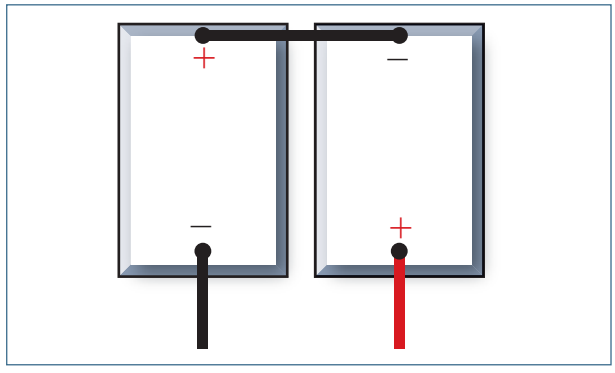


Figure 41.11 Two 12-volt batteries connected in series will double the voltage to 24 volts

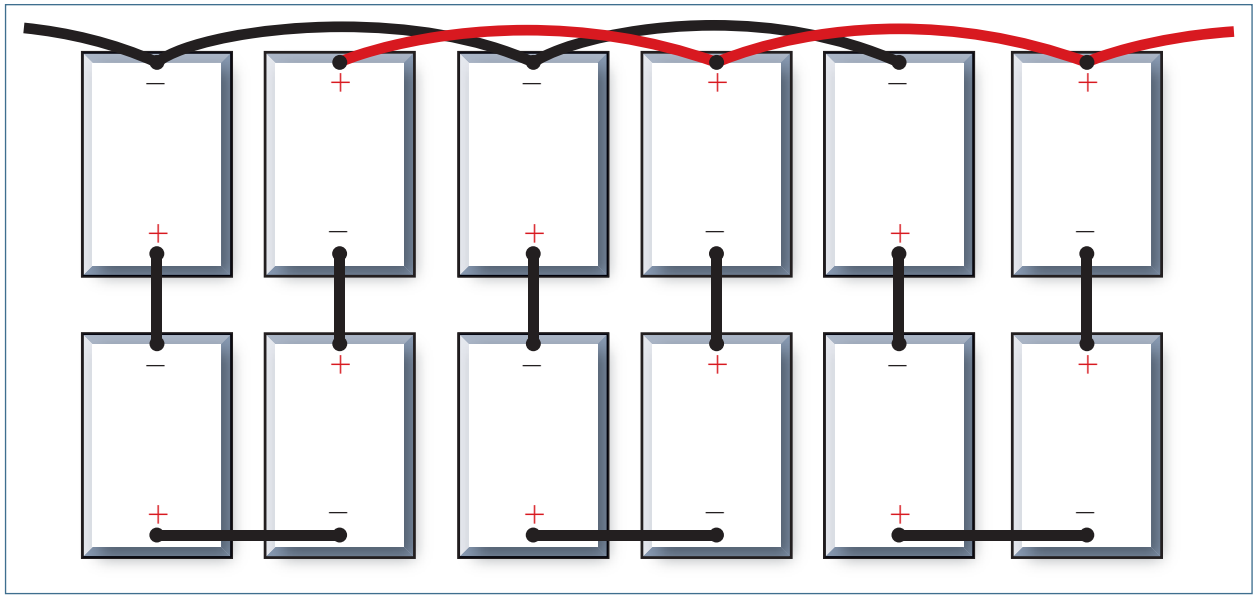


Figure 41.12 Batteries connected in series and parallel to create 48 volts

41.7.1 Cold cranking amps

The most severe load imposed on an automotive battery occurs immediately after the starter is engaged and when it is just starting to turn (crank) the engine. This load or *current draw* is greatest when the engine is cold. The cranking current that can be provided by a battery is therefore important as it needs to maintain sufficient performance to supply other electronic and electrical equipment at a minimum level.

The actual test, which is an SAE performance test, measures the load in amps that a new, fully charged battery can deliver for 30 seconds while maintaining a voltage of 1.2 volts per cell or higher. The battery is then given a cold-cranking-amps (CCA) rating based on its performance.

41.7.2 Ampere hour @20 Hr

This measures a battery's storage capacity to deliver power over a 20-hour period in a controlled environment of 25°C. When the battery falls to 10.5 volts, it is deemed flat. The amount of current used to reach this state is the rating, for example, 100 AH@20 Hr.

41.7.3 Reserve capacity

Reserve capacity (RC) is the time in minutes that a new, fully charged battery will supply a constant load of 25 amps without its voltage dropping below 10.5 volts for a 12-volt battery.

41.8 Battery testing

With the introduction of new battery technology, the process of testing batteries has changed. Where previously there were just hydrometer and load tests, there are now additional tests to consider.

Safety: Never disconnect a battery while an engine is running as this will destroy electronics.

41.8.1 State of health

State of health (SOH) is a *measurement* that reflects the general condition of a battery and its ability to deliver the specified performance compared with a fresh battery. It takes into account such factors as charge acceptance, internal resistance, voltage and self-discharge. SOH measures the long-term capability of the battery and gives an indication (not an absolute measurement) of how much of the available *lifetime energy throughput* of the battery has been consumed, and how much is left.

41.8.2 State of charge

A knowledge of the state of charge (SOC) is particularly important for large lithium batteries. Of all the common cell chemistries, lithium is the most chemically reactive and the only one which needs electronic BMS to keep the battery within a safe operating window and ensure a long life cycle. Control of the SOC is a major function of the BMS where lithium batteries are used and in ISS vehicles with AGM batteries.

41.8.3 Battery tests

There is no one single method of testing all batteries. The testing procedure depends on the type of battery. Tests that can be done are:

- internal resistance , reflecting capability to deliver current
- self-discharge , reflecting mechanical integrity and stress-related conditions
- impedance and conductance testing
- hydrometer testing, reflecting specific gravity and the state of the electrolyte
- high-rate discharge testing, which is testing under load .

Safety: Standard battery testing equipment should not be used to test ISS batteries.

Before a battery is tested, it is important that it is fully charged but has had the surface charge removed. Even a slightly discharged battery can give a false reading and suggest that the battery is faulty when all that is required is a recharge. A digital battery tester is the preferred option as they are safe to use and do not

stress the battery. They are also easy to use and offer a quick diagnosis of many types of batteries (including ISS batteries) that do not operate in a fully charged state.

41.8.4 Testing safety requirement

Before testing a battery:

- check which type of battery is to be tested
- determine which is the positive and negative connection before connecting test equipment
- refer to workshop manuals for the vehicle and the charger for any safety precautions and procedures .

41.8.5 Visual inspection procedures

To visually inspect a battery, it has to be removed from the vehicle to check the case and terminals fully. Look for any cracks or signs of weaknesses, such as abrasion caused by battery movement or incorrect mounting. If there is any sign of a weakness in the case, replace the battery before it leaks acid onto the vehicle.

41.8.6 Hydrometer-testing lead acid batteries

As previously stated, the electrolyte loses sulphuric acid to the plates as it is discharged, becoming less dense and more like water. Measuring the density of the electrolyte will therefore show the state of charge of the battery. There are fewer batteries on the market whose cells can be accessed for testing the electrolyte as many batteries are now maintenance free.

A hydrometer is used to measure the electrolyte density, as shown in Figure 41.13. The bulb on the top of the hydrometer draws electrolyte from a battery cell up into the clear tube. The float inside the tube will float high in the electrolyte when it is dense (battery charged) and low in the electrolyte when it is less dense (battery discharged). The stem of the float is graduated to show the electrolyte density and the state of battery charge.

Figure 41.13 Checking a battery with a hydrometer

Checking a battery

Measure the density of the electrolyte in each cell with a hydrometer. All the readings should be approximately the same. If they are not, the following points apply.

1. If one cell gives a reading much lower than the others, this indicates a faulty cell.
2. If all cells are low , then the battery is discharged. It should be recharged and then tested.
3. If the level of the electrolyte is so low that a hydrometer reading cannot be tak en, the cell should be topped up with water and charged for at least 30 minutes before an accurate reading will be obtained.

41.8.7 High-rate discharge testing

A high-rate discharge tester consists of a voltmeter for reading the battery voltage, an ammeter capable of reading high current (over 200 amps) and a carbon-pile rheostat for applying a load to the battery (Figure 41.14).

The connections are made to the battery and the load adjusted by turning the rheostat knob. The load is adjusted until the current shown on the ammeter is three times the ampere hour capacity of the battery. So, for a 50-ampere hour battery, a current of 150 amps is required. After 15 seconds, the voltmeter

Figure 41.14 Battery capacity test—the battery is tested under load

should show a battery terminal voltage of 9.25 volts or more for a 12-volt battery. (Note that by using a current of three times the battery capacity, the size of the battery is taken into account during the test.) The cranking-current rating of the battery can be used instead of ampere hours. In this case, half the specified cranking current is used.

Safety: Do not use this test on gel, A GM or lithium batteries as the stress on the battery may damage it. Use an electronic tester suitable for the battery type .

Figure 41.15 Electronic battery tester and wireless printer COURTESY CENTURY YUASA BATTERIES PTY LTD

41.8.8 Electronic battery testing

The same test can be carried out using an electronic tester, without the need for a high-current draw from the battery. The test unit is connected to the battery as shown in Figure 41.15. The data of the battery being tested are then entered into the tester. Electronic testers test for resistance and conductance (the battery's ability to conduct current) by passing a small AC voltage at a known frequency and amplitude across the cells and measuring the in-phase AC current. A paper readout of the results can be provided from a wireless printer (also shown in Figure 41.15). This type of testing can be used for different cell chemistries, with the equipment appropriately set. (Not all electronic testers are suitable for all types of batteries and a separate electronic tester may be required for each test.)

Electronic testing is accurate, reliable, safe and fast and does not affect the battery's performance. It can be carried out while the battery is in use to continuously monitor its performance, avoiding the need for load testing or discharge testing.

41.8.9 Battery drain

When a vehicle is put into 'shut down' or 'sleep', with its alarm system fully armed and the doors, hood and boot closed and the key removed, there is a small amount of current flow from the battery. This is known as *parasitic load* or *quiescent drain* and is normal if it is within the manufacturer's specifications. The small continuous current draw is to maintain on-board data (system and control module settings etc.) and to monitor its inputs to either unlock or flag intrusion. A flashing dash-top light will indicate that the vehicle is still drawing power. These power drains should only be measured after the required shut-down time has elapsed (this can be found in the workshop manual, and could be up to 60 minutes). Typically, the current draw will be around 20 to 40 milliamps. With this amount of current draw, it would take 20 to 30 days for the battery to reach 50 per cent state of charge.

41.8.10 Battery leakage test

To test for battery leakage, place the positive lead of a digital multimeter to the top surface of the battery case and the negative to an earth on the vehicle. If any voltage is evident on the meter, there is leakage. If leakage is detected, remove the battery, clean and refit it, and then retest. If leakage continues, replace the battery.

41.9 Battery faults

41.9.1 Overcharging

A battery that requires frequent topping up is probably being overcharged. This over-stresses the active material in the plates, damaging them and shortening the life of the battery. Overcharging boils the water away from the electrolyte, and the electrolyte level is likely to fall below the tops of the plates, exposing them to the air. This will ruin the plates and could also affect the separators.

Handy hint: Where overcharging is suspected, the alternator output should be checked and the voltage regulator replaced.

41.9.2 Undercharging

If the battery is discharged, it should be recharged. In addition, an attempt should be made to determine the cause of the discharged battery. Potential causes include malfunction of the alternator or regulator, defective connections in the charging circuit between the alternator and the battery or excessive load demands on the battery. A battery that has been allowed to stand idle for long periods could be flat from self-discharge. If a battery will not recharge, it could be defective due to its age.

41.9.3 Alternator check

Where overcharging or undercharging is suspected, a quick check of the charging system can be made by connecting a voltmeter to the terminals of the battery as shown in Figure 41.16. Note that the connections are made positive to positive and negative to negative.

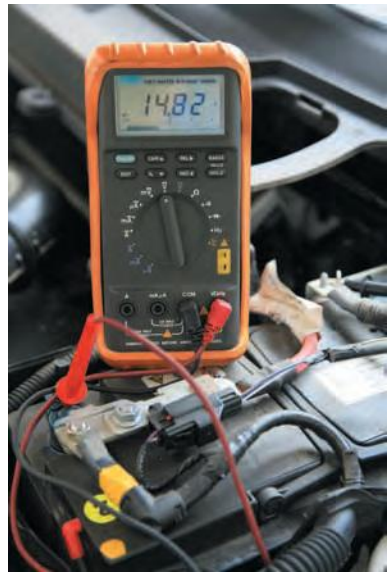


Figure 41.16 A voltmeter connected to the battery terminals checks that the alternator is working

With the engine stopped, the voltmeter should read approximately 12.6 volts or more. With the engine running at a reasonable speed, the voltmeter reading should be higher but not more than about 14.5 to 15 volts. The actual reading will depend on the state of charge of the battery and whether the vehicle has a smart charging system, which can have charge rates that are occasionally much higher.

Handy hint: This is a quick method of checking whether the alternator is working.

41.9.4 Poor topping up

If the electrolyte level is too high due to overfilling, electrolyte can be forced through the hole in the vent caps and cause corrosion of the terminals and other parts. If the level is allowed to get too low, the battery will become damaged internally.

41.9.5 Sulphation

Normally, the active materials in the plates are converted into lead sulphate while the battery is being discharged and reconverted into active material while the battery is being recharged. However, if the battery is allowed to stand for long periods in a discharged condition, the lead sulphate becomes converted into a hard, crystalline substance that is difficult to reconvert into active materials by normal charging processes. A battery in this condition would be replaced.

41.9.6 Damaged case

A cracked or damaged case could result from excessively loose or tight hold-down clamps. A bulged case could be caused by over-tight hold-down clamps, high temperatures or age. The plates warp as the battery ages and this can distort the case.

41.9.7 Corroded terminals

Corrosion is a condition that occurs on battery terminals and is due to acid in electrolyte vapour (Figure 41.17). It can occur more on some batteries than others. Any corrosion should be removed from the battery post and terminals. Cable terminals should be disconnected from the battery posts and

Figure 41.17 Corroded battery terminals is the most common battery problem

the posts and terminals cleaned. After the clamps are replaced, they should be coated with a light grease or petroleum jelly to retard corrosion.

41.9.8 Corroded battery carrier

Some vapour from the battery electrolyte escapes through the vents in the filler plugs as the battery is being charged, and the battery mounting may become corroded from the effects of the acid. Corrosion can be cleaned off (when the battery is removed) with a wire brush or a common baking-soda solution. The soda solution is applied and, after the foaming stops, flushed off with clean water.

Handy hint: Dirty battery connections are the most common cause of a starter failing to operate .

41.9.9 Dirty battery case

If it not cleaned periodically, the top of the battery can collect a coating of grime with traces of electrolyte. This should be cleaned off with a wet rag. If a baking-soda solution is used on the battery, care should be taken that the solution does not get into the cells and ruin the battery.

41.9.10 Battery failure

Batteries deteriorate over time and with use. The active material of the plates is gradually reduced by the actions of charging and discharging and by vibration. Eventually, the plates lose so much of their capacity that the battery is no longer of any use. What appears to be a sudden failure of a battery is usually due to the slow corrosion of grids and electrical connections until the electrical circuit through one of the cells is finally broken. The battery will then have an open circuit.

41.10 Battery charging

Always read the manufacturer's instructions before attempting to charge a battery and ensure you use a good quality, Australian-approved battery charger. The battery type and the internal technologies will determine which type of charger is required.

Safety: Identify what type of battery is to be charged and take any necessary precautions before proceeding. If the battery is to be charged while in the vehicle, it should be isolated by removing both battery cables before connecting the battery charger.

41.10.1 Gel and AGM batteries

Batteries fitted with a VRLA (gel and AGM) have special charging requirements. Over-charging or constant charging will damage the battery by drying out the electrolyte as it will cause the hydrogen and oxygen to be vented. Only use battery chargers that are designed for these batteries.

41.10.2 Lead acid and calcium batteries

Safety: When recharging, lead acid batteries produce hydrogen gas, which is explosive. Charge batteries in a well-ventilated area, away from flames and sparks.

A slow charge is the best way to charge a lead acid battery because the chemical reaction required in both plates takes time. Fast charging only converts the lead sulphate on the outside of the plates, and if not controlled can damage the plates.

Slow charging

The charger has two leads with battery clips for attaching the charger to the battery (Figure 41.18). These are marked positive (+) and negative (−). The (+) clip is connected to the (+) battery terminal, and the (−) clip is connected to the (−) battery terminal (positive-to-positive and negative-to-negative connections).

Figure 41.18 A battery charger is connected to the battery with positive to positive and negative to negative

The charger provides a slightly higher voltage than the battery, so that current flows from the charger to the battery. For normal slow charging, this is adjusted to provide a charging rate of 4 to 6 amps. The charging is continued until the battery is gassing freely and there is no further rise in density for two hours. The charging voltage is held at a constant value. The battery, as it approaches a charged condition, increases in resistance to the charging current. This causes the current input to taper off gradually until, when the battery is fully charged, it will be reduced to a few amps.

Fast chargers

These operate by charging the battery at a high rate for a short period (up to 30 minutes) so that it is brought up to a reasonable state of charge before its temperature increases excessively. Provided that temperatures can be controlled, fast charging does not appear to damage the battery. The temperature when charging should not exceed 60°C. To bring a battery up to full charge, it is necessary to complete charging by a slow-charging method.

Handy hint: Batteries in doubtful condition should not, in general, be fast charged as complete failure could result.

41.11 Battery selection

Most manufacturers list several alternatives for battery selection. The advent of computerised systems such as BMS has made reference to the manufacturer's minimum requirements vital when selecting a battery. This is because batteries such as the silver calcium battery have a higher charge rate, so fitting a standard lead acid battery may have detrimental effects. When calcium is used in a battery, it will generally be maintenance free.

Hybrid batteries are now available. These use new technology in old-style chemistry, such as glass matt separators and thicker plates. They enhance the durability of the battery in harsher conditions, for example in boats, motorbikes or heavy trucks, where vibration and pounding are a problem.

Always follow the manufacturer's recommendations when fitting new batteries. This is particularly important with ISS battery management systems or intelligent battery sensors. Never fit a conventional battery in a vehicle with ISS technology as this may disable the ISS functionality and lead to premature battery failure. Vehicles with these systems must have the system reset because of the memory held by their computers. Resetting the system ensures that the sensors and computer management system are compatible with the battery's properties.

When selecting a battery for replacement, always consult the manufacturer's recommendations to make sure you get the correct type. Also consider:

- terminal location and type
- case size
- cold cranking amps (C CA) or performance
- the battery mounting method
- the application or type of vehicle .

41.12 Battery replacement procedures

If a new battery is to be installed, it must have a rating that is the same or greater than the original battery. The cold cranking amps rating is the easiest way to compare battery ratings.

The battery must be fit for the purpose it is going to be used for. Off-road and commercial vehicles require stronger internal construction because of vibration and jolting on rough roads. Recreational vehicles, for example mobile homes, use deep-cycle batteries that are designed to be completely discharged and recharged. Car batteries are not suitable for this type of use, nor for marine applications.

The external dimensions of the battery and the type of posts must also be suitable. While most modern vehicles will take a fairly standard type of battery, others may need a squat (lower height) battery, or one with lugs or smaller posts. The method of holding the battery in its mounting can vary, and some batteries have a bottom or side ledge so they can be clamped in the carrier.

41.12.1 Installing a battery

Apart from being clean and secure in its mounting, the battery must be installed the right way, that is with its negative terminal connected to earth. The alternator or other electrical equipment could be damaged if

the battery were installed with its polarity reversed. Figure 41.19 shows the points to be checked on an installed battery during service.

Handy hint: A 'battery saver' should be installed before removing the battery to save computer codes and personal settings on audio and climate control systems.

The procedure for installing a battery is:

1 Identify the positive and negative cables.
2 Identify the positive and negative posts of the battery and install the battery in its carrier so that the posts are in the right position for the cables.
3 Fit the holding clamp on the battery so it does not move when the terminals are fitted. Do not over-tighten the clamp .
4 Fit the terminal of the positive cable to the positive battery post first.
5 Fit the terminal of the negative cable to the negative battery post.
6 Tighten the battery terminals firmly and apply a light coating of grease to protect them against corrosion.

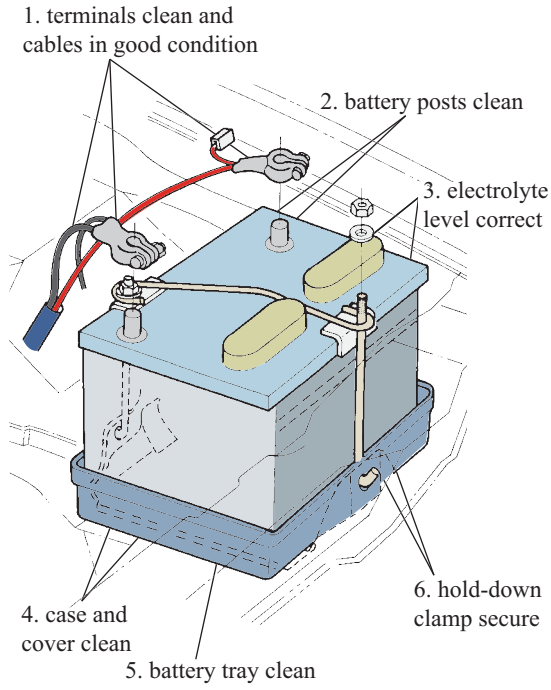


Figure 41.19 Battery and mounting—points to be check ed during service GM HOLDEN LTD

Handy hint: To prevent short-circuiting the battery , the negative (earth) terminal should be removed first and replaced last.

Batter y shroud

Some vehicles provide a shroud into which the battery is fitted. Figure 41.20 shows the arrangement of a shroud that has an air scoop. This directs cooler outside air through the shroud and around the battery. Batteries are mounted in the engine compartment, the boot or behind seats; the shroud provides some protection from the heat of the engine.

41.13 Batter y terminal disconnection and system recalibration procedures

When replacing the battery in many later-model vehicles, particularly ISS vehicles, there will be a procedure to be followed to get some of the electronic and electrical systems working correctly, as shown in Figure 41.21. The reason for this is that the BMS has stored information that relates to the old battery. This information may have put the vehicle into a power save mode which will affect items such as the air-conditioner, electric/hydraulic steering systems, advance keyless entry systems and stability control systems. Another consideration is the clearing of detected trouble codes (DTC). Reference to the correct workshop manual will need to be made to obtain the correct procedure for each vehicle. This may be also required even if you remove the negative cable which has the battery sensor attached. Some vehicles have two different-sized batteries fitted. One is used to start the vehicle and the other to run the electrics and

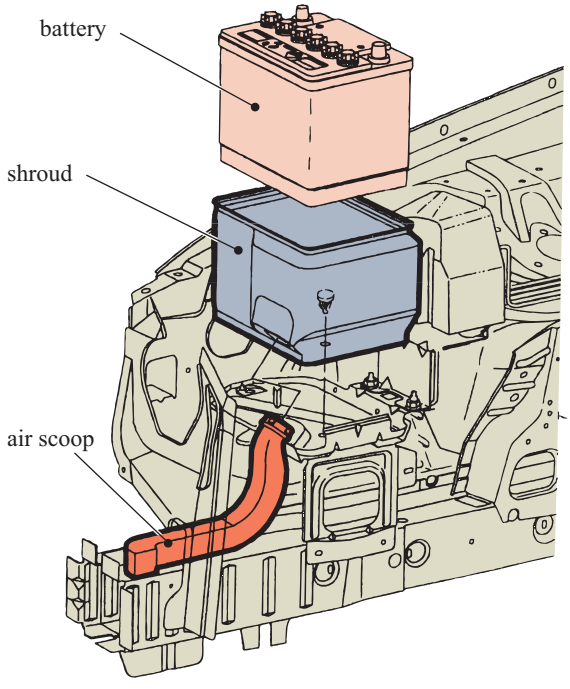


Figure 41.20 A battery shroud with an air scoop FORD

keep all the functions of the vehicle working. The advantage here is that the start battery would still operate if, for example, a car was stuck in traffic for an extended time with the air conditioner on (a circumstance that might flatten the battery).

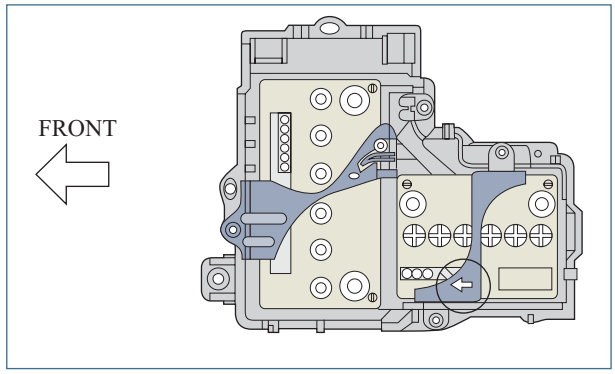


Figure 41.21 When replacing batteries in an ISS vehicle, the correct procedures must be followed

41.14 Battery jump start procedure

The use of jumper leads for emergency starting is not just a case of connecting two batteries together, and it can be dangerous if not done correctly. With the amount of electronic equipment that is now fitted to vehicles, extra precautions must be taken to prevent damage to electronic components from high voltages. To counteract this, special jumper leads are available. These have light-emitting diodes to show that the cables are connected with the correct polarity. They also have voltage-spike protection. Always follow the information in the particular vehicle handbook or service manual.

Safety: The safest way to deal with a flat battery is to replace it with a charged battery. With jumper leads, voltage spikes can be generated under some conditions. These are sudden surges of high voltage that can damage electronic components.

41.14.1 Jump-starting procedure

The following points summarise the recommended procedure for using jumper leads:

1. Both the booster battery and the discharged battery must be of the same voltage.
2. If the booster battery is fitted in another vehicle, the vehicles should not be touching. Both batteries must have the same polarity in the vehicle (negative to earth).
3. Switch off the ignition, the lights and all other electrical equipment.
4. Check that the vent caps of both the booster battery and the discharged battery are tight and place a cloth over the filler caps of both batteries.
5. With the red jumper lead, connect the positive terminal of the discharged battery to the positive terminal of the booster battery. (The sequence of connecting the batteries is shown in Figure 41.22.)

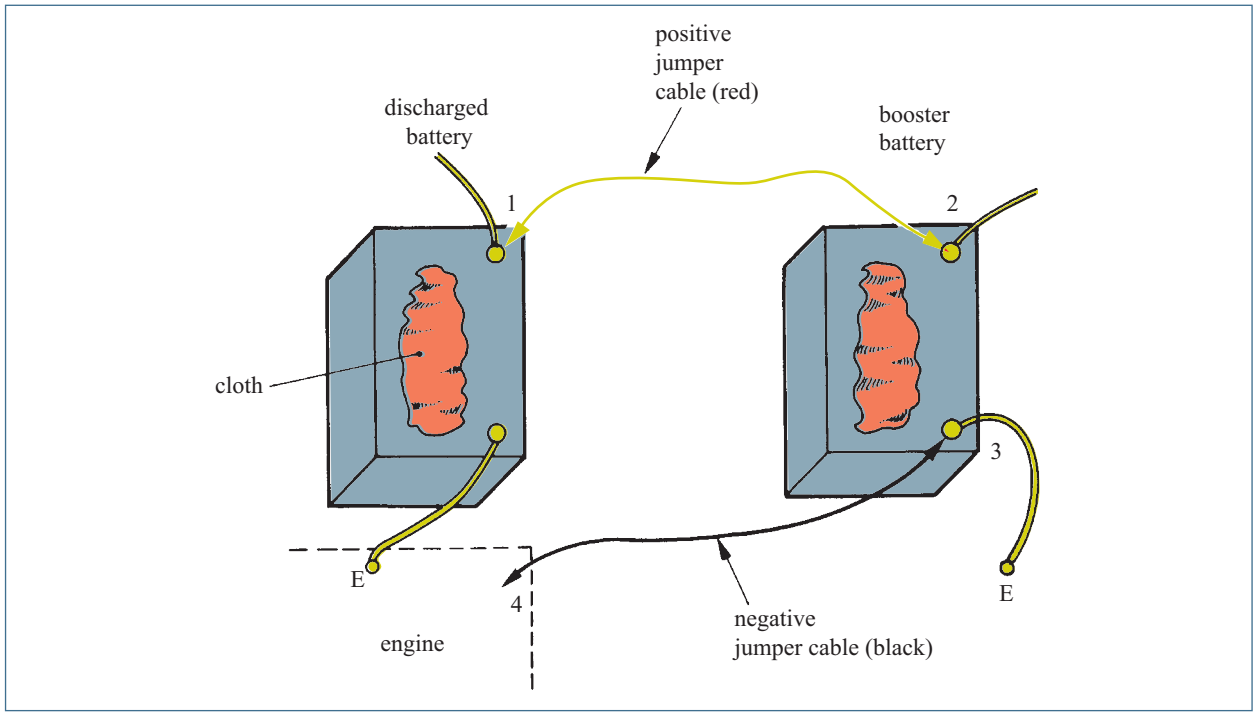


Figure 41.22 Connecting a booster battery for emergency starting—the connecting sequence is shown as 1, 2, 3, 4

6 Attach one end of the black jumper lead to the negative terminal of the booster battery and the other end to an earth on the engine away from the battery (not to the negative battery terminal). Both vehicles would normally have their batteries installed with negative to earth.
7 Start the engine of the vehicle with the booster battery and let it idle for a few minutes. Then start the engine of the vehicle with the discharged battery .
8 Allow both engines to run for a few minutes to allow the batteries to stabilise .
9 Disconnect the jumper leads carefully in the reverse order to that used when connecting them.
10 Dispose of the cloths used to cover the filler holes (they could contain acid).

Safety: The cloths are placed over the filler caps to absorb the gas that comes from the cap vent holes. This is an explosive gas that could be ignited by a spark.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- identify the hazards presented by batteries and resulting environmental requirements
- describe basic battery construction
- explain the chemical actions that tak e place during charging and discharging
- list the correct voltages of a fully charged battery
- list the properties of gel and A GM batteries
- explain the precautions that should be tak en when charging batteries with VRLA
- explain the part calcium plays in the construction of a battery
- identify lithium-ion and lithium polymer batteries
- explain what the different classifications of batteries mean
- list the testing requirements of different batteries
- list the types of battery fault
- describe the charging requirements of the different types of batteries
- list the items to be considered when selecting a replacement battery
- describe the battery replacement procedure and explain the need for recalibration
- describe the procedure for jump-starting a vehicle using jumper leads.

REVIEW QUESTIONS

1 What is the purpose of the battery ?
2 Name the parts of a battery .
3 Why is a section of the battery referred to as a lead-acid cell ?
4 What actions occur when a battery is being charged?
5 What are ampere hours ?
6 What is meant by density ?
7 By means of a sk etch, show how the cells of a battery are connected together to provide 12 volts. Show the polarity of each cell.
8 Explain how the density of the electrolyte is check ed.
9 A 12-volt battery in good condition is tested with a voltmeter while under heavy load. What is the voltmeter likely to show?
10 Describe the various ways in which specifications for batteries are given.
11 State the items that would be check ed when servicing a battery .
12 What are some of the possible causes of a discharged battery ?
13 If an engine will not start because of a discharged battery , what can be done to rectify the problem ?
14 Outline the procedure to be used when connecting batteries with jumper leads for emergency starting.
15 What particular safety precautions should be observed when using jumper leads ?
16 On some modern vehicles a calibration process is required when a battery is replaced. Why is this necessary ?
17 When selecting a replacement battery for a vehicle what should be considered?

PART 8

Electrical systems

CHAPTER 42

Starting systems

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

- identify and understand what starting systems and associated components do and how they work
- follow diagnostic testing procedures for starting systems, including the use of scan tools
- test electrical systems, and understand procedures for doing so
- identify repair procedures for starting systems
- follow post-repair testing procedures for starting systems.

During start-up , two actions occur: the pinion of the starter motor engages with the flywheel ring gear , and the starter motor operates to 'crank' the eng ine .

In pre-computerised systems, the starting system consisted of the battery , cables, starter motor , flywheel ring gear and the ignition switch. In computerised systems, when the start button is pressed or ignition key turned to the start position, the ECM is energised and checks the signals for the mobilisation code (in the key) and other programmed safety-related units such as clutch and brak e switches, transmission control module (TCM), battery monitoring module (BMM),body control module (BCM)and other sensors. When all systems are check ed and verified, the ECM activates the starter motor .

For idle start stop (ISS) vehicles, there are extra considerations that vary by manufacturer and type of vehicle .

The starter motor is an electric motor mounted on the engine block; it draws power from the battery of the vehicle during the starting operation. It has a high torque at low speeds as it has to start the engine 's crankshaft turning from the stationary position, and keep it turning until the engine fires and runs on its own.

42.1 Basic starter motor

Figure 42.1 shows a starter motor (or starter) with its external parts identified. The three main parts are:

1 Solenoid. This includes the starter switch that connects the starter motor to the battery . It is also used to engage the pinion with the ring gear on the flywheel.
2 Starter motor . This is a special type of electric motor operated from the battery .
3 Starter drive . This consists of a pinion and a clutch. The pinion is meshed with the ring gear fitted to the flywheel or a drive plate by a lever that is operated by the solenoid.

42.1.1 Solenoid

So that the solenoid starter switch can carry a high current, it has a heavy copper disc which bridges across the switch contacts to operate the starter motor (Figure 42.2). When the ignition switch is turned to *start*, the solenoid winding is connected to the battery.

Current flowing through the winding produces magnetism. This pulls the plunger in, forcing the disc against the switch contacts. The plunger also operates the shift lever to engage the pinion.

The solenoid actually has two windings, a *pull-in* and a *hold-in winding*. They work as follows:

1. The windings combine to pull the solenoid plunger in.
2. The pull-in windings are shorted out when the switch contacts close as they are in parallel with the switch. This de-energises the pull-in windings, which are no longer needed.
3. During cranking, the pinion is held in mesh with the ring gear by the hold-in windings, which draw much less current than the pull-in windings.
4. When the ignition key is released from the start position, the hold-in windings are de-energised, and the spring on the shift lever (or in the solenoid) pulls the pinion out of mesh.
5. The overrunning clutch operates to prevent excessive armature speeds after the engine starts and before the pinion comes out of mesh.

42.1.2 Starter motor

The starter motor operates by producing electromagnetism, which requires a number of windings to produce strong magnetic fields. Two parts of the starter motor have these windings—the *armature* and the *field coils* inside the yoke (Figure 42.3).

The armature is located inside the field assembly and is supported by a bearing at each end. When the starter is connected to the battery by the starter switch, the magnetic fields react, causing the armature to rotate.

42.1.3 Starter drive

The drive pinion is mounted on the armature shaft. Through a lever action, the solenoid engages the pinion with the ring gear before the starter motor begins to rotate. When the switch contacts in the solenoid are closed, the armature rotates and the pinion turns the ring gear.

Handy hint: The gear ratio of the pinion and the ring gear is about 15:1.

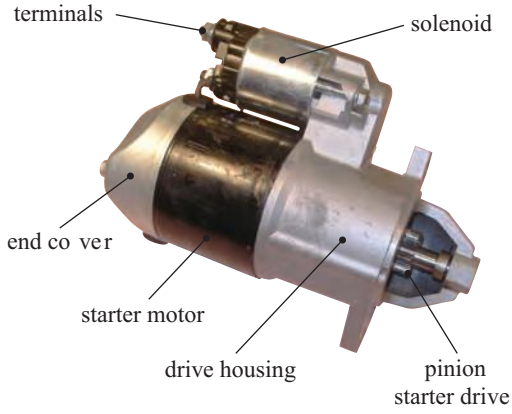


Figure 42.1 A starter motor assembly with the external parts identified

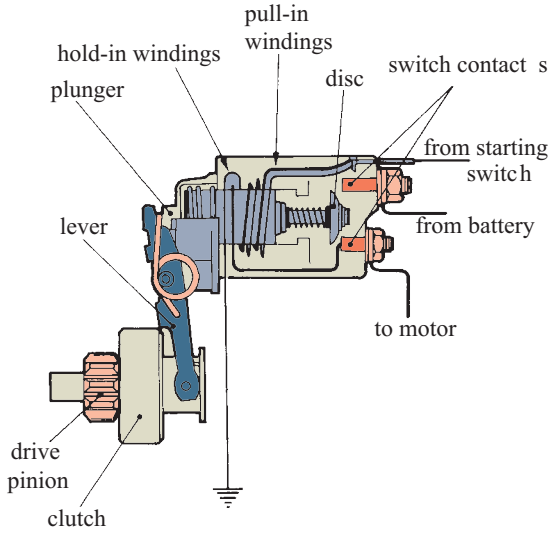


Figure 42.2 Starter solenoid and starter drive

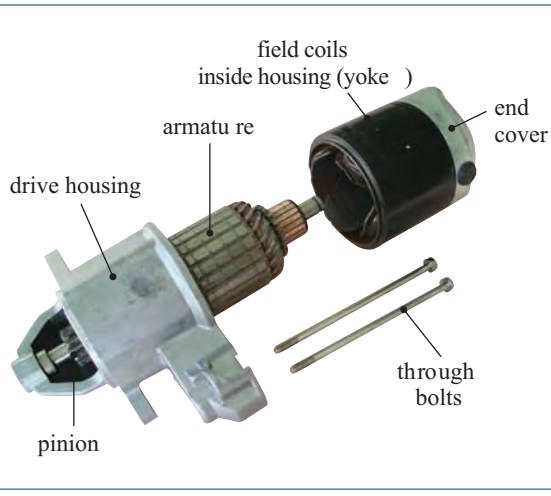


Figure 42.3 The drive housing and armature removed from the starter yoke—the yoke contains the field coils

42.2 Basic motor principles

All electric motors, including the starter motor, operate by the force produced between two magnetic fields (Figure 42.4). One of the fields is produced between the north and south poles of a permanent magnet. The other is an electromagnetic field produced by a current flowing in a conductor.

With the conductor between the poles of the magnet, there is a reaction between the two fields. The magnetic lines of force combine to produce a strong field on one side of the conductor and a weak field on the other. The effect of this is shown in Figure 42.5.

The bent lines of force on the left side of the conductor are trying to straighten and are applying a force to move the conductor to the right. If the current in the conductor is increased, there will be more lines of force and a stronger field to move the conductor.

Handy hint: Using a stronger magnet also increases the force against the conductor .

42.2.1 Basic motor operation

The basic parts of an electric motor are the armature and the field, as shown in Figure 42.6. A U-shaped conductor (or loop) connected to a split copper ring forms the armature, and a permanent magnet provides the field. The split ring is a *commutator* that provides a contact for the brushes.

When the electric motor is connected to a battery, as in Figure 42.6(a), current will flow through the brushes, the commutator and the loop conductor. The magnetic field around the conductor forces one side of the loop up and the other side of the loop down, as in Figure 42.6(b), so that the loop rotates.

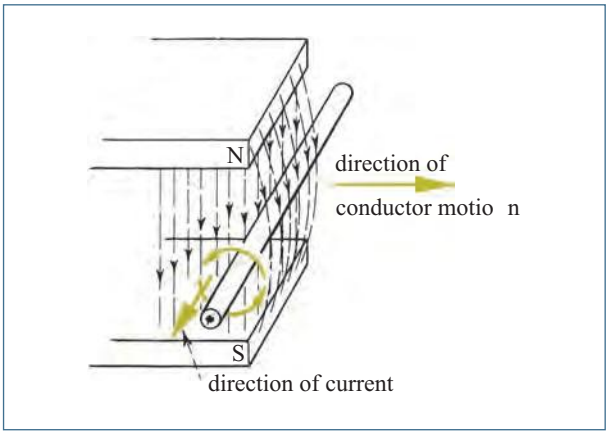


Figure 42.4 Conductor in a magnetic field with current flowing through it—this is the basic principle of an electric motor

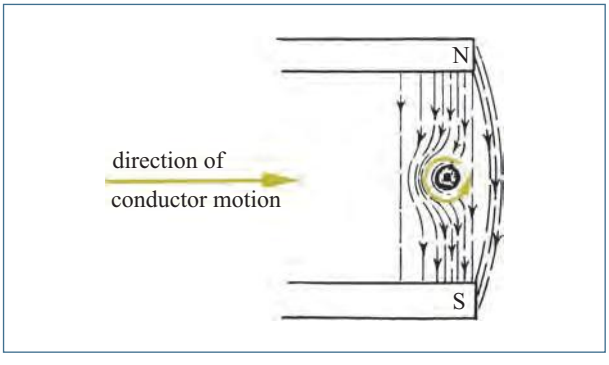


Figure 42.5 Distortion of the field around the conductor when current is flowing in the conductor

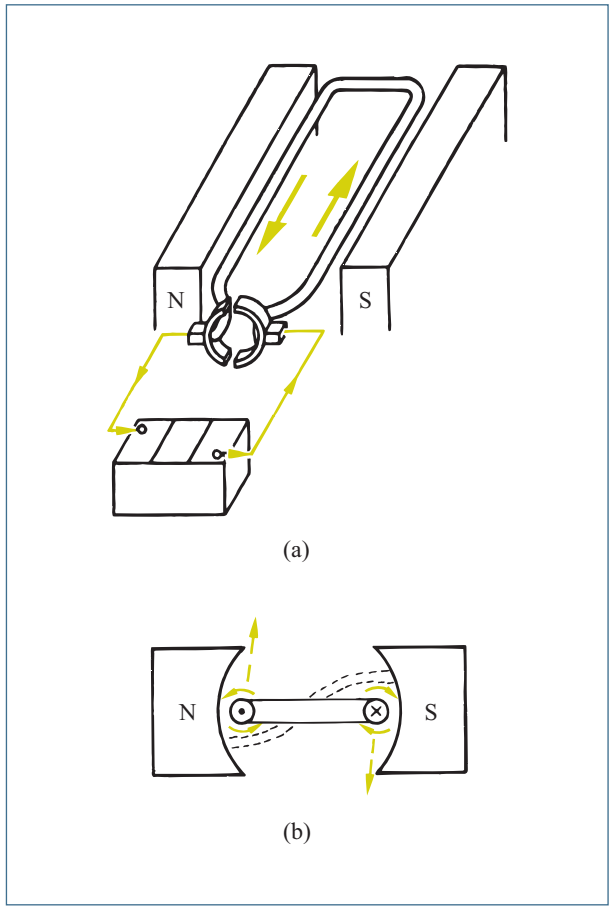


Figure 42.6 Simple electric motor: (a) loop with a two-segment commutator (b) section showing the magnetic fields that move a conductor

The commutator rotates with the loop so that the current always flows through the loop in the same direction (as shown by the arrows). This maintains the correct magnetic polarity so that the loop continues to rotate.

Handy hint: The commutator and brushes form a rotary switching device .

42.3 Starter motor operation

A starter motor needs an armature with many loops, or conductors, to produce strong magnetic fields. The loops are connected to a commutator with a number of segments. Starter motors can have permanent magnets, or field windings which produce a strong magnetic field between the field poles. An armature and a yoke containing the field windings are shown in Figure 42.7.

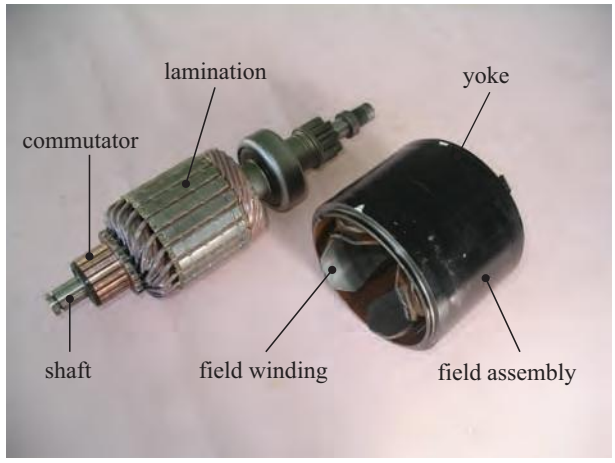


Figure 42.7 The two major parts of a starter motor

42.3.1 Armature

The armature consists of a number of soft-iron laminations mounted on a shaft. These form a core with slots to carry the armature windings, the ends of which are connected to the segments (or bars) of the commutator, which is insulated from the armature shaft.

The segments of the commutator are insulated from each other. When the starter is operated, current flowing in the armature windings produces a strong magnetic field.

42.3.2 Field assembly

The field assembly consists of the yoke, the field poles and the field windings. When the starter is operated, the field windings produce a strong magnetic field between the field poles. The reaction between the magnetic field of the armature and the magnetic field of the field poles causes the armature to rotate.

42.3.3 Internal circuit

Figure 42.8 is a simple wiring diagram of the internal circuit of a starter motor. There are two field poles, each with a winding, and a commutator with two brushes.

The circuit is from the starter motor terminal, through the field windings, then through the insulated brush to a segment of the commutator. From there, the circuit is through an armature winding (not shown) to the opposite segment of the commutator and through the earthed brush, completing the circuit to earth. Both the field windings and the armature windings are energised when current flows through the circuit.

Starter motors with their windings arranged like this are described as *series-wound* or *series-connected,* because the field and armature windings are connected in series. Figure 42.9 shows a simple starter motor with windings of this type.

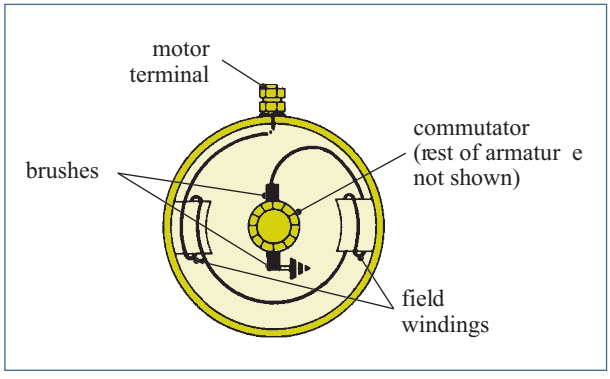


Figure 42.8 Simple diagram of the internal circuit of a starter motor—the field windings are connected in series

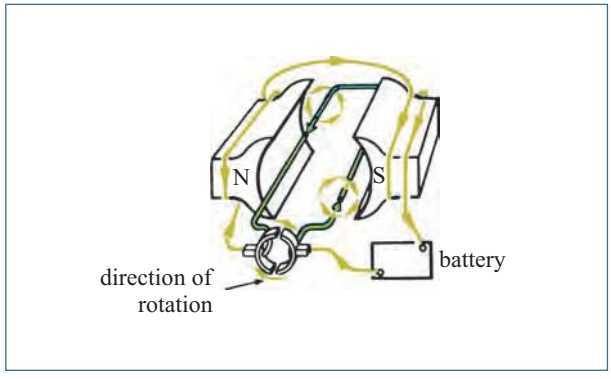


Figure 42.9 Simple starter motor with field and armature windings

42.4 Starter motor characteristics

High torque is obtained when the field windings and armature windings are connected in series. Although high torque is needed to start the crankshaft turning, the starter can provide the lower torque needed once the crankshaft is rotating.

When the starter pinion is first engaged, a heavy load is imposed on the starter. This causes a high current to flow from the battery through the field and armature windings. The same current flows through both windings, producing strong magnetic fields.

However, once the crankshaft starts to turn, there is less load applied to the starter and the current drops off. This weakens the fields so there is less torque.

The series windings of a starter motor provide the characteristics needed. A starter has a heavy current flow (around 150 amps) from the battery at low cranking speeds. At higher cranking speeds, this drops off to around 50 amps.

Handy hint: Reduced current at higher speeds is caused by a back EMF being induced in the armature windings as they rotate . This opposes current flowing from the battery—the faster the armature rotates, the less the current flow .

42.4.1 Series and compound windings

Electric motor windings can be arranged in three different ways: *series-wound, shunt-wound* or *compound-wound.* Figure 42.10 shows the basic circuits for these.

Series-wound

The wiring diagram in Figure 42.8 is of a two-pole, two-brush starter motor with series windings. As already indicated, series motors have high torque at low speeds.

Shunt-wound

Shunt-wound motors have their armature and field windings connected in parallel. They have low torque at low speeds and operate at a fairly constant speed.

Compound-wound

Compound-wound motors (or series shunt motors) have some series windings and some shunt windings. This gives them a high torque at low speed and a controlled high speed. Starter motors have four brushes and four poles and are usually compound-wound. Figure 42.11 shows the internal circuit of a compound-wound starter motor.

42.4.2 Permanent magnet field

Some starters do not have field windings, but have permanent magnets that form the field. Figure 42.12 shows the yoke and one set of magnets for a starter of this type. Six permanent magnets are used and these are retained inside the yoke.

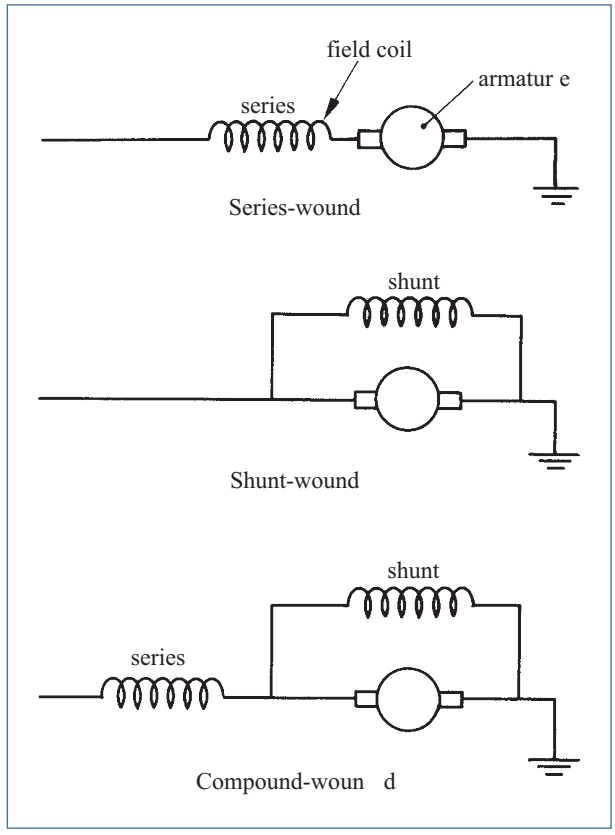


Figure 42.10 Types of starter motor windings

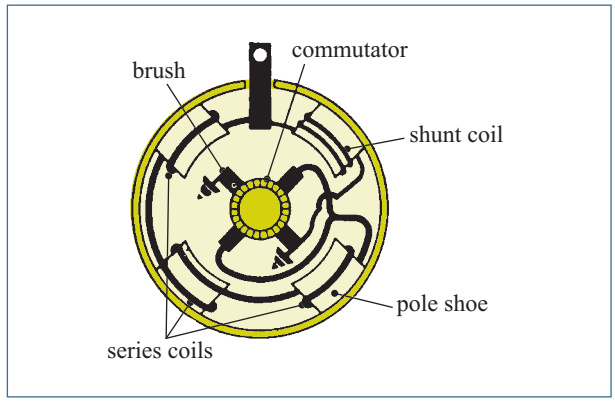


Figure 42.11 Wiring circuit of a four-pole compound-wound starter motor

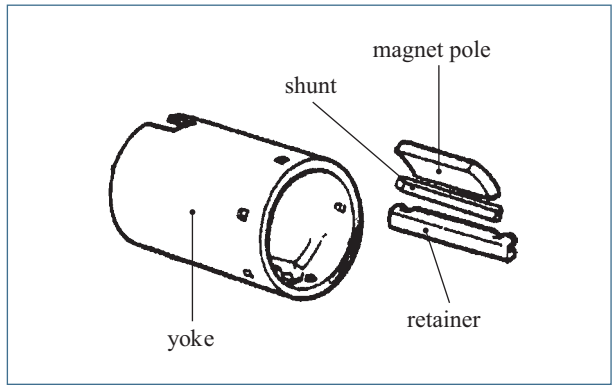


Figure 42.12 Starter yok e with magnet field poles—there are six magnets but only one is shown

The six magnets combine to produce a strong magnetic field. The armature has the normal windings which, when energised, react with the field of the permanent magnets to produce rotation. Permanent magnet starters can produce 2.5 kW of power. For gear reduction, magnet starters can be used in petrol motors up to 6.2 litres and for diesel motors up to 4 litres.

42.5 Direct-drive starters

A diagram of the arrangement of a direct-drive starter is shown in Figure 42.13. This type of starter is widely used and is referred to as a direct-drive starter because the drive pinion and the overrunning-clutch assembly are mounted directly on splines on the armature shaft.

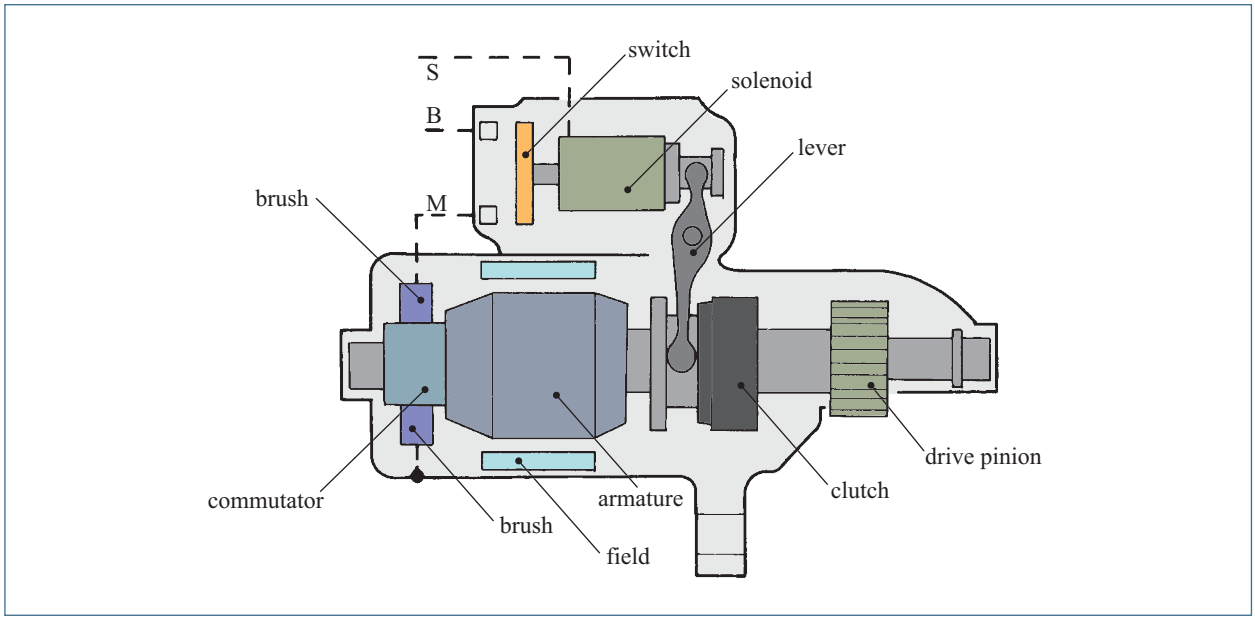


Figure 42.13 Schematic arrangement of a direct-drive type starter—the connections are: S solenoid B battery M motor

42.5.1 Starter operation

When the ignition switch is turned to *start*, the pinion and clutch are moved along the armature shaft by the action of the solenoid plunger and shift lever. This brings the pinion into mesh with the ring gear. Once the pinion is engaged, the switch contacts in the solenoid are closed and the starter cranks the engine.

Once the engine starts, the pinion must be disengaged quickly to prevent the armature from being spun at excessive speeds and the resultant centrifugal force throwing the conductors out of their slots in the armature core. To guard against this, the pinion has an overrunning clutch that disengages as soon as the engine is turning faster than the starter motor. A return spring in the solenoid then moves the pinion out of mesh.

Figure 42.14 is a sectional view of a direct-drive starter, showing the solenoid, shift lever and drive assembly.

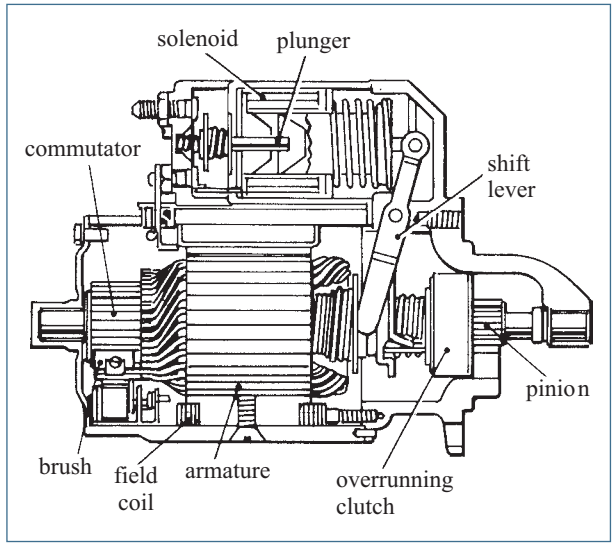


Figure 42.14 Sectional view of a direct-drive starter

Starter drive

The starter drive includes the over-running clutch, the drive pinion and a collar for the shift lever. In some cases, there is also a spring between the shift-lever collar and the clutch. The spring compresses

if the pinion teeth abut against the teeth of the ring gear instead of meshing. As soon as the starter turns slightly, the teeth of the gears will align and the spring is able to move the pinion teeth into mesh.

42.6 Reduction-type starters

Reduction-type starters have a set of gears between the armature shaft and the drive, giving a reduction of around 4:1. The gearing enables the starter to produce more torque for the size of the motor. Two types of gears are used–*spur gears* and *planetary gears.*

42.6.1 Spur reduction gears

Figure 42.15 is a schematic arrangement of a starter with spur gears. The small gear on the armature shaft is meshed with a larger gear on the drive shaft. The solenoid and shift lever operate in the normal way. Note: the only difference between this and a direct-drive starter is the reduction gearing.

42.6.2 Planetary reduction gears

The arrangement of a starter with planetary gearing is shown in Figure 42.16. This has a small sun gear machined in the armature shaft and pinions mounted on a carrier on the drive shaft. The pinions walk around inside the stationary internal gear, providing a gear reduction between the armature and the drive shaft.

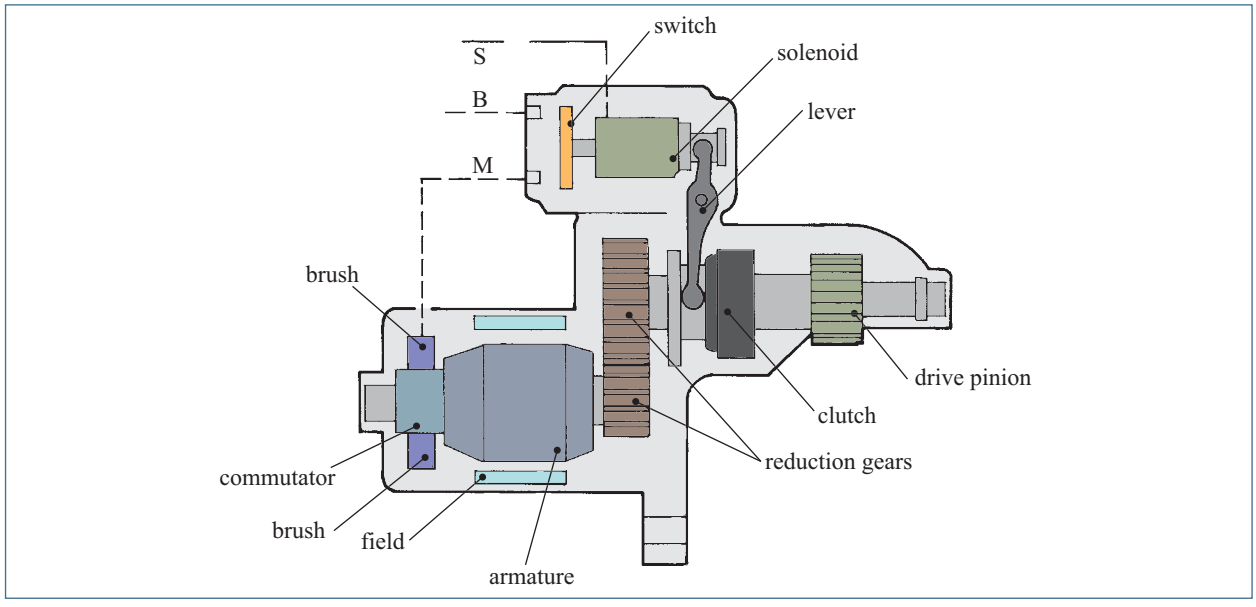


Figure 42.15 Schematic arrangement of a reduction-type starter assembly with spur gearing

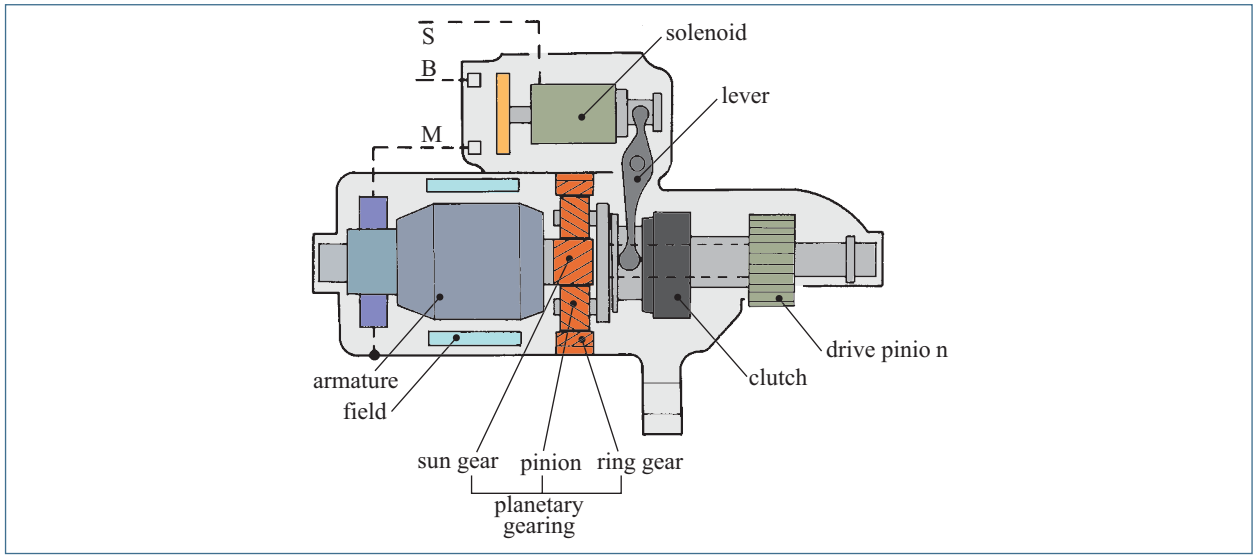


Figure 42.16 Schematic arrangement of a reduction-type starter assembly with planetary gearing

42.7 Starting electrical system

Figure 42.17 shows the starting electrical system. It includes the battery, ignition switch, solenoid, starter relay, fuses and the automatic-transmission inhibitor switch.

This is a typical system in which the starting switch is part of the ignition switch. It operates as follows:

1 When the ignition key is turned to the start position, the battery is connected to the starter relay through the inhibitor switch.
2 The relay coil closes the internal contacts, energising the starter solenoid.
3 The solenoid pulls its plunger in. This shifts the pinion into mesh with the ring gear and then closes the switch contacts to operate the starter.
4 The solenoid has pull-in windings and hold-in windings.

Handy hint: With an overrunning clutch, the pinion is allowed to spin faster than the armature until it comes out of mesh.

42.7.1 Other circuit switches

Vehicles with automatic transmissions have a special safety switch in the starting circuit. Located between the ignition switch and the starter solenoid, it is referred to as a *neutral switch,* isolator switch or inhibitor switch.

The switch prevents the starter from operating unless the transmission selector lever is in the N or P positions. These are the only positions where the switch contacts are closed. The switch is *off* in all other selector positions to prevent current from reaching the solenoid.

Some manual transmissions have a clutch-pedal safety switch; the clutch pedal has to be depressed before the starter will operate, which prevents the engine from being started with the transmission in gear.

Engine management starter systems

Most starter motors are activated by the engine ECU. When the start position is selected, a start request is sent to the ECU.

When a computer-managed engine system is used, the BCM will check multiple systems, such as battery voltage, security code from the key, brake switch or clutch switch, park/neutral switch before sending an authorisation to the ECU to activate the starter. This will only take milliseconds (Figure 42.18).

Stop/start systems

To meet emission requirements and increase vehicle efficiency, manufacturers use ‘stop/start’ systems in some vehicles. These stop the engine when the car is brought to rest. Using sensors on the vehicle, the vehicle’s starter motor automatically starts the engine when the driver presses the accelerator pedal to move off again. These systems can be turned off or on by the driver.

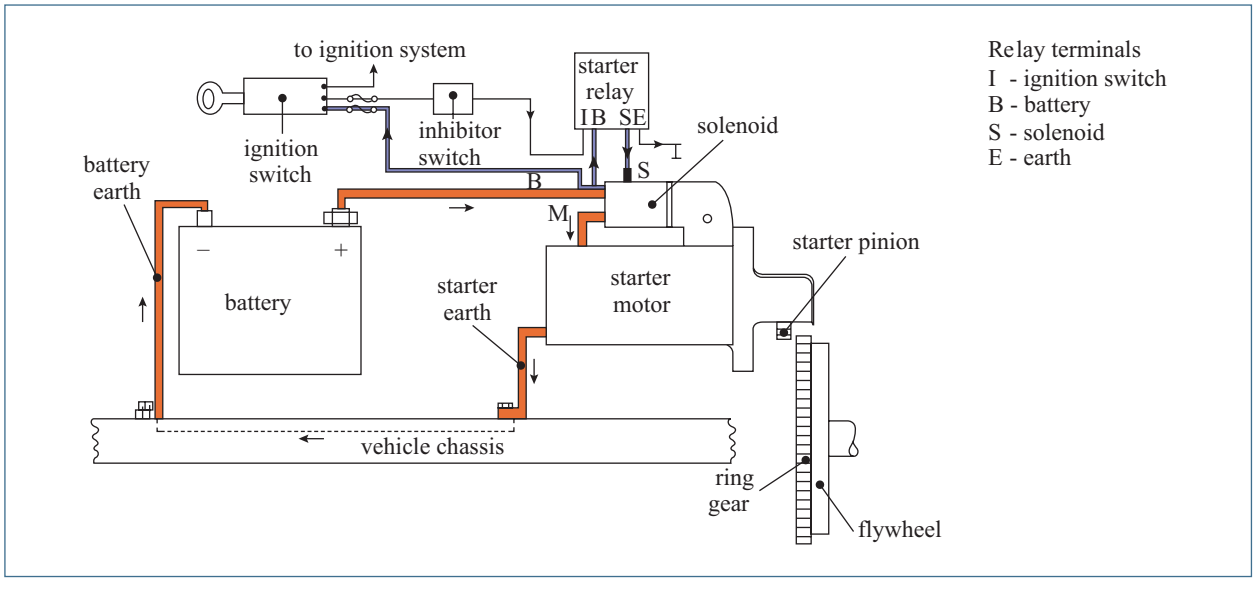


Figure 42.17 Basic electrical starting system: arrows show the current flow

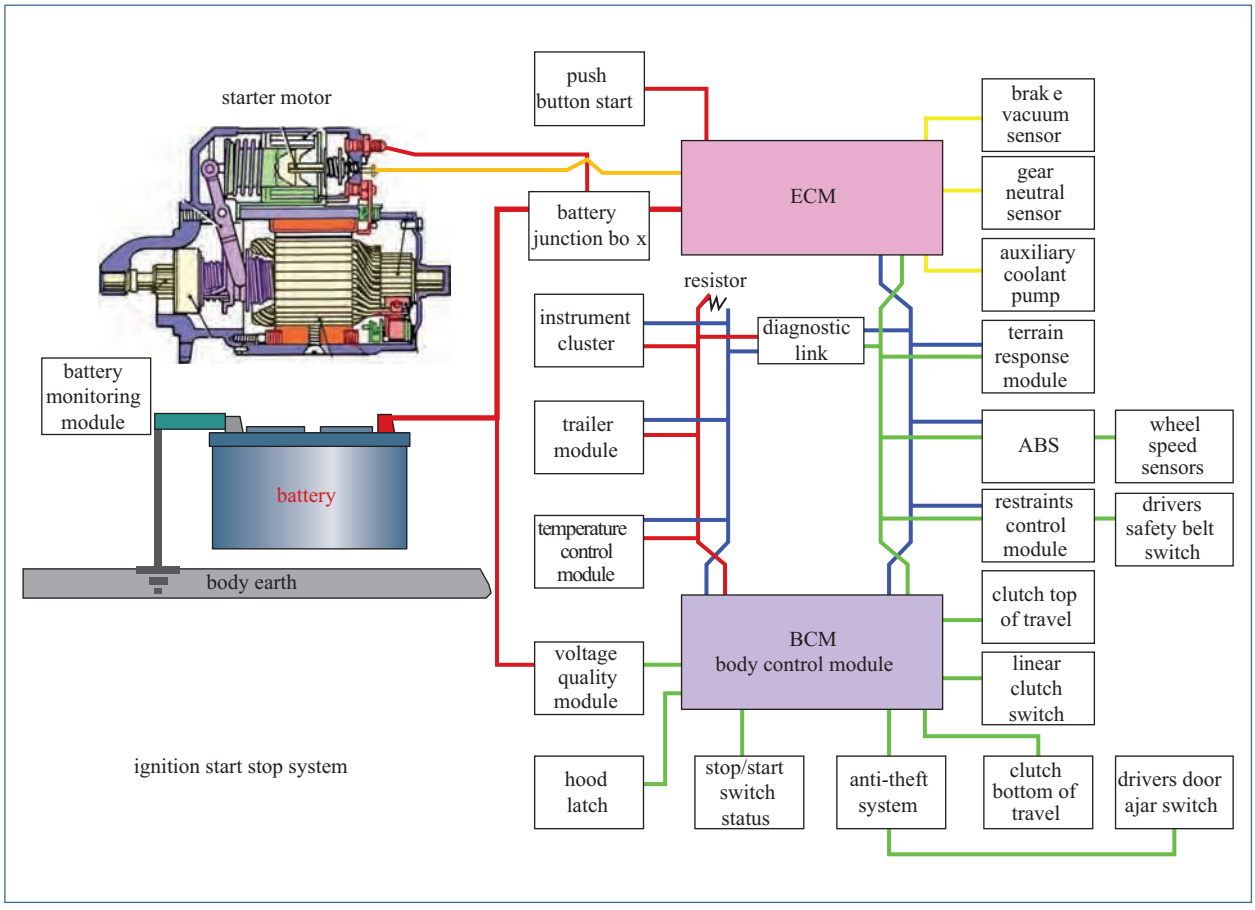


Figure 42.18 This diagram shows the complexity of a typical ISS system. A scan tool will be needed to find the D TC if it is not the battery or starter motor

In some circumstances, vehicles that have direct petrol injection use the alternator to rotate the engine onto a power stroke, utilising the direct injection system to start the engine. This enables the vehicle to be started without the starter motor.

42.8 Removing and installing starters

With most starters, the end of the drive housing fits into a hole in the engine block. The starter is then held against its mounting by two mounting bolts (Figure 42.19).

With the battery isolated, the starter cable and switch wiring can be disconnected and the mounting bolts removed. The starter can then be taken away from the engine.

Safety: Before removing a starter , the battery earth cable should be disconnected. This will avoid any accidental grounding of a live terminal.

When the starter has been reinstalled, the cables and connections at both the starter and battery should be clean and tight. Corroded battery cables should be renewed.

42.8.1 Starter with flange mounting

Most (though not all) starters are mounted to the engine with bolts through the flange of the drive housing, as in Figure 42.19.

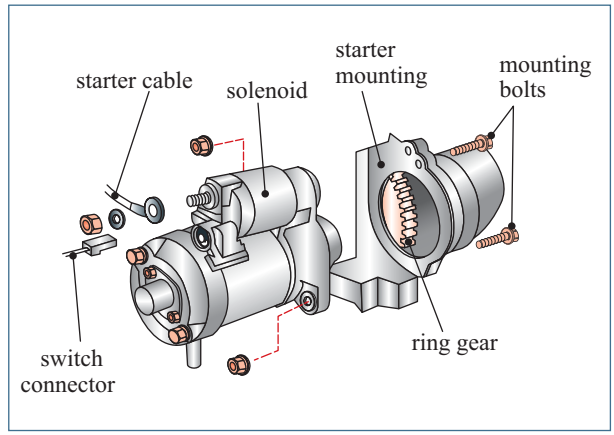


Figure 42.19 Removing and replacing a starter

Handy hint: Corroded battery terminals are the most common of all starter problems.

Figure 42.20 shows a starter motor with a different type of drive housing and mounting. The housing has a flange by which it is mounted to the engine block. The depth of mesh of the pinion teeth in the ring gear can be adjusted on this type of starter. Shims are used between the flange and its mounting to alter the position of the starter.

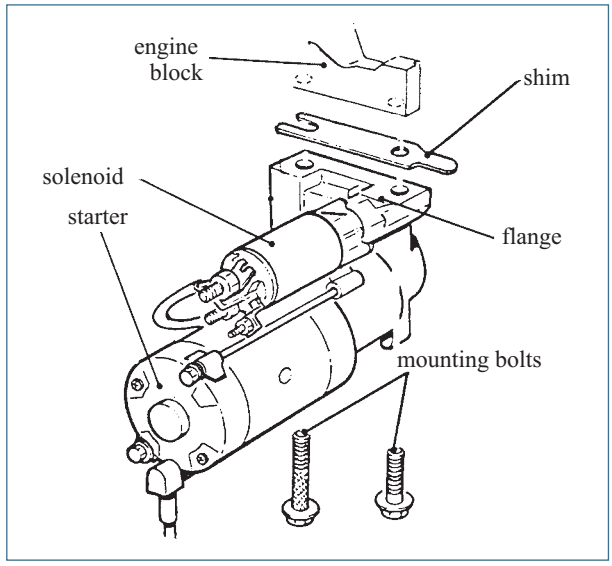


Figure 42.20 Starter with a flange mounting to the engine block GM HOLDEN LTD

42.9 Starter circuit checks

If starter motor operation is sluggish, the fault could be in the starter motor, the starter circuit or the battery. A voltmeter can be used to check both the starter and the circuit. Refer to Chapter 41 for battery tests.

Voltage readings can be taken at different points in the circuit by using a voltmeter with a 0 to 20-volt scale. The *voltage drop* across various parts of the circuit can be checked with a voltmeter that has a 0 to 2-volt scale.

Voltage checks and voltage-drop checks are carried out with the starter cranking the engine so that the circuit is under load. The ignition and fuel systems should be isolated during the tests so that the engine will not start. Cranking tests should be kept as short as possible.

Handy hint: An alternative way of checking circuits is to use an ohmmeter , which checks the actual resistance of cables and connections in the circuit.

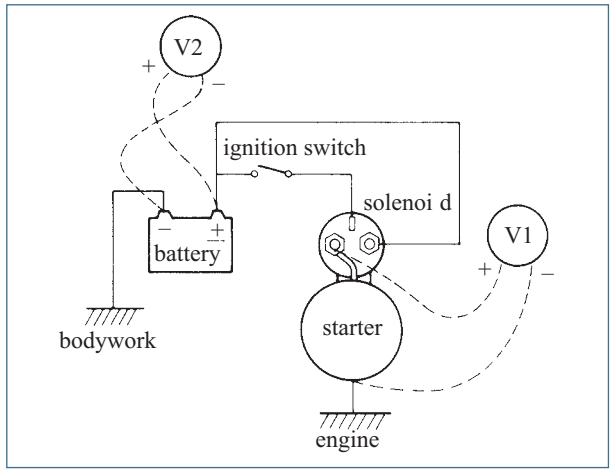


Figure 42.21 Checking the voltage of a starting system V1 voltage starter , V2 battery voltage

42.9.1 Checking cranking voltage

This check shows the voltage available at the starter when it is cranking the engine. The connections for the voltmeter are shown in Figure 42.21.

The checking procedure is:

1 Connect a 0 to 20 range voltmeter between the starter terminal and a good earth on the starter , as shown by V1. Operate the starter and note the reading. The starter should spin at a good speed and the reading should not be less than 9 .5 volts.
2 Connect the voltmeter across the battery terminals (voltmeter 2), and again note the reading with the starter operating.

Handy hint: These tests can also be performed with a scan tool.

The difference in readings represents the voltage drop of the circuit and should be a maximum of 0.5 volt.

Interpreting the voltmeter readings

A reading higher than 0.5 volt indicates excessive circuit resistance, which must be located. If the difference between the above two readings is within 0.5 volt, but the readings at the starter motor and the battery are both considered low, then the starter motor may be at fault and should be checked.

Handy hint: The condition of the battery should also be check ed as it will influence the readings.

42.9.2 Checking voltage drop

Figure 42.22 shows the various points at which a voltmeter can be used to check the *voltage drop* in the circuit. The voltmeter should have a 0 to 2-volt scale and the starter must be in operation during the checks.

Any abnormal resistance in the circuit, such as that caused by poor connections, will increase the voltage drop. This will show on the voltmeter as a higher-than-normal reading.

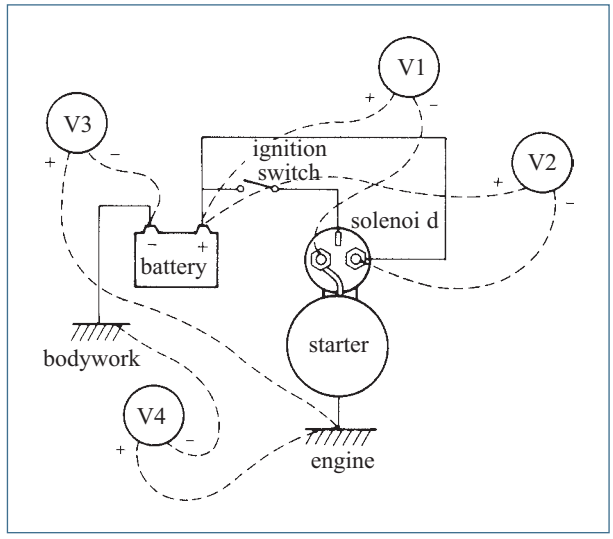


Figure 42.22 Voltmeter connections for checking voltage drop in the different parts of the starting system

1 With the voltmeter (0 to 2-volt scale) connected between the positive battery terminal and the starter motor terminal, as shown by V1 in the illustration, the maximum reading should be about 0 .4 volt. This tests the starter cable , the connections and the switch.
2 With the connections between the positive battery terminal and the switch terminal, as shown by V2, the reading should be no more than about 0.2 volt. This tests the starter cable as before , but without the switch contacts and connections.
3 With the positive voltmeter terminal connected to the engine ground and the negative voltmeter terminal connected to the negative battery terminal, as shown by V3, the reading should not be more than 0 .1 volt. This tests the earth side of the system. V1 and V3 can be up to 0 .5 volt, as stated previously .

Other parts of the circuit can be checked in a similar manner. Wherever resistance is suspected, or when attempting to isolate a problem, voltage-drop readings can be taken—for example, between the engine and bodywork (V4). In general, these readings should not exceed 0.1 volt.

The most common causes of voltage drop are loose, dirty or corroded cable connections at the battery, starter and engine earth points.

Star locking washers, which cut through paint and provide good contact, should be refitted or replaced whenever the cables are disturbed. Too small a cross section in the positive + and earth − cables can also cause a voltage drop. Slightly loose starter mounting bolts can also cause voltage drop, especially after replacing starters or engines.

42.9.3 Load testing starters in vehicle

With the starter motor mounted on the engine so that a load is applied to the starter, place an inductive amp clamp over the battery positive + supply to the starter motor. Disconnect the fuel system if diesel or the ignition system if petrol to prevent the engine from starting. Crank the engine for no more than five seconds. The battery voltage should not go below 10 volts and the current draw should be less than the figures in Table 42.1.

These figures are only approximate; correct information for each vehicle should be sourced from the manufacturer. If the engine is cold there will be a small increase in current draw.

The correct current draw will vary from one manufacturer to another. As battery voltage drops, the current draw will increase so it is important that the battery is in good condition and fully charged.

A low current draw may indicate an electrical fault in the starter motor. If the current draw is too high and the engine cranks slowly, it may indicate a mechanical fault (tight engine), polling in the starter motor or a short within the starter motor.

Table 42.1 Maximum current draw for warm diesel and petrol engines

	Petrol warm engine	Diesel warm engine
4 cylinder	160 amps	300 amps
6 cylinder	200 amps	400 amps
8 cylinder	250 amps	600 amps

42.10 Diagnostic testing and scan tool use

42.10.1 Types of diagnostic tools

There are two main tools for performing diagnostic checks.

1 A high-quality digital multi meter (DMM) with an internal resistance of 10 000 ohms (see Chapter 38).
2 A scan tool. Whether this is a factory-recommended or a generic unit, it needs to be able to read the codes on the vehicle being tested (see Chapter 40).

There is another diagnostic tool that can be used to identify more complex issues, and that is a live data reader or an oscilloscope (see Chapter 40).

42.10.2 Live data and freeze frame data

Live data refers to reading information as it is being produced. This can be given in a numeric value or as a graph on a screen (Figures 42.23 and 42.24). The advantage of the latter is that it can show the smallest problem when results fluctuate. For an electric motor (fuel pump or starter motor), every segment of the commutator can be measured for current draw as the motor rotates in real time. This is invaluable as any weakness can be seen before a failure. Freeze frame data on the other hand is a snap-shot.

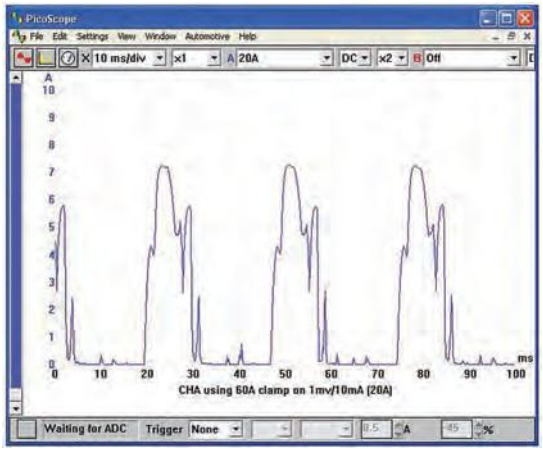


Figure 42.23 A freeze frame using an oscilloscope to capture the current draw of a faulty motor . The vertical scale is current draw and the horizontal scale is time as the motor revolves PICO TECHNOLOGY

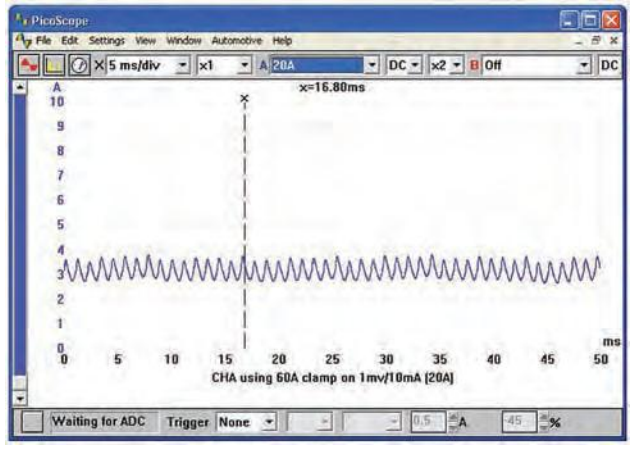


Figure 42.24 A freeze frame capture of a good electric motor current draw using an oscilloscope . The vertical scale is current draw and the horizontal scale is time as the motor is revolving PICO TECHNOLOGY

42.10.3 Diagnostic flow chart

The complexity of modern computerised vehicles means that it is vital to refer to the correct manual for the vehicle being tested Table 42.2 shows an example of a flow chart.

Table 42.2 A typical flow chart for a vehicle that has a computerised engine management system but not ISS

Inspection and verification	Mechanical	Electrical
1 Verify customer concerns		
2 Visually inspect for obvious signs	Battery Starter motor Gear selection	Battery Fuses Wiring damage Corrosion at connections ECM

Table 42.2 Continued

3 Consult symptom chart		
SYMPTOM CHART		
Symptom	Possible cause	Action
Engine does not crank (starter does not turn)	Gear selector not in P or N position Battery Harness/connectors Starter motor Starter relay Start switch Transmission control module (T CM) Engine control module (ECM) Engine seized	Refer to battery diagnosis Check for D TCs. If found, refer to the manufacturer' s technical manuals
The engine does not crank (starter motor does turn)	Starter motor installation Starter motor Ring gear	Check ring gear teeth
Engine cranks too slowly	Battery Harness/connectors Starter motor Engine oil incorrect grade	Check the battery condition and state of charge
Engine cranks too fast	Low engine compression	Check the engine compressions
Excessive starter motor noise	Starter motor Starter motor installation/casing Ring gear	Check the starter motor installation

42.11 Starter construction

Direct-drive starters and reduction-type starters with gears have different constructions. Figure 42.25 shows the dismantled parts of a direct-drive starter, while Figure 42.26 shows the dismantled parts of a reduction-type starter. These examples enable the various internal parts to be identified.

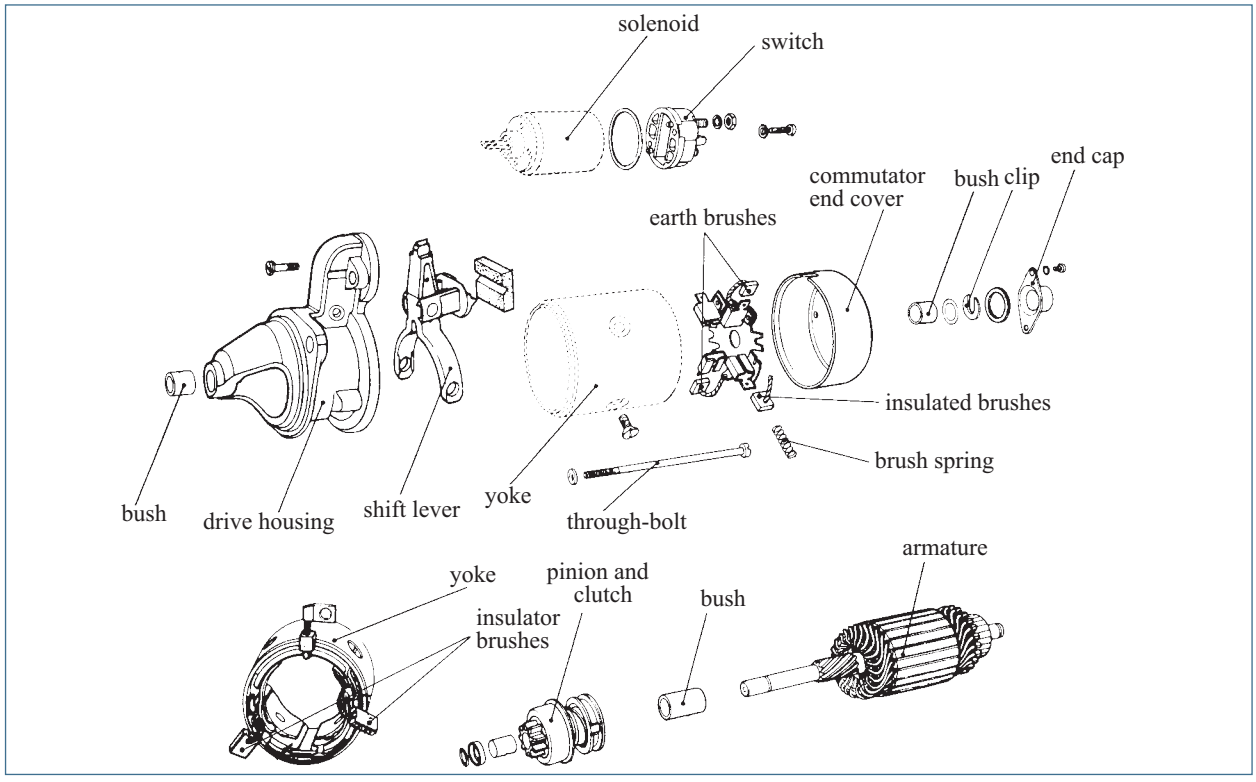


Figure 42.25 Dismantled parts of a direct-drive starter GM HOLDEN LTD

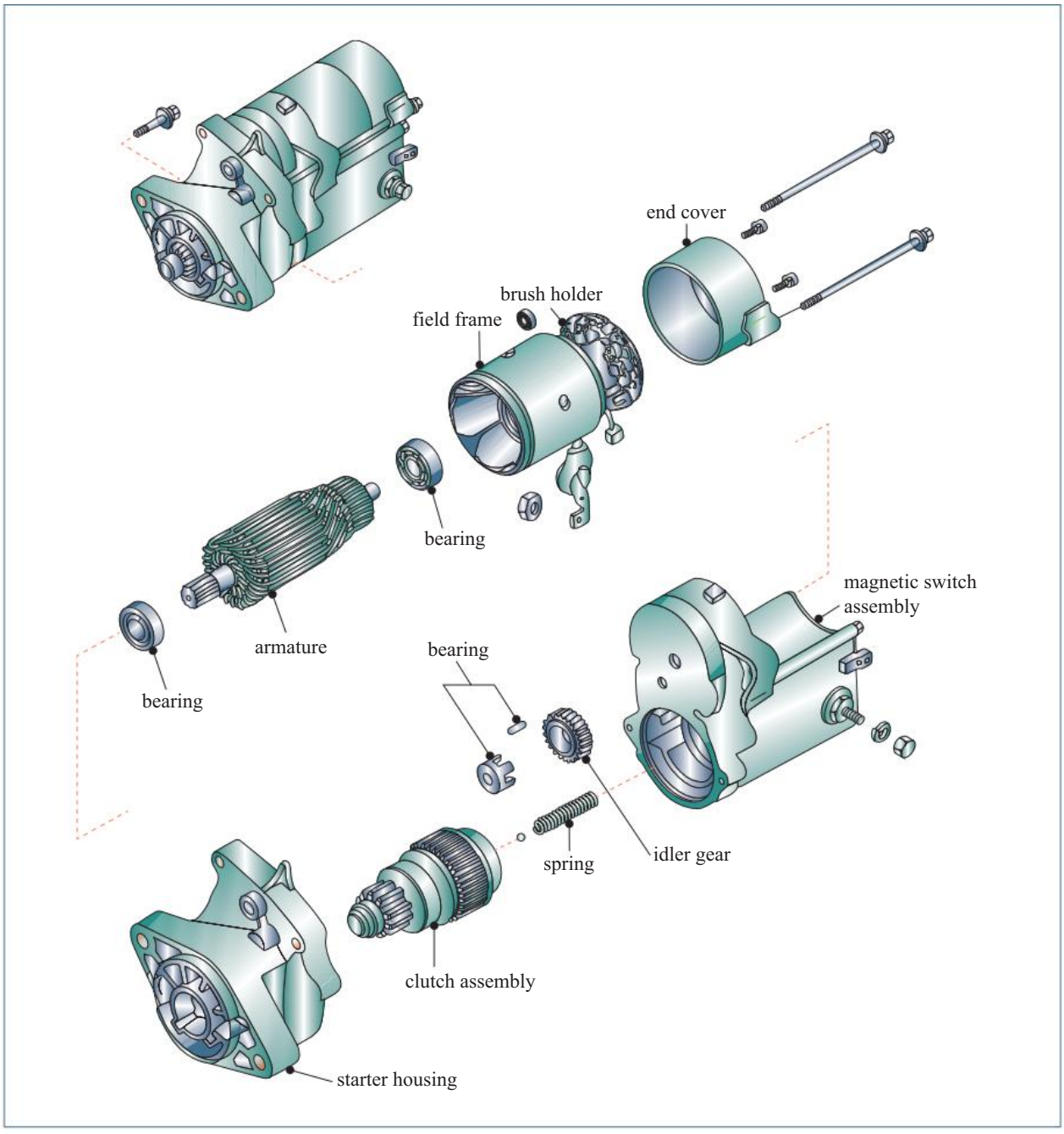


Figure 42.26 Reduction-type starter in which the motor is mounte d on top of the magnetic switch assembly

42.12 Component testing

After dismantling the starter motor, the individual components can now be inspected and tested to determine the cause of the failure. Check the armature and field coils first for shorts and open circuit. If these components are faulty, it would be best to replace the starter motor.

42.12.1 Field winding test

To perform a field coil test, use a good quality DMM and check for continuity and shorts. Identify the way the field coils are wound and identify the earth and power in. It is important to know this to get the correct readings. The coils should be isolated from the yoke of the starter and there be not continuity between the coils and the body. Any reading will indicate a leakage (Figure 42.27).

42.12.2 Armature test

To perform an armature test, use a growler (Figure 42.28) to induce a magnetic field into the armature. Test the armature by running a small hacksaw blade across its top while rotating it. If there are any shorts in the armature, the hacksaw blade will vibrate. This happens because the growler is like the primary stage of a transformer and the armature is the secondary windings. If there is a short in the windings it will create a magnetic field in the armature. Other tests can be carried out with a DMM (as in Figure 42.29).

If the armature is verified as being electrically safe, the commutator end will need to be cleaned up if it is to be reused. If the commutator is worn, check the smallest diameter allowed to see if it is serviceable (Figure 42.30). If it is serviceable, it may be machined and/or cleaned with emery paper, depending on its condition (Figure 42.31). The insulation in the commutator must be undercut to stop the brushes from 'skipping' and not making full contact (Figure 42.32).

42.12.3 Brush holder test

To check the brush holder, connect a DMM with one end to the positive and the other to earth (Figure 42.33). There should be no continuity. If continuity exists, replace the brush holder. Check the length of the brushes with a Vernier and consult the technical data to check minimum length (Figure 42.34).

42.12.4 Drive pinion check

To check the drive pinion overrunning clutch, take the body of the pinion with one hand and the pinion teeth with the other. Try to turn the pinion in both directions. It should turn smoothly in one direction and not turn in the other. Check the condition of the teeth for damage while assessing the pinion (Figure 42.35).

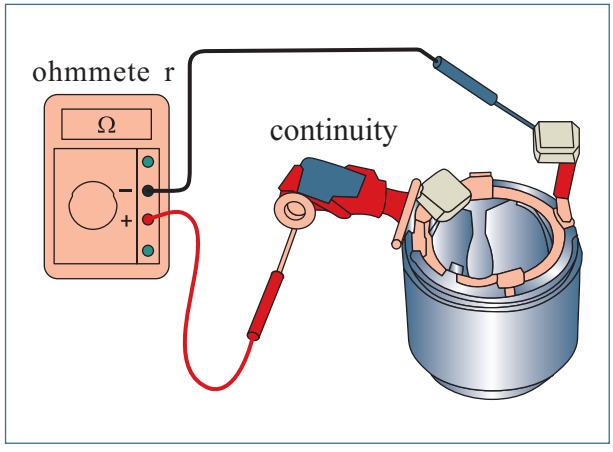


Figure 42.27 Testing field coils with a DMM

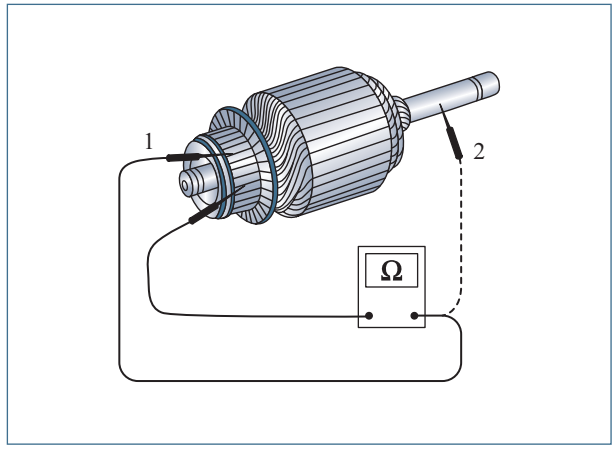


Figure 42.29 Testing an armature for shorts and grounds with a DMM

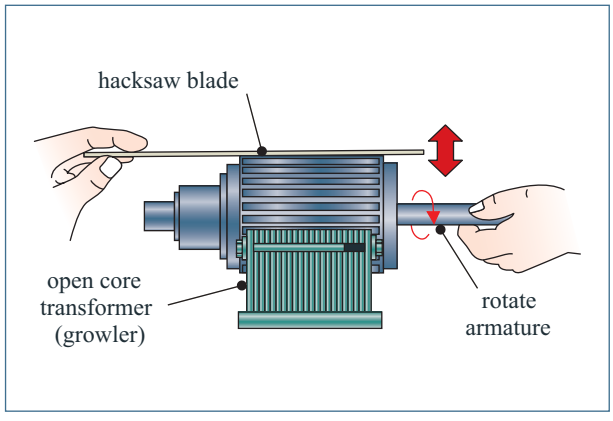


Figure 42.28 Testing an armature with a hacksaw blade when the armature is placed on a growler

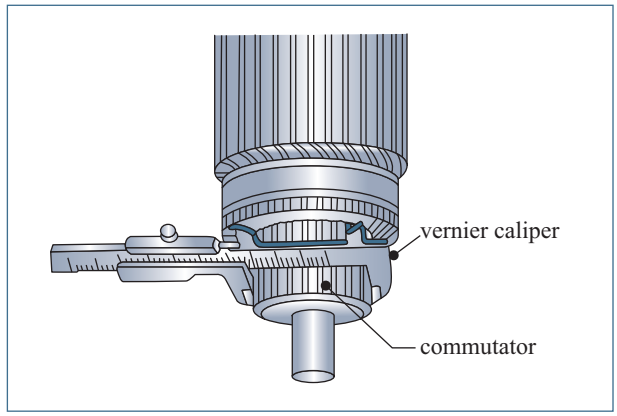


Figure 42.30 Check for excessive wear on the commutator

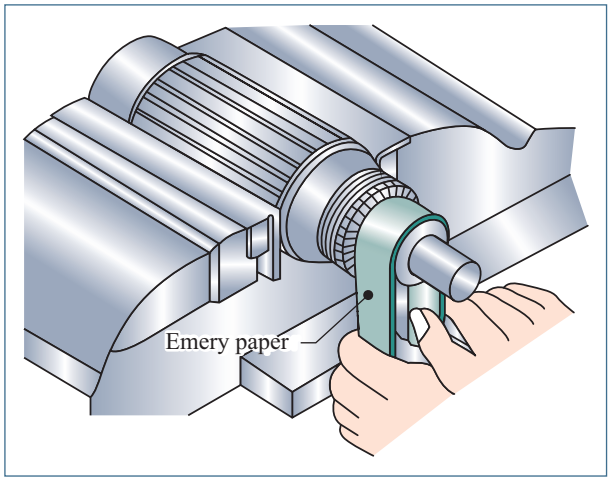


Figure 42.31 Clean up the copper segments on the commutator

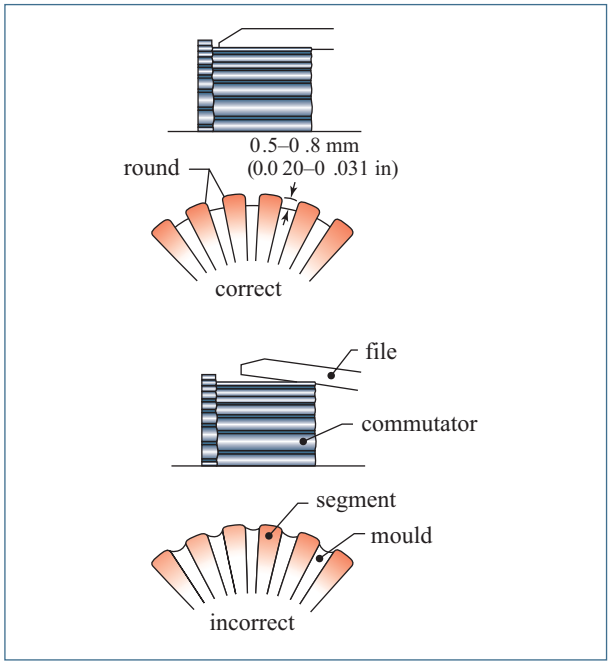


Figure 42.32 Cut the fibre insulation down to stop the brushes ‘ skipping’ to prevent arcing

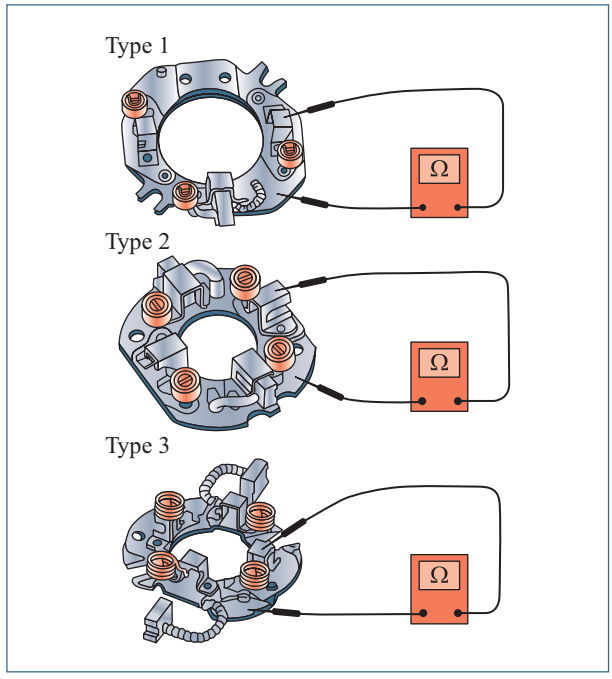


Figure 42.33 Testing the brush holder with a DMM

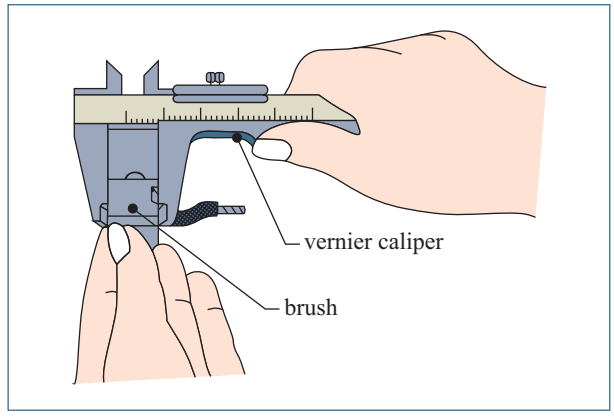


Figure 42.34 Check the serviceable length of the brushes

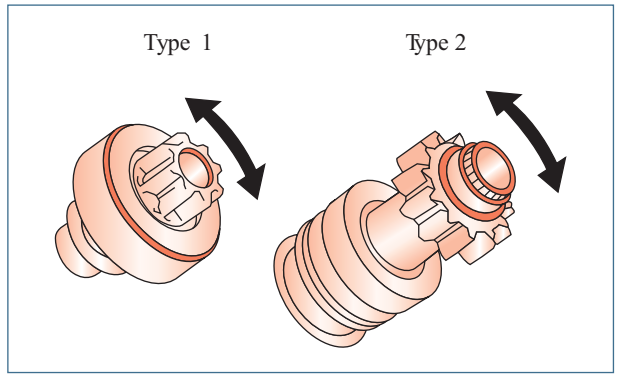


Figure 42.35 Check the one-way clutch. The image shows the ramp effect of the rollers in the clutch

42.12.5 Ring gear wear

Figure 42.36 shows a portion of a ring gear and a drive pinion on which possible wear or damage to the gear teeth is indicated. Ring gears do not wear evenly over all the teeth, but tend to show wear or damage over only a few teeth, at different places on the gear. These are the teeth where the pinion is engaged when the engine is being started.

The crankshaft comes to rest at particular places when the engine is stopped, because it stops when one of the cylinders is on its compression stroke. For example, there will be two places where the crankshaft stops for a four-cylinder engine; three places for a six-cylinder engine; and four places for an eight-cylinder engine. These are the places where the starter pinion engages the ring gear and where wear and damage could occur.

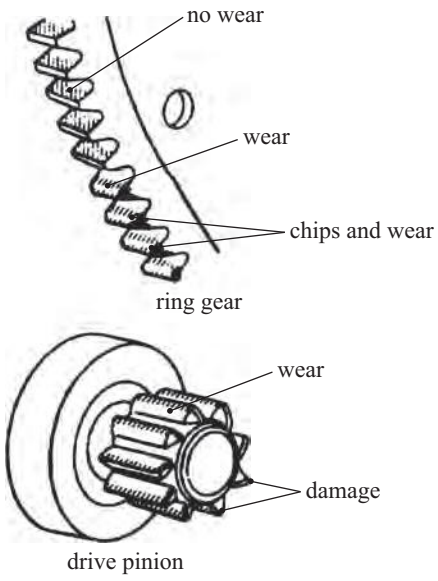


Figure 42.36 Possible wear locations of a ring gear and starter drive pinion FORD

Figure 42.37 Test bench used to test starter motors under load and no load (alternator shown in image) DURST

42.13 Bench tests

No-load and torque tests can be performed on starter motors when they have been removed from the vehicle. A torque test requires a starter test bench or jig, which allows the starter pinion to be loaded or held so that it produces its maximum torque. During this test, the torque is measured. At the same time, a check is made of the current draw and voltage drop. Tests of this type are usually made only after overhaul of the starter. A normal-sized starter under test can produce 14 Nm and draw around 300 amps (Figure 42.37).

42.13.1 No-load test

A limited no-load test can be performed without a test bench, although the starter must be held securely against the reaction that will occur when it starts to rotate.

The procedure is as follows:

1 A battery is connected to the starter as shown in Figure 42.38, with an ammeter that is capable of reading up to around 100 amps, included in the circuit.
2 A jumper lead, connected between the B and S terminals of the solenoid, is used to energise the solenoid and operate the starter . When this connection is made , the pinion should move its full travel and the starter should spin freely at speed.
3 The ammeter should read around 50 amps.

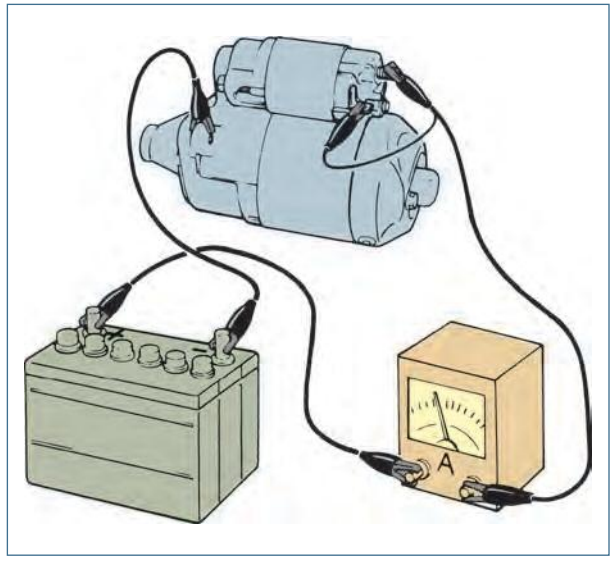


Figure 42.38 Starter no-load test: a battery is connected to spin the starter–the ammeter shows the current GM HOLDEN LTD

Handy hint: The battery being used must be fully charged and capable of maintaining 11 volts.

Test results

Low speed and a high-current draw indicate a problem. This could be a bent shaft or worn bearings (which would allow the armature to pole), or it could be a ground in the armature windings.

Failure of the starter to operate and no current draw would indicate some form of open circuit. Checks would have to be made of the starter switch, the connections and the starter brushes.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- explain the principles of how starter motors work
- identify different types of starters and their construction
- describe starting electrical systems and how to remove starters for repairs
- explain how to check starter electrical circuits and identify voltage drop
- demonstrate diagnostic testing with a scan tool and multimeter testing of components
- identify ring gear and pinion wear
- state how to bench test a starter motor.

REVIEW QUESTIONS

1 What is the purpose of the starter?
2 Name the main parts of a starter.
3 What is a starter solenoid?
4 Name the parts of a starter drive.
5 Name the parts of a simple electric motor.
6 Briefly explain how a simple electric motor works.
7 Which parts of a starter produce electromagnetism?
8 What is the purpose of the overrunning clutch?
9 Explain briefly what occurs inside a starter solenoid when the ignition key is turned to start.
10 What is series-wound and shunt-wound?
11 What are compound windings?
12 What is a direct-drive starter?
13 What is a reduction-type starter?
14 What types of gears are used in reduction-type starters?
15 Explain what pull-in windings and hold-in windings do.
16 What checks can be carried out on a starter when it is mounted on the engine?
17 Name the various checks that can be made of a starter circuit.
18 How are checks made for voltage drop in a circuit?
19 What is cranking voltage?
20 How is cranking voltage checked?
21 How does cranking voltage compare with battery voltage?
22 How is a no-load test carried out on a starter?

CHAPTER 43

Charging systems and service

LEARNING OBJECTIVES:

On completing this chapter , you will be able to:

1 explain generating principles
2 identify the attributes of a simple alternator
3 describe the changes that result from A C to DC rectification
4 describe alternator construction
5 explain rectification and the use of diodes
6 describe the process of voltage regulation
7 describe the alternator and regulation circuit
8 explain and interpret battery management systems
9 diagnose faults in alternator charging systems
10 identify simple generator systems
11 outline the regulator system of generators
12 apply a procedure to test the output of generator systems.

The charging system supplies electrical energy for all the vehicle 's electrical components. The battery provides the electrical energy for starting, and, once the engine is running, the alternator (or generator) supplies energy to all the electrical components. It also charges the battery , replacing the energy used to start the engine . A generator (also called a dynamo) produces direct current (DC)and an alternator produces alternating current (AC). For an alternator , the current must be rectified to DC to charge the battery: batteries can only be charged with a constant electromotive force (EMF) of direct current.

43.1 Generating principles

Alternators and generators operate on the principle of *electromagnetic induction.* This is described in Faraday's law, which says that if there is movement between a conductor and a magnetic field, then an EMF (voltage) will be induced in the conductor. This, the basic principle of all electrical generation, is illustrated in Figure 43.1.

The diagram shows the north and south poles of a magnet with a conductor between them. When the conductor is moved in the direction of the arrow, it cuts the lines of force of the magnetic field, inducing a voltage in the conductor. If the conductor is connected to a circuit, current will flow in the direction shown. There would only be a very small voltage and current in such a simple generator.

Handy hint: Electromotive force (EMF) is a technical term for voltage .

43.1.1 Rotating field

The simple generator described above has a stationary field, but an alternator has a rotating field. This is illustrated in Figure 43.2, where a bar magnet that is able to rotate is shown. As it spins, it produces a rotating field.

The conductor is stationary, but is in the path of the moving field. Each time a pole of the magnet passes, voltage is induced into the conductor. Because the magnetic polarity changes with each half-turn of the magnet, the polarity of the voltage will also change. As a result, the current induced in the conductor will flow first in one direction and then in the other.

43.2 Simple alternator

Figure 43.3 shows a simple alternator with a single-loop conductor. The stationary loop of wire is the *stator,* and the rotating magnet is the *rotor.* The rotor provides a rotating field, inducing a voltage in the stator.

In Figure 43.3(a), the north pole (N) of the magnet is passing the top of the loop and the south pole (S) is passing the bottom. This causes current to flow in one direction in the top part of the loop and in the opposite direction in the bottom part. However, because the conductor has been formed into a loop, the current will flow from one end of the loop to the other in the direction shown.

In Figure 43.3(b), the magnet has rotated a half-turn, so the N pole is now at the bottom and the S pole is at the top. Current again flows in the loop, but now it is in the opposite direction to that in Figure 43.3(a). This simple alternator is producing an alternating current. As the magnet continues to rotate, voltage will be induced. Current will flow in the loop, first in one direction and then in the other.

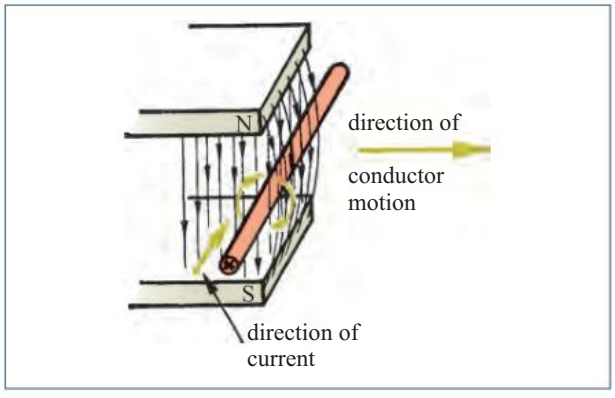


Figure 43.1 A conductor that is moved through a magnetic field has a voltage induced into it—this is the basic principle of electrical generation

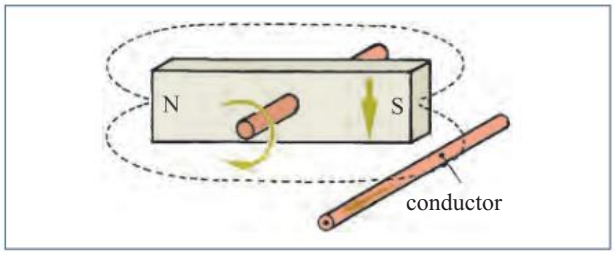


Figure 43.2 A rotating magnet has a rotating field that cuts the conductor and induces an EMF—the conductor will have a small current

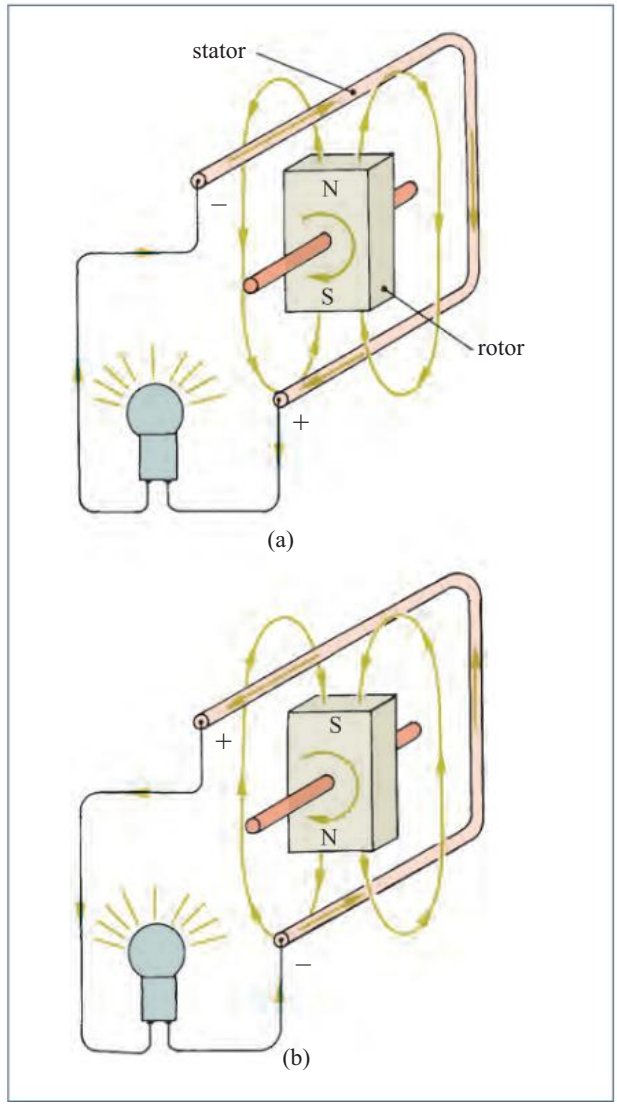


Figure 43.3 Simple alternator consisting of a single stationary loop and a rotating bar magnet

43.2.1 Improving the alternator

The simple alternator can be improved by using an electromagnet instead of a permanent magnet. A rotor with a coil is used to produce an electromagnetic field (Figure 43.4). The field from the electromagnet can be made stronger than that of a permanent magnet, and, most importantly, its strength can be varied and used to control the alternator voltage.

The rotor has its coil wound on a soft-iron core, the ends of the coil being attached to a pair of slip rings. These have stationary brushes connected to the battery. Current from the battery energises the rotor coil to provide the magnetic field. The slip rings and brushes allow the rotor to spin and still be supplied with current.

43.2.2 Inducing an electromotive force

The following points summarise the production of an EMF (voltage):

1 A magnetic field and a conductor or conductors are required.
2 Either the field or the conductor must move .
3 Lines of force must be cut—parallel movement has no effect.
4 Increasing the speed of cutting increases the induced EMF .
5 Increasing the field strength increases the induced EMF .
6 Increasing the number of conductors increases the induced EMF .

The points above apply to an actual alternator as well as to a simple alternator. An alternator has a magnetic field and a number of conductors. Its field rotates at high speed to cut the conductors, and is varied to regulate alternator voltage.

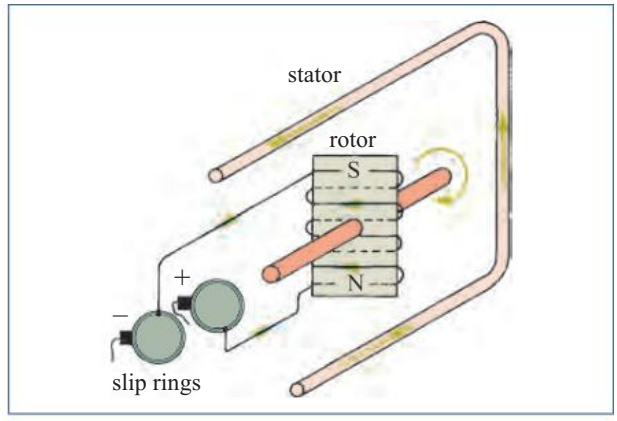


Figure 43.4 Simplified alternator showing the rotor field windings connected to slip rings

43.3 Changing AC to DC (rectification)

The rotor induces an alternating current (AC) in the loop of the stator, and this has to be changed to direct current (DC). That is, the current in the stator, which is constantly changing its direction, must be directed so that it always flows the same way. This process is known as *rectification.*

Diodes are used as rectifiers, acting as one-way valves in the alternator circuit (Figure 43.5). Current flows through the diodes in one direction, with flow in the opposite direction blocked. In this way, the AC produced in an alternator is changed to DC before it leaves the alternator.

In the arrangement in Figure 43.6, only half the alternator voltage is used; this is called *half-wave rectification.* When the top end of the loop is positive, current will flow to the battery. When it is negative, current will be blocked.

Figure 43.7 shows four rectifying diodes, arranged so that current can flow from either end of the stator loop to the battery. As the direction of current changes in the loop, current will flow through the appropriate diodes; all the voltage induced is used. This is known as *full-wave rectification* (Figure 43.8).

Handy hint: The current has to be rectified because A C cannot be used with the battery or the other electrical components of a **motor vehicle**.

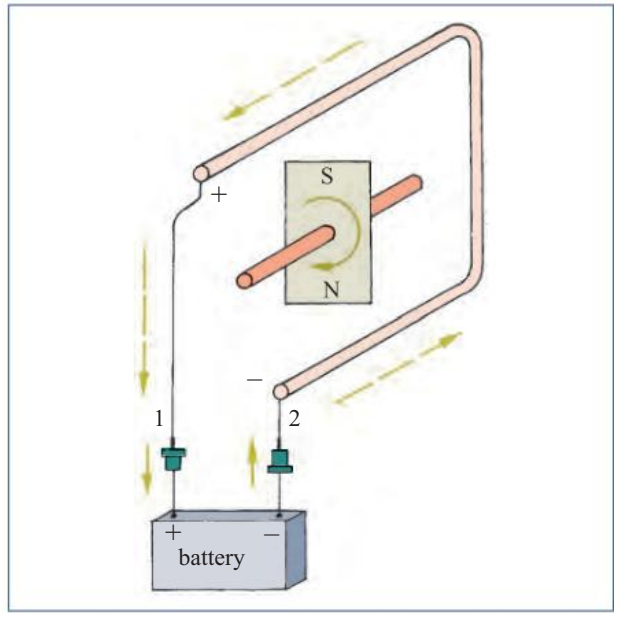


Figure 43.5 Simple alternator with the circuit from the stator windings connected to the battery by diodes 1 and 2

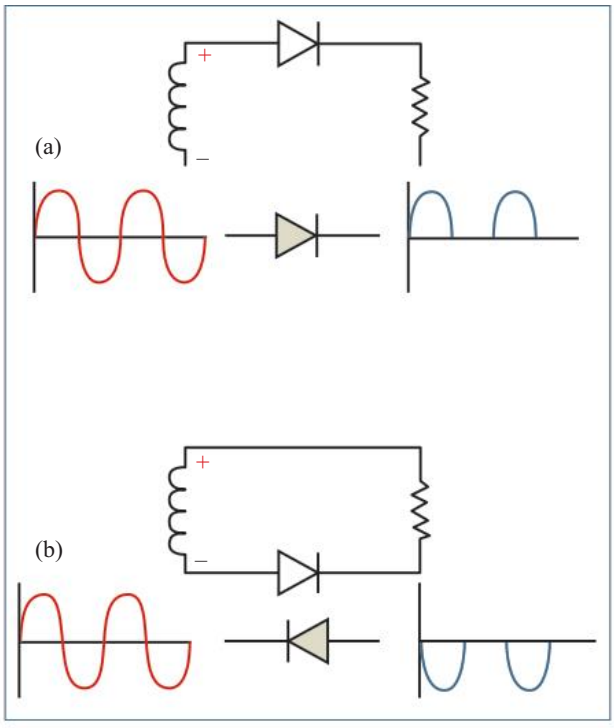


Figure 43.6 Half-wave rectification with the diode (a) positively based (b) negatively based

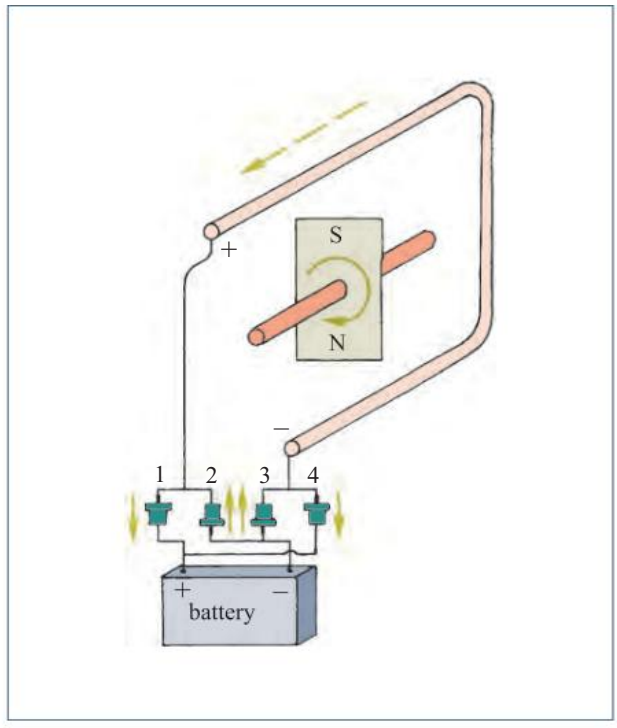


Figure 43.7 Four diodes are now used to connect the stator to the battery terminals

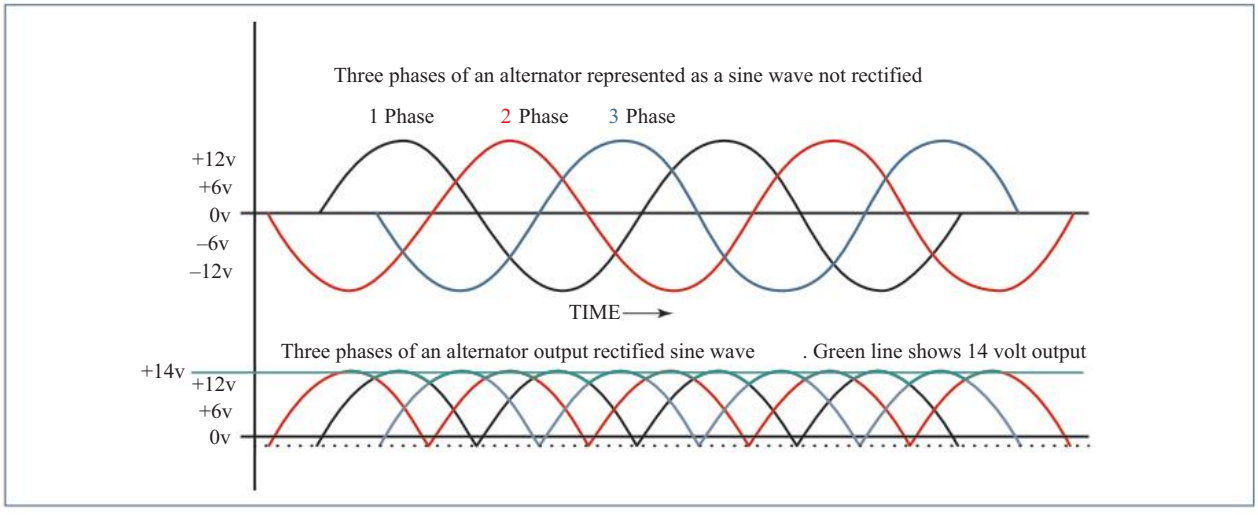


Figure 43.8 A three-phase alternating current sine wave on the t op row and a rectified-to-direct-current sine wave on the bottom row . This shows full-wave rectification. As the alternato r rotates very fast, the output rise and fall is levelled, with very little movement

43.4 Alternator construction

Automotive alternators have the same basic parts as the simple alternators discussed, but they have more conductors and stronger fields to produce the voltage needed. These basic parts can be identified in the sectional view in Figure 43.9. They are shown dismantled in Figure 43.14 and in part-section in Figure 43.28.

43.4.1 Stator

The stator has three phase windings. These are three separate windings assembled into slots in a soft-iron frame. Each has a number of loops to produce a uniform voltage. The windings are connected so that the voltage produced in all the loops is combined.

The windings can be connected in two different ways, as shown in Figure 43.10. These are known as *star* and *delta.* Both operate in a similar way, although star windings are more frequently used. In both

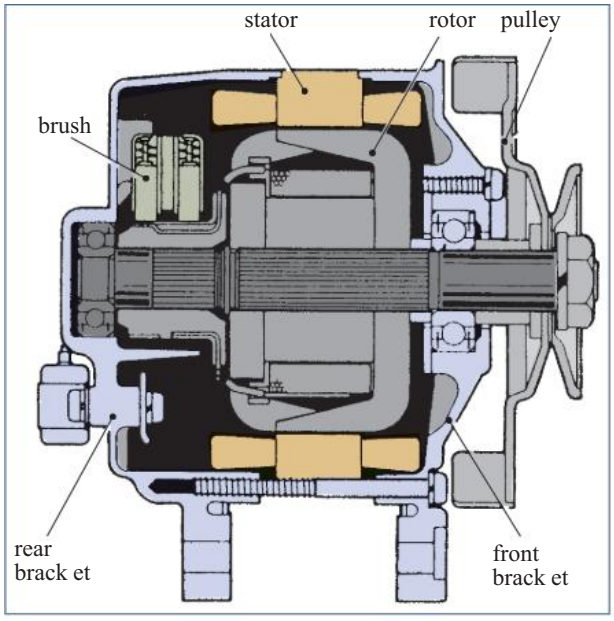


Figure 43.9 Section through an alternator with the parts identified

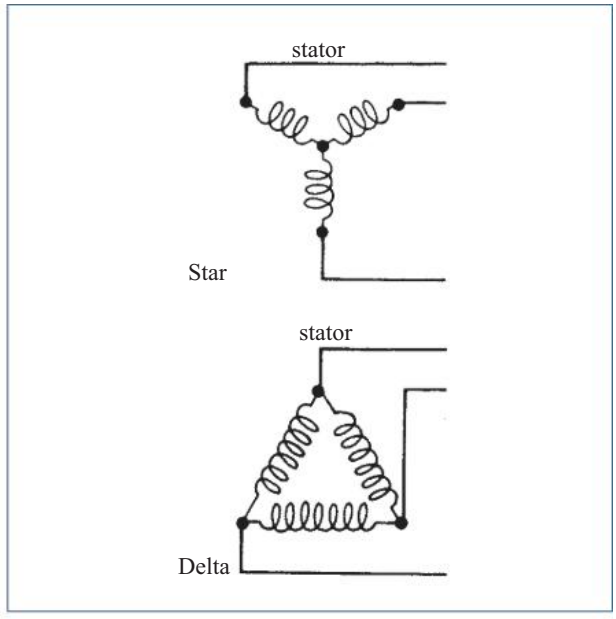


Figure 43.10 Methods of connecting alternator windings—star or delta

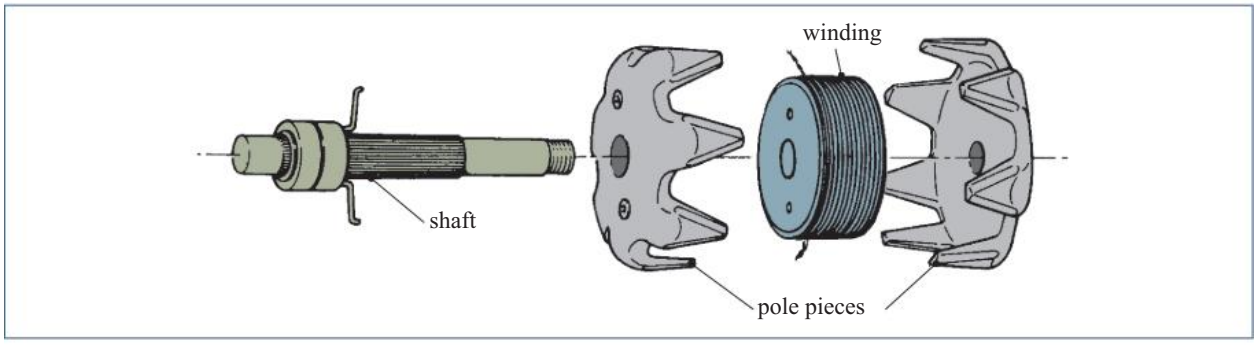


Figure 43.11 Construction of a rotor—the parts cannot be separated

arrangements, three ends of the stator windings are connected to the rectifying diodes.

43.4.2 Rotor

Figure 43.11 shows the construction of a rotor. It has two claw-shaped pole pieces mounted on the rotor shaft. The windings of the rotor field coil fit between the poles. The shaft also carries two slip rings, to which the ends of the field coil windings are connected.

The rotor field coil is connected to the battery through the slip rings and brushes. The brushes provide a continuous slipping contact with the slip rings as the rotor turns. When the field coil is energised, one end of it becomes a north pole, and the other end a south pole. As shown in Figure 43.12, the assembled rotor has claws that become alternate N and S poles. This is like having a number of magnets rotating inside the stator.

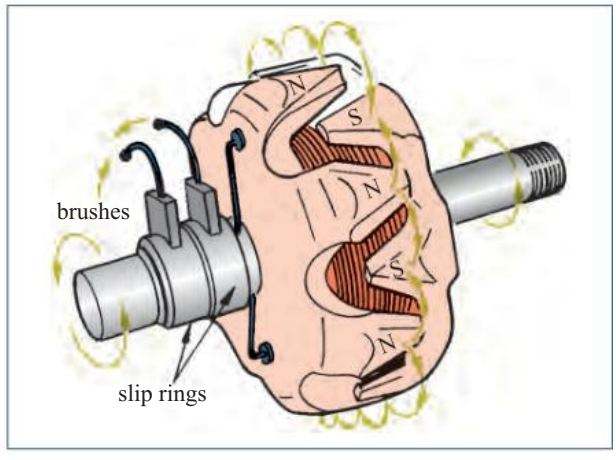


Figure 43.12 Alternator rotor showing the field resulting from the claw-shaped pole pieces—slip rings and brushes supply the rotor current

The rotor is supported in ball or roller bearings in the front housing and the rear housing. Driven by a belt and pulley, it can reach speeds of 12 000 rpm.

Handy hint: The rotor is shown here as a number of parts, but an actual rotor cannot be dismantled.

43.4.3 Heat sink and diodes (rectifier)

Figure 43.13 shows a rectifier connected to the three ends of the stator windings. It consists of a heat sink with six diodes. Six diodes are needed to convert three-phase AC to DC. Three are positive diodes, three are negative. The diodes are fitted into the heat sink, which absorbs the heat they produce.

Safety: Care must be taken when working on alternators. Diodes will prevent reverse current under normal conditions, and they cannot withstand excessive currents in either direction: any overload will quickly ruin them.

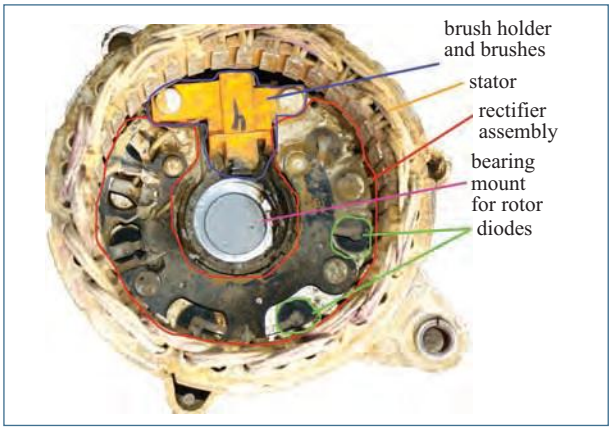


Figure 43.13 Stator and rectifier assembly—arrows show the ends of the stator windings connected to the diodes

43.4.4 Brush holders and brushes

Two small brushes rest on a pair of slip rings (these can be seen in Figure 43.12). The slip rings are insulated from each other and are kept small in diameter to reduce the slipping speed. The arrangement of the slip rings and brushes allows the rotor to receive current from the battery or from rectified stator current. With some alternators, the brushes are part of the voltage regulator assembly.

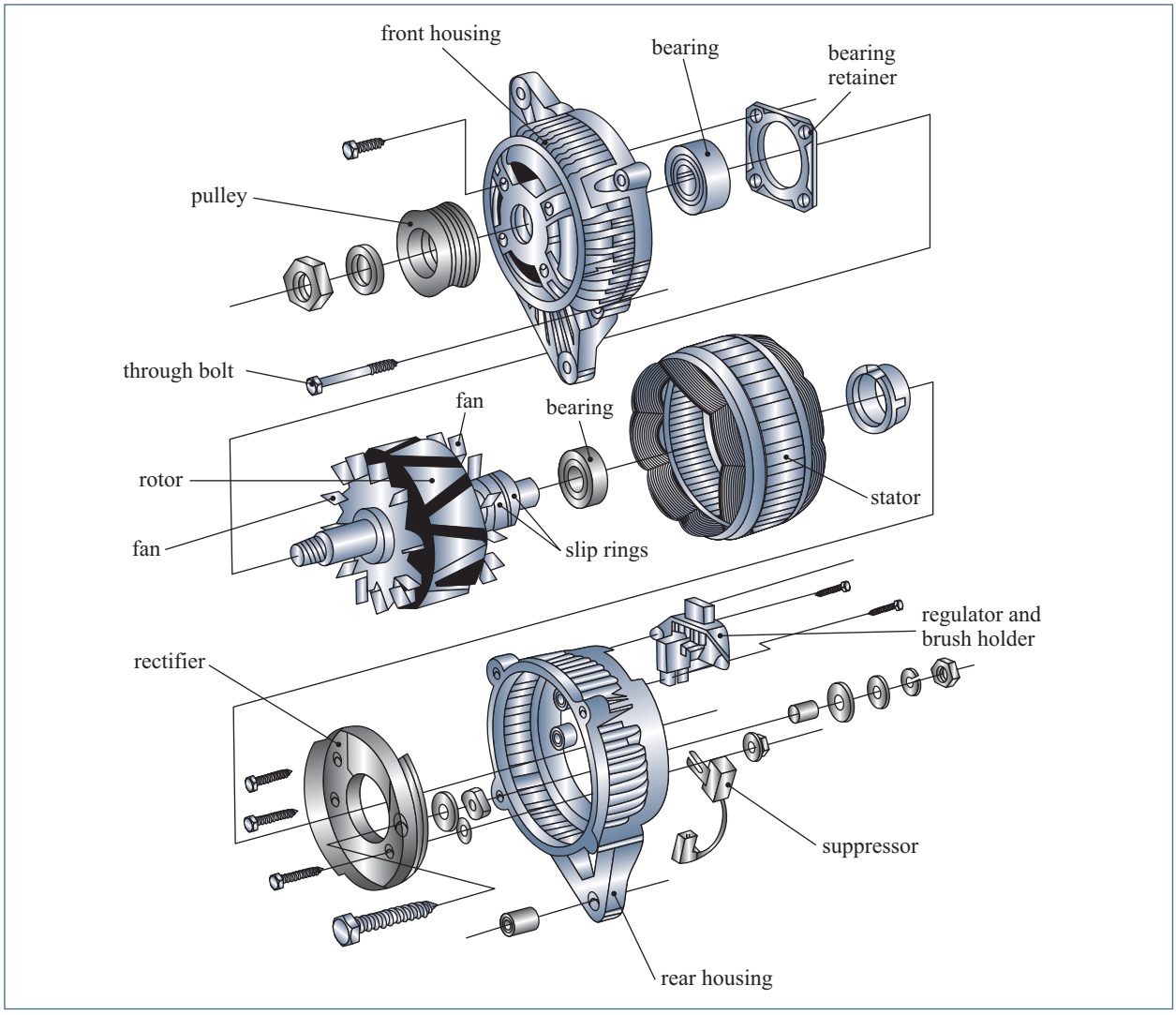


Figure 43.14 Dismantled alternator with parts identified

43.4.5 Alternator cooling

Alternators are cooled in two ways:

1 By the use of a fan behind the drive pulley , which draws air from the back of the alternator and expels it from the front. Some alternators are fully sealed because of the operating condition.
2 Water cooling controls the higher heat generated from higher output in late-model vehicles, which is particularly an issue with start-stop vehicles. An electric cooling pump is used to continue the circulation of coolant when the vehicle is stopped.

43.5 Rectification and diodes

Automotive alternators have diode rectifiers that change the generated AC to DC output. The symbol used to represent diodes is shown in Figure 43.15. This consists of a bar and an arrow. In a circuit, current flows in the direction of the arrow and is blocked from flowing in the opposite direction by the bar.

Figure 43.16 shows four diodes arranged to rectify single-phase AC. Single phase has a single source of current which flows first in one direction and then in the other. In the diagrams, the black diodes are conducting and the heavy lines are carrying current. Figure 43.16(a) has a pair of diodes conducting. In Figure 43.16(b), the direction of current has changed and two different diodes are conducting. This enables the current to continue to flow to the correct battery terminal.

43.5.1 Three-phase rectification

Alternators need six diodes (three pairs) to rectify the current from their three stator windings. Each winding needs a positive and a negative diode to allow current to flow to or from its windings at the appropriate time. The arrangement for star windings is shown in Figure 43.17; the arrangement for delta windings is shown in Figure 43.18.

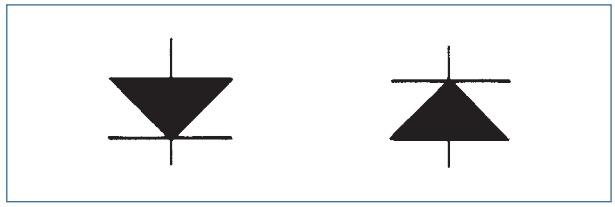


Figure 43.15 Diode symbols—current can flow only in the direction of the arrow

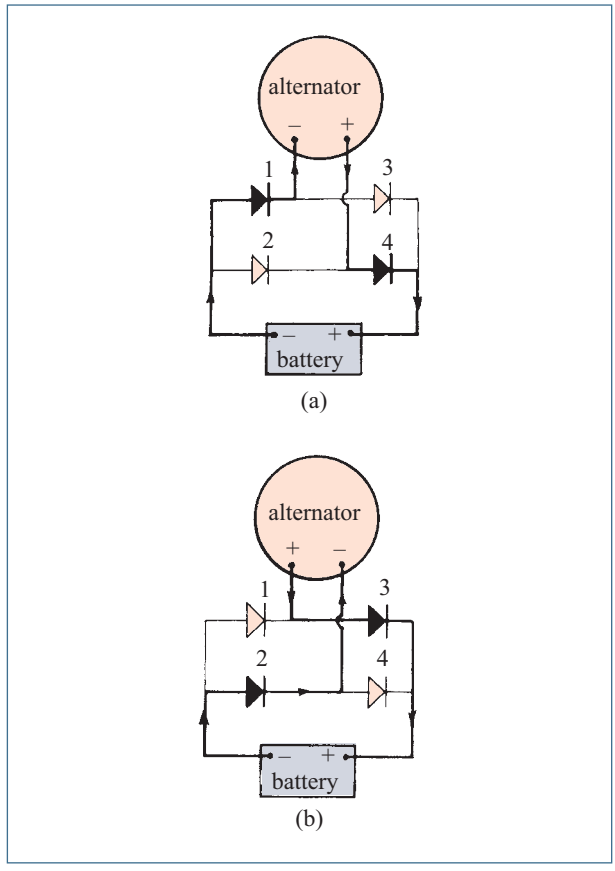


Figure 43.16 Diode arrangement for a simple alternator (a) diodes 4 and 1 are conducting (b) the polarity of the alternator has changed and diodes 3 and 2 are conducting

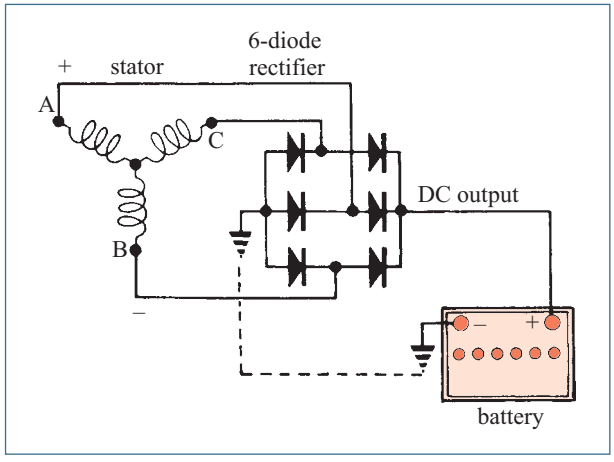


Figure 43.17 Wiring circuit of an alternator with six diodes and star-connected stator windings

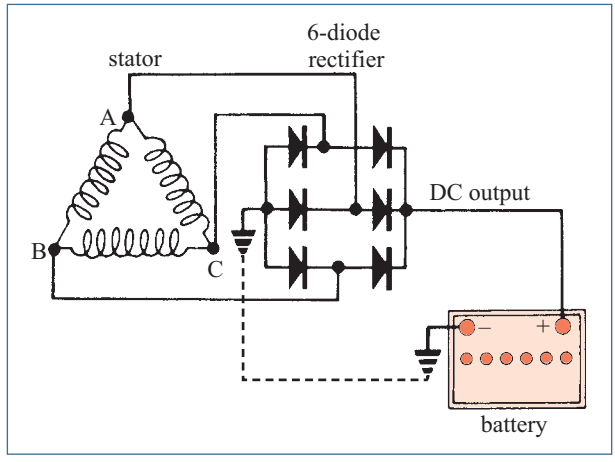


Figure 43.18 The wiring circuit of an alternator with six diodes and a delta-connected stator

The positive diodes (on the right) are connected to the positive battery terminal. The negative diodes (on the left) are connected to the negative battery terminal through the earth.

With the diodes arranged as shown, the end of each stator winding will always supply current to the correct battery terminal—there is always a path through one diode, with the other diode of the pair blocking current from flowing in the wrong direction.

For the star windings in Figure 43.17, there are six separate circuits through which current can flow from the alternator to the battery. The three connections (A, B and C) on the alternator will be constantly changing their polarity. At any one instant, connection A will be positive, and at the next it will be negative. The same applies to all three connections. The delta circuit acts in a similar way to the star circuit.

Handy hint: The path should be traced on the diagram from the end of each winding (A, B and C) to the battery , and also the return path from the battery to the windings.

43.5.2 Field diodes and excitation

The rotor field windings must be energised (excited) to enable the alternator to operate. Current is provided to the rotor via the slip rings and brushes. The current can be obtained from the battery, the alternator itself or the ECM. When current from the battery is used, the alternator is referred to as being *externally excited.* When current from the alternator stator is used, the alternator is *self-excited.* ECM-powered field windings are part of the battery management system shown in Figure 43.26.

Self-excited alternators use three extra diodes, making nine in total. These three diodes are known as *field diodes* or *exciter diodes,* and the other six as *power diodes.* A simplified circuit using exciter diodes is shown in Figure 43.19. A simplified rotor field coil (on the right of the diagram) is energised by direct current. This is AC from the stator windings which has been rectified by the exciter or field diodes.

Externally-excited alternators use current from the battery circuit or from the alternator external circuit to energise the rotor field coil.

43.6 Voltage regulation

43.6.1 Simple electronic voltage regulator

Alternators have a regulator to control their voltage. A voltage regulator is needed because the alternator produces a rising voltage which is related to alternator speed—the faster the rotor spins, the higher the voltage. Regulation is achieved by varying the strength of the rotor field. Figure 43.20 shows a simple arrangement of the circuit of an alternator and an electronic regulator. This has a transistor (T1), a resistor (R) and a Zener diode (Z). (An actual regulator would have more electronic components.)

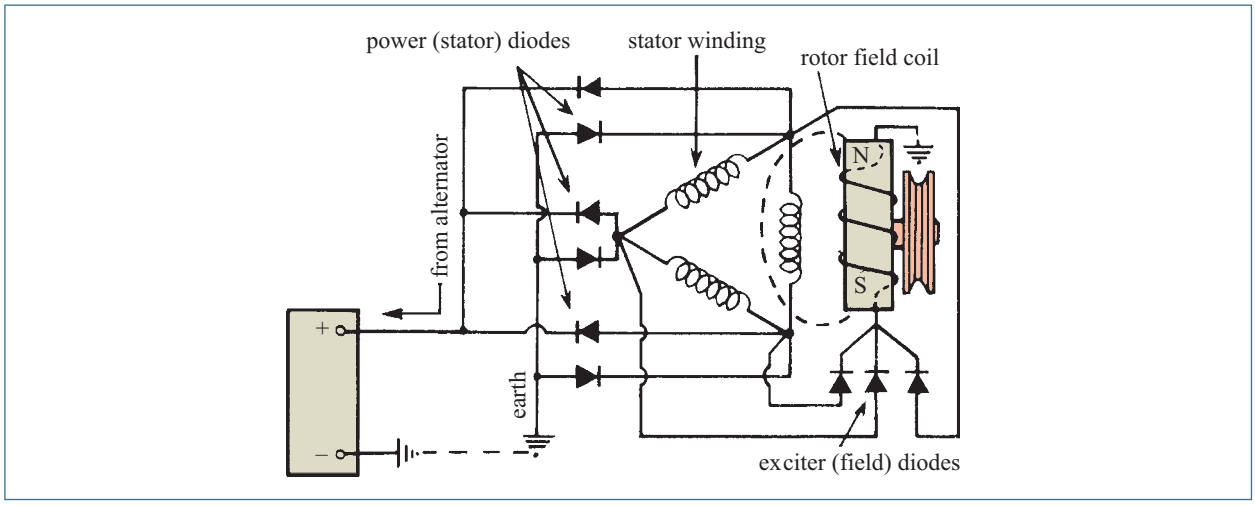


Figure 43.19 Simplified alternator circuit with three ex citer or field diodes and six power diodes

There are two parts to the circuit:

1 The rotor or field circuit. The rotor coil (field coil) is provided with excitation current from the stator at B+, and the circuit is completed through the transistor from C to E and to earth.
2 The regulator circuit. This is from the alternator terminal B+ to the resistor R, and to the base B of the transistor.

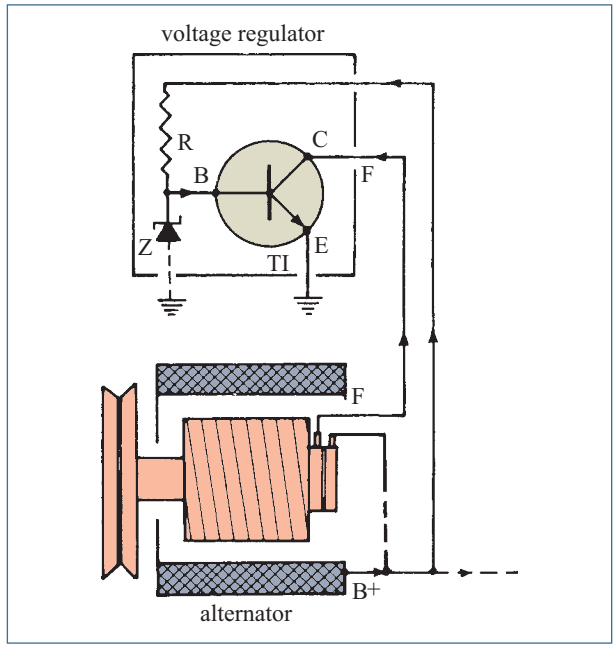


Figure 43.20 Schematic arrangement of an alternator and a simplified electronic voltage regulator with one transistor—the rectifying diodes are not shown

43.6.2 Transistor switching

The transistor is an electronic switch with three terminals: base B, emitter E and collector C. If a small current is passed between B and E, the transistor will act as a switch to conduct a much larger current between C and E. The transistor will be conductive only while the small operating current is flowing. At other times, it is non-conductive (off).

The voltage regulator (see Figure 43.20) operates as follows:

1 The transistor is non-conductive until the alternator starts to operate.
2 Current from the alternator will then reach the base of the transistor, B, to operate its base circuit from B to E.
3 This makes the transistor conductive (on) from C to E to complete the rotor field circuit to earth.
4 When the regulator voltage setting is reached, the transistor is made non-conductive (off) by the action of the Zener diode. The rotor circuit is broken, causing the alternator voltage to drop.
5 The transistor becomes conductive again (by the action of the Zener diode) to complete the field circuit (through the rotor coil) and restore alternator voltage.

The cycle continues, with the transistor being switched on and off rapidly to provide a regulated output voltage.

Handy hint: Conductive as used here simply means 'on', while non-conductive means 'off'.

43.6.3 Action of the Zener diode

The Zener diode, also referred to as a *breakdown diode,* determines the voltage setting of the regulator. This is set during manufacture and cannot be adjusted. A Zener diode prevents current flow like a normal diode, but only up to a certain voltage (the *breakdown* voltage). When this voltage is reached, the Zener diode breaks down and allows current to flow.

In Figure 43.20, the Zener diode is connected between the base B of the transistor and earth. It operates as follows:

1 The Zener diode blocks current when the alternator voltage is low, so has no direct effect on the transistor.
2 When its voltage setting is reached, the Zener diode breaks down and provides a current path to earth.
3 This short-circuits the B to E section of the transistor and so switches the transistor off.
4 As soon as the alternator voltage drops, the Zener diode stops conducting and the transistor is again switched on.

In this way, the Zener diode enables the regulator to react to alternator voltage—the voltage affects the Zener diode and the transistor does the switching of the field (rotor) circuit.

43.7 Alternator and regulator circuit

Figure 43.21 shows an alternator and regulator circuit. This has six power diodes—three positive, three negative. Alternating current produced in the alternator windings is rectified by the diodes and directed to the alternator output terminal B+. This terminal is connected to the positive battery

terminal. The alternator is permanently connected to the battery, which is prevented from discharging back through the alternator windings by the diodes.

43.7.1 Electronic voltage regulator

A voltage regulator has a number of electronic components. These are shown as separate components in the illustration (Figure 43.21), but in an actual regulator integrated circuits are also used. Although this regulator has a number of electronic components, its transistors and Zener diode act in a similar way to those previously described for the simple regulators.

In the diagram, the three resistors R5, R6 and R7 are connected in series between the terminals D+ and D− to form a voltage divider. R7 is in parallel with the Zener diode and so influences it. R7 is set during manufacture and determines the operating voltage of the regulator. The diode D2 has a negative temperature coefficient and is used for temperature compensation of the Zener diode. This keeps the voltage regulator setting constant at different temperatures.

Most battery systems developed before computer-managed systems have the regulator and brush holder as a single unit mounted in the alternator, saving space and wiring costs.

43.7.2 Hybrid electronic circuit

The alternator-regulator circuit in Figure 43.22 has eight power diodes and a hybrid regulator circuit. Six of the power diodes are connected to the ends of the star windings to rectify the current in the usual way.

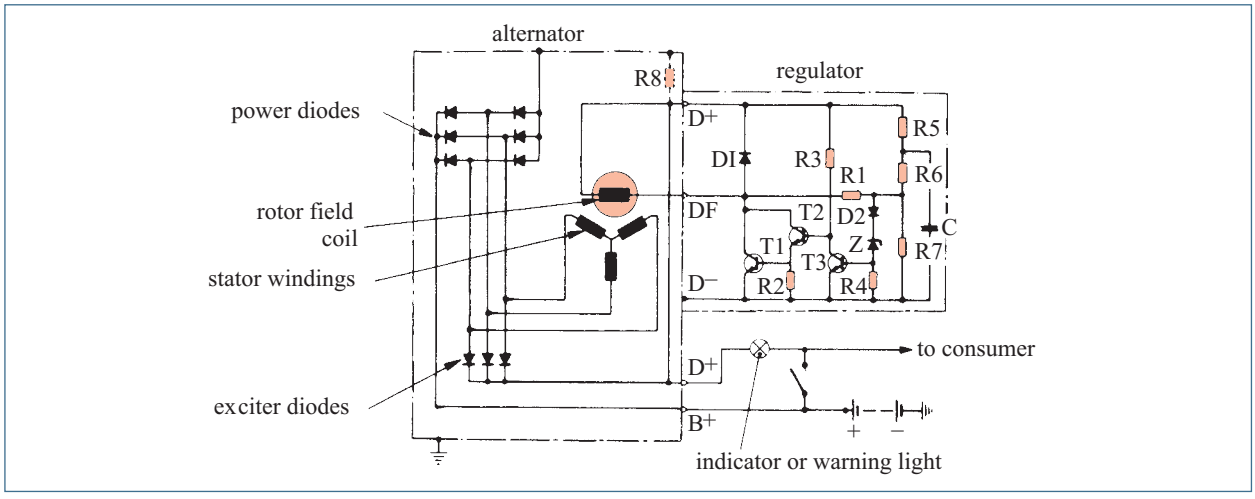


Figure 43.21 Circuit of an alternator and electronic voltage regul ator R resistors, D1 and D2 diodes, C capacitor , Z Zener diode MITSUBISHI

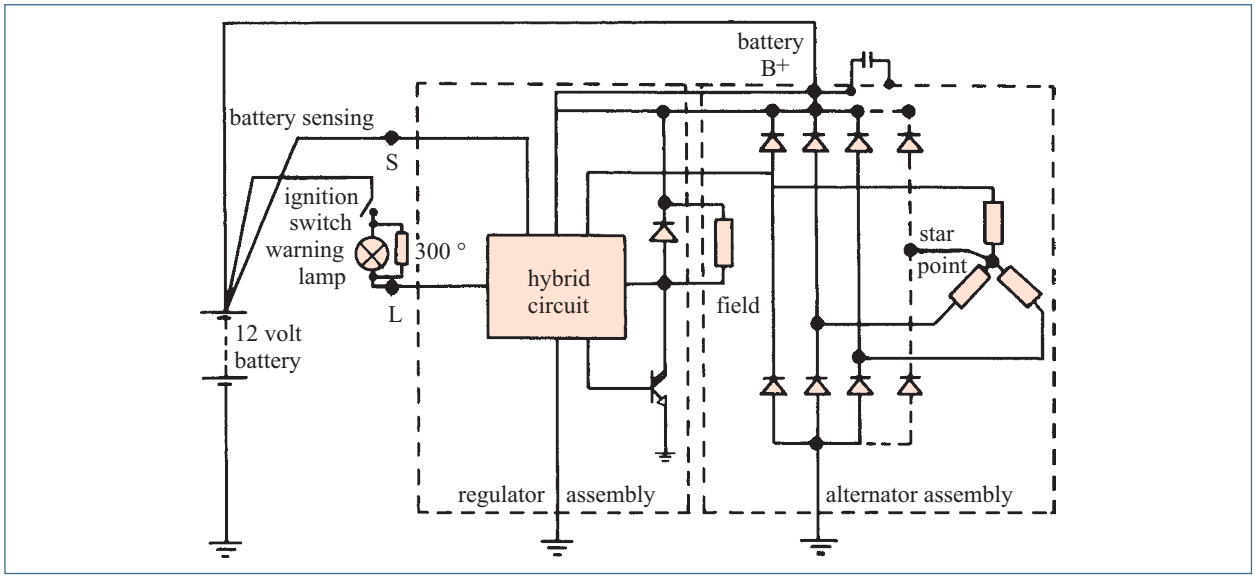


Figure 43.22 Charging-system circuit with eight power diodes and a hybrid circuit in the regulator GM HOLDEN LTD

The two extra diodes are connected to the star point of the windings, their purpose being to increase the alternator output. At certain times during alternator operation, the star point has electrical potential which is above battery voltage. The extra diodes allow this to be used to help alternator output.

The hybrid circuit of the regulator is an arrangement of electronic elements and an integrated circuit. The alternator does not have separate field diodes, but the regulator controls the rotor field coil.

Sustainability: Save all old charging units as they have a high copper content that can be recycled.

43.8 Servicing the charging system

Work on the charging system can involve alternator output and circuit checks, as well as replacing alternator parts. Where a problem exists, checks should be carried out to isolate it to a particular part of the system.

43.8.1 Charging-system checks

If the charging system appears to have a problem, check the following:

1. The drive belt should be in good condition and at the correct tension to prevent slip at high speeds.
2. The alternator indicator lamp (on some alternators) must be functioning to give initial ex citation of the fields. It should also be of the correct wattage .
3. The battery should be in sound condition. Check the state of charge , cleanliness of the terminals etc.
4. All circuit connections should be check ed, taking care not to accidentally earth the circuit (which could damage the alternator or regulator).
5. The system can be given a quick check by connecting a voltmeter across the battery terminals (Figure 43.23). With the alternator operating at reasonable speed, the voltmeter reading should be higher than battery voltage , and should read appro ximately 14 volts.

Common problems

Some common problems in charging systems are indicated by the following:

1. If a warning light remains on after the engine is started, the alternator is not charging.
2. A battery that remains flat may be in poor condition or the alternator output could be too low.
3. A battery that needs frequent topping-up indicates ex cessive alternator output.

43.8.2 Charging-system precautions

Precautions should be taken to avoid short circuits, open circuits, incorrect polarity of the battery or any other irregular connection to the charging system. These could overload the diodes in the alternator or the semiconductor devices in the voltage regulator and cause immediate damage. The following points should be observed:

1. Remove the battery terminals before working on any part of the charging system. When refitting them, the positive (+) terminal should be connected first, then the negative (−).
2. The battery must be installed with the correct polarity to avoid damaging the diodes before the engine is started.
3. If the battery is to be charged with a battery charger while it is installed in the vehicle , the terminals should be disconnected. A battery charger connected with incorrect polarity , or producing a high voltage , can damage the diodes and other semiconductor components.

Figure 43.23 Connect a voltmeter to the battery to check that the alternator is working—with the engine running, the voltage should be higher than when it is stopped

4 Earthing the alternator output terminal or cable will damage the alternator or regulator . This applies whether the engine is running or not.
5 The alternator should not be run on open circuit at any time . Circuit connections should not be brok en when the alternator is operating.

43.9 Alternator checks

The alternator can be given a quick check, as previously described. If necessary, the following more detailed check can be made with the alternator under *no-load* and *load:*

1 With the engine stopped, connect a voltmeter across the battery terminals (Figure 43.23). A reading of appro ximately 12.6 volts or slightly higher should be obtained for a healthy battery .
2 Start the engine . With the alternator operating, the voltage reading should increase as the engine speed is slowly increased. If not, the alternator has no output. (A fault could exist in the alternator , the regulator or in the circuit connections.)
3 Increase the engine speed gradually from idle . At a moderate engine speed, the voltmeter needle should flicker slightly and then remain stationary at around 14.5 volts. This is the regulated voltage . Smart charging systems may be higher—check the manufacturer' s specifications.
4 Switch on the headlamps and watch the voltmeter . The voltage reading may drop slightly , but still remain stable . This is normal.
5 Stop the engine . The voltmeter reading will remain higher than the original battery voltage . The battery plates have a surface charge , and this can be reduced by switching the headlamps on until the battery voltage drops to about normal.
6 Restart the engine and recheck the voltage setting as before .

43.9.1 Quick checks

If a voltage higher than battery voltage cannot be obtained, the alternator or the regulator could be at fault. All circuit connections should first be checked, including earth connections.

For a system with an electronic regulator, the indicator light should be checked (or, if fitted, the resistor in the wiring). If the bulb is blown or the resistor is open-circuited, there will be no initial excitation of the rotor field, and the alternator will not start to charge. If alternator output is still not obtained, consideration will have to be given to removing the alternator for dismantling and testing.

Handy hint: Electronic regulators cannot be adjusted so faulty regulators have to be replaced.

43.9.2 Checking with a voltmeter and ammeter

A voltmeter and an ammeter give a more precise check. The voltmeter is connected between the alternator output terminal and earth. The ammeter is connected into the circuit by disconnecting the cable from the output terminal of the alternator. The ammeter is then connected between the cable and the output terminal (Figure 43.24). Alternatively, an induction-type ammeter can be used so that the positive cable from the alternator does not need to be removed.

The alternator voltage is checked as before, and a reading is taken of the ammeter current. If the voltage reading at engine idle is 14 volts or slightly higher, and there is a reading on the ammeter, the system is operating correctly.

43.9.3 Checking the alternator under load

The alternator can be checked under load by using a carbon-pile rheostat as an auxiliary load on the battery. Alternatively, some loading of the battery can be obtained by turning on the headlamps, the air-conditioner blower motor and other electrical accessories (Figure 43.25).

The check is made by running the engine and noting the meter readings. An example of these is

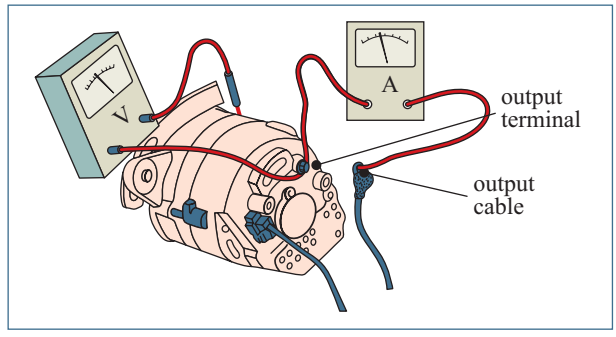


Figure 43.24 Voltmeter and ammeter connected to an alternator

14.0 to 14.7 volts and 10 amps at idle. At 2000 rpm, the readings would be 14.0 to 14.7 volts and 30 amps. The regulated voltage is the same at both speeds.

Engines using electronic management systems could show 30 amps at 2000 rpm with only the engine running unloaded, increasing to 60 amps with headlamps on high beam and the air-conditioner blower fan on full speed. If voltage readings drop more than 0.25 volts between unloaded and loaded tests, the alternator output and circuit voltage drops need to be checked and corrected.

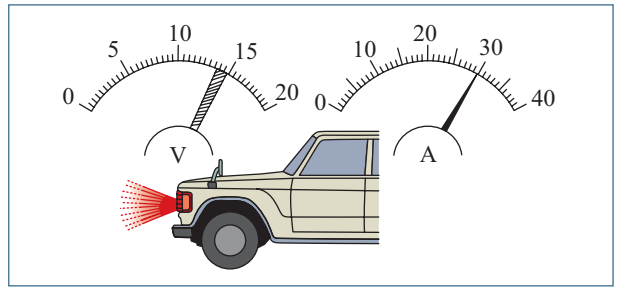


Figure 43.25 The headlamps and other electrical components are switched on to check the alternator under load

Handy hint: There are variations to the general methods described and reference should be made to the vehicle 's service manual for checks and specifications.

43.10 Battery management systems

Safety: Always consult the correct technical data for any warnings or precautions before commencing work on computerised systems.

43.10.1 Alternator requirements

There are many electrical requirements in modern vehicles, which now have electric/hydraulic steering, electric water pumps, electric-motor-driven air-conditioner pumps, start-stop systems and many other power-consuming accessories. The charging system must cater for the extra electrical equipment and keep the battery fully charged in a start-stop vehicle. Some alternators are rated at 180 amps to meet these demands.

43.10.2 Battery management systems

Different vehicle manufacturers may have different terminology for computer modules. It is vital that no damage is done to components when the system is being repaired. The term *smart charging* is often used to describe the computer battery management system (BMS). These systems require the correct type of battery to be installed as per the manufacturer's recommendations in order to function correctly.

Operation

Vehicles with smart-charging systems will have a BMS, with modules to monitor parameters such as engine temperature, battery temperature and electrical demand. Not all smart-charging systems are designed to fully charge the battery. This is done to try to extend battery life.

Battery management systems such as that shown in Figure 43.26, manage the alternator's output by direct control of its stator voltage. The body control module (BCM) monitors the battery's state of charge (SOC) and temperature, and communicates with the ECM. The BCM contains software maps that provide a mathematical model of the battery condition. Based on the information received, the BCM communicates with the ECM via a high-speed CAN Bus, predicting the output voltage required for the alternator to charge the battery. The ECM communicates via a local interconnect network (LIN) Bus connection to the alternator. This control cycle is repeated in a closed loop condition at high speed.

In some vehicles, smart charging can be used when the battery is cold to raise the charge voltage to above 15.5 volts for a short time, then temporarily back off to allow the battery to stabilise. Once the battery has settled, charging will resume to normal range of 13.5 to 14.7 V. If the battery is detected as 'charged', the BCM or ECM will drop the output to a 'floating' voltage of about 13 volts to help reduce alternator load and improve fuel economy.

Start-stop technology

In start-stop vehicles, the battery monitoring module sends information to a voltage quality module (VQM) concerning the battery's condition and SOC. The VQM maintains support voltage to crucial vehicle systems for uninterrupted power during sudden current draw.

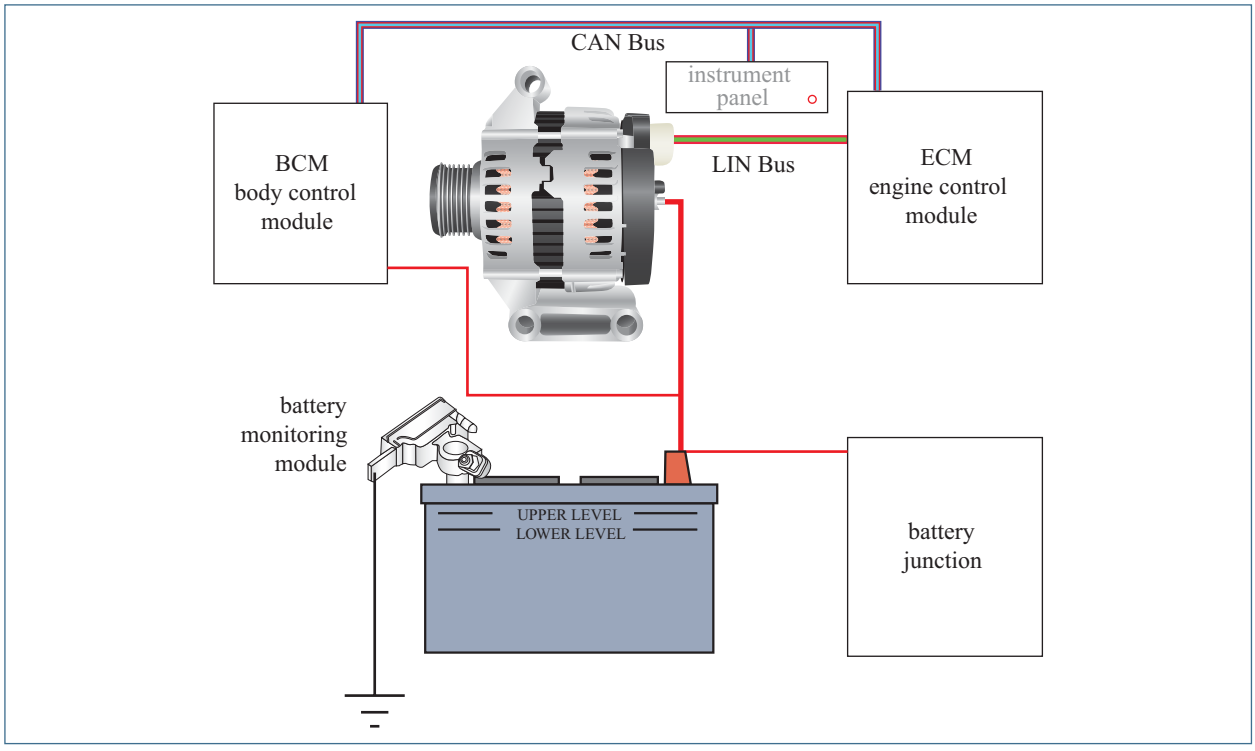


Figure 43.26 Communication links between alternator , ECM, BCM and battery

Some manufacturers have adapted the starter motor to include regenerative braking to reclaim lost energy. Regenerative braking can be done at the wheels, or making starter motors and generators as one. The configuration will depend on the manufacturer.

Fitting a heavy-duty starter that also acts as a generator recovers energy through regenerative braking. This energy is stored in capacitors to restart the engine, reducing stress on the battery and electrical system. Figure 43.27 shows an example of this type of starter.

Safety: When working on vehicles that have 'proximity keys', always place the key away from the vehicle to prevent accidentally starting the engine .

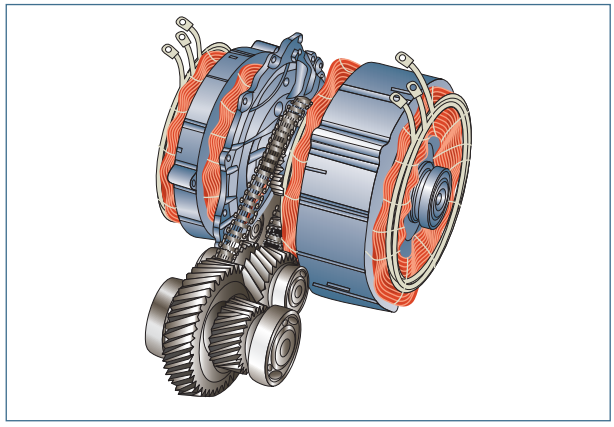


Figure 43.27 Starting and charging unit from a Toyota Prius

43.11 Alternator service

43.11.1 Dismantling and reassembling

Figure 43.28 shows a part-sectional view of an alternator; Figure 43.14 shows a dismantled alternator. These illustrations can be used to identify various alternator parts. Points relating to dismantling an alternator include:

1 The main parts are held together by through-bolts, which fit from the front housing through the alternator to the rear housing.
2 When the through-bolts are removed, the main parts of the alternator can be separated, but care should be taken during dismantling.
3 The stator windings are often soldered to the diodes in the heat sink, and the connections must be unsoldered before the alternator can be completely dismantled.
4 In some alternators, the connection to the electronic voltage regulator is soldered and must be unsoldered before the regulator can be removed.

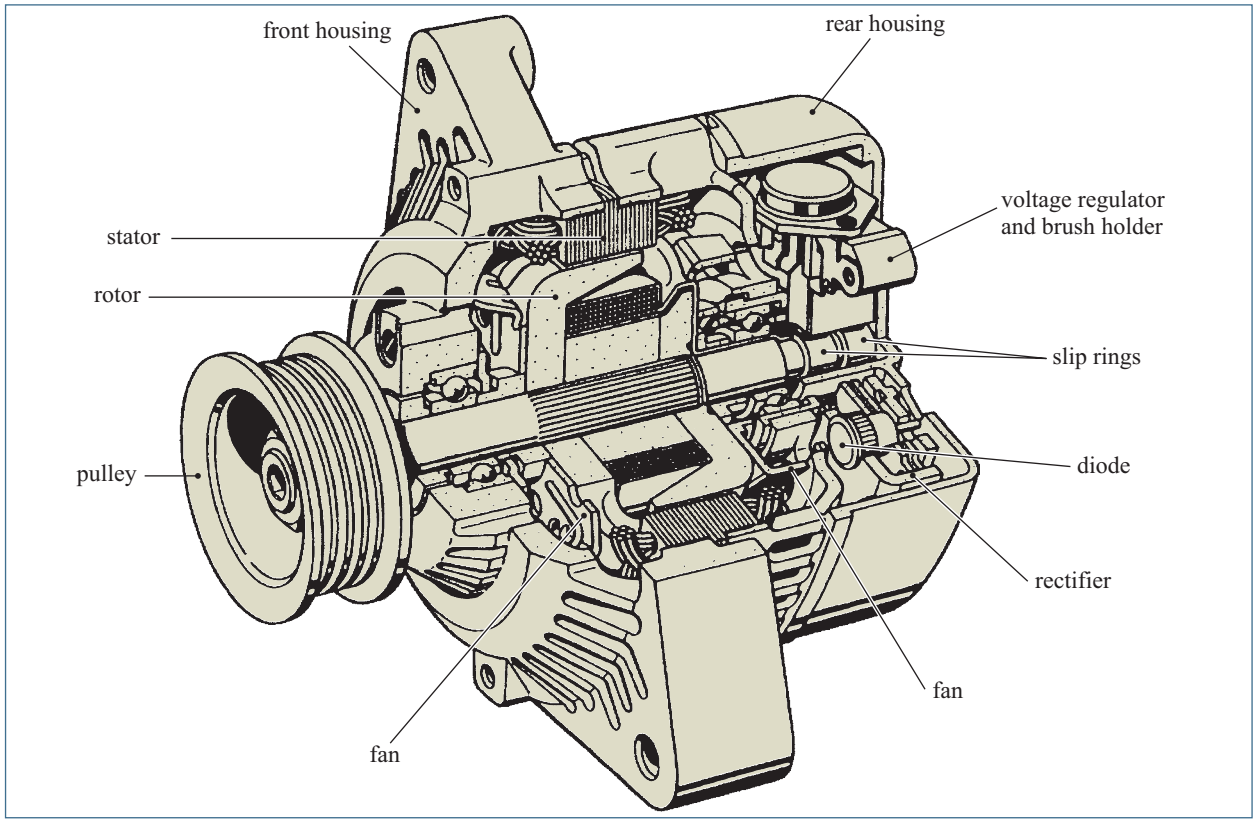


Figure 43.28 Alternator in part section BOSCH

5 During reassembly , the connections must be resoldered. The lead being soldered should be held near the connection with a pair of pliers, as shown in Figure 43.29, and the soldered connection made as quickly as possible . The pliers absorb heat and reduce overheating.

Safety tip: Excessive heat must not be applied as this will damage electronic components.

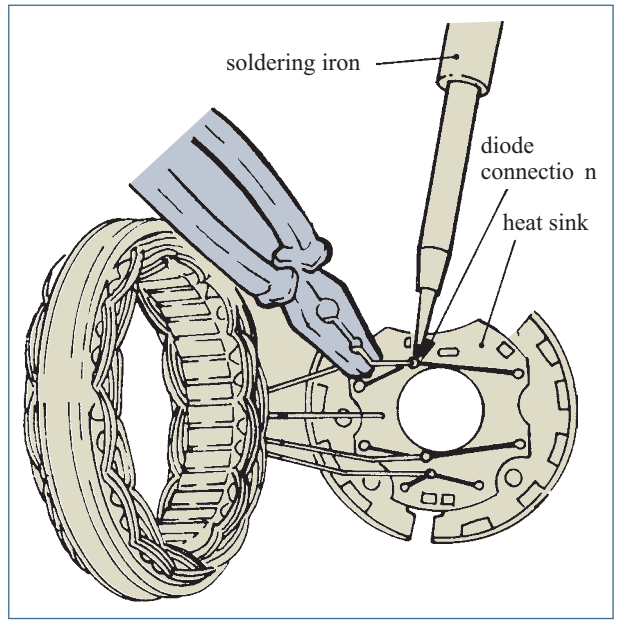


Figure 43.29 Making a soldered connection to a diode in a heat sink FORD

43.11.2 Checking components

The electrical components of the alternator can be checked for three basic electrical faults:

1 open circuits
2 short circuits
3 grounds.

The rotor consists basically of a single coil of wire, and the stator consists of three coils of wire joined together. If these are treated like any other coil of wire, the basic electrical checks can be used to determine whether or not the components are serviceable. Other possible faults are open-circuited or short-circuited diodes, worn or sticky brushes, dirty slip rings or noisy bearings.

Diodes

Each diode can be checked by connecting it in series with a test bulb and a 12-volt battery, as shown in Figure 43.30, and then reversing the connections. The bulb should light during one test only, indicating that current can flow in one direction and not in the other.

If the bulb does not light, this indicates an open-circuited diode; if it lights for both tests, this indicates a short-circuited diode. In some cases, the diodes can be renewed by pressing them in and out of the heat sink; but in most cases, the complete rectifier will have to be replaced. Alternatively, some DMMs have a diode test facility.

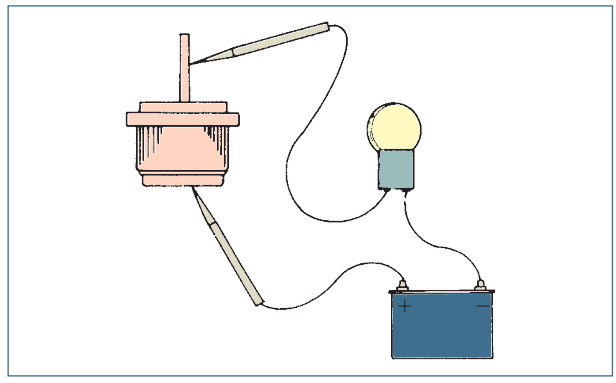


Figure 43.30 Checking a diode with a test lamp

Stator

The stator must be disconnected from the rectifier before testing. Using a test lamp or an ohmmeter, check between the ends of the windings for open circuits, and between the ends of the windings and the core for grounds, as shown in Figure 43.31. If an ohmmeter is used to check the resistance of the windings, each winding should have the same resistance.

Rotor

The rotor field coil can be tested with a test lamp or an ohmmeter. An *open circuit* test is made between the slip rings, and a test for *ground* between the slip rings and the rotor poles (Figure 43.32). A test for *short circuits* can be made with an ohmmeter, or by connecting a battery across the slip rings with an ammeter in series. This will show the current drawn by the field, which should be in the vicinity of 2.5 to 3.5 amps, depending on the particular alternator.

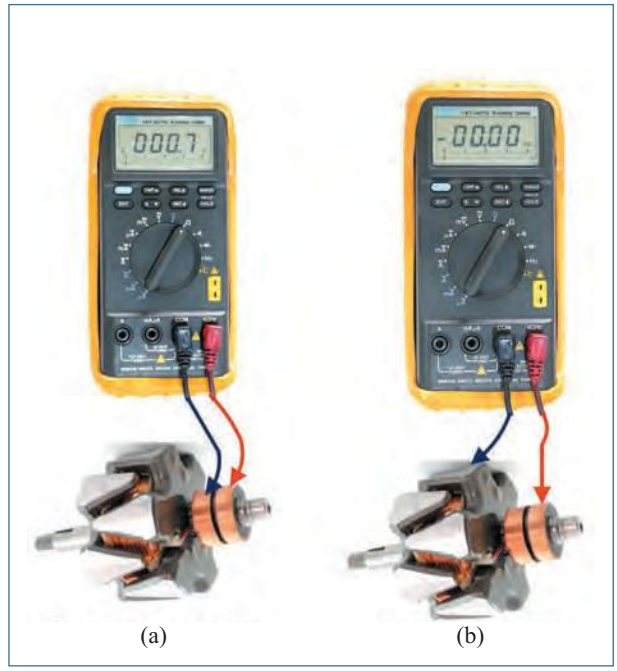
A quick checking method involves connecting a battery directly to the slip rings. This energises the field coil and magnetises the pole pieces. A piece of metal can be used to detect whether or not the pole pieces are magnetised.

Brush holder and brushes

The brushes should move freely in the brush holders, and should be of serviceable length. Sticky brushes can be cleaned with a petrol-moistened cloth. If necessary, the sides of the brush can be lightly polished against the flat surface of a smooth file.

(a) (b)

Figure 43.31 Checking stator windings with a test lamp or an ohmmeter (a) check for connectivity , (b) check for ground



(a) (b)

Figure 43.32 Checking a rotor (a) check for continuity and shorts (b) check for ground

43.12 Regulator service

Electronic regulators are sealed and adjusted during manufacture and cannot be serviced. If checks show that a regulator is faulty, it should be renewed. Figure 43.33 shows a regulator removed from the rear of the alternator. The regulator is attached by screws and is part of the brush assembly. The cable to the regulator must be disconnected before it can be removed.

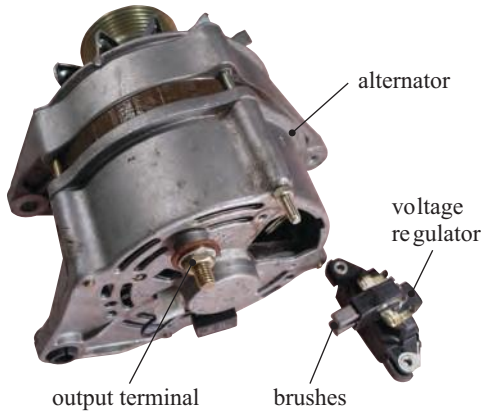


Figure 43.33 Electronic voltage-regulator assembly removed from the rear of an alternator

43.13 Diagnostics of alternator charging system

Always use the manufacturer's recommended scan tool. Most generic code readers only read the first alphanumeric code to four or five digits, whereas the manufacturer's tool may read to seven digits. Before performing any charging system tests, ensure that the battery is in good, fully-charged condition to ensure correct operation of the system. Also, ascertain from the vehicle owner what the symptoms are and perform a visual check of system components.

43.13.1 Charging-system checks

If the charging system appears to have a fault, proceed as follows:

1 The drive belt should be in good condition and at the correct tension to prevent slip at high speeds.
2 The alternator indicator lamp (on some alternators) must be functioning to give initial ex citation of the fields. It should also be of the correct wattage .
3 The battery should be in sound condition. Check the state of charge, cleanliness of the terminals etc.
4 Check all circuit connections, taking care that the circuit is not accidentally earthed (damage to the alternator or regulator could result).
5 The system can be given a quick check by connecting a voltmeter across the battery terminals (see Figure 43.23). With the alternator operating at reasonable speed, the voltmeter reading should be higher than battery voltage and should be appro ximately 14 volts. If the system has a smart-charging system or battery management system, the engine will need to be run for a short time until normal charging voltage is reached.

43.13.2 Charging system diagnostic flow chart

Table 43.1 should be considered a generic diagnostic flow chart for a charging system. Each manufacturer will have their own procedures that should be followed.

Table 43.1 Charging systems diagnostic flowchart

Symptom	Possible cause	Action
Charge warning lamp does not illuminate	Warning light/lamp circuit fault Generator/alternator internal fault CAN Bus circuit fault Engine control module internal fault	Check warning lamp function with ignition on and off . Repair the circuit as necessary . Check for D TC indicating an alternator , CAN or engine control module fault.
Charge warning lamp stays on/battery discharges	Accessory drive belt fault Alternator pulley slipping on shaft Alternator internal fault Battery cable fault	Check the battery and alternator cables. Refer to the electrical guides. Check for D TC indicating an alternator fault. Check the accessory drive belt condition and tension.
Charge warning lamp intermittent	Accessory drive belt slipping Battery cable fault Alternator circuit fault Alternator internal fault CAN Bus circuit fault	Check the accessory drive belt condition and T ension. Check the battery and alternator cables refer to the electrical guides. Check for D TCs indicating a generator or C AN circuit fault.

(continued)

Table 43.1 Charging systems diagnostic flowchart (continued)

Symptom	Possible cause	Action
Battery discharges without the charge warning lamp staying on	Battery fault Battery quiescent drain Intermittent generator fault	Check the battery condition. Check for battery quiescent drain. Check for D TCs indicating a generator fault. If no other reason for discharge can be found, check the circuit. Refer to the electrical guides.
Noise (mechanical)	Accessory drive belt slipping	Check the accessory drive belt condition and T ension. Disconnect the accessory drive belt and check that the generator rotates freely .

43.13.3 Scan tool

When using a scan tool, follow the manufacturer's processes for obtaining live data and/or a data freeze-frame of the data if fault codes are detected. Clear the codes after capturing the data and re-check for DTCs; sometimes they can be intermittent and certain codes may indicate an area that is preventing the charging system from working until cleared. (For more information on live data and freeze-frame captures, see Chapter 40.) If DTCs persist, follow the system of the DTCs to be checked. A DTC does not always indicate that a particular component is at fault but it does indicate that the system has a fault and further test will be required to isolate the problem. This should be done using the manufacturer's procedures and not by replacing parts unless they are faulty.

43.14 Simple generators

Generators (also called dynamos) use the same principle as alternators to create an electrical output. The main difference is the EMF comes from the armature (the rotating component), and not from the stationary component (field coils); see Figure 43.34.

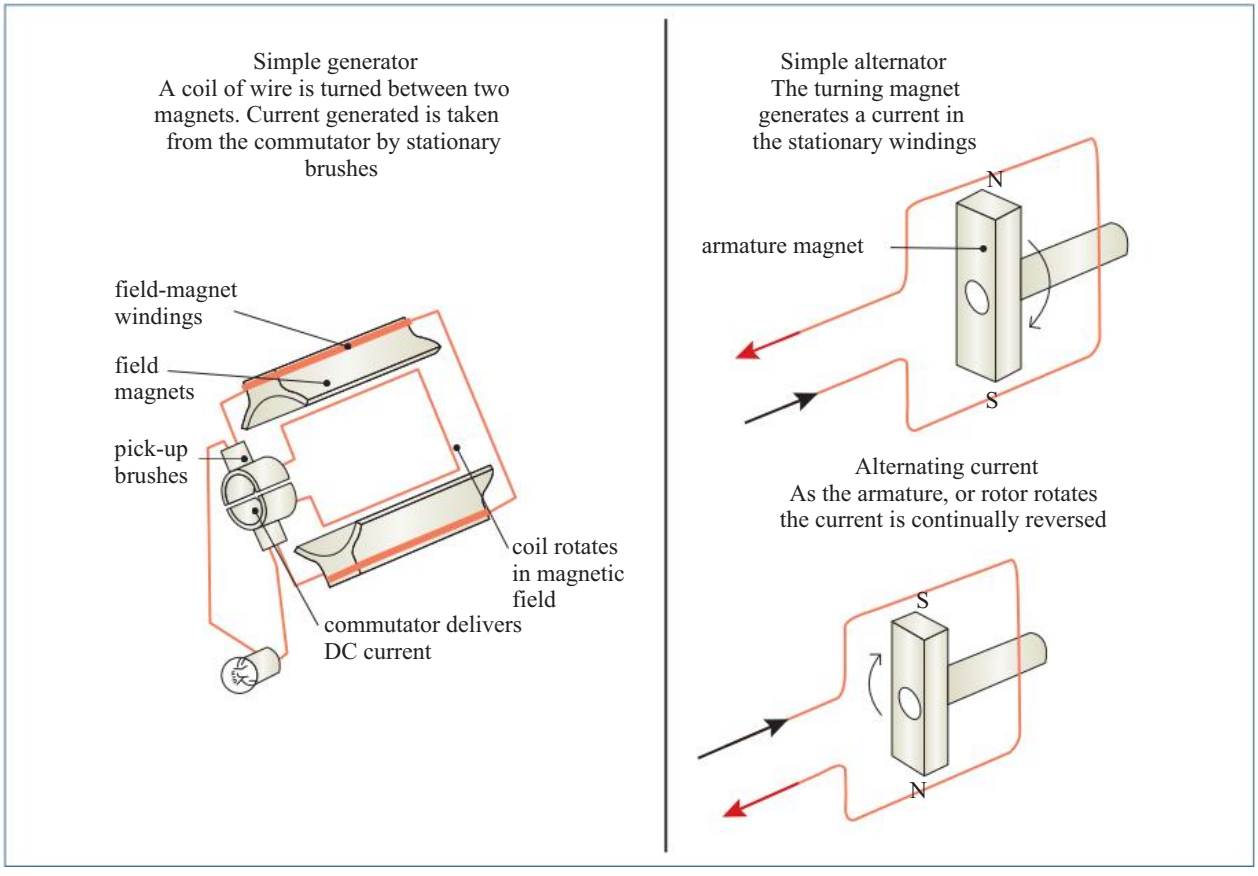


Figure 43.34 Simple comparison between an alternator and a generator , showing electrical flow

43.14.1 Construction

A generator consists of a round, tube-like body with two field shoes and wire coils forming two electro magnets (Figure 43.35). Between the magnets is an armature with 28 coils of wire. The ends of each coil are joined to copper segments that form a commutator at the end of the armature. A set of spring-loaded carbon brushes is connected to the armature.

43.14.2 Operation

When power is applied to the fields and the armature is turning within the magnetic field, a current is produced (Figure 43.36). The stationary carbon brushes transmit the EMF from the armature.

In this process, one brush always receives a negative current and the other a positive current. The output is a DC current and no rectification is needed. The amount of current from the armature depends on the strength of the magnetic field.

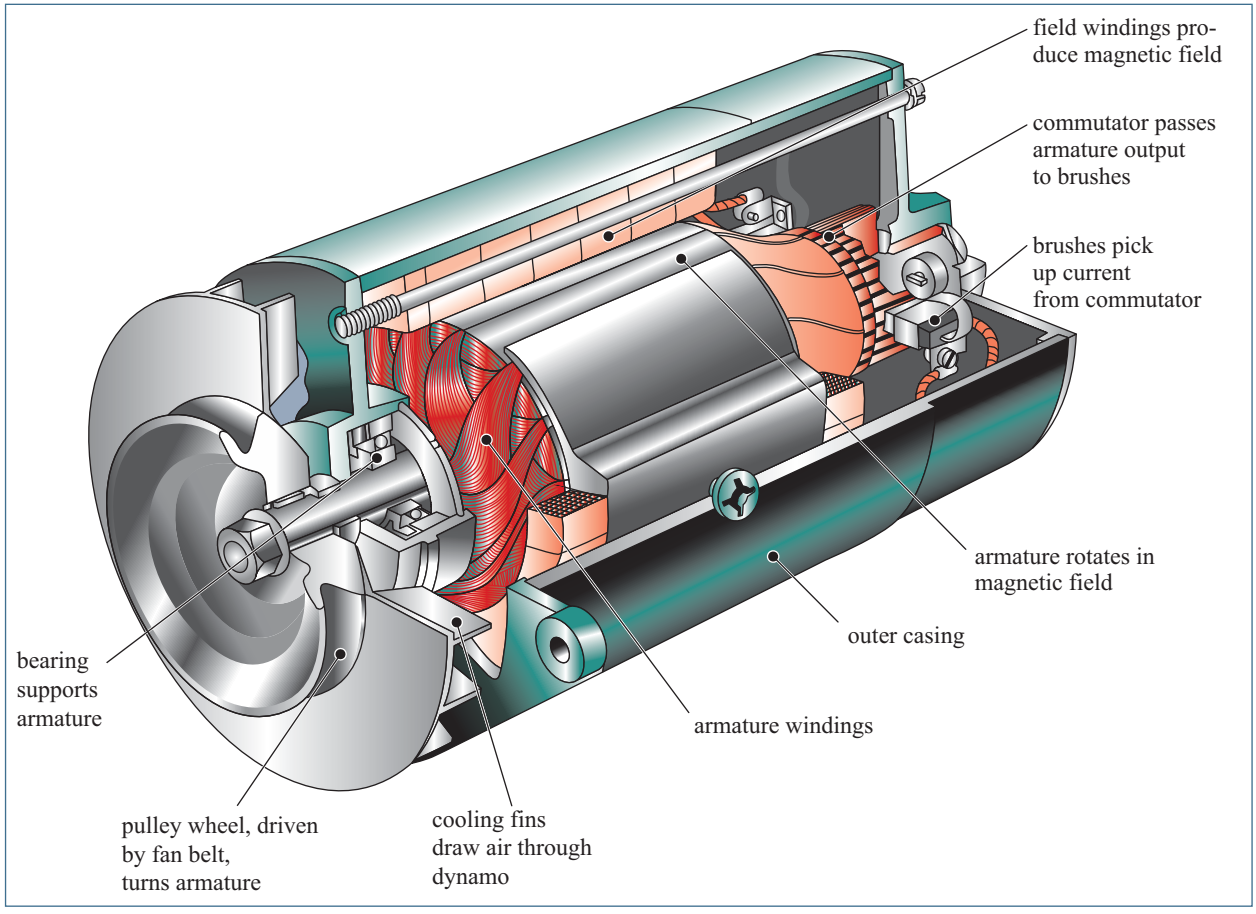


Figure 43.35 The internals of a generator/dynamo

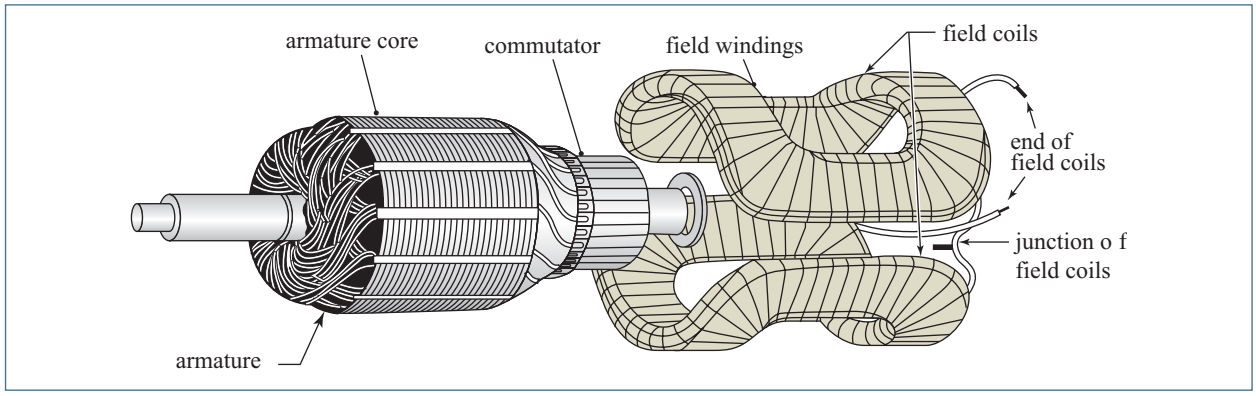


Figure 43.36 The main components of a generator . The armature produces the output and the fields provide the magnetic field

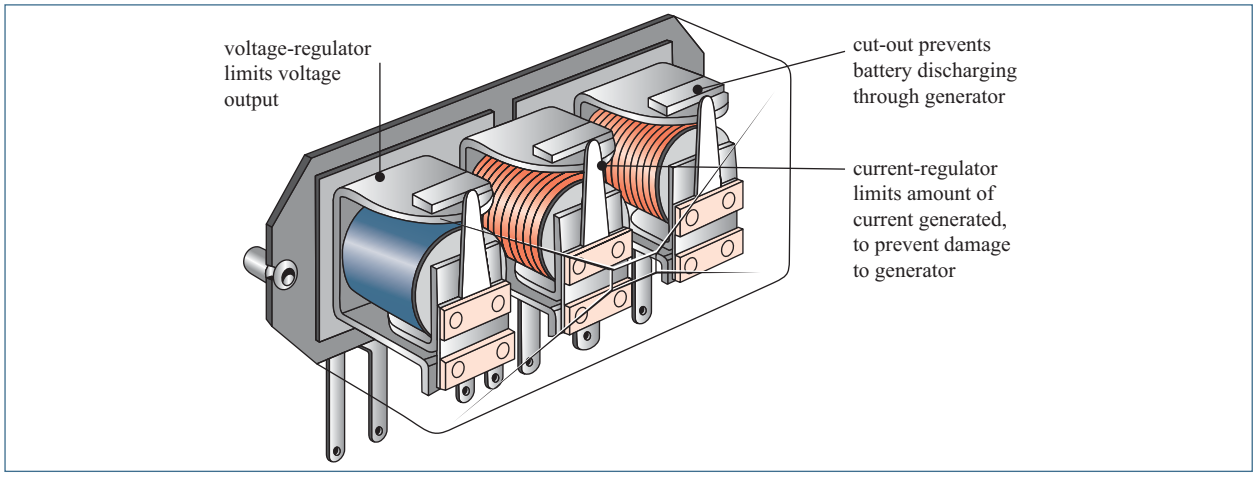


Figure 43.37 A regulator with the cover off

43.15 The generator regulator

The output of the generator is managed by a regulator which controls the EMF to the fields. (A generator's output increases as the speed of the armature increases.) The regulator acts as a voltage control, a current control and a cut-out when the engine stops, halting the flow of power through the fields. Figure 43.37 shows the construction of a regulator.

43.15.1 Voltage regulator

The operation of the voltage regulator unit is the same for a generator or an alternator, as shown in Figure 43.38. The voltage regulator prevents the generator and system voltage from exceeding a predetermined safe maximum. It also maintains a practically constant generator voltage which causes the generator to provide a charging rate in reverse ratio to the state of battery charge. By controlling generator voltage, the generator output current is also controlled to suit battery condition.

43.15.2 Current regulator

The current regulator is constructed in a manner similar to the voltage regulator, except that the winding consists of a few turns of thick wire through which full generator output current passes. When the generator output reaches rated maximum, the current passing through the regulator winding is sufficient to overcome the armature spring tension and separate the regulator points. This inserts the resistance into the generator field circuit, causing the generator output to drop off. As soon as the generator output current is reduced, the magnetic attraction of the regulator winding is reduced also, so that it can no longer hold the points

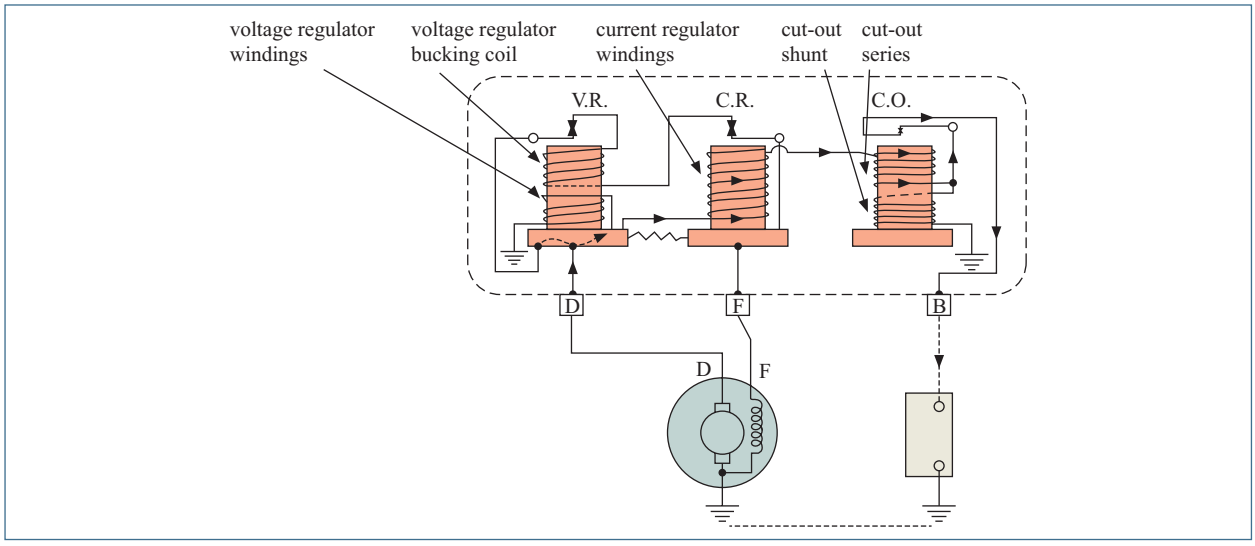


Figure 43.38 The internal windings of a regulator for a generator

open. The points close, the generator field circuit is directly connected by them and the generator output increases. This cycle is repeated very rapidly, causing the current regulator to limit the current output of the generator to the value for which the generator is rated.

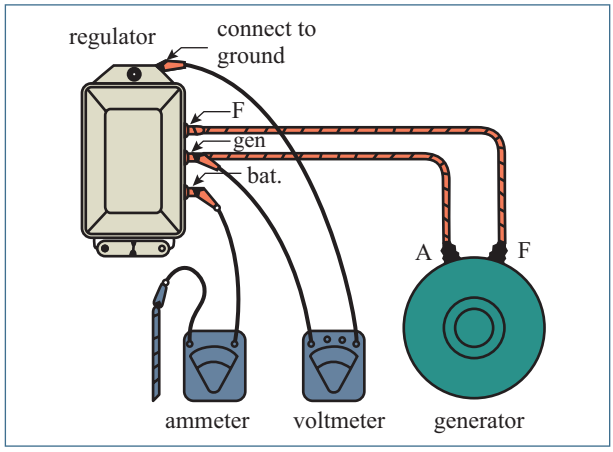


Figure 43.39 Connections for an ammeter and voltmeter to test a generator system 's performance

43.15.3 Combined action of voltage and current regulators

Either the voltage regulator or the current regulator operates at any one time; they never operate simultaneously. When the load requirements are high and the battery is low, the current regulator operates to prevent the generator output current from exceeding its safe maximum. The voltage is not sufficient to cause the voltage regulator to operate. However, if the load requirements are reduced, or if the battery begins to come up to charge, the system voltage will increase to a value sufficient to cause the voltage regulator to operate. As the voltage in the system increases, the generator output current is reduced; it falls below the value required to cause the current regulator to operate. All regulation is then dependent on the voltage regulator.

43.15.4 Cut-out operation

As the generator armature rotates, a voltage is induced into its windings. The field is being energised because it is connected in parallel with the armature, as shown by the dotted line. As previously described, the generator voltage is imposed on the cut-out windings, so current flows through both sets of windings to earth. This sets up a magnetic field, which attracts the armature to close the cut-out contact points. Current can now flow through the points to the battery.

The cut-out points close when the generator is producing a voltage slightly above battery voltage and open when the generator voltage drops slightly below the battery voltage. The cut-out is therefore an electromagnetically-operated switch, which cuts the generator in and out of the circuit as required.

43.16 Testing generator output

To test the output of a generator system, connect a voltmeter and an ammeter to the charging system as shown in Figure 43.39. Start the engine and raise the rpm above idle; the 'cut-out' contacts should close and charging will commence. The voltmeter should read between 13.5 and 14.5 volts. The amps should read approximately 18 to 30 amps, depending on the battery state of charge and the generator output. After a short time, the amps should fall back to 8 to 10 amps. Turn on the headlights and the amps should increase to compensate for the extra load. To test the output further, a carbon pile load can be connected to the battery to give a variable load to check the charging system through a range of loads. Output voltage should remain between 13.5 and 14.5 volts.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain how magnetic fields induce an electric current in a coil of a conductor
- explain alternating current and direct current
- describe the construction, purpose and function of each component in an alternator
- demonstrate how to change alternating current to direct current with diodes in a rectifier
- demonstrate the use of a computer to sense a battery' s state of charge and control the charging rate

- apply a testing procedure for an alternator
- demonstrate charging systems for start–stop vehicles
- describe the construction of a generator or dynamo and how to service and repair them
- explain what is meant by controlling generator output
- apply testing procedures for generator/dynamo systems.

REVIEW QUESTIONS

1 Name the parts of a charging system.
2 What is the purpose of the alternator ?
3 Name the external parts of an alternator .
4 Give a simple explanation of how an EMF (voltage) is induced in a conductor .
5 Explain how a simple alternator works.
6 State the difference between A C and DC.
7 Why is AC changed to DC ?
8 How is AC changed to DC in an alternator?
9 Using Figure 43.8, describe the action of a simple alternator .
10 Name the main internal parts of an alternator .
11 What is the purpose of the rotor?
12 Draw a diode symbol and indicate the direction in which current would flow .
13 Show how stator windings can be connected together in two different ways.
14 What is meant by three phase ?
15 In Figure 43.19, trace out the current flow from the stator windings under all lik ely conditions.
16 Explain briefly how the voltage of an alternator is regulated.
17 What is the purpose of the field or exciter diodes ?
18 What is a heat sink ?
19 What is an electronic voltage regulator ?
20 Explain how a simple electronic-voltage regulator works.
21 What is the purpose of a Zener diode in an electronic voltage regulator?
22 State the precautions that are needed when working on a charging system.
23 State the basic checks that can be made on a charging system.
24 How can an alternator be check ed to see if it is charging ?
25 If a voltmeter is connected across the battery , what reading is lik ely to be shown:
(a) with the engine stopped?
(b) with the engine running ?
26 What is the purpose of a battery management system ?
27 What is meant by the acronym SOC?
28 How does a generator differ from an alternator?
29 List the main components of a generator .

CHAPTER 44

Body electrical systems and service

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 describe the environmental issues relating to lead solder
2 identify the types of wiring systems found in vehicles
3 describe and apply correct procedures to repair electrical wiring harnesses **and** looms
4 fit electrical accessories
5 describe and apply correct procedures to repair complex wiring systems
6 describe and apply correct procedures to repair C AN Bus wires
7 repair terminal plugs
8 describe and apply correct procedures to solder electrical wiring
9 describe and apply correct procedures to strip and crimp terminals and joins **in wiring.**

Repairing wiring harnesses and looms requires identifying and locating faults in wiring or components, replacing components and installing electrical accessories. These tasks require an understanding of electrical circuits and the ability to use basic electrical test instruments and equipment.

⚠ Safety: Care must be tak en when working on the electrical systems of vehicles equipped with airbags and seatbelt pretensioners.

44.1 Environment

Solder is a mixture of metals (normally lead and tin) whose melting point is below that of its constituents. Applying solder can cause toxic lead fumes if a gas/air flame or an electric soldering iron is used. When resin core lead solder is heated the lead forms lead oxide fumes which can result in lead poisoning if inhaled. The resin flux, made from Colophony, produces toxic fumes when heated. These fumes may cause clinical asthma. Always work in a well-ventilated work area.

Excess solder should be removed with care, to ensure that fine lead dust is not produced; it can be toxic if inhaled. Solder spillage and filings should be collected and removed promptly to prevent air contamination by lead.

44.2 Workplace procedures

Each workplace will have its own procedures and practices. These may require, for example, wiring joints to be soldered and not crimped; or they may require all vehicle details and owners' requirements to be completed on work orders and signed off before work commences. These procedures must be followed.

Safety: The correct workshop manual and wiring diagrams should be consulted before starting any work on a vehicle .

44.3 Simple wiring systems installations

44.3.1 Trailer electrical connections

Vehicles used for towing have associated wiring and a special trailer socket. (Trailers and caravans have corresponding plugs and wiring.) The plug and socket are wired with a flexible seven-core cable, with wiring following a standard trailer colour code. The correct wire connections must be made, whether a new installation is being done or faults in an existing one are being located.

Handy hint: Before starting any work on a vehicle , check for any D TCs (diagnostic trouble codes) **and record them. P**ost-work procedures should include checking for D TCs before returning the vehicle .

44.3.2 Trailer connector plugs and sockets

The Australian automotive environment includes vehicles from many countries, and consequently there are several plugs and sockets used for trailer plug connections. These are as follows:

- small round in either 6- or 7-pin configurations
- large round in either 5- or 7-pin configurations
- flat plug in 12- or 7-pin configurations
- round 13-pin Euro plug
- EBS (electronic brak e system) 7-pin (used for anti-lock braking system trailer brak es).

With the exception of the 7-pin EBS, all trailer plugs use the same colour coding for each terminal destination. As each pin for each lamp or accessory is in a different location in the plug, plugs are not interchangeable (Figures 44.1 and 44.2). The plug may fit, but if it is the wrong one the wrong lights will illuminate. Adaptors are available that allow different plugs and sockets to be connected (Figure 44.3). The correct fitting of wiring to a plug is shown in Figure 44.4.

Some four-wheel-drive vehicles have two trailer plug outlets. One will be for the trailer lights, the other for extra connections such as ABS, refrigerator, reversing lights, separate earths and sensing devices. The extra plug may use different colours.

When installing the wiring for a trailer socket, connections have to be made to the vehicle wiring. This can usually be done at a harness connector or at a cable connection near the lamp. 'Breakout' kits for some vehicles allow the trailer loom to be plugged in rather than cutting into existing wiring systems. The colour code of the wiring can be identified by checking the wires at the lamps or referring to the wiring diagram for the vehicle.

Handy hint: The colour code of the vehicle will be different from the standard colour code for trailers.

When the wires have been connected to the socket, the installation can be checked with a test lamp. Switch the different circuits on in turn and check for voltage at the appropriate connector terminal. A similar check can be made when looking for a fault. When checking the connections, look for DTCs to ensure that other systems have not been affected.

As most vehicles now use body-control computers to activate lighting, refer to the manufacturer's manual before fitting trailer wiring. Often, a specialised wiring harness will be required, integrating a computer module to allow the additional trailer lights to work in conjunction with the vehicle's existing lights. For wiring connected to higher current draw in items such as refrigerators and brakes, power should come from a suitable supply point in the wiring, and protection devices such as a fuse should be added.

SMALL ROUND*

*Cable entry view

7 Pin Round Plug & Socket

PIN No.	CIRCUIT	COLOUR
1	Left-hand turn	Yellow
2	Reversing signal	Black
3	Earth return	White
4	Right-hand turn	Green
5	Service brakes	Blue
6	Stop lamps	Red
7	Rear lamps, clearance & side marker lamps	Brown

7 Pin Plug

7 Pin Socket

6 Pin Round Plug & Socket

PIN No.	CIRCUIT	COLOUR
1	Rear lamps, clearance & side marker lamps	Brown
2	Left-hand turn	Yellow
3	Right-hand turn	Green
4	Stop lamps	Red
5	Service brakes	Blue
6	Earth return	White

6 Pin Plug

6 Pin Socket

FLAT*

12 Pin Flat Plug & Socket

PIN No.	CIRCUIT	COLOUR
1	Left-hand turn	Yellow
2	Reversing signal	Black
3	Earth return	White
4	Right-hand turn	Green
5	Service brakes	Blue
6	Stop lamps	Red
7	Rear lamps, clearance & side marker lamps	Brown
8	Battery charger/winch	Orange
9	Auxiliaries/battery lead	Pink
10	Earth return	White
11	Rear fog lamp	Grey
12	Auxiliaries	Violet

12 Pin Plug

12 Pin Socket

7 Pin Flat Plug & Socket

PIN No.	CIRCUIT	COLOUR
1	Left-hand turn	Yellow
2	Reversing signal	Black
3	Earth return	White
4	Right-hand turn	Green
5	Service brakes	Blue
6	Stop lamps	Red
7	Rear lamps, clearance & side marker lamps	Brown

7 Pin Plug

7 Pin Socket

LARGE ROUND*

7 Pin Round Plug & Socket

PIN No.	CIRCUIT	COLOUR
1	Left-hand turn	Yellow
2	Reversing signal	Black
3	Earth return	White
4	Right-hand turn	Green
5	Service brakes	Blue
6	Stop lamps	Red
7	Rear lamps, clearance & side marker lamps	Brown

7 Pin Plug

7 Pin Socket

5 Pin Round Plug & Socket

PIN No.	CIRCUIT	COLOUR
2	Left-hand turn	Yellow
3	Earth return	White
5	Right-hand turn	Green
6	Stop lamps	Red
7	Rear lamps, clearance & side marker lamps	Brown

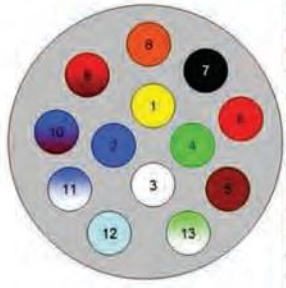
5 Pin Plug

5 Pin Socket

13 PIN EURO

13 Pin Euro plugs are fairly common on a lot of overseas model vehicles. The 13 pins allow for a lot more accessories to be wired in if needed. For Australian Trailers, simply wire in the 5 or 7 required wires and leave the rest empty.

13 Pin Wiring Diagram



Pin	Colour	Function
1	Yellow	Left Indicator
2	Blue	Fog Light
3	White	Earth
4	Green	Right Indicator
5	Brown	Right Side Light
6	Red	Brake light
7	Black	Left Side Light
8	Orange	Reverse
9	Red/Brown	Permanent Live
10	Blue/Brown	Fridge
11	Blue/White	Earth
12	None	Not Allocated
13	Green/White	Earth

Figure 44.1 Colour chart for trailer plugs used on the A ustralian mark et COURTESY OF NARVA

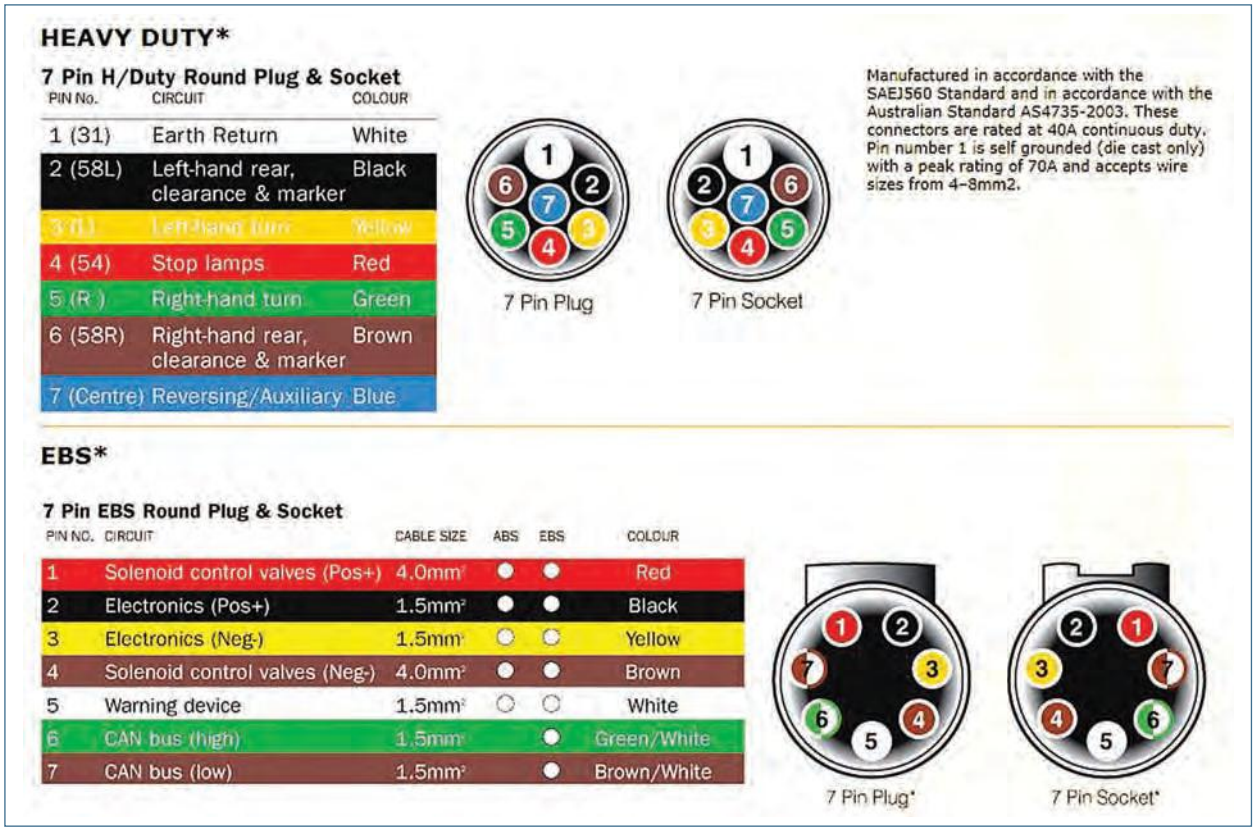


Figure 44.2 The EBS (electronic brak e system) and the heavy-duty large round plug that is used for higher current COURTESY OF NARVA

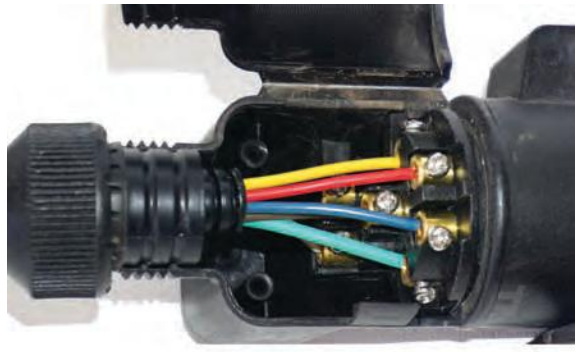
Figure 44.3 Typical adaptor used to convert a 7-pin flat to a 7-pin large round

If the vehicle has a rear fuse box (Figure 44.5), there will be a main supply that can be used for heavier current loads.

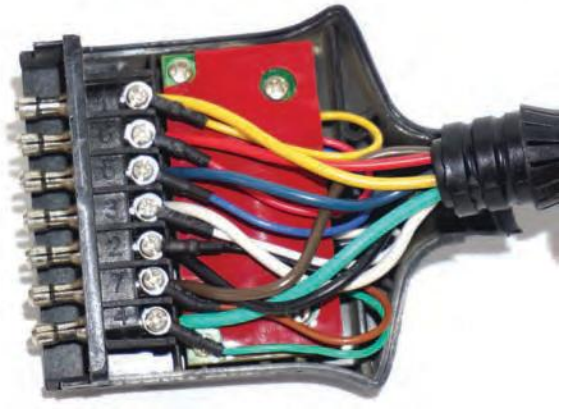
44.3.3 Driving lights harness

For country driving, fitting extra driving lights, fog lights or bar lights allows the driver to see further at night. Before fitting extra lights the following procedures should be followed:

1 Establish the mounting location for the lights and ensure that the mounting complies with A ustralian Design Rules (ADR s). Check that the customer is happy with the location.
2 Establish the mounting position for the switch, and agree this with the customer , too



(a) 7-pin large round



(b) 7-pin flat

Figure 44.4 The internal connections of 7-pin trailer plugs

(modern vehicles do not have many places to mount extra switches). Take care when cutting holes in dashboard panels.

3 Check the vehicle's wiring diagram (Figure 44.6) to establish which wires to make connections to.

4 Check ADRs about the number of lights that may illuminate at any one time and the regulations for fitting bar lights (regulations are different in each state).

5 Check that the alternator can supply the extra current while satisfying existing requirements.

When fitting accessories such as lights, a relay should be used to reduce the current draw on the existing systems. New light and globe technology gives more lumens for less current draw, but a relay should still be used. Many wiring kits (such as the one in Figure 44.7) are available.

Driving lights and bar lights must be connected via the high beam lighting (Figure 44.8) so that they will turn off when selecting low beam. Power to activate the light relay is taken from the high beam circuit and must go via an independent cut-out switch.

Depending on the vehicle's wiring configuration, power for the lights should come from a main battery distribution box via the light relay. Look for a suitable place to add a fuse at the point power is taken from (as in Figure 44.9). Body control modules (BCMs) may monitor the current draw of each globe and report fault codes if it is incorrect, showing a fault as a short or open circuit. After a lighting system has been fitted, check that the BCM has not detected a fault.

Figure 44.5 As the rear fuse box is located next to the spare wheel, it is ideal for taking heavy loads for accessories

44.3.4 Accessory wiring harness

Modern vehicles have many convenient features and generally do not need many accessories, except for special functions such as those of a

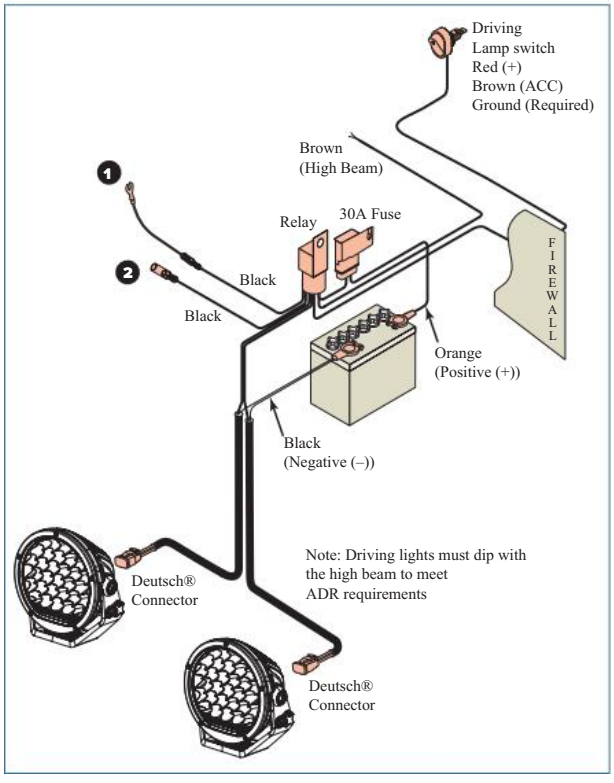


Figure 44.6 Wiring diagram for driving lights COURTESY OF NARVA

Figure 44.7 Typical contents of a driving light wiring kit COURTESY OF NARVA

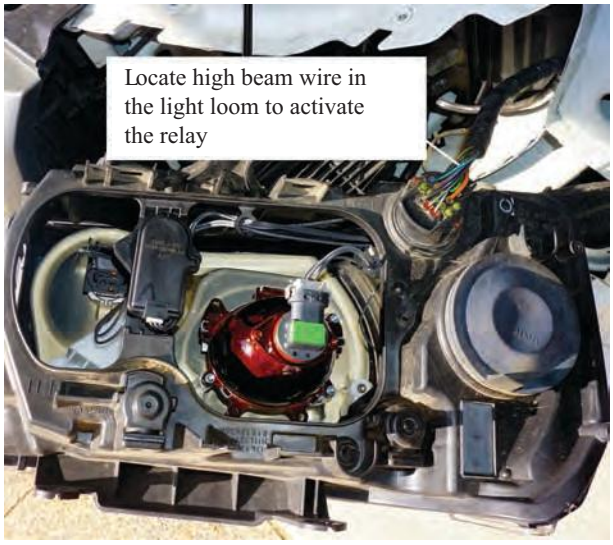


Figure 44.8 In some vehicles, an easy route for attaching to the high-beam lighting system is from behind the headlamps

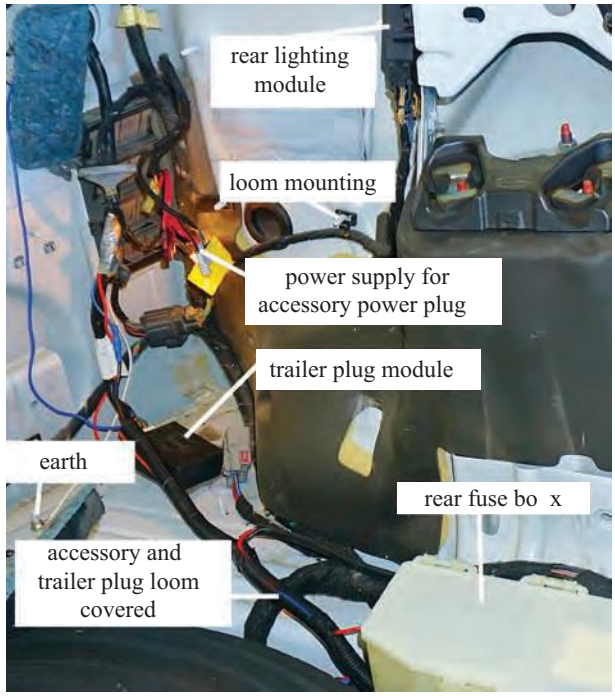


Figure 44.9 Location of secondary fuse bo x, loom mounting, wires for accessory outlets and trailer wire connections

car fridge-freezer, electric trailer brakes, USB outlets or other power outlets. Before starting to fit the power outlet, check the vehicle technical manual for relevant precautions and the location of a suitable cable to which to attach the wiring of the accessory. Some modern vehicles have a secondary fuse box in the rear to provide power to trailer connections and lighting (Figure 44.9). This fuse box will have a main supply from the front of the vehicle at the battery junction box. Fit a relay if a separate switch is required. Fit an inline fuse in the supply to the power outlet, mounting the accessory outlet socket on the interior trim panel (Figure 44.10). Check the system and replace the panel.

Figure 44.10 Connections to 12-volt power and USB outlets at rear of vehicle

44.4 Complex wiring system repairs

44.4.1 Looms with multiple-size wiring

Vehicle looms can vary from just a couple to a hundred wires; and within the multi-wired looms, multiple-sized cables carry different loads (Figure 44.11). In the case of a damaged main loom, repair can be complex. When carrying out repairs for multiple-sized cables, simple but worthwhile rules to follow are:

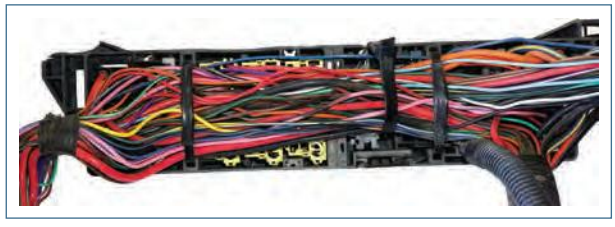


Figure 44.11 Typical main wiring loom

1 Ensure that the original cause of the failure is located and/or known (and prevented from happening again).
2 Do not replace parts as a trial-and-error method of locating the fault.
3 Consult the technical information on the wiring loom for the correct size for each cable and its function. If no information is available , measure the cross-section of each wire to be repaired. Complete the repair with the correct size and load-carrying-capacity wire (Figure 44.12).
4 Try to place the joints for each repair in a slightly different spot to avoid excess bulk in one area.

5 Ensure that the repair cable is correctly insulated to avoid further shorts. Ensure the loom is positioned correctly and secured to prevent further damage or faults.

44.5 CAN Bus wiring repair

CAN Bus wiring has several speed or Baud rate standards. (Baud is the rate at which information is transferred.) Where the damaged cables are a twisted pair that is not shielded (enclosed by a common conductive layer) or covered by a foil, they can be repaired with like cable (Figure 44.13).

If the damaged cable is shielded or has a foil surrounding the wires, it will need to be completely replaced; this type of cable is generally not repairable. Shielded cables are used when there is a high Baud rate or a risk of electrical interference (Figure 44.14).

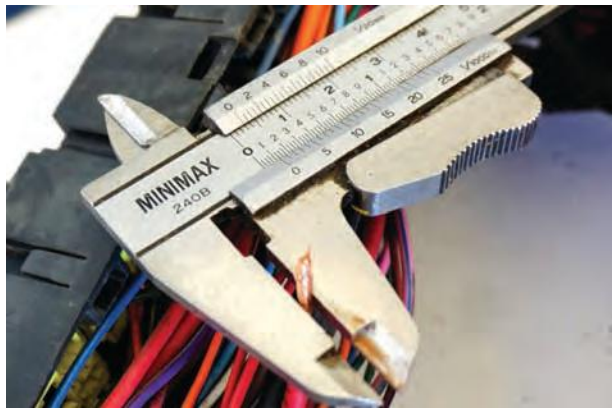


Figure 44.12 Measure the cable cross-section to ensure that any replacement is of the same capacity

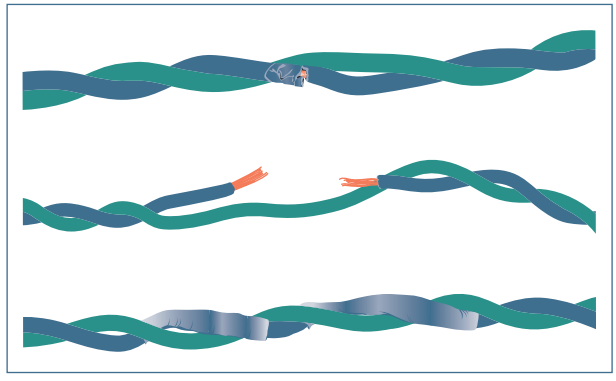


Figure 44.13 Repair of C AN Bus wires using solder and heat shrinkwrap

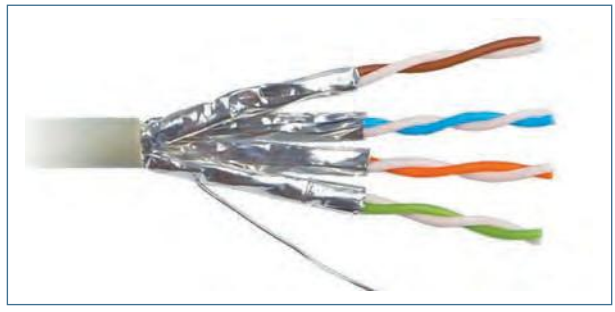


Figure 44.14 A shielded cable with four pairs of twisted CAN Bus wires

44.6 Removal and replacement of wiring and components

44.6.1 Removing panels

Interior panels often have to be removed. Some are held by simple push-in clips while others may be more complex and require several other components such as seating, door seals or other panels to be removed first.

Always consult the workshop manual to check the procedure before commencing work. There may be airbags or airbag sensors fitted under panels that have to be removed. Disconnect the battery and wait the recommended time for the power in the electrical system to dissipate. The specified waiting time may vary from one manufacturer to another.

To remove a panel, check on the location and type of clips used in the manufacturers' specifications. Special panel clip tools made of non-scratch material such as plastic should be used when possible to pull the panel clips from the body panels. Some clips will have dust seals and can only be purchased as a genuine part, so care must be taken to avoid damage.

Establish which tool will be best for releasing the panel clip (Figure 44.15). There are many different types of clips, and care must be taken to ascertain and understand the correct release method.

44.6.2 Removing components

Due to the complexity of modern automotive electrical systems, manufacturers' official procedures should always be followed. If the components that are to be removed or worked on are electrical, disconnect the battery first. If possible, remove the connecting plug before the component. Some components such as electric door locks and electric window motors can be difficult to access. With systems that use intelligent key systems, every panel that locks will be controlled and monitored via the body control module (BCM).

If any of the following needs to be done during the work, the system must be initialised when the work is completed so that all functions will work again. To initialise a system, the procedure set out by the manufacturer must be followed. This applies to any of the following items:

- interruption of electric power supply to power window switch or motor by blown fuse or disconnecting the battery cable
- removal and installation of the window regulator assembly
- removal and installation of the motor from the window regulator assembly
- removal and installation of the harness connector of the power window switch
- operation of the regulator assembly as a unit
- removal and installation of the door glass
- removal and installation of the body side weather-strip and door weather-strip
- disconnection and connection of the negative terminal of the battery .

When work on vehicles with an intelligent key system is completed, the manufacturer's procedure must be followed to reactivate all functions. On completion of the task, check the operation of the unit and look for DTCs.

Figure 44.15 Trim and door handle clip removal tools

44.7 Soldering

Solder melts at a lower temperature than copper and will adhere to it to create an electrically sound and physically strong join. Only resin core solder should be used on electrical wires: the resin in the centre of the solder acts as a flux to assist in the bonding process.

When solder is used on electronic components, the heat can damage them if it is not controlled. To absorb heat, a pair of pointy-nose pliers can be used to hold the wire on the component side of the soldering.

Before using a soldering iron, make sure that its tip is cleaned and 'tinned' (coated with a thin layer of solder). This will ensure a well-formed connection. To clean the tip, use a file or wire brush to remove any oxide and then apply resin core solder to the hot iron.

There are some tools that are useful for carrying out soldering and repairs to automotive electrical systems (Figure 44.16).

Care should be taken to ensure the solder flows into the connection of the wires. Applying insufficient heat may cause a 'dry solder join' that is structurally and electrically weak and may fail

Figure 44.16 Tools and aids that are useful when soldering wiring in vehicles

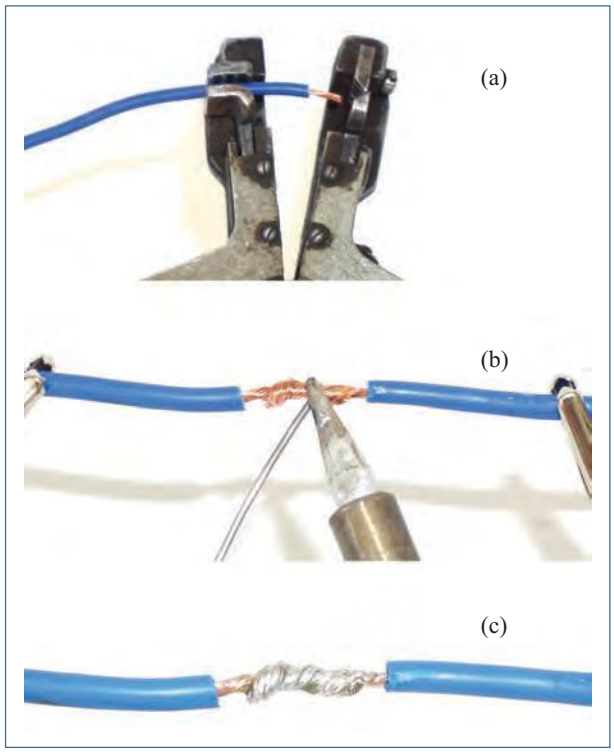


Figure 44.17 Twisting wires before soldering (a) strip the wire cover to a suitable length (b) twist together (c) apply the solder

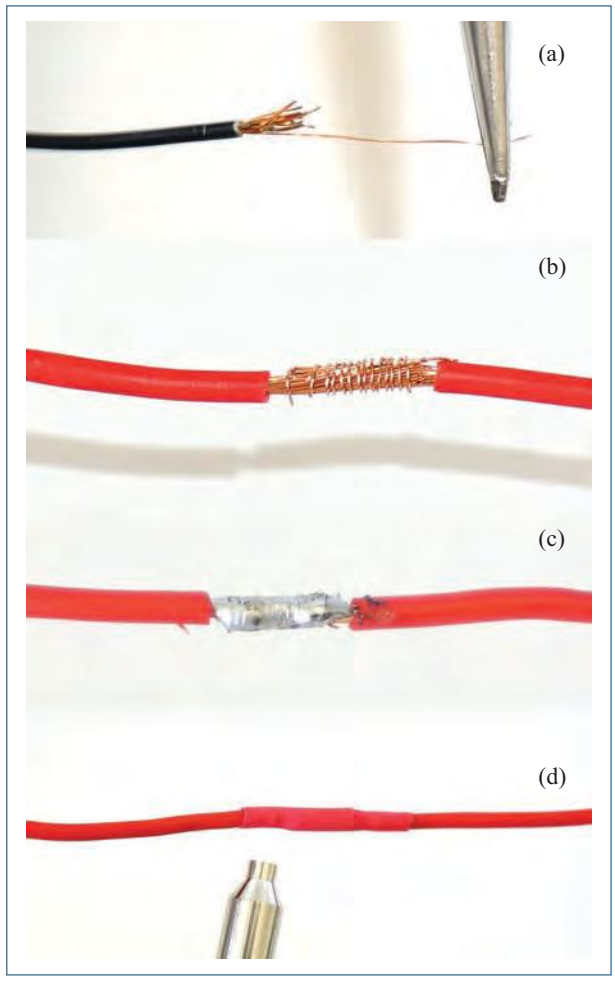


Figure 44.18 Binding wires before soldering (a) pull a fine strand of copper wire from a short length of cable (b) bind the join to hold it together (c) solder the join (d) place a small length of shrink wrap over the join and apply heat until the wrap is firmly cladded to the join

or cause a high resistance. Electrical wiring can be twisted (Figure 44.17) or bound (Figure 44.18) at the joins before soldering. This holds the wires together during the soldering process.

To insulate the soldered connection, heat shrink wrap is effective due to its finished size and sealing qualities (Figure 44.18). Other materials such as PVC tape or liquid tape can be used. Liquid tape is an excellent product to use on awkward shapes and marine or mining applications to keep out corrosion (and can be purchased in matching colours), as in Figure 44.19.

44.7.1 Heat shrink terminals

Heat shrink terminals and wire joiners are relatively new (Figure 44.20). They operate via heat being applied to the outer casing by a gas-operated heat gun. The heat gun needs to be of a good quality to generate sufficient heat. With sufficient heat, the solder splice will melt and bond to the copper cable, and the insulation will shrink. Heat shrink terminals can be purchased as a colour-coded item (red for 1.5 to 2.5 mm cable, blue for 2.5 to 4.5 mm cable and yellow for 4.5 to 7 mm cable). They are fast to fit and waterproof when fitted correctly. These products should be used wherever possible to minimise the risk of inhaling solder and resin fumes.

44.8 Wire stripping and terminal crimping

Terminal crimping should only be carried out with good-quality tools and correct terminals and cable sizes that match. Crimp-type terminals are colour coded to simplify the matching of cable size and terminal size. Some pliers can strip and crimp wires, while others are exclusively dedicated to either stripping or crimping. The crimping pliers will have colour coding to indicate where the terminal should be placed for the correct crimp pressure (Figures 44.16 and 44.21).

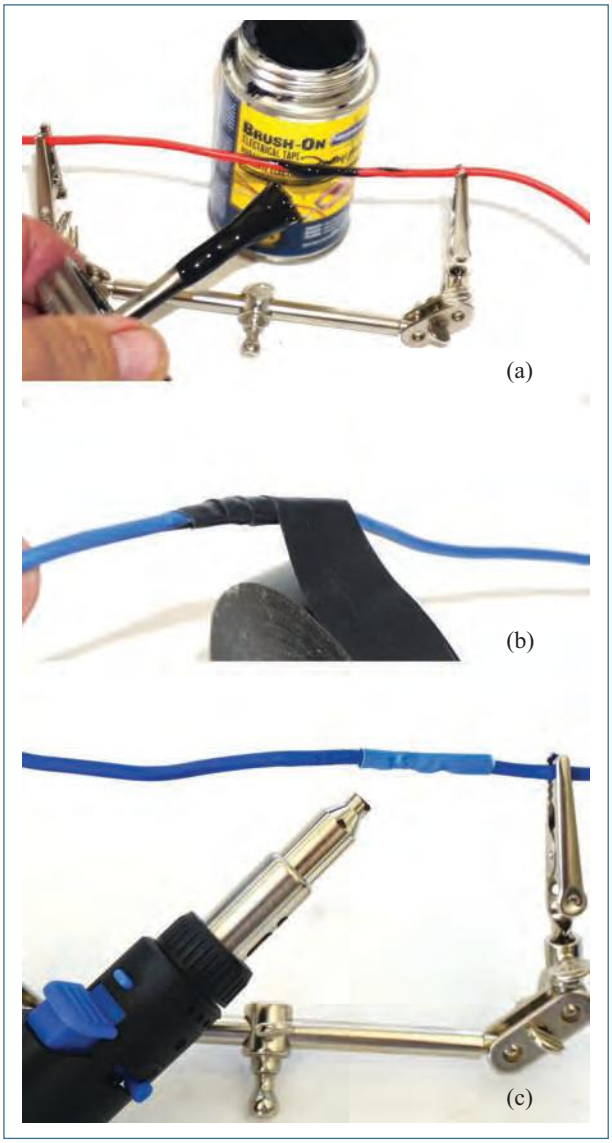


Figure 44.19 Three different ways to insulate and cover a solder join: (a) with a brush on liquid tape (b) with PVC tape (c) with heat shrink

Figure 44.20 Heat shrink joiner before and after fitment

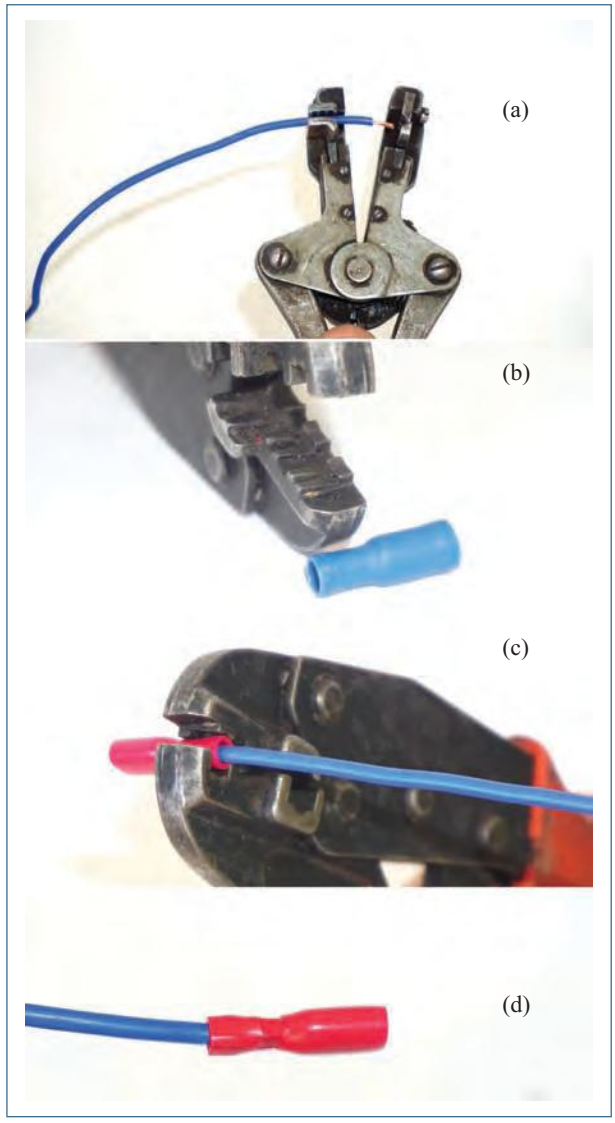


Figure 44.21 Crimping terminals (a) stripping PV C coating (b) different locations for terminals (c) crimping terminal (d) the finished crimp

When stripping the PVC cover from electrical wire, do not take off too much; only remove enough to allow for a good electrical connection with the terminal. Testing the crimp on a terminal connection can be done by a visual inspection, a resistance test and a tensile test. To test the tensile strength of a crimped terminal, grab the terminal in one hand and pull on the cable with the other. The join should not release from the cable.

44.9 Terminal replacement

44.9.1 Handling multipin connectors

There are two basic types of connecting plugs: waterproof for the exterior of a vehicle and non-waterproof for internal connection. The waterproof plugs have seals for each cable and for the mating areas. Figure 44.22 shows examples of both types.

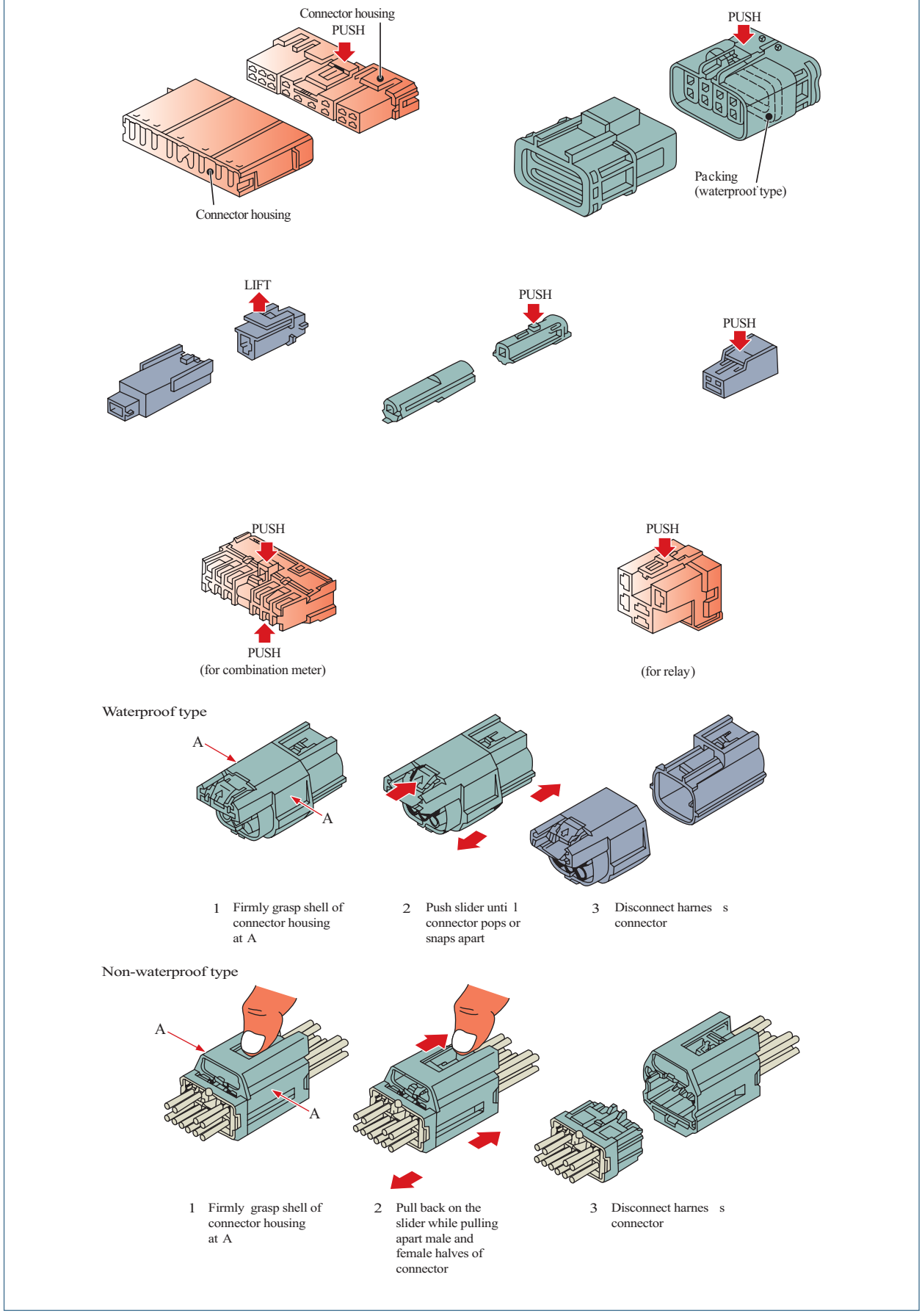


Figure 44.22 Examples of waterproof and non-waterproof connecting plugs

Multipin connectors usually have a locking device that holds the two parts of the connector together. The plug of the connector has a small tang which engages with a slot in the socket when the two parts are connected.

To disconnect the plug from its socket, the tang must be depressed to clear the slot before the parts can be separated. When refitting the plug in the socket, it must be pushed firmly into place until the lock engages.

There are many different connecting plugs on the market, and each manufacturer may use a different supplier for the plugs they use. For this reason, it is important to consult the technical manual for information on the plugs that are to be worked on to ensure that they are not damaged.

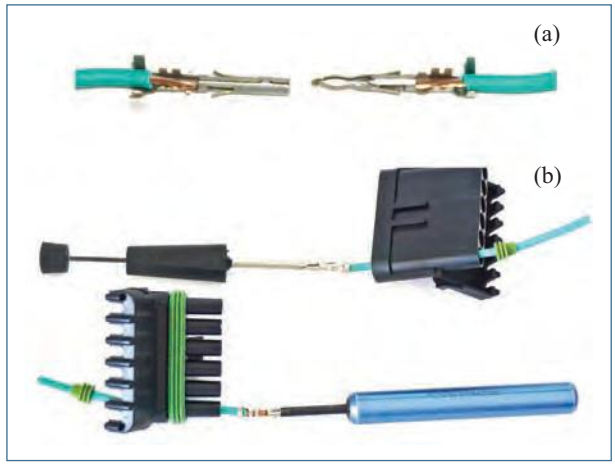


Figure 44.23 (a) Tools to release the terminal pin (b) and the catches on the terminals

44.9.2 Removing connector terminal pins

The metal terminals (or pins) of connectors are held into the plastic body by a small catch, and this has to be released before a terminal can be removed. Different-shaped terminals are released in different ways, and some require special tools (Figure 44.23). The catches in the terminals are visible.

In the method shown in Figure 44.24, a small screwdriver is inserted into the back of the connector to hold the catch down. This enables the wire and the terminal to be pulled out of the connector body. When refitting the terminal, the screwdriver is used to push it back into the body until it is held by the catch. The connector in the illustration has the catch as part of the body, but in some connectors the catch is made as part of the terminal.

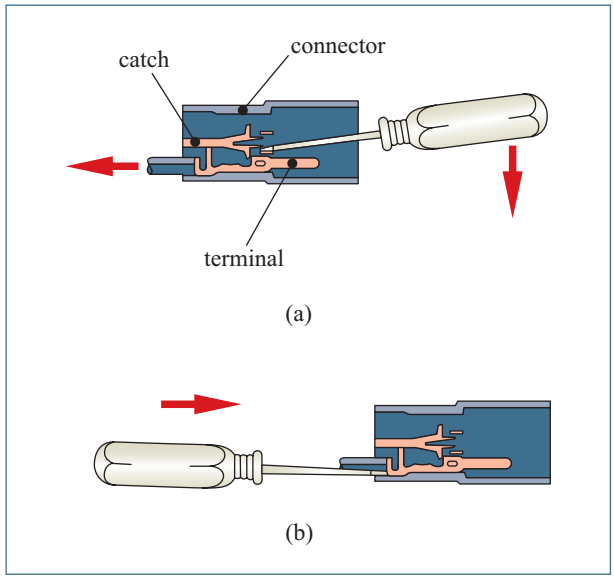


Figure 44.24 Multipin connector (a) removing a terminal (b) refitting the terminal

44.10 Testing procedures for electrical systems

Handy hint: Although many low-cost test lights come with pointed probes, never use them to pierce the insulation of wiring systems as this can cause wiring to corrode . The probe is there to allow you to 'back probe ' connecting plugs.

Safety: Always refer to the relevant technical manual to find the correct procedure before attempting to mak e repairs to a vehicle .

44.10.1 Accessing electrical terminals without damaging the connectors or wiring

There are hundreds of different connector plugs that are used by different manufacturers. Figure 44.25 illustrates an example of the wiring system in a modern vehicle and Figure 44.26 shows just some of the hundreds of connectors available for use. There may be more than 50 different types of connecting plugs used on one vehicle. They will vary in terms of the number of wires they can accommodate, be of different colours to assist in identification and be waterproof or not waterproof. For this reason, consulting manufacturers' wiring information is vital when diagnosing system problems (Figure 44.26).

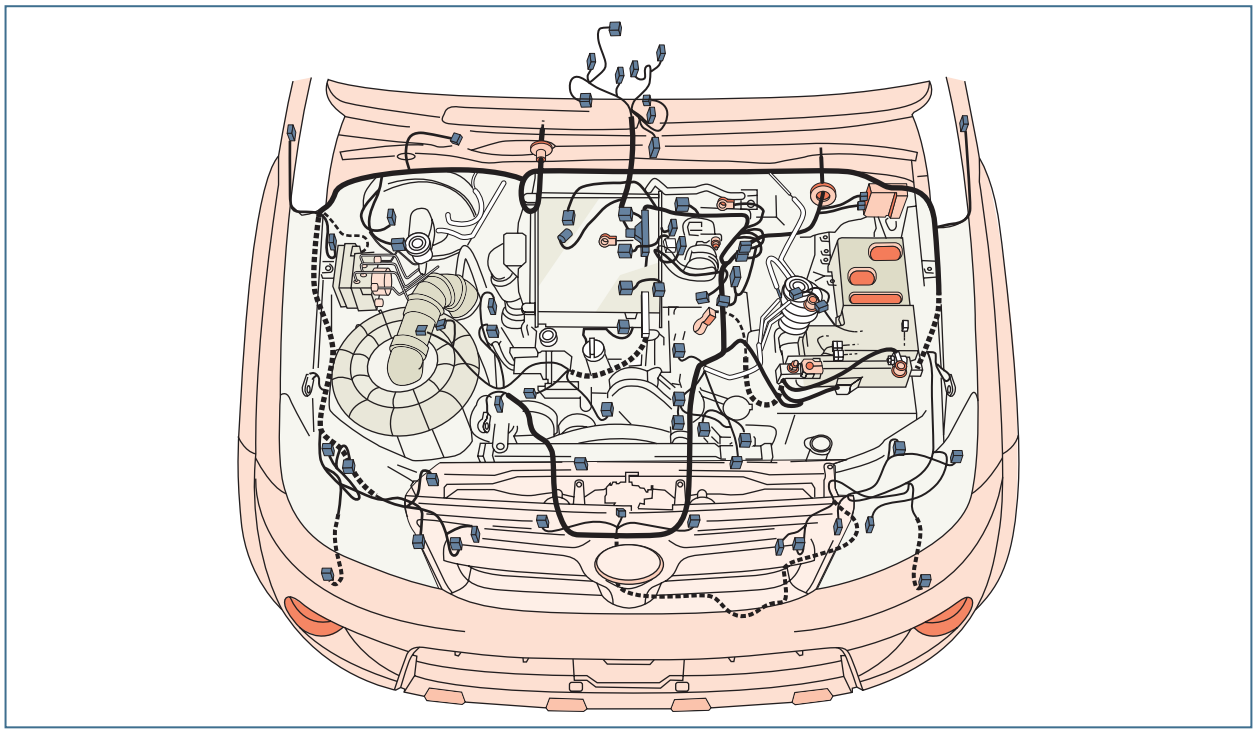


Figure 44.25 The modern vehicle has a complex wiring system, of which this image shows only a small part

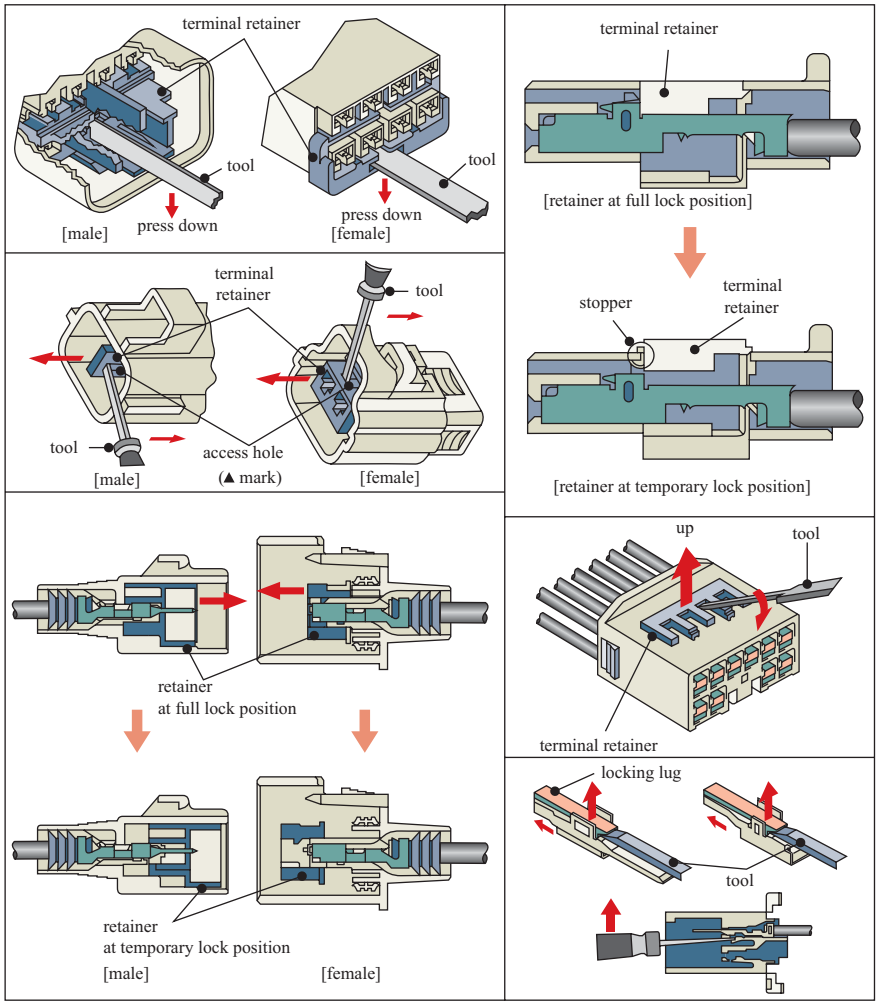


Figure 44.26 The chart shows a small sample of the huge range of connecting plugs used in the automotive industry . Each manufacturer uses different suppliers and plugs, so following the correct manual for the work to be carried out is vital

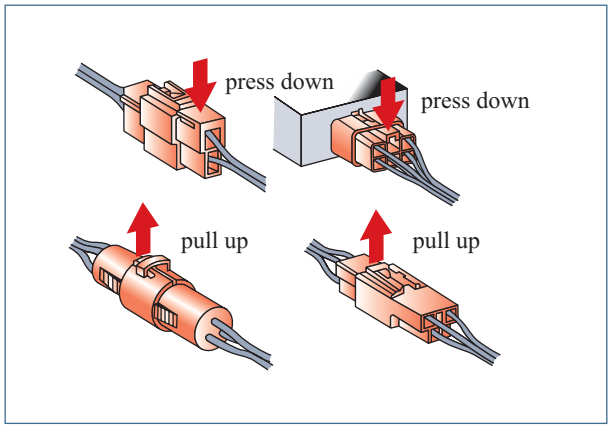


Figure 44.27 The image shows how to release a couple of connecting plugs. There are many ways of releasing connecting plugs—be sure to use the correct tool and follow the manufacturer's procedure

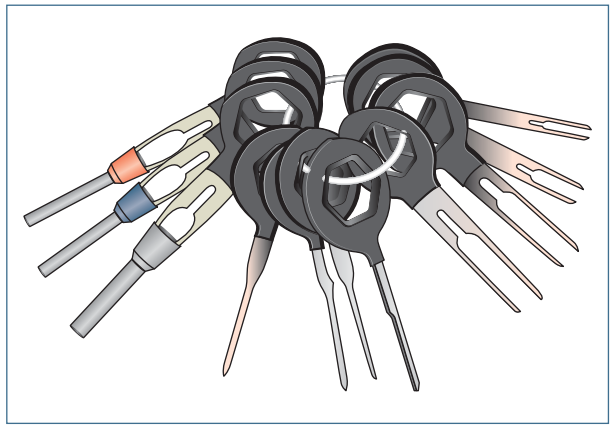


Figure 44.28 A range of connector release tools can be purchased to suit most connecting plugs

Each manufacturer will provide details on how to remove the connecting pins from the plugs and how to disconnect the male from the female connecting plug (Figure 44.27). It is vital to understand the procedure to prevent damage and to use the correct tool.

Many of the modern connecting plugs used in automotive applications will require special tools to remove the male and female pins. Each connecting pin has a locking mechanism to hold it in the plug body and a special tool is required to release the locking pins (Figure 44.28).

The correct way to test circuits with a multimeter when tracing a wiring system is to 'back probe' at the plugs. This can be very difficult with waterproof plugs. To back probe a plug, it is best to use a fine metal probe. If such a probe is not available, use a large straightened paper clip to probe from the back of the connector past the rubber seal. Care must be taken to not damage any seals.

There are many new tools on the market today that are relatively cheap and can be used to trace wiring faults such as the Automotive Short and Open Finder (Figure 44.29). These tools can be very handy in a difficult situation.

Figure 44.29 Shorts can be detected by the use of a signal generator and a receiver

Sustainability: Collect all old and discarded materials such as electrical cabling for recycling.

44.11 Protecting harnesses and looms

Wiring harnesses are multiple wires bundled together to carry the cables in a neat and organised way. This is also a means of keeping the wires clear from harm from heat or abrasion. A single loom may have multiple types of coverings over its length (Figure 44.30).

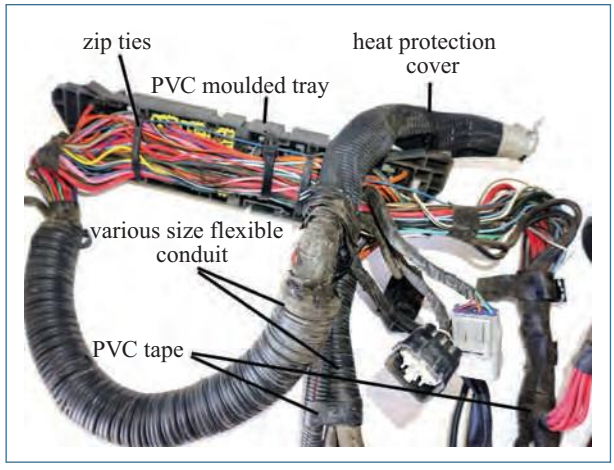


Figure 44.30 The different covers on a single loom (including heat protection)

Any new looms that are added should be encased and secured clear of body fasteners, heat, vibration and abrasion to avoid damage such as shorts and open circuits.

When working on vehicle wiring systems, it is not unusual to have to enter the loom cover to access a wire. If this is a requirement, it is important when completing the work that the loom is re-covered and secured.

44.12 Post-repair testing

When carrying out repairs on electrical systems on the modern vehicle, it is imperative to:

- check, record and clear D TCs
- check all systems and confirm they are functioning correctly
- check that the k ey is initialised to the systems if required
- check for any D TCs after testing all functions
- check the vehicle for cleanliness.

If any DTCs are detected, further testing will be required to isolate the cause. When adding accessories, the current draw on many of the wires that supply electrical units such as lights are monitored by the BCM (body control module). Any change may create a fault code.

Handy hint: In the modern vehicle , many items are monitored by the BCM. This can include items that seem unrelated, such as external rear view mirrors, the bonnet or a reversing lamp globe . It can be very easy to cause an unrelated fault code to arise when working on modern vehicles; even simply disconnecting the battery may cause failure of some functions. Some codes may put the vehicle into a limp or fail-safe mode if faults are not corrected. Always check for D TCs before returning a vehicle **to its owner**.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- demonstrate the safe handling of solder dust
- apply procedures for wiring different trailer plugs
- connect driving light systems in accordance with ADR s
- replace shielded cables in C AN Bus wiring
- repair unshielded cables in C AN Bus wiring
- remove and replace electrical components
- disconnect the systems that are connected to BCMs
- apply solder to create bound and twisted wire joins and apply appropriate insulation
- remove terminal pins from connecting plugs
- disconnect wiring plugs
- demonstrate how to care for wiring looms
- demonstrate procedures for post-repair testing and check for D TCs.

REVIEW QUESTIONS

1 What are the two basic types of wiring systems ?
2 What is a wiring harness ?
3 What is a circuit?
4 List three different styles of trailer plugs that are available on the Australian market.
5 How can a CAN Bus wire be identified and can it be repaired?
6 When soldering, what is the correct solder to use ?
7 Why is it best to tin the tip of the soldering iron or the areas that are to be soldered?
8 What precaution should be observed when stripping wires to fit a terminal?
9 Why should testing be done on all circuits after an electrical system repair?
10 Why is it important to follow the Australian Standard when connecting a trailer plug to a harness ?
11 When fitting any accessories to a motor vehicle , what checks must be carried out before connecting any wiring to the accessory ?
12 Before fitting external or internal accessories to a motor vehicle , what information should you obtain from the client?
13 Why should fault codes be checked at the diagnostic connector after light bulbs are replaced?
14 When fitting new accessories, what is the best way to protect the wires ?
15 When fitting driving lights to a vehicle , why should the Australian Design Rules be consulted?

CHAPTER 45

Instruments and warning systems

LEARNING OBJECTIVES

On completing this chapter, you will be able to:

1 identify instrument panel construction and components
2 recognise the application, purpose and operation of instruments and warning systems
3 identify instruments with magnetic operation
4 recognise mechanical gauges
5 recognise digital electronic gauge systems
6 identify diagnostic testing procedures with instrument warning systems
7 recall repair and testing procedures for instrument systems
8 describe and name turning light systems components
9 understand testing computer managed instrument systems with a scan tool
10 understand testing procedures for analog sender units.

Various instruments and indicators are used in motor vehicles. Instruments and gauges provide actual readings such as quantity, pressure and speed, while warning lights and indicators provide information via a light being either on or off.

There are a number of different types of instruments and gauges. They can have magnetic, electrical, electronic or mechanical operation, with electronic being the most common today.

Warning lights and indicators perform similar functions. Generally, indicators are lights that show whether or not a unit is in operation, while warning lights show that a problem exists.

Some vehicles also have a sound-warning system. Buzzers or musical notes are used to attract the driver's attention if, for example, a door is ajar, headlamps have been left on or a seatbelt has not been engaged.

45.1 Instrument panel

Figure 45.1 shows the construction of an instrument panel (cluster). The various instruments and indicators identified are those used in older systems. The two main and largest instruments are the speedometer, which shows the vehicle road speed, and the tachometer, which shows the engine rpm. There are four other instruments: a coolant temperature gauge, a fuel level gauge, a voltmeter and an oil pressure gauge.

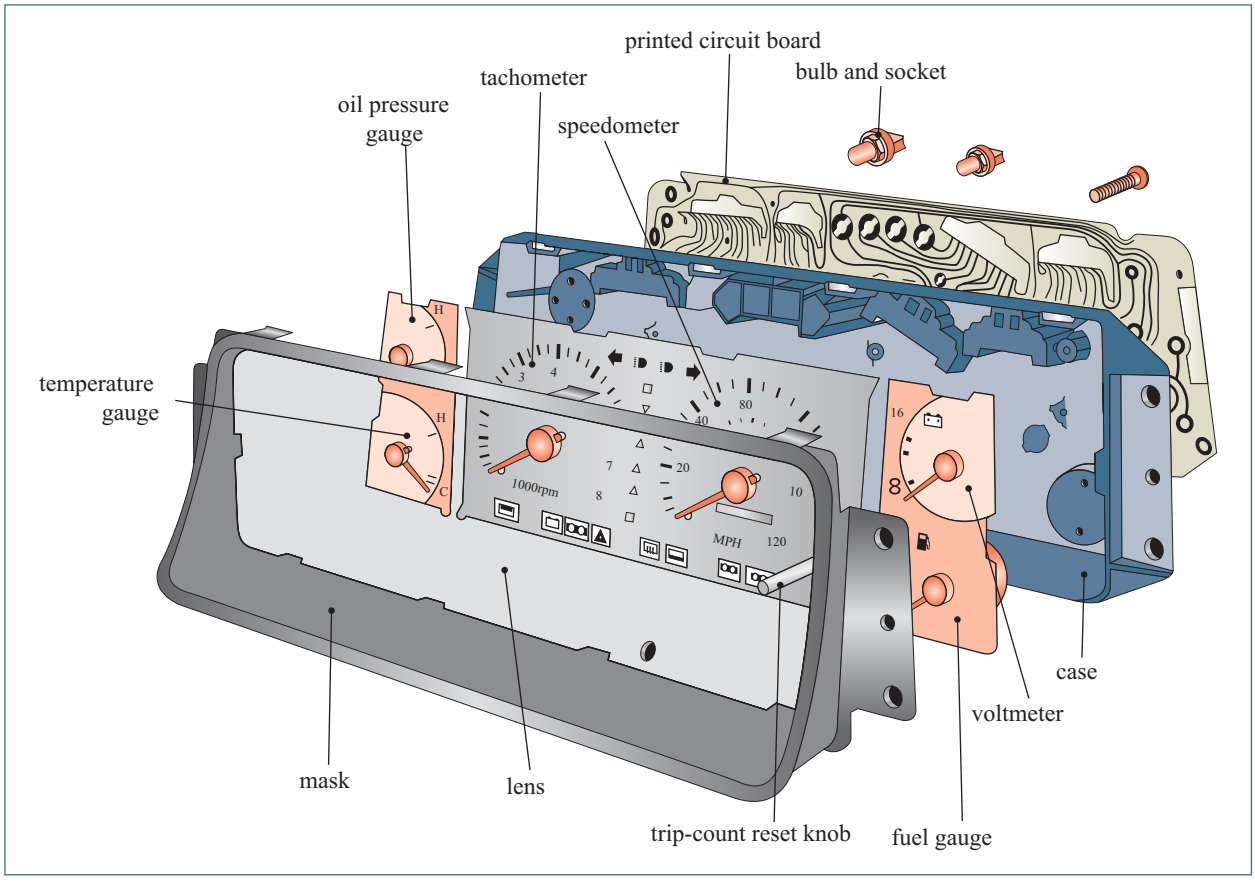


Figure 45.1 Instrument panel construction

The turn-signal indicators are shown as arrows at the top of the panel and various indicator and warning lights are at each side panel. Modern vehicles have many more warning lamps and indicators than the one shown, some of which are in the form of a message display. Older vehicles were more basic, with indicator and warning lights for the headlamp high-beam indicator, the seatbelt warning and the low-fuel warning light. Warning lights have illuminated symbols to represent their components, and also lenses of different colours to help with identification.

Handy hint: The group of instruments, indicators and warning lights of an instrument panel are often referred to as a cluster .

There are many different designs of instrument panels and clusters. The cluster shown has analog instruments, that is, instruments with pointers. Other clusters have digital instruments or a combination of analog and digital.

45.2 Instrument panel construction

Figure 45.1 shows the construction of an older-style instrument panel. The instruments are mounted in a plastic case. A printed circuit board fits on to the back of the case, and a mask and clear lens assembly fit onto its front to enclose the instruments.

The instruments and gauges are mounted so that they make electrical contact with the conductors on the printed circuit board. The parts of the instrument panel are held together by clips moulded in the plastic and screws. The panel is fixed to the dash with screws.

45.2.1 Printed circuits

Printed circuit boards, which carry all the conductors for the instruments and indicators, form the back of the instrument panel (Figure 45.2). These have metal conductors (approximately 0.05 mm thick) printed on a polyester film which is attached to a hard-insulating board. The ends of the conductors are connected to one or more multipin connectors which, in turn, are connected to the wiring harness.

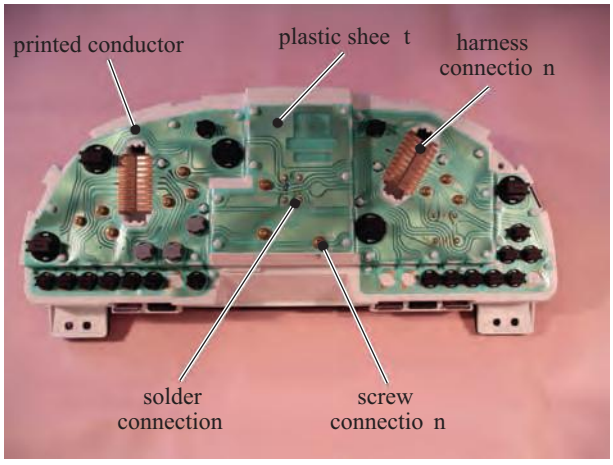


Figure 45.2 An instrument panel with a printed circuit board

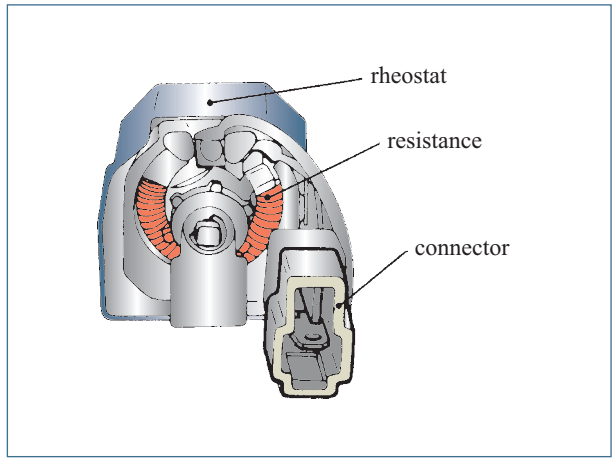


Figure 45.3 Rheostat for controlling the brightness of the panel lights—rear view MITSUBISHI

The instruments are mounted directly on to the conductors of the printed circuit board and do not need any other wires. The bulbs for indicators, warning lights and illumination are mounted in small bulb holders. These are plugged into holes in the printed circuit board. When in place, they make contact with their conductors.

Printed circuits are used because they are cheaper to manufacture and much more compact than lots of separate wires. They are also easier to assemble into the back of the instrument panel during manufacture.

45.2.2 Panel illumination

The panel is illuminated by small panel bulbs or LEDs. Fluorescent tubes are also used, while backlighting highlights the face of the instrument.

The brightness of the panel lighting is controlled by either a rheostat or an electronic control. For conventional instruments, the panel lights have a rheostat in the circuit. Its control knob moves a blade across a wire-wound resistor. This varies the resistance in the circuit and the brightness of the lights. The rear of a rheostat is shown in Figure 45.3.

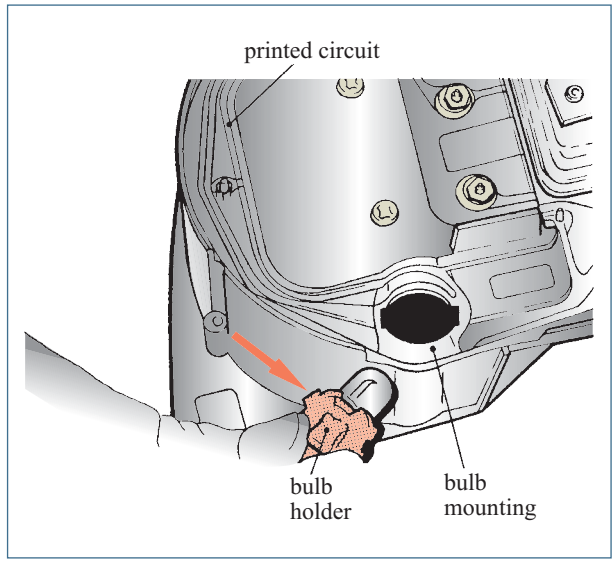


Figure 45.4 Removing a bulb and bulb holder from the back of a panel FORD

Replacing panel bulbs

The bulb holders for panel bulbs are removed from the rear of the instrument panel (they are not always easy to reach). The bulb holder, complete with the bulb, is removed by turning it 90° (Figure 45.4). Most panel bulbs are capless and can be pulled straight out of the bulb holder. The new bulb is simply pushed into it. Instrument panels with LEDs or cold cathode discharge tubes have a different method of attachment.

45.2.3 Removing a panel

Before working on a panel, it must be isolated by disconnecting the negative battery terminal. If the printed circuit board is short-circuited, it will immediately melt the conductors. The following is a general procedure for removing a panel:

1 Remove the panel screws to release the panel from the dash.
2 Disconnect the harness connectors from the printed circuit board.
3 Disconnect any earth connections from the bodywork.
4 Remove the speedometer cable from the back of the speedometer .
5 Remove the panel.

The actual procedure will depend on the design of the particular vehicle. There could be dash mouldings, steering-column covers or other fittings that have to be removed before the panel is accessible.

45.3 Instruments with magnetic operation

In magnetically operated instruments, the magnetic effect of an electric current through a conductor or coil is used to operate a pointer on a scale. Ammeters and voltmeters are individual units mounted in the panel. Fuel gauges, temperature gauges and electrically operated oil pressure gauges consist of two parts: a *dash unit* mounted in the instrument panel and a remote *sender unit* in another part of the vehicle.

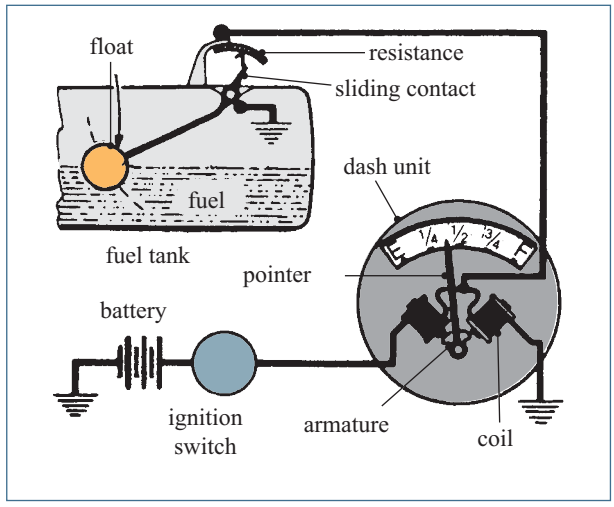


Figure 45.5 Circuit and components of a magnetic (balancing-coil) fuel gauge

45.3.1 Voltage regulated gauges

As the voltage output from the charging system and the battery can vary from 12.6 volts to 14.5 volts in older analog instrument panels, a voltage regulator or stabiliser is fitted. This brings the operating voltage of electric gauges down to approximately 10 Vdc. Without a stabiliser, the gauges would fluctuate according to the voltage. In computer-managed instrument panels, the body control module (BCM) controls the operating voltage.

45.3.2 Magnetic fuel gauge

Figure 45.5 shows the arrangement of a magnetic fuel gauge. It has two separate parts: a dash unit and a tank unit.

The dash unit has two small coils wound on soft-iron cores—an *empty* coil and a *full* coil. An armature with a pointer is pivoted between them. The coils produce a magnetic field which influences the armature and so alters the position of the pointer on the scale of the gauge.

The tank unit has a wire-wound resistance with a sliding contact. The contact is attached to an arm and float inside the fuel tank. This provides a resistance which varies as the float rises and falls with the level of fuel in the tank.

This type of sender unit is still used in computerised instrument systems, but construction may vary.

Handy hint: This type of instrument is referred to as a balancing-coil gauge .

Gauge operation

With the ignition switched on, current from the battery passes first through the empty coil and then through the full coil to earth. It also passes through the resistance in the tank unit to earth.

The resistance is in series with the empty coil and is shunted across the full coil. As the resistance is varied, it alters the current flow in both coils and varies their magnetic fields, but it has a much greater effect on the full coil. The empty coil has a fairly constant magnetic field, while the full coil has a variable magnetic field.

When the fuel tank is empty, the tank unit has minimum resistance, and so very little current flows in the full coil. The empty coil controls the armature, and the gauge will register *empty*.

When the fuel tank is full, the float is raised and there is maximum resistance in the tank unit. Current is increased in the full coil and its stronger magnetic field attracts the armature. The gauge will register *full*.

For levels between full and empty, the pointer is balanced by the magnetic forces of the two coils, and this is controlled by the current flowing through each. The current, in turn, is determined by the float level and the resistance of the tank unit.

Handy hint: Some fuel gauge systems work on a high resistance when empty and a low resistance when full. This is opposite to the description above . Before buying a new gauge or sender , check their operating range of resistance .

45.3.3 Magnetic temperature gauge

The arrangement for a magnetic temperature gauge is illustrated in Figure 45.6. Its operation is similar to that of the balancing-coil type of fuel gauge, except that it is calibrated in degrees. The dash unit operates in the same manner as the fuel gauge, except that the current in the coil is controlled by an engine (sender) unit. This is fitted into the cooling system in contact with the coolant.

The resistance of the engine unit has a negative temperature coefficient (NTC). That is, its resistance decreases as the coolant temperature increases. As the temperature rises, the current flowing in the coil increases and the gauge pointer moves across the scale to register the temperature.

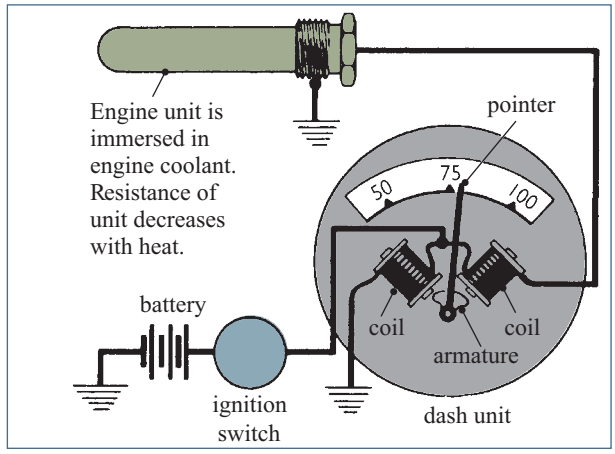


Figure 45.6 Diagram of a balancing-coil temperature gauge

45.3.4 Magnetic oil-pressure gauge

The dash unit of a magnetic oil-pressure gauge also has balancing coils similar to those of a magnetic fuel gauge, except that the scale is marked in kilopascals. The sender unit on the engine provides a variable resistance to operate the gauge.

The sender unit (Figure 45.7) is screwed into the engine block and receives oil pressure from the main oil gallery of the engine. The pressure acts against a diaphragm which moves a contact across a resistance in the unit. This provides a variable resistance that is related to the oil pressure. Resistance variations operate the gauge.

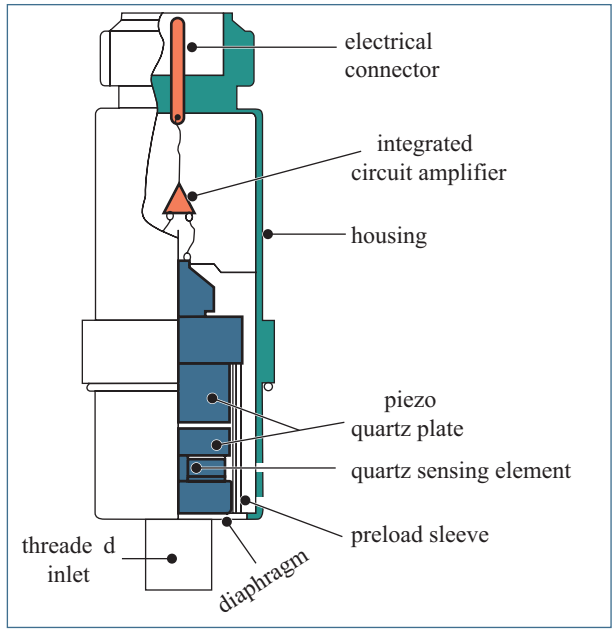


Figure 45.7 Construction of an oil-pressure gauge sender unit

45.3.5 Voltmeter

Voltmeters are used to indicate the voltage of the electrical system. With the engine stopped, battery voltage will be shown. When it is running, the voltmeter will show alternator voltage, which should be higher than battery voltage.

Voltmeters operate magnetically, using the magnetic effect of an electric current in a coil to position a pointer on a scale graduated in volts. Any variation in voltage applied to the coil will alter the magnetic effect and change the position of the pointer on the scale.

Handy hint: The terms pointer and needle are interchangeable in relation to instruments and gauges.

45.4 Mechanical gauges

Gauges can be operated by mechanical means, although these have generally been replaced by other types of gauges. However, a mechanical gauge is used with LPG fuel systems. Conventional speedometers are another form of mechanical gauge.

45.4.1 LPG fuel gauge

Figure 45.8 shows a fuel gauge assembly for an LPG cylinder. This has a direct reading gauge that shows the quantity of gas in the cylinder. It also has an electrical sender unit connected to the dash unit of the fuel gauge.

The LPG fuel gauge has a float on an arm similar to the unit for a petrol tank. The float rises and falls with the level of the liquid in the gas cylinder. The float is not connected directly to the pointer or to the resistance, but it is connected to a magnet.

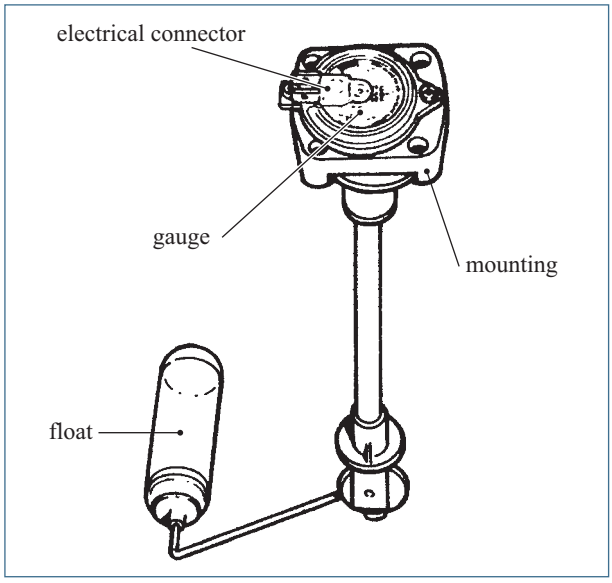


Figure 45.8 LPG cylinder fuel gauge assembly
GM HOLDEN LTD

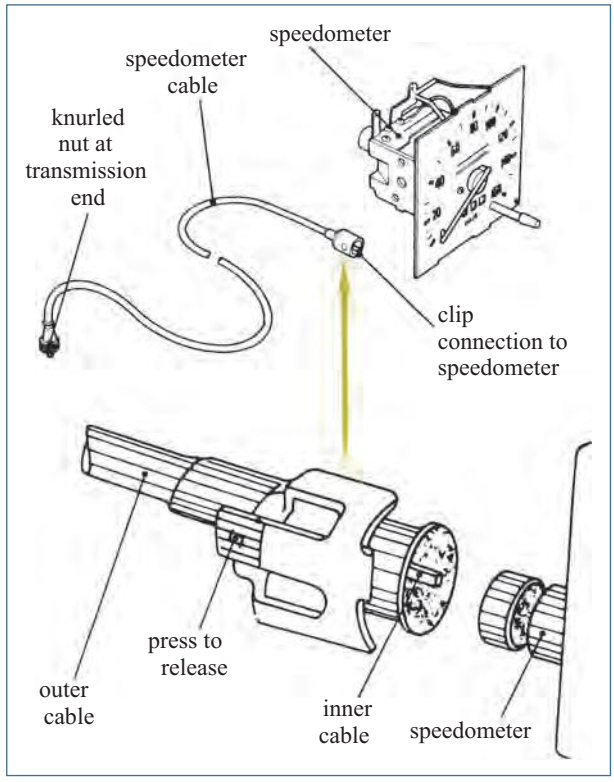


Figure 45.9 Conventional speedometer and cable assembly FORD

The gauge head also has a magnet that moves the pointer across the face of the cylinder gauge. This also alters the resistance of the sender unit for the fuel gauge in the instrument panel. The magnets are used as a means of transferring movement of the float, which is sealed within the cylinder, to the external parts of the gauge unit.

45.4.2 Mechanical speedometers

Conventional speedometers operate mechanically. The speedometer head is connected by a flexible cable to a speedometer drive gear at the rear of the transmission. The cable consists of an outer and an inner cable. The transmission end of the outer cable is connected to the housing of the speedometer drive gear.

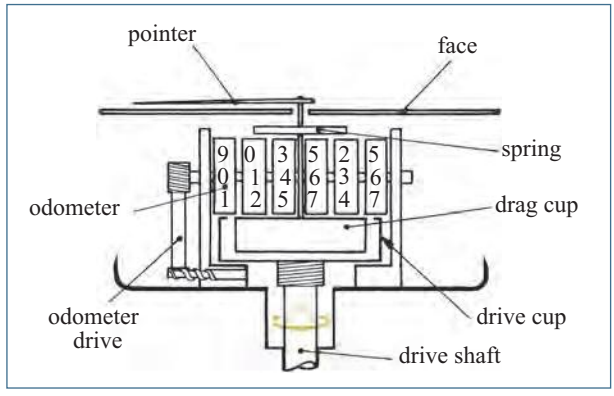


Figure 45.10 Internal arrangement of a conventional speedometer and odometer

At the speedometer end, the outer cable is connected to the speedometer head by a clip which has to be pressed before the cable can be removed from the speedometer (Figure 45.9). The inner cable transfers rotation to the speedometer head which has a pointer to show the road speed in kilometres per hour. It also has an *odometer* to record kilometres travelled.

Speedometer operation in analog instruments

The arrangement of a speedometer head is shown in Figure 45.10. It has a drag cup attached to a pointer which fits into a larger cup. The larger cup is driven by the speedometer cable and is rotated at a speed that is related to road speed. The cups are not connected, but the larger cup produces a magnetic effect that causes the drag cup to turn. This is resisted by a spiral spring which limits the drag cup movement so that the pointer remains on the scale and registers the vehicle speed.

Handy hint: The magnetic effects that occur between the cups are referred to as eddy currents .

The odometer has six drums marked with numerals 1 to 9 and 0. These are connected by a series of gears that turn the drums at the correct speed so that they record the kilometres that the vehicle travels.

Figure 45.11 Instrument panel for a computer-managed vehicle: 1 tachometer, 2 engine temperature, 3 fuel level, 4 speedometer, 5 message centre, 6 warning indicator lamp display

There are two windows in the face of the instrument: one to show the total kilometres travelled and one to show the trip kilometres. The trip kilometres can be reset to zero via a button.

45.5 Computer-managed instruments

The instrument panel of the modern computer-managed vehicle can display a vast amount of information (Figure 45.11). The trend for digital-type instruments has passed, and things have reverted to analog gauges controlled by a body control module. The instrument panel is connected to the BCM and other modules on the CAN Bus system. Information on the status of monitored sensors can be instantly fed back to the operator via the CAN Bus modules to the instrument panel.

Safety: The information in this chapter is generic. Manufacturers may connect their systems differently and may provide different information in the warning systems.

45.5.1 Analog gauges in computerised systems

Tachometer

The tachometer is driven by the engine speed signal generated by the crankshaft position sensor (CPS). The signal is transmitted first to the ECM; then it moves by a high-speed CAN Bus system to the BCM; then it moves to the instrument panel by medium- or high-speed CAN Bus. When the instrument panel microprocessor receives the signal, it transmits to the tachometer.

Engine temperature gauge

The coolant temperature sender transmits a signal to the ECM, which transmits a CAN Bus message to the BCM; from there it goes to the instrument microprocessor. Depending on the operating temperature range of the motor, the temperature gauge will have preprogramed positions for a given temperature. These could be, for example: beginning of normal range 75°C; end of normal range 110°C; end of hot 120°C.

Fuel level gauge

Fuel gauges use different types of sensors. For this description, the vehicle will use a variable resistance (a mechanical device in the fuel tank). The fuel gauge sender is wired to the BCM, and it converts the analog signal to a CAN Bus signal before transmitting it to the microprocessor in the instrument panel. To eliminate an oscillating fuel level needle, the micro processor dampens the signal to ensure a stable reading. If no signal is received from the BCM, the gauge goes to empty.

Speedometer

The speedometer signal is received from the ABS sensors on each wheel, and is averaged over all four wheels. It travels from the wheels to the ABS module, and is transmitted from there to the BCM via a CAN Bus. From the BCM, it is transmitted to the instrument panel microprocessor and then to the speedo.

Figure 45.12 Warning indicators in the instrument panel of a moder n vehicle: 1 Ignition/No charge indicator , 2 Low oil pressure warning indicator , 3 Malfunction indicator lamp , 4 Safety belt warning indicator , 5 Supplemental restraint system (SRS) warning indicator , 6 Left hand (LH) turn signal indicator , 7 Brake warning indicator (low fluid/emergency brak e assist (EBA)), 8 High engine coolant temperature (ECT) warning indicator , 9 Headlamp high beam indicator , 10 Tyre pressure monitoring system (TPMS) indicator , 11 Antilock braking system (ABS) warning indicator , 12 Low fuel indicator , 13 Right hand (RH) turn signal indicator , 14 Parking brak e indicator - not used, 15 Parking brak e indicator , 16 Rear fog lamp indicator , 17 Front fog lamp indicator , 18 Adaptive front lighting system (AFS) indicator , 19 Speed control indicator , 20 Trailer indicator , 21 Low washer fluid indicator , 22 Low engine coolant level warning indicator , 23 Transmission warning indicator , 24 Hill descent control (HDC) fault indicator , 25 Door open indicator , 26 Engine management system warning indicator , 27 Side lamp indicator , 28 Dynamic stability control (DSC) indicator , 29 HDC active indicator , 30 Anti-theft alarm indicator , 31 Glow plug indicator (diesel vehicles only), 32 Fuel-fired booster heater indicator (if fitted)

45.5.2 Warning indicators

Warning indicators in the instrument panel of a modern vehicle

The warning lights in the instrument panel (Figure 45.12) are either externally activated from another control system or illuminated by the microprocessors in the BCM (which is driven by software logic).

45.5.3 Message centre

The message centre is an LCD mounted with the instruments. It has several operational modes:

1 System pre-check
2 Normal, where only the ambient temperature is displayed
3 Ambient air temperature and trip computer displayed
4 Status and warning information only
5 Terrain response (relates to snow , mud, sand)
6 Diagnostics.

Computerised systems allow a huge amount of information to be fed back to the driver. Messages are prioritised with priority given to safety and engine system faults via a chime (Figure 45.13 and Table 45.1.).

Figure 45.13 LED display for showing messages and other warnings

Table 45.1 A list of messages that can be displayed in the message L CD panel

Check all tyre pressures	Check all tyre pressures Front left low	Check all tyre pressures Front right low	Check all tyre pressures Rear left low
Cranking will commence after glow period	Driver door open	DSC switched off	Lights on
Cruise control not permitted	Front passenger door open	Grass gravel snow	Low coolant level
DPF full	Left rear door open	Grass gravel snow program selected	Low washer fluid
DPF full Visit dealer	Right rear door open	HDC fault system not available	Oil service required Visit dealer
Eco stop/start fault	Tailgate open	HDC not available in this gear	Press brak e when starting
Eco stop/start off		HDC not available speed too high	Press clutch when starting
Eco stop/start on	Reduced engine performance	HDC temporarily not available system cooling	Program change in progress
Eco stop/start unavailable	High engine speed for cooling	HDC switched off	Recommend starting in 2nd gear for slippery conditions
Engine system fault	Memory 1 stored	Recommend command shift for deep soft sand	Select neutral to restart
Fuel tank cap loose or missing	Select park or neutral to start engine	Mud ruts	Restart required Press clutch
Key in ignition	Terrain response special programs not available	Mud ruts program selected	Transmission command shift selected
Special programs off	Terrain response special programs off	Sand	Transmission fault
Special program temporarily not available	Terrain response system faulty	Sand program selected	Transmission fault and overheat
System check in progress	Terrain response system not available	Transmission fault. Limited gears available	Transmission fault Traction reduced
Tyre pressure monitoring system fault	Tyre pressures low for speed		Transmission overheat Slow down

45.6 Turning and hazard lights

Early turning signal and hazard systems used a flasher can that would make and break the circuit through current draw heating a bi-metallic strip. As the strip heated, it would bend and break the circuit. As it cooled because of the disconnection, it would resume its position and make contact again (Figure 45.14). Fault diagnosis on these systems requires a test light or multimeter.

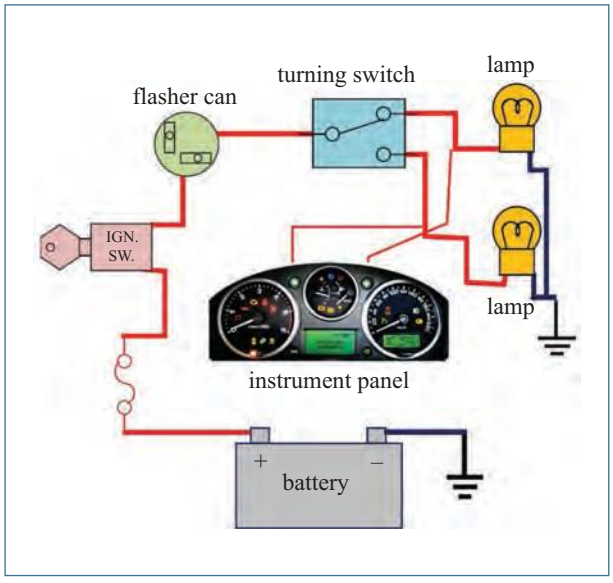


Figure 45.14 Turning lamp system that uses a flasher unit

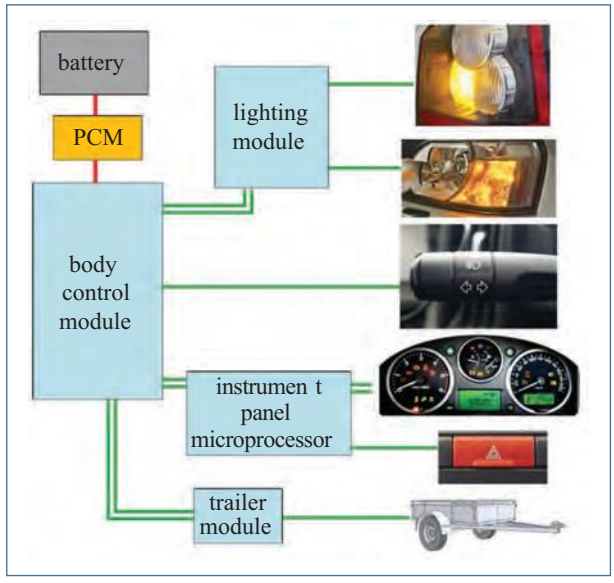


Figure 45.15 Schematic of a turning light system in the modern vehicle using C AN Bus systems

For computerised systems using CAN Bus communications, the body control module is programmed to control the flashing rate and report globe or system failures (Figure 45.15). Fault diagnosis on these systems requires a scan tool and a multimeter.

45.7 Fault diagnosis in computerised systems

When looking for a fault in a computerised system, use a systematic process such as the one that follows. This will avoid wasting time and a poor or incorrect diagnosis.

1. Listen to the vehicle driver' s views and obtain as much information as possible about the malfunction.
2. Check and verify suspicious symptoms.
3. Carry out a scan/diagnostic tool check.
4. Print out the data from the checks and get a freeze-frame capture of the data.
5. Inspect the circuit and perform tests to isolate the faulty item.
6. Repair the circuit or replace the component.
7. Test the circuit to mak e sure it is repaired.
8. Carry out a final check and record all relevant information, including a finished job freeze-frame capture of the data.

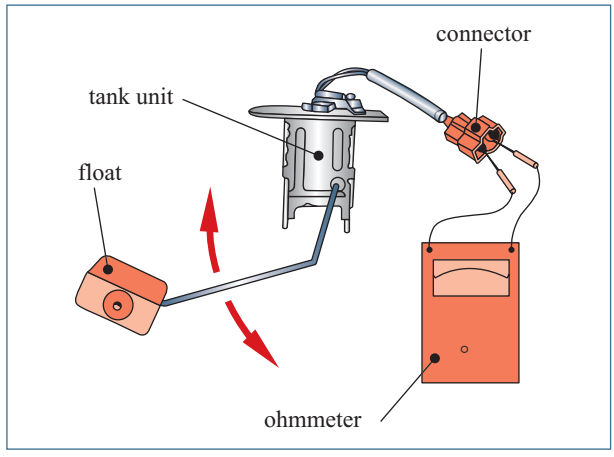


Figure 45.16 Checking the resistance of a fuel-gauge tank unit with an ohmmeter

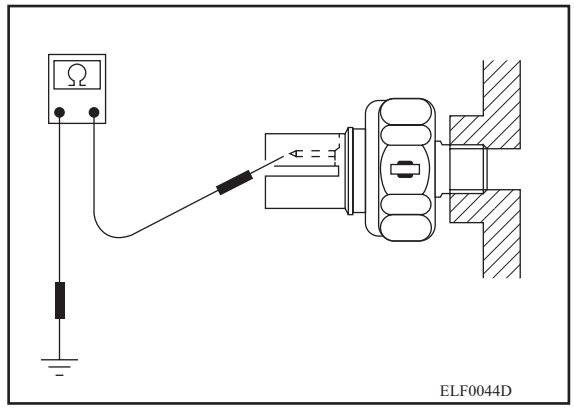


Figure 45.17 Testing an electric oil pressure gauge with a multimeter

45.7.1 Testing of analog senders

Sender units of a mechanical/electrical construction such as fuel level sender, oil pressure sender and temperature senders can be checked with an ohmmeter/ multimeter (Figures 45.16 and 45.17). The sender units should be disconnected before testing. The sender system can also be tested with a scan tool. However, to confirm that the problem lies with the sender and not the wiring, further testing of the sender and loom is required. To test the wiring and the gauge, a specifically designed variable resistor can be used in place of the sender unit (Figure 45.18).

For other types of senders such as yaw, acceleration, battery sensors, airbag sensors, fuel pressure sensors and smart sensors, the manufacturers' data will need to be consulted for the correct process as not all sensors are of the same construction.

Testing of fuses and wiring for faults is discussed in Chapter 39. Testing smart sensors is discussed in Chapter 40.

Figure 45.18 A variable resistor 0-300 ohms used to test where an analog gauge system is used to replace the sender to check the wiring and gauge system

45.7.2 Testing of electronic instrument systems

Many modern components are only sold as units that are not repairable as the manufacturer does not supply components for them. In a computerised vehicle, the driver is notified of a fault by the monitoring system in the instrument panel. The technician will need to connect a diagnostic/scan tool to the diagnostic plug to obtain the fault code and then check the system that relates to it.

45.7.3 Scan tool information

A scan/diagnostic tool can read data from all areas of the vehicle, such as the ABS, engine, lighting, transmission and drive systems, and the passenger safety and comfort systems. Figure 45.19 shows the connectivity of a scan to to the vehicle systems. The driver will be alerted as soon as any issue arises. Faults that are not engine- or environment-related will not activate the engine light. Figure 45.20 shows a generic scan tool.

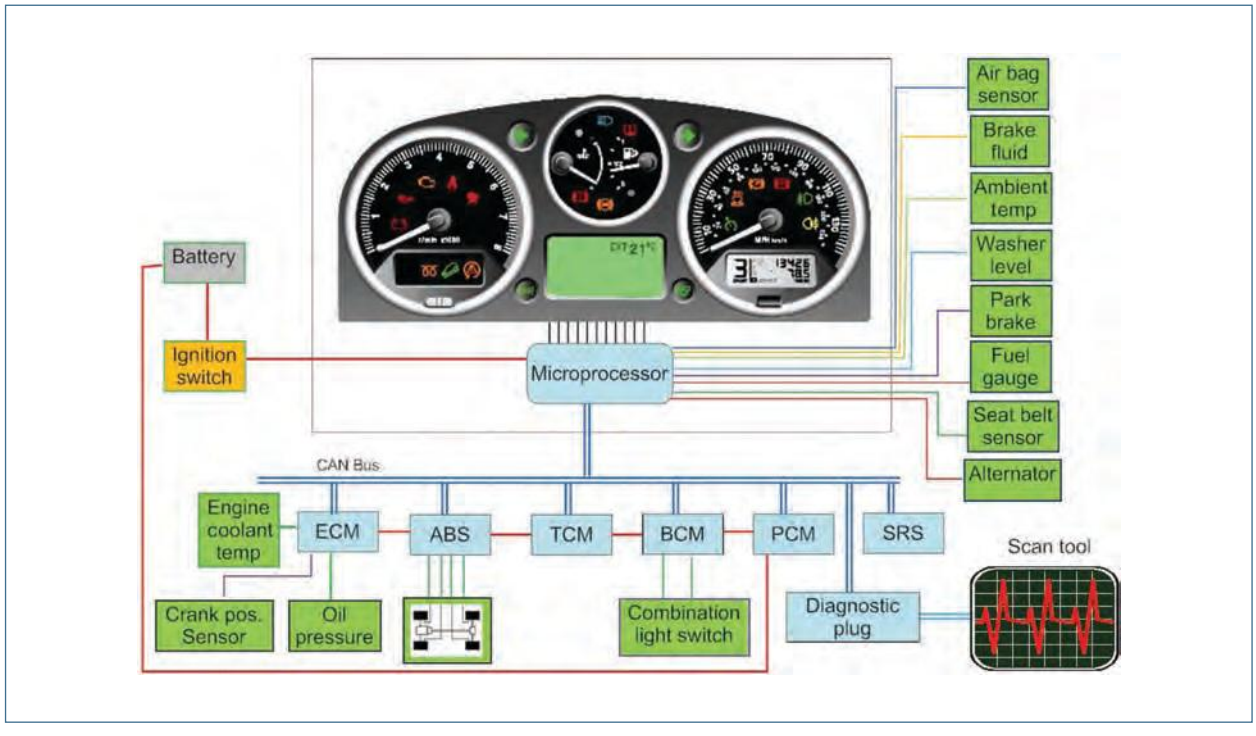


Figure 45.19 A typical computer-managed C AN Bus instrument panel system. Connectivity may vary from one manufacturer to another

When connecting the scan tool to the diagnostic plug, set the scanner to check the system for any faults and record a freeze-frame capture. Then follow the relevant procedures set out by the manufacturer of the scan tool or vehicle manufacturer. Generic scan tools may not provide the same level of information as those supplied by the vehicle manufacturer (Figure 45.21).

Figure 45.20 Bluetooth diagnostic tool connected to the diagnostic plug

After following the procedure to isolate the locality of the fault, the next step is to test the component or the connectivity of the system that connects the component. Connectivity can be CAN Bus, LIN Bus or simple wiring. It is important to have an understanding of the systems in the vehicle in order to trace the cause and carry out non-destructive testing. For example, the message centre may produce a warning that the ABS or four-wheel-drive system has a problem. The diagnostic tool check indicates a problem in one ABS sensor. The problem may be as simple as low air pressure in the tyre. This causes the sensor to detect a slower speed than that expected by the software parameters so a message and fault will appear. A fault code does not always indicate a faulty component, only that something is not within the correct parameters within the system.

For information on scan tools, checking sensors and/or actuators of computerised systems, refer to Chapter 40.

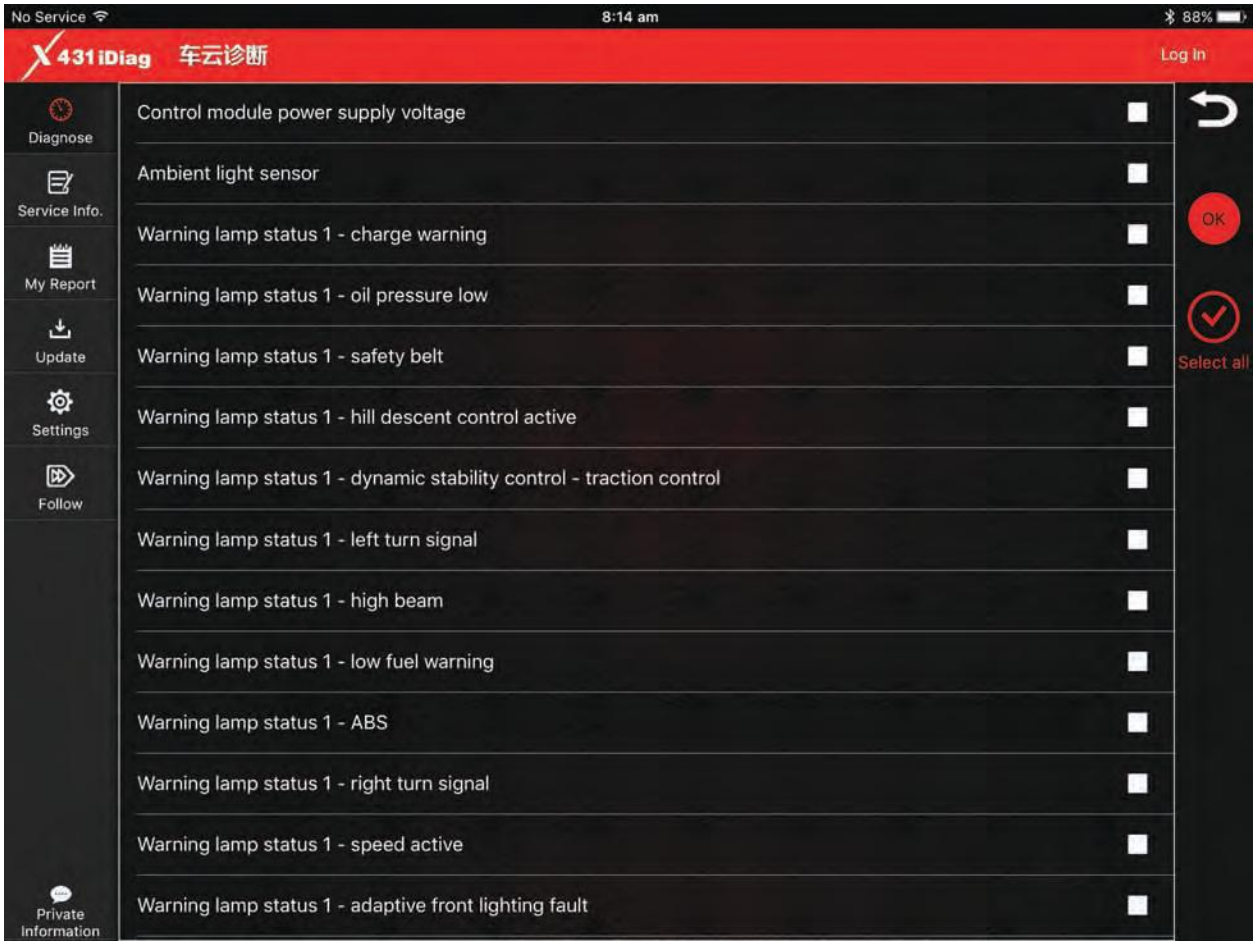


Figure 45.21 Screenshot showing some of the selection options when checking the instrument panel system via the diagnostic connection CN LAUNCH

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- explain the purpose of the instrument panel
- describe the construction of the instrument panel
- explain how analog instruments work
- state how to test analog instruments
- explain how computerised instrument systems work
- state how to check electronic/computerised systems, instrument panels and systems
- state how to check analog senders
- explain how turning-light systems work.

REVIEW QUESTIONS

1 Name the instruments and indicators that are usually located in an instrument panel.
2 What is a printed circuit ?
3 Where is a printed circuit used?
4 Name the parts of an instrument panel.
5 Why should the negative battery terminal be removed before working on or near instruments ?
6 What is the basic principle of magnetic gauges ?
7 What are the two main parts of a magnetic fuel gauge ?
8 What is a sender unit ?
9 Where is a mechanical gauge used?
10 Briefly explain how a speedometer works.
11 How is an electronic speedometer different from a conventional speedometer?
12 What are digital instruments ?
13 How would a temperature gauge sender be checked?
14 How would a fuel tank sender unit be checked?
15 How does a brake failure warning light work?
16 Name three lights that could be classed as warning lights, and three that could be classed as indicators.
17 What would a scan tool be used for?

CHAPTER 46

Vehicle computer systems

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 explain door locking using Bus communication systems
2 describe the principles of k ey programming in automotive systems
3 describe anti-theft system operation
4 identify power window C AN Bus system operation
5 outline the principles of C AN and LIN Bus systems used in lighting
6 outline the operation of navigation systems
7 describe the features available in infotainment systems
8 recognise passenger comfort systems
9 identify the requirements of transmission management from engine management systems.

46.1 Introduction

The systems and components on most modern vehicles are controlled or affected by on-board computer systems. As vehicles move towards more autonomy (self-control) these systems will increase in number and complexity. This chapter examines the computer systems that improve security, safety, comfort and performance.

46.2 Central door locking and power door locks

Figure 46.1 shows a basic door-locking system managed by a body control module (BCM). The systems used in individual vehicles vary according to the level of luxury provided.

Remote handsets (or, more technically, transponders) work by transmitting a signal to the vehicle's receiver. Often incorporating an anti-theft system, they contain a unique code that is programmed to the vehicle's BCM. When the remote is used, its pre-set radio frequency (RF) receiver communicates with the BCM via a LIN Bus that is programmed with the code. If the code matches, the BCM sends a signal to the driver's door module to unlock it.

The transponder incorporates a battery that charges when inserted into the start control module when the engine is running. Remote handsets generally have an emergency key blade.

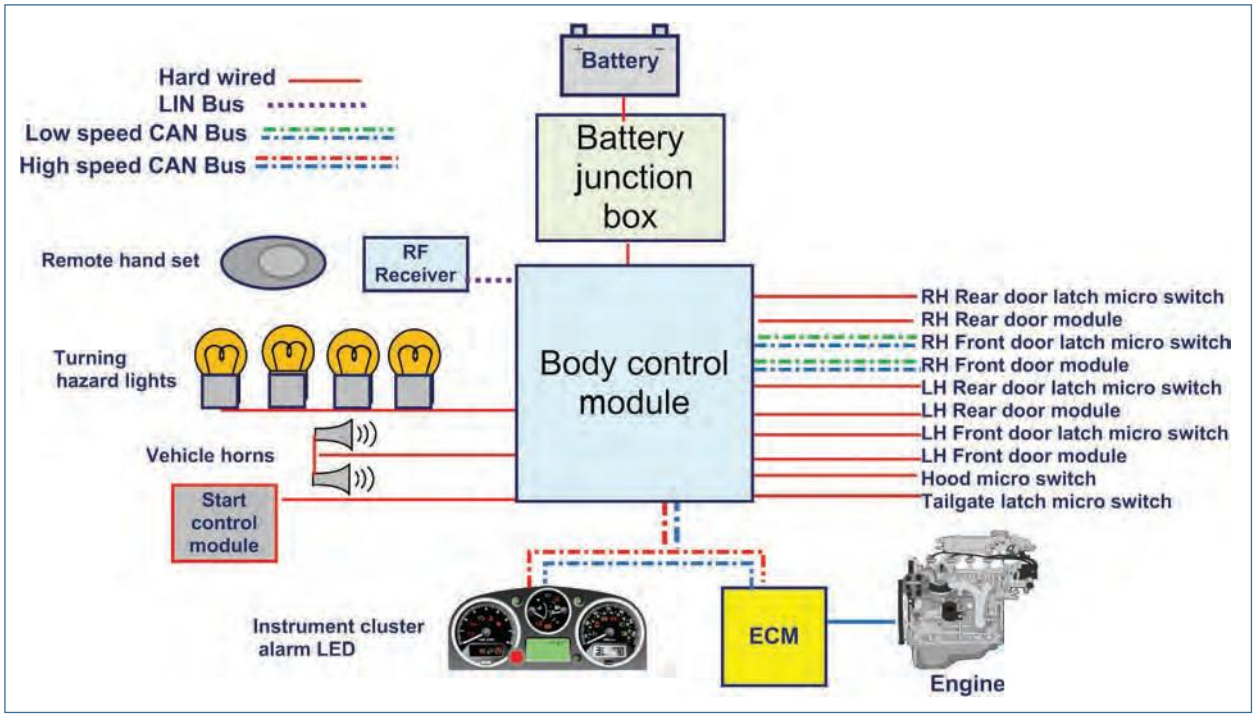


Figure 46.1 Connection of a BCM-managed door lock system

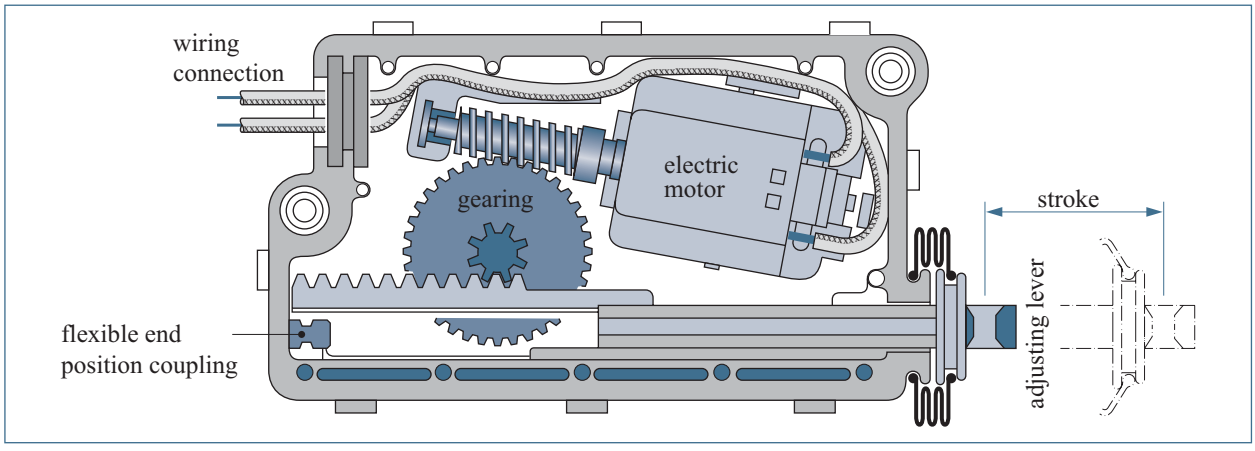


Figure 46.2 Central locking mechanism with an electric motor dr ive BOSCH

As well as the remote handset, a vehicle has door controls that are either mounted on the driver's door or in the dash. If the driver activates the lock or unlock switch, a message is sent to the BCM and a signal forwarded to the doors. Some vehicles have a built-in safety feature that will not allow the doors to unlock unless it is moving at less than 5 km per hour.

Most luxury vehicles have a double-lock mechanism. When the doors are locked by pressing the remote lock function once, the indicators will flash. If the remote lock function is pressed twice, it will 'dead lock' (or double-lock) the vehicle and the indicators will flash again. This will disengage the external and internal door handles.

Some vehicles have automatic locking when they reach a pre-set speed. (This may be programmed to work—or not work—by the dealer with the aid of the factory scan tool.) The trend is to use electric motors to operate door locks as they consume a lower current and are quieter in operation (Figures 46.2 and 46.3). Locking the doors usually activates the anti-theft system.

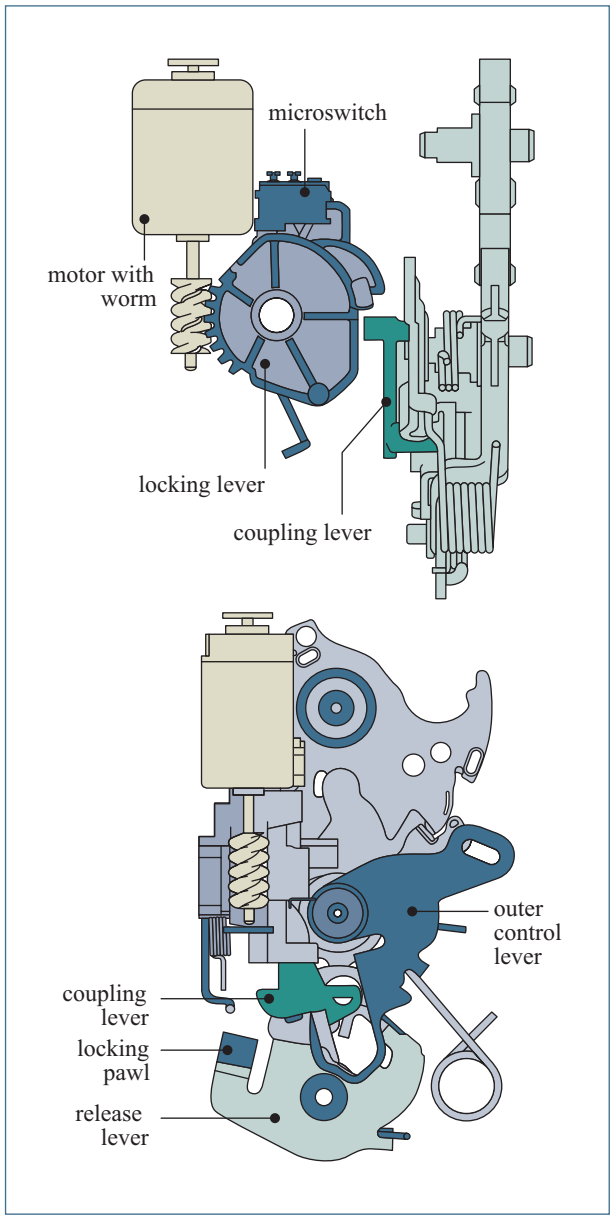


Figure 46.3 Central locking mechanism assembly BOSCH

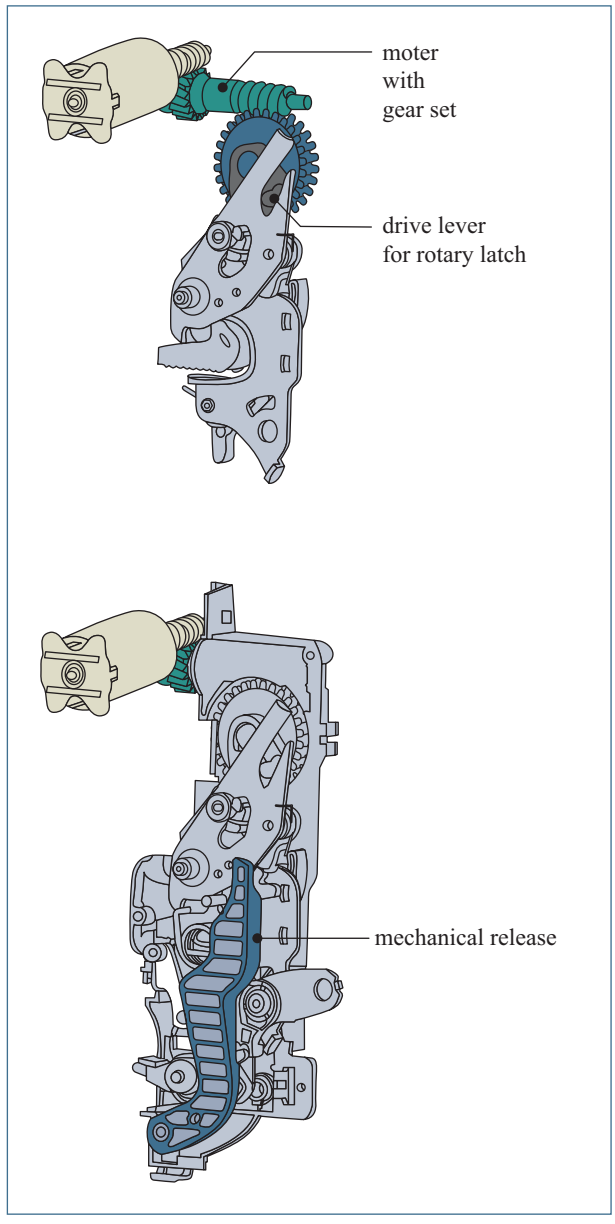


Figure 46.4 Power-assisted door closer BOSCH

Handy hint: Make sure both transceivers are used regularly to keep the batteries charged.

Safety: Never double-lock a vehicle when a person is inside it as they will be unable to get out.

Power-assisted closing is used in some vehicles, as shown in Figure 46.4. This was developed to obtain a tighter seal of the door with less effort from the operator, who only needs to close the door to the first latch area; from there, an electric motor operates the latch mechanism, pulling the door in.

46.2.1 Central locking modes

There are several types of central locking modes. These include:

- Mislock. Occurs if a hinged opening is not closed (including the bonnet and tailgate). A message is sent to the driver via the horn sounding and the vehicle will not lock.
- Speed-dependent locking . The vehicle locks the doors automatically at a pre-determined speed set by the manufacturer .

- Crash unlocking . If the vehicle is involved in an accident and the airbags are deployed, the BCM automatically unlocks the doors.
- Repetitive lock and unlock . The door locks have a thermal overload to protect the system from misuse .
- Automatic re-lock . Occurs if the vehicle is accidentally unlock ed with the remote handset; if no door or panel is opened, the BCM will automatically relock after a short time .

46.2.2 Fault finding

If door lock problems occur and the manufacturer's procedures are not available, the following general procedure can be used.

1. Establish the nature of the problem with the vehicle owner (if possible).
2. Visually inspect the area(s) of concern and look for any physical or electrical faults, including fuses.
3. Check for diagnostic trouble codes (D TCs).
4. If no DTCs are logged, remove the door panel from an individual non-functioning door lock. Modern vehicles use Bowden cables to connect to the lock mechanism. Check that they are in place and that the external and internal handles function correctly . Check the operation of the child safety lock. When the door is open, use a screwdriver to simulate it being closed by tripping the latch mechanism and check the locking function.
5. If the vehicle owner has mentioned a 'door ajar' light on the dash, check the adjustment of the door or try to manually operate the switch.

If these checks fail to find the fault, it may be necessary to consult a technical manual.

46.3 Key coding

Motor vehicle keys are supplied in several configurations. These include:

- A key with a remote control
- A transponder with a normal k ey attached and a code matched to a sensor in the steering lock
- A transponder that is the same as that in point 2 but has no k ey. This key is inserted into a docking station and holds a code matched to the start module .
- A transponder that goes into a docking station and has a unique code and a rolling code created by the BCM each time the k ey is used. These systems are very secure .
- A smart k ey, also referred to as a 'pro ximity key'. This type of k ey can stay in the driver' s pock et when operating the vehicle . In these systems, other security measures can be put in place . The driver will have to operate certain sensors in the vehicle in conjunction with the key to control features such as seat position and climate control. These keys also use the rolling code system, making the vehicle very secure.

Occasionally, transponders may not work due to external radio interference (usually from locations with very strong interference, such as TV broadcasting towers). Transponders have batteries that may fail or go flat if not used for long periods of time.

46.3.1 Programming transponders

Key coding requires specialised equipment as the radio receiver and the key (transponder) need to be programmed together (Figure 46.5). The process required depends on the type of key used. Transponder programming devices are available, but most newer vehicles require the dealer to use their OEM scan tool to complete the process. Any vehicle whose transponder uses rolling codes has to be programmed by the relevant dealership as a specialised programming tool is required.

Transponder codes are aligned to vehicle identification numbers (VINs). If a key is lost, the VIN is required to access the code. An old key that still works for programming new transponders could also be used. When new transponders are programmed, there may be a waiting period before they can be used. This is an added security feature.

Safety: When working on motor vehicles with ' smart transponders ' that do not have to be inserted into the transponder dock for the car to start, always store the transponder away from the vehicle to prevent accidentally starting the engine .

(a) (b)

Figure 46.5 (a) Transponder (b) transponder programming tool SHUTTERSTOCK

46.4 Anti-theft

The following information is general and does not apply to all vehicles. Individual manufacturers set their own parameters and conditions for anti-theft systems, and these should be consulted.

Computer-managed vehicles allow for anti-theft measures to prevent unauthorised entry and use of a motor vehicle by disarming many of its functions. Passive anti-theft systems can disable the gateway module, engine control module, electric steering, start control module and the ABS. The systems work by using a uniquely-coded remote handset (key) and encoded data between modules. When a vehicle is locked, the engine control model (ECM) prevents unauthorised starting by immobilising the engine crank system, fuel system and ignition system.

46.4.1 Anti-theft system operation

The process starts with the key sending a coded message to the RF receiver, which is passed on to the body control module (BCM). If the code matches the information stored by the BCM, it will allow the start module to activate the systems.

The ECM will only allow the engine to crank and spark (in the case of petrol vehicles) or injectors to work (in the case of diesel vehicles) if the following takes place.

1. A signal comes from the park or neutral transmission selection to the transmission control module , or TCM (this applies to automatic transmissions). The T CM may also be called the power train control module (PCM).
2. An ignition signal is received from the BCM. This can only happen if encrypted data are ex changed with the start control module to validate the remote handset (k ey).
3. A crank signal is received from the BCM.
4. An encrypted data signal is ex changed between the instrument panel and the ECM and is verified.

If the alarm has been activated, it activates the LED light on the dash, indicating that the system has been set off. If unauthorised entry to the vehicle happens by door switch activation, the connected systems such as ignition and cranking will not function.

Intrusion detection

As well as the normal hinged-opening monitored systems, some luxury vehicles have a volumetric intrusion sensor. This detects any movement in the vehicle whether a door has been opened or not, and sets off the horns and hazard lights. Figure 46.6 illustrates the function of an ultrasound detector.

Tilt sensor

Some vehicles have a tilt sensor. Usually mounted under the roof lining, it sets off the horn and hazard lights if the vehicle is lifted at one end.

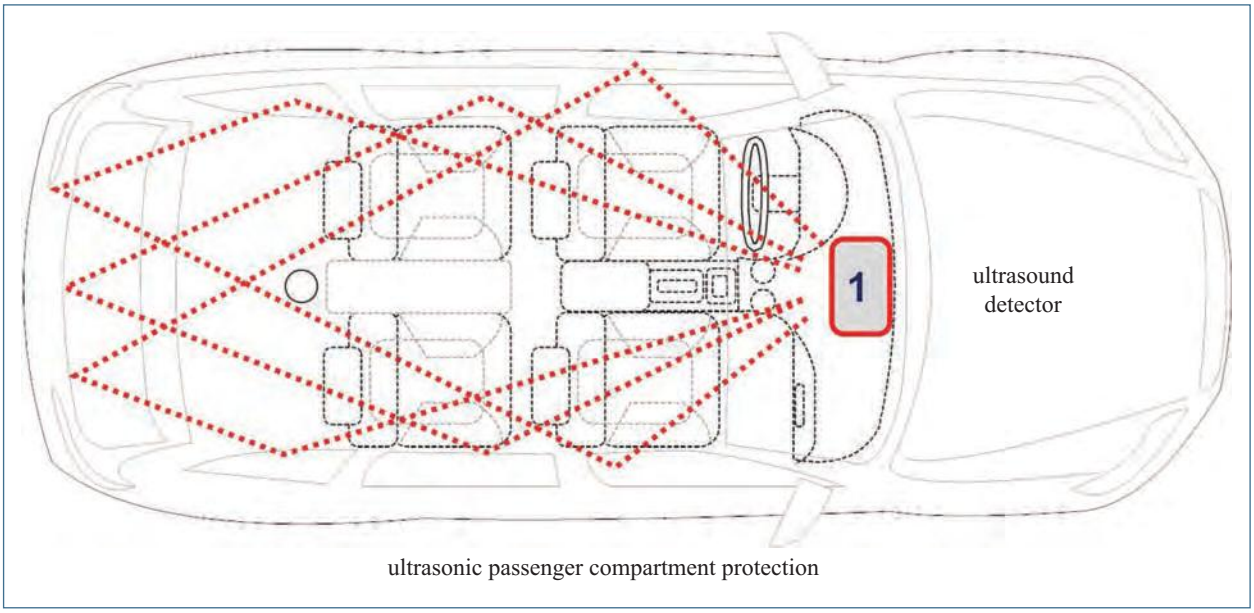


Figure 46.6 Intrusion detection with the use of an ultrasonic sens or

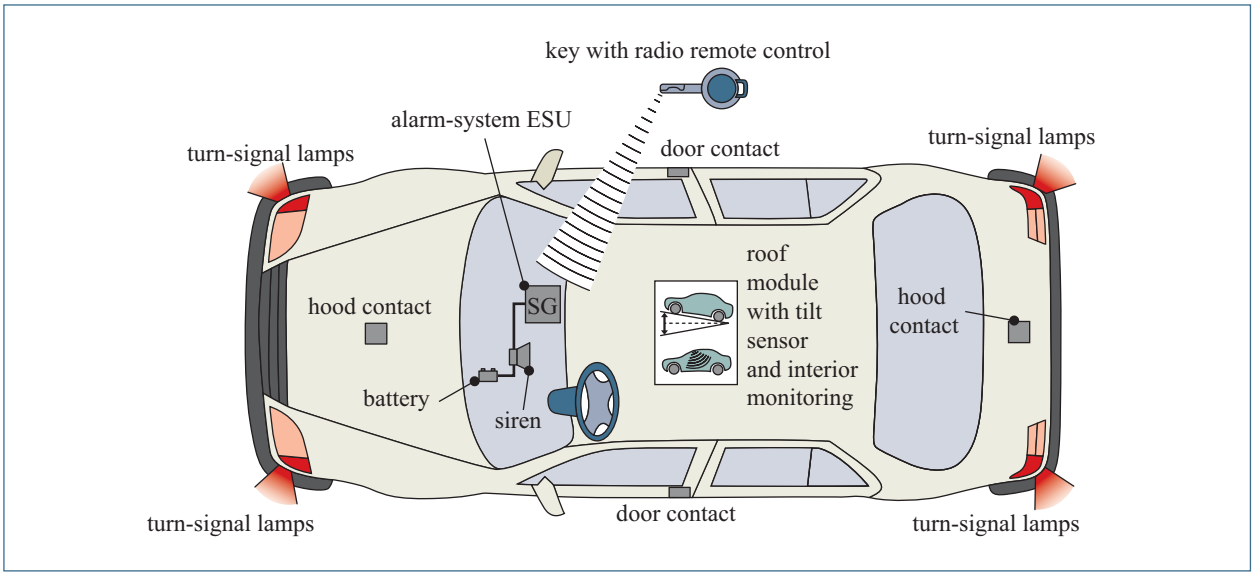


Figure 46.7 Items included in theft deterrent systems BOSCH

Panic mode

Some remote handsets have a panic button which, if pressed for more than a few seconds (or if repeatedly pressed), activates the horn and hazard lights. Figure 46.7 shows the location of these systems.

46.5 Power windows in BCM vehicles

The power windows of non-BCM systems, as discussed in Chapter 39, use old technology that is now being replaced. To a driver, there is little difference between operating the window control switches in a hard-wired system or a CAN-based system; but to a technician, there is a difference in the operation.

The windows in modern vehicles are managed by the BCM (Figure 46.8). The door switches send signals to the BCM, which in turn sends a signal to the node in the door to operate the window (Figure 46.9). (Each window mechanism has its own node.) The driver's door is connected to a low-speed CAN Bus system as it is the control for all windows. All other windows are connected via a LIN Bus system to individual nodes.

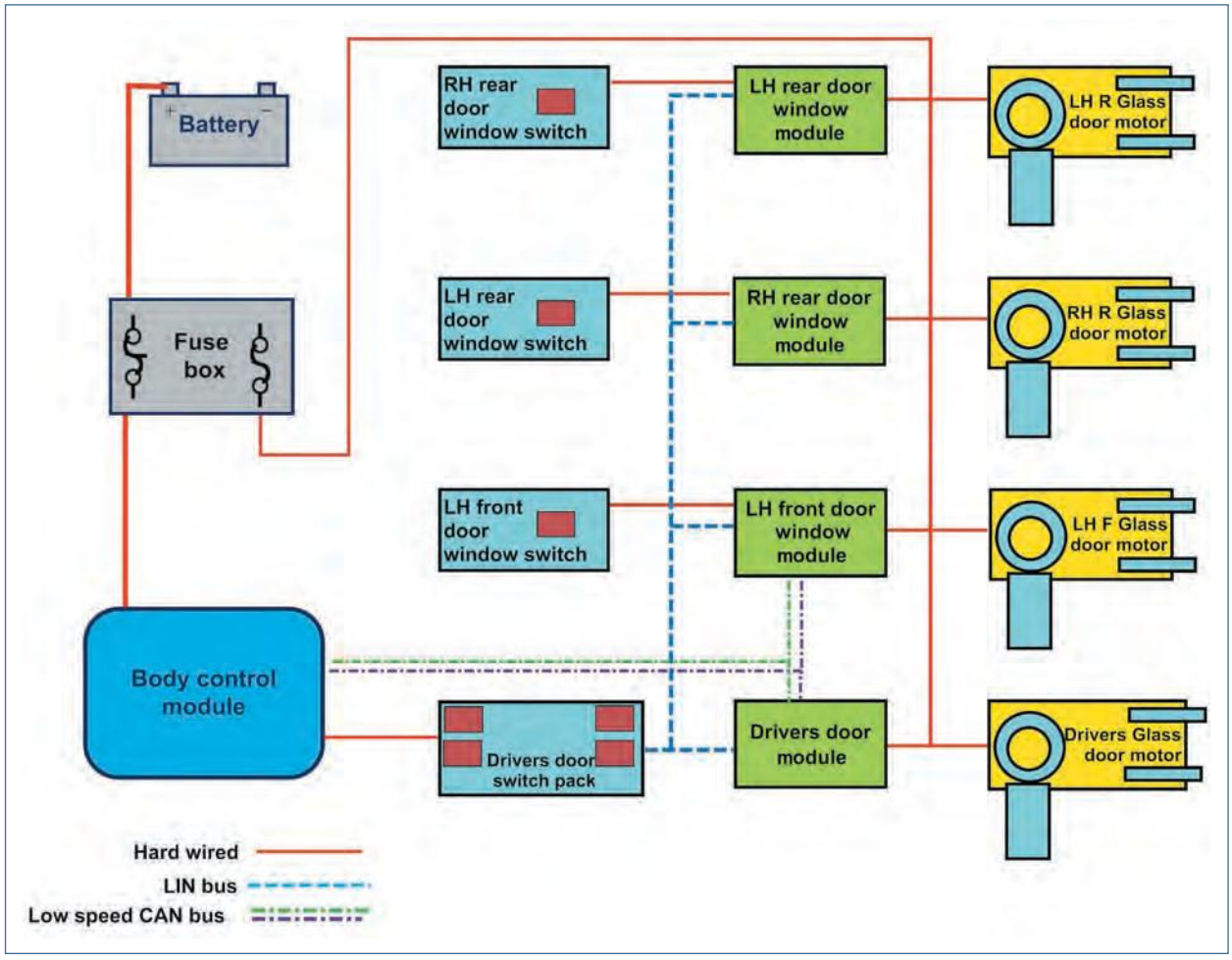


Figure 46.8 Window operating system using a BCM with C AN Bus and LIN Bus systems

More modern systems use electric motors with a node or processor attached (Figure 46.10). The node/module can sense overload and acts to protect the system. The electric motor drive is connected to the window slide by a Bowden cable. Power is supplied to all devices in the system directly from the fuse box.

46.5.1 Power windows service

If a module is replaced in service, it will need to be initialised. This process may have to be carried out on all modules or both front-door window modules simultaneously to ensure they have the same software and operation.

Fault codes for windows are generally preceded by the letter B (for 'body') if the problem is caused by the power supply to the motors. If the control modules fail or the CAN Bus lines have a fault, a 'U' precedes the fault code. If there is a faulty sensor or a LIN Bus line fault, a 'C' precedes the code in the scan tool. Individual manufacturers provide detailed fault code information for vehicles.

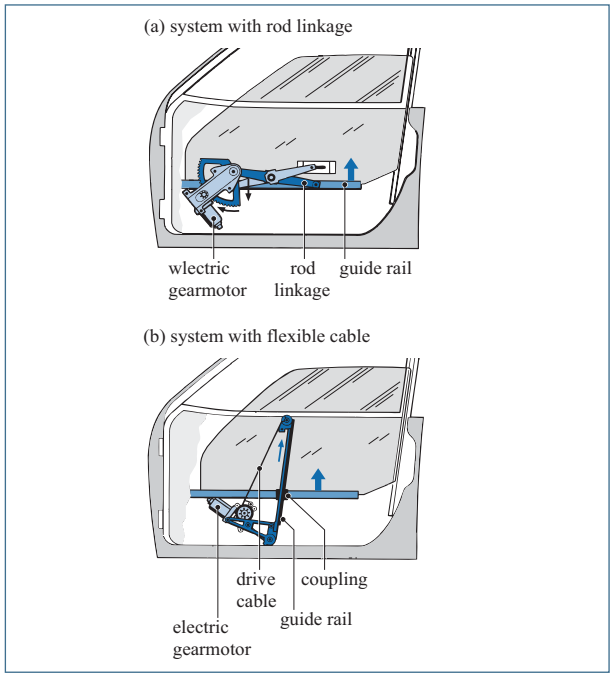


Figure 46.9 Electric motor and window-regulator mechanism showing (a) the older arm lift and (b) the newer style that uses cables BOSCH

46.6 Lighting with CAN Bus systems

Lighting systems operated by CAN Bus systems may seem to function in the same way as others, but the schematics are different (Figure 46.11). The main advantages of CAN-based systems are their ability to reduce copper wire, and to self-monitor and report back to the technician via fault codes. This can have a negative effect if changing globes to LED (lower power consumption) or higher-wattage globes (higher power consumption). The BCM senses that power is out of the set parameters and signals a fault. To counteract this, aftermarket globe manufacturers offer resistors that stop fault codes arising.

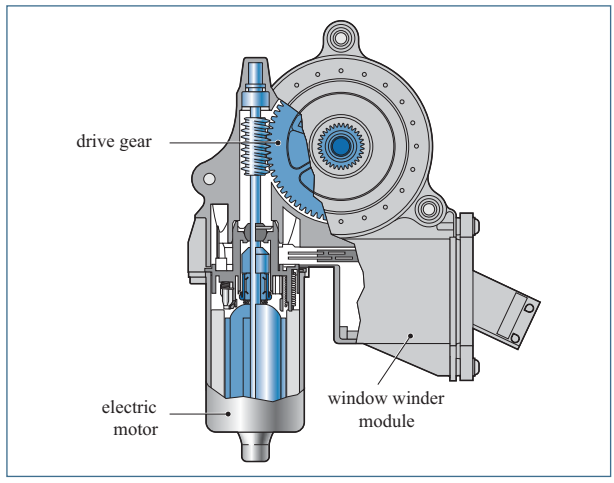


Figure 46.10 Power window motor BOSCH

46.6.1 Xenon headlamps

Modern lighting systems may include xenon headlamps, which operate on high voltage. When changing xenon globes, the following should be considered:

1 Make sure globes are seated securely in the globe holder , to avoid melting either or both.
2 Never perform high-intensity (HID) circuit inspection with a tester .
3 Never touch the globe with skin or put oil or grease on it.
4 Never use organic solvent to remove contaminants.

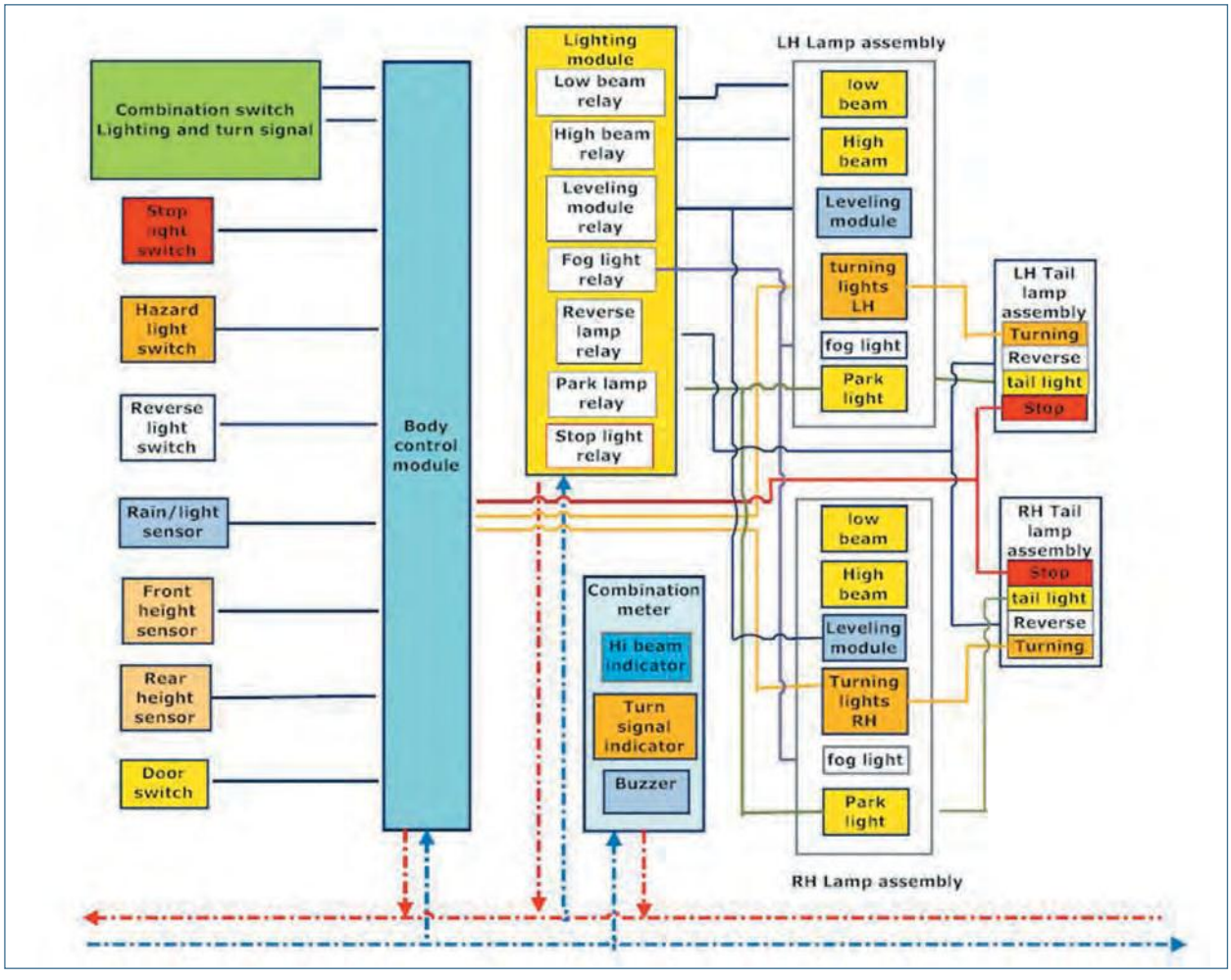


Figure 46.11 Schematics of a C AN Bus lighting system

46.7 Navigation

Navigation systems are now common in most vehicles, either as standard equipment or as aftermarket purchases. Navigation units, also called global positioning systems (GPS), may be part of the infotainment system or be stand-alone units. Manufacturers offer packages that include traffic updates, speed camera location data and locality services, such as restaurants, airports and hospitals. Vehicles that come equipped with units often offer better options that can integrate with voice and phone systems.

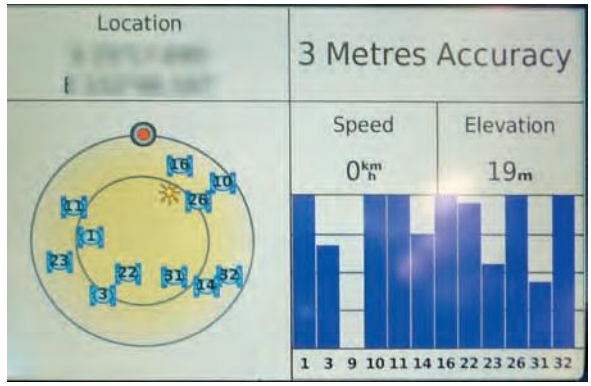


Figure 46.12 Signals being received by a GPS, the relative position of the satellites and their signal strength

46.7.1 Navigation operation

Navigation systems work on global positioning using satellites and trigonometry to establish a current position on the map that is loaded into the unit (Figure 46.12). Maps require upgrading almost every year. GPS systems are based on data from 24 US military satellites (Figure 46.13). To obtain the signal required to provide all the features of the GPS unit, at least four satellites must be connected at any one time. They emit a special signal at the rate of 50 times a second; when the signals are received from at least three satellites, the latitude and longitude of the GPS can be calculated. When a fourth satellite signal is received, the height above sea level can also be calculated. The greater the angle that the satellites transmit from, the greater the accuracy of the position. The GPS unit is constantly comparing its position against the digital maps that are loaded in the unit, and also compares the signal to the map. The GPS makes corrections to match the map as the signal is only accurate to a distance of between 2 and 5 metres. When a GPS is an integral part of a vehicle, it can use other information such as that from yaw sensors and acceleration sensors to assist in its reporting.

There are many hidden tools and screens in GPS units that are not mentioned in operator's handbooks. For example, they can report delays and accidents. Traffic management information is transmitted in encoded form on radio frequencies called radio data systems (RDS) on FM radio. This information is integrated into the information on the maps to show where there are traffic hold-ups. The GPS can then suggest an alternative route.

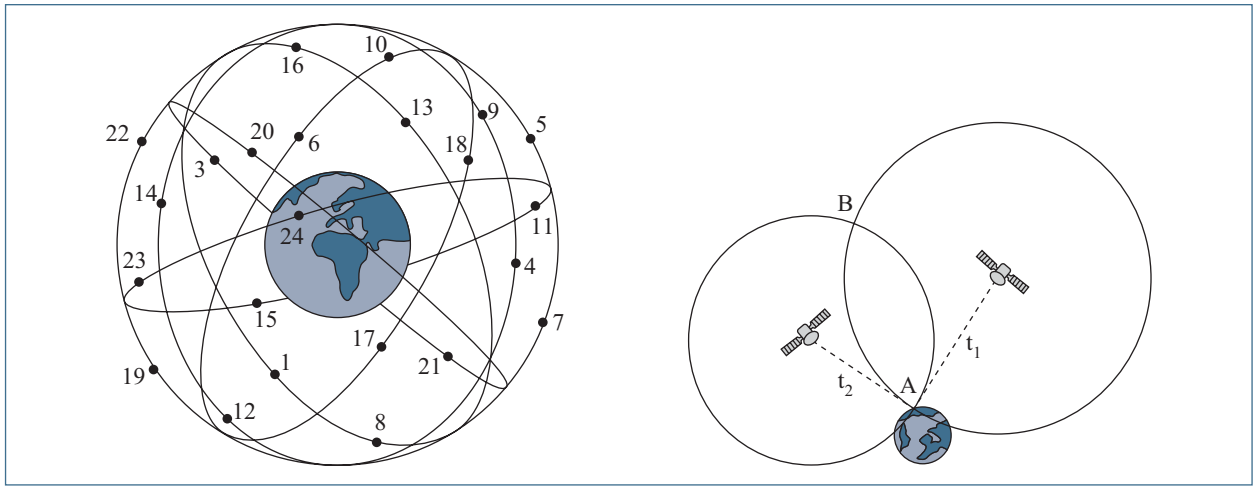


Figure 46.13 How trigonometry pinpoints vehicle location using data from the 24 US military satellites

46.8 Infotainment

Infotainment refers to a combination of entertainment and information. Infotainment units in a vehicle typically include the radio, DVD player, MP3 player, USB facility, an auxiliary jack, reversing camera and Bluetooth connectivity, as well as possibly a navigation system (some vehicles have navigation as a separate device while others incorporate all systems into one unit). DVD players and radios are developed into standard sizes

described as *single DIN* and *double DIN* (Figure 46.14). *DIN* refers to the size of the unit. The double DIN is now the more popular as it can facilitate all the features required in the modern vehicle.

Modern infotainment units that use double and single DIN systems may incorporate:

- radio (FM1, FM2, AM)
- Bluetooth (hands-free phone and other accessories such as reversing cameras and microphone)
- MP3 with ID3 tag
- USM connection
- DVD
- auxiliary in jack for plug and play
- clock
- secure digital (SD) memory card slot
- GPS
- graphic equaliser
- TV
- phone book
- MP3 player
- tyre pressure monitoring.

46.8.1 Connection of infotainment systems

Aftermarket units that offer many features can be fitted to vehicles. For example, single-DIN units can be purchased with larger hinged screens to match double DINs. When infotainment units are fitted by the manufacturer, they are connected to the low-speed CAN Bus or LIN Bus systems (Figure 46.15).

Single DIN

Double DIN

Figure 46.14 The difference between single and double DIN units

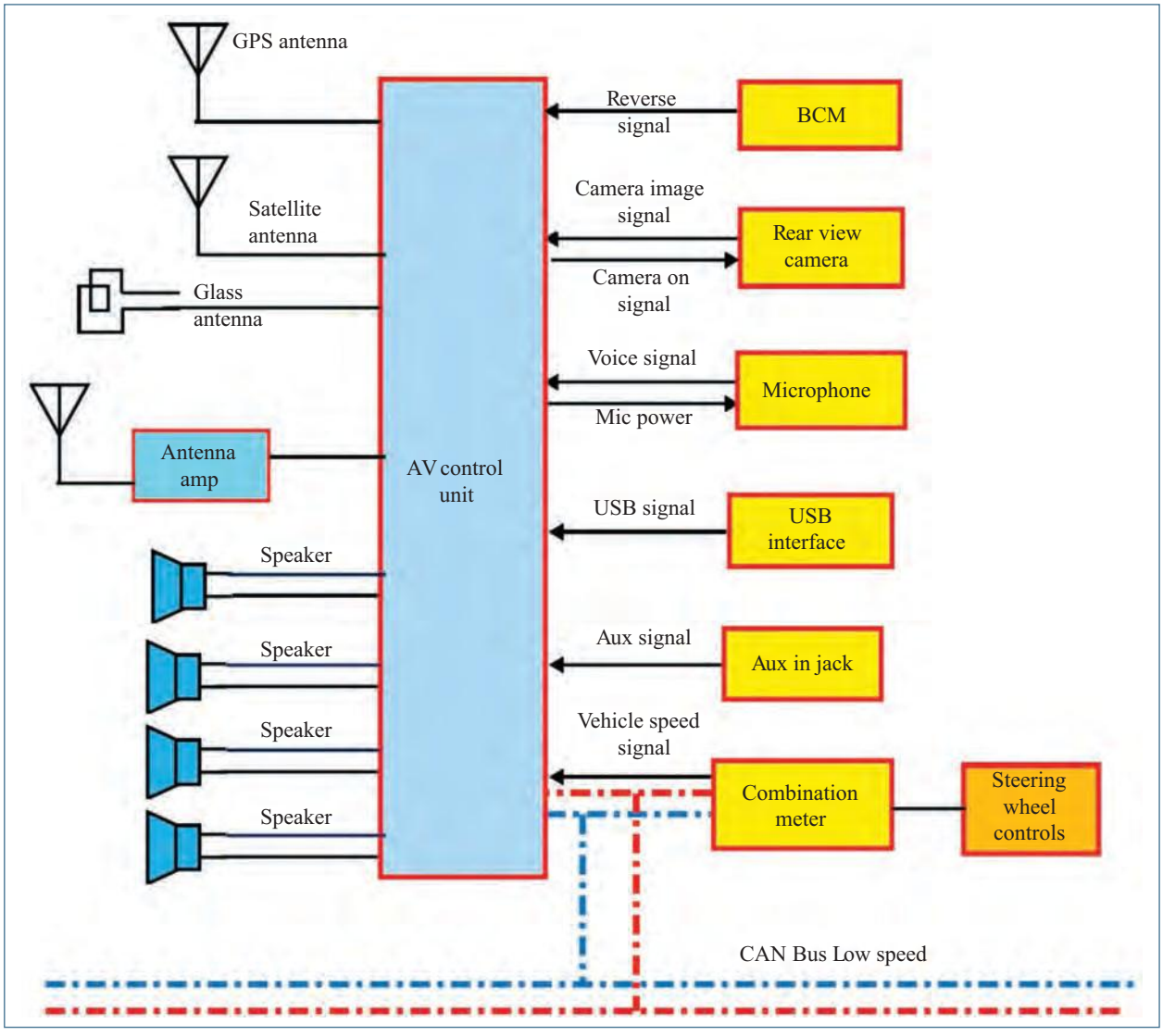


Figure 46.15 The connectivity of an infotainment unit

This allows faults to be recorded within the data link connector (DLC) and gives connectivity to other systems in the vehicle.

Luxury vehicles may use the MOST (fibre-optic system connection) system, where the optic fibre is a plastic material that allows for flexibility and vibration resistance. MOST systems are not subject to electromagnetic interference (EMI), improving the sound quality.

DLC fault codes in an infotainment system generally start with the letter B (for 'body'), unless the fault lies within the CAN Bus system, in which case it will start with the letter U.

46.9 Passenger comfort systems

Climate control systems can be separated into two categories: heating and cooling. Cooling systems are integrated with heating systems to manage cabin temperature control and comfort (Figure 46.16). These systems may incorporate humidity sensors, pollen sensors, air filtering, electric boosted heaters or fuel-fired heaters in luxury European vehicles. With the increase in sales of many such models, the market now offers a variety of ways of managing vehicle occupier comfort, largely depending on the vehicle's country of origin.

46.9.1 Comfort systems operation

The heater and evaporator cores are mounted in series so that the air entering the cabin can have the temperature controlled at all levels. This also helps to control humidity, which can cause window fogging. Figure 46.17 shows the composition of a climate control system.

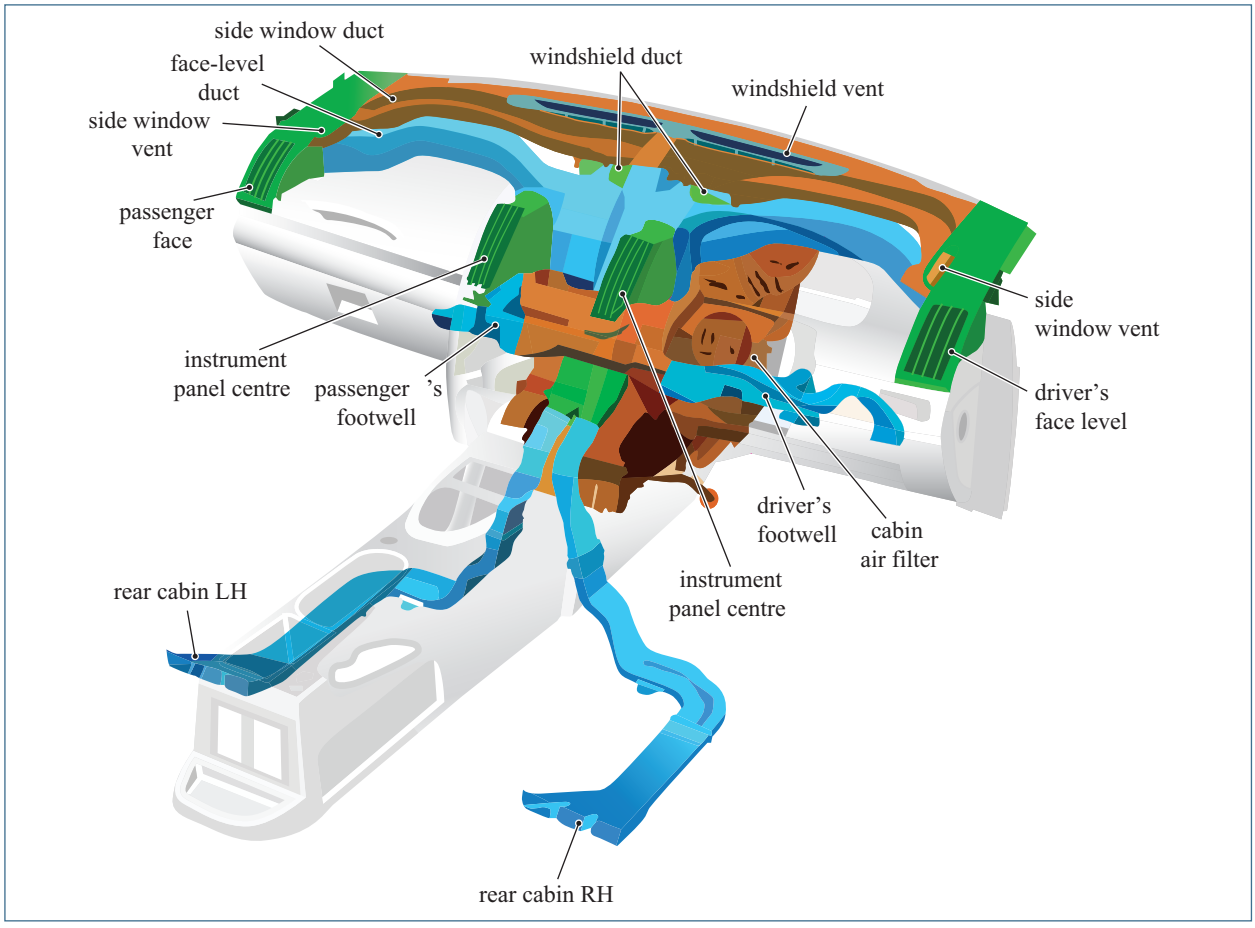


Figure 46.16 How heating and cooling are distributed to all areas of the vehicle

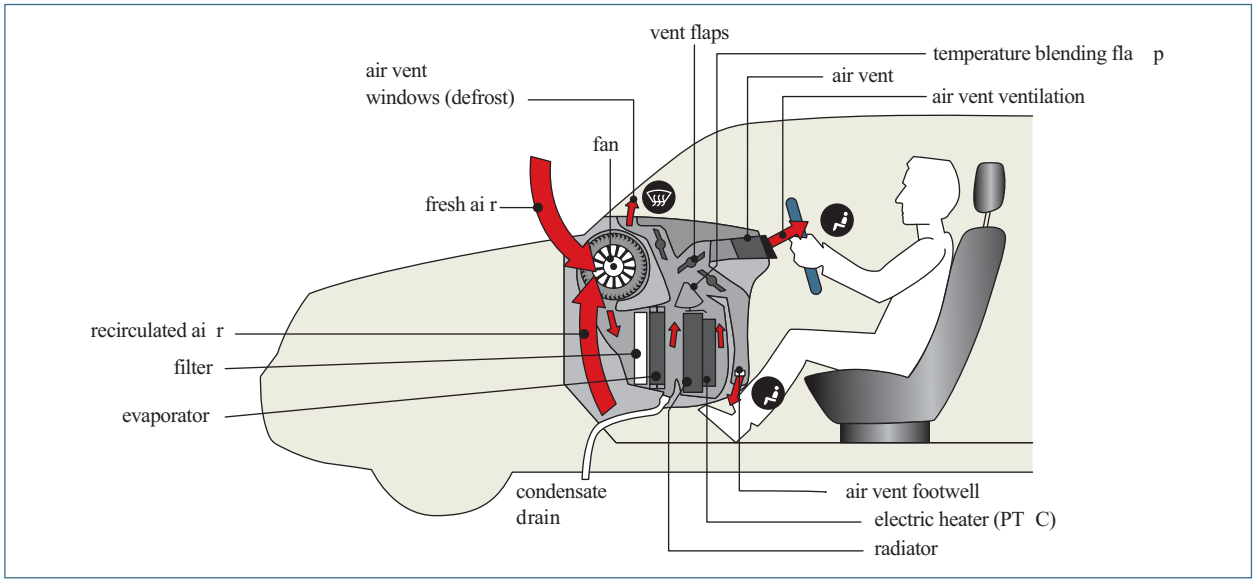


Figure 46.17 Component relationship of a climate control system

When vehicles have an idle stop-start engine management system, other considerations need to be taken into account in relation to heating and cooling. If the engine stops, there will be no air conditioning or heating as the coolant is no longer being circulated by the water pump. An electric coolant pump is incorporated for heating and is directly connected to the ECM. This will continue the flow of the engine's coolant. In countries that experience extreme cold, a fuel-fired heater is added to maintain cabin temperatures. To maintain cooling, the start-stop function can be overridden to keep the air conditioning compressor functioning.

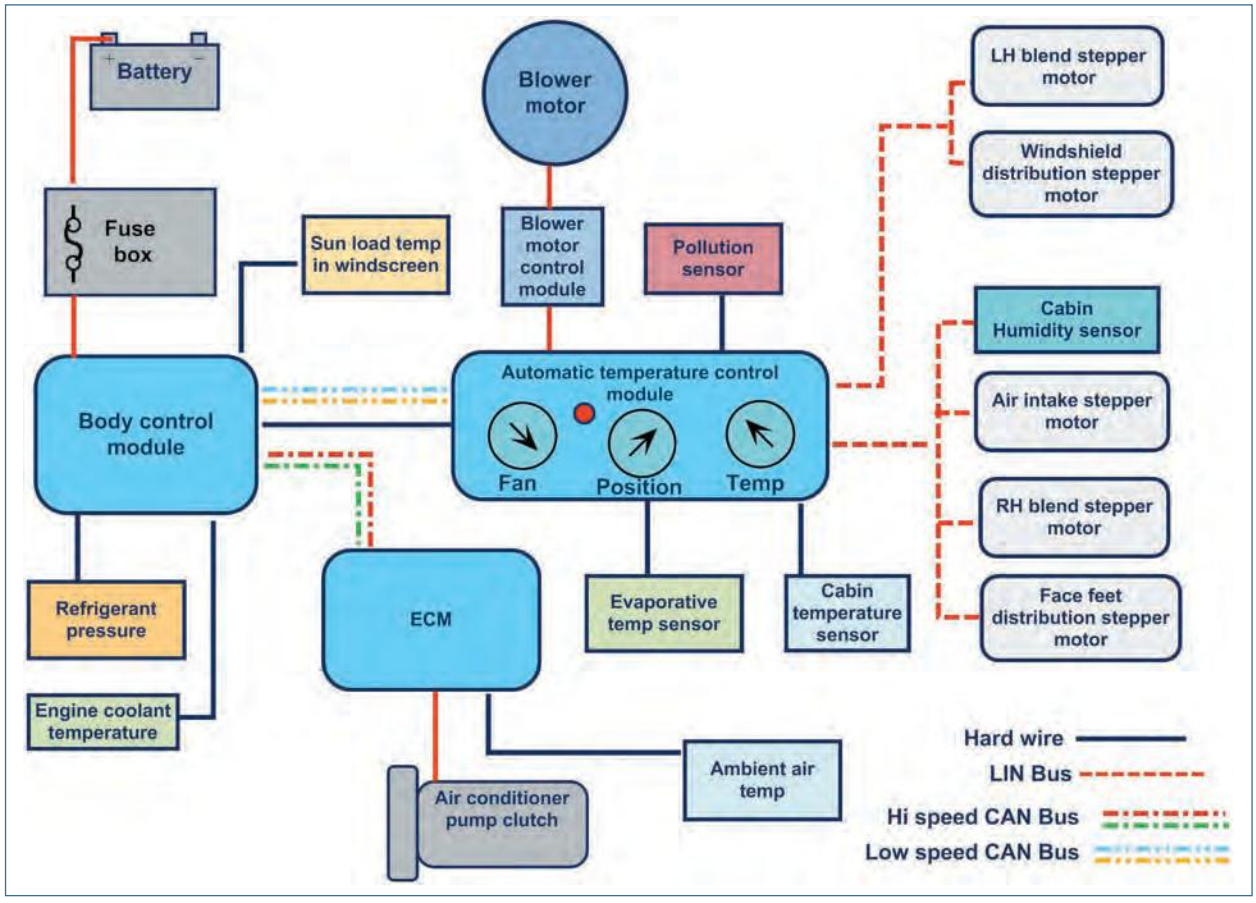


Figure 46.18 The connection of the passenger comfort system

When pollution sensors are fitted, the sensor will react if pollutants are detected, causing the auto control to close the air intake flap and run recycled air.

The humidity sensor calculates the likelihood of the windscreen fogging up. When the control unit receives a message from the sensor, it adjusts the blower speed, engaging the air conditioner and redistributing the air to prevent fogging.

The automatic temperature control unit communicates directly with the ECM to control all aspects of heating, cooling and ventilation via a high-speed CAN Bus system. Communication to the stepper motors that control the airflow may be via several methods. Figure 46.18 shows a LIN Bus connection from the automatic temperature controller.

46.10 Transmission and engine integrated systems

For an automatic transmission to function properly, the control module needs data from several sources (Figure 46.19). The data include:

- engine speed or input shaft speed
- engine temperature
- engine throttle position
- vehicle speed or output shaft speed
- lateral acceleration or steering angle
- linear acceleration or torque
- selector position
- transmission oil temperature
- brak e pedal sensors (stop light switch).

Some of the TCM's requirements may be accessed from the engine's ECU and BCM, or from within the transmission itself. The method of sourcing the information varies according to the manufacturer's management systems and the sophistication of the transmission system.

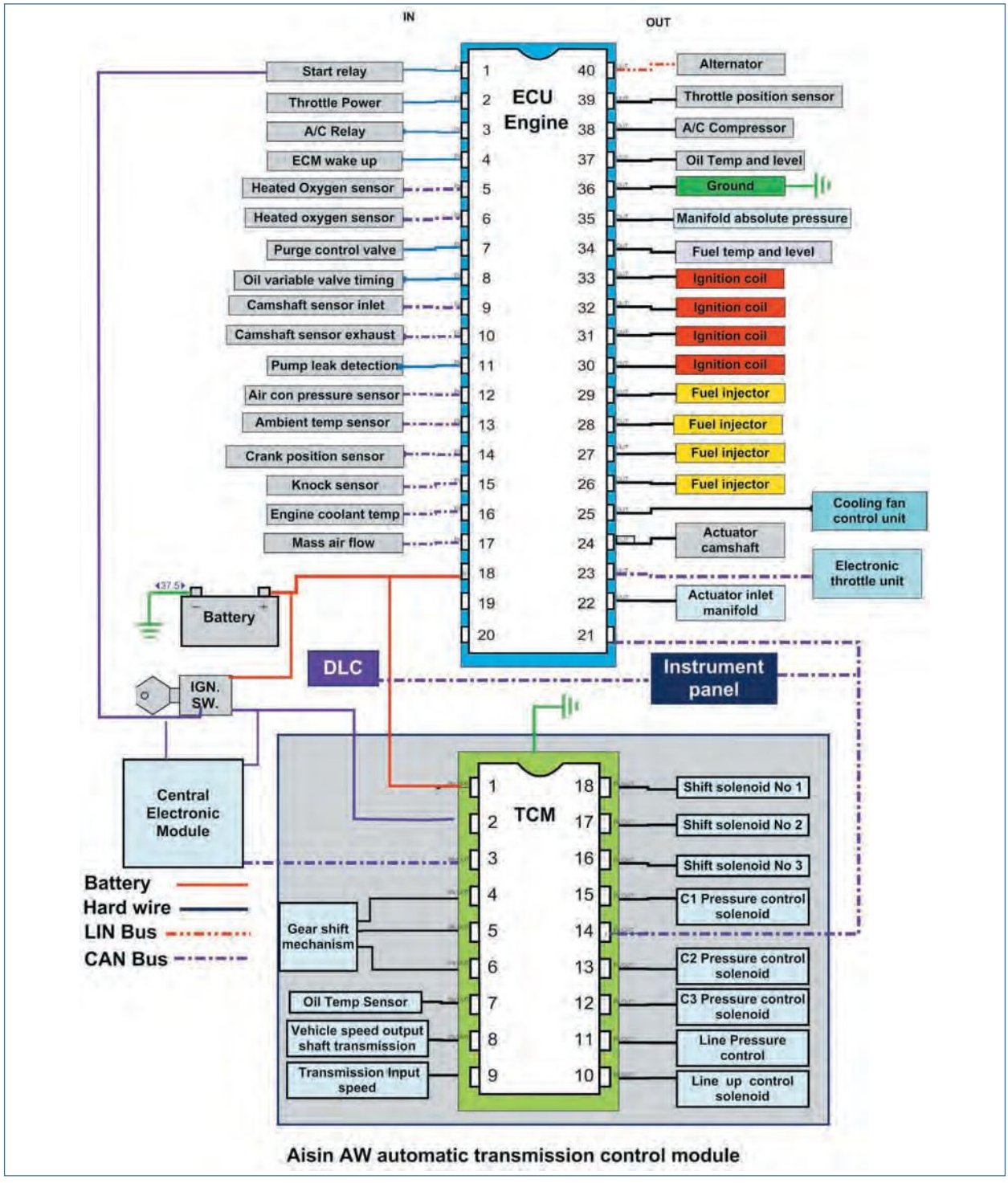


Figure 46.19 The connectivity of the ECM, T CM, instrument panel and diagnostic link —not all the engine information is required for the T CM to perform correctly

From the information gathered, the TCM determines what gear range or clutch pack and oil pressure should be applied in the transmission (Figure 46.20). The outputs from the TCM are:

- first clutch pack
- second clutch pack
- third clutch pack
- first pressure control
- second pressure control
- third pressure control
- line pressure
- torque converter lock -up clutch.

The transmission clutch packs and pressure control valves are operated by modulation, by whose action the timing and pressure of oil applied to clutches can be controlled. The decisions made by the TCM are based on the logic and software within the module.

Manufacturers take the following into account when they design vehicle CAN Bus and LIN Bus systems:

- the data rate required
- whether the information has to go one way or both ways
- EMI
- fault tolerance
- the number of modules
- how many modules share power supply
- the level of error checking
- the level of access in a Bus system.

Figure 46.20 Transmission control module mounted to the transmission, showing the connection of the selection control

Handy hint: Electronic transmission gear changes can be affected by EMI from units such as coil packs. If when testing for faults none can be found from the DL C, use an EMI meter to scan for stray electromagnetic interference around items such as ignition coils and HID lighting.

Handy hint: Low battery voltage and poor earths can cause many intermittent faults that are very difficult to trace . A battery may test satisfactorily but still cause erratic transmission shift patterns.

46.10.1 Inputs

Ignition signal

The signal from the ignition switch or engine's ECU creates the wake-up call for the TCM to begin its work.

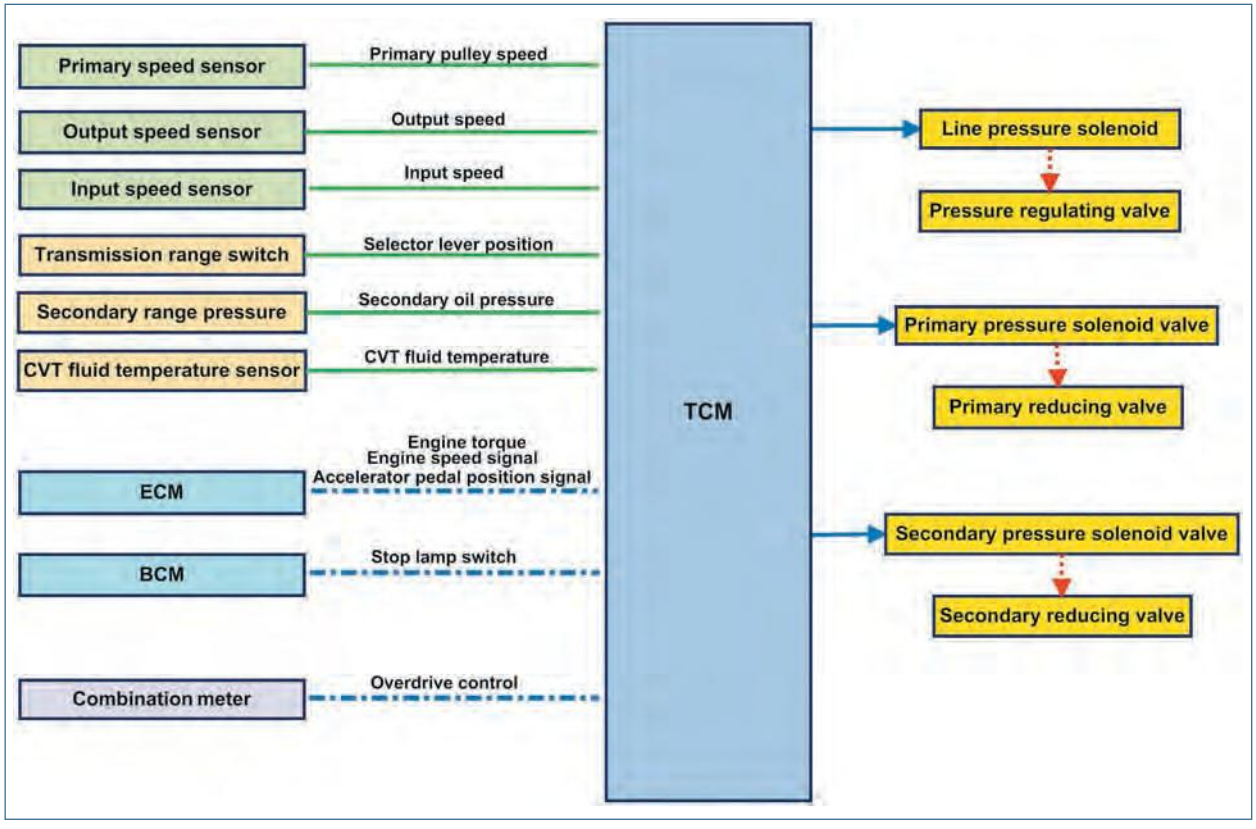


Figure 46.21 The connectivity of a continuously variable transmissi on (CVT) system. The basic inputs are the same as other electronic automatic transmissions

Selector position

This is the next signal the transmission needs, and specifies whether the vehicle is in park, neutral, reverse or drive. If it is in any position other than neutral or park, the inhibitor switch will prevent the engine from being started. Some automatic transmissions have a manual selection facility, which will allow the driver to select the up and down shift manually. This feature's name varies according to manufacturer, even if the same transmission is used.

Transmission oil temperature

The viscosity of the oil affects the shift patterns. This is also used to change shift patterns if the temperature gets too high from situations such as heavy loads.

Engine temperature

This is required so that the overdrive is not selected until the engine has warmed up sufficiently. This reduces load on the engine and also helps to reduce pollution by warming up the engine and running at a few more rpm for a short time.

Throttle position

The throttle position allows the transmission to process the load being placed on it. When the load is increased, the hydraulic pressure needs to increase to hold clutch packs tighter. In older automatic transmissions, this was done by a cable connected to the throttle that went down to the transmission and increased spring pressure on the throttle valve or a vacuum-operated servo.

Engine speed

Information about the engine's speed may come from the engine ECU or from the input shaft of the transmission. Some transmissions have most of the sensors built in, so require very little outside information (Figure 46.22).

Output shaft speed or vehicle speed

This information can come from within the transmission or from the ECU or ABS sensors (Figure 46.23).

Mass airflow sensor or MAP sensor

Information from either of these may also be used to calculate the load in conjunction with the throttle position sensor.

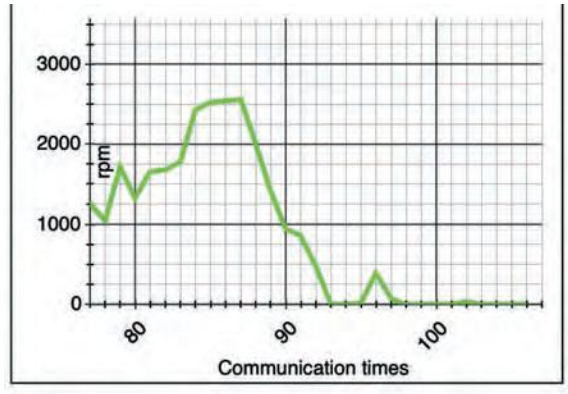


Figure 46.22 Graph of gearbo x input shaft speed. The input speed can come from the engine or the transmission

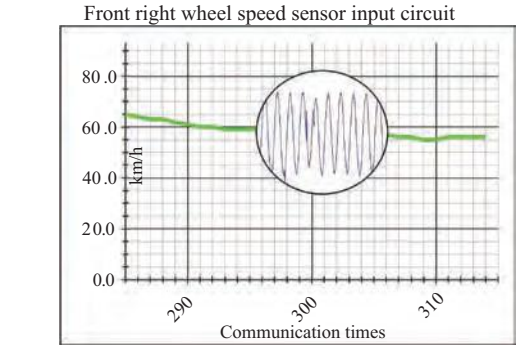


Figure 46.23 Output speed can be measured from the ABS wheel sensor or the transmission output shaft; when ABS sensors are used, the ECM calculates the average of the four wheels

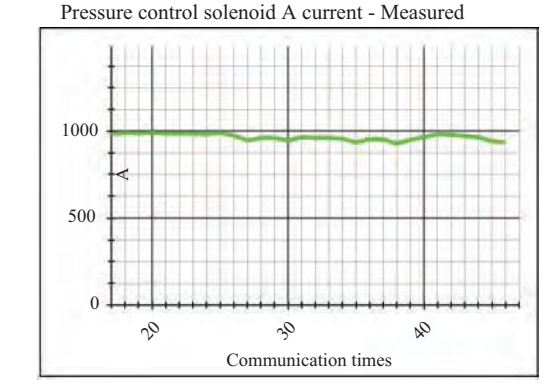


Figure 46.24 Control valves have a modulating voltage to manage pressure

Transmission oil pressure sensor

This sensor monitors the pressure to assist in the transmission's behaviour in shift patterns and is a verification for the TCM of what is happening within the transmission (Figure 46.24).

Steering angle sensor and ABS module

These systems also supply data to the TCM on the high-speed CAN Bus system. The TCM uses this data to suspend gear changes when the vehicle is cornering and/or the ABS module is controlling braking or traction control.

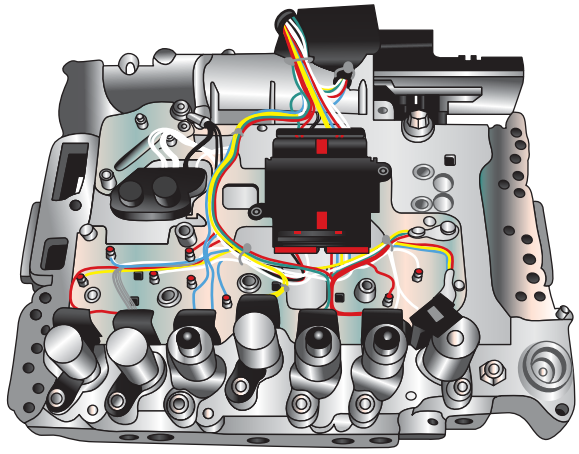


Figure 46.25 Valve body showing the electronic modulating and pressure-controlling valves

46.10.2 Outputs

The TCM outputs are based on information from the inputs. The TCM applies current modulation to the various shift valves and pressure control valves to manage the correct application and timing within shift patterns. The TCM also provides information to the instrument panel showing what gear is selected and (if fitted) an overdrive light.

Limp home mode

This is provided by the TCM if it detects a fault from a message failure to any of the electronic control units. The TCM only allows the transmission to operate in a single forward gear and reverse gear so that the vehicle can be driven to a place of repair.

Many electronic transmissions are sealed for life and do not require oil changes. They generally use synthetic oil, and care should be taken to ensure the correct oil is used.

46.11 Removing and replacing ECMs

Manufacturers' procedures must be followed in the *exact order* when removing or replacing an ECM. Some modules are pre-programmed and do not need re-programming; others do.

The following are considerations when removing and replacing ECMs:

1. Save the current vehicle specifications and any information from a module that is available before starting. Some modules store information and some are programmed to individual model versions.
2. While the module may fit several versions of vehicle , certain features may need to be turned off or on so that error codes are not produced. Some error codes put the vehicle into limp mode.
3. Be sure that the fault has been evaluated correctly as electronic modules are not returnable if they have been incorrectly diagnosed.
4. Follow the manufacturer' s instructions exactly .
5. After replacement of a module , an initialisation will be necessary to set the parameters. Failure to do so may create further damage to systems or units.
6. Every vehicle is different, so collecting the configuration information is important.
7. When fitting a new module , go to 're-programming' on the scan tool.
8. If a new BCM is being fitted, the transponder needs to be initialised and registered. This will be required following the scan tool procedure .
9. When ordering some modules, the VIN will need to be given as the module may be factory set for the vehicle.
10. When major components such as a transmission are changed, the T CM must be reprogrammed to match them. If this is not done , the module may act in accordance to the previous transmission and have incorrect shift patterns.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain remote door-locking systems
- identify different types of transponders and explain how they are programmed
- explain how the anti-theft system is interconnected to the ECM, transmission and BCM
- describe how the BCM manages the signals from the window switching system and controls the actuators
- identify lighting systems managed by BCMs
- explain satellite navigation systems
- describe the function and operation of infotainment units
- state the operation of climate control systems
- explain the connectivity between the engine control unit and a transmission control unit and how the electronic transmission and actuators function
- state the correct procedure for safely removing and replacing ECMs.

REVIEW QUESTIONS

1 What is speed-dependent locking in relation to door locks ?
2 How does a remote door lock control connect with a vehicle ?
3 What is another name for the remote used to lock and unlock a car door?
4 What precaution should be observed when locking a car when a person is still in the vehicle ?
5 When a vehicle that has a body control module and an engine control module is lock ed, which systems are locked out so they will not function ?
6 What must be done when a new electric window control motor is replaced?
7 What letter will a fault code start with if a window fails to operate because of a fault?
8 Which letter is most lik ely be the start of a fault code of the C AN Bus?
9 If changing globes to a lower wattage what might happen when the vehicle has a body control module BCM?
10 When replacing Xenon globes , what precautions should be observed?
11 In an engine and transmission integrated system list five different sensors that would be utilised for correct operation of the transmission.
12 What is the name of the module that controls the transmission ?
13 Why is the engine temperature sensed for correct transmission operation ?
14 What information does the MAP or MAF sensor provide for the transmission operation ?
15 How does the output signal to the shift valves in the transmission control the shift pattern ?
16 What is a double DIN unit ?
17 List eight features that are incorporated in a double DIN infotainment unit.
18 How does a GPS identify your location when driving ?
19 When replacing a remote control for a vehicle , what must be done so that it will operate ?

PART 9

Alternative drive systems

CHAPTER 47

Hybrid, all-electric and fuel-cell vehicles

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 state the operating principles of hybrid, all-electric and fuel-cell vehicles
2 follow correct safety procedure requirements when working on hybrid, all-electric and fuel-cell vehicles
3 explain terms and procedures relevant to carrying out inspection, servicing and repair tasks on hybrid, all-electric and fuel-cell vehic les
4 accurately inspect, document and interpret results relating to hybrid, all-electric and fuel-cell vehicles
5 service (and diagnose faults in) a range of hybrid, all-electric and fuel-cell vehicles
6 work in accordance with workplace and manufacturer requirements and specifications.

A motor vehicle that combines two or more power sources that directly or indirectly drive it is called a hybrid. Most are petrol-electric hybrids, but there are also diesel-electric hybrids. Some vehicles have an all-electric drive system; fuel-cell drives are new and still evolving.

All of these types of vehicle are good for the environment because they use less fuel and produce fewer emissions. They achieve these benefits as a result of highly technical control systems, as well as engine operation that is assisted by different transmissions and regenerative braking.

47.1 Identifying hybrid and all-electric vehicles

Hybrid and all-electric vehicles (HEVs) usually have some visual identifying features. These may be external, internal and/or in the engine compartment. Figure 47.1 shows the exterior of one hybrid vehicle, with Figure 47.2 showing its engine compartment.

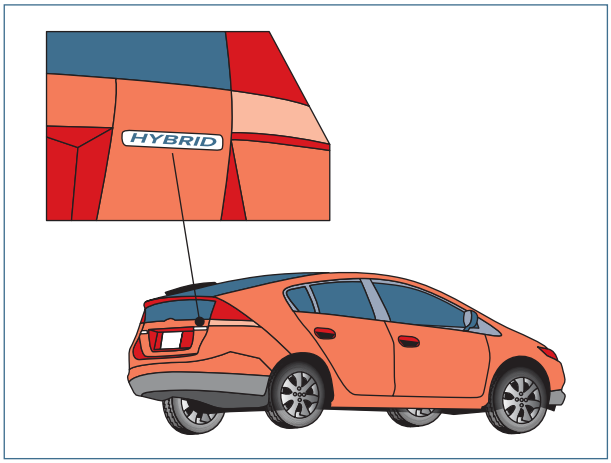


Figure 47.1 Hybrid exterior identification

Figure 47.2 Hybrid engine bay

The following are identifying features of hybrids:

- hybrid badges
- distinctive body shape
- specific instruments and controls
- distinctive gear levers
- decals in the engine compartment
- components in the engine compartment
- engine compartment arrangement
- number-plate stick er decals.

47.2 Hybrid vehicle arrangement

Figure 47.3 shows the basic arrangement of a hybrid vehicle with front-wheel drive. The hybrid parts of the diagram are noted below.

47.2.1 Petrol or diesel engine

This is a conventional passenger vehicle engine, either petrol or diesel. As fuel economy is the main reason for having a hybrid, the engine is usually of smaller capacity than one in a similar, non-hybrid vehicle. It has the usual systems needed for an internal combustion engine, such as the fuel, exhaust, cooling and electrical systems.

47.2.2 Electric motor assembly

Used in conjunction with the engine, the electric motor assembly provides the electric drive for the vehicle and also recharges the hybrid battery. Power is provided by a high-voltage battery and a generator.

47.2.3 Hybrid battery

Located at the rear of the vehicle, the hybrid's high-voltage battery is recharged by a generator which is part of the electric motor assembly, and also by the regenerative effect that occurs during deceleration and braking. There is no provision for externally recharging the battery.

47.2.4 Hybrid transaxle assembly

The hybrid transaxle assembly is functionally similar to a non-hybrid vehicle transmission. Some hybrids have a conventional transmission, others a continuously variable transmission (CVT). As well as providing the normal transmission functions, the assembly has a power-splitting arrangement that allows the vehicle to be driven by the engine, the electric motor or a combination of both.

47.2.5 Power cables

Special power cables connect the high-voltage battery to the electric motor assembly.

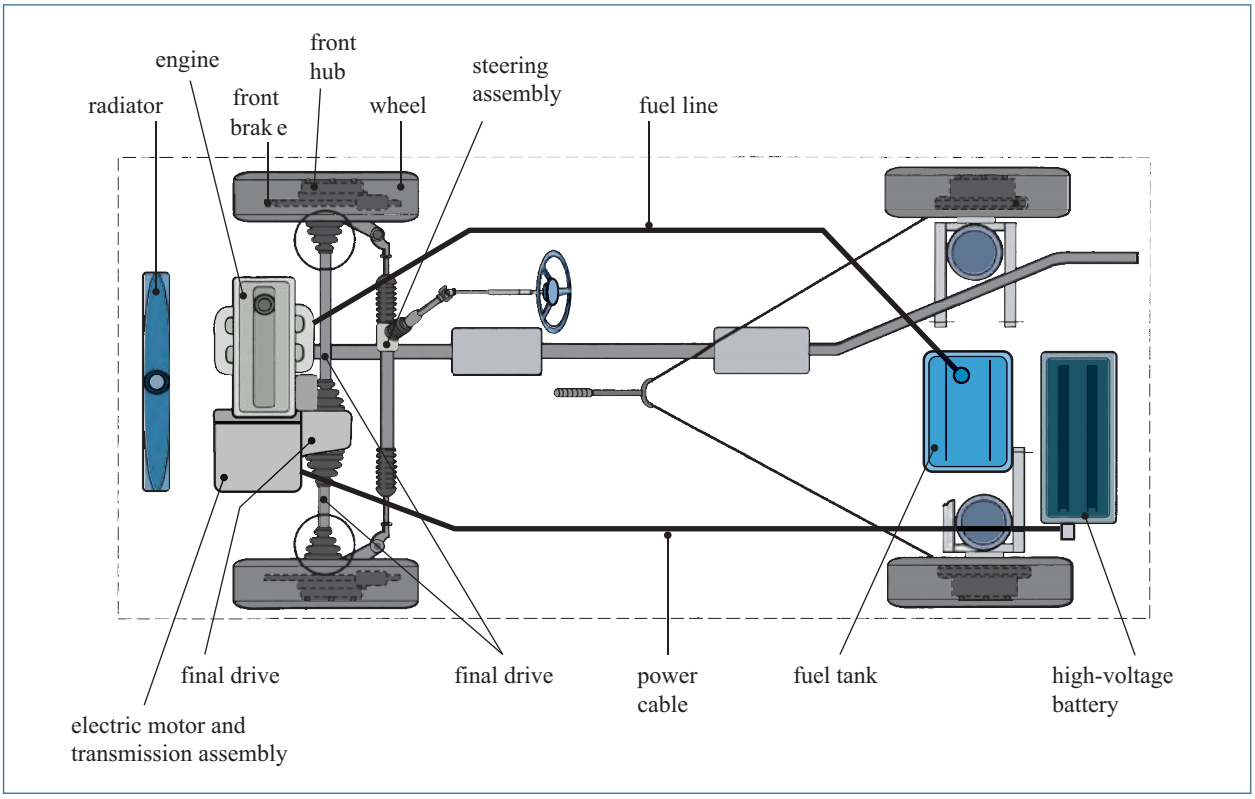


Figure 47.3 Skeletal arrangement of a hybrid-powered vehicle

47.2.6 Other hybrid components

In addition to the basic components shown in the illustration, there are a number of other main components in a hybrid system. These are noted below.

Electric-motor/altern ator

The electric motor assembly of a hybrid vehicle, with its motor/alternator arrangement, has very sophisticated components with advanced electronic controls. It acts as a motor to drive the vehicle and as an alternator to charge the batteries.

Handy hint: Where the term 'generator' is used in this chapter , it relates to an AC generator or alternator . Where appropriate , the term 'alternator' has been used on its own.

Inverter

The electric inverter, located above the transaxle, is used to convert DC to AC and AC to DC between the main electric motor, the recharge motor and the high-voltage battery. These conversions are made to suit the battery (which can only provide or receive DC) and the electric motors (which operate only on AC).

The underside of the inverter is a DC converter. It is used to transform (reduce) the high-voltage battery output, which can be in excess of 270 volts DC, to 12 volts DC. This 12-volt system is then used to recharge the 12-volt auxiliary battery, which can be located in the boot or the engine compartment. These vehicles have standard 12-volt electrical systems.

Usually, an electric pump circulates coolant from a dedicated radiator for the inverter and the electric motors when the ignition is switched on.

Power-split device

The power-split device is a gearing arrangement located inside the transaxle. Its main function is to split the drive between petrol-engine operation and the main electric motor.

Drive gears/tr ansmission

The transmission on a hybrid vehicle is functionally similar to that on a standard vehicle. Some hybrids use conventional transmissions, but most use a continuously variable transmission (CVT). This type of transmission is covered in the four earlier chapters on automatic transmission (Chapters 27–30).

47.2.7 RESS batteries in hybrid vehicles

Two types of high-voltage rechargeable energy storage system (RESS) batteries (Figure 47.4) are used in hybrid vehicles:

- NiMH (nickel-metal hydride) batteries
- lithium-ion batteries.

These are located at the rear of the vehicle, in the boot area (Figure 47.5), behind the rear seat under the floor pan.

Figure 47.4 High-voltage battery pack (RESS)

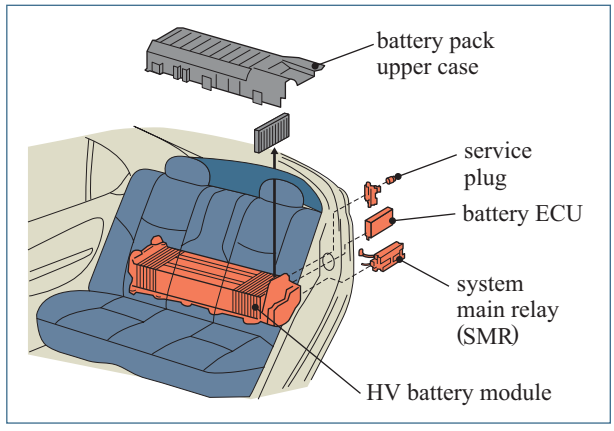


Figure 47.5 Location of HV high-voltage battery pack

47.3 Hybrid system designs

There are three main variations of hybrid drive systems.

47.3.1 Series

Mechanical output of the engine is used to generate electrical power with an alternator that charges the battery system or provides power for the electric motor. The engine does not directly propel the vehicle.

47.3.2 Parallel

The mechanical output of the engine is transmitted to propel the vehicle through a splitter device, generally using a continuously variable transmission. The electric motor is also linked directly into a splitter device, and is continuously used in parallel with the engine.

47.3.3 Series-parallel

This is a combination of series and parallel designs. The engine can directly propel the vehicle through the splitter device and also power an electrical motor/alternator that recharges the batteries. The batteries provide power to the electric motor which can also directly propel the vehicle through the splitter device.

47.4 Hybrid drive system

Figure 47.6 shows a parallel hybrid drive (this is a power-split type of hybrid). It has two driving sources—the petrol engine and the main electric motor. These are used separately or in combination, depending on the driving conditions. It also has a recharge motor (alternator). All three components form an assembly and are connected to the power splitter, which then connects to the driving gears and the rear wheels. The components in the illustration operate as follows:

1 The petrol engine (internal combustion engine, or ICE) provides drive for most driving conditions, except when the vehicle is starting from rest or driving at low speeds. It is connected to the power splitter and then to the drive gears and wheels.
2 The electric motor draws power from a high-voltage battery pack and drives the vehicle. This AC motor is the source of power when starting the vehicle from rest and under light driving conditions.
3 The recharge motor is an alternator that is driven by the engine. It provides electrical power that recharges the hybrid battery. It also provides power during regenerative braking.
4 The inverter changes direct current (DC) from the battery to alternating current (AC) for the electric motor. It also changes AC from the recharge motor (alternator) to DC to charge the battery. It also increases or decreases voltage.
5 The power splitter, which is part of the transmission, is a mechanical device that enables power from the engine and/or the electric motor to drive the vehicle.

47.4.1 Hybrid system operation

Figures 47.6 to 47.9 show the power flow in a hybrid system for different conditions of operation.

Standing start and low load

Figure 47.6 shows the power flow for starting the vehicle moving, for low loads and for driving at low speeds. The electric motor is the only available source of power when the vehicle is stationary. It is used during light acceleration, in slow-moving traffic, at low road speeds and during deceleration. Under these conditions, the engine is relatively inefficient and is automatically switched off so that there is no fuel consumption and no exhaust emission.

Normal driving

For normal driving conditions (Figure 47.7), the engine is generally used on its own, but the electric motor is also used whenever extra power is required. When the engine is in operation, its power output can be used to drive the wheels and charge the hybrid battery. The control system will run the engine more

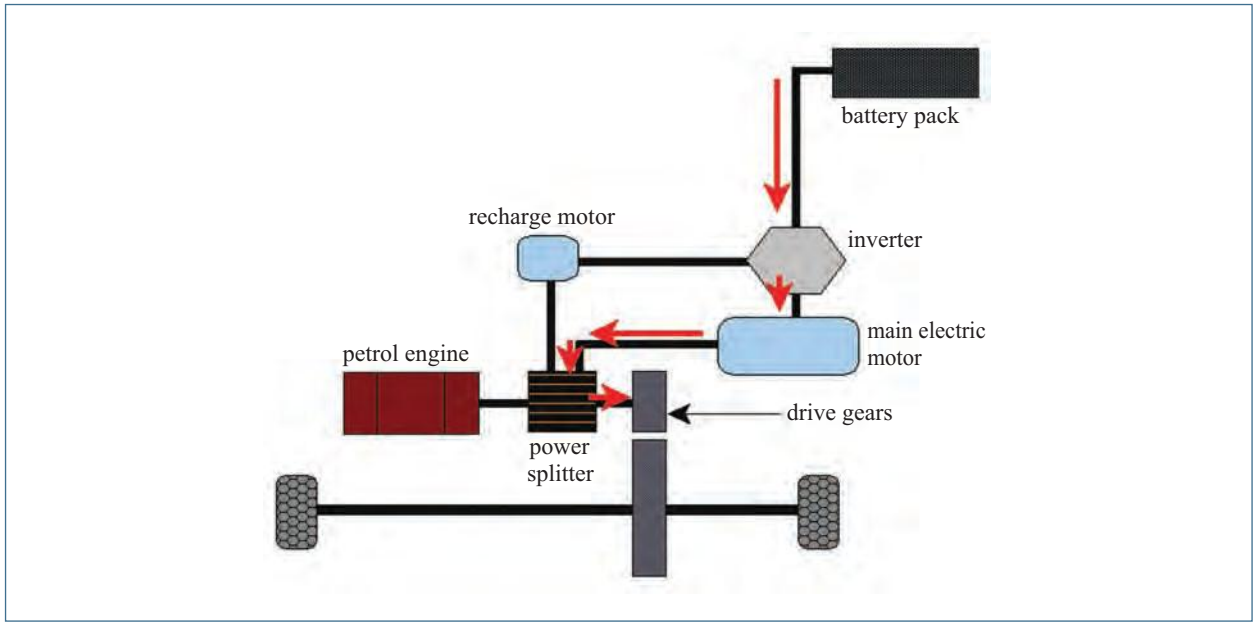


Figure 47.6 Standing start and low load—electric motor only

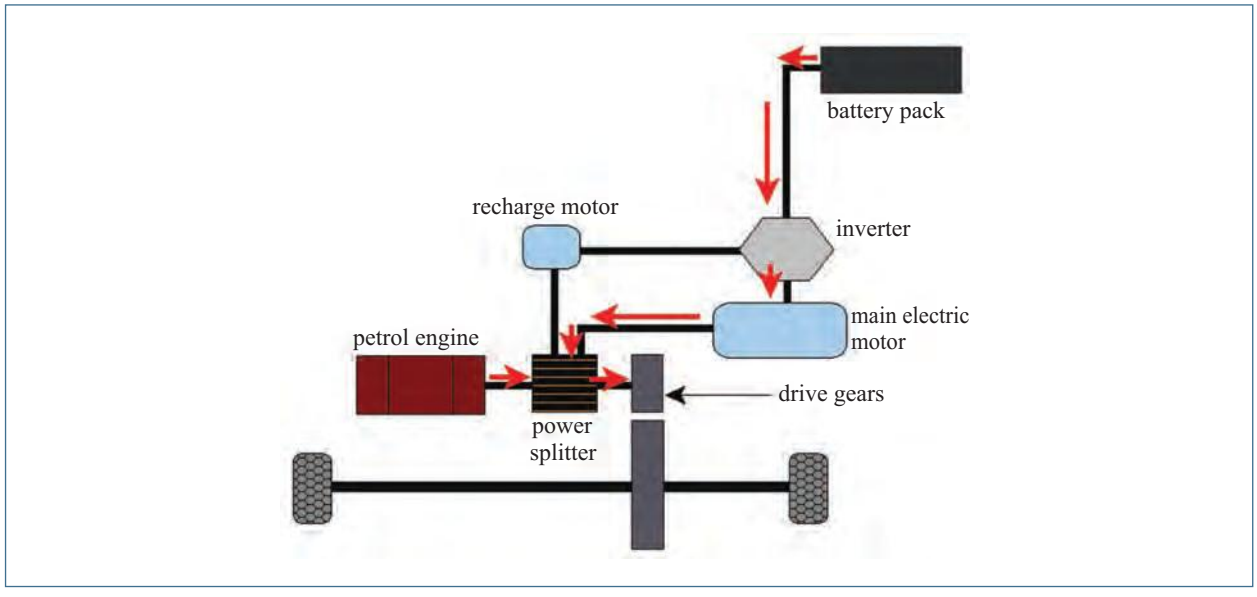


Figure 47.7 Normal driving—petrol engine and/or electric motor , depending on conditions

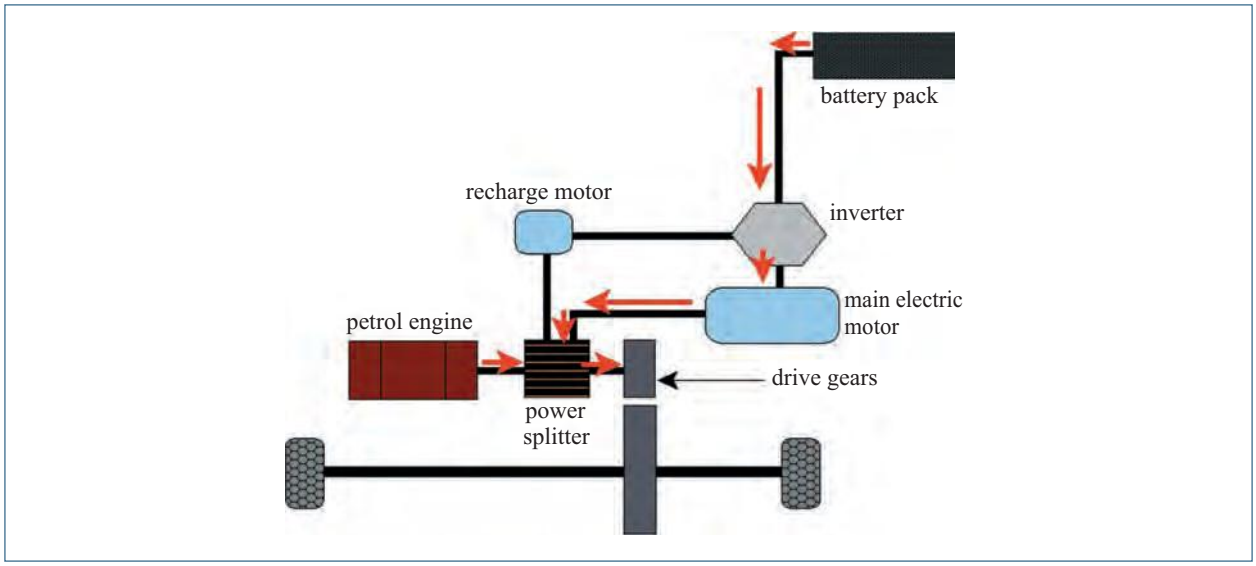


Figure 47.8 Acceleration and power—petrol engine and electric motor

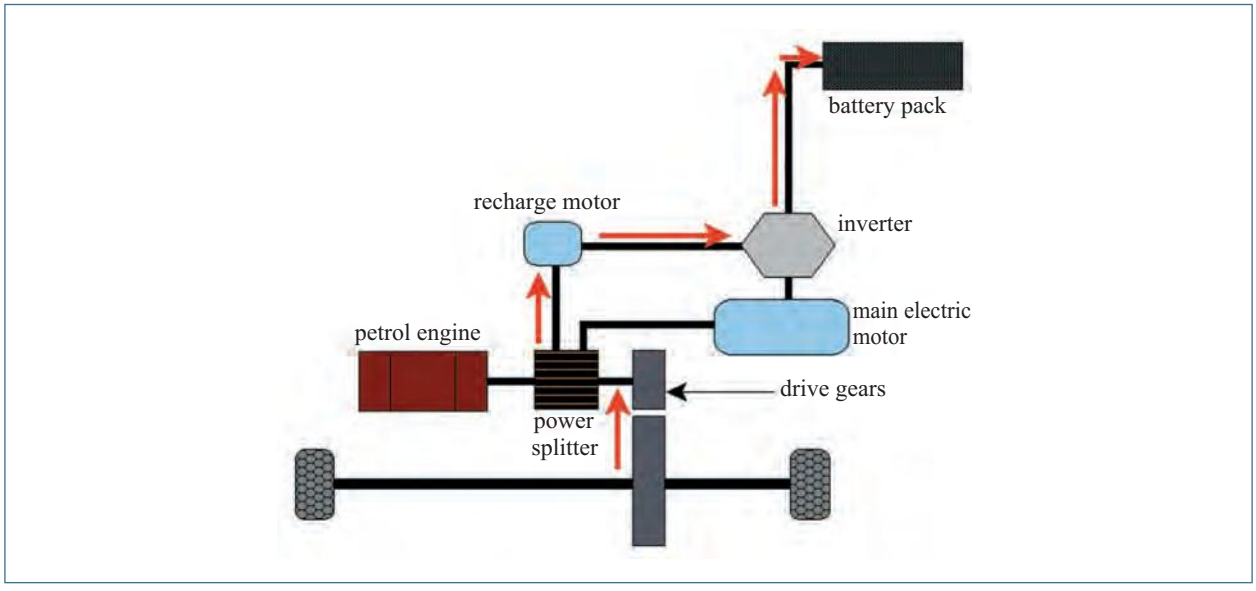


Figure 47.9 Deceleration and braking—recharge motor

frequently if the battery charge is low. In this situation, some of the engine's power is used for drive and some for charging the battery.

Acceleration and power

Figure 47.8 shows the power flow for acceleration or power, where the engine and the electric motor combine to provide power to the driving wheels. The power flow is the same as for normal driving but increased output can be obtained from both the engine and the electric motor. For maximum power, the electrical energy stored in the hybrid battery and that produced by the recharge motor are used by the electric motor.

Deceleration and braking

During deceleration and braking, the power flow to the wheels is actually reversed (Figure 47.9), with the vehicle driving the electric motor. The kinetic energy of the moving vehicle charges the hybrid battery.

The electric motor acts as a motor when driving the vehicle and as a generator (alternator) during deceleration and braking. This is referred to as *regenerative braking*. It not only provides a load to slow the vehicle but charges the battery at the same time.

There are two advantages with a regenerative braking system: reduced brake wear and elimination of the need for battery charging from an external source. A small percentage of the engine's output is also used to charge the battery cells under certain conditions.

Handy hint: Kinetic energy is a term for the energy possessed by a body in motion—in this case , **the vehicle**.

47.5 Continuously variable transmission

One design of front-wheel-drive transaxle, which was purpose-developed to suit hybrids, has two permanent-magnet AC electric motors (generators), MG1 and MG2 ('MG' refers to motor/generator). MG1 is used to recharge the hybrid vehicle battery and supply the electrical power directly to drive MG2.

By regulating the amount of electrical power generated, MG1 also controls the continuously variable function of the transmission.

MG2 motor's primary role is to drive the wheels of the vehicle. Its maximum power output is 33 kW from between 1040 and 5600 rpm, while torque is 350 Nm between 0 and 400 rpm. At maximum torque, the motor draws 351 amperes.

When the regenerative braking system is activated, MG2 also converts the vehicle's kinetic energy into electrical energy to charge the high-voltage battery. The power-splitting device inside the transaxle is used to switch the petrol engine operation to MG2 assistance. This charges the high-voltage battery and generates power for driving MG2.

47.6 Range extender electric vehicle systems

Some electric vehicle systems can be compared to the series-hybrid system, in that they have a petrol engine. The petrol engine does not drive the wheels; it drives a generator to charge the system and batteries. All-electric vehicles, which do not use an engine for drive, can be plugged into an external charging station or charging unit when the batteries need charging.

47.6.1 Hybrid electric system

These are commonly called extended-range electric vehicles (EREVs). The components are shown in Figure 47.10. This system uses the stored energy in the high-voltage battery and an electric motor to propel the vehicle. The vehicle has a petrol engine which can be used to recharge the battery to extend the travel distance beyond the battery-only distance. However, the petrol engine is not used to propel the vehicle.

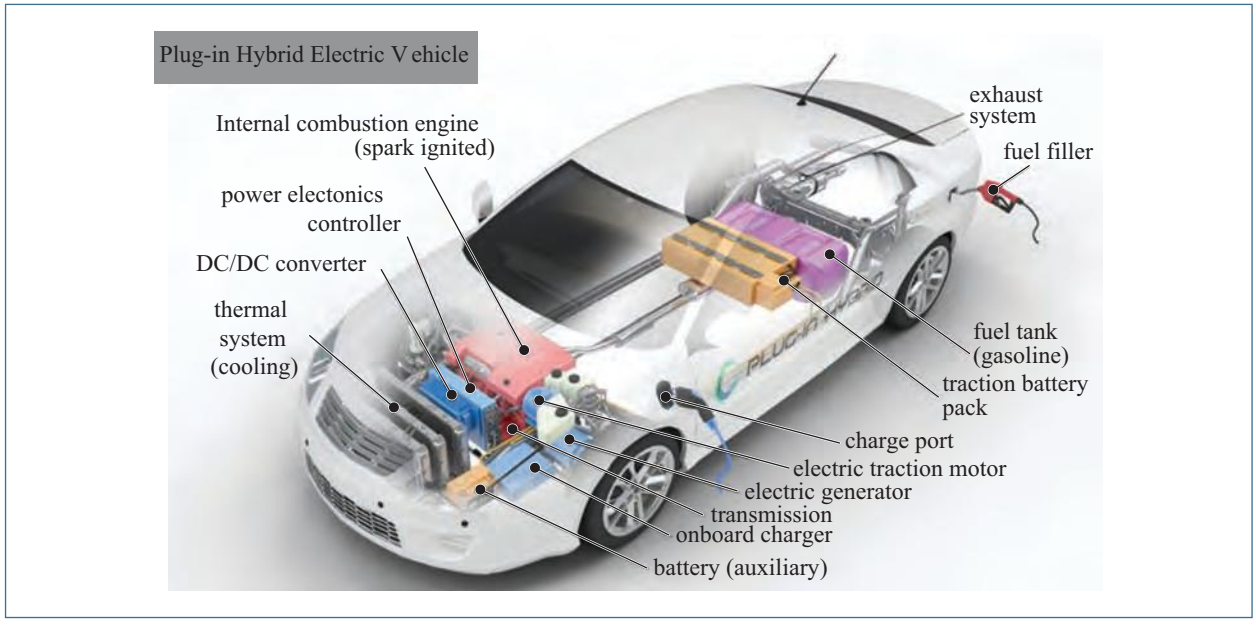


Figure 47.10 Hybrid electric system components and operation ALTERNATIVE FUELS DATA CENTRE

The system can operate and propel the vehicle for approximately 64 km. When the battery reaches a low charge, the system will start the petrol engine to drive the generator to propel the vehicle, still using electrical power. This is referred to as the 'extended range' mode.

Figure 47.11 Electrolyte leaking from RESS battery, causing corrosion ART'S AUTOMOTIVE, C.A.

47.6.2 Rechargeable energy storage systems

RESS battery construction

RESS high-voltage NiMH (nickel metal hydride) battery systems can vary by make and model, and range between 200 and 600 volts DC. They are comprised of multiple low-voltage NiMH battery modules (7.2, 9.6 or 14.4 V) connected in series by a bus bar. There are 38 modules of six NiMH cells each (some models have eight). Each module has a voltage of between 6.5 and 8 V, depending on the state of charge (SOC). The NiMH battery electrolyte contains an alkaline solution of potassium hydroxide. The battery electrolyte is absorbed in the cell plates and will not normally leak out if the module if damaged or cracked.

RESS high-voltage lithium-ion battery packs weigh less than NiMH types and consist of multiple linked modules, each containing around 200 battery cells and supplying up to approximately 360 V DC. The location of the high-voltage battery pack can vary by vehicle make and model.

RESS battery issues

Terminal corrosion can occur on the RESS high-voltage battery cell connections, resulting in high resistance and battery problems. This corrosion can be caused by electrolyte leaking from the battery (due to overcharging) onto terminals (Figure 47.11), as well as by moisture and climate factors which must be checked and, if necessary, rectified at set times.

Using a diagnostic scan tool and looking at the RESS high-voltage battery live data elicits valuable information, including the SOC of the battery.

Safety: Only people with appropriate training should work on the internals of a RESS **high-voltage battery**.

Safety with RESS batteries

Potential RESS battery hazards can be classified as chemical, electrical, high-voltage and those relating to fire or explosion.

Safety: Wear proper PPE such as gloves and safety glasses when working with RESS, and refer to MDS information. If fire occurs, follow correct safety produces and alert the Fire Brigade via 000.

Sustainability: Non-renewable resources in hybrid HV batteries should be retained and recycled to avoid environmental damage .

47.6.3 Low-voltage battery

Also known as the absorbent glass mat lead-acid (12-volt) battery, this is generally located in the rear compartment under the floor. It supplies low voltage to modules that control the high-voltage battery systems and the vehicle's normal low-voltage systems.

47.6.4 Power inverter module

Mounted on top of the transmission on the driver's side of the engine compartment, the module converts the direct current from the high-voltage battery into three-phase alternating current. The three-phase supply is used by high-voltage three-phase motors in the transmission to propel the vehicle.

47.6.5 Accessory power module

Located in the rear compartment under the floor, this module effectively replaces the 12-volt belt-driven alternator of a conventional vehicle. It converts the voltage of the high-voltage battery into the low-voltage DC needed for the vehicle's normal 12-volt electrical systems.

47.6.6 High-voltage battery charger

This particular vehicle system has an on-board charging system that recharges the high-voltage battery. The charger is located behind the passenger front bumper and headlamp assembly. A vehicle charge port provides the interface connection.

47.6.7 Petrol engine

The 1.4-litre petrol engine rotates the drive-motor/generator to allow charging of the high-voltage battery, which increases driving distances. The engine is not used to propel the vehicle.

47.6.8 Transmission

This is fully automatic and electronically controlled. It also has two electric motors/generators that are used to propel the vehicle, generate and receive energy and start the petrol engine when required.

47.7 All-electric system

Figure 47.12 shows the arrangement of a system of the all-electric system. The vehicle has a standard 12-volt battery for the normal vehicle electrical systems, and a high-voltage lithium-ion battery to power the traction motor that propels the vehicle. It has no charging system of its own and an external power supply is needed to charge the battery (there is some additional charging through the regenerative charging system).

47.7.1 RESS high voltage battery

This system consists of many internal components to control the battery energy to propel the vehicle. The battery is a lithium-ion battery pack that weighs around 275 kg. Located under the vehicle, its multiple-linked modules supply up to approximately 400 volts DC.

47.7.2 Power distribution module

Located in the engine compartment, the power distribution module (PDM) includes an on-board charger, a DC converter and a high-voltage junction box. The on-board charger is used to increase the voltage of a normal household power outlet and convert it to supply DC for charging the high-voltage lithium-ion battery.

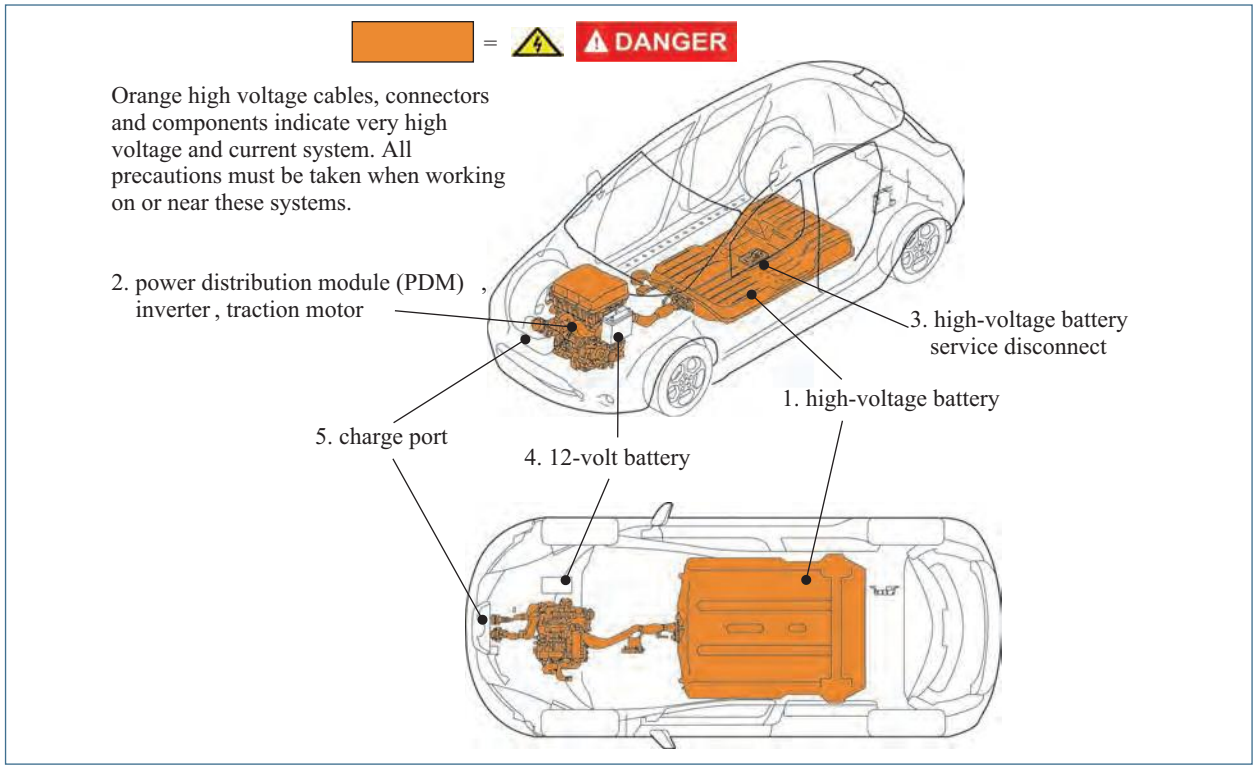


Figure 47.12 All-electric system components and operation

The DC converter also reduces the voltage of the lithium-ion battery to a lower voltage to power the 12-volt battery that is used by all the vehicle's low-voltage electric systems.

The high-voltage junction box distributes electric power from the lithium-ion battery to all high-voltage systems and their components.

47.7.3 Traction motor and inverter

The traction motor is in the engine compartment. It is a three-phase AC motor that propels the vehicle. It contains the inverter, which converts the high-voltage DC from the lithium-ion battery to three-phase AC for the traction motor. It controls the motor torque by regulating the current supply.

47.7.4 High-voltage battery service disconnect

This arrangement, shown in Figure 47.13, allows the high-voltage system to be completely isolated from the battery.

47.7.5 12-volt battery

The 12-volt battery is used for the normal operation of the vehicle's low-voltage electric components, such as controls, lighting, heating, cooling safety and security.

47.7.6 Charge port

This is the connecting port for the electric vehicle supply equipment (EVSE), and is located at the front of the vehicle (Figure 47.14). There are two connectors: one for normal charge and one for quick charge.

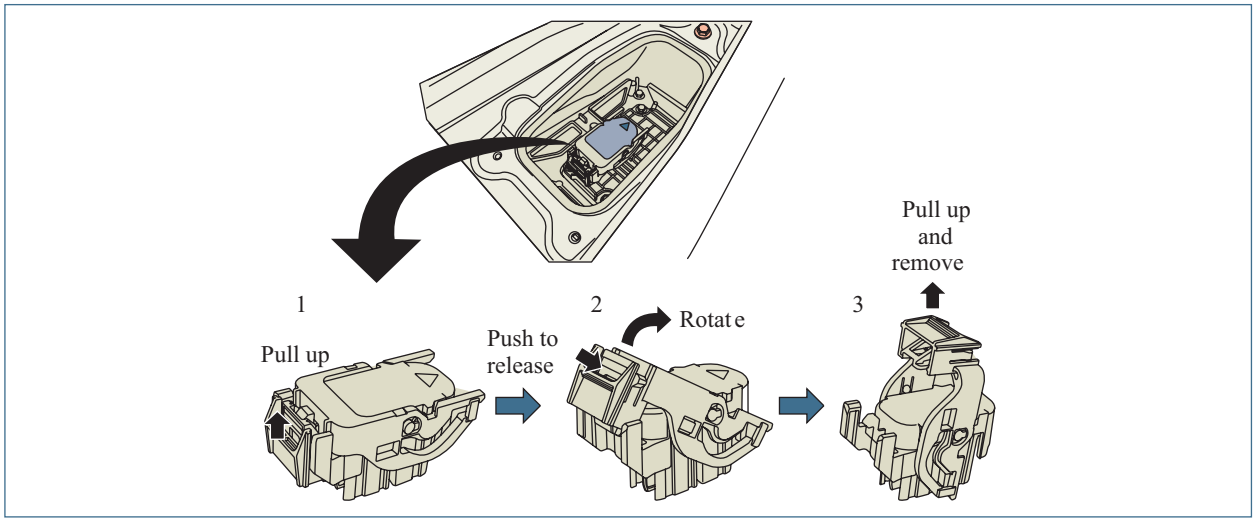


Figure 47.13 High-voltage battery service disconnect

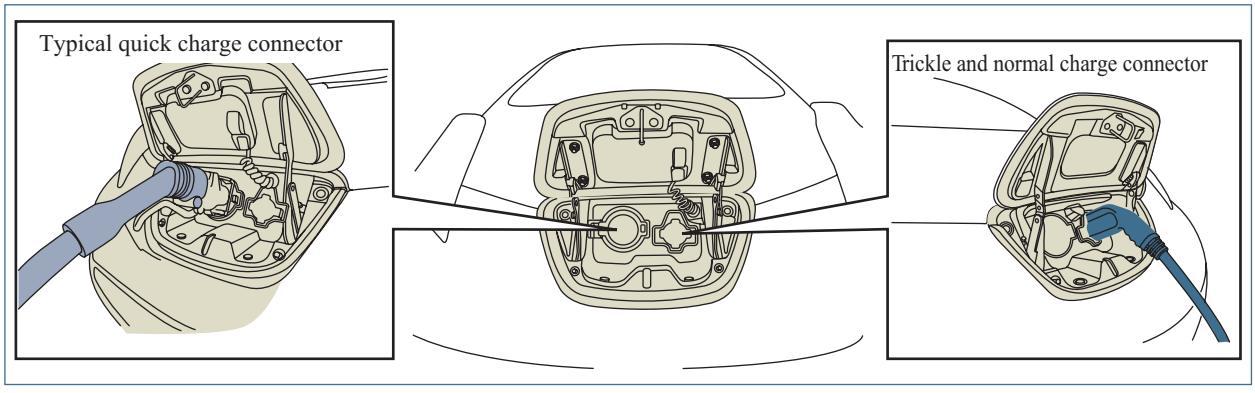


Figure 47.14 Charge port

47.7.7 High-voltage cables, connectors and components

Located in the engine compartment and also under the vehicle, these are coloured orange to show that they are high-voltage cables and that they carry high currents. All relevant precautions must be taken when working on or near these systems.

47.8 Hybrid and electric system safety

Hybrid/electric vehicles (HEVs) have different safety concerns from those of conventional petrol and diesel vehicles, mainly because of the high-voltage system (which can range from 200 to 650 volts). All high-voltage wiring is coloured orange, as shown in Figure 47.15.

Many hybrid and electric vehicle manufacturers have produced emergency response guides (ERGs). Although the following information can generally be applied to any hybrid or electric vehicle, detailed information for specific vehicles should be obtained from the particular manufacturer.

Safety: HEVs have high-voltage systems and present a potential for high-voltage electrical shock hazard, which can prove fatal. Always wear appropriate PPE, including high-voltage safety gloves, which must be tested before each use . Remove all metallic jewellery and follow high-voltage system procedures, as per manufacturers ' instructions.

47.8.1 Running silent

When the vehicle is stopped, the engine and electric motor are switched off, allowing it to *run* silently; however, the vehicle remains *on* and operational.

47.8.2 Vehicle ready and operating

HEVs use a *ready* indicator light that is illuminated when the vehicle is *on* and operational. When it is on and the wheels are stopped, the fuel engine and/or electric motor may be off, allowing the vehicle to run silently.

47.8.3 Operational status

The engine may stop and start at any time while the vehicle is on and the ready indicator is illuminated. Never assume that the vehicle is shut off just because the engine is *off* and the vehicle is silent. Always check the illuminated *ready* indicator.

47.8.4 Starting and shutting down procedure

Some vehicles have conventional key-operated systems, while others have *smart-key* systems. These arrangements are shown in Figure 47.16, with a conventional key at the top of the illustration and a smart key on the left.

Handy hint: The starting and shutting-down procedures of the two systems differ. The smart key procedure is shown in the illustration; a conventional k ey is used in the normal way .

47.9 High-voltage safety cables and connectors

All high-voltage power cables and connectors are colour-coded bright orange. The power cables and connectors are insulated to prevent contact with the bare wire conductor. Figure 47.17 shows the different arrangements for low- and high-voltage systems.

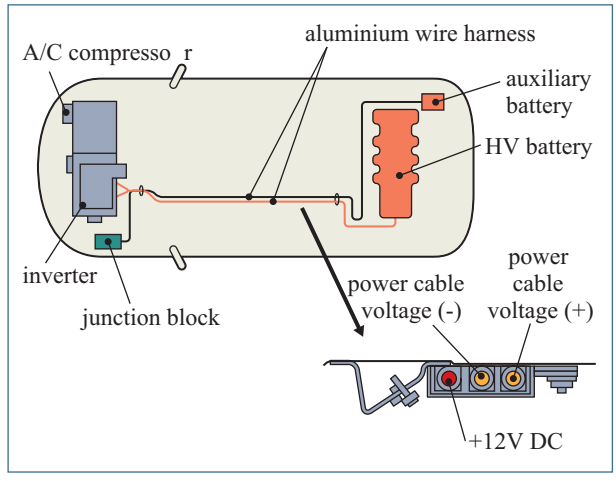


Figure 47.15 Hybrid system high-voltage orange wiring

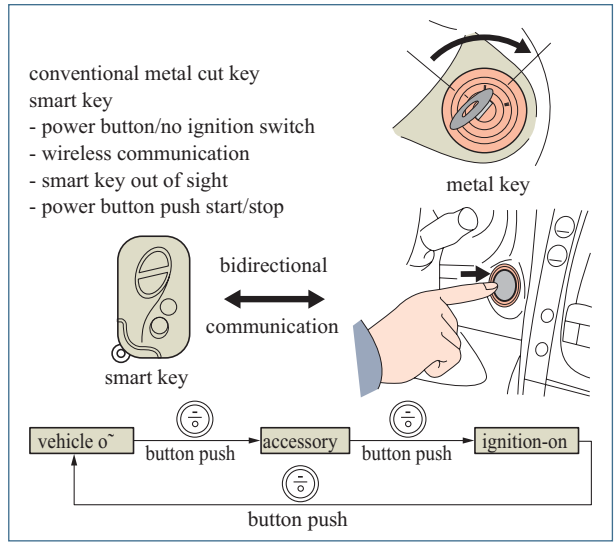


Figure 47.16 Starting and shutting-down procedures

The 12-volt low-voltage circuit uses the vehicle metal body as a ground. The high-voltage circuit has a separate ground cable connected between the battery and the component (which are both insulated from the vehicle metal body).

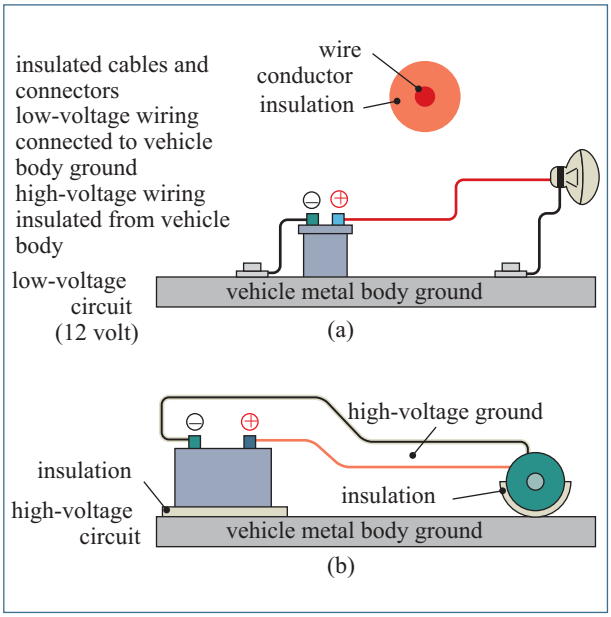


Figure 47.17 High-voltage safety (a) low-voltage circuit (b) high-voltage circuit

47.9.1 Hybrid vehicle high-voltage circuit

Figure 47.18 is a diagram of a hybrid's high-voltage circuit showing the safety-related components. The high-voltage battery pack is shown on the right of the diagram as a lightly-shaded box. It contains the individual low-voltage cells that are connected in series to produce high voltage. High-voltage orange power cables are routed underneath the vehicle to the inverter/converter in the engine compartment.

Inside the high-voltage battery pack is a fuse; there are also relays (green boxes) on the positive and negative battery terminals. These relays are normally open and operate on 12-volt battery power. They are switched by the ignition switch or the power button and the hybrid computer (blue-shaded boxes).

The circuit operation is outlined under the following headings.

Vehicle off

With the ignition switch or power button turned *off*, the 12-volt battery power is not supplied to the hybrid computer, which keeps the high-voltage battery pack positive and negative relays open (green boxes). The high-voltage circuit is *off*, and no electricity flows from the high-voltage battery pack to the orange power cables.

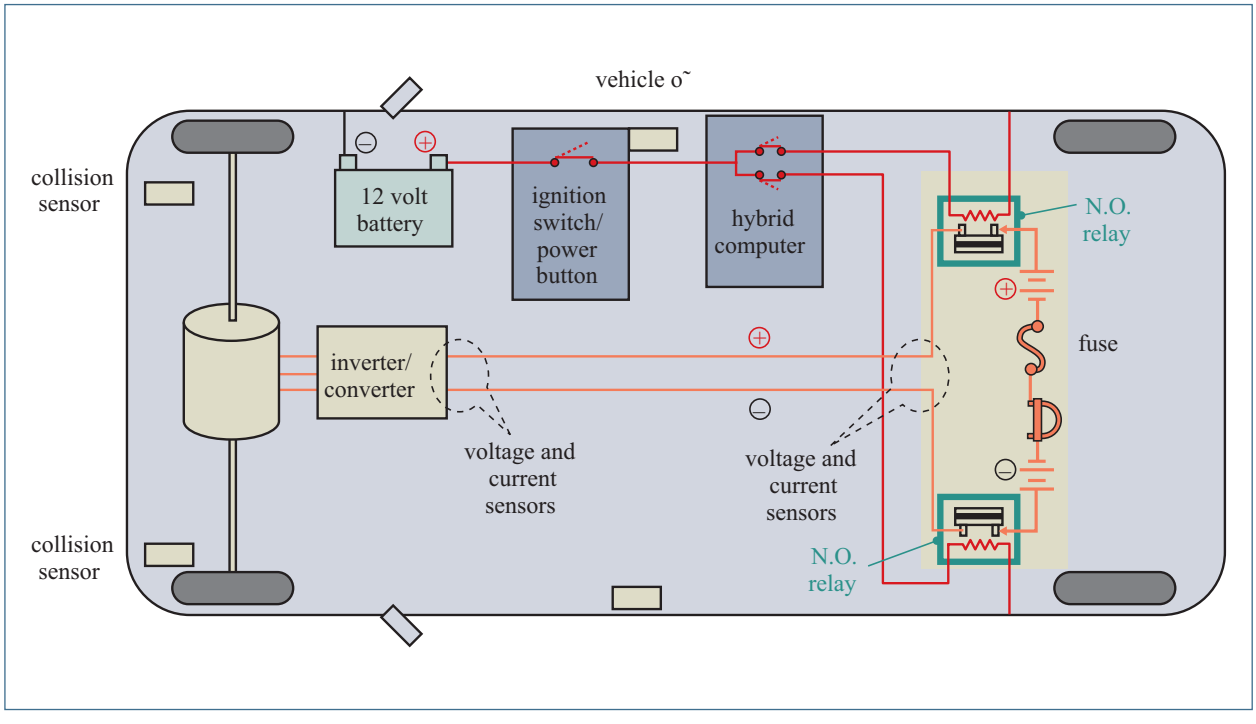


Figure 47.18 High-voltage circuit

Vehicle on

With the ignition switch/power button turned *on,* 12-volt battery power (red lines) is supplied to the hybrid computer. The hybrid computer powers the high-voltage battery pack positive and negative relays (green boxes), which will allow them to close (orange contacts). Once the relays close, the high-voltage circuit is *on* and electricity flows from the high-voltage battery pack to the power cables (orange solid lines).

Manual protection

Turning the ignition switch or power button off manually disables the high-voltage system.

Automatic protection

The hybrid computer provides automatic disabling of the high-voltage system.

SRS collision sensors (yellow-shaded boxes) and high-voltage current/voltage sensors (black-dashed callouts) are monitored by the hybrid computer. When airbags deploy or a current/voltage imbalance is detected, the hybrid computer automatically opens the positive and negative relays to stop electrical flow from the high-voltage battery pack to the power cables.

A fuse in the high-voltage battery pack also provides automatic high-voltage disabling during an overload condition.

47.10 Safety procedures

Incorrectly performed system repairs could cause electrical shock, battery leakage or even an explosion. Always perform the following safety procedures when servicing the hybrid vehicle's high-voltage system or hybrid control system:

1. Follow the relevant vehicle manufacturer' s approved high-voltage system shut-down procedures.
2. Use only approved A S 2225 rubber or synthetic rubber insulating gloves, rated for 1000 V A C (Class 0), that are tested and free of faults. Safety glasses and/or an Arc-rated face shield should be worn.
3. Work on an approved HEV mat.
4. Refer to A ustralian S tandards A S 5732:2015, Electric vehicle operations—Maintenance and repair . These are available at https://infostore .saiglobal. com/store/details.asp x?ProductID =1814257

47.10.1 Jump starting

If the vehicle does not start and the ready indicator remains off, the vehicle may be jump-started just like a conventional vehicle, provided that all the usual precautions are taken. Connect a booster battery to the 12-volt auxiliary battery. Check the battery label under the bonnet for the location of the 12-volt auxiliary battery. The vehicle will usually have jumping points in the engine bay.

47.11 Servicing hybrid and electric vehicles

Much of the servicing and repair of HEVs is similar to that of any other vehicle. The engine system has electronic fuel injection, and the transmission is a constant variable type. The general mechanical systems such as brakes, steering and suspension are all fairly standard. The only system that may be substantially different is the high-voltage system.

If there are any doubts about vehicle servicing or preparation for repair, always consult the relevant manual and follow the manufacturer's guidelines. Most manufacturers require a double-sided sign to be placed on the top of the vehicle to indicate danger when it is being serviced or repaired (Figure 47.19).

Safety: Always shut off a hybrid vehicle 's high-voltage system before working on or around the engine , battery pack or high-voltage harness.

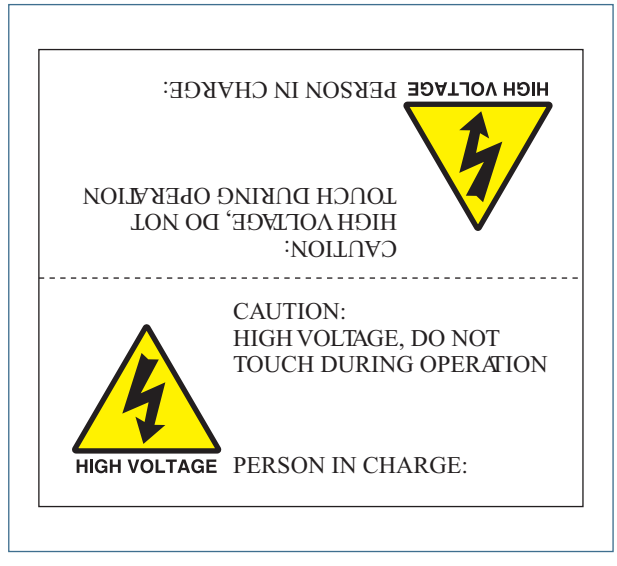


Figure 47.19 Safety sign

47.11.1 High voltage

For safety reasons, all high-voltage terminals are sealed and/or isolated. The high-voltage harness is coloured orange. Do not handle these harnesses without wearing high-voltage approved insulated gloves that are in good condition—even a pinhole can draw current seeking a ground. Never probe the orange harnesses through the insulation—a hole in a high-voltage harness can allow current to migrate.

47.11.2 Shut-off switch

Some vehicles have a shut-off switch on the intelligent power unit (IPU) which contains the battery pack and controls. It may be mounted horizontally in the rear deck area or vertically, behind the rear passenger seat (Figure 47.20). To disarm the high-voltage system on either model, remove the small cover on the IPU and move the switch to the off position. The main fuse can also be removed.

47.11.3 Cooling systems

Hybrid and electric vehicles can have up to three cooling systems: an engine cooling system, an inverter cooling system and a transaxle cooling system.

47.11.4 Malfunction indicator lamps

HEVs have malfunction indicator lamps (MIL) on the instrument panel. Fault codes are used to indicate system or circuit faults. The specific manufacturer's scanning device reads these codes, which are used to diagnose and isolate most problems in hybrid systems.

47.12 Fuel-cell vehicles

A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is an electric vehicle which uses a fuel cell rather than a battery (or in combination with a battery or super capacitor) to power an electric motor. Fuel cells generate electricity using oxygen from the air and compressed hydrogen. Hydrogen is the simplest, lightest and most common of all the elements. It is normally found in conjunction with oxygen as water (H_2O) or with carbon as hydrocarbon (HC). Most fuel cell vehicles are classified as zero-emissions vehicles as they emit only water and heat.

A fuel cell (Figure 47.21) is an electrochemical conversion device that is similar to a storage battery; but it operates very differently. Electric current produced through this conversion process drives the electric motors at the wheels. There is no combustion which means there are no harmful emissions or reliance on fossil fuels.

The fuel cell in Figure 47.22 has in its centre a proton exchange membrane (PEM), coated on either side by a catalyst. The PEM is sandwiched on one side by an anode (positive) electrode and on the other by a cathode (negative) electrode. When hydrogen flows onto the anode, protons are allowed to pass through the membrane while electrons are not. They have to take a different path to get to the other side, producing electric current. A number of fuel cells are put together to form a stack.

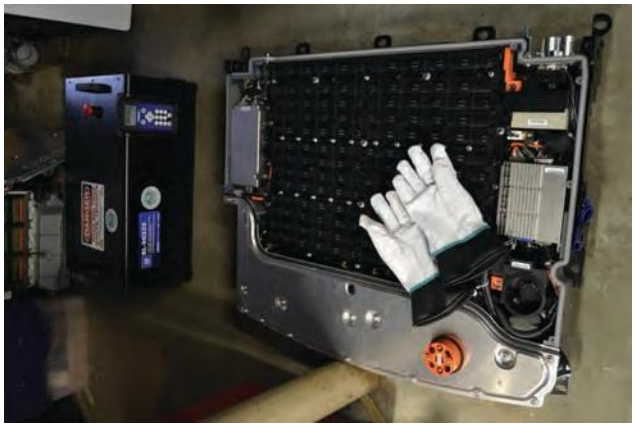


Figure 47.20 High-voltage battery module

Figure 47.21 A fuel cell SHUTTERSTOCK

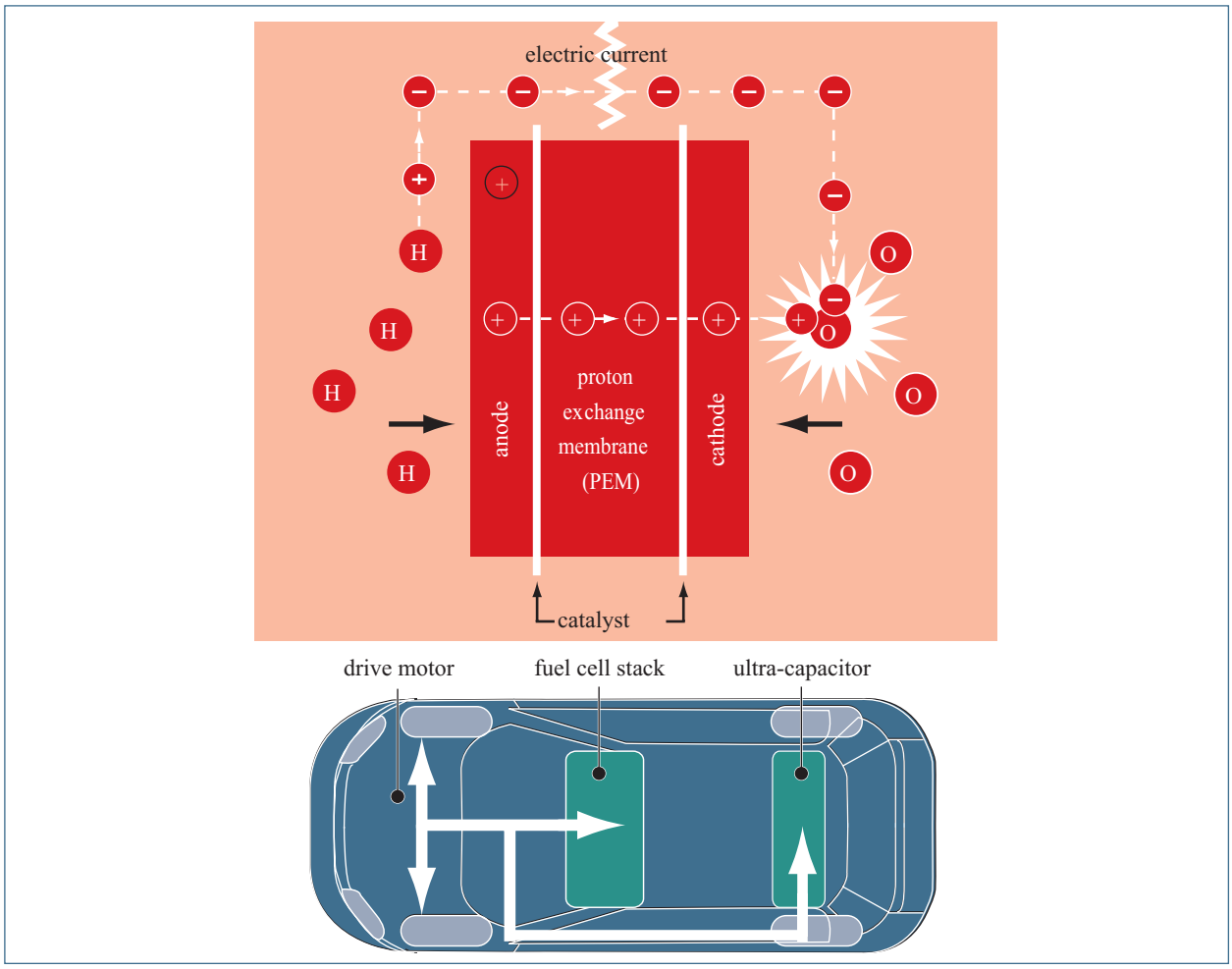


Figure 47.22 A simple illustration of a proton ex change membrane in operation

Battery electric vehicles (BEVs) can be impractical because of their recharging time. Some of the small HEVs suffer from driving range limitations. Fuel cell vehicles provide the same benefits as EVs but with no environmental impact, quiet operation and a range similar to most petrol vehicles (with a faster refuel factor of less than five minutes).

Fuel cell vehicles use hydrogen which is stored in high-pressure tanks and carried to the fuel cell at a reduced pressure. Air is passed through the fuel cell stack via an electrically driven compressor arrangement. By changing the rate of gas flow through the stack, the electrical output of the fuel cell system can be controlled.

Hydrogen-powered vehicles are not that different from electric vehicles. They still have a high-voltage battery pack or an ultra-capacitor to store the energy that comes from the fuel cell.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- identify the various types of hybrid, all-electric, range extender and fuel-cell vehicles
- identify hybrid and electric vehicles from badges, body shape and the engine compartment
- identify hybrid and electric vehicle components
- describe hybrid design systems, including series, parallel and series–parallel systems
- apply safety procedures when working with high-voltage vehicles and RESS battery packs, including the use of appropriate PPE and HEV mats
- apply correct shut-down procedures and checking for residual voltage .

REVIEW QUESTIONS

1 What is meant by hybrid?
2 What is a parallel-hybrid system?
3 How can a hybrid or electric vehicle be identified externally?
4 How can a hybrid or electric vehicle be identified internally?
5 How can a hybrid vehicle be identified by checking in the engine compartment?
6 What is the nominal high voltage produced in a hybrid system?
7 What systems are controlled by the hybrid vehicle's standard voltage system?
8 What is the purpose of the inverter?
9 What is NiMH?
10 What colour is the high-voltage wiring in a hybrid system?
11 Where is the high-voltage battery located in a hybrid or electric vehicle?
12 In a break down situation, what precautions need to be taken with a hybrid vehicle?
13 What are the general safety precautions that need to be taken when working with hybrid vehicles?
14 In a hybrid or electric vehicle, what component would be removed to isolate the high-voltage?
15 Which specialised tools must be used when working on HEVs?

PART 10

Safety , security and convenience

CHAPTER 48

Braking: ABS, traction control and vehicle stability

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify operating principles of light vehicle dynamic co ntrol systems and associated components
2 recall the application, purpose and operation of light vehicle dynamic control systems and associated components
3 apply diagnostic testing procedures for light vehicle dynamic control systems
4 apply repair procedures for light vehicle dynamic control systems
5 apply post-repair testing procedures for light vehicle dynamic control systems.

Anti-lock braking systems (ABS) prevent wheels from locking during heavy braking conditions, reducing the stopping distance and providing safer driving. ABS can also help with steering control when the brak es are applied.

This chapter also includes information about anti-lock braking system developments, such as the traction control system (TCS), electronic brak e-force distribution (EBD) and the electronic stability program (ESP).

48.1 Overview of anti-lock braking systems

An anti-lock braking system controls the hydraulic pressure of all four wheels of a vehicle during sudden braking and braking on slippery or uneven road surfaces. Without ABS, when the brakes are suddenly applied, the wheels can lock and the tyres will skid, causing the vehicle to veer to the side where the tyres have most friction with the road surface.

ABS works by modulating the hydraulic pressure in the brake system. It can hold, decrease or restore brake pressure to provide the most effective braking for the road conditions.

Its operation is similar to a driver pumping the brake pedal so that the brakes are applied and released to prevent skidding; but ABS does this far more effectively than a driver could.

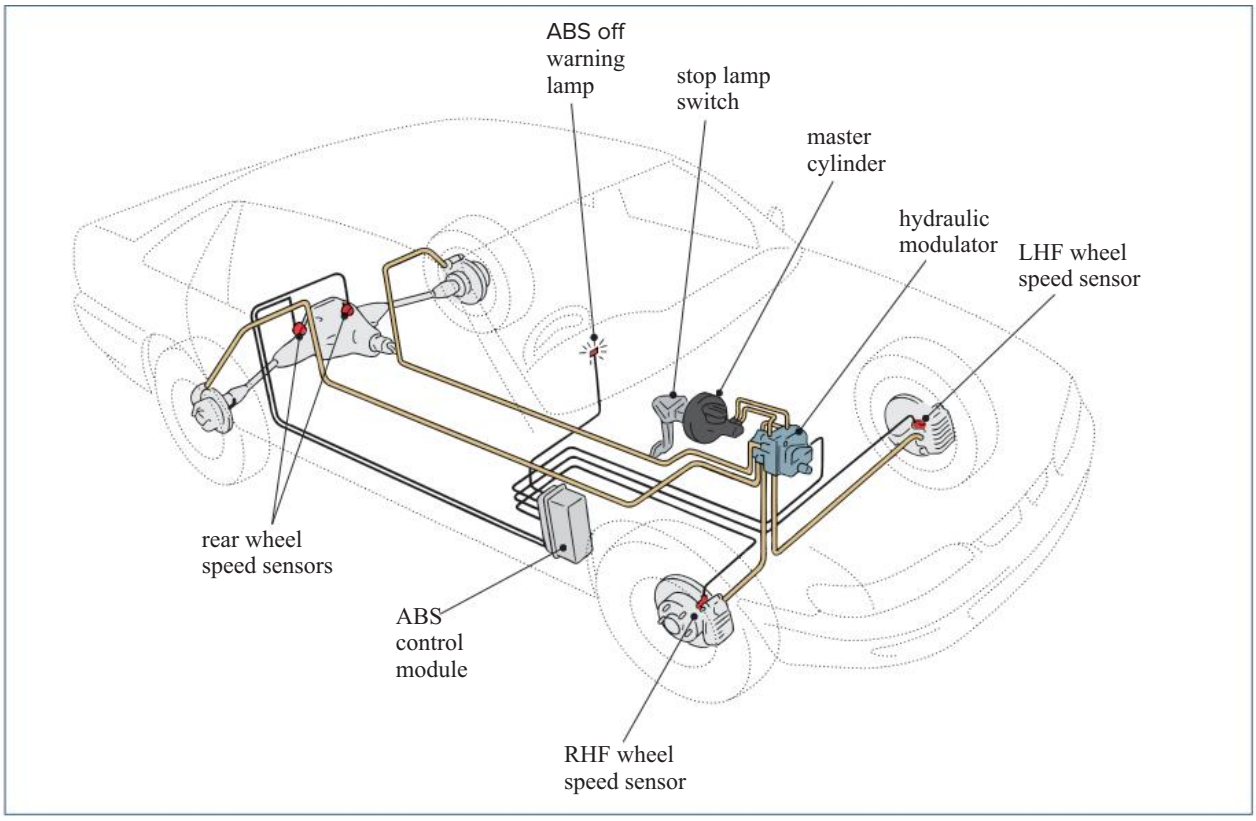


Figure 48.1 ABS with four channels fitted to a rear-wheel-drive vehicle with independent rear suspension GM HOLDEN LTD

ABS and its electronic controls enable traction control (or torque control) to be fitted to a vehicle, using the ABS components in a somewhat opposite way to braking. The brakes are still used but are applied to prevent wheel-spin during acceleration.

Generally speaking, ABS does not reduce the braking distances. In fact, in some circumstances it is possible for braking distances to be increased.

48.2 Main system components

The location of the main parts of an anti-lock braking system are shown in Figure 48.1. The master-cylinder assembly and the disc-brake assemblies at the wheels are normal brake-system components. The ABS parts of the system are:

- a hydraulic control unit (HCU) (or hydraulic modulator).
- an electronic control unit (ECU)
- speed sensors at the wheels
- an electrical circuit.

A separate electronic control unit is shown in the illustration, but many systems have the ECU combined with the hydraulic control unit. This forms a hydraulic-electric control unit, sometimes referred to as an HECU.

The main components of an anti-lock braking system are shown in Figure 48.2. These are the hydraulic control unit and the electronic control unit, the master cylinder, brake lines and the wheel-speed sensors.

48.2.1 Hydraulic control unit

The hydraulic control unit (HCU) is mounted in the engine compartment, adjacent to the master cylinder (Figure 48.2(a)). It has two hydraulic lines that connect it to the master cylinder and, being a four-channel system, there are four hydraulic lines that connect it to the calipers of the brake assemblies.

The HCU contains the solenoid valves, hydraulic pumps, non-return valves, accumulators and connecting passages.

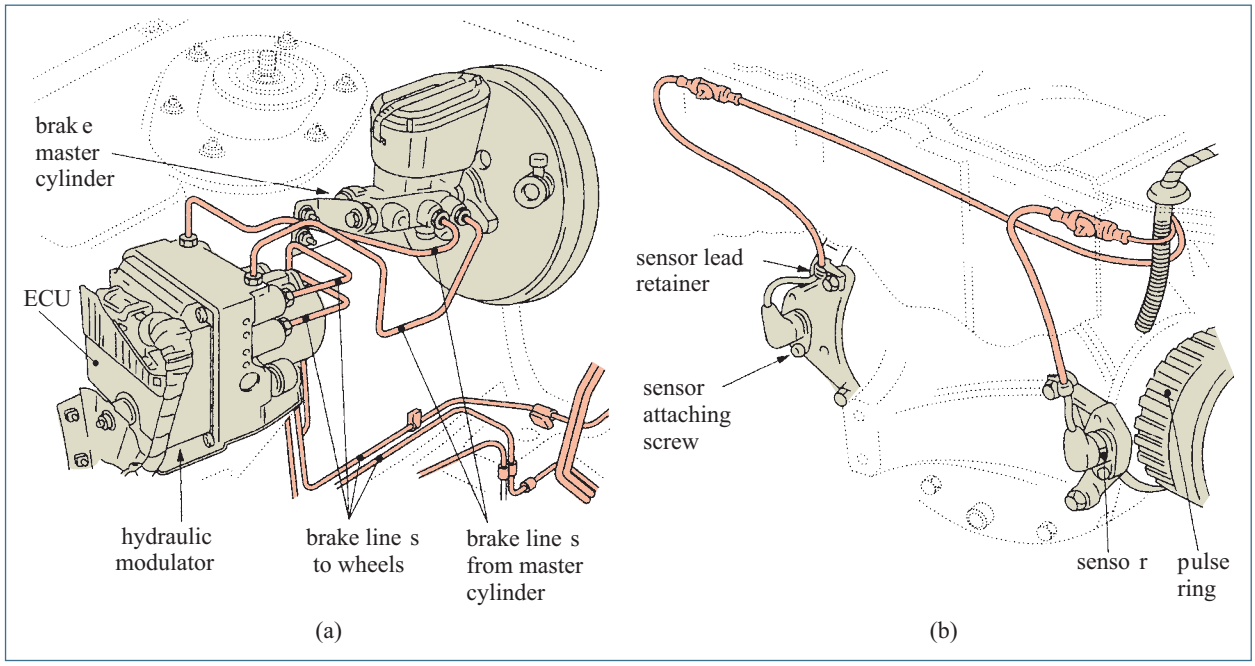


Figure 48.2 Components of an anti-lock braking system (a) master cylinder and hydraulic modulator (b) wheel-speed sensor for an independent rear suspension GM HOLDEN LTD

Master cylinder and lines

The master cylinder and booster are the same as those used for a brake system without ABS. The difference with ABS fitted is that the brake lines from the primary and secondary parts of the master cylinder are connected to the hydraulic control unit and do not go directly to the brake assemblies at the wheels.

48.2.2 Electronic control unit

The electronic control unit (ECU) is attached to the hydraulic control unit assembly. A multipin connector joins the ECU to the wiring harness.

The ECU receives signals from the sensors at each wheel, processes them and then signals the hydraulic control unit to make the necessary changes in hydraulic pressure. It also operates the ABS warning light on the instrument panel.

48.2.3 Wheel-speed sensors

The sensors and pulse rings (toothed rotors) shown in Figure 48.2(b) are used with an independent rear suspension. The pulse rings are mounted to the differential housing and fitted to the drive shafts. Independent rear suspension enables a four-channel system to be used.

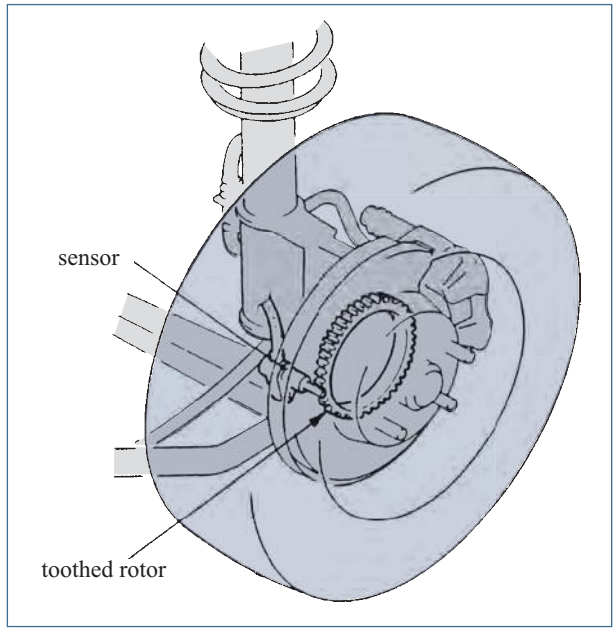


Figure 48.3 ABS sensor for a front wheel FORD

The wheel hub or drive shaft has a pulse ring that rotates with the wheel and a sensor that is mounted close to it. As each tooth of the pulse ring passes under the sensor, a small voltage pulse is induced in the sensor. The pulses are sent as input signals to the electronic control unit.

The frequency of the pulses is related to road speed, and the control unit uses the signals to determine the rate of deceleration which could produce skidding. If the brake is about to lock, the pressure is relieved for a moment and skidding is prevented.

Front-wheel sensors

Figure 48.3 shows how a passive front-wheel sensor and pulse ring are mounted to a front hub. Sensors can be located at the wheel hubs or on drive shafts.

Active wheel-speed sensors are a further development. These look like passive wheel sensors but are more accurate at lower speeds and can detect very low speeds. They can also detect if the vehicle is moving in reverse. The trigger wheel is either integrated into the wheel bearing seal or included as part of the wheel bearing assembly (Figure 48.22). *Trigger wheel, pulse ring* and *toothed rotor or toothed ring* are all names that are used for these gear-type rotors.

48.2.4 General operation

When the brakes are applied, the parts of the system covered above work like this: the sensors supply wheel-speed information to the electronic control unit; the electronic control unit operates the hydraulic unit; the hydraulic unit adjusts the pressure at the brakes to prevent the wheels from skidding.

Figure 48.4 shows a simplified anti-lock braking system. There are two main subsystems: the hydraulic system and the electronic control system. ABS can be used with diagonally split brake systems, or front–rear split systems.

48.3 Hydraulic system

The hydraulic system has a conventional master cylinder with primary and secondary pistons and conventional disc brake assemblies at the wheels. The hydraulic control unit controls brake pressure. It has eight solenoid valves—two for each hydraulic circuit of a four-channel system.

For all normal braking, when the ABS is not operating, pressure from the tandem master cylinder reaches the hydraulic control unit and passes on through the brake lines to the calipers. The braking system acts like a conventional system.

When the ABS comes into operation, fluid pressure from the master cylinder is controlled by opening and closing the solenoid valves in the hydraulic control unit to provide maximum braking while simultaneously preventing skidding.

48.3.1 Three-channel system

Vehicles with a rigid rear axle have a three-channel system, while those with independent rear suspension have a four-channel system. (‘Channels’ refers to the lines, or circuits, to the wheels.)

A three-channel system has a hydraulic line and a sensor at each wheel. The hydraulic control unit has a pair of solenoid valves for each front wheel, but only one pair of solenoid valves for both rear wheels.

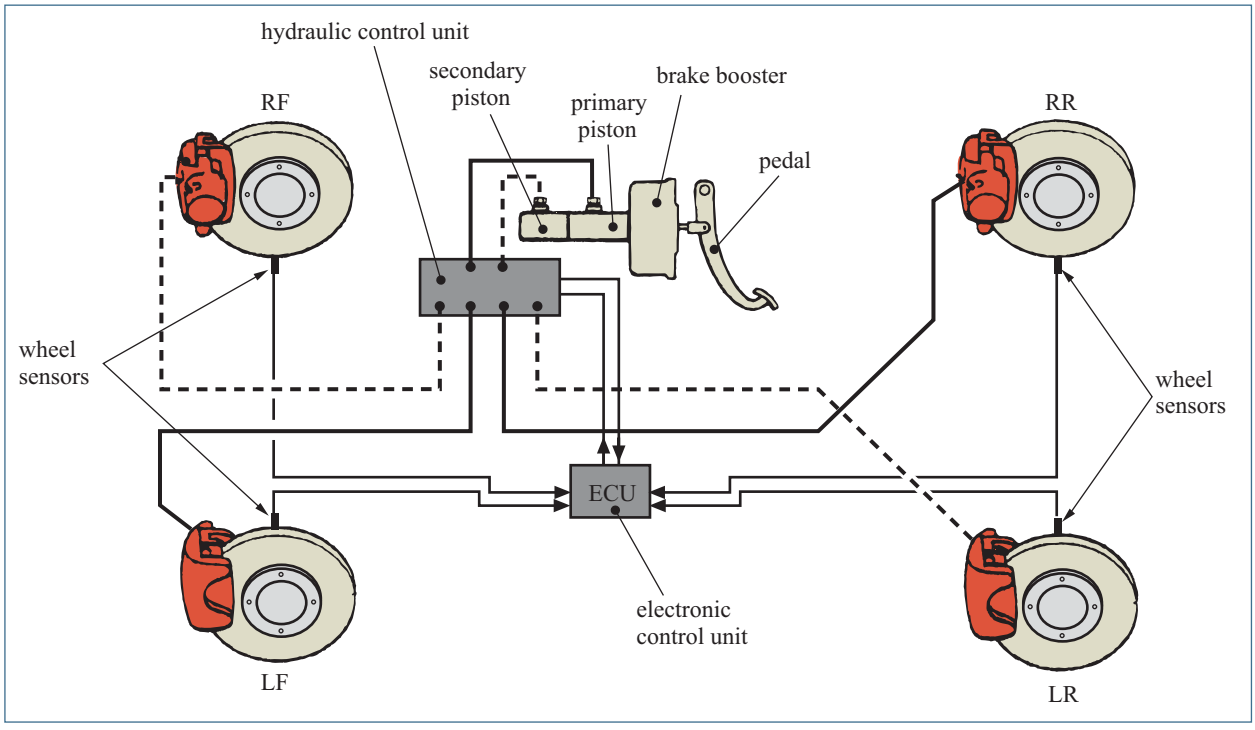


Figure 48.4 Arrangement of an anti-lock braking system

This means that a lock-up sensed at one of the rear wheels will cause a reduction in hydraulic pressure to both wheels.

Handy hint: With a rigid rear axle, each rear wheel has its own sensor, but there is only one channel to serve both wheels. So, if the pressure at one wheel has to be altered, the pressure at both wheels will be altered.

48.3.2 Four-channel system

With independent suspension at both the front and the rear of vehicle, a four-channel system can be used. Each wheel has its own sensor and its own hydraulic line. The hydraulic control unit has separate solenoids and valves for each channel, so each wheel can be controlled independently. (The diagram in Figure 48.7 is of a four-channel system.) There are two solenoid-operated valves for each channel.

Information: Where a vehicle has independent suspension at both front and rear, the pressure at each of the wheels is adjusted separately.

48.4 Electronic system

The electronic control system has sensors at the wheels and an electronic control unit in the engine compartment (or other convenient location). The wheel sensors send speed signals to the control unit, which monitors them and decides when wheel lock is about to occur.

Before the wheel locks, the electronic control unit operates a solenoid in the hydraulic control unit. The solenoid valve reduces the hydraulic pressure to the brake of that particular wheel and so prevents the brake from locking and the wheel from skidding.

When the possibility of skidding has been overcome, the solenoid is again operated to restore normal brake pressure at the wheel.

48.4.1 Basic operation

Figure 48.5 shows the basic operation of the electronic system and illustrates how it is part of a closed-loop system. The wheel sensors measure rotational speed of the wheels and signal this to the electronic control unit. The ECU processes the signals to determine the deceleration and skid of the wheels. It then signals the hydraulic modulator, which influences brake pressure in the system.

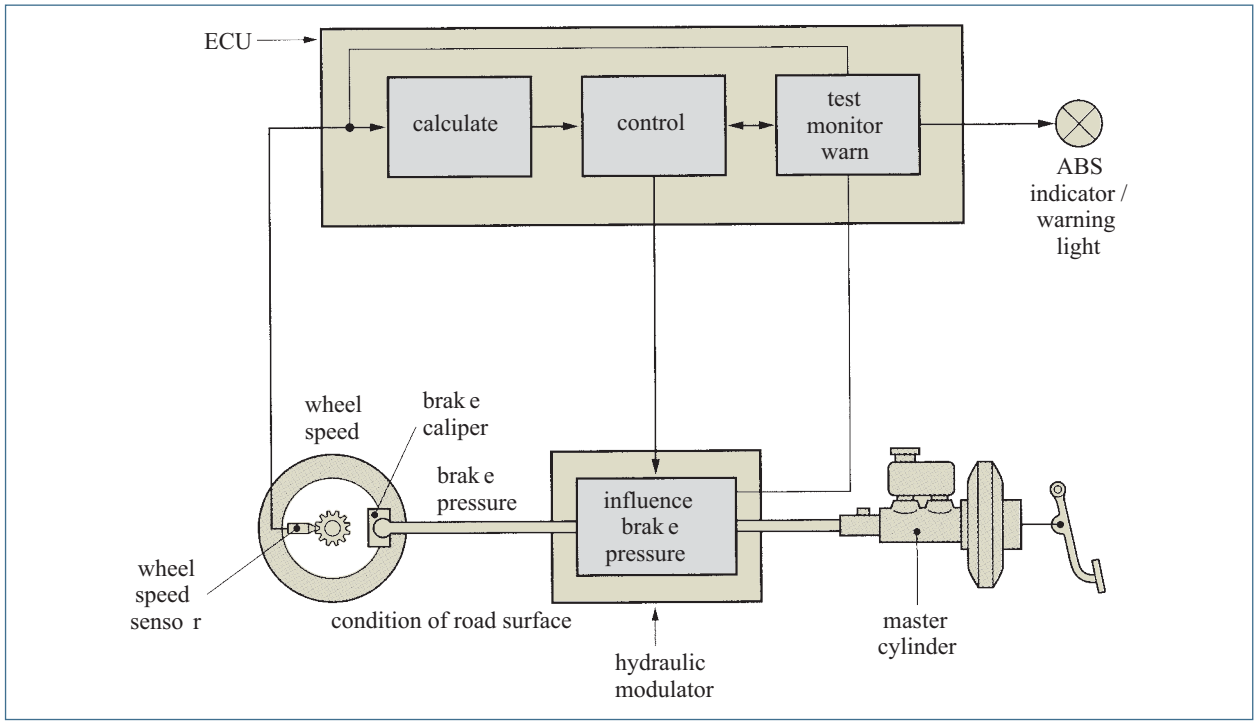


Figure 48.5 ABS schematic showing the basic operation of the electronics and hydraulics GM HOLDEN LTD

Handy hint: The system includes a test function, a monitoring function and a warning function.

48.5 Hydraulic operation

The arrangement of the hydraulic system is shown in more detail in Figures 48.6, 48.7 and 48.8. These show the different pressure conditions that can occur during brake operation. They are referred to as 'modes' or 'phases'.

48.5.1 Operation of the hydraulic system

Figure 48.6 shows part of a hydraulic system schematically. This is a front–rear split brake system and, for the sake of simplicity, only the rear-wheel brakes are shown. The front brakes operate in a similar way.

The parts of the hydraulic control unit are enclosed by a border line. In the actual unit, the parts inside the border form the hydraulic control unit.

The illustration shows the following parts:

1 Master-cylinder reservoir —holds the hydraulic brak e fluid for the system.
2 Return pump and electric motor —returns hydraulic fluid to the master cylinder .
3 Accumulator —holds fluid under pressure during certain conditions.
4 Inlet valves —solenoid-operated valves that control fluid to the brak es.
5 Outlet valves —solenoid-operated valves that control fluid from the brak es.
6 Bypass valves —help return fluid to the reservoir when the brak es are released.

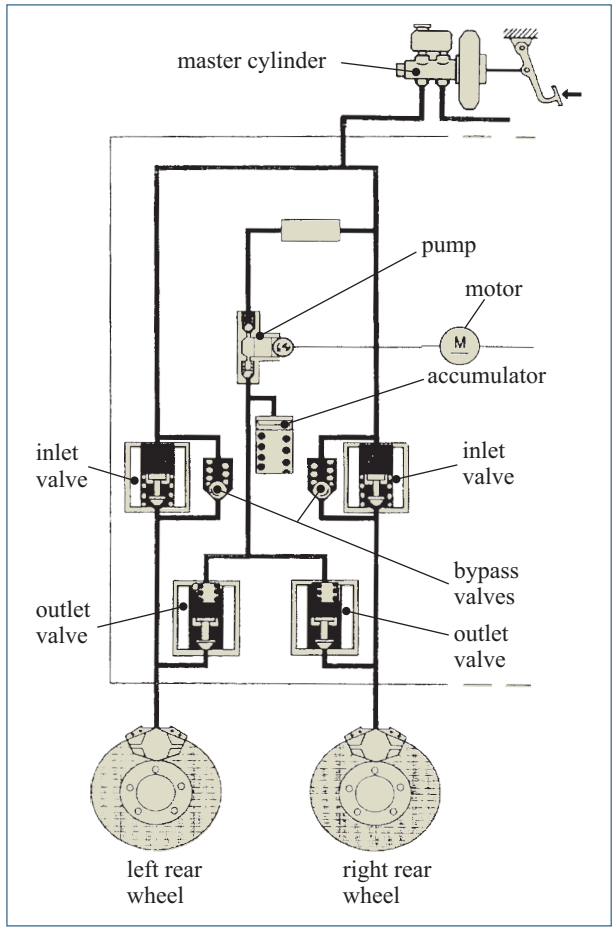


Figure 48.6 Hydraulic arrangement for the rear wheels of a four-channel ABS FORD

48.5.2 Operating modes

With ABS, the hydraulic system has four operating modes as far as fluid pressure in the system is concerned. In operation, the pressure is quickly changed from one mode to the other to obtain the maximum braking effect without locking the wheels.

The fluid pressure modes are:

- non-ABS braking pressure
- holding pressure
- reducing pressure
- increasing (restoring) pressure .

These pressures are outlined in relation to Figure 48.6 for one rear brake only. (A diagram of the complete system is shown as Figure 48.7.)

The inlet and outlet valves control the fluid in the hydraulic control unit. They are solenoid valves that can be opened or closed by energising their solenoids via an electrical signal from the electronic control unit.

The inlet valves are *normally open* but are closed when their solenoids are energised. The outlet valves are *normally closed* but are opened when their solenoids are energised. Each valve can be operated independently by signals from the electronic control unit.

Handy hint: The inlet valves control pressure fluid to the brak es, and the outlet valves control pressure fluid from the brak es.

48.5.3 Non-ABS braking pressure

The following descriptions should be related to one wheel of the diagram in Figure 48.6—for example, the right wheel. Each wheel can operate independently of the others, so there could be a different pressure at each wheel if this was needed for the particular braking conditions. When the brakes are being used normally and there is no ABS action required, the system acts as follows:

1 The inlet valves are held open and the outlet valves are held closed.
2 When the brak e pedal is pressed, fluid flows through the open inlet valve to the calipers to apply the brak es in the normal way .
3 When the brak e pedal is released, fluid flows back through the inlet valve to release the brak es.
4 Braking occurs in the usual way , with pressure in the system dependent on the force applied to the brak e pedal by the driver .

48.5.4 Holding pressure

When the electronic control unit detects the sudden deceleration of a wheel, indicating that the wheel is about to skid, it signals the hydraulic control unit to hold the pressure at that brake:

1 The outlet valve is already closed and the signal from the electronic control unit closes the inlet valve .
2 Fluid under pressure is then held in the part of the circuit between the inlet valve , the caliper and the outlet valve .
3 This pressure will remain constant regardless of any change in pressure at the master cylinder as long as the outlet valve remains closed.

48.5.5 Reducing pressure

If the electronic control unit detects that the pressure at a wheel needs to be reduced to prevent skidding, the following occurs:

1 The outlet valve is opened by a signal from the electronic control unit.
2 Fluid flows through the outlet valve to reduce pressure at the brak e.
3 The fluid flows to the accumulator and to the pump .
4 The accumulator holds fluid under pressure and the pump sends fluid back to the master cylinder .

48.5.6 Increasing pressure

After the pressure at the wheel has been reduced and the wheel is no longer about to skid, the pressure can be increased:

1 The outlet valve is closed so that fluid cannot pass to the accumulator and pump .
2 The inlet valve is opened so that pressure fluid from the master-cylinder circuit can again reach the caliper .
3 The braking effort is restored.

The cycle of reducing and increasing the pressure at the brakes to prevent skidding will continue as long as the brake pedal is held depressed.

Handy hint: Pressure can be decreased and increased in the braking circuit by ABS action, but it cannot be increased above the master-cylinder pressure .

48.5.7 Accumulator and pump operation

The accumulator is basically a spring-loaded piston in a cylinder. It comes into operation during the pressure-reduction mode. Fluid from the outlet valve is temporarily stored in the accumulator. The pump starts to operate and fluid is returned to the master cylinder.

By providing somewhere for the fluid to flow, the accumulator causes a quick reduction of pressure at the brakes. The fluid cannot flow directly back to the master cylinder because its pressure is higher than the brake pressure at this time.

The master cylinder pressure is blocked from entering the pump by the pump outlet valve, but when the pump comes into operation, it creates a fluid pressure that is a little higher than master cylinder pressure. This enables the pumped fluid to pass through the pump outlet valve and be returned to the master cylinder.

48.6 Complete four-channel system

Figure 48.7 is a diagram of the hydraulic system of a four-channel braking system. The following should be noted:

1 The components of the hydraulic control system are contained within a border .
2 There is an inlet solenoid valve and an outlet solenoid valve for each channel.

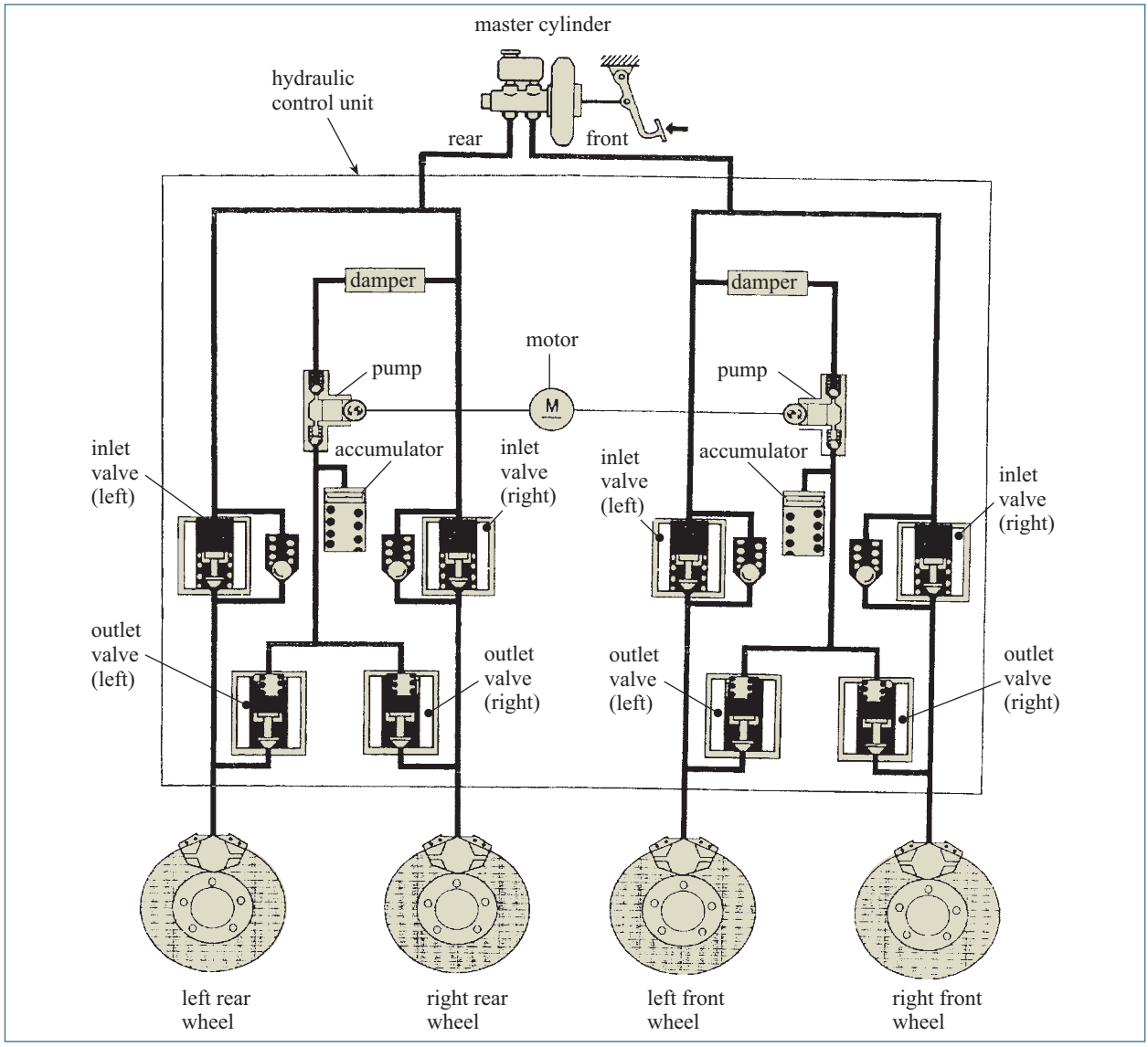


Figure 48.7 Diagram of the hydraulic control of a four-channel ABS FORD

3 Because it is a four-channel system, each brak e can have its pressure modified independently of the others.
4 The bypass valves only allow fluid to flow away from the calipers.

48.7 Summary of ABS operation

Following is a summary of ABS hydraulic operation as shown in Figure 48.8. This has four simplified diagrams of the hydraulic circuit for a right rear wheel. The parts shown are: the master cylinder, one caliper, an inlet valve, a bypass valve, an outlet valve, the accumulator and the return pump and its valves.

The hydraulic actions shown by the diagrams are:

1 Non-ABS braking. The fluid flows through the open inlet valve to the caliper to apply the brak e (Figure 48.8(a)). When the brake pedal is released, fluid returns to the master cylinder through the open inlet valve and also through the bypass valve to release the brak e. (The outlet valve is closed.)
2 Holding pressure . When the wheel is about to skid, the inlet valve is closed (Figure 48.8(b)). This holds fluid under pressure in the caliper and prevents any further increase in pressure . (Both valves are closed.)
3 Reducing pressure . If the pressure at the caliper would cause the wheel to skid, then the outlet valve opens to reduce the pressure (Figure 48.8(c)). (Inlet valve is closed.) Fluid flows into the accumulator and the pump returns fluid to the master cylinder .
4 Increasing pressure . When the skid has been prevented, the pressure at the caliper can be increased by opening the inlet valve (Figure 48.8(d)). (Outlet valve is closed.)

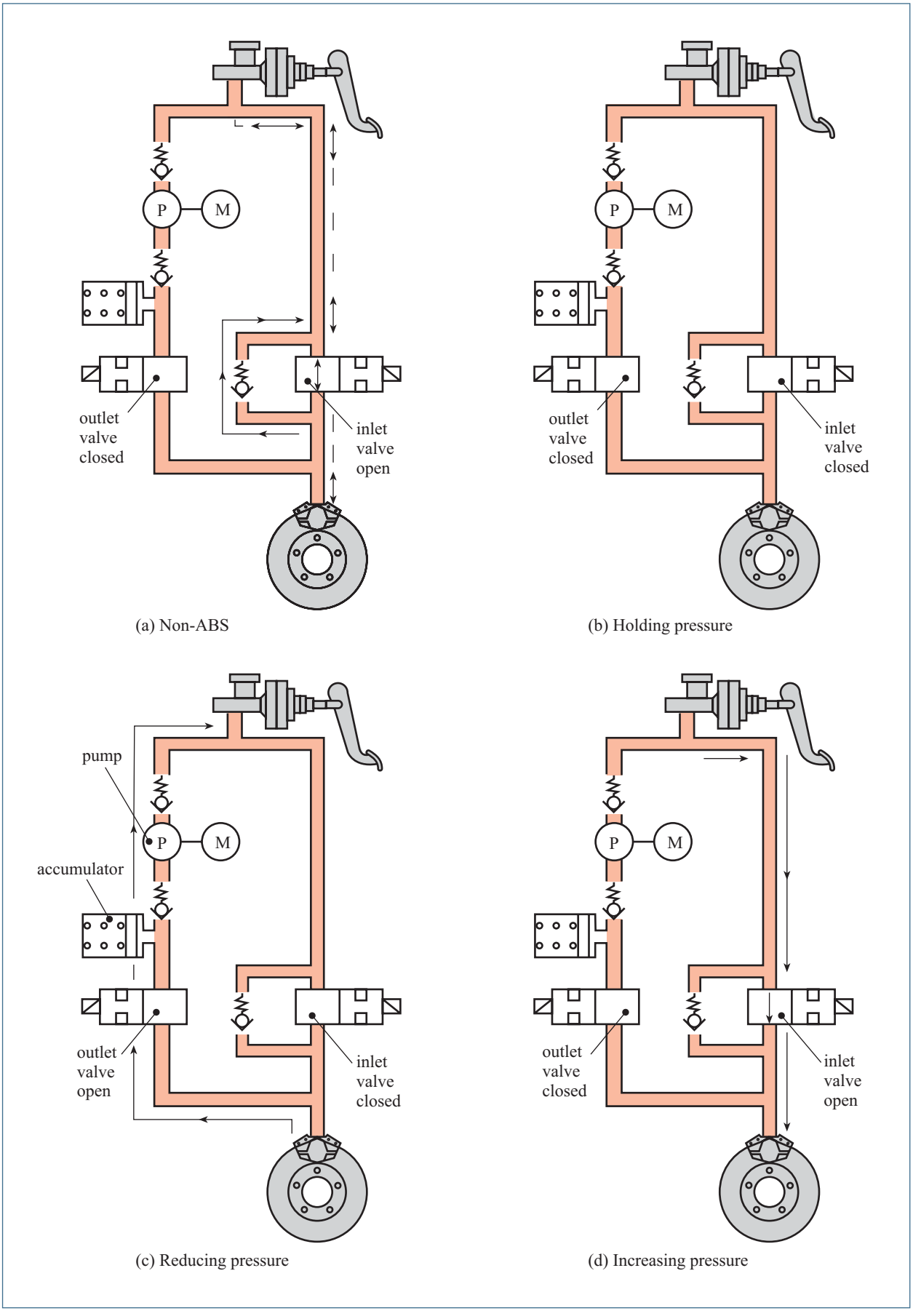


Figure 48.8 Simplified ABS operation: only the pressure modes are highlighted (there is pressure in other parts of the system)

48.8 Electronic brake-force distribution

Some vehicles have electronic brake-force distribution (EBD). This distributes pressure between the front and rear brakes, as required, for maximum braking effect. EBD is an extension of the anti-lock braking system and is carried out using the ABS components.

Hydraulic brake systems that do not have ABS have a way of distributing the hydraulic pressure (and the braking force) between the front and rear of the vehicle. This can be by means of a hydraulic valve in the master cylinder, or other valves in the system.

With EBD, the brake-system's ECU has extra programming to carry out brake-force distribution. The EBD program monitors the rear wheels through the ABS wheel sensors and compares this with information from the front-wheel sensors.

If rear-wheel slip (skid) is detected, the rear inlet valves in the ABS hydraulic unit are switched to *hold* so that there is no further increase in rear-wheel pressure. In this way, the electronic controls act to proportion the pressure between the front and rear brakes.

48.8.1 Distribution of brake force

The distribution of brake force between the front and rear brakes is shown as a graph in Figure 48.9. The ideal relationships between the front and rear are shown as dotted lines—there is a curve for a full load and another for a light load. Solid lines on the graph show how EBD can keep the actual brake force close to the ideal.

48.8.2 EBD operation

Electronic brake-force distribution occurs ahead of anti-lock braking. Its electronic program operates the inlet valves to the rear brakes. The valves will be opened and closed, as required, to control the fluid pressure applied to the rear wheels.

EBD uses its computer program to operate the ABS components. The anti-lock braking function of the ABS will not be in operation (it will only come into operation if required for the particular driving or braking conditions).

48.8.3 Braking with EBD

When the brakes are applied on a level road with a normal surface, there is a natural shift in force from the rear to the front of the vehicle. The front tends to drop and the rear to rise. This action is resisted by the suspension and shock absorbers, but there is still an effective transfer of force to the front of the vehicle. The extent to which this occurs will depend on the speed of the vehicle, the force applied to the brake pedal by the driver and how quickly the vehicle is slowed or stopped.

Without some means of adjusting the brake force between the front and the rear brakes, the rear brakes could lock and the rear wheels skid. EBD prevents this by adjusting the pressure to the rear brakes.

With EBD, the rear-wheel pressure is controlled and the vehicle stops in the direction in which it is being driven. Without EBD, the rear wheels could lock and skid and provide reduced braking as a result.

Safety: If the rear wheels were to lock, the rear of the vehicle could become unstable and slide across the road.

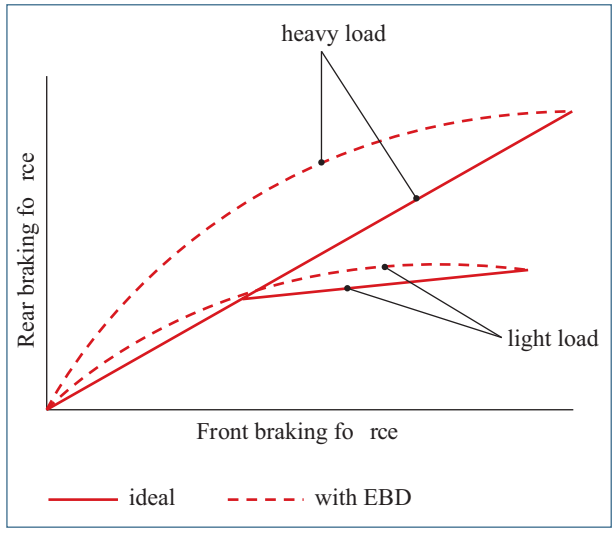


Figure 48.9 Graph showing how the rear braking force is reduced for a light load and increased for a heavy load

48.9 Traction control system

A traction control system (TCS) prevents wheel spin during acceleration by reducing engine torque and thus reducing the traction between the tyres of the driving wheels and the road surface.

Traction control can also assist steering. A vehicle accelerating on a curve will tend to understeer;

to control the vehicle, the driver will turn the steering wheel more or slacken off the accelerator (probably both). Traction control with a steering sensor can reduce traction automatically and improve driving safety.

Handy hint: The TCS is the basis of the electronic stability program (ESP) that is discussed later .

48.9.1 Traction control system arrangement

Figure 48.10 shows the parts of a traction control system. The ABS/TCS hydraulic modulator is the same as the modulator for ABS, except that it has additional valves.

The ECU contains the electronic program. It receives inputs from the front- and rear-wheel sensors and also from the engine's power control module (PCM). Its output signals go to the ABS/TCS modulator and to the engine's PCM.

The PCM receives signals from the accelerator pedal switch and other sources. For the traction control system, it sends signals to the engine's fuel and ignition systems.

Handy hint: The ABS/TCS electronic control unit is shown as being separate from the hydraulic modulator , but they can be combined.

48.9.2 Traction control operation

Traction control operates by reducing engine torque, and this reduces traction between the tyres and the road. It can also use ABS to apply the brakes to reduce wheel spin.

Engine torque can be decreased in three ways:

1 By reducing or cutting off fuel from the injectors.
2 By retarding the ignition.
3 By closing the throttle valve .

Where traction control is fitted, the ABS electronic control unit has extra programming for traction control and often extra valves in the modulator.

When driving conditions are such that traction control is needed, the ABS/TCS electronic control unit sends a signal to the engine PCM, telling it to reduce engine torque. The engine ECU then reduces the fuel from the injectors, retards the ignition or, in some systems, closes the throttle valve.

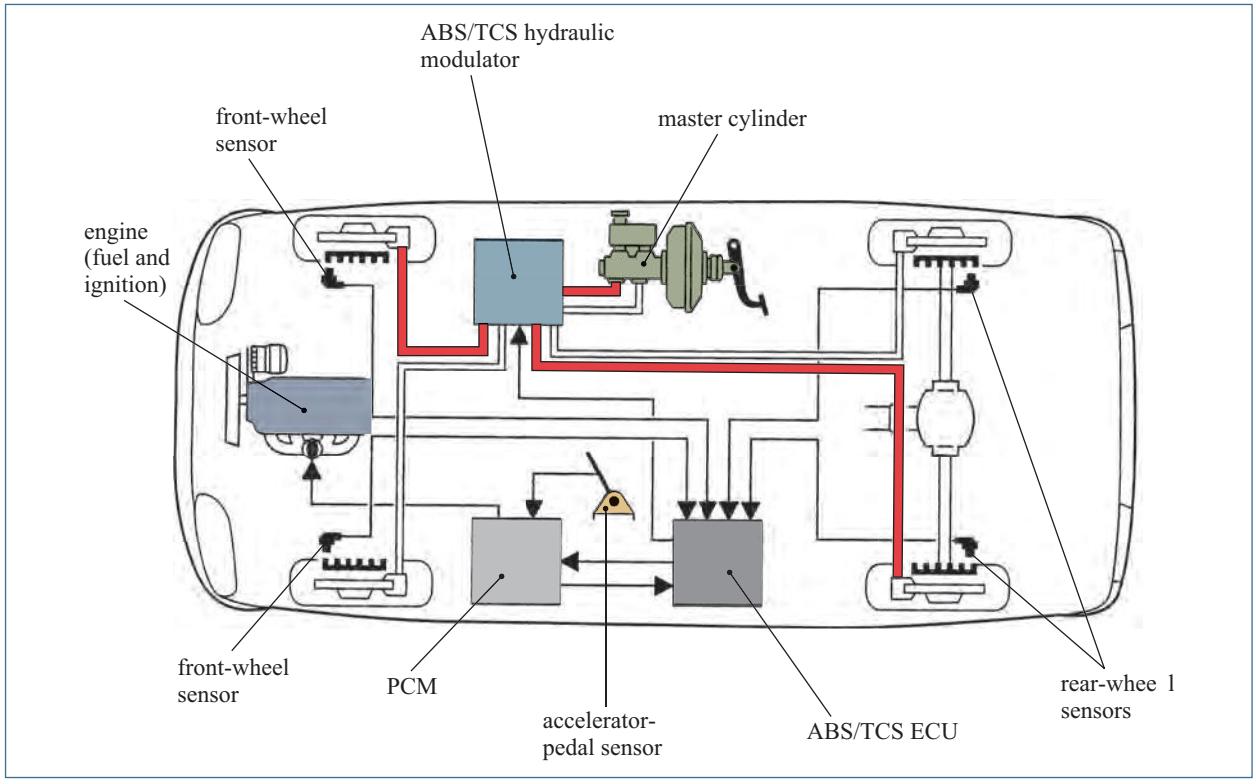


Figure 48.10 Schematic arrangement of the components of ABS/TCS BOSCH

Traction control is active whenever the engine is running, but it only comes into operation when it is needed. While it is actually in operation, the traction control (TC) indicator light flashes (Figure 48.11).

An on–off switch is provided so that traction control can be switched off.

48.9.3 Traction control and ABS

The anti-lock braking system can operate in conjunction with traction control. With ABS, the hydraulic modulator uses its internal hydraulic pump to boost or reduce the master cylinder pressure.

For traction control at lower speeds, hydraulic pressure from the pump is used without the driver applying the brakes. The ABS/TCS electronic control unit processes inputs from the wheel sensors and applies a brake when needed. The ABS/TCS hydraulic modulator has extra valves for traction control. These are the priming and switching valves. They are opened and closed by the ECU to control the brake fluid flowing to and from the master cylinder.

48.9.4 Electronic throttle control for TCS

Electronic throttle control, or *drive by wire,* is a device that can be used with traction control. This does away with the conventional throttle linkage or cable.

Figure 48.12 shows the way such a system could be arranged. The accelerator pedal is connected to an electronic sensor which signals the throttle position to the engine ECU (or PCM). The engine ECU then operates a servo motor connected to the throttle valve.

For normal operation, when traction control is not working, signals pass through the engine ECU and the servo motor opens the throttle valve in proportion to accelerator pedal movement.

With the traction control in operation, the engine ECU takes into account signals from the anti-lock braking system/traction control ECU and adjusts the throttle valve opening accordingly.

Handy hint: With TCS, there are other inputs to the engine ECU, such as engine speed and temperature.

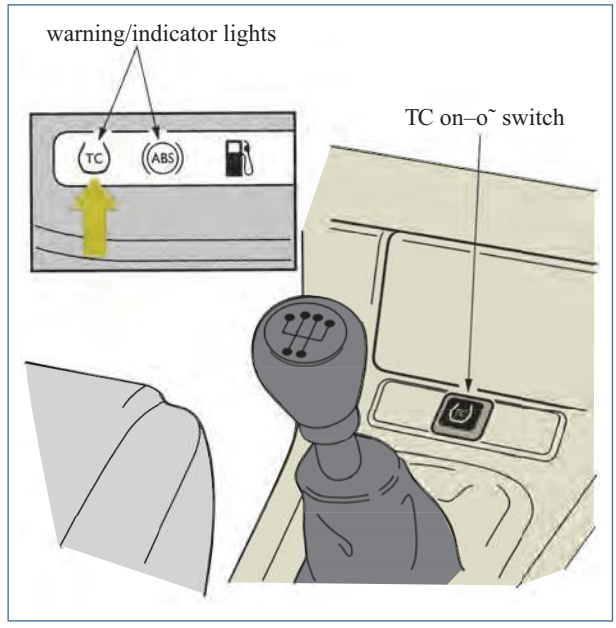


Figure 48.11 Traction control switch and warning/indicator lights for ABS and T CS GM HOLDEN LTD

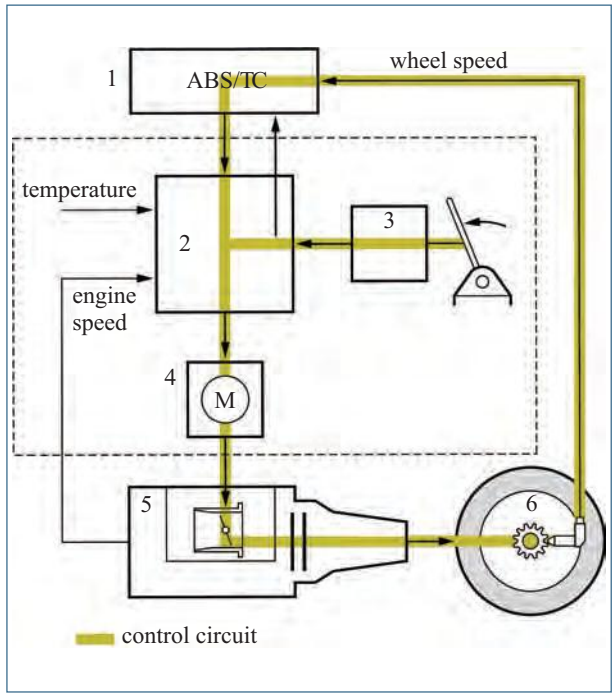


Figure 48.12 The concept of electronic throttle control for use with traction control 1 ECU for anti-lock braking system/traction control 2 engine PCM 3 accelerator pedal sensor 4 servo motor 5 throttle valve 6 wheel speed sensor BOSCH

48.9.5 Hill descent control

The hill descent control (HDC) system allows a controlled hill descent in rough terrain without the driver needing to touch the brake pedal. With the system on, the vehicle will descend using the ABS braking system to control each wheel speed through sensor input. If the vehicle accelerates without driver input, the system will automatically apply the brakes to slow down to the desired vehicle speed. Control buttons can adjust the speed to a comfortable level. Applying pressure to the accelerator or brake pedal will override the HDC system.

48.10 Electronic stability program

The electronic stability program (ESP) is an active safety system. It uses additional electronic controls to operate the brakes, in conjunction with ABS, to provide vehicle stability. This is applied particularly during cornering. ABS senses the need to apply or release the brakes on each wheel independently and ESP makes use of this facility.

A brief comparison of an electronic stability program (ESP) with the other systems is: the *anti-lock braking system* (ABS) prevents the wheels from locking and skidding; the *traction control system* (TCS) prevents the wheels from spinning and the *electronic stability program* (ESP) provides steering stability.

ESP can stabilise steering by *intervention* in two different ways: by braking selected wheels, or by accelerating the driving wheels. This helps to keep the vehicle stable on the road.

Handy hint: Intervention is a term that is used with these systems to denote that a different action has been introduced.

48.10.1 ESP closed-loop system

A schematic arrangement of the main components of an ESP is shown as Figure 48.13. There are *sensors* that send signals to the ESP control unit, *controllers* for ABS, TCS and ESP within the ESP control unit and *actuators* that receive signals from the ESP control unit.

The sensors for ESP that are additional to those in ABS and TCS are the *yaw sensor,* the *steering-wheel angle sensor* and the *brake-pressure sensor.* These sense the direction of vehicle travel (see Figure 48.14).

The various parts and sensors for ESP have the following functions:

1 Yaw sensor . Detects any tendency for the vehicle to rotate about its axis. It also detects any sideways movement (lateral acceleration) of the vehicle .
2 Steering wheel angle sensor . Registers the turning angle of the steering wheel. It provides an input from the driver that indicates the direction in which the vehicle is intended to be steered.
3 Pressure sensor . Monitors the brake pressure in the system as applied by the driver .
4 Wheel sensors . Signal the wheel speeds.
5 Hydraulic modulator . Responsible for applying the brakes and controlling the brake pressure .
6 Brakes . Selectively applied by the hydraulic modulator .
7 PCM. An engine control module that is directed to control the engine functions.
8 Ignition timing . Controlled by the PCM, it is retarded to reduce engine torque .

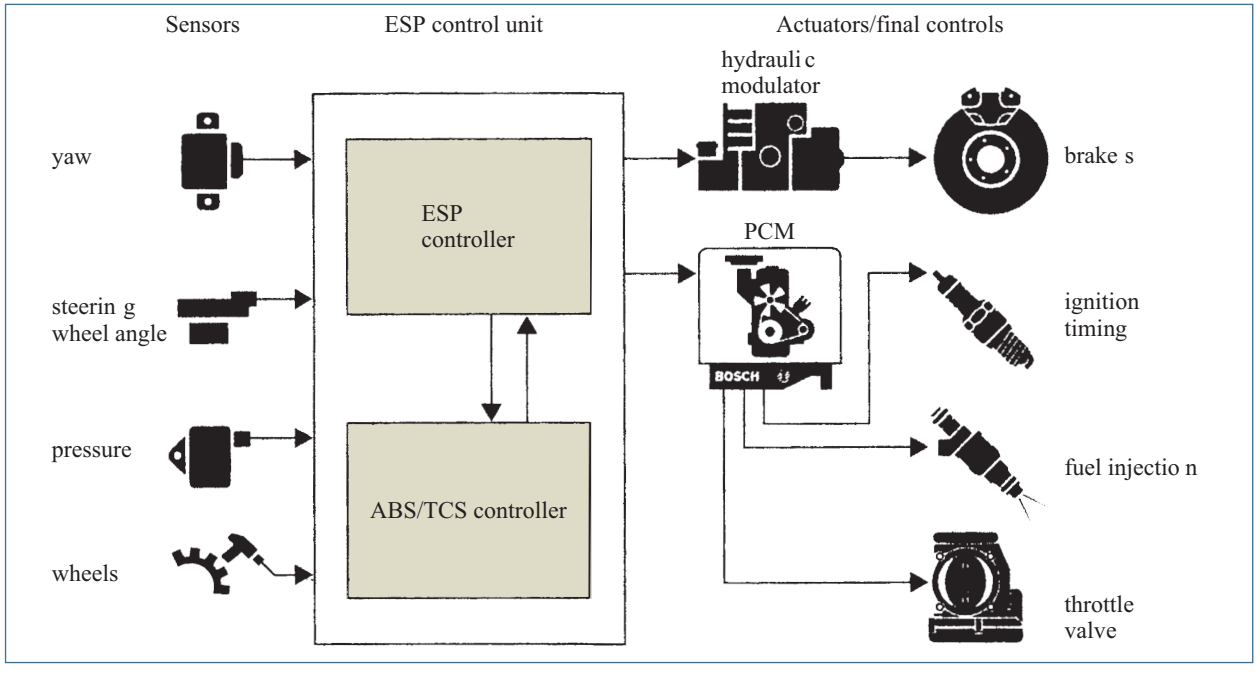


Figure 48.13 ESP components and closed-loop system BOSCH

9 Fuel injection . Also controlled by the PCM, injection is reduced to decrease engine torque .
10 Throttle valve —also controlled by the PCM, it is closed to reduce engine torque .

Handy hint: Engine ECU and power control module (PCM) are different terms for the same component. Both are used by vehicle manufacturers.

48.10.2 Vehicle stability

Figure 48.14 shows the various directions in which it is possible for a vehicle to travel and which are controlled as far as possible by ESP. Normally, the desired direction, or track, that the vehicle travels is controlled by the driver. However, in some operating conditions, other forces can take over and the direction of travel will be different from that desired.

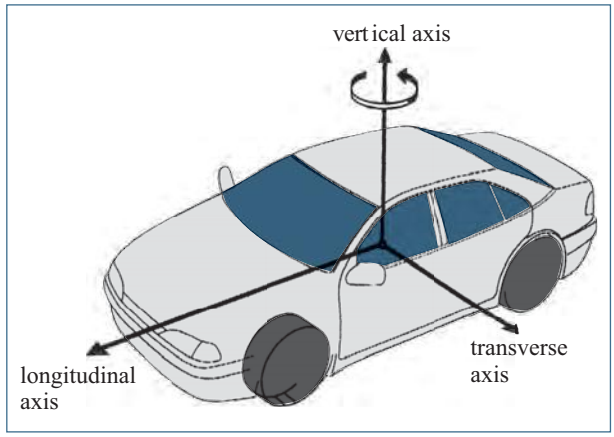


Figure 48.14 Directions in which vehicle travel could take place BOSCH

The illustration shows three axes about which movement can occur. These are the *vertical axis,* the *transverse axis* and the *longitudinal axis.* In adverse conditions, vehicle movement could occur in any of these directions, and the possibility of movement in these directions exists even during normal driving. Actual movement would only be apparent when control of the vehicle became difficult.

Forces acting on a vehicle

Some of the conditions that influence vehicle operation are:

1 Centrifugal force . An outward force on curves that increases with speed, it can cause lateral instability and produce an overturning force .
2 Weather conditions. Poor conditions reduce visibility and create slippery road surfaces. Side winds can cause lateral instability .
3 Road surfaces. Different types of road surfaces can have different frictional effects on tyres. This can affect braking, traction, side-slip when cornering and general driveability .
4 Driver fatigue . This causes drowsiness and slow reactions.
5 Load conditions. Vehicle stability will be different with light and heavy loads.
6 Other . Wind effects of larger passing vehicles can cause instability . Animals, objects on the road or the behaviour of other drivers might require a panic stop or evasive action, affecting general vehicle stability .

Steering: understeer and oversteer

The terms *oversteer* and *understeer* refer to a vehicle's steering characteristics.

1 Oversteer is where the vehicle is over-responsive when cornering and tends to move further into the curve than it is actually being steered.
2 Understeer is the opposite: the vehicle is not as responsive to steering as it should be and tries to k eep out wide on a curve .

Oversteer and understeer are not directly related to the steering system but result from the overall vehicle design—suspension system, distribution of weight, vehicle load, type of drive and so on. It is usually a combination of factors that produces an understeer or oversteer tendency.

Active rollover protection

Active rollover protection is a system which prevents a vehicle from rolling over from excessive lateral force.

There are two ways to control this:

1 Electronic stability program (ESP) . Comprising traction control, anti-lock braking and yaw control.
2 Active suspension . Adjusts the suspension if the yaw sensor detects a possible rollover .

48.10.3 Yaw sensor

The yaw sensor measures a vehicle's rotation from its vertical axis (how far to the left or right the vehicle's angle is from its centre) and how far it has deviated from a straight line. It ties into the vehicle's traction

control, stability control and anti-lock braking systems to alert the driver when the tilt of the vehicle is reaching an unsafe level. Once this happens, it adjusts the vehicle's traction and stability controls to compensate and reduce the lateral force.

48.10.4 Vehicles with and without an electronic stability program

Figure 48.15 shows the possible tracks taken by a vehicle both with and without an electronic stability program (ESP).

Without ESP, a vehicle driven into a curve at high speed could become unstable. The front of the vehicle is steered into the curve and the rear tends to catch up. Attempts at correction might fail and the vehicle could become uncontrollable.

With ESP, the brakes are automatically applied to help steering and correct the direction. The right-front brake is applied (as shown by the arrow) on a left bend in the road—this helps to keep the vehicle in the centre of the lane. Then the left-front brake is applied on a right bend, and this again helps with a steering correction. In this way, the vehicle maintains a regular track within its lane.

48.10.5 Forward collision avoidance technology

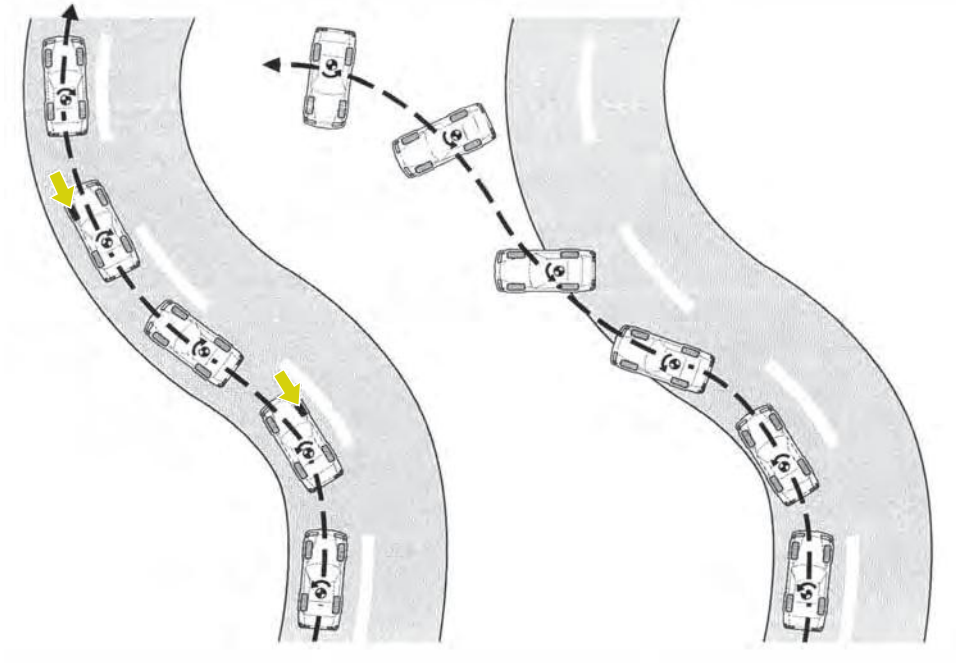
Forward collision avoidance technology (FCAT) systems sense other road users or objects in front of the vehicle. They react (either with driver assistance or autonomously) to possible crash hazards by priming braking systems, warning the driver and applying appropriately more gentle or aggressive braking.

48.11 Electronic parking brake (EPB)

On vehicles with an electronic parking brake (EPB), the electronic control unit operates the parking brake. Some systems apply and release with a driver-applied button. Others utilise sensors which have the ability to apply automatically when the vehicle comes to a full stop. Sensors can also provide incline detection, backward motion detection, boot, bonnet or doors being opened and the driver's seatbelt not being latched.

48.11.1 Operation of the EPB

From the driver's seat, the EPB can only be released when the brake pedal is being pressed. It also can be used as an emergency brake and as a hill start assist. With the vehicle stopped and the brake pedal pressed,



(a) With ESP (b) Without ESP

Figure 48.15 Comparison of the actions of a vehicle with ESP and without ESP under particular driving conditions BOSCH

pulling the EPB switch applies the parking brake. The driver can release the switch and brake pedal, and the EPB will release automatically when the accelerator is pressed.

There are two different types of EPB. One uses a single electric motor to pull a cable on an otherwise conventional cable-operated parking brake system (Figure 48.16).

The other type, shown in Figure 48.17, has small electric motors on each rear caliper that mechanically operate the caliper piston.

In each system the control unit operates in both directions as needed. An electric motor, with a transmission to multiply its torque, holds the vehicle in place.

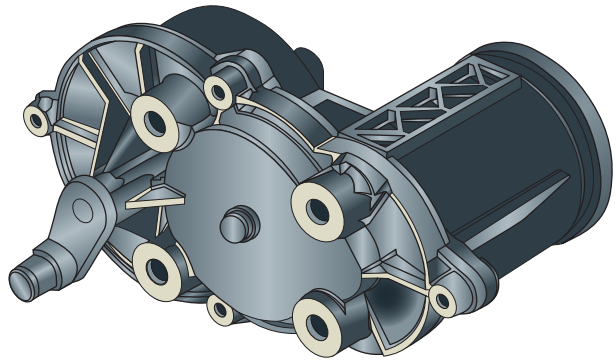


Figure 48.16 Electronic park brak e cable actuator

Figure 48.17 Electronic park brak e caliper BOSCH

48.11.2 EPB indicator light

The parking brake indicator light (on the instrument panel) communicates messages to the driver. It illuminates any time the EPB switch is turned ON. When the EPB is engaged with the ignition switch OFF, the EPB light will turn ON for a limited amount of time. If the light blinks continuously after turning the EPB switch ON, the brake has not attained sufficient clamping force to hold the vehicle (there should be a notification on the instrument panel display).

If a malfunction is detected in the EPB system, the warning light illuminates and a notification appears on the instrument panel display. A scan tool is required to diagnose the nature of the malfunction.

48.11.3 Hill-start assist

Hill-start assist prevents the vehicle from rolling backwards when starting on an uphill slope by maintaining the brake pressure while the driver shifts from the brake to the accelerator pedal. This can be performed by either the ESP or EPB.

48.12 Service points

48.12.1 ABS-ECU check function

The ECU of the ABS will perform an initial check when the vehicle is started and a monitoring check while the vehicle is in operation.

Initial check

When the vehicle reaches a speed of approximately 6 km/h, the ECU will check the operation of the solenoid valves and the pump unit of the hydraulic unit. If a malfunction is detected, the ABS will be isolated and the warning lamp will be switched on.

When the ECU receives signals from the wheel sensors, it checks the sensor operation. If an incorrect signal is received, or if there is no signal, then the ABS will also be isolated and the warning lamp switched on.

Monitor check

The ECU will constantly monitor the system. The ECU has two microprocessors that receive identical input signals and should therefore have identical output signals. If this is not the case, there is a malfunction in the system and ABS operation will be shut down. Components that are checked are: the stop-light switch, the sensors and the circuits. Also, the speeds of the sensors are checked against a reference value.

Fail-safe function

If a failure is detected by the system's self-diagnosis function, the ABS will be isolated. The brakes will act like a normal system that does not have ABS. The warning lamp will light and remain on.

48.12.2 Fault diagnosis

Possible ABS faults can be separated into hydraulic faults, electrical faults and electronic faults. ABS hydraulic faults are the same as those likely to be encountered in a system without ABS. These include faults in the master cylinder, calipers, hoses, leaks and so on. Electrical faults could be related to cables and connections and might be found by a close inspection. Electronic and component faults can only be located with instruments or by the self-diagnostic function of the system. An ABS warning lamp in the instrument cluster will light up when ABS faults are present (Figure 48.18).

Fault codes can be accessed through a diagnosis connector (Figure 48.19). These are read with a scan or multifunction test instrument. Table 48.1 shows typical fault codes using an OBDII-compatible scan tool.

48.12.3 ABS checks

Many items that affect the operation of ABS, TCS and ESP apart from the basic systems components themselves. The systems work through the vehicle's brakes, so a thorough inspection of the braking system should be carried out before ABS components are replaced. Particular attention should be paid to:

- tyre pressure (recommended pressures are important)
- tyre size – all tyres must be the same size , with no significant difference in tyre wear (differences in circumference will indicate to the ECU difference in wheel speed)
- disc pad and rotor condition
- brak e hoses and pipe condition
- wheel bearing condition and adjustment
- master-cylinder operation
- brak e fluid level and condition.

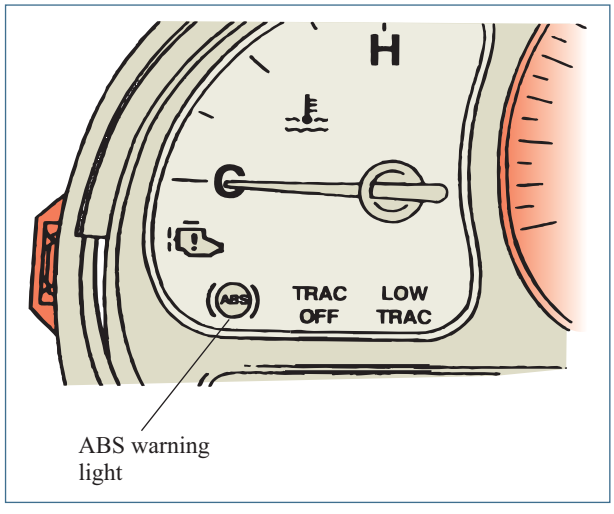


Figure 48.18 ABS warning light on an instrument panel GM HOLDEN LTD

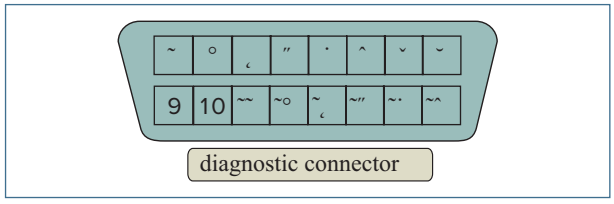


Figure 48.19 Diagnostic connector FORD

Table 48.1 ABS fault codes

B1342	ECU fault
B1676	Battery voltage out of range
C1093	Traction control switch failure
C1095	Pump motor fault
C1145	Right front wheel-speed sensor continuity fault
C1148	Right front wheel-speed sensor output plausibility fault
C1155	Left front wheel-speed sensor continuity fault
C1158	Left front wheel-speed sensor output plausibility fault
C1165	Right rear wheel-speed sensor continuity fault
C1168	Right rear wheel-speed sensor output plausibility fault
C1175	Left rear wheel-speed sensor continuity fault
C1178	Left rear wheel-speed sensor output plausibility fault
C1222	Wheel-speed sensor frequency fault
C1266	Valve relay/valve relay power supply fault
C1288	Hydraulic modulator internal pressure sensor valve
P1571	Brake lamp switch failure
U0073	CAN communication Bus fault
U2501	CAN message from PCM failure
U2503	Hybrid electronic C AN message failure

Table 48.2 The ECM connector

	Expected outputs from the ECM connector	Action	Result
1	Wheel-speed sensor right rear negative	Ignition ON Wheel turning slowly	AC waveform
2	Wheel-speed sensor right rear positive	Ignition ON Wheel turning slowly	AC waveform
4	Wheel-speed sensor right front negative	Ignition ON Wheel turning slowly	AC waveform
5	Wheel-speed sensor right front positive	Ignition ON Wheel turning slowly	AC waveform
6	Wheel-speed sensor left front negative	Ignition ON Wheel turning slowly	AC waveform
7	Wheel-speed sensor left front positive	Ignition ON Wheel turning slowly	AC waveform
8	Wheel-speed sensor left rear negative	Ignition ON Wheel turning slowly	AC waveform
9	Wheel-speed sensor left rear positive	Ignition ON Wheel turning slowly	AC waveform
11	Diagnostic connector terminal 7	Serial data	N/A
12	ATCP module (if fitted)	BUS negative	Serial data
13	ATCP module (if fitted)	BUS positive	Serial data
14	Brake lamp switch signal	Ignition ON Brake pedal at rest Brake pedal depressed	<0.5 volts Battery volts
15	Ignition power	Ignition ON	Battery volts
16	Ground	All times	<0.5 volts
17	Valve relay power supply	All times	Battery volts
18	Valve relay power supply	All times	Battery volts
19	Ground	All times	<0.5 volts
20	ABS warning lamp	No specifications available	N/A
21	EBD warning lamp	No specifications available	N/A
22	Vehicle speed signal to PCM	Ignition ON Vehicle moving	Voltage pulse
29	CAN low	Serial data	N/A
30	CAN high	Serial data	N/A
31	Traction control OFF switch	Ignition ON Switch open Switch closed	High volts Low volts

Checking wheel sensors

Passive wheel sensors have a permanent magnet built into them and will attract iron particles or objects. Sensors should be cleaned and tested with a multimeter if a fault code is detected. When the wheel is rotated by hand, an AC voltage should be present. The voltage can be measured at the sensor two-pin connector or at the ECM connector (shown in Table 48.2 and Figure 48.20).

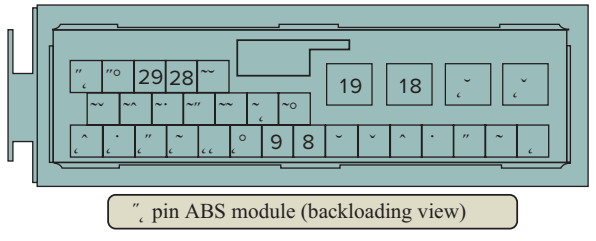


Figure 48.20 ECM connector FORD

For example, an electrical test of the left front wheel-speed sensor would require location of the correct pins from Table 48.2. These are pins 6 and 7. A multimeter could then be applied to pins 6 and 7 at the ABS ECM connector shown in Figure 48.20. Rotation of the left-hand front wheel with the ignition ON should produce an AC voltage, or waveform, as shown in Figure 48.21.

Active wheel speed sensors consist of an integrated circuit that produces a DC, square-wave voltage signal. These sensors are tested with the ignition ON and by checking reference or supply voltage to the sensor using a DC voltmeter. A typical wheel-speed sensor circuit is shown in Figure 48.22. This particular sensor should be tested for a reference voltage of 8 volts. Signal voltage can also be tested by turning the wheel and checking for a square wave pattern. This test can check the electronic operation of the sensor or identify trigger-wheel faults (Figure 48.23).

Brake bleeding

If air is present in the ABS module, a compatible scan tool is normally required to correctly remove air from the system. Manufacturers' instructions must be followed as pressures in the fluid higher than normal could be encountered. Replacement of brake fluid can be carried out in the usual manner.

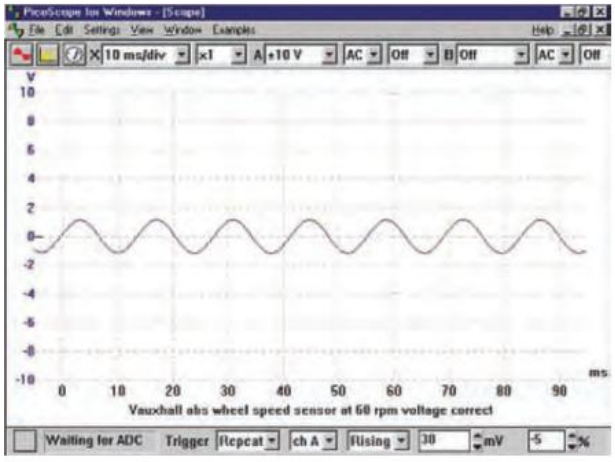


Figure 48.21 ABS sensor waveform—passive sensor PICO TECHNOLOGY

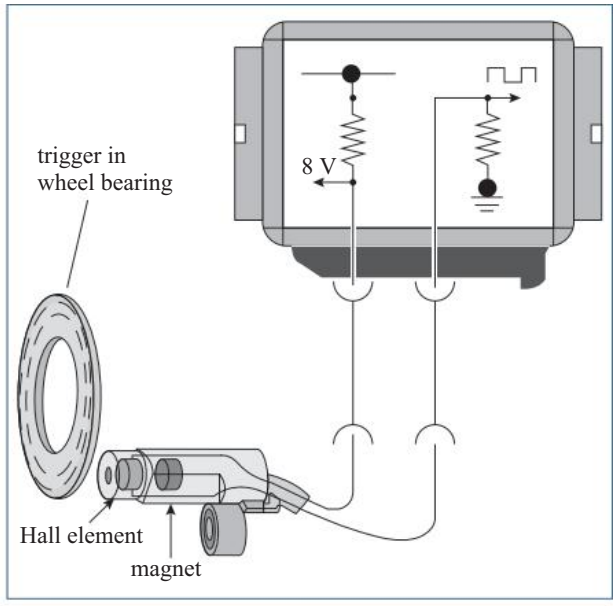


Figure 48.22 A typical active wheel speed sensor circuit

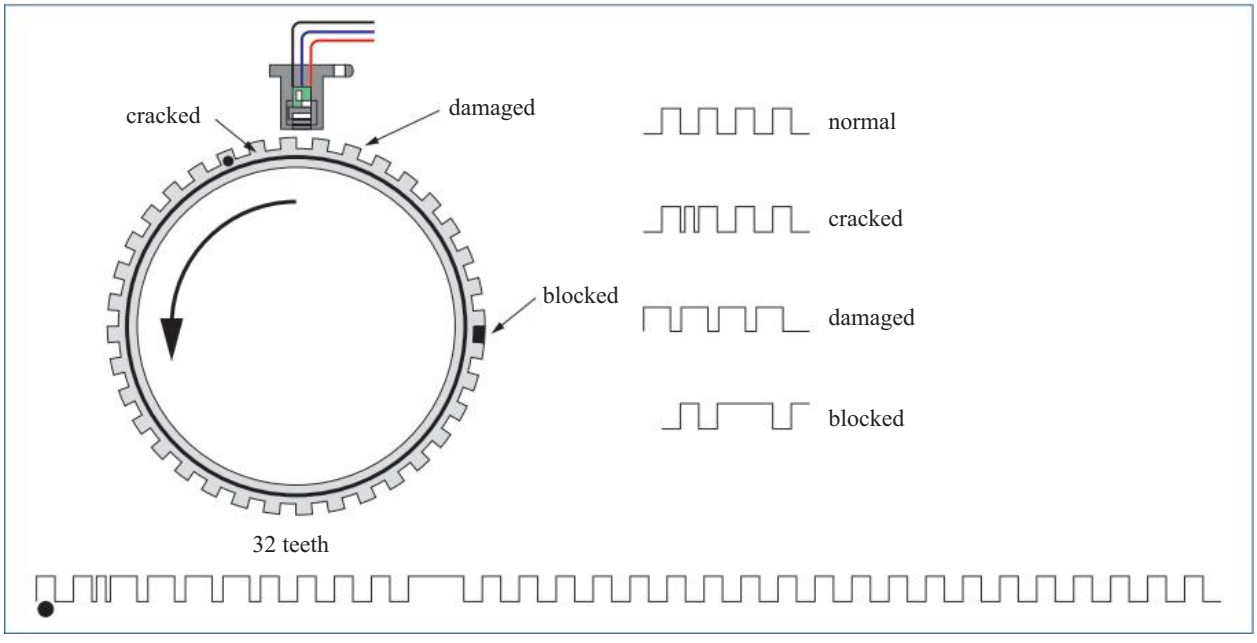


Figure 48.23 Abnormal waveform patterns caused by trigger-wheel faults

Safety: On hydraulic braking systems that use a pressurised accumulator , do not loosen fittings or open hydraulic lines until the system has first been depressurised. Some systems operate at pressures of up to 17 000 kP a. The manufacturer' s service and safety instructions must be followed.

One way to depressurise the system is to pump the brake pedal 30 or so times with the ignition turned off. The pedal feel will get harder as the pressure in the system drops. The system must be fully depressurised before attempting any work on the hydraulic system.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- explain the anti-lock braking system (ABS)
- explain the operation of the ABS module
- explain traction control systems
- explain electronic stability programs
- identify and describe diagnosis and service points.

REVIEW QUESTIONS

1 Why is ABS fitted to motor vehicles ?
2 What are the three main parts of an ABS system ?
3 Name the main parts of the hydraulic system of ABS.
4 What is the difference between a three-channel and a four-channel brak e system ?
5 What is the function of the wheel sensors ?
6 What part does the ECU play in an anti-lock braking system ?
7 What is the hydraulic modulator ?
8 How does a hydraulic modulator influence brak e pressure ?
9 What is the purpose of the solenoid valves in the hydraulic modulator?
10 How does traction control prevent wheel spin (briefly)?
11 How is engine torque reduced by the traction control system ?
12 What is meant by ESP?
13 What is the purpose of a steering wheel sensor in an ESP?
14 How is steering assisted by ESP (briefly)?
15 If an ABS warning light remains on, what does this tell the driver?
16 If the TC light or symbol flashes, what would this indicate ?
17 What is the purpose of the accumulator in the hydraulic control unit?
18 What is meant by fail safe ?
19 How is the driver made aware that an ABS has a fault?
20 How could a sensor be check ed for serviceability ?
21 What visual checks can be carried out on an ABS system ?

CHAPTER 49

Air conditioning

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 identify operating principles of light vehicle air-conditioning systems and associated components
2 recall the application, purpose and operation of light vehicle air-conditioning systems and components
3 apply diagnostic testing procedures for light vehicle air-conditioning systems, including testing procedures
4 apply repair procedures for light vehicle air-conditioning systems
5 apply post-repair testing procedures for light vehicle air-conditioning systems.

The air-conditioning system provides cooling and heating. The comfort zone for the average person is between 20°C and 28°C, with a relative humidity of between 30% and 70%. In other words, cool, reasonably dry air is required for personal comfort. The air conditioner cools air, removes some of its moisture and filters it before it rea ches the interior of the vehicle .

49.1 Heat

All substances contain heat, and removing it makes them cooler. This is what an air-conditioning system does. Heat will always transfer from a warm object to a cooler one, by conduction, convection or radiation—or combinations of the three.

Handy hint: More information on heat, temperature and heat transfer can be found in Chapter 20.

49.1.1 Heat transfer

Figure 49.1 shows how heat is transferred (or exchanged) in an automotive air conditioner. It has an evaporator inside the vehicle, a condenser at the front of the vehicle and pipes to circulate the refrigerant between them. The system acts as a heat exchanger. The evaporator is colder than the air inside the car, so heat is transferred to it. This reduces the interior temperature. Heat is absorbed by the refrigerant in the evaporator and is carried to the condenser at the front of the vehicle, where it is transferred to the outside air.

Figure 49.2 shows how the refrigerant changes from a liquid to a vapour, and then from a vapour to a liquid as it circulates through the system. Heat from inside the vehicle boils the liquid refrigerant in

the evaporator to turn it from a liquid to a vapour. This occurs because the refrigerant has a very low boiling point, much lower than water.

In the condenser at the front of the vehicle, heat is removed by the cooler outside air, and the vapour turns back to a liquid. Liquid refrigerant from the condenser is returned to the evaporator inside the vehicle to complete the cycle.

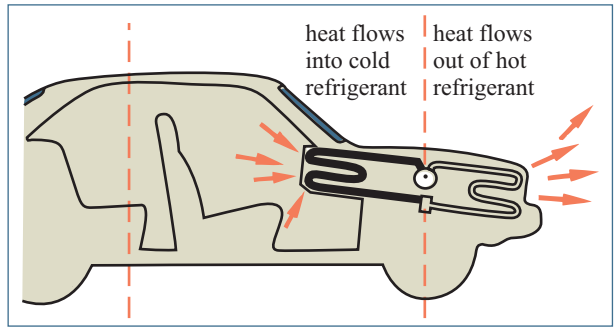


Figure 49.1 Heat transfer in an air-conditioning system

49.2 Principles of operation

Figure 49.3 shows a basic air-conditioning system and the refrigeration cycle. Refrigerant in the system passes from the compressor, through the condenser and receiver dryer at the front of the vehicle to the evaporator inside the vehicle and then back to the compressor. The system has the following parts.

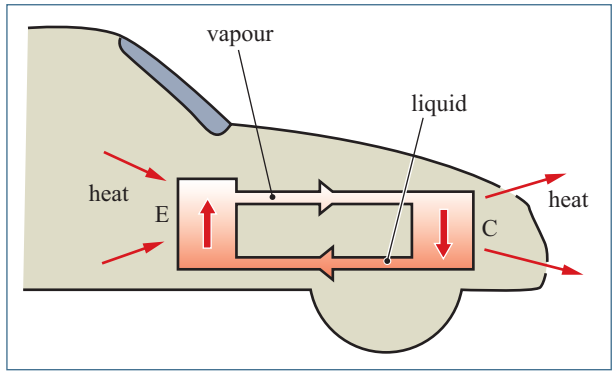


Figure 49.2 Refrigerant flow in the system E evaporator C condenser . The refrigerant changes from a liquid to a vapour and from a vapour to a liquid as heat is added or removed

49.2.1 Compressor

The compressor circulates the refrigerant through the system, drawing it in as a vapour and compressing it. This also increases its temperature, so the refrigerant passes from the compressor to the condenser as a high-pressure, high-temperature gas.

49.2.2 Condenser

The refrigerant gas enters the top of the condenser. The airflow through the condenser draws off heat and dissipates it to the outside air. The vapour is condensed to a liquid, still under high pressure, before passing from the bottom of the condenser to the receiver-dryer.

49.2.3 Receiver-dryer/Accumulator

The receiver-dryer acts as a container to hold and filter the refrigerant. It also dries the refrigerant by removing any water vapour that is present. The refrigerant then passes to the expansion valve.

An accumulator has the same functions as a receiver-dryer but is located on the low pressure side of the system between the evaporator and the compressor

49.2.4 Expansion valve

This valve provides a restriction in the system so that the liquid refrigerant at high pressure is converted to a low pressure at a lower temperature. The refrigerant then passes on to the evaporator.

There are two types of expansion valves in common use:

- thermal expansion valve (tx)
- fixed orifice

49.2.5 Evaporator

The refrigerant in the evaporator absorbs heat from the air moving over the evaporator. This causes the liquid refrigerant to boil, or turns it into a vapour. The vapour is drawn into the suction side of the compressor, where it is compressed, and the cycle recommences.

49.2.6 Blower fan

The blower fan inside the vehicle blows air over the evaporator. This cools the air, which is then blown into the passenger compartment. Air can be taken from outside the vehicle and cooled, or air from inside it can be cooled and recirculated. For heating, air is blown through the internal heater to provide warm air.

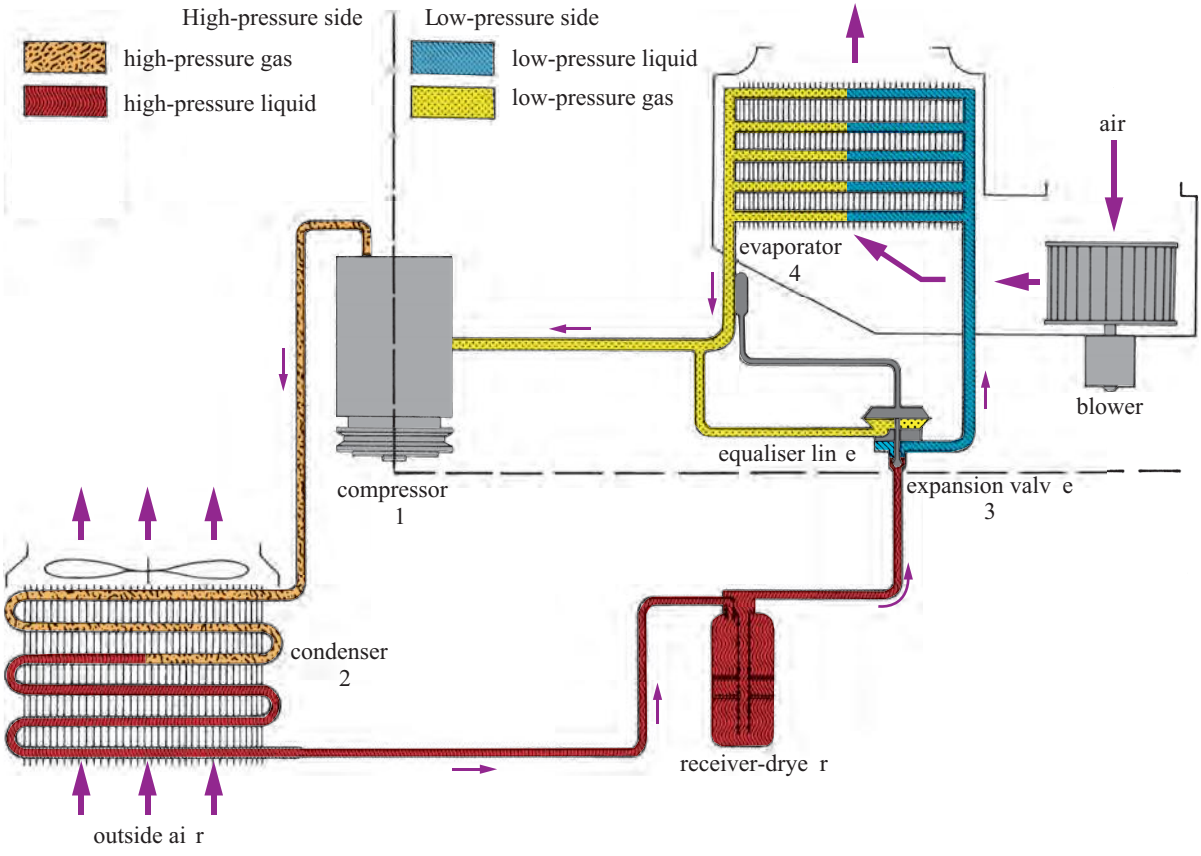


Figure 49.3 Refrigeration cycle FORD

49.3 High- and low-pressure sides

The system has a high-pressure side and a low-pressure side (this is relevant to servicing). In Figure 49.3, these sides are shown by the dotted line drawn through the compressor and the expansion valve.

The suction side of the compressor is on the low-pressure side of the system, and the discharge side of the compressor is on the high-pressure side. The expansion valve has high pressure on its inlet side and low pressure on the outlet side. This is because the flow of refrigerant is restricted by the valve.

49.3.1 Behaviour of the refrigerant

The refrigerant changes its state as it is pumped through the system, changing from a liquid to a vapour and then to a liquid. This happens because heat is added or removed. To understand the effect of heat on the refrigerant, we will first consider the effect of heat on water.

Water is a liquid, but when heat is applied it absorbs the heat and its temperature rises. When it reaches 100°C, it boils and produces steam. When the water vapour cools, it condenses, turning back into a liquid. Simple definitions of these terms are:

- Evaporation . Changing from a liquid to a vapour as a result of heat added; this occurs in the evaporator .
- Condensation . Changing from a vapour to a liquid as a result of heat removed; this occurs in the condenser .

Handy hint: The two important functions performed by the refrigerant are evaporation and condensation.

49.4 System components

The arrangement of the components of an air conditioner in a vehicle is shown in Figure 49.4, with the refrigerant flow through the system shown by arrows. The cycle can be followed through the various components in the system, starting from the compressor.

The expansion valve is located behind the evaporator (and is not shown separately in the diagram). The vacuum-switching valve and the actuator are part of the idle-up control which increases the throttle opening at idle when the engine has the load of the compressor. The construction and operation of each of the major components of the system are as follows.

49.5 Compressors

The three types of compressors used on air-conditioning systems for passenger and light commercial vehicles are *axial-type* compressors, *scroll-type* compressors and *vane-type* compressors.

The compressor parts are lubricated with a special type and specific quantity of compressor oil. This is put into the compressor when it is installed and does not normally have to be checked or replenished, except when the air-conditioning system is serviced. The compressor oil mixes and circulates with the refrigerant inside the system.

Handy hint: The oil has to mix with the refrigerant and provide lubrication, so only approved refrigerant oil is used.

49.5.1 Axial-type compressors

Figure 49.5 shows a simple arrangement of an axial compressor. A swash plate, also referred to as a *wobble plate* or *rotor*, operates a number of small pistons in cylinders. As it rotates, it moves the pistons backwards and forwards in their cylinders.

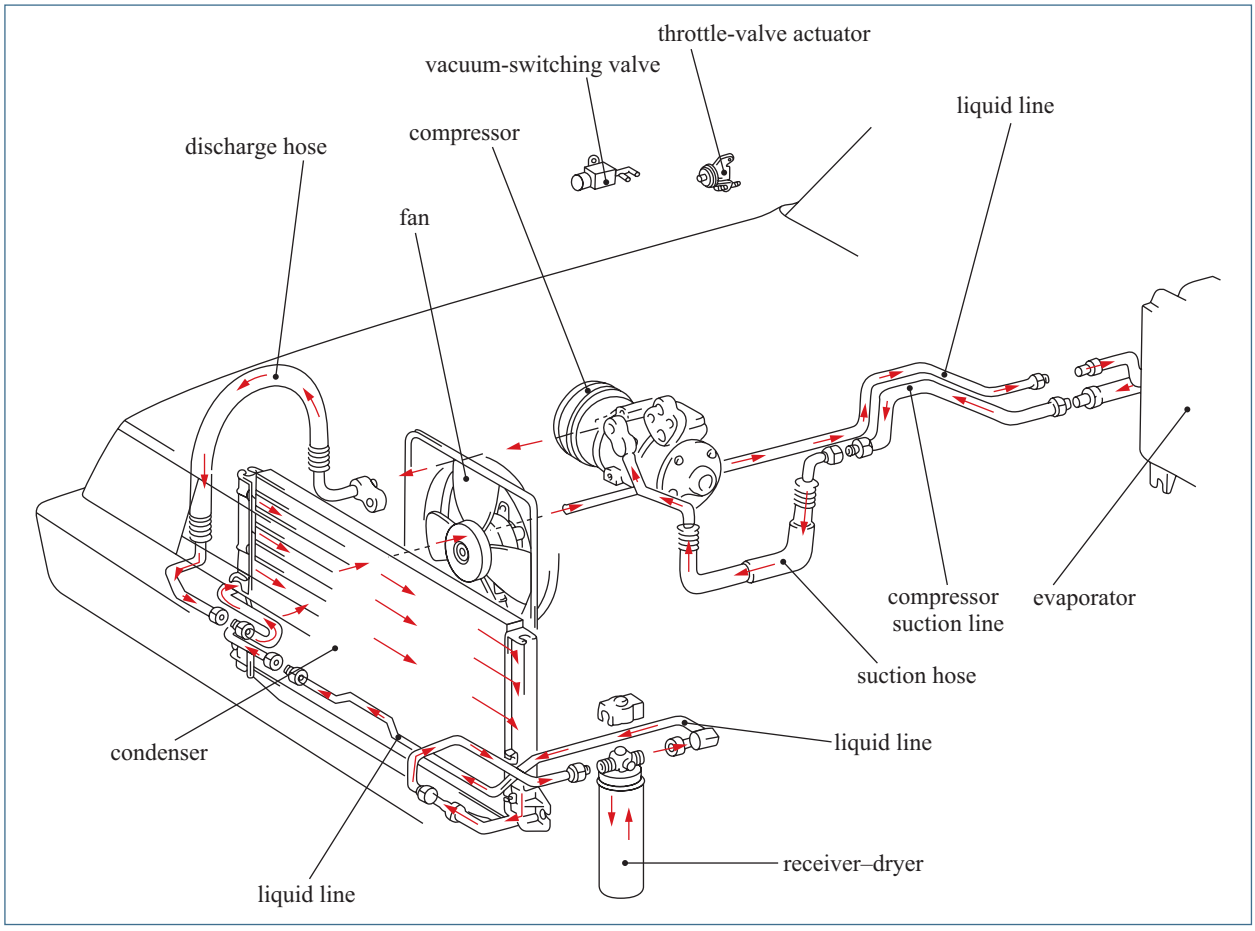


Figure 49.4 Arrangement of air-conditioner components in a veh icle

The compressor has a pulley, which is belt-driven from a pulley on the engine's crankshaft. The pulley has an electromagnetic clutch which enables the compressor to be started and stopped when the engine is running.

With the engine running and the electromagnetic clutch engaged, refrigerant vapour at low pressure is drawn into the suction side of the compressor on each inward stroke of a piston. On each outward stroke, the vapour is compressed and passed from the compressor at high pressure and high temperature.

Figure 49.6 shows a sectional view of an axial compressor. It has five cylinders (located on its left end), with the pistons operated by a swash plate. The swash plate is in contact with a cam rotor which is driven by the compressor pulley. The action of the cam gives the swash plate an eccentric motion, but it is prevented from rotating by being meshed with a stationary gear. Movement from the swash plate is transferred to the pistons by connecting rods.

Inlet and discharge valves are provided in a valve-plate assembly which fits under the cylinder head. Star-shaped leaf valves are used with the five inlet and five discharge ports. The valves are normally held closed by their spring action, but are opened as required by suction or pressure in the cylinders.

Handy hint: The increase in temperature is a natural result of the increase in pressure .

Variable-displacement axial compressor

Some axial-type compressors, such as the one shown in Figure 49.7, can change the length of the stroke of their pistons while in operation. This enables the output to be varied to suit the cooling load on the air-conditioning system.

A solenoid valve is located on the discharge side of the compressor, between the low-pressure and high-pressure passages. The length of stroke of the pistons is changed by varying the pressure on each end of the pistons. This varies the output of the compressor.

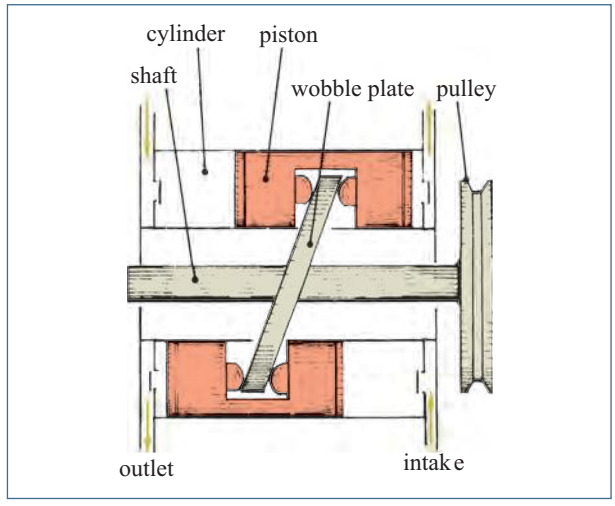


Figure 49.5 Principle of an axial compressor

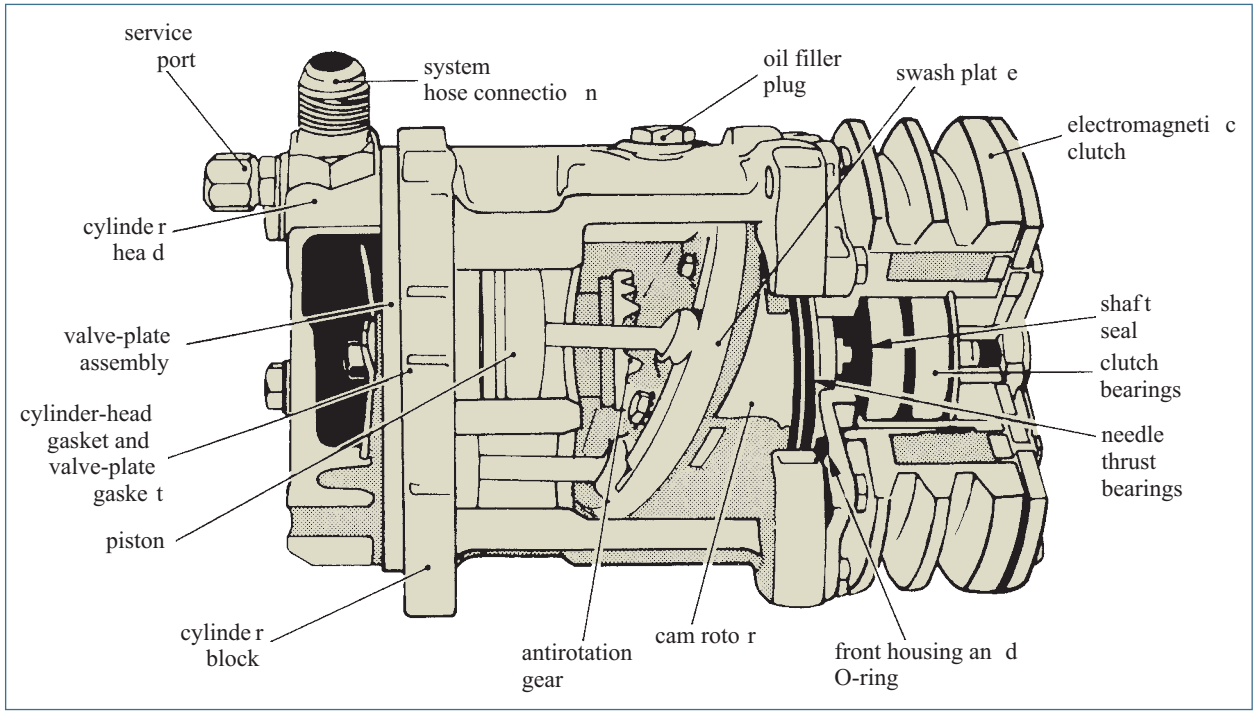


Figure 49.6 Sectional view of an axial compressor MITSUBISHI

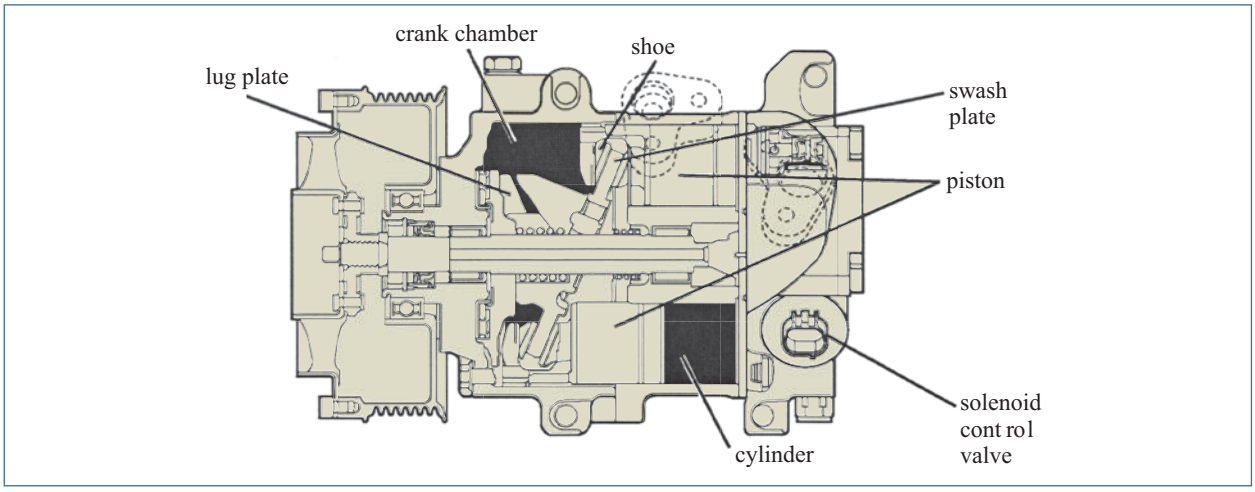


Figure 49.7 Variable-displacement axial compressor (sectional view showing the major components)

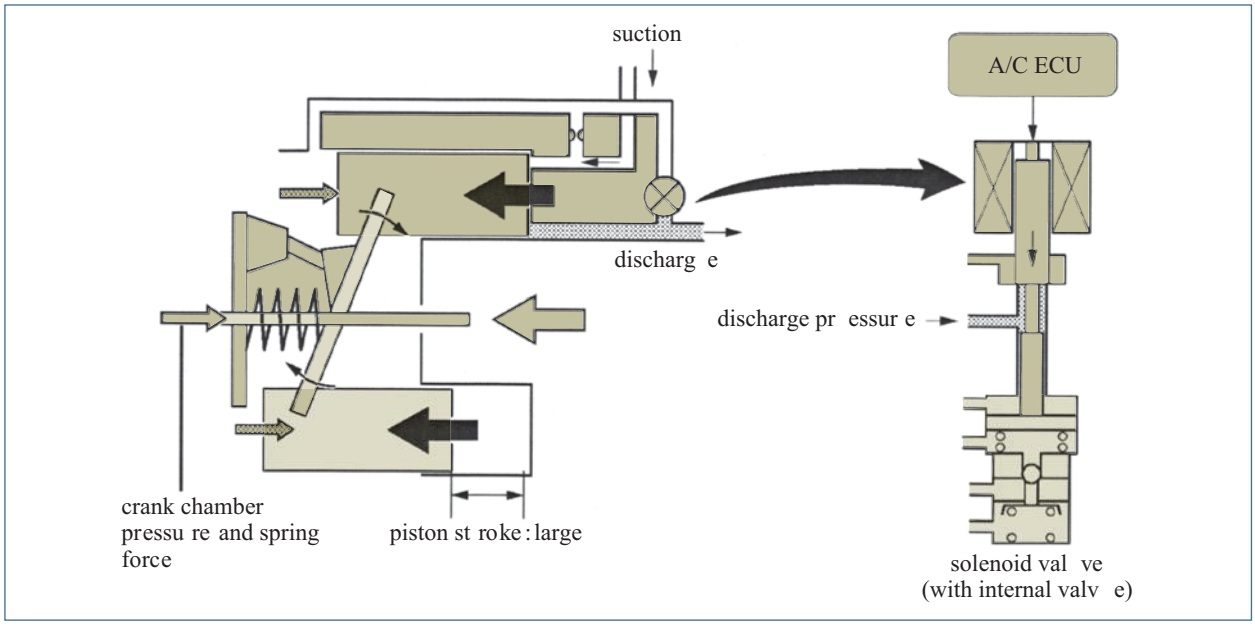


Figure 49.8 Basic illustration of a variable-displacement axial compressor with the swash plate in the maximum strok e position

Figure 49.8 is a simplified drawing of this type of compressor. When the solenoid valve is closed, the pressure on the right-hand end of the piston is greater than the pressure on the left-hand end. The spring is compressed and the swash plate tilted to increase the length of the stroke of the pistons.

When the solenoid valve is open, there is pressure on both ends of the pistons and this alters the angle of the swash plate to vary the output of the compressor. With equal pressure on both ends of the piston, the swash plate will be in a neutral position and there will be no compressor output.

49.5.2 Scroll-type compressor

Figure 49.9 shows a scroll-type compressor. This has the usual electromagnetic clutch, but also has a pair of scrolls which compress the refrigerant. One scroll is fixed and the other is movable. The scrolls are meshed with each other. The movable scroll is driven by a crank and eccentric bush so that it orbits within the fixed scroll.

The action of the scrolls is shown in Figure 49.10. The space formed between them changes as the movable scroll orbits. It gradually moves towards the centre, compressing the refrigerant as it does so. The eccentric motion of the movable scroll is produced by offsetting the eccentric bush on the stud pin.

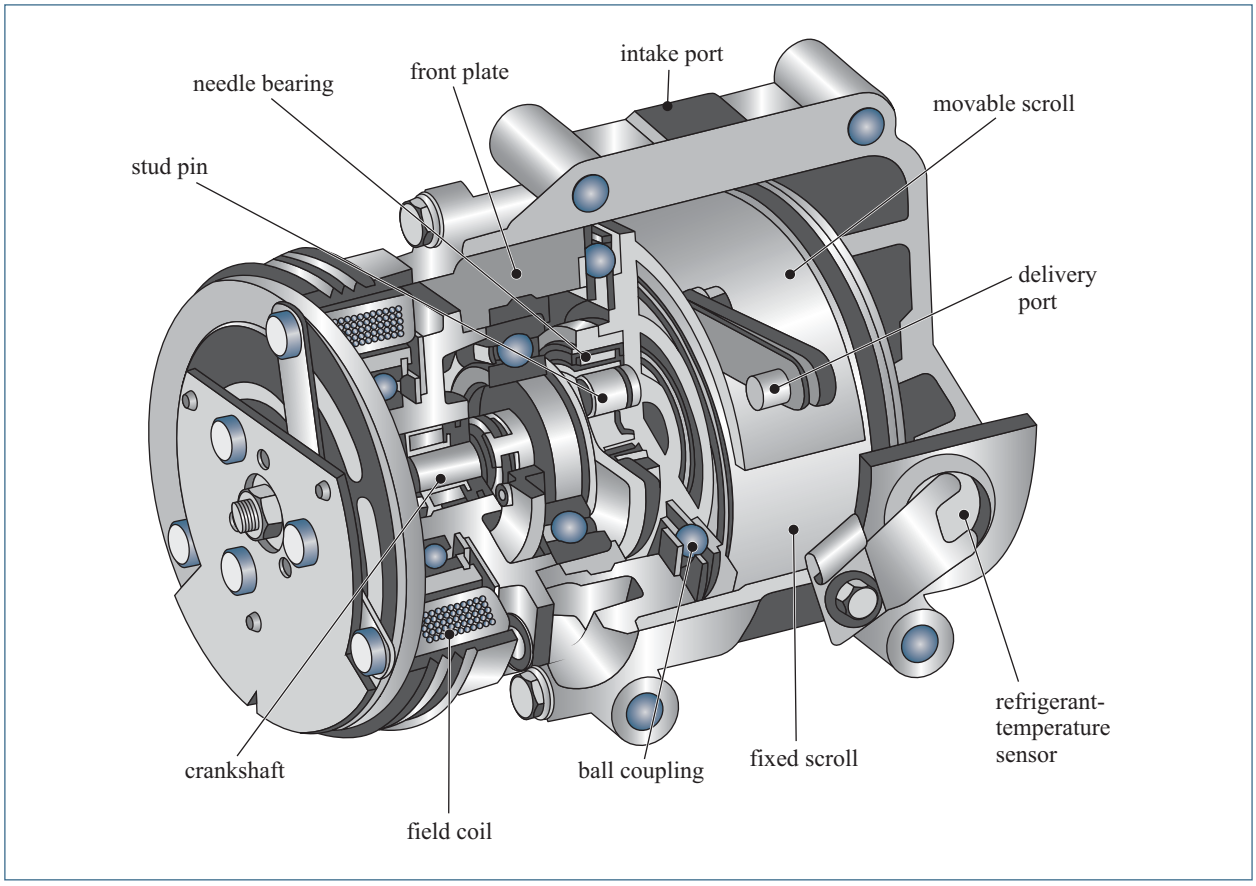


Figure 49.9 Sectional view of a scroll-type compressor

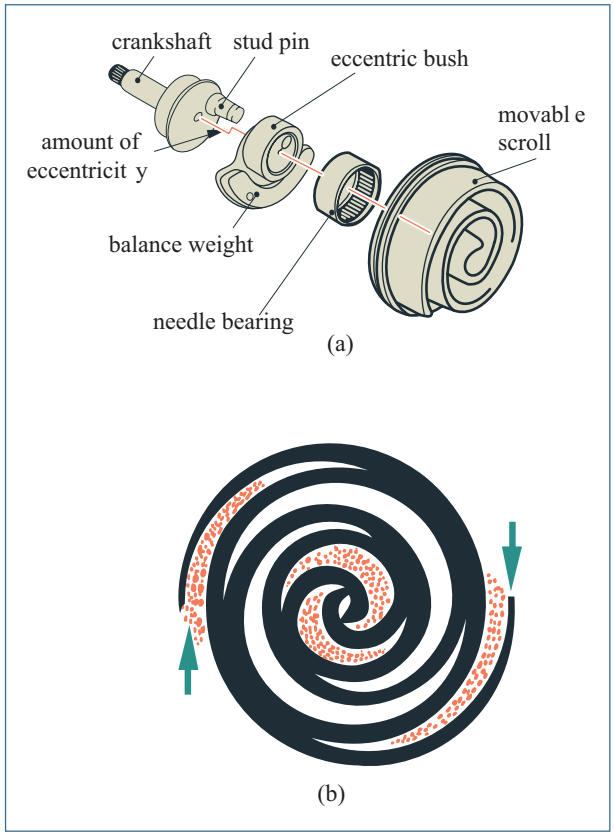


Figure 49.10 Scroll-type compressor (a) moving parts (b) pumping action of the scrolls

49.5.3 Vane-type compressor

This type of compressor has vanes fitted into slots in a rotor (Figure 49.11). The rotor is mounted off-centre in the pump housing, so that the size of the pumping chamber is reduced to compress the refrigerant as the rotor turns in its housing.

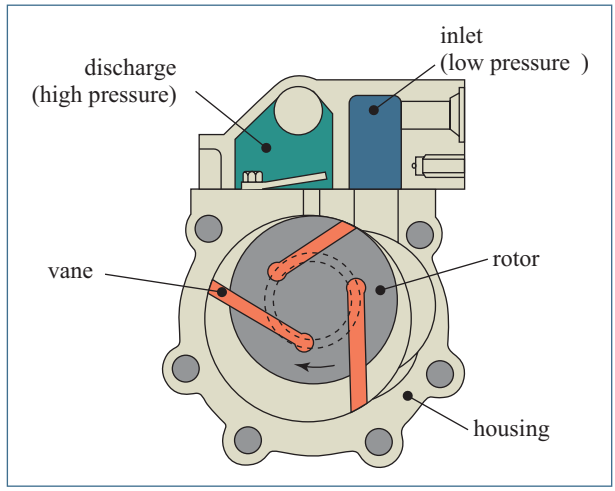


Figure 49.11 Arrangement of a vane-type compressor

49.6 Other components

49.6.1 Electromagnetic clutch

Figure 49.12 shows an electromagnetic clutch. The field coil, which can be seen in Figure 49.9, is secured to the compressor body and does not turn. The clutch centrepiece is attached to the end of the compressor shaft.

The pulley is mounted on a bearing and is free to rotate. When the field coil is energised, the magnetic field attracts the centrepiece and holds it against the face of the pulley, engaging the clutch. The pulley, clutch and shaft will then rotate together.

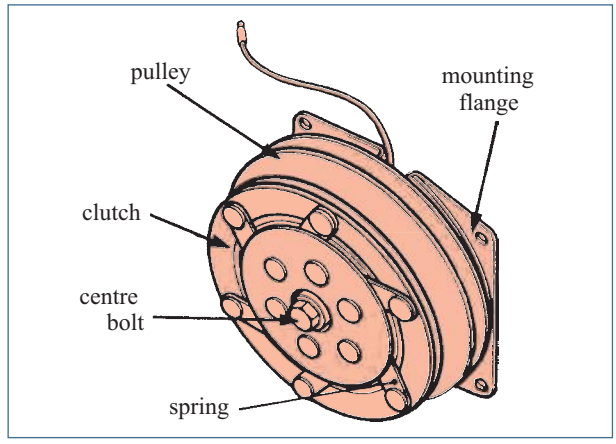


Figure 49.12 Electromagnetic clutch of a compressor

The clutch allows the compressor to be stopped and started with the engine running. When the air conditioning is not in use, only the pulley is turning—the compressor is stationary.

49.6.2 Condenser

The condenser consists of tubes to carry the refrigerant and thin cooling fins to transfer heat to the air passing over them. Figure 49.13 illustrates the design of the condenser. It is, in effect, a small radiator and it performs the same function as the radiator in the engine's cooling system.

Refrigerant from the compressor enters the top of the condenser as a high-pressure, high-temperature vapour. As the temperature of the refrigerant is higher than that of the outside air, heat will be removed from the refrigerant via the tubes and fins of the condenser and dissipated to the air. This causes the refrigerant to change its state, and it becomes a high-pressure, high-temperature liquid as it leaves the condenser.

The condenser is mounted at the front of the radiator where it is exposed to the air. A larger engine fan, or an additional electric fan, is fitted to ensure that an adequate airflow is provided.

49.6.3 Receiver-dryer

This is a reservoir or container in which the high-pressure liquid is filtered and stored before being delivered to the thermal expansion valve. A receiver-dryer is shown in Figure 49.14. Liquid refrigerant from the condenser enters through the inlet connection and passes down through the filter and desiccant

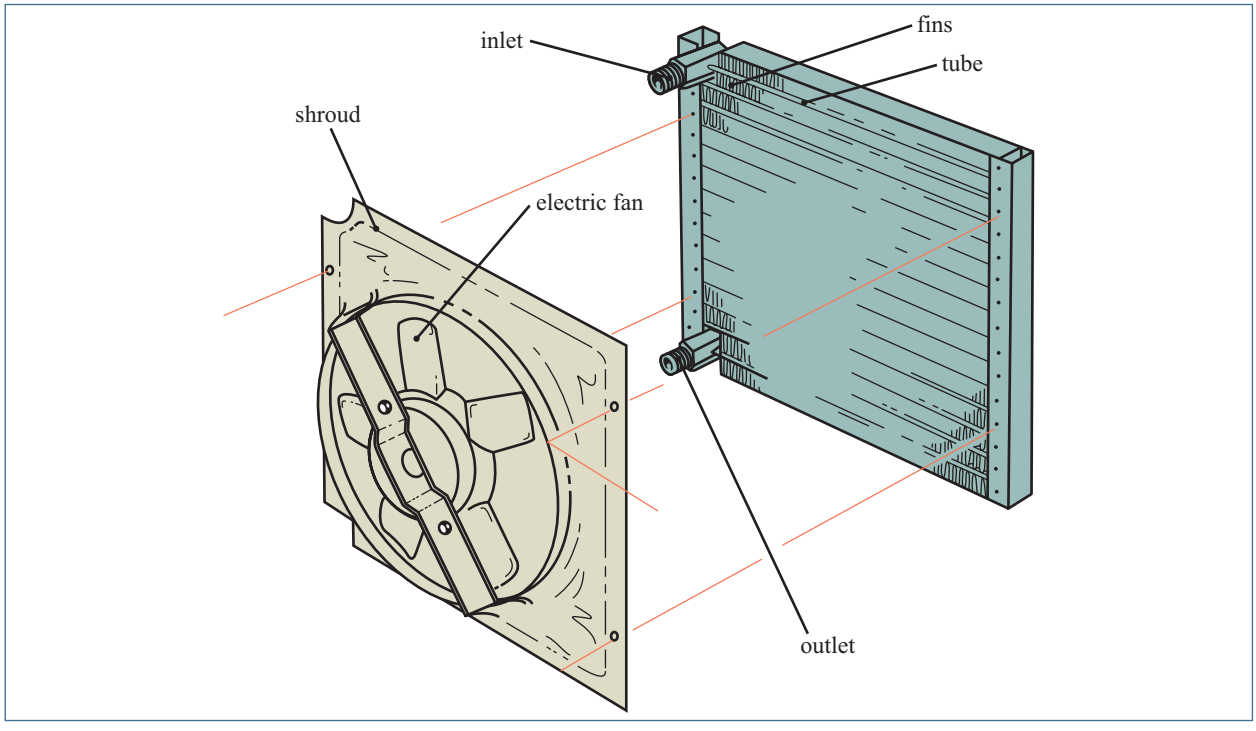


Figure 49.13 Air-conditioner condenser and fan

(drying agent). The desiccant removes moisture (water) from the refrigerant before it is drawn from the bottom of the container through the pickup tube and outlet to the expansion valve.

Handy hint: The container in some systems that performs the same functions as a receiver-drier is referred to as an accumulator.

49.6.4 Expansion valve

A simple thermostatic expansion valve (TX valve) consists of a diaphragm in a chamber operating a valve (Figure 49.15). The amount of refrigerant passing through the valve is metered by the valve opening. This causes a drop in pressure on the outlet side of the valve and also a drop in temperature, because pressure and temperature are related. A low-pressure, low-temperature liquid then passes into the evaporator.

The chamber above the diaphragm is connected by a capillary tube to a temperature-sensing bulb. This is attached to the outlet end of the evaporator coil. The bulb and capillary tube are filled with gas, which expands and contracts as the temperature of the evaporator increases or decreases. This expansion or contraction is transferred through the capillary tube to the chamber above the diaphragm.

The action of the diaphragm and valve are controlled by the pressure on top of the diaphragm from the capillary tube and a spring beneath the valve, as follows:

1 When the temperature of the evaporator drops, the pressure in the bulb and capillary tube also drops. This allows the spring under the valve to move the valve towards the closed position, reducing refrigerant flow.
2 When the temperature of the evaporator rises, the pressure in the bulb and capillary tube also rises. This causes the diaphragm to move the valve towards the open position, increasing refrigerant flow.

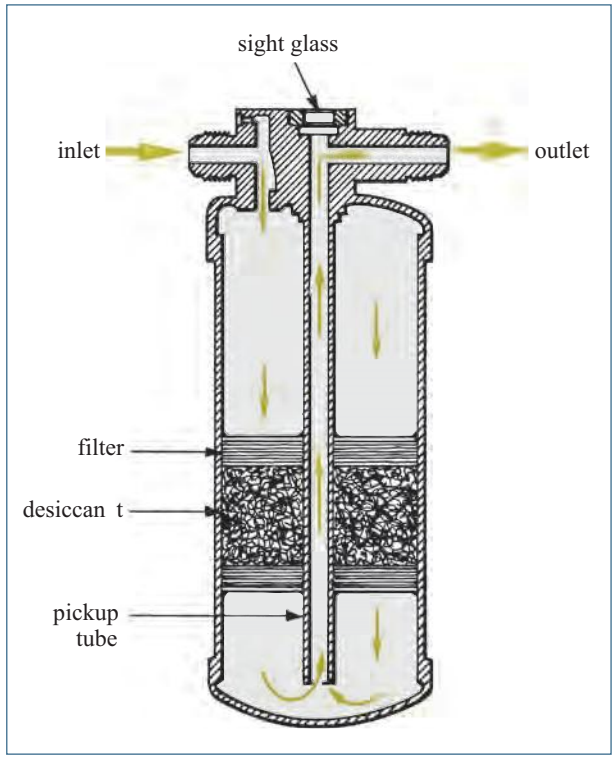


Figure 49.14 Section through a receiver-dryer

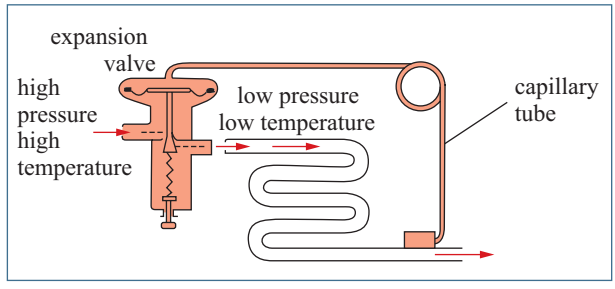


Figure 49.15 Simplified expansion valve

Some systems use a fixed restrictor or orifice in the same position as the TX valve. A pressure/temperature drop occurs on the evaporator side of the restrictor.

49.6.5 Orifice tube

A fixed orifice tube is shown in Figure 49.16. The refrigerant is forced to flow through a fine restriction (or orifice). This causes both a pressure and temperature drop in the refrigerant entering the evaporator. The rate of flow depends on the pressure difference across the restriction. A fine gauze filter at the inlet and outlet sides of the orifice tube filters any contaminants, preventing them from passing onto the evaporator. Orifice tubes have different size restrictions, depending on the A/C system; the different sizes can be identified by the outer plastic tube colour. The tube is fitted in the same location as a TX valve.

49.6.6 Accumulator (orifice tube system)

The accumulator shown in Figure 49.17 stores refrigerant, filters particles, absorbs moisture and separates vaporous refrigerant R134a from liquid R134a. The orifice tube system works normally when the refrigerant leaves the evaporator as a mixture of vapour and liquid. The liquid enters the accumulator and falls to the bottom; the vapour rises to the top and continues onto the compressor. The liquid R134a in the bottom of the accumulator gradually vaporises off. This vapour rises and then returns to the compressor.

Orifice tube system operation

The temperature at the evaporator outlet is controlled by interrupting the flow of refrigerant in the system. This is achieved by switching the compressor clutch on or off. This is known as a *cycling clutch* method. The clutch switch is operated by a pressure switch (not shown) normally fitted to the accumulator on the low pressure side. The switch cuts power to the clutch when the pressure gets too low. This also prevents damage to the compressor.

49.6.7 Evaporator

The evaporator unit is mounted inside the vehicle. It has a tube-and-fin construction (Figure 49.18). Warm air from the blower motor is blown through the evaporator. As the air passes through the evaporator, it is cooled and dried before entering the passenger compartment. The heat from the air causes the refrigerant in the evaporator to boil and turn to a vapour. Heat is absorbed by the refrigerant and carried through the system to the compressor.

The evaporator also tends to reduce the humidity of the cooled air. As the air is cooled, moisture in the air condenses on the fins of the evaporator and is drained away as water. Some particles of dust may collect in the moisture on the evaporator and, to some extent, the air is also cleaned.

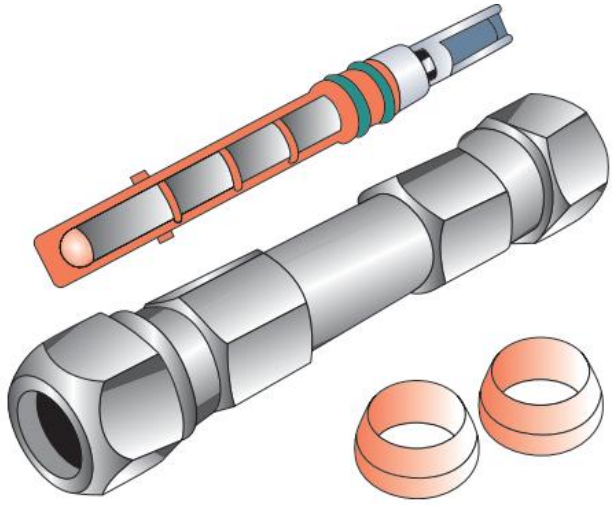


Figure 49.16 A fixed orifice tube and housing

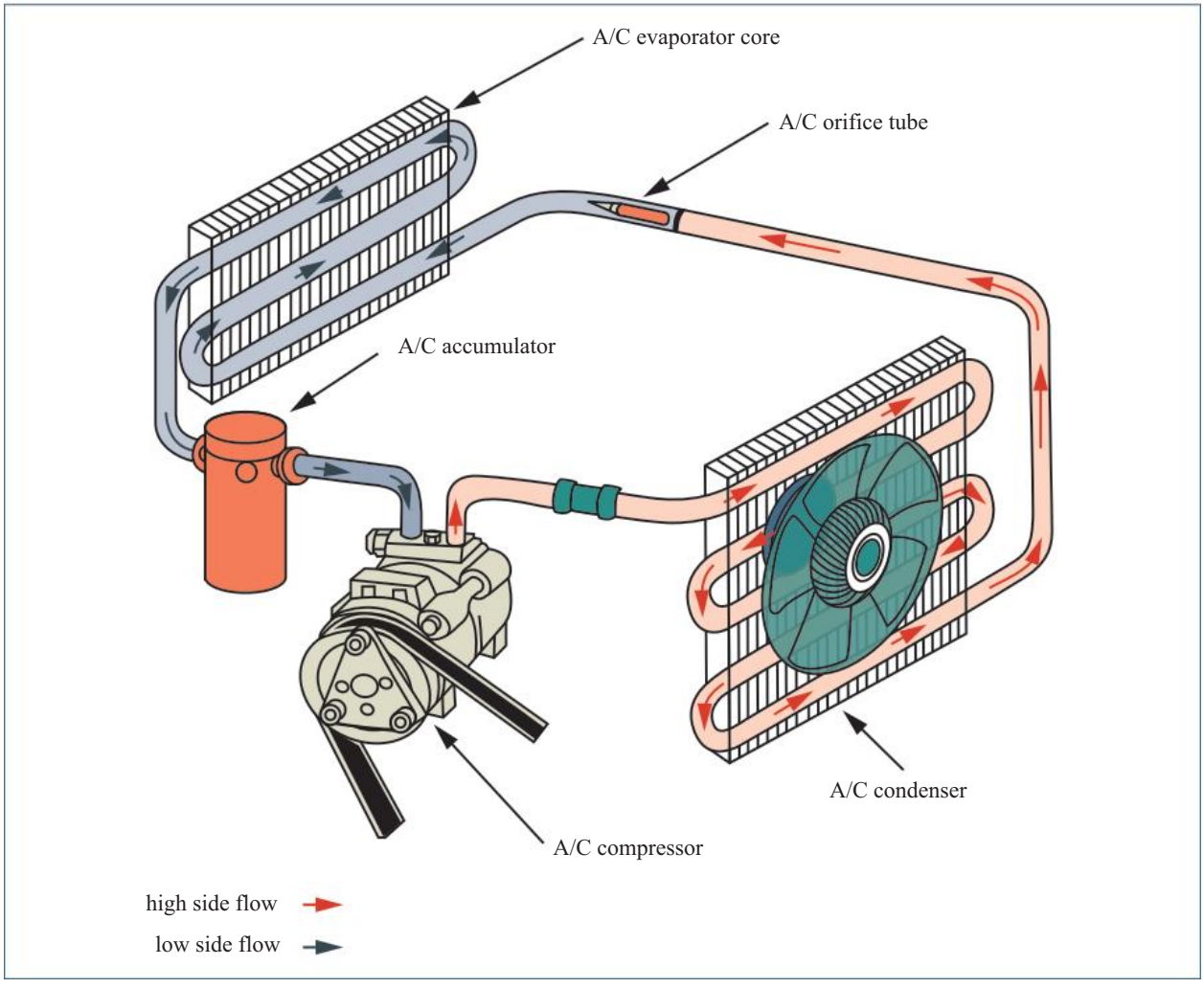


Figure 49.17 A simple orifice tube system showing the location of major components

Figure 49.19 illustrates the two functions of the evaporator:

1 Liquid is entering the evaporator tube from the expansion valve (at the left) and leaving the tube as a vapour (on the right).
2 Air is being drawn into the ends of the blower , as shown by the large arrows, and then blown across the coils of the evaporator .

Figure 49.19(a) illustrates the heat-absorption process. Heat is absorbed from the incoming air so that cool air passes into the interior of the vehicle.

Figure 49.19(b) illustrates the dehumidifying process. Wet air enters the blower, the moisture in the air condenses on the evaporator and comparatively dry air passes from the evaporator to the interior of the vehicle.

49.6.8 Thermostat

The thermostat is fitted to the evaporator and senses its temperature. Depending on the temperature, the thermostat switch either energises or de-energises the coil of the electromagnetic clutch to cut the compressor either in or out of operation.

With the switch contacts closed, the compressor operates normally to provide a flow of refrigerant through the evaporator. However, when the temperature of the evaporator nears freezing point, the sensor of the thermostat opens the switch contacts to stop the compressor.

Once the temperature of the evaporator increases, the thermostat cuts the compressor in again to provide cooling. In this way, the compressor is cycled in and out of operation to maintain the evaporator at the required temperature.

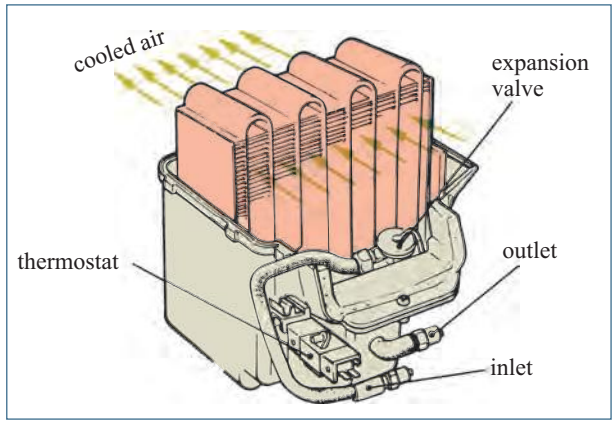


Figure 49.18 Evaporator inside the vehicle cools the air GM HOLDEN LTD

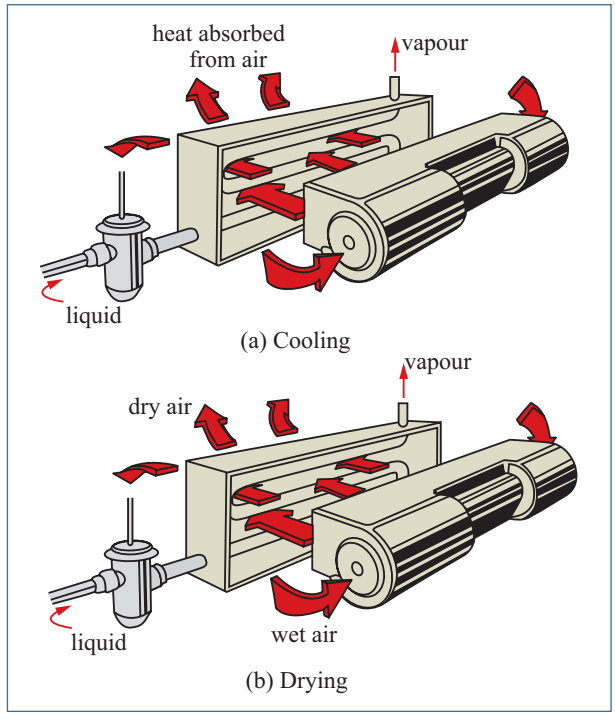


Figure 49.19 The two functions of the evaporator

49.7 Refrigerant and compressor oil

49.7.1 R12 refrigerant

R12 refrigerant has the following properties:

- non-poisonous
- non-to xic
- non-corrosive
- non-explosive
- easily mix ed with oil
- vaporises (boils) at –30°C
- heavier than air .

The refrigerant has such a low boiling point that it becomes a vapour at normal temperatures. For this reason, it must be contained under pressure in special cylinders. When pressurised, it becomes a liquid, so that the cylinder contains liquid with the space above the liquid filled with saturated vapour.

Sustainability: If a system has to be serviced, any R12 must be collected in a refrigerant recovery unit and returned to the refrigerant supplier for correct disposal. It is illegal to release it into **the atmosphere**.

49.7.2 R134a refrigerant

The properties of R134a are similar to those of R12, except that R134a vaporises (boils) at a slightly higher temperature of −26° C. The desiccant in an R134a receiver-dryer is different, so an R12 receiver-dryer must not be used.

Vehicles with R134a refrigerant have a placard in the engine compartment showing its presence. The type of oil is also shown. Older systems that have been re-gassed should have a placard showing that R12 is still used in the system.

49.7.3 Hydrocarbon (HC) and hydrofluoroolefin (HFO) refrigerants

Hydrocarbon (HC) R600a and R290 refrigerants are blended as a replacement in automotive air-conditioning systems. This blend is more environmentally friendly than CFC (R12) and HFC (R134a). Storage and handling is the same as for LP gas cylinders, and it is safe to use.

R1234yf is a hydrofluoroolefin (HFO) refrigerant. HFO refrigerants, which are composed of hydrogen, fluorine and carbon atoms, are now being used in some vehicles, their presence being indicated by decal and by the different service ports. Due to its composition, R1234yf does not damage the ozone layer and has minimal global warming impact.

Both of these refrigerants are flammable; HC highly so, HFO mildly so.

⚠ Safety: Care should always be taken when using flammable refrigerants. Eliminate all ignition sources, including cigarettes, open flames and spark-producing tools when handling them.

49.7.4 Precautions with refrigerant

The following precautions should always be taken with refrigerant:

1. Wear gloves and safety glasses. The low temperature at which refrigerant evaporates is dangerous to skin.
2. Work in a well-ventilated area. As refrigerant is heavier than air, it will displace air if released in a confined space, causing a shortage of oxygen.
3. Do not allow refrigerant to be released into the atmosphere. Refrigerant is detrimental to the environment. A recovery station must be used when a system is being discharged (see 'Servicing the system').
4. Keep dismantled systems capped. While refrigerant on its own is non-corrosive, it will produce corrosive chemicals if associated with water. Special methods remove air and moisture from the system before it is recharged.
5. Keep heat sources away. Heat from welders, steam cleaners or heaters should not be applied to, or used near, components or lines that contain refrigerant—heating could cause high pressures.
6. Handle and store containers correctly. Containers of refrigerant should be handled with care and stored upright in a cool place.

49.7.5 Refrigerant (compressor) oil

The compressor contains a measured quantity of oil that lubricates its moving parts. The oil is put into the compressor when it is first installed and normally does not need checking or servicing. All the oil does not remain within the compressor, but some circulates through the system with the refrigerant. If a compressor is removed, the oil would be drained and a measured quantity replaced, as shown in Figure 49.20.

The quantity of oil in the system will be reduced if the refrigerant is lost or if a part of the system is removed. As an example, a system might require a total of only 600 grams of oil, and if a receiver-dryer is removed, about 25 grams would be lost (and for a condenser, about 60 grams would be lost).

⚠ Safety tip: These are examples only; the exact quantity of oil must be used for the particular system.

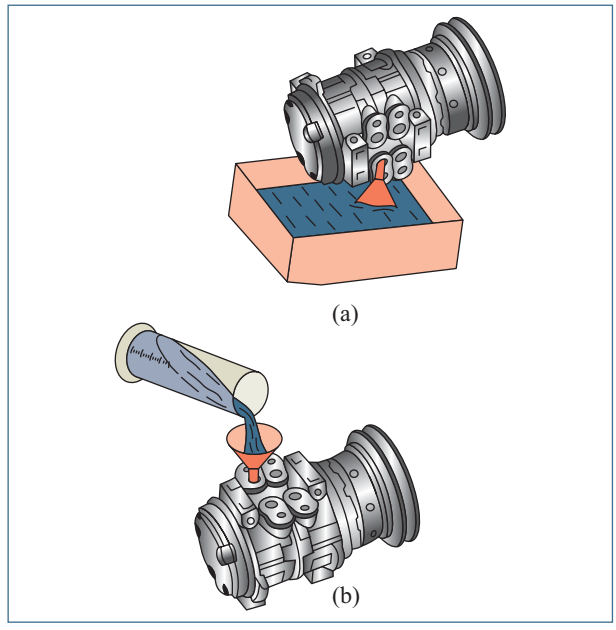


Figure 49.20 Compressor (a) draining the compressor oil (b) replacing the oil

There are different types of compressor oil for use in R12 and R134a systems. These oils must not be mixed because compressor damage will occur. The R12 system uses a mineral-type oil and the R134a system uses a *synthetic ester oil*, or *polyalkylene glycol* (PAG).

The following are precautions that should be taken with polyalkylene glycol oils:

1 Oil should not be allowed to contact bare skin. Gloves should be worn.
2 Avoid breathing the mixture of oil and refrigerant.
3 Oil spilt on the paintwork should be washed off immediately .
4 Oil containers should be k ept closed unless being used. The oil is hygroscopic, which means that it will absorb water .
5 Components and parts of the system that are dismantled should be sealed to prevent the entry of moisture that could mix with the oil.

49.8 Air-conditioner controls

Figure 49.21 shows a basic arrangement of air conditioning controls, although there are many different arrangements. The basic controls for an air conditioner are:

- an on–off switch with an indicator light
- a switch to adjust the blower speed (a rotary switch or a lever)
- a lever to select fresh outside air , or to recirculate the inside air
- vents with vanes that can be adjusted to direct the flow of air
- a lever control with cables to open and close flaps in the ducts to direct the cool air to different vents .

There is also a lever for the car heater which is not part of the actual air conditioner. This controls the flow of coolant through the heater and provides heated air at different temperatures. The controls can provide a mixture of air from the air conditioner and air from the heater. The result is warm, dry air inside the vehicle.

49.8.1 Ducting

A diagram of the ducting for an air-conditioning and heating system is shown in Figure 49.22. This has flaps that open or close parts of the ducting to direct air to the various vents.

The blower takes in outside air or recirculated air, depending on the position of the intake flap. The air leaving the blower passes through the evaporator, where it is cooled before being directed to the vents selected by the driver.

An air-mix flap allows warm air from the heater to be mixed with cool air from the evaporator. With the air conditioner turned on, fresh air is dehumidified (the moisture is removed) as it passes through the evaporator and is then warmed in the heater. This mixture of cold and warm air is used for weather conditions where the windscreen and windows tend to fog up.

Handy hint: Warm, dry air directed towards the windscreen will clear fogging from the inside surface .

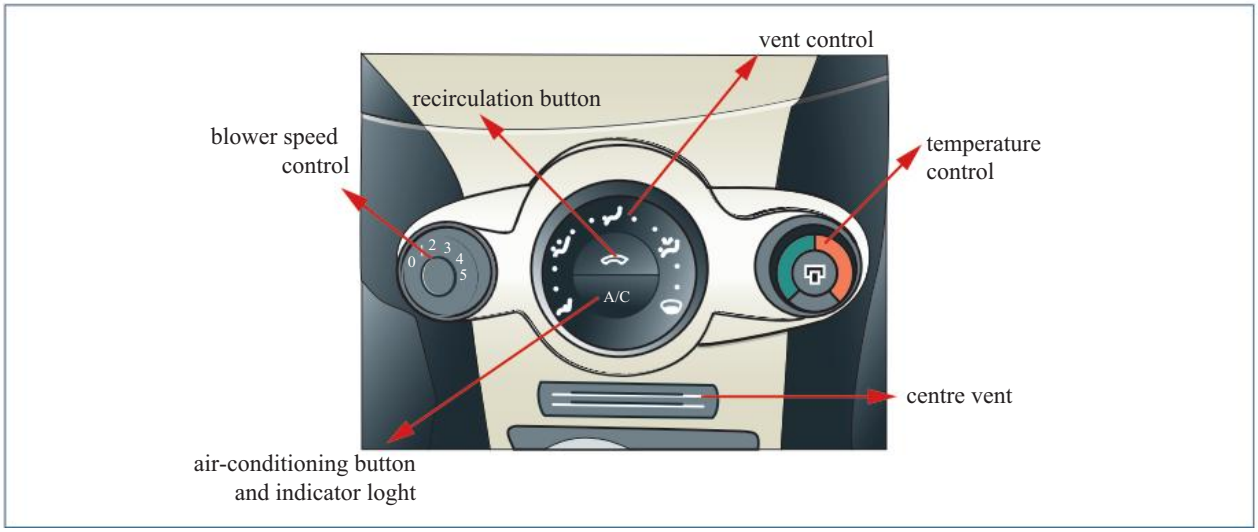


Figure 49.21 Basic controls for an air-conditioning and heating syst em

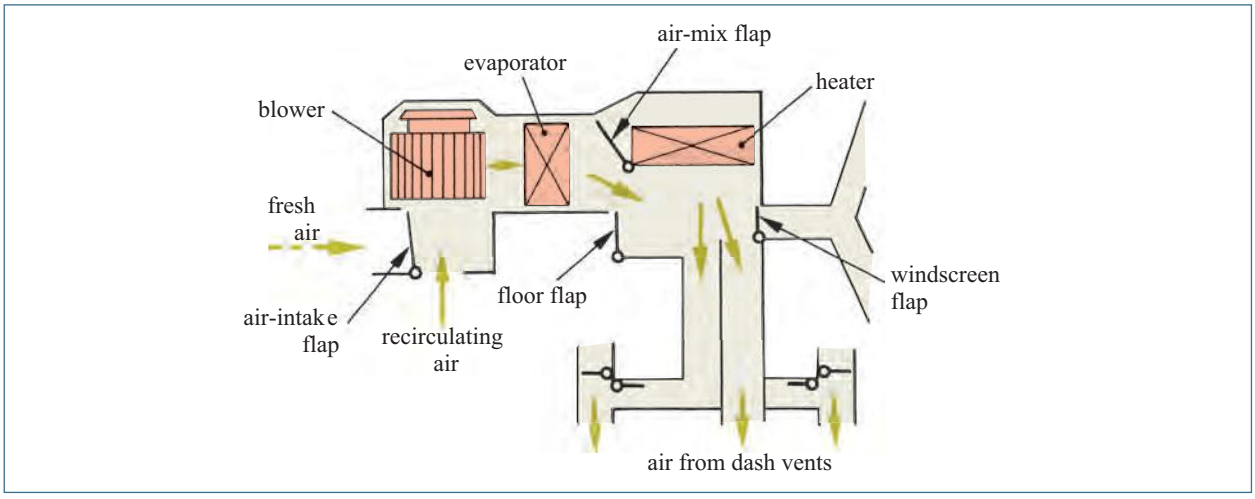


Figure 49.22 Diagram of the ducting for an air-conditioning and h eating system FORD

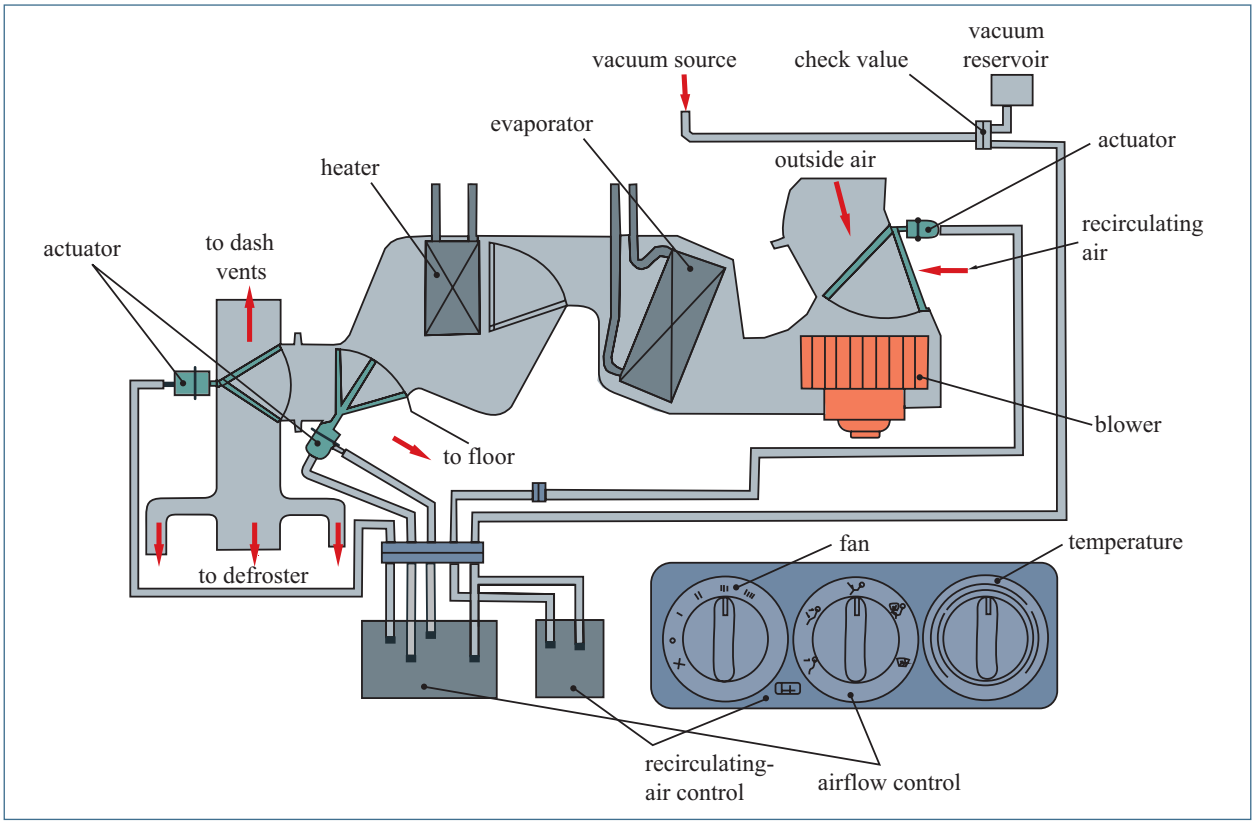


Figure 49.23 Arrangement of vacuum-operated flaps in the ducts of an air-conditioning and heating system

49.8.2 Vacuum controls

While levers and cables usually open and close the flaps in the ducting, some systems use vacuum or electrical controls for this purpose. With vacuum controls like those shown in Figure 49.23 the flaps have actuators operated by engine vacuum. Vacuum switches on the panel are connected by small pipes to a vacuum reservoir and to the actuators of the flaps. Rotating the airflow control directs vacuum to the required actuator to open or close the flap.

Handy hint: In the diagram, the flaps are shown in their alternative positions. Operating the actuator swings the flap from one position to the other .

Figure 49.23 shows rotary controls that direct vacuum to the different actuators. The air-mix flap between the heater and the evaporator is positioned by a cable or by an electric motor (these are not shown). This flap controls a mixture of hot and cold air.

Vacuum actuator

Figure 49.24 shows a vacuum actuator. Vacuum directed to its vacuum ports overcomes the spring force to move the control rod as shown. The control switch can direct vacuum to only one of the ports, or to both ports.

This is a two-stage actuator that gives its control rod three possible positions. This enables its flap to be moved to three different positions. The flap can be fully closed, opened half-way as a first stage, and then opened fully as a second stage.

49.9 Air-conditioner electrical circuit

Figure 49.25 shows a simplified electrical circuit for an air-conditioning system. The three main operating parts are the *blower,* the *compressor clutch* and the electric *engine/condenser* cooling fan. There are three relays shown, and a number of switches. Points relating to the circuit are:

1 The blower switch has four positions to select the four different speeds of the blower motor .
2 The blower can operate independently of the air conditioner . It can supply outside air , recirculated air , cool air or warm air.
3 The air conditioner will operate only if the blower is switched on. R elay 1 must be energised before the compressor can operate .
4 The engine/condenser cooling fan starts when the air conditioning is switched on. It is operated by relay 2 and runs whenever the compressor is running.
5 The thermostat switch opens and closes to engage and disengage the magnetic clutch to cycle the compressor .
6 The dual-pressure switch protects the system. It is normally closed but will open if the pressure in the system becomes too high or too low . This will stop the compressor from operating to prevent damage .
7 Relay 3 operates the magnetic clutch.

Handy hint: In an electronically controlled system, the blower switch would be replaced with an electronic control.

49.10 Automatic climate control

Air-conditioning systems can have automatic controls known as *electronic climate controls.* Extra components are used with the vacuum or electrical control systems. The systems automatically provide cool air from the air conditioner, or warm air from the heater, or a mixture of cool and warm air, to maintain the inside of the vehicle at a regulated temperature.

An automatic system has a number of sensors which gauge:

- ambient air temperature
- temperature inside the vehicle
- evaporator temperature
- coolant temperature in the heater
- sunlight through the windscreen.

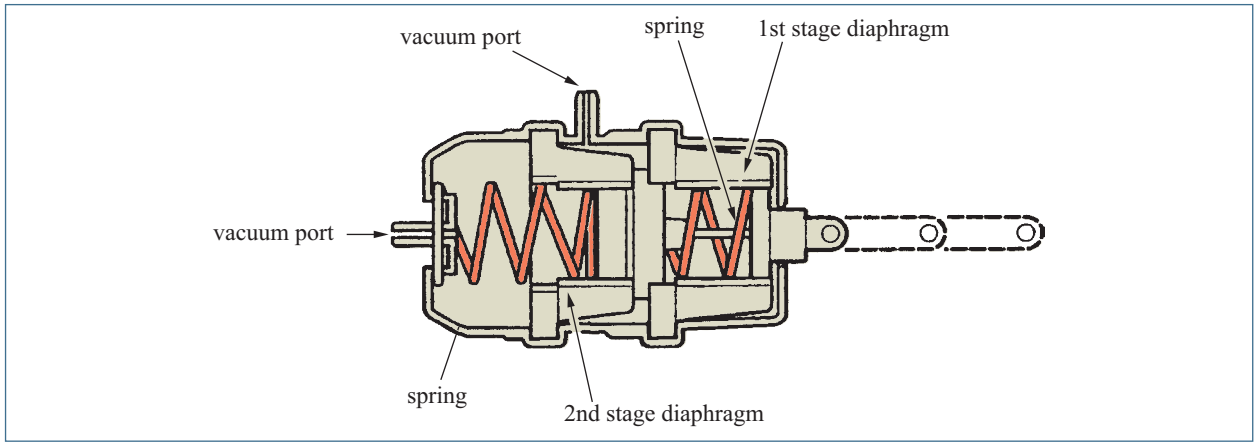


Figure 49.24 A two-stage vacuum actuator for controlling the po sition of the flaps in the air-conditioning ducts
GM HOLDEN LTD

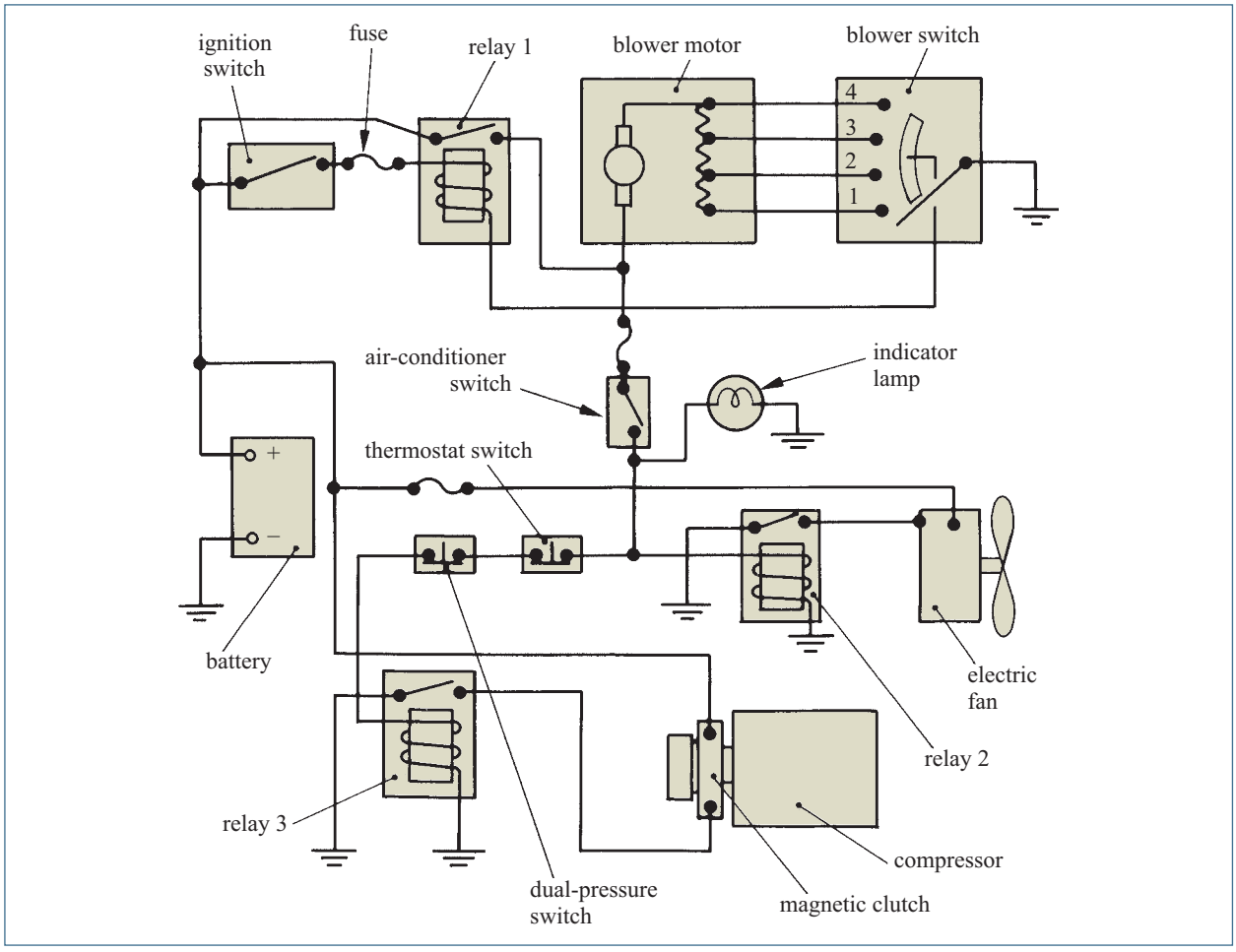


Figure 49.25 Simplified air-conditioner electrical circuit—includes a variable-speed blower, electric cooling fan and the compressor magnetic clutch

This information is fed to an ECU which provides outputs to the compressor clutch to engage and disengage, to the blower to vary its speed, to solenoids to control the vacuum units and flaps and to the coolant valve of the heater.

Handy hint: Ambient air temperature is the outside air temperature, which is taken by a sensor at the front of the vehicle.

A control panel for an automatic air conditioner is shown in Figure 49.26. This has a display panel that shows outside and inside temperatures, distribution mode and blower speed and switches and controls for automatic operation and for manual operation.

49.10.1 Electronic control system

Figure 49.27 is a schematic of an electronic climate control. This shows the basics of electronic control. A micro-processor has inputs from a number of sensors and also from the engine's electronic control unit. It has an output that controls the air-mix flap motor and outputs that operate a bank of solenoid valves. There is a solenoid valve to control the blower speed, another for the heater coolant valve and one for each of the flap actuators.

In automatic mode, the driver sets the controls to the desired level of comfort. The microprocessor monitors the input signals from the sensors and sends output signals to the blower, the air-mix flap motor and the solenoid valves.

The output signals energise or de-energise the appropriate solenoids. This alters the blower speed, opens or closes the coolant valve and operates the actuators to move the flaps. Various combinations are available to automatically control the comfort conditions inside the vehicle.

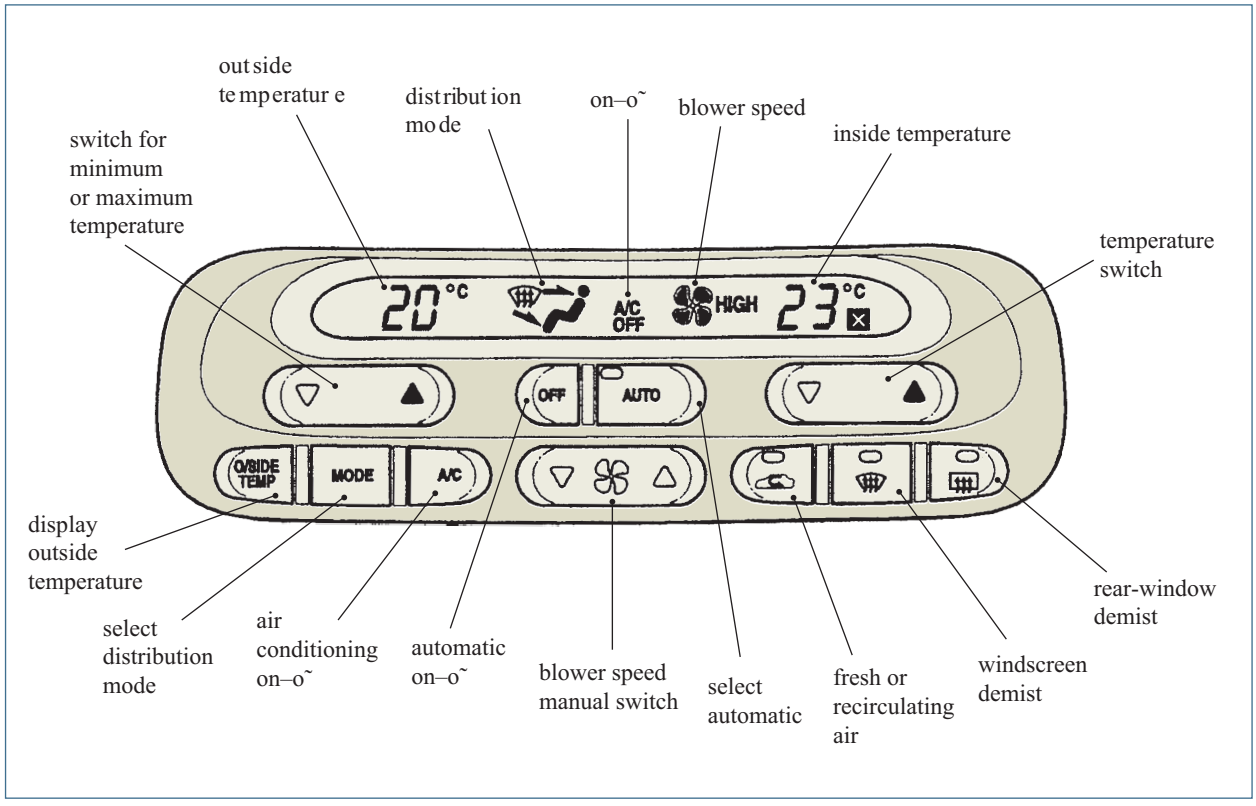


Figure 49.26 Automatic air-conditioning controls and display panel GM HOLDEN LTD

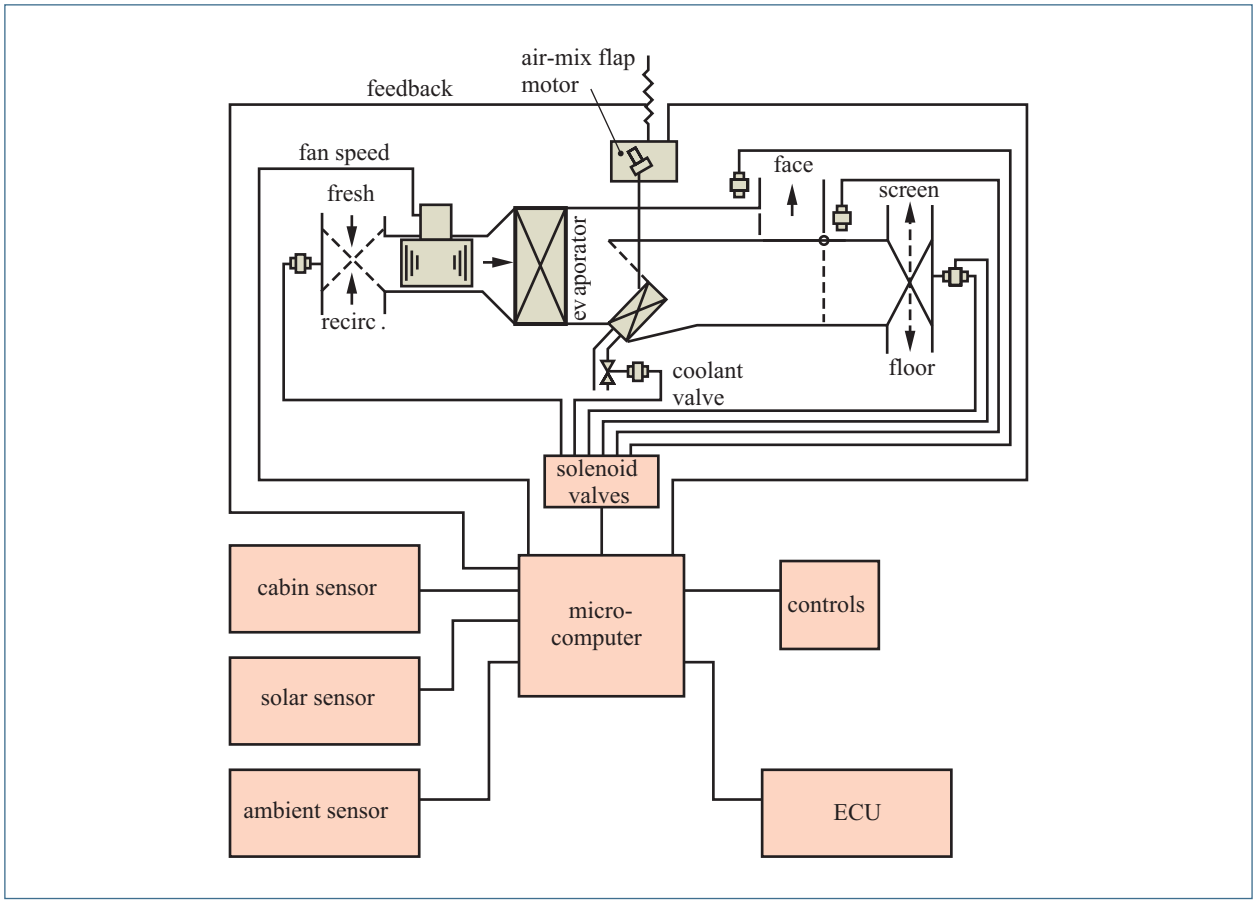


Figure 49.27 Schematic arrangement of an electronic climate control FORD

49.11 Inspection and maintenance

The air-conditioning system should be operated weekly for about 15 minutes during winter months to ensure that it is lubricated. Periodic checks should be made of the following items.

49.11.1 Compressor drive belt

Check for condition and tension. The deflection of the belt in the middle of the longest span should be between 6 mm and 10 mm when checked by hand.

49.11.2 Hose fittings and connections

The system is subjected to a high pressure and will leak refrigerant if connections are not tight. When being installed, refrigerant oil should be used on all hose fittings and connections.

Where fitted, new O-rings should be used and should be the correct type for the refrigerant. Some examples of pipe and hose connections are shown in Figure 49.28.

Inspect all joints and connections closely—a refrigerant leak will usually show up as an oily residue. The oil in any refrigerant that leaks out will pick up dust and dirt, and this will gradually build up and look like dirt-impregnated grease.

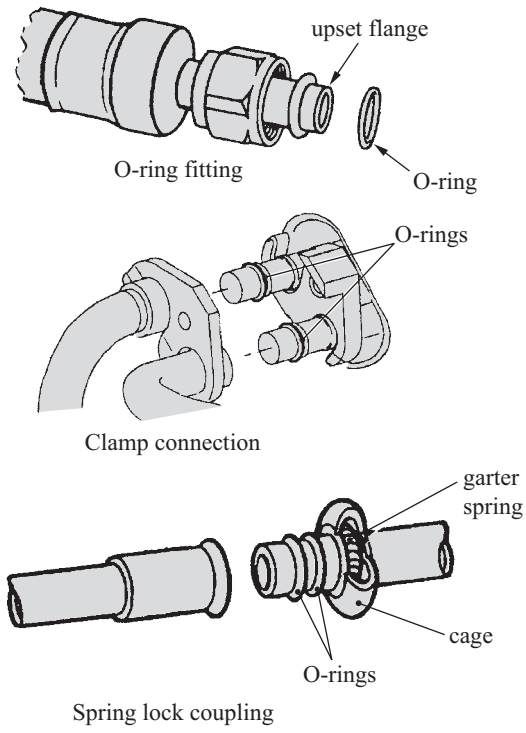


Figure 49.28 Hose and pipe connections

49.11.3 Condenser

The condenser fins should be kept clean and clear of insects so that the airflow is not restricted and cooling efficiency is maintained.

49.11.4 Sight glass

A sight glass on top of the liquid tube enables the flow of refrigerant in the system to be observed. A clear glass generally indicates the correct amount of refrigerant, but it could also indicate no refrigerant. Bubbles and oil streaks could indicate insufficient refrigerant or contamination.

49.12 Servicing the system

49.12.1 Qualifications

To comply with national regulations, people who work on air-conditioning systems must be qualified and licensed to do so. They must either be, or work for an employer who is, the holder of a trading authorisation issued by the Australian Refrigeration Council (ARC). A logo with an 'ARCtick' symbol identifies businesses and licensed individuals.

49.12.2 Pollen filters

Pollen filters are now fitted in most vehicles. They capture tiny particles such as pollen, dust and plant spores and come in two types: cabin filters and active carbon cabin filters. The latter remove even smaller particles, as well as odours and harmful gases such as exhaust fumes and ozone. Pollen filters should be checked and/or replaced as part of the vehicle service, especially during an air-conditioning service or repair.

49.12.3 Equipment

Special equipment is needed to service an air-conditioning system. This is contained in a refrigerant recovery unit that discharges, evacuates and recharges the system. The equipment includes a manifold

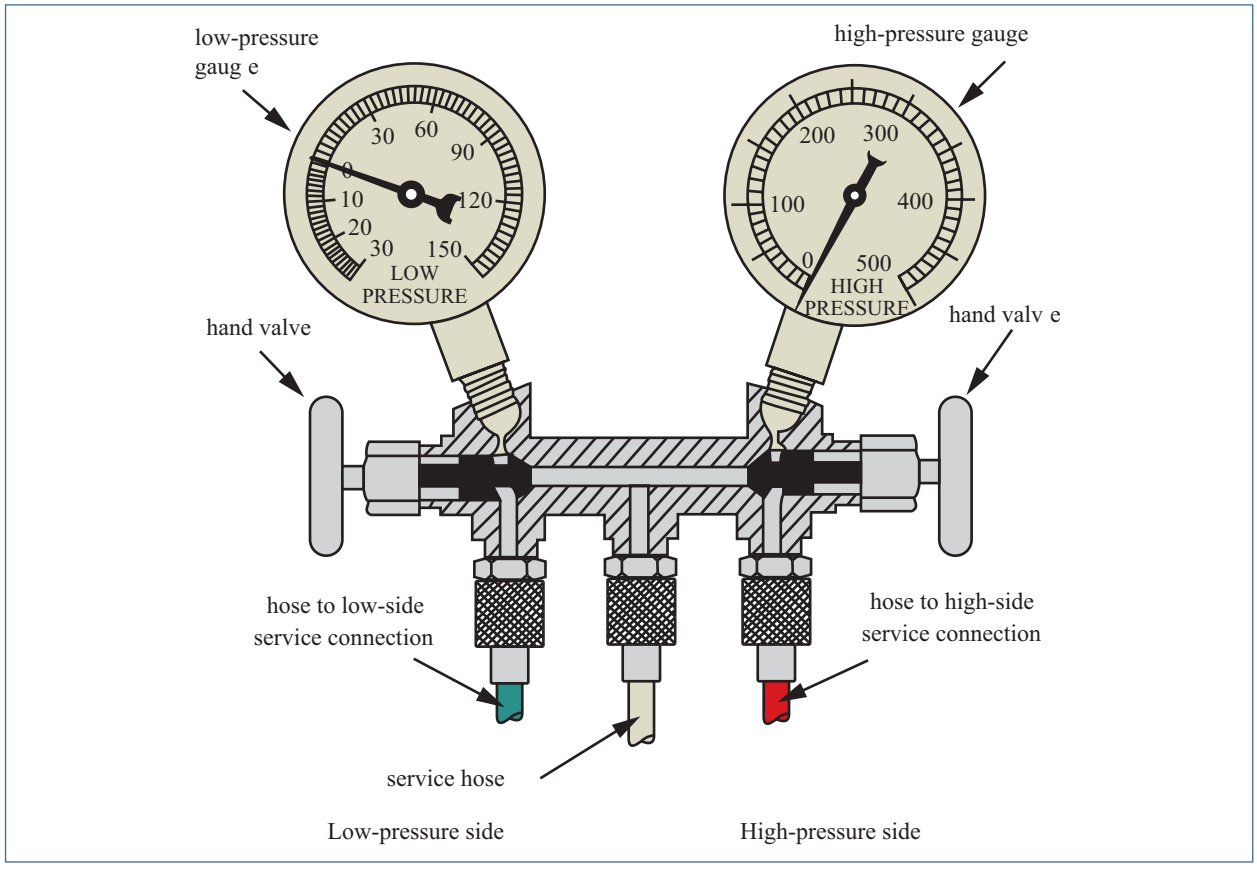


Figure 49.29 Manifold gauge set

gauge set, a compressor, a vacuum pump, an oil separator with a sight glass to show the quantity of oil removed, and a recovery cylinder into which the refrigerant from the system is pumped (see Figure 49.31 below).

Safety: The refrigerant must not be released to the atmosphere , but should be held in the cylinder for storage and returned to the supplier for recycling or disposal.

49.12.4 Manifold gauges

Figure 49.29 shows a manifold gauge set. This has a high-pressure gauge and a low-pressure gauge, two hand valves and three hoses. One hose, coloured *red,* is connected to the high-pressure side of the vehicle's system using a self-sealing coupling. Another hose, coloured *blue,* is connected to the low-pressure side of the vehicle's system by the same method. The third (service) hose is connected to the recovery unit.

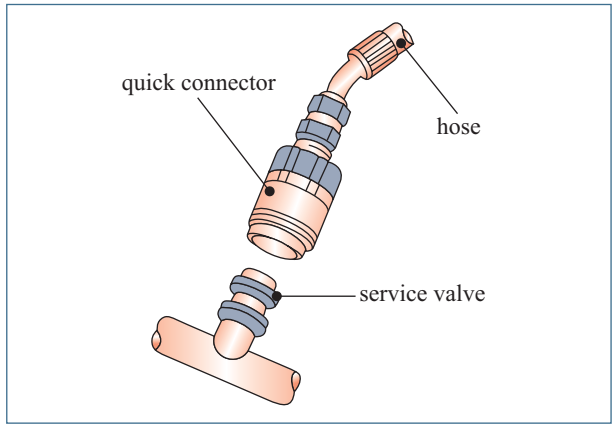


Figure 49.30 Service valve and quick connector of a gauge hose for R134a system

The gauges enable pressure readings to be taken of the high-pressure side of the system, and pressure or vacuum readings to be taken of the low-pressure side of the system. The gauges shown are graduated in kilopascals. Other gauges are graduated in both *kilopascals* and *bars.*

Handy hint: One bar is equal to 100 kilopascals (kP a).

The system in the vehicle has service valves that are located on or near the compressor to which the hoses are connected. The service valve connection used for R134a is shown in Figure 49.30. There are different hose and gauge connections for R134a and R12 systems—they cannot be interchanged.

49.12.5 Discharging

The manifold gauge set of the recovery station is connected to the vehicle's system. The hand wheel on the high-pressure side is opened slightly to allow the refrigerant to bleed out slowly. If the system is bled too quickly, the refrigerant will carry too much oil out with it. Finally, the valve on the low-pressure side is also opened. The compressor of the recovery unit operates automatically until all of the refrigerant has been removed and the low-pressure gauge registers a minus pressure.

49.12.6 Evacuating

The system must be evacuated to remove all moisture and air from the system after it has been opened. Moisture in the system will react with the refrigerant to form harmful acids. These can corrode the internal parts of the system. Also, air is a poor conductor of heat, and air in the system would affect the performance of the air conditioner.

Evacuation can only be achieved by connecting a vacuum pump to the centre hose. The pump is operated for a minimum of 30 minutes at a vacuum reading of 29.6 in.Hg. At this vacuum, the moisture inside the system will boil and will be drawn out through the vacuum pump.

49.12.7 Charging

The service components that evacuate and charge the system are shown in Figure 49.31. There are special procedures for discharging, evacuating and charging.

For charging, a supply cylinder of R134a is used. This is shown in the inverted position so that there is liquid withdrawal when its valve is opened. This enables a measured quantity of liquid refrigerant to pass from the supply cylinder into the charging cylinder.

With the system evacuated and the high-pressure valve of the gauge set opened, the refrigerant from the charging cylinder enters the high-pressure side of the system. Workshop manuals provide details of the procedures.

Handy hint: Refer to the A ustralian R efrigeration Council for the A ustralian A utomotive Code of Practice , 2008.

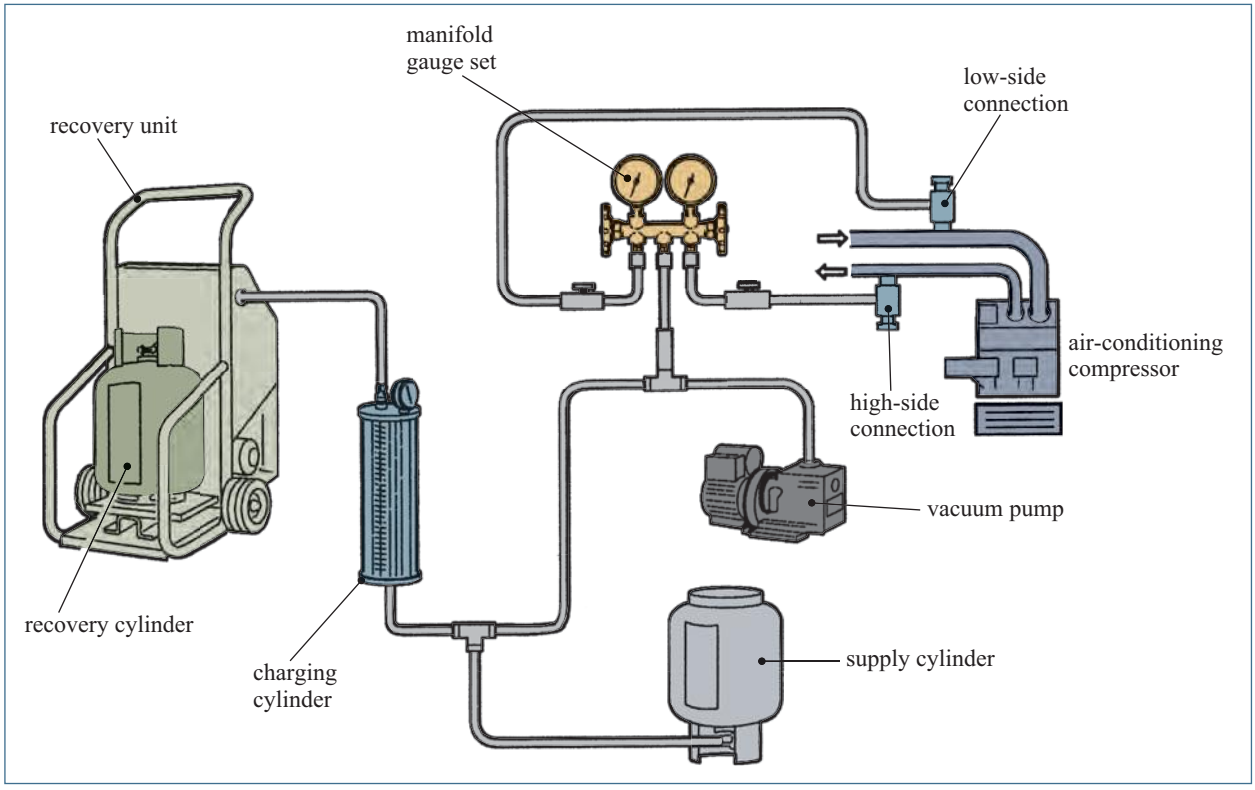


Figure 49.31 Recovery unit with components to evacuate and cha rge an air-conditioning system GM HOLDEN LTD

⚠ Safety: Each system is designed to hold specified quantities of refrigerant and oil that should not be ex ceeded.

49.12.8 Checking for leaks

Pressurise the system with dry (oxygen-free) nitrogen–a pressure of up to 10 bar g (150 psig) is usually sufficient to find leaks (bubbles) using a soap solution around joints and components.

A gas-leak detector checks the system for leaks, which can occur at hose connections, the most likely source of problems.

An electronic leak detector (Figure 49.32) has a sensor probe on a flexible cable that is moved around the system to pick up any refrigerant vapour that has leaked out. Refrigerant gas is heavier than air, so the test probe of the leak detector should be placed under the area being checked. It should be moved around slowly to allow the refrigerant to take effect. The high-pressure part of the system should be checked during operation and the low-pressure part during shutdown (when the refrigerant pressure has equalised in the system).

Another method of checking for leaks is to add a fluorescent dye and hydrocarbon refrigerant to the system. This is suitable for slow leaks that are hard to locate. The dye can be left in the system and checked after a few days, using an ultraviolet light. A fluorescent green stain will appear around any joints or connections from which refrigerant is leaking.

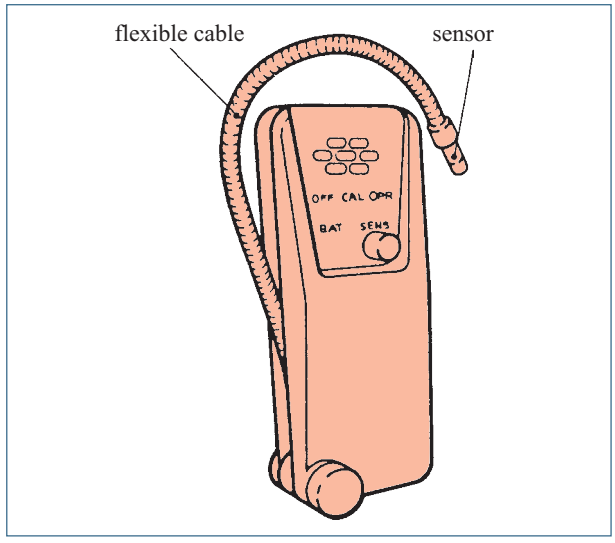


Figure 49.32 Electronic leak detector

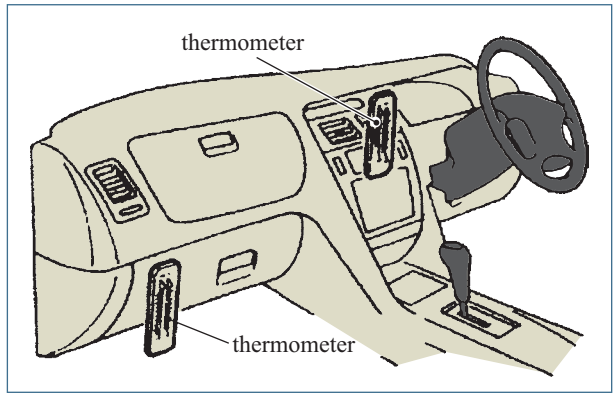


Figure 49.33 Temperature check of an air conditioner MITSUBISHI

49.12.9 Sealing the system during servicing

Whenever the system is opened by removing a component, hose or pipe, it must be sealed to prevent entry of air. The refrigerant will absorb moisture from the air, and this will cause deterioration of the fluid and corrosion problems.

The receiver-dryer needs particular care. It contains moisture-absorbing chemicals that will be rendered useless if too much moisture is absorbed. A receiver-dryer should be sealed whenever it is disconnected from the system. When a new part is to be fitted, it should remain sealed until it is about to be installed.

49.12.10 Performance test

A thermometer checks the cooling performance of the system (Figure 49.33). With the vehicle in the shade and the windows and doors closed, the engine is run at a fast idle for 20 minutes. The controls are set with the blower speed on highest, the air directed to *face* and the internal air being recirculated.

The thermometer is placed in the vents and the temperature checked. This would be around 3°C to 4°C after 20 minutes of operation.

49.12.11 Work health and safety, and occupational health and safety

Service work on air conditioners should be carried out in a well-ventilated area. Protective gloves and glasses should be worn and direct contact with refrigerant or oil should be avoided. The following lists summarise some of the do's and don'ts of servicing air conditioners. They relate to both the safety of the individual and the performance of the system.

Do's

1. Do consult an air-conditioner repair manual and gather all necessary information before attempting any service work.
2. Do reclaim the refrigerant from the refrigeration system before disconnecting any joints or removing any parts from it.
3. Do evacuate the system of air after carrying out such an operation.
4. Do use refrigerant oil on all joints.
5. Do leak-test the system after charging it with refrigerant.
6. Do use the correct tools for the job in hand.
7. Do cap or plug any parts removed temporarily, to prevent moisture or foreign material getting into the system.
8. Do renew the receiver-dryer if it has been exposed to air for longer than one hour.
9. Do renew any damaged parts and the receiver-dryer if the refrigeration system has been holed in an accident.

Don'ts

1. Don't attempt any repairs or service work without the necessary tools.
2. Don't puncture or open any refrigerant container (including the air conditioner) without the necessary equipment.
3. Don't allow refrigerant that is escaping from any pressurised container to contact exposed parts of the body.
4. Don't expose an air conditioner or refrigerant container to excessively high temperatures.
5. Don't smoke while working with an air conditioner or while handling refrigerant.
6. Don't expose refrigerant to a naked flame.
7. Don't release refrigerant into the atmosphere. Use a recovery system.
8. Don't inhale refrigerant or polyalkylene glycol (PAG) oil.

49.13 Fault diagnosis

Air-conditioning problems can be either electrical or mechanical, and may also be internal or external to the system. Electrical problems include faulty connections in the electromagnetic clutch circuit or the blower circuit. All external circuit connections should be checked before suspecting faults within the clutch. Similarly, the blower circuit should be checked if the blower is malfunctioning.

Electronic systems have a self-test which can be accessed by calling up fault codes on the air-conditioner display panel. The codes cover the sensors, connections and electronic control unit, but it is vital to refer to the appropriate service manual for details of the test method and interpretation of the codes.

On some electronic systems, air-conditioning problems can be accessed with a multifunction or scan tester that is used for other systems of the vehicle. The tester is plugged into the vehicle's diagnostic connection.

Mechanical problems include leaks and loss of charge. A gradual loss of charge can occur, but any noticeable loss, particularly if indicated by oil leaks, requires rectification. Compressor oil also requires replenishing if this condition exists.

Cleanliness of the external parts of the condenser and the evaporator will ensure their maximum efficiency. Correct fanbelt tension or operation of the electric fan will ensure that the air flow through the condenser is adequate.

The sight glass (relevant to R12 only) will indicate the operating conditions inside the system. Its small window enables the refrigerant to be observed as it circulates. Traces of oil usually indicate refrigerant leaks.

49.13.1 Testing and diagnosis with manifold gauges

Manifold gauge testing is an important part of any service and performance test of an air-conditioning system. High and low sides can be checked at the same time. Figure 49.34 shows the normal condition of an air-conditioning system, while Figure 49.35 shows two examples of possible fault readings. Tests should be carried out with the vehicle out of direct sunlight, as readings may vary with changes in ambient temperature and humidity.

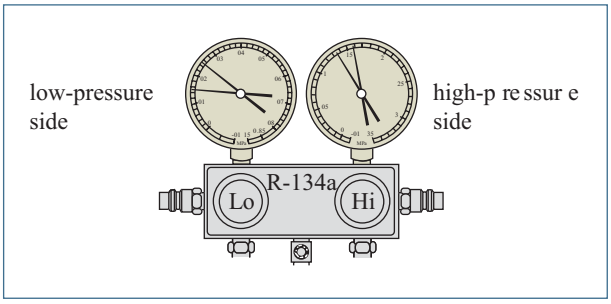


Figure 49.34 Gauge readings for an air-conditioning system without faults

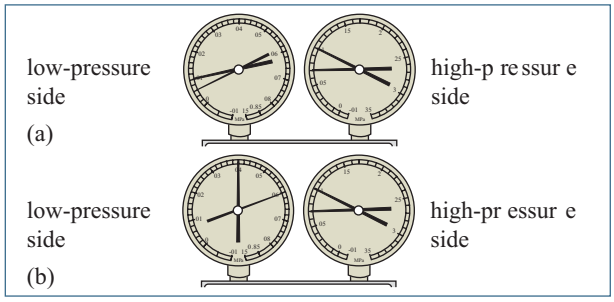


Figure 49.35 Examples of gauge readings that indicate faults (a) refrigerant fault (b) compressor fault

The readings in Figures 49.34 and 49.35 were taken under the following conditions:

- inlet air temperature is 30–35°C
- engine is at 1500 rpm
- blower control is on high and air is set to recirculate
- temperature is set at maximum cool.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. Y ou will be able to:

- describe how an air conditioner transfers heat from inside the vehicle to the outside
- identify the components of an air-conditioning system
- identify refrigerants and refrigerant oils
- operate service equipment correctly
- state the legal requirements for servicing systems
- diagnose and read pressures using a manifold gauge set
- apply procedures to check the operation of components.

REVIEW QUESTIONS

1 Why are air conditioners fitted to motor vehicles ?
2 Why is heat transfer of interest in relation to air conditioners ?
3 Name the parts of a basic air-conditioning system.
4 What is meant by the high-pressure side and the low-pressure side of the air-conditioning system ?
5 Explain the purpose of the following parts: compressor , evaporator and condenser .
6 Why is an electromagnetic clutch fitted to the compressor?
7 What is refrigerant ?
8 What are the main properties of the refrigerant used in automotive air conditioners ?
9 Why is it important that hose and pipe connections are tight?
10 What are some of the safety precautions that should be observed when working on air conditioners ?
11 What is the purpose of the sight glass that is used in some systems ?
12 What equipment is needed to discharge and charge the system ?
13 Why is an air-conditioning system evacuated?
14 What is used to evacuate the system ?
15 Why is refrigerant not released to the atmosphere ?
16 What is climate control ?
17 What is a recovery unit ?
18 What are some of the ways of locating leaks in an air-conditioning system ?
19 State some of the do 's and don 'ts that relate to air conditioners and their servicing.

CHAPTER 50

The environment and the automotive service industry

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 state the legal requirements to meet environmental best practice in an automotive workplace
2 state how work shops can avoid water contamination to stormwater and land
3 state how solid waste can be recycled
4 identify airborne hazards and state how they can be prevented or reduced
5 state the causes of noise in the work shop and how they can be reduced or contained
6 state how sustainability best practice can be applied in a work shop .

50.1 Introduction

The environment is not ours to do with as we please but belongs to future generations to enjoy as well. If we continue to treat our environment as we have been doing, we will suffer serious economic, health and social problems. We are all responsible for protecting the environment. Everyone can do something to help recycle, and to reduce waste and pollution. A motor vehicle uses many of the world's resources during its lifetime, and has a significant effect on the environment. Tyres, batteries, lubricants, fluids, mechanical parts, body parts, wiring, trim, glass, water, paper and packaging are all consumed, and all of these can be recycled.

The automotive industry has introduced environmental competencies into the national training package. Many automotive associations have codes of practice for their members as well as government legislation and regulations to assist the industry. This chapter is designed to meet the environmental and sustainability competency in the Automotive Industry Retail, Service and Repair Training Package. Certificates I to IV in the Service and Mechanical streams are covered in this supplement.

50.2 Legal responsibilities

Federal, state and local governments each have laws and regulations with which the automotive industry must comply. All owners and managers of businesses must understand what their responsibilities are with respect to these laws. Employees, contractors and sub-contractors need to be aware of the management's policies and procedures and follow their instructions.

The National Environment Protection Council (NEPC) is the federal body that sets and monitors national environmental standards. It is also responsible for monitoring compliance with international conventions to which Australia has agreed. More information is available at NEPC@environment.gov.au.

Each state has environmental legislation and an Environment Protection Authority (EPA) to administer these regulations. Penalties, such as heavy fines or imprisonment, can be enforced on corporations or individuals for serious breaches of any legislation. Costs for cleaning up and remedial work can also be charged to offenders. Information on specific penalties can be obtained by visiting the EPA website for your state (see below).

For example, if oil has spilled into a creek at the rear of a workshop, the owner can be fined for the offence and charged for the clean up, plus they must carry out works to make sure that such an event does not happen again. However, it is much better for the environment (and less costly for everyone) if it doesn't happen in the first place. Local councils, water supply authorities, waterways authorities and police may also issue penalty infringement notices (on-the-spot fines) for certain offences.

Sustainability: All managers and staff must notify their local council or EP A as soon as a pollution incident occurs that has the potential to harm the environment or cause stormwater pollution.

An example of some of the relevant legislation for the automotive service industry in NSW, for example, includes:

- Dangerous Goods Act 1975
- Environmentally Hazardous Chemicals Act 1985
- Contaminated L and Management Act 1997
- Ozone Protection Act 1989
- Waste A voidance and R esource R ecovery Act 2001
- Workplace Health and Safety Act 2011.

All states and territories have similar legislation. You can check on specific state websites for more information:

- www.epa.nsw .gov.au
- www.epa. wa.gov.au
- www.epa.sa. gov.au
- www.epa. vic.gov.au
- www.epa. qld.gov.au
- www.dpiw.tas. gov.au
- www.environment.act. gov.au.

50.2.1 Risk management

Managers must be aware of their responsibilities in risk management. They must be active in identifying hazards in the workplace, assessing the level of risk, then eliminating the hazard or reducing the risk of the hazard which may cause injury or harm to the environment. Control measures should be regularly monitored and reviewed to assess whether they are effective and meet current standards.

50.3 Water quality

The automotive industry can affect the quality of our waterways in two ways:

1. stormwater
2. trade wastewater .

50.3.1 Stormwater

Only rainwater is allowed to enter the stormwater system. Anything that enters the stormwater system eventually enters our waterways untreated. Half a litre of oil can cause an oil slick the size of a football field

if it reaches a large waterway. It can take up to twenty years for an aquatic ecosystem to recover from a large oil spill. Preventing polluted rainwater from entering the stormwater system is an important issue in the workplace. Wilful or accidental disposal of polluted rainwater, or any other liquid, is an offence and carries heavy penalties (Figure 50.1).

Polluted water can enter our waterways in three main ways:

1 through stormwater inlets on unprotected driveways, car parks and storage areas
2 as a result of waste products leaching through the soil into subsoil water
3 from the illegal disposal of waste products into stormwater drains and sewage systems.

Figure 50.1 Stormwater pollution

Sustainability: There are approximately **3.2 million vehicles registered in NSW**. If every vehicle was washed once a week using five buckets of water (40 L), it would mean that more than **1500 million** litres of polluted water would be produced, which could end up in NSW waterways.

50.3.2 Trade wastewater

Trade wastewater is water that becomes polluted in the normal course of conducting business and could include:

1 vehicle washing
2 parts washing
3 staff hand-washing
4 polluted rainwater, for example, rainwater falling onto the driveway of a service station or outdoor refuelling area.

Safety tip: Polluted rainwater must be treated the same as trade wastewater.

Trade wastewater can be disposed of in two ways:

1 water can be collected in a sump or pit and pumped out by a licensed contractor
2 water can be treated onsite and discharged into the sewage system.

Discharge of pre-treated water into the sewage system requires a permit from the local water authority and/or the local council. After the system has been installed, the business is responsible for ongoing maintenance and monitoring of water quality. The company will be required to pay fees to the issuing authority.

50.3.3 Good management practice

1 Store used oily or greasy parts under cover on a hard surface.
2 Keep waste bins covered and under cover.
3 Use drip trays and drop sheets if work has to be done outside (e.g., mobile repairers). These should be used to catch drained liquids and to stop accidental spills.
4 Always sweep or mop workshop floors, never hose out the workshop.
5 Clean up spills immediately.
6 Separate work areas from stormwater runoff areas with bunds – bunds can be raised sections of the floor that form a barrier between work areas and possible wet areas.
7 Check stormwater drains regularly to make sure they are clean and free of waste materials.

50.3.4 Spill kits

Spill kits are emergency response kits specifically designed to deal with oil and other liquid spills (Figure 50.2). They come in a variety of sizes and materials for different situations. A spill kit should be positioned close to where spills are most likely to happen. Staff should be trained in the use of such kits. Figures 50.3–50.10 show some of the main steps involved in using a spill kit on a small liquid spill.

Figure 50.2 Spill response kit for small spills lik ely to occur in an automotive work shop ENRETECH

Figure 50.3 Pouring sawdust onto a spill ENRETECH

Figure 50.4 Spill showing sawdust applied ENRETECH

Figure 50.5 Sweeping up the spill ENRETECH

Figure 50.6 Sock containing spill and starting to apply sorbent ENRETECH

Figure 50.7 Rolling up sock ENRETECH

Figure 50.8 Spreading sorbent ENRETECH

Figure 50.9 Disposing of sorbent ENRETECH

50.4 Liquid waste and chemical storage

The day-to-day operation of an automotive business requires the storage, use and disposal of a wide range of liquids and chemicals. These could include:

1. engine crankcase oil
2. transmission and hydraulic oil
3. brake fluids
4. radiator coolants
5. cleaning solvents, detergents and degreasers
6. contaminated fuels.

Sustainability: More than 500 million litres of lubricating oil is sold in Australia each year. Only half is collected or recycled. The rest is unaccounted for.

Figure 50.10 Applying a stuff pillow – these may be used to absorb fluids from around and under bowsers and other equipment ENRETECH

Businesses must ensure that all liquids and chemicals are stored correctly and clearly labelled. Some substances may be classified as dangerous goods and come under the *Dangerous Goods Act 1975*. These would include petrol, liquefied petroleum gas (LPG), acids etc. For more information, contact your local EPA or see Australian Standard AS1940, 'The storage and handling of flammable and combustible liquids'.

50.4.1 A safety data sheet (SDS)

A safety data sheet (SDS) should be available for every hazardous substance that is stored in the workplace. It provides important information on first aid and what to do in an emergency, and other useful technical information. An SDS for each product should be available from the supplier and they should be kept in a central location for easy access. More information on SDSs can be found in Chapter 2, Workshop Safety.

50.4.2 Good management practice

1. Waste oils should be stored under cover on a concreted area surrounded by a bunded area at least 100 mm high. The bunded area should be 10 per cent more than the maximum capacity of the stored oil.
2. Waste oil can be recycled. Storage containers should be regularly emptied by a licensed contractor or recycler.
3. Brake and clutch fluid should be kept in a container separate to other waste oil and removed by a licensed contractor.

4 Radiator coolant can be recycled onsite using commercially available recycling and filtering machines. Some savings can be made by recycling, depending on the quantity used. Coolant that cannot be recycled must be stored separately because it contains heavy metals and ethylene glycol. It must be removed by a licensed contractor.
5 Cleaning solvents and degreasers in open tanks can cause many problems including skin, eye and throat irritations. They also release hydrocarbons into the atmosphere and contribute to photochemical smog. If solvents must be used, tanks should be covered when not in use, the area should be well ventilated, and personal protective clothing must be worn.
6 Water-based cleaners and biodegradable detergents should be used. Ultrasound cleaners are now widely used for small components and are less harmful to the environment.
7 Contaminated fuels, such as petrol, come under the Dangerous Goods Act and must be stored and disposed of accordingly. Diesel fuel can be treated as waste oil.
8 Labels must be clearly placed on all waste materials. For more information on oil recycling and the nearest collection facility visit the Department of Environment and Heritage at www.deh.gov.au/oilrecycling.

50.5 Solid waste

Solid waste can be recycled. It is important that items for disposal or recycling are stored properly. Some of the more common items are:

1 used mechanical parts and assemblies
2 oil filters
3 packaging
4 tyres (Figure 50.11)
5 batteries
6 glass.

Sustainability: Some 20 million waste tyres are generated in Australia each year.

Figure 50.11 Tyre recycling is the most effective way of disposing of old tyres

50.5.1 Good management practice

1 Metal parts should be stored under cover on a hard surface in a bunded area. A higher financial return can be gained if ferrous (iron/ steel) metals are separated from non-ferrous (aluminium, copper etc.) metals for collection.
2 Components containing oil should be drained and stored in trays. Up to 20 per cent of the oil can remain in the component. Rotate the component upside down and gravity drain or use a commercial evacuation unit to remove the last 20 per cent.
3 Oil filters can be crushed and the remaining oil removed. They should be stored separately and collected be the recycler.
4 Cardboard boxes and other types of packaging waste can be compressed in a bale press (Figure 50.12).

Figure 50.12 Compressed cardboard recycling

5 Batteries should be stored undercover in acid resistant leak-proof trays and removed by a metal recycler. Ensure that there is no chance of damage to the battery to cause acid leakage.
6 Tyres can be recycled as re-treadable cases, shredded for civil engineering or granulated for the production of other rubber products. A licensed tyre recycler will process the tyres.

50.6 Air quality

Activities in the workshop affect the air quality in the workshop itself and can also contribute to urban air pollution. Pollution can be caused by dust, fumes and gases.

Dust may contain heavy metals, asbestos from older brake and clutch linings or other toxic substances and can be a major problem. Fumes from solvents and fuels and from vehicle exhausts also need to be controlled.

Exhaust gas can contain carbon monoxide (CO) which is toxic and dangerous in confined spaces. It causes poisoning or death. Other exhaust emissions that have an effect on the environment include hydrocarbons (HC), oxides of nitrogen (NO_x) and carbon dioxide (CO_2). Proper servicing by technicians of emission-related systems and components is essential.

Gases in the workshop are mainly refrigerants, LPG and welding gases. Older vehicles with refrigerant R12 contain chlorofluorocarbon (CFC), which is an ozone-depleting agent. The new blends, such as R134a, contribute to greenhouse gases if released into the atmosphere. A licence is required to purchase and use refrigerants.

It is illegal to modify or remove any component or software that affects the exhaust emissions from motor vehicles. Heavy fines can be imposed on corporations or individuals. Customers who make such requests are asking the repairer to break the law and should be refused.

50.6.1 Good management practice

1 Clean the workshop using an industrial vacuum cleaner or wet mops.
2 Dust collected should be placed in a bag to stop dust becoming airborne when the bin is emptied.
3 Brake parts should be wetted down prior to dismantling. Do not use compressed air to remove dust. Commercial cleaning units are available.
4 Vehicles should be connected to an exhaust extraction system when engines are running and the area should be well ventilated. When vehicles have to be moved, run engines for the shortest possible time.
5 Provide fume extraction systems where welding is carried out.
6 Spray painting must be carried out in an approved spray booth.
7 Gases should be properly stored and regularly checked for leaks.
8 Refrigerants must not be released into the atmosphere. They can be recycled onsite or collected by a licensed recycler. Different refrigerants and refrigerant lubricants must be clearly labelled.
9 Personal protective equipment (PPE) (Figure 50.13) should be worn where dust is present and other control measures are not sufficient.
10 The benefits of regular checking and servicing of emission systems should be promoted to customers.

Figure 50.13 PPE can be used to prevent injury caused by noise or air quality issues.

50.7 Noise

Noise is always present in our lives and has been identified as a major source of environmental pollution and a workplace health and safety issue. Excessive noise can cause deafness in extreme cases, or lead to partial hearing loss or industrial deafness. Noise can also lead to other accidents through lack of concentration.

Exposure to excessive noise can be eliminated or reduced by careful management, workshop design and layout, equipment selection and personal protection. Some of the sources of noise in the workshop are:

1 running engines for tuning, testing etc.
2 air tools
3 metal grinding
4 public address systems
5 air compressors.

50.7.1 Good management practice

1 Tuning of engines should be in a sectioned area of the work shop with acoustic protection where possible .
2 Dynamometers should be in an isolated test cell.
3 Noisy hand tools should be used for the minimum amount of time and personal protective equipment used. Electric power tools are quieter .
4 Public address system use should be k ept to a minimum and other forms of communication, such as pagers, used in preference .
5 Air compressors should be located outside the building and built in.
6 Exhaust components fitted to vehicles must meet A ustralian Design Rules for both noise and emission standards.
7 Schedule noisy activities during break s to reduce the impact on other work ers.

50.8 Sustainability

Environmental sustainability in the workplace means to *reduce* the resources that you use, *reuse* what you can and *recycle* your waste materials. A well-designed workshop with good sustainability practices uses less resources and is more profitable.

Some of these can be in the building design, such as skylights and insulation in the roof, solar hot water and low energy lighting systems to reduce electricity consumption. Others can be practices, such as maintenance to repair leaking water taps and toilets, leaking compressed air pipes and fittings.

Many of the practices discussed previously, such as the recycling of materials, also contribute to sustainability.

50.8.1 Good management practice

1 Develop an environmental sustainability plan.
2 Regularly monitor the resources the work shop uses.
3 Fit low energy lighting.
4 Regularly check for water and compressed air leakage .
5 Look for less to xic cleaning materials.
6 Recondition and reuse parts where possible .
7 Recycle parts that can 't be reused.

50.9 An environmental checklist

The environmental checklist on the following pages has been prepared to help you confirm you are doing the right thing in relation to the environment. The questions are designed to help you think about the various aspects of your business that could be affecting the environment and to give you some ideas on how you could improve your environmental performance.

Can you answer yes to these questions? If you answer no to any of them you could be harming the environment, breaking the law and/or leaving your business vulnerable to fines and prosecution under environmental legislation. If you answer no, you may need to revise your current work practices.

Water quality management

Stormwater

Do you have any features or procedures in place to prevent stormwater pollution ?

Yes ☐ No ☐ N/A ☐

Are the stormwater drains around your business free of pollution (such as litter , grease , oil, etc.)?

Yes ☐ No ☐ N/A ☐

Do you do all the work inside your work shop ?

Yes ☐ No ☐ N/A ☐

Is your work shop fully enclosed and sealed?

Yes ☐ No ☐ N/A ☐

Do you store all parts so that there can be no spill or leak age into the stormwater system ?

Yes ☐ No ☐ N/A ☐

Do you store all waste oil and chemicals in a covered, bunded area or inside the work shop in an area that drains to a corrugated plate interceptor (CPI)?

Yes ☐ No ☐ N/A ☐

Do you use a broom instead of a hose to sweep and clean up the surface areas around your premises ?

Yes ☐ No ☐ N/A ☐

Wastewater

Do you have a trade waste agreement or permit?

Yes ☐ No ☐ N/A ☐

Do you have a CPI for pre-treatment of your wastewater?

Yes ☐ No ☐ N/A ☐

Is your CPI regularly maintained?

Yes ☐ No ☐ N/A ☐

Waste management

Are all your wastes stored in a contained area to prevent pollution of stormwater drains ?

Yes ☐ No ☐ N/A ☐

Have you look ed at all the waste generated from your business ?

Yes ☐ No ☐ N/A ☐

Do you separate any of your wastes (items for reuse , return to supplier , recycling)?

Yes ☐ No ☐ N/A ☐

If a supplier was willing to tak e back pack aging wastes (such as crates and plastic drums), would you use this service ?

Yes ☐ No ☐ N/A ☐

Do you recycle or reuse any of the following ?

- Oil

Yes ☐ No ☐ N/A ☐

- Scrap metal and parts

Yes ☐ No ☐ N/A ☐

- Batteries

Yes ☐ No ☐ N/A ☐

- Solvents

Yes ☐ No ☐ N/A ☐

- Aluminium cans

Yes ☐ No ☐ N/A ☐

- Glass containers

Yes ☐ No ☐ N/A ☐

- Paper and cardboard

Yes ☐ No ☐ N/A ☐

- PET plastic

Yes ☐ No ☐ N/A ☐

- Other

Yes ☐ No ☐ N/A ☐

Do you have a waste contractor to transport and dispose of the following materials ?

- Waste oil

Yes ☐ No ☐ N/A ☐

- Waste solvents

Yes ☐ No ☐ N/A ☐

- Waste acidic and caustic cleaning chemicals

Yes ☐ No ☐ N/A ☐

- Waste oil filters

Yes ☐ No ☐ N/A ☐

- Waste tyres

Yes ☐ No ☐ N/A ☐

Air quality management

Do you try to stop dust and fumes from leaving your premises ?

Yes ☐ No ☐ N/A ☐

Do you use water-based or biodegradable strippers, cleaners and degreasers wherever possible ?

Yes ☐ No ☐ N/A ☐

Do you use a dedicated part cleaner with a lid?

Yes ☐ No ☐ N/A ☐

Hazardous materials

Do you store your hazardous materials (such as coolants, fuels and solvents) in a bunded, covered area that will not allow any materials to be spilled or washed into stormwater?

Yes ☐ No ☐ N/A ☐

Do you know whether you store any dangerous goods ?

Yes ☐ No ☐ N/A ☐

If you store dangerous goods (such as petrol and LPG) do you know whether you need a licence from the WorkCover authority ?

Yes ☐ No ☐ N/A ☐

Do you have all relevant material safety data sheets (MSDS)?

Yes ☐ No ☐ N/A ☐

Do you have a spill procedure or kit?

Yes ☐ No ☐ N/A ☐

Noise management

Are you aware of the effects of your noise on your neighbours ?

Yes ☐ No ☐ N/A ☐

Do you regularly check and carry out maintenance on noisy equipment (such as forklifts, lathes and computers)?

Yes ☐ No ☐ N/A ☐

Management of premises

Do you have an environmental policy or plan ?

Yes ☐ No ☐ N/A ☐

Are your staff aware of your commitment to improving the environment?

Yes ☐ No ☐ N/A ☐

Are your customers aware of your commitment to improving the environment?

Yes ☐ No ☐ N/A ☐

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

1 apply the legal requirements to meet environmental best practice in an automotive workplace
2 apply procedures in the workshop to avoid water contamination to stormwater and land
3 apply procedures to recycle solid waste
4 identify airborne hazards and apply methods to prevent or reduce them
5 identify the causes of noise in the workshop and show how they can be reduced or contained
6 apply sustainability best practice methods in a workshop.

REVIEW QUESTIONS

1 Who is responsible for protecting the environment?
2 Name the federal body responsible for setting national standards on the environment.
3 Name the government department in your state/territory responsible for environmental protection.
4 Can individuals and corporations be penalised for committing offences?
5 List four acts of parliament that relate to protection of the environment.
6 What is the only liquid that should enter the stormwater system?
7 State three ways in which polluted water can enter waterways.
8 What is a bund?
9 What is a spill kit?
10 List three sources of trade wastewater.
11 State four ways of preventing waste entering the stormwater system.
12 State four hazardous substances used in the workshop. How should they be disposed of?
13 List five items of solid waste that can be recycled.
14 What is the most dangerous vehicle exhaust emission to individuals?
15 What is best practice when running engines in the workshop?
16 Can refrigerants be released into the atmosphere?
17 What is required for you to be able to purchase and handle refrigerants?
18 State two ways of reducing dust in the workshop.
19 What are two effects of excessive noise on an individual?
20 State four ways of eliminating or reducing the effects of excessive noise.
21 What is meant by sustainability?
22 State four ways to reduce energy consumption.
23 How can regular maintenance improve sustainability?

CHAPTER 51

Identify basic automotive faults using troubleshooting processes

LEARNING OBJECTIVES

On completing this chapter you will be able to:

1 identify and apply a range of effective communication strategies
2 provide an outline of basic troubleshooting processes as applied to a range of vehicle systems and components
3 demonstrate the correct use and application of basic diagnostic charts.

The operating principles of a modern vehicle are extremely complex and this results in a range of difficult and challenging problems for automotive technicians to solve. In order to correctly and efficiently resolve vehicle system faults, it is essential to have an excellent understanding of the function and operation of each component and system.

51.1 Safety

Before commencing work on any troubleshooting process, ensure that all risks associated with the task are reduced to an acceptable level. Never work on a system or component if you are unsure of the correct procedures or the potential safety risks. Always check the manufacturer's recommendations prior to working on a system or component to ensure that everyone is provided with a safe working environment.

A basic outline of the hazards associated with fault diagnosis is as follows:

- Using a hoist or hydraulic jack Always use equipment with the correct Safe W orking Load (SWL), ensure it is properly located under the vehicle and that jack stands are used.
- Brake dust Dust should not be blown from brak e or clutch parts. Airborne dust can be inhaled, presenting a health hazard.
- SRS airbags The vehicle manufacturer' s procedures and precautions should always be followed when working on vehicles that have airbags.

- Engine Be aware of hot or rotating parts.
- Cooling system Be aware of heat and e xcessive cooling system pressure .
- Exhaust system Always run a vehicle in a well ventilated area and be aware of e xcessive heat generated by the e xhaust.
- Electrical system The ignition system produces e xceedingly high voltages, and contact with any part of the ignition system while the engine is running should be avoided.
- Fuel system Remove all ignition sources, work in a well ventilated area and be aware of high system pressures.

Safety: As a basic precaution, always wear the correct personal protective equipment and follow the manufacturer' s recommendations for any work carried out.

51.2 Confirming the nature of a fault or problem

Often the first information regarding a vehicle fault comes from a discussion with the customer. This interaction can provide a diverse range of information regarding the fault, even before the vehicle is inspected or test driven.

This means that the way we communicate with our customers is vitally important. By asking the correct questions, and asking them in a way that the customer understands, we can potentially reduce the time required to diagnose a vehicle fault. The following suggestions may assist with effective communication strategies.

51.2.1 Don't use jargon

Jargon means the words used within a particular working environment that others will find extremely difficult to understand. For example, using the technical words or names of complex mechanical components without providing an explanation will confuse the customer and may lead to misunderstandings. Another source of confusion for customers is the use of acronyms that abbreviate specific systems or components. While acronyms such as ECU, EBD, MAP, CV joint or BEM are examples of commonly used language among automotive technicians, they are not suitable and should not be used when speaking with a customer.

51.2.2 Don't assume that the customer understands what is being explained to them

In many instances, misunderstandings occur when automotive technicians believe that the customer understands what has been explained to them. Automotive systems are complex and faults need to be explained in a way that the average person can understand.

51.2.3 Ask the correct questions

When discussing a mechanical fault with a customer it is vital that the correct questions be asked. A closed question will limit the amount of information provided, for example, 'Was the engine hot or cold when the warning light came on?' Closed questions can be used to keep the conversation focused on the topic and can gain a lot of information quickly.

By using open questions, the customer is allowed to provide a longer and more detailed response. 'When did you hear that the noise in the engine was louder?' will get a different answer from 'Was there a noise in the engine when it was idling?' The use of an open question allows for more information to be communicated than when asking a question that requires a simple yes or no answer.

51.2.4 Never assume anything about a customer's mechanical knowledge

Be mindful of the vast array of mechanical knowledge that may be held by a customer. If there is a fault that has been difficult to diagnose or repair, describe the solution as clearly and accurately as possible.

51.3 Diagnosing faults

The correct diagnosis of a fault is vitally important as it can be very time consuming for the technician and expensive to the customer. A good technician will use all of the information provided to think through a range of potential causes before conducting repairs. A critical aspect of fault diagnosis is to take note of all the symptoms that the fault has caused as this may be the key in defining the problem. For example, look for clues about what is happening, such as whether there are different noises, odours, vibrations or heat that can provide more information regarding the cause of the fault. Often, the symptoms experienced are not the fault, rather the symptoms are a product of the fault.

Figure 51.1 highlights the differences between a symptom and an actual fault. During this process, it is important that all potential scenarios be thoroughly considered to test if a specific repair will result in the fault being rectified. This is a critical stage of the fault and troubleshooting process, as a technician must not guess what the problem is in the hope that the repair will fix the fault. Correct diagnosis and repair will eliminate problems associated with unnecessary repairs (Figure 51.2).

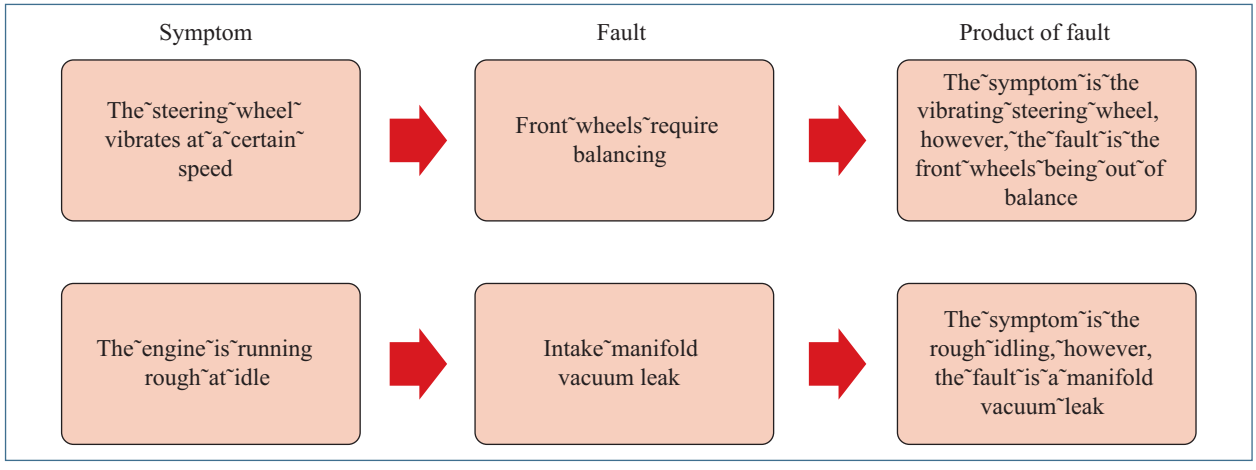


Figure 51.1 Products of system faults

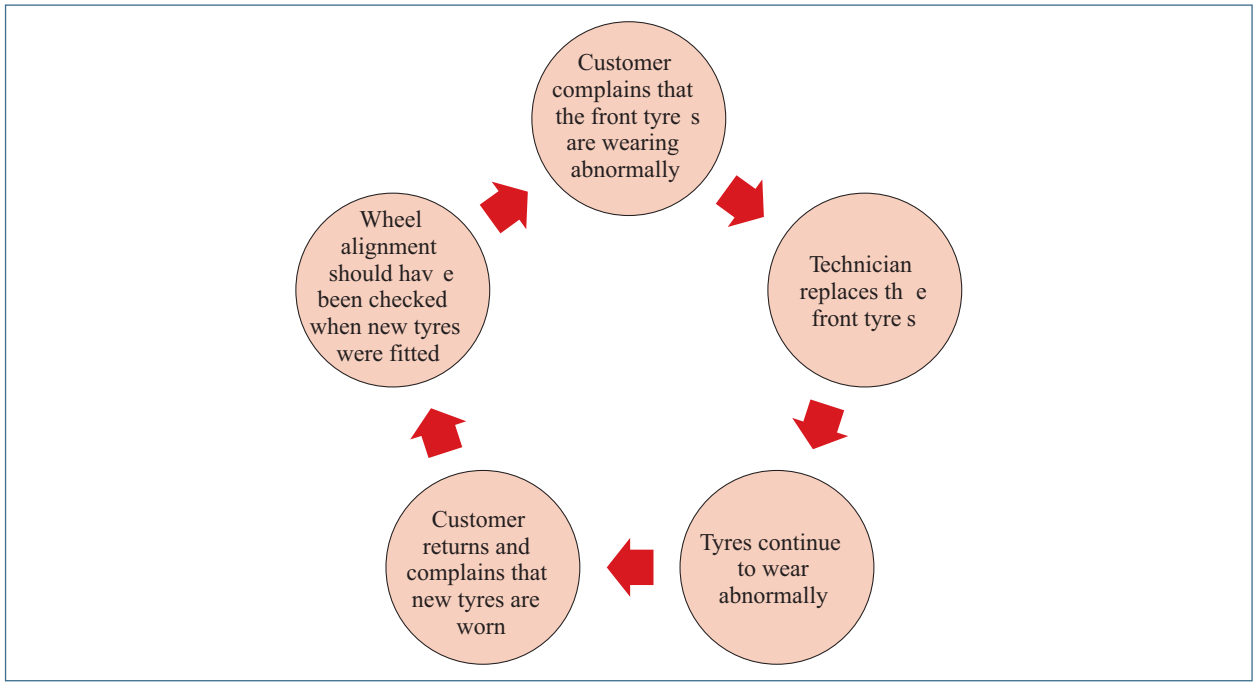


Figure 51.2 An example of unnecessary repairs

51.4 Steps in diagnosis

A good technician will utilise a range of strategies so that they can efficiently and correctly diagnose a mechanical fault. This will involve following a number of processes to ensure that the customer is well informed and the fault is diagnosed and rectified in an efficient manner. Figure 51.3 outlines the five basic steps that can be used to correctly identify and rectify mechanical faults.

Always ensure that when the repair has been completed, the vehicle is test driven under normal operating conditions to ensure that the fault has been rectified and repaired correctly.

Handy hint: If possible, seek a second opinion from another technician regarding your diagnosis **and intended method of repair.**

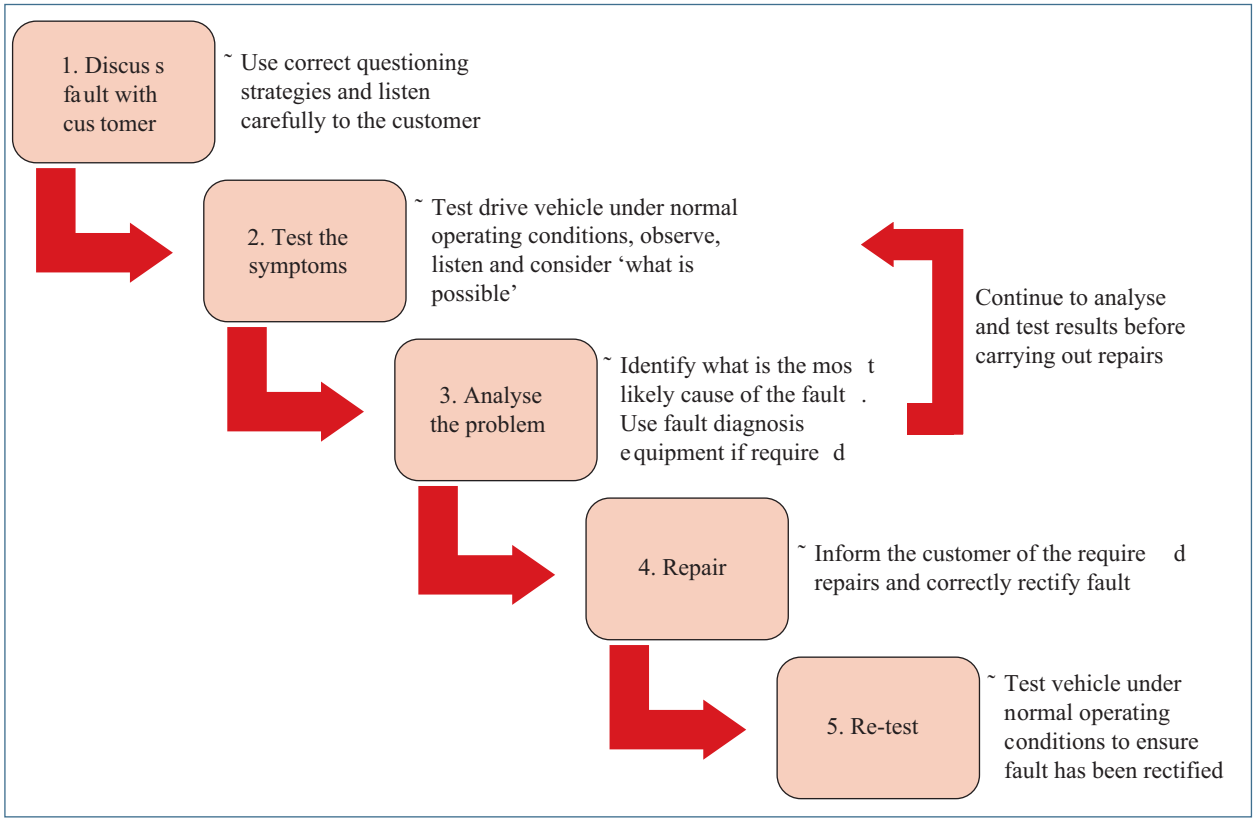


Figure 51.3 Five basic steps involved in troubleshooting and repair processes

51.5 Technical support

Technicians can access a variety of information to assist them in diagnosing and repairing vehicle faults. The information can be obtained from a variety of sources including:

- workshop manuals
- manufacturer technical support
- other technicians
- automotive industry technical associations
- service bulletins
- product guides.

To assist with technical support, a range of peak automotive industry bodies within Australia can be viewed at https://www.mtaa.com.au/.

51.6 Diagnostic charts

Manufacturers use a range of diagnostic charts to help technicians diagnose system faults. These charts vary not only in structure but also complexity. Depending on the system being analysed, diagnostic charts can vary as follows.

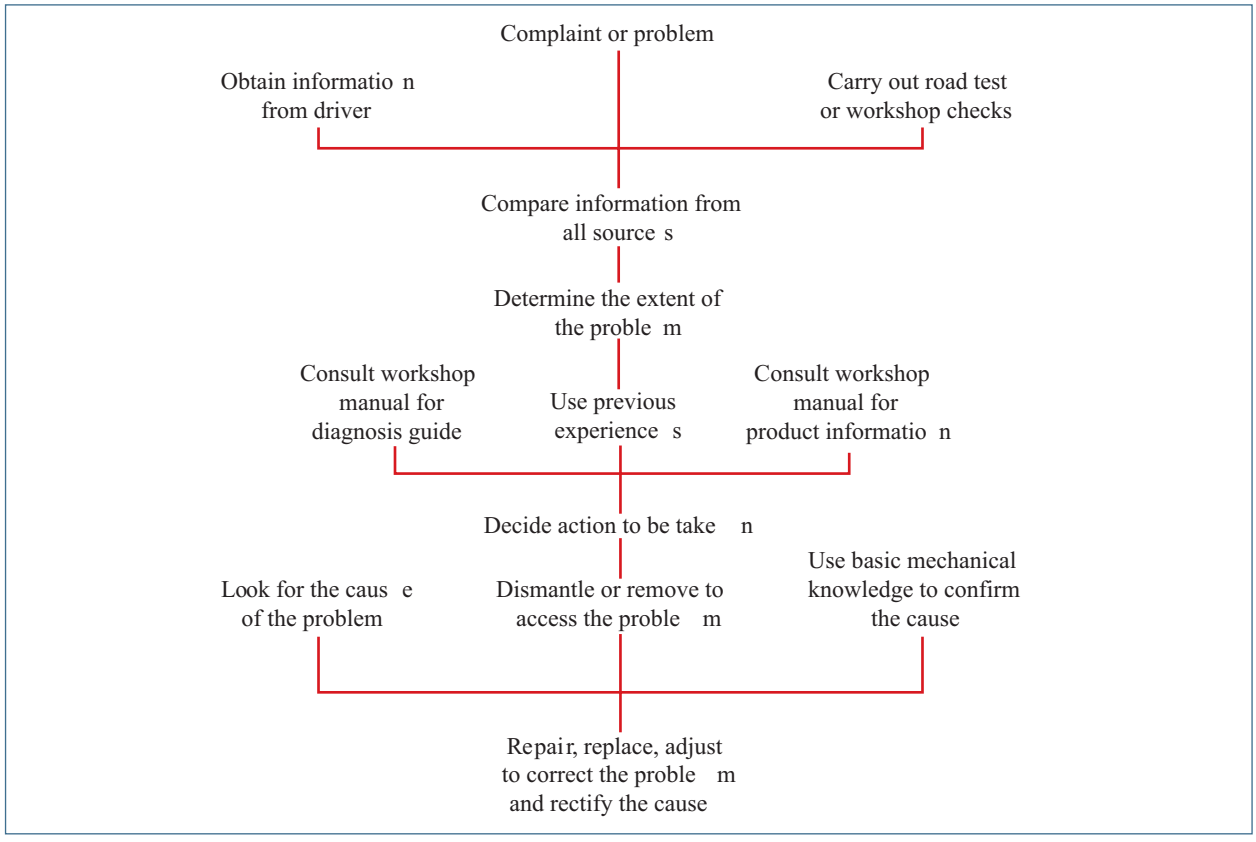


Figure 51.4 Diagnostic flow chart

51.6.1 Flow chart

This is a line drawing which outlines the general processes that should be followed. Each step in the process contains a brief explanation of the checks that should be made. A flow chart is linked together with arrows that guides the user through a system of steps. Figure 51.4 below is an example of a diagnostic flow chart.

51.6.2 Pictorial drawings

These are three-dimensional drawings of the system or component being checked. They show the full shape of the object, allowing the user to gain a clear understanding of the components and how they are arranged.

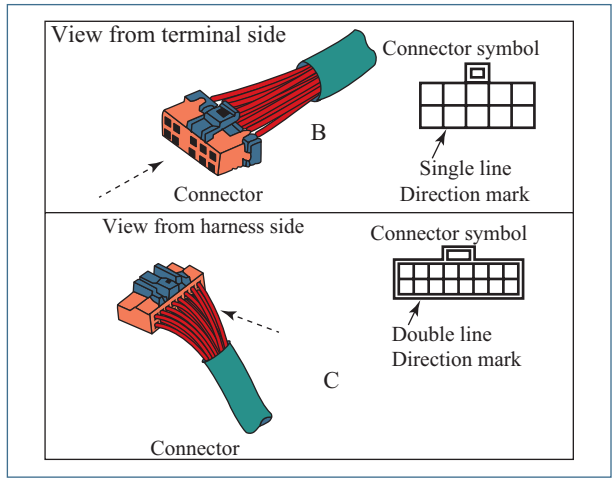


Figure 51.5 Pictorial drawing

51.6.3 Schematic drawings

These are simplified drawings in which parts are not drawn to their true shape. Instead, outlines of the parts are drawn, or the parts are represented by symbols or numbers. Figure 51.5 shows a simplified drawing of an automatic transmission wiring system. When diagnosing a fault within this system, a technician would use the diagram to correctly identify the data input wires to the relevant system, for example, the throttle output sensor is located at terminal or port number 39.

Handy hint: Workshop manuals include diagnosis guides and charts which should be used to identify the likely causes of a problem.

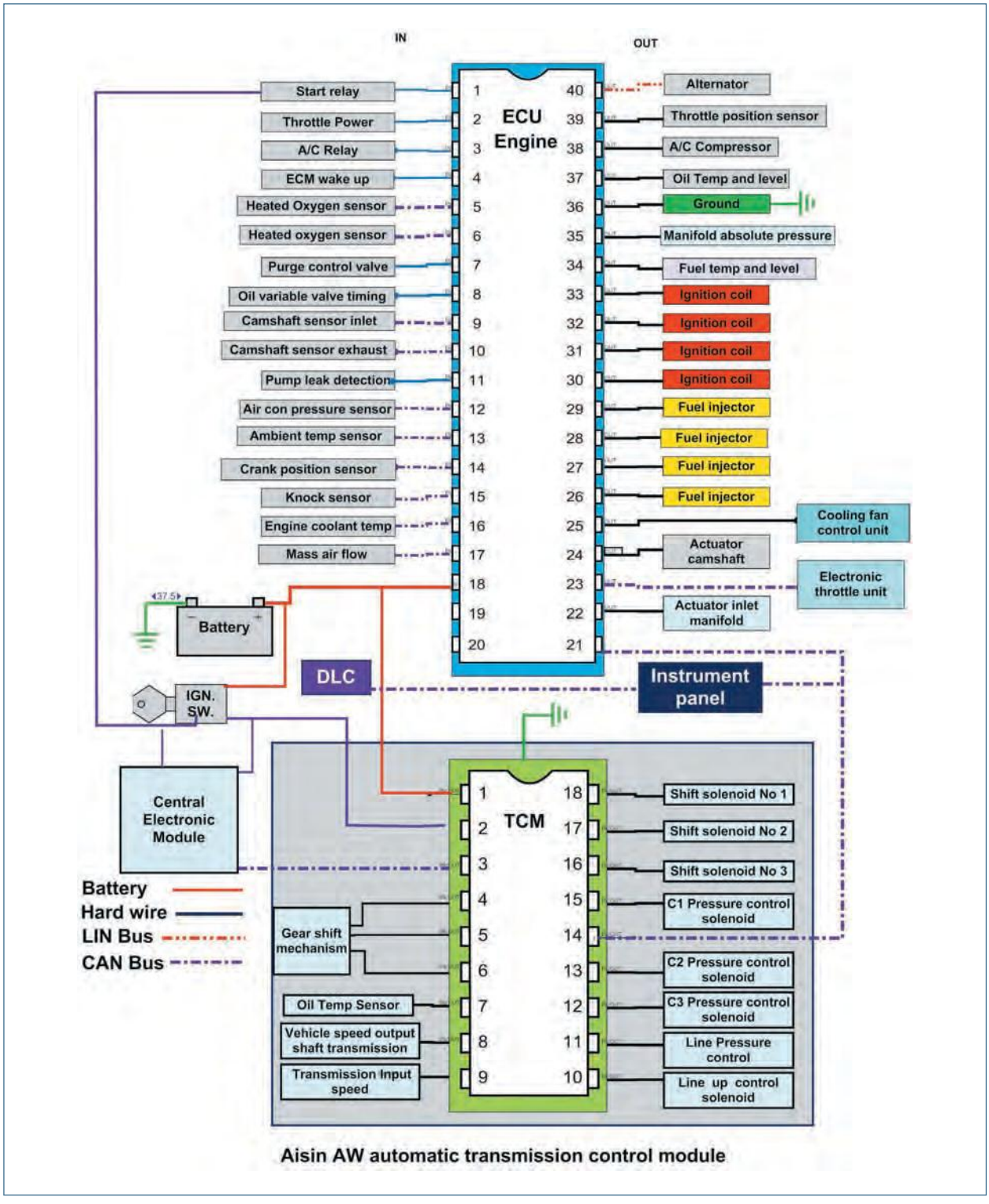


Figure 51.6 Schematic diagnostic chart

51.7 Fault codes

A scan tool is used to check the vehicle's electronic control system through the data link connector. While being used to scan for faults, the scan tool might indicate, for example, the error code P1320 for an electronic distributorless ignition system. The technician then checks the service literature for an interpretation of the code. For this particular example, the code P1320 indicates that the ECU has no signal from the crankshaft

position sensor, or that it has an unrecognisable signal. The P1320 fault code requires that the crankshaft position sensor is checked. The diagnostic flow procedure for code P1320 from the workshop manual is shown in Table 51.1. Starting with A1, each item on the chart is followed through until the correct action to rectify the fault is found.

Table 51.1 Flow chart for checking the crank shaft position sensor (CKP is crank shaft position)

Test step after signal has been confirmed missing/ faulty by using an oscilloscope	Result	Action to tak e
A1 Is the sensor fitted correctly ?	Yes ☐ No ☐	Go to A2 Rectify and retest
A2 Check sensor continuity using ohmmeter Is the reading from 300 to 400 ohm ?	Yes ☐ No ☐	Go to A3 Check sensor and wiring R ectify and retest
A3 With the sensor disconnected, measure the resistance across the connector for a possible short in EEC or wiring Does a short e xist?	Yes ☐ No ☐	Rectify and retest Go to A4
A4 Measure the resistance from CKP(+ve) to ground and CKP(−ve) to ground for possible short Does a short e xist?	Yes ☐ No ☐	Rectify and retest Go to A5
A5 Check wiring for open circuit Does an open circuit e xist?	Yes ☐ No ☐	Rectify and retest Check sensor and tone wheel for damage Rectify and retest

51.8 Vehicle system faults

Due to the ongoing research, development and continuous technological advances made to vehicles, the complexity associated with any fault finding and troubleshooting processes will increase. Fault finding and troubleshooting is a skill that is developed throughout the career of an automotive technician. The technician must have a good understanding of the operating principles belonging to each system and component so they can think logically about which issues may be presenting, and the steps that can be taken to rectify the problem.

Some vehicles will develop common faults which are easily diagnosed. Manufacturers rectify these issues when designing and manufacturing newer models within the production series. In other instances, vehicles can develop a range of faults that can be either easily rectified or are extremely complex to diagnose. Whenever conducting fault finding tasks, the following considerations may assist with the troubleshooting process:

- the number of kilometres the vehicle has travelled
- the vehicle 's service history
- the operating conditions in which the vehicle operates
- any previous repairs that have been conducted on the vehicle
- commonly known faults of a particular mak e or model.

Due to the complex and wide range of vehicle faults that occur, it is not possible to provide a standard range of problems and solutions. Mechanical problems may become evident through a diverse range of symptoms which, when correctly diagnosed, will be rectified by correcting the fault. This is where the troubleshooting and fault finding process must be carefully and thoughtfully conducted.

A broad range of vehicle faults are described below, along with the common possible troubleshooting processes that may be considered.

51.8.1 Engine

Engine systems are extremely complex and can present a vast array of faults. For further information on engines, refer to the following chapters:

- Chapter 15: Engine fundamentals
- Chapter 16: Engine construction
- Chapter 17: General engine service
- Chapter 21: Engine-lubricating systems

Sustainability: Always follow correct disposal and recycling requirements when disposing of any mechanical waste product.

51.8.2 Engine management system

When checking for engine management faults, start with the basics. Do not assume that the problem lies with the electronic controls. If the engine will not start, is hard to start, varies in idle speed, runs 'rough' or has poor acceleration, begin by checking the following:

1. Power supply Check the battery , battery terminals, the fusible link and the fuses.
2. Alternator output Check for voltage output, current output and signal trace .
3. Body earths Check for poor or loose connections that could have resistance and cause voltage loss or voltage spik es.
4. Fuel supply Check the fuel lines (leak s, deterioration, and tension), the filter (leak s, service interval) and the fuel pump (noise , flow rate , output pressure).
5. Ignition system Check the spark plugs, cables, distributor (if fitted) and connections.
6. Emission-control system Check crank case ventilation and the EGR system, and check for vacuum leak s.
7. Others Check ignition timing and idle speed.
8. Connectors Problems with EFI systems are often caused by poor contact at the connections. Check all connectors and mak e sure that they are secure . Make sure connector plugs are fully clipped in and that waterproof boots are fitted correctly .

More detail on engine management systems can be found in Chapter 31 EFI and petrol fuel systems.

51.8.3 Manual transmission

Table 51.2 outlines a range of possible manual transmission faults and troubleshooting processes.

Table 51.2 Manual transmission fault diagnosis

Complaint	Possible cause	Check or correction
Hard gear shifting	Clutch not releasing fully	Adjust
	Gearshift linkage out of adjustment Incorrect	Adjust
	lubrication of linkage	Lubricate
	Shift fork bent	Replace or straighten
	Sliding gear tight on splines S ynchromesh unit	Clean splines or replace
	damaged	Replace defective parts
	Interlock sticking	Free or replace parts
	Incorrect lubricant	Change lubricant
Sticking in gear	Clutch not releasing	Adjust
	Gearshift linkage out of adjustment	Adjust
	Incorrect lubrication of linkage	Lubricate
	Detent balls (selector) stuck	Free up
Slipping out of gear	Gearshift linkage out of adjustment	Adjust
	Weak detent springs	Replace
	Excessive mainshaft end-play	Replace parts or adjust
	Gear teeth worn	Replace gears
	Synchromesh unit worn or defective	Replace worn parts
	Excessive end-play of gears	Replace gears or thrusts

Table 51.2 Manual transmission fault diagnosis (*continued*)

Complaint	Possible cause	Check or correction
No power through transmission	Clutch slipping Clutch disc worn or brok en Cable or linkage defective Shifter fork or other part brok en Gear or shaft brok en	Adjust or replace parts Replace parts Replace cable or repair Replace parts Overhaul transmission
Noisy in neutral	Input shaft bearing faulty Gears worn Countershaft or bearings worn	Replace bearing Replace gears Dismantle and replace shaft and/or bearings
Noisy in gear	Mainshaft bearings worn Gear teeth worn Constant-mesh gear bearings worn Final-drive gears Differential side bearings worn Drive shaft components loose or dry	Replace bearings Replace gears Replace bearings Check or adjust Replace Replace and lubricate
Gears clash in shifting	Clutch not releasing fully Synchromesh unit defective Driver forcing a gearshift Interlock faulty	Adjust clutch Replace parts Shift correctly Adjust

More detail on manual transmissions can be found in Chapter 24 Manual transmissions, transaxles, four-wheel and all-wheel drive service.

51.8.4 Automatic transmission

Table 51.3 outlines a range of possible automatic transmission faults and troubleshooting processes.

Table 51.3 Automatic transmission fault diagnosis

Problem	Possible causes
No starter operation in N or P	8, 29, 39
Starter operates in other than N or P	8, 29
No engagement in D	18, 8, 19, 22
No engagement in any selector position	8, 19, 14, 30, 7, 18
Delayed engagement	22, 19, 9, 29, 31, 40, 41
Slip or noise on tak e-off in D	18, 9, 23, 14, 13, 15, 26, 34, 35
Slip or noise on tak e-off in reverse	18, 9, 19, 23, 14, 13, 15, 26, 34
Harsh engagement all positions	1, 9, 22, 23, 21, 34, 35
Poor acceleration in first	2, 4, 12, 13, 14, 15
Poor performance and overheating in third	2, 3, 28

Problem	Possible causes
No 1–2 shift	6, 15, 27, 34, 40, 41
Slip during 1–2 shift sometimes	18, 9, 23, 14, 15, 13, 25, 19, 34
Harsh 1–2 shift	9, 22, 23, 21, 34, 35, 30, 40
No 2–3 shift sometimes	8, 13, 25, 27, 30, 34, 40, 41
Slip during 2–3 shift	18, 9, 22, 19, 34, 40, 41
Harsh 2–3 shift	9, 22, 21, 34, 35, 40, 41
Soft shifts	19, 14, 15, 9, 34, 35, 38
No 3–4 shift	37, 30, 13, 14, 15, 27, 30, 34, 40
Shift speeds incorrect	9, 22, 26, 27, 31, 38, 40, 41
No engine braking in 1 position	14, 15, 25
Whine in N with engine running	11

(continued)

Table 51.3 Automatic transmission fault diagnosis (*continued*)

Problem	Possible causes
Grating noise from transmission	10, 16, 17
Knocking noise from converter	4, 5, 7
Park will not hold	8, 10
Transmission overheating	28, 18, 3
No converter clutch lock-up	5, 6, 7, 22
Transmission binds	25, 14, 20, 24
Engine stalls	1, 2
Engine flare between shifts	20, 14, 15, 18, 40, 41
Vehicle has e xcessive creep	1
No forced downshift	9, 36

Key to possible causes
Engine
1. Idle speed
2. Lack of power
Torque converter
3. Stator O WC stuck
4. Stator O WC not locking
5. Converter clutch
6. Pressure low
7. Converter damage
Mechanical/power train
8. Selector cable or linkage adjustment
9. Throttle cable or linkage adjustment
10. P arking pawl or mechanism damaged
11. Oil pump worn or damaged
12. Transmission O WC not locking

Key to possible causes
13. Clutch plates worn
14. Band adjustment
15. Brak e bands or plates worn
16. Gearing worn or damaged
17. W orn bearings or thrusts
Hydraulic system/controls
18. Fluid level low
19. Low line pressure
20. Internal fluid leak s
21. High line pressure
22. Valves sticking
23. Vacuum control fault or leak
24. Clutch piston sticking
25. Servo piston
26. Governor valve sticking
27. Shift valves sticking
28. Cooler inefficient or line block ed
Electronics/electrics
29. Isolator/selector-position switch adjustment, or fault
30. Wiring or connectors
31. Throttle-position sensor adjustment, or fault
32. Speed-sensor fault
33. Oil-temperature sensor
34. Shift solenoid
35. Pressure-regulator solenoid
36. Kickdown switch or solenoid
37. OD switch fault
38. ECU fault
39. Anti-theft system armed
40. Loose or corroded battery terminal
41. Low alternator output

More information on automatic transmissions can be found in Chapter 30 Automatic transmission service.

51.8.5 Driveline

Vibration within a vehicle can be caused by a mechanical system other than the drive line. A worn centre bearing or universal joint can cause a vibration within the driveline. Additionally, a loose, bent or misaligned spline or shaft within the drive line can produce vibration and noise, as can a faulty rim or tyre. By test driving the vehicle and listening carefully to the noise, the technician can differentiate between a driveline or tyre fault.

More information on the driveline can be found in Chapter 25 Drive lines and shafts.

Handy hint: Whenever a drive shaft has been repaired or replaced, always road test the vehicle to ensure that the fault has been rectified.

51.8.6 Final drive

Tyre noise changes with road surfaces, while rear-axle noise does not. When coasting in neutral, tyre noise is usually more noticeable than rear-axle noise. Generally, it is uncommon to hear tyre noise at lower speeds. Inflating the tyres to a higher pressure, rotating or changing them to a different position on the vehicle can assist with locating tyre noise.

Worn, damaged or incorrectly adjusted front-wheel bearings can cause a noise similar to tyre noise. However, a wheel-bearing fault can produce a noise when cornering or a constant noise which is noticeable when driving.

Faulty rear-axle bearings produce a growling type noise, which can be misdiagnosed as a fault within the differential. However, a differential noise varies under speed, load, while coasting and backing off, while a rear-axle bearing noise is constant and will be more noticeable when coasting in neutral.

Noise within the final drive is most noticeable when accelerating, as the gear teeth within the differential are under load. In this instance, the bearings are also under load, therefore incorrect bearing and gear preload will allow the gear teeth to change their area of contact with each other, which results in a whining noise.

Worn bearings in a differential will produce noise, and tend to magnify crown wheel and pinion noise. A worn bearing will not hold the gears within the correct location, and as a result the tooth contact will change under different load conditions resulting in both bearing and gear noise.

More information on final drive can be found in Chapter 26 Rear axle and final drive services.

51.8.7 Braking systems

Table 51.4 outlines a range of possible braking system faults and troubleshooting processes that can be followed.

Safety: Never use compressed air to blow away brak e dust.

Table 51.4 Braking system faults

Possible fault	Likely cause
Excessive pedal travel	Brake shoe adjustment required Excessive disc runout Insufficient fluid, or leak s Air in the hydraulic system Loss of fluid in one hydraulic circuit
Spongy pedal	Air in the hydraulic system Insufficient fluid
Springy pedal	Incorrect shoe adjustment Distorted brak e shoes Badly installed shoes
Pedal gradually goes to floor	Leak in hydraulic system Faulty cups in master cylinder allow fluid to pass
Hard pedal	Brake booster inoperative Pedal linkage damaged or dry Brake hoses or line restricted Wheel cylinder pistons seized Caliper piston stuck Wet brak e linings
Pedal pulsates	Out-of-round or off-centre drum Excessive disc runout Normal effect of ABS
Brake drags	Incorrectly adjusted shoes No free play at pedal Fluid or grease on linings or pads Sticking piston in wheel cylinder or caliper

Possible fault	Likely cause
	Master cylinder fault Blocked compensating port Faulty brak e hose or line Parking-brak e cable binding
Brake grabs	Fluid or grease on linings or pads Faulty brak e drum or disc Faulty return spring Piston sticking in wheel cylinder or caliper
Vehicle pulls to one side	Fluid or grease on linings or pads Faulty or incorrect return spring Seized piston in wheel cylinder Piston stuck in caliper Brake hose or line restricted One hydraulic circuit inoperative Low tyre pressure or worn tyre
Rear brak es lock	Proportioning valve inoperative Rear tyres worn Master cylinder faulty
Brake chatters	Fluid or grease on linings or pads Loose suspension parts Drum or disc out of round Loose mounting
Brakes squeal	Glazed or contaminated linings Type of friction material Dirty or scored drums

More information about braking systems can be found in Chapter 11 Brakes.

51.8.8 Electrical system

Electrical systems are extremely complex and can present a vast array of faults. Knowledge of electrical system faults requires a clear understanding of basic electrics, basic electronics and vehicle computer systems. For further information on electrical systems, refer to the following chapters:

- Chapter 31: Electronic fuel injection and engine management
- Chapter 32: Ignition systems and service
- Chapter 38: Basic Electrics
- Chapter 39: Effects and applications of electric currents
- Chapter 40: Basic electronics
- Chapter 44: Body electrical systems and service
- Chapter 46: V ehicle computer systems.

Safety: Electrical systems contain e xtremely high voltage which can cause severe injury or death if correct safety precautions are not followed. Always adhere to manufacturers ' warnings when working on a vehicle 's electrical system.

51.8.9 Steering system

Table 51.5 outlines a range of possible steering system faults and troubleshooting processes.

Table 51.5 Steering system fault diagnosis

Symptom	Possible causes
Loose steering	Incorrect front-wheel bearing adjustment Loose linkage ball joints Loose steering-bo x mounting Wear or maladjustment of steering bo x Worn or loose idler arm
Heavy steering	Power steering inoperative Incorrect tyre pressure Incorrect front-wheel a lignme nt Lack of lubrication Tight steering-bo x adjustment
Steering and suspension rattles	Loose linkage connections Loose mountings Loose suspension joints Broken spring
Steering shimmy (wobbles when vehicle travelling at speed)	Out-of-balance wheels Incorrect front-end alignment Loose linkage connections
Vehicle pulls to one side	Tyre pressures uneven Front-wheel alignment incorrect Sagging or brok en spring Mismatched tyres
Tyre squeals on turns	Low tyre pressure Incorrect wheel alignment Bent steering arm
Wander from side to side of road	Incorrect wheel alignment Loose steering connections Loose steering-bo x adjustments Sagging spring Incorrect tyre pressure Uneven tyres

More information can be found in Chapter 13 Steering systems.

51.8.10 Suspension system

Table 51.6 outlines a range of possible suspension faults and troubleshooting processes.

Table 51.6 Suspension system fault diagnosis

Problem	Possible cause
Squeaks	Spring mountings Lack of lubricant Worn bushes in control arms Leaf spring insulators worn or damaged Shock absorber mountings worn
Rattles	Worn or loose shock absorber mountings Stabiliser bar mountings worn or loose Stabiliser bar bushes worn Ball joints worn and loose Control arm bushes worn
Vibration	Tyre pressures high Wheel out of balance Shock absorber inoperative
Other noises	Lack of lubrication Loose wheel nuts Loose or faulty wheel bearings Tyre noises
Worn tyres	Misaligned suspension Bushes worn in control arms or other suspension parts Inoperative shock absorbers Damaged or bent suspension parts
Vehicle bounces	Shock absorbers weak or inoperative Spring weak
Vehicle steering	Tyre pressure low on one side Sagged spring Incorrect wheel alignment Bent steering or suspension part Worn or loose bearing

⚠ Safety: Be aware of stored energy within the suspension system. Always use the correct tools and equipment when working on coil springs.

More information can be found in Chapter 12 Suspension systems.

51.9 Reporting of findings of identified faults

Accurate reporting of the work completed is a vital component of any vehicle repair. Generally, automotive repair and service centres will use job cards for technicians to report on the work that was conducted. Depending on the system used, job cards as shown in figure 49.12 can be filled out manually or the information can be entered into an electronic reporting system. The information on the job card is then used by service managers and service advisors to produce an invoice for the customer. It is important that a job card is accurately completed so that the correct information is passed on to the customer. The reporting of work completed on a job card should explain in detail the work that was done as part of the diagnosis and repair. Additionally, it is important to document the following:

- time spent on the task
- specialised equipment that was used
- parts used
- any further work that needs to be conducted.

The reporting of work completed to a vehicle is not only used for the purposes of a particular service or repair centre. These reports can also form an integral part of other services such as:

- warranty repairs
- insurance repairs
- investigations used for settling disputes.

Job Card	Job Number:	

Technician Name: _____ Date : _____

Vehicle Details

Vehicle Make: _____ Model: _____

Year: _____ VIN: _____

Odometer: _____ Registration No: _____

Customer Details:

Name: _____ Address: _____

Contact number : _____ Email: _____

Description of work to be carried out:

Estimated cost of service repair: _____

Authority to service/repair-Customer signature: _____

Time on: _____ Time off: _____ | Quality check: Yes ☐ No ☐ Initials: ☐

Description of work completed

Recommended further work to be completed

Parts used:	Cost	Parts used	Cost

Specialised equipment used:

Service Manager check and authorisation:

Name: _____ Date: _____ Signature: _____

Figure 51.7 Sample job card

SUMMARY

The diagnosis and repair of vehicle system faults involves a range of tasks which are not limited to simply working on the problem. A technician must focus on excellent communication strategies that will first provide a clearer understanding of the symptoms, then test and analyse the symptoms, and finally, repair the fault. When correct troubleshooting processes are followed, fewer unnecessary repairs will be carried out, resulting in a more efficient and productive workplace.

REVIEW QUESTIONS

1 Describe the difference between a symptom and a fault.
2 Explain why correct diagnosis of mechanical faults is important.
3 Outline the five steps involved in fault diagnosis and repair .
4 Describe the actions involved in the following steps of diagnosis:
   1 Test symptoms
   2 Analyse the problem
   3 Re-test.
5 Provide six sources from which additional technical support can be obtained.
6 List the main characteristics of the following diagnostic charts:
   a flow chart
   b pictorial drawing
   c schematic drawing.
7 A scan tool is used to check the vehicle 's electronic control system. A t what point on a vehicle is the scan tool connected to the vehicle ?
8 List the five further considerations that may assist with the troubleshooting process when conducting fault finding task s.
9 Using Table 51.3, diagnose the following automatic transmission faults:
   a The vehicle has e xcessive creep .
   b Park will not hold.
   c There is a whine in N (neutral) with the engine running.
   d The engine stalls.
   e The starter operates in other than N (neutral) or P (park).

CHAPTER 52

Workplace communications

LEARNING OBJECTIVES

On completing this chapter , you will be able to:

1 Identify the objectives of communication
2 Describe the uses of different styles of communication
3 Understand how communications is applied in an automotive workplace
4 Learn the different types of communication skills
5 Identify sources of information in an automotive workplace .

This chapter is aimed at helping the automotive technician to understand the processes and benefits of good workplace communications. Good communication is the lifeblood of any successful business. Communication can be defined as the exchange of ideas or information and the sharing of feelings . This definition implies a two-way process. Putting a notice on the workshop noticeboard is not considered communication. It is simply providing information rather than an e xchange of information.

There is always a sender , a receiver and feedback in the communication process. The role of sender or receiver is not fix ed and will change continually during a normal conversation.

52.1 Objectives of communication

Information must reach the receiver at the right time, in the right format and in language that can be understood by the receiver. Whether a business is large or small, the objectives will remain the same, although the communication tools may vary.

52.2 Benefits of good communication

Everyone benefits from good communications in the workplace. A more productive and safer environment is the main outcome of good communication. Other benefits include:

- a healthy and happy workforce
- improved customer relations
- good relationships with co-work ers and supervisors
- a stable industrial relations environment.

Poor communication will usually have the opposite outcome. Productivity may drop and relationships between management and employees may become strained. High absenteeism and staff turnover are two signs of poor communication.

52.3 Who do we communicate with?

The diagram in Figure 52.1 shows the people a technician may come in contact with on a normal day at work. This diagram represents a medium-size workshop and will vary at each workplace depending on the size.

The way we communicate with each person will be different. It is important to consider *who* and *how* we communicate with each person. For example, the best way to explain a technical problem to a fellow worker will be different from the way to explain the same problem to a customer who has no technical background.

Communication can be divided into two main types: *verbal* or *spoken communication* and *non-verbal communication.*

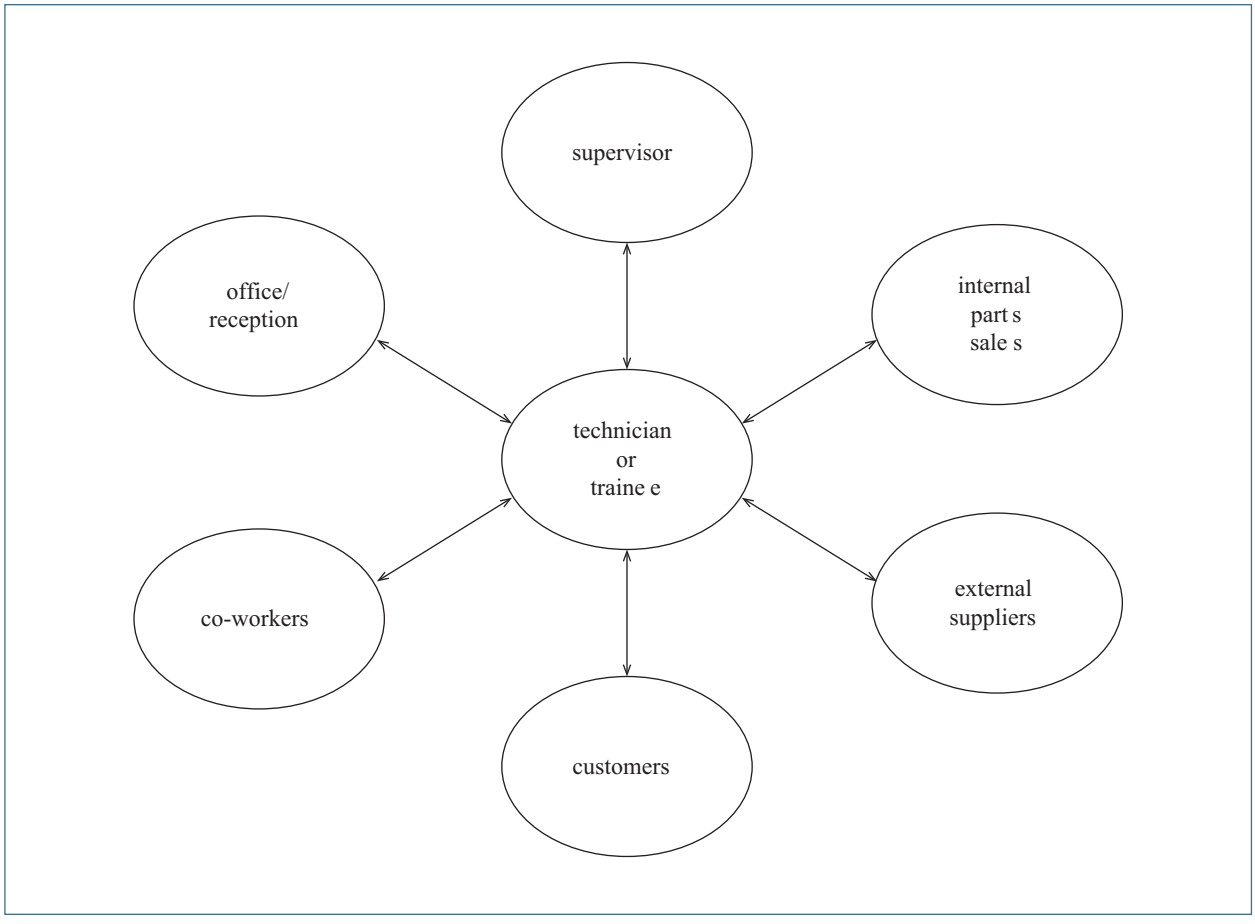


Figure 52.1 Communication diagram for a medium-size automotive work shop

52.4 Verbal communication

Verbal communication can be face to face with an individual or groups, over the telephone or by video link. Verbal communication is the most effective way to communicate information and ideas. It is also the communication channel that can cause the most problems.

52.4.1 Questioning skills

There are many types of questions that can be used for different situations. A question can be used as a greeting – 'How are you?' – or to start a conversation – 'How is the rain affecting you?' – but the most common use of questions in the workplace is to gain information.

Reminder: You get the right answers when you ask the right questions.

There are basically two main types of questions used to gain information: *closed questions* and *open questions.*

Closed questions

These are used when a limited answer is required, for instance, 'Was the engine hot or cold when the warning light came on?' They are used to keep the conversation focused on the topic and can gain a lot of information quickly.

Open questions

Open questions allow a longer and more detailed response.'What do you think of the new engine analyser?' will get a different answer from 'Do you think the new engine analyser is easier to use than the old one?' The first question allows more information to be communicated than the second question, which requires only a yes or no answer.

The careful use of questions is very important in customer relations. Figure 52.2 shows a service manager questioning a customer about her car. It can build a bond, so that the customer has confidence in the repairer – but avoid asking too many questions. The conversation can turn into an interrogation and turn the customer off.

Figure 52.2 Service manager questioning a customer about her car

52.4.2 Using the telephone

A telephone call is often the first contact a person will have with the workplace. Every caller should be treated as a potential customer, so it is important to make a good impression.

Many workplaces have a set procedure to follow when answering the phone. Figure 52.3 shows a phone call being logged on the computer. If a set procedure is not provided, the following simple procedure could be used:

- Begin with a greeting: ' Good morning/afternoon '.
- Provide the business name: 'This is XYZ W orkshop '.
- Give your first name .
- Request the person 's name .
- Ask: 'How can I help you ?'

When using the telephone always:

- Speak clearly.
- Use a polite and friendly tone of voice .
- Write down and repeat important information.
- Record the time of the call.
- Let the caller know you are listening by saying 'yes I have got that' or 'I understand' occasionally .
- If you cannot answer the inquiry , make sure it is followed up .
- Inform the caller what will happen ne xt.
- Let the caller hang up first.

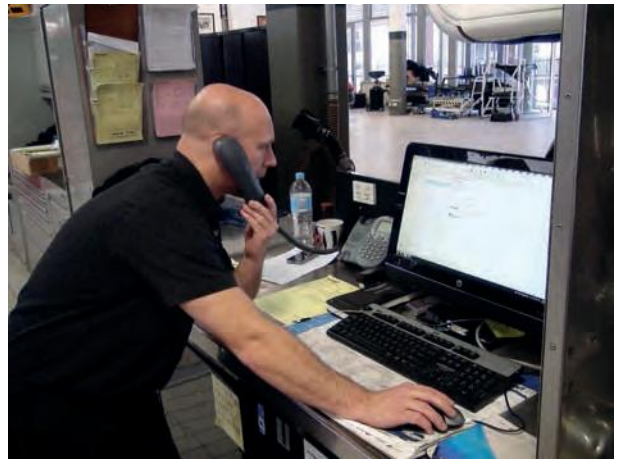


Figure 52.3 A telephone inquiry being logged directly onto the computer

52.5 Non-verbal communication

Non-verbal communication is any form of communication that does not use speech. It is just as important as verbal communication. One form of non-verbal communication is often referred to as *body language*. It includes such things as:

- facial expressions
- eye movement
- personal grooming and clothing
- hand movements and gestures
- how and where a person stands in relation to the other person.

Body language is usually instinctive, which means the person is not aware that he or she is doing it. Feelings such as boredom, aggression, frustration, attentiveness and relaxation can all be relayed through body language. A good communicator will be in tune with the other person's body language and his or her own.

If the body language during a conversation is negative – for example, folded arms and a bored look on the face of the listener – the speaker should change the conversation to include the listener. Asking questions is a good start to re-engage the listener.

Non-verbal communication, such as using hand signals, is often useful in a noisy environment. Figure 52.4 shows a car being guided onto a hoist. The driver cannot hear the person guiding, so hand signals are the best method of communication.

Figure 52.4 Guiding a car onto a hoist

52.5.1 Listening skills

Active listening is a technique in which the listener provides feedback to the speaker. The feedback can be verbal – 'I understand' – or non-verbal – nodding of the head to show the speaker that you are listening. Active listening is a skill that can be practised and developed by using some or all of the following techniques:

- Maintain eye contact with the speaker when possible.
- Take written notes of important points.
- Don't be distracted.
- Ask questions to clarify anything that is not fully understood.
- Summarise the main points when the speaker has finished.

Reminder: A good listener is an active listener.

52.5.2 Email

Email is almost universal as a tool for communication in the workplace. There are many advantages to using email over other forms of communication:

- The message is transmitted almost instantaneously to the receiver.
- Attachments such as reports or quotes can be included.
- The receiver can respond to the email when it best suits him or her.
- Keeping copies can be done electronically, saving paper and space.

Disadvantages include:

- Unwanted mail that has to be dealt with, causing wasted time.
- Excessive mail build-up if not regularly answered.

Tips for safe and effective use of email include:

- Open email from a trusted source only.
- Don't open attachments immediately. Use spyware software to check attachments before opening
- Don't use a work computer for private email.
- Always log out when you are finished.

52.6 Barriers to good communication

Communication breaks down when it is obvious the message is not getting through to the right person at the right time. Some of the more common barriers to good communication are listed here:

- Use of the wrong communication channels, for example, the use of an email when a phone call would be quicker.
- Not clarifying or checking the main points.
- Use of inappropriate language, for instance, including terms that are too technical for the customer to understand.
- Poor body language, sending mixed signals to the receiver.
- Not listening or being distracted during a conversation.

Identifying why communication has broken down is essential to resolving the problem.

52.6.1 Writing skills

Writing in the workplace is usually limited to reports, memos and service recording documents. Writing must be neat and readable. Keep sentences as short as possible.

Use correct technical terms, for example, 'The shock absorbers require replacement' – not 'The shockies have had it'. A verbal explanation can be given to the customer later if required. The correct terms become more important if there is a dispute over repairs.

Keep copies of all reports or any written information given to the customer.

52.6.2 Reading skills

The purpose of reading in the workplace is to find and use information. Reading skills required may vary from quickly skimming or scanning a document to gain a general idea, to reading a procedure in detail to make sure you fully understand the material.

52.7 Sources of information

Technicians need to be able to access a variety of information in order to diagnose and repair faults on vehicles. The information can be found in various formats and locations, such as books and magazines, on electronic compact discs (CDs), websites and on the vehicle in the form of decals.

The most common sources of information are:

- workshop manuals
- vehicle owner's handbook
- service and tune-up guides
- standard times guides
- product guides
- on the vehicle
- the internet.

52.7.1 Workshop manuals

Vehicle manufacturers publish workshop manuals for their vehicles. In some instances, technical information is also available on CDs. As well as this, an *owner's manual* is supplied with each new vehicle.

Workshop manuals are divided into a number of sections, each covering a major part of the vehicle. There are procedures for major and minor repairs as well as information on maintenance, adjustments, fault diagnosis and specifications.

Manuals are often divided into a number of volumes, with separate volumes for the engine, transmission, body and so on. An automotive mechanic must be able to refer to workshop manuals and interpret the information that they contain.

Workshop manuals have a contents page at the front of the book and a contents list at the start of each section. These should be the starting point when looking for information.

Handy hint: Workshop manuals are also known as service manuals or repair manuals. Many are available online.

Technical information

The following types of technical information can be found in workshop manuals:

1 Descriptions. The features and construction of a component or a system are often described at the start of a section as a means of introducing a component.
2 Principles of operation. The principles of operation of various components and systems are described – it is necessary to know how things function before they can be properly serviced, particularly when diagnosing problems.
3 Maintenance and service . These are procedures that should be carried out at regular intervals to maintain the vehicle in a sound condition.
4 Service adjustments. Manuals include descriptions of how adjustments are carried out and when they should be done .
5 Tune-up procedures. These are the services that should be done periodically to maintain engine efficiency .
6 Repair operations. These are the detailed descriptions and illustrations of both major and minor repairs. They include methods of dismantling, repairing, installing and adjusting the various components and systems.
7 Special tools and equipment. Information is provided on special tools and equipment needed to service the particular model of vehicle .
8 Technical data. This is important information that includes specifications, torque settings, capacities (fuel, oil and coolant), sizes, wear limits, clearances and other information that is needed during servicing or repairs.
9 Wiring diagrams. These show the electrical wiring for the various parts of the vehicle . They include the colour code for the wires and the connections to all the electrical components.

Technical illustrations

Illustrations are used in workshop manuals to support the text and the same types of illustrations are used in this book. There are a number of different types of illustrations.

1 Line drawings. These show only one view of an object and so have only two dimensions – width and height, depth and height, or depth and width.
2 Pictorial drawings. These have three dimensions – width, height and depth. They show the full shape of the object.
3 Photographic illustrations. These are photographs of the actual object.
4 Exploded views. This type of illustration is used to show the parts of a component that has been dismantled. The parts are laid out in the correct order for reassembly .
5 Sectional views. These have a section of the object cut away to show the internal parts. Cross-hatched lines drawn across the housing show where it has been cut.
6 Schematic drawings. These are simplified drawings in which parts are not drawn to their true shape . Instead, outlines of the parts are drawn, or the parts are represented by symbols. Wiring diagrams are of this type .
7 Block diagrams. Block diagrams are used to show the relationship of parts of a system. The actual parts are not drawn to shape , but rectangles (blocks) are used to represent the parts (Figure 52.5 is an example).

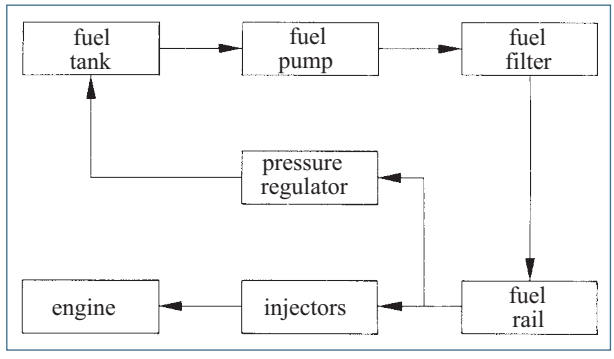


Figure 52.5 A block diagram that shows the flow of fuel in the fuel system

Tables and charts

Tables and charts are used to show specifications, pressures, thread sizes or other data. They provide information in a form for easy reference.

Some charts are known as tree charts because they have branches thatlead from one item to another. A chart used for diagnosing problems is shown in Figure 52.6. This shows a logical sequence to follow when trying to solve a problem.

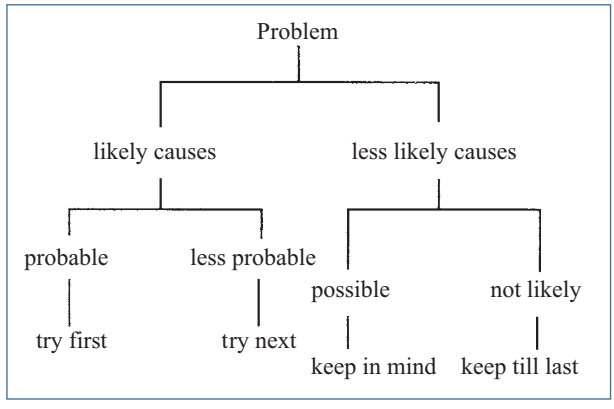


Figure 52.6 The tree chart shows a path to follow when diagnosing a problem

52.7.2 Vehicle owner's handbook

Details of the location and correct operation of the vehicle's controls are found in the owner's handbook. The meaning of symbols on the instrument cluster, operation of switches, and adjustment of seats and steering position are just some of the elements that can be found in the handbook. Emergency, safety and vehicle care information are also included in handbooks.

52.7.3 Service and tune-up guides

These publications provide information on routine servicing for the general repair workshop. They include topics such as service intervals, fluid and lubricant types, locations and quantities. They also include specifications for the engine, fuel and electrical systems.

Vehicles are listed in alphabetical order, with the most common locally produced and imported vehicles represented. Electronic versions are available, with additional information including pictures of components and test procedures.

These guides are designed for the technician who is experienced in service and repair procedures. They are not designed to replace vehicle workshop manuals.

52.7.4 Standard times guides

A standard times guide provides a list of the common repairs, services and adjustments for a range of vehicles and the expected time needed to carry out the task. The time is stated in hours or parts of hours; 2.5 hours equals 2 hours 30 minutes.

Vehicles are listed in alphabetical order and the tasks arranged in sections such as engine, transmission, brakes etc.

These publications are useful when quoting the cost of repairs to customers. They are only a guide, however, because they don't take into account problems that may occur when repairing older vehicles.

52.7.5 Product guides

Manufacturers provide guides on the products they produce and the vehicles on which they are used. Filters, lubricants, spark plugs and timing belts are just some examples of products with accompanying guides that can be found in most workshops. They are normally supplied free of charge on request from the parts suppliers or are available on their website.

52.7.6 On the vehicle

All vehicles must be supplied with information on tyre size and recommended pressures, exhaust emissions and engine adjustments. The information is normally provided on decals or 'stickers' that are stuck onto the vehicle in various locations. Other decals can be found that provide information on air-conditioning refrigerants and timing belt replacement. Figure 52.7 shows typical locations of plates and decals.

Figure 52.7 (a) Tyre information located on the driver's door pillar (b) refrigerant and service information located under the bonnet

52.7.7 Internet

The internet is a popular source of information. All vehicle manufacturers, product suppliers, and tool and equipment manufacturers have websites that provide information about their products and services. If the website address is not known, it can usually be found by searching the name of the product.

52.7.8 Vehicle identification

Manuals contain general information about the vehicle, including vehicle model identification. All vehicles are fitted with both a *compliance plate* and a *data plate*. These metal plates are fixed to a body panel in the engine compartment and must never be removed.

Compliance plate

A compliance plate (Figure 52.8(a)) shows the make, model and the vehicle identification number (VIN). It also states that the vehicle was built to comply with the *Motor Vehicle Standards Act*.

Vehicles must conform to Australian Design Rules, which cover safety, emission control and consumer protection. All vehicles are built to these standards and must carry a compliance plate.

Data plate

A data plate (Figure 52.8(b)) contains the manufacturer's information about the vehicle, such as the model, body type, trim, colour code, suspension and transmission type. These are shown as codes consisting of letters and numbers.

The date the vehicle was built is also shown. This is the date that the vehicle was driven from the production line.

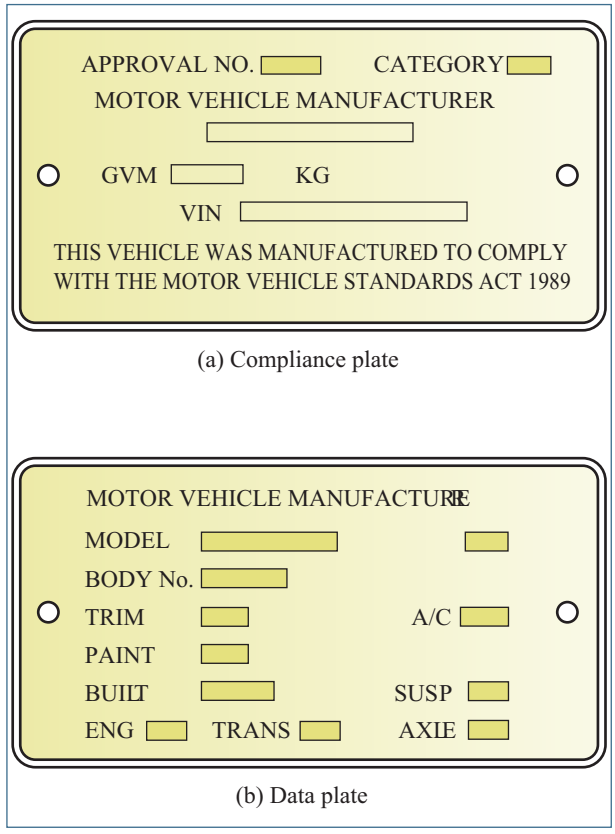


Figure 52.8 Compliance plates and data plates are fitted to every vehicle

Handy hint: Data from the data plate is used to identify the vehicle and components when obtaining replacement parts.

Manuals explain this data and also show where to find the body number, the engine number and the transmission number. Serial numbers stamped on these parts are used for identification purposes.

52.8 Workplace documents

All important information in the workplace needs to be documented and filed. Documents may need to be kept for up to seven years for taxation or warranty purposes. Most workplace documents are in a fixed format or a *form*.

The following forms are commonly used in automotive workshops for the service and repair of vehicles.

52.8.1 Quote

A quote is a statement of the proposed cost of repairs provided to the customer by the repairer. It would normally include the cost of parts, labour and any consumables such as oil, rags etc. If the quote is accepted and signed by the customer and the repairer, it is legally binding on both parties.

52.8.2 Repair order/job card

The repair order (RO) records all of the essential information relating to the repair, which is needed to invoice the customer. This information would include:

- business name and details
- reference number and date
- customer's name and contact details
- vehicle details including registration and VIN
- odometer reading and fuel level
- description of the job to be carried out
- extra work required
- parts and labour used
- discounts and promotions.

The repair order and job card can be combined into one document or may be separate depending on the needs of the workshop.

It is essential that the customer signs and authorises all repairs on the repair order.

52.8.3 Invoice

An invoice is a request for payment for the goods or services provided by the repairer. The invoice details the repairs and materials used. It also states the method and terms of payment. For example, 'A discount of 5% will apply if the account is paid in cash when collecting the vehicle' or 'Payment is due within 30 days'.

52.8.4 Receipt

A receipt is a record of payment. The receipt can be handwritten or generated electronically. Often the invoice is stamped 'PAID' when payment is made. The stamped, dated and signed invoice then becomes the receipt.

Reminder: All documents must comply with Goods and Services Tax (GST) requirements.

52.8.5 Warranty tags

When a faulty component is replaced while it is still under the manufacturer's warranty, a warranty tag is attached to the component. Each manufacturer has its own warranty tags and procedures. A car may also have a number of separate warranties that apply. If a tyre has a defect, for example, the tyre manufacturer will be responsible rather than the car manufacturer.

It is important that all of the information regarding the faulty component is recorded on the repair order and the warranty tag, or the claim may be rejected.

SUMMARY

Now that you have completed this chapter you can transfer your knowledge into practical situations within an automotive service and repair context. You will be able to:

- identify the objectives of communication
- describe the uses of different styles of communication
- explain how communications is applied in an automotive workplace
- explain the different types of communication skills
- identify the sources of information in an automotive workplace.

REVIEW QUESTIONS

1 Define the term communication.
2 State the two main types of communication.
3 List the people that would normally communicate in the workplace .
4 State six benefits of good workplace communication.
5 What are three reasons for asking questions ?
6 Give an example of a closed question.
7 Give an example of an open question.
8 List five steps when answering a telephone call.
9 What is active listening ?
10 List five types of information that would be found in a workshop manual.
11 In this textbook, find an example of the following: a line drawing, a circuit diagram, a pictorial view , a sectional view and an exploded view .
12 What is a compliance plate , and where is it likely to be located?
13 What type of information is a data plate likely to contain ?
14 State five barriers to good communication.
15 What is a quote ?
16 List nine items of information that should be listed on a repair order .
17 What is an invoice ?
18 When is a warranty tag used?

Glossary

liquefied petroleum gas (LPG) petroleum gas compressed into a container, where it becomes liquid; a mixture of propane and butane
abrasion wear due to rubbing
abrasive hard substance used for grinding or sharpening
accelerator pedal connected to the throttle valve to control engine speed and power
accumulator (brakes) with ABS, a type of hydraulic reservoir
accumulator (electrical) another name for a rechargeable battery
accuracy exactness; without errors
Ackermann principle steering system that enables the inner wheel to turn through a greater angle than the outer wheel
actuator a device that performs an action in response to an electrical signal
adaptive learning strategy a self-learning function of a computer
adaptor a fitting to connect one part to another
additives chemicals that are added to fuels, lubricants and coolants
advance (ignition) the spark is advanced so that it occurs before top dead-centre
afterburn the burning of particles of fuel which remain in the exhaust gases after they leave the cylinder
aiming adjusting headlamps so that they point to the right place on the road
aiming board a board or screen at which headlamps are aimed
air bleed a small hole or jet which bleeds air into the fuel that is being discharged into the barrel of a carburettor
air cell a design of auxiliary combustion chamber in a diesel engine
air cleaner a filtering device for removing dust and providing clean air to the engine
air gap the gap between a set of contact points; for a spark plug, it is the gap between the electrodes across which the spark jumps
air horn the upper part of a carburettor through which the air enters
air injection an exhaust-emission control which injects air into the exhaust manifold
air lock air trapped in a system that normally contains only liquid
air pollution harmful gases from the exhaust system and other sources that are discharged into the atmosphere
air-bleed correction correcting the air–fuel ratio in a carburettor by bleeding air into the fuel at the discharge nozzle
air-cooled removal of heat by air blown by a fan; an air-cooled engine is cooled by air blown across fins on the cylinder block and head
airflow sensor a sensor used to measure the quantity of air flowing through the air-intake system of an EFI engine
air–fuel mixture the mixture of air and fuel for the engine
air–fuel ratio the ratio of air to fuel in the air–fuel mixture, measured by mass; the ideal ratio is 14.7:1
alignment when parts are correctly positioned
alloy mixture of metals with special characteristics
all-wheel drive a drive system that uses all four wheels to drive a vehicle
alternating current electric current that continuously reverses its direction of flow
alternator device that changes mechanical energy to electrical energy; it produces alternating current (ac), which is rectified to direct current (dc)
aluminium alloy a mixture of aluminium and other metals
ambient air temperature the temperature of the surrounding air
ambient temperature temperature of the surrounding air
ammeter electrical instrument for measuring current flow
ampere unit of electrical current
ampere hour 1 amp for 1 hour; used as a basis for measuring the capacity of a battery
ampere-turns the product of the number of turns in a coil winding and the current flow; this affects the electromagnetism produced
amplify increase in size or sound
analog instrument an instrument with a face and pointer
analyser a test instrument, or group of test instruments
angularity the angle of one part in relation to the vertical or to another part
anneal removing the hardness from metal by heating and cooling; steel is cooled slowly; copper is quenched in water
annulus a ring; the outer gear of a planetary gear set
anode the positive pole or plate of an electrical device
antifreeze chemicals added to the engine coolant to prevent it from freezing; usually ethylene glycol
antifriction bearings ball and roller bearings; they roll over the surface and so have reduced friction
antifriction metal special bearing metals that are used with engine bearings
antiknock additives chemicals that are added to petrol to increase its octane rating and so reduce knocking
apex the top or peak
aquaplaning tyre of a wheel that is locked by braking and planes on a wet road
arc an electric spark
arc welding welding by means of an electric current that produces an arc between the welding electrode and the metal being welded
armature the rotating part of a starter or an electric motor
asbestos a fibrous mineral that is resistant to heat; no longer used because of health problems
aspect ratio the height/width ratio of a tyre; the tyre profile
assembled valve height the height of the valve stem above the spring seat. It changes when seats and valves are machined
atmospheric pressure normal air pressure
atom a small particle of matter that contains positive and negative charges
atomisation with fuel, changing into a fine spray
auxiliary an extra part that helps a main part
axial along the axis; lengthwise
axle shaft supporting the wheels; shaft driving the wheels
axle ratio the ratio of the final-drive gears

back EMF an EMF (voltage), generated in an electric motor, which opposes the normal flow of current in the armature windings
back leakage fluid that leaks back past a pump plunger, or past the needle of a diesel injector
back off with a screw adjustment, to unscrew a specified number of turns
back pressure pressure in the exhaust system due to a blocked muffler or other restriction
backfire a charge that fires in the manifold instead of in the combustion chamber
backlash free movement allowed by the clearance between gear teeth
baffle a plate to regulate or divert the flow of liquid, gas or sound; used in petrol tanks to prevent surging, and in exhaust mufflers to reduce noise
balance to have equal mass; with tyres, weights are added to balance heavy spots
balance shaft a shaft, with balance weights, that is driven by gears or a chain from the crankshaft; used to reduce engine vibration
balance weights masses on the crankshaft that balance the effects of the cranks
balancing-coil gauge a fuel or temperature gauge where the needle is located (balanced) between two electromagnetic coils
ball joint a flexible joint used with steering and suspensions to allow parts to move
ballast resistor a wire resistor that reduces the voltage at the ignition coil; used with breaker ignition

ballrace a bearing with steel balls running between an outer and inner race
bank of cylinders the cylinders on one side of a V-type engine
bar a unit of atmospheric pressure
barrel the cylindrical part of the carburettor through which the air and fuel mixture flows
battery capacity the size of a battery, based on its ability to maintain current flow
battery charging reversing the current flow through a battery to restore its charge
battery voltage the voltage between the terminals of a battery, nominally 12 volts
baulk ring the part of a transmission synchromesh unit that is used to synchronise the speed during a gearshift
bead (of tyre) the reinforced edge of the tyre that mounts on the wheel rim
beam the rays of light from a headlamp; also a horizontal structural member
beam axle a solid front axle with kingpins and stub axles; a rigid rear axle
bearings support in which a shaft rotates; can be a plain bearing, a ball bearing or a roller bearing
bed in to allow surfaces that rub together to settle in
bellmouth somewhat bell-shaped; a hole that is worn tapered at the opening
bevel an angle; a gauge to measure angles
bevel gears two gears that operate at an angle
bezel the outer rim of a dial gauge or other round instrument
bias ply the plies in a tyre fabric that run in a criss-cross direction
bi-directional universal signalling (BUS) a two-way serial data communications system between computers
big end the large (lower) end of a connecting rod
big-end bearing the bearing at the big end of the connecting rod where it attaches to the crankshaft
bimetal two different metals joined together, used as a thermostatic spring; when heated, the spring distorts because the two metal layers have different rates of expansion
biodegradable materials that are capable of being decomposed by bacteria
Birfield C V joint a commonly used type of constant-velocity joint
bleed to remove air from a system
bleeding brak es removing air from the brake system; the air compresses and gives a spongy pedal
block the cylinder block; the main and largest part of the engine
blow-by combustion gases that leak past the piston rings into the crankcase
blower air blower used with some diesel engines; also a name used for a supercharger
Bluetooth short-range wireless communication system
boiling point the temperature at which a liquid boils–at this point, it changes from a liquid to a gas
bonded joined tightly together; brake linings bonded to the brake shoes by a heat process
boost pressure from a turbocharger or supercharger
booster a device that provides extra force or pressure, such as the brake booster
bore a hole, often a large hole; an engine cylinder, or a hydraulic cylinder
bore of cylinder the diameter of the cylinder; also used in relation to the internal wall of the cylinder
boring bar a machine used to rebore engine cylinders
boss a reinforced area around a hole, pin or shaft
bottom dead centre (BDC) the position of the piston at the bottom of a stroke
Bourdon tube gauge a gauge for measuring pressure; it has a curved tube that straightens under pressure, and this moves the gauge pointer
brak e band a band around a brake drum
brak e disc the cast-iron disc of a disc-brake assembly; when the brake is operated, the brake pads are clamped against the disc
brak e drum a cast-iron drum that rotates with the wheel–brake shoes inside the drum expand when the brakes are applied
brak e fade loss of braking efficiency due to brakes overheating
brak e fluid special fluid for use in hydraulic brakes
brak e horsepower a method of measuring engine output; now superseded by kilowatts
brak e lining composition material used to line brake shoes and pads
brak e pad metal back with friction material used with disc brakes
break er ignition an ignition system with breaker, or contact, points
break er points the points, or contacts, used in a distributor to break the primary circuit of an ignition system; not used with electronic ignition
breather a vent that allows for expansion and contraction of fluid in a container or housing
brinelling damaged condition of a ball or roller bearing
bronze an alloy of tin and copper; used for bushes
brush (electrical) small carbon or copper alloy blocks that carry current to the sliprings of an alternator, or to the commutator of a starter or an electric motor
brushes conductors used with alternator slip rings and also with starter and motor commutators
buck et tappet a type of tappet or cam follower used in some overhead-camshaft engines
bulkhead *see* firewall
bump stop large rubber stop at the limit of suspension movement
bund a raised section of the floor to contain liquids
burnish to produce a finish by rubbing or polishing
bush or bushing a sleeve fitted into a hole as a bearing for a shaft or a support for a pin; can be of metal, rubber or nylon
butane petroleum gas that is liquefied and used as a gas fuel
butterfly short for butterfly valve; a disc on a spindle (*see also* throttle butterfly)
bypass to direct around; a passage that passes around
bypass valve a valve that controls the flow through a bypass passage

cable a flexible wire made up of a number of strands; often used with an outer cable to operate the parking brake, clutch and accelerator
cable (electrical) strands of copper wire covered with plastic insulation
calibrate adjust; can relate to checking and setting test instruments or gauges
calibrated accurately adjusted; refers to the correct setting of test instruments or gauges
caliper (brak e) the part of the disc brake that straddles the disc and carries the pistons and brake pads
calipers adjustable measuring tool that is set to size and read against a steel rule; outside calipers for external measurements and inside calipers for internal measurements (*see also* vernier caliper)
cam a device to change rotary motion to reciprocating motion; the camshaft has cams that open and close the valves
cam angle the number of degrees that the distributor cam rotates from the point at which the contact points close to the point where they just open
cam grinding grinding a piston to a shape that will allow for heat expansion
cam lift the height that the cam raises the cam follower
cam profile the shape of a cam
camber the angle that a wheel leans inwards or outwards; also the crowned surface of a road
camshaft shaft with cams to open and close the engine valves; it is driven at half engine speed (*see also* overhead camshaft)
candlepower an old method of indicating the power of a light bulb
capacitor an electrical component capable of storing an electrical charge; also called a condenser
carbon a black non-metallic element used for alternator brushes and some electric motor brushes; term used for the deposits that form in combustion chambers, on piston heads and in spark plugs
carbon dio xide (CO_2) a gas that is relatively harmless
carbon mono xide (CO) a dangerous exhaust gas
carburettor a device that supplies the engine with petrol and air in the correct proportions
Cardan joint an original design of universal joint from which the cross-and-yoke universal joint was developed
cartridge a small container
castellated nut slotted nut that is locked with a cotter (split) pin
casting a part made by pouring molten metal into a shaped mould
catalyst a substance that promotes a chemical reaction, but which itself remains unchanged by the reaction

catalytic converter a type of muffler in the exhaust system that reduces harmful exhaust emissions; it has a honeycomb core coated with noble metals—platinum, palladium and rhodium—which act as catalysts on the exhaust gases

cathode a negative electrical pole or plate

cell (battery) a compartment that contains a number of positive and negative plates suspended in electrolyte

centre of gravity the point about which a body balances. If an article is suspended at its centre of gravity, there are no heavy spots and it always remains in the position in which it was placed. A motor vehicle needs a low centre of gravity for stability

centrifugal advance a spark advance mechanism that uses weights and centrifugal force to provide spark advance

centrifugal force the force that pulls outwards on a rotating body. As applied to a vehicle on a curve, the force resists turning and tries to keep the vehicle moving in a straight line

cetane number a measure of the performance properties of distillate

change of state a change from a solid to a liquid or from a liquid to a gas (and vice versa)

charcoal canister a container to which the petrol tank is vented; the charcoal or carbon absorbs the fuel vapour until it is taken into the engine and burnt

charge (battery) *see* battery charging

chassis the frame of a vehicle on which the body is mounted; the term is also used to include all the mechanical components of a vehicle except the engine

chassis dynamometer a machine with rollers which are rotated by the driving wheels of a vehicle; it is used to check power output

chatter vibration; term applied to a clutch that vibrates when being engaged, or a brake that vibrates when being applied

check valve a valve that allows flow in one direction but blocks flow in the other

chlorofluorocarbon (CFC) a gas used as a refrigerant

chok e a venturi; a restricted passage

chok e valve flap at the top of a carburettor that closes off the air supply during starting

chromium a metal used in alloys and for electroplating

circlip a circular wire clip that fits into a groove; term tends to be interchangeable with snap ring

circuit a path or loop; the term is used for electrical circuits and hydraulic circuits

circuit (electrical) the path of an electric current; with conventional current flow, in a direction from positive to negative

circuit break er a protective device, for an electrical circuit, that opens a set of contacts to break the circuit in the event of an overload; some reset themselves while others have to be reset

class of bolts bolts of a particular strength

clearance designed space between parts; a working clearance that allows parts to move without binding, for example, clearance between gear teeth or between a shaft and bearing

clearance volume the volume of the combustion chamber with the piston at TDC

clevis a forked end of a rod with holes for a clevis pin; used to connect linkage or cables

clockwise movement in the direction of the hands of a clock

closed loop system with a sensor that provides feedback

closed-loop system a system that provides feedback and is able to adjust itself accordingly

cluster a group of parts

cluster gear a number of gears joined together; another name for the countershaft (cluster) gears in the transmission

clutch a mechanical device for connecting and disconnecting parts that carry power; the clutch is engaged and disengaged to connect and disconnect the transmission from the engine

coast to allow a vehicle to move without power

code a system of identification

coefficient of friction a measure of the friction of two surfaces in contact

coil (electrical) a number of turns of copper wire around a former; current in the coil produces electromagnetism

coil (ignition) an induction coil that produces high-tension voltage for the spark plugs; it transforms low voltage to high voltage

coil output the voltage produced by the ignition coil

cold spark plug a spark plug that does not become hot enough for a particular engine

collet a retainer, usually circular in shape

colour code a code of different colours used to identify electrical cables

combination switch a switch on the steering column, near the steering wheel, which combines the switches for a number of items

combustible capable of being burnt

combustion burning of the air–fuel mixture in the combustion chambers of an engine

combustion chamber the part of the cylinder head (chamber) above the piston in which the air–fuel mixture is burnt

combustion pressure the pressure produced by the burning gases in the combustion chamber

combustion temperature the temperature of the burning gases in the combustion chamber

commutator a series of copper bars connected to the armature windings of a starter motor, or other electric motor; brushes are used against the commutator to carry current

compensating jet a jet, in a carburettor, that is used for mixture correction; *see* mixture correction

compound gearing gears that are joined or combined compound planetary

compressed natural gas petroleum gas that has been compressed for storage; known as *natural gas for vehicles (NGV)*

compression reducing or trying to reduce in size; the stroke of an engine that compresses the air–fuel mixture in the cylinder

compression ignition the method of igniting the charge in a diesel engine by means of the high temperature reached during compression

compression ratio the amount that the charge is compressed in the cylinder; this is the ratio of the volume of the cylinder (and combustion chamber) with the piston at the bottom of its stroke and the volume with the piston at the top of its stroke

compression rings piston rings that are used to hold against pressure

compression strok e the upstroke in the engine cycle that compresses the charge in the cylinder

compression test checking the compression of the cylinders with a special pressure gauge

compressor a device for compressing gases; used with air conditioners and with some brake systems on heavy vehicles

computer a central control unit used for engine management; can also be used for automatic transmission control. Referred to as an electronic control unit or a central control unit

concentric having the same centre

condensation moisture obtained from the air; liquid obtained from a gas when cooled

condense change of state from a gas to a liquid

condenser component of an air conditioner that condenses the refrigerant gas; electrically, for ignition, *see* capacitor

conduction with heat, the conducting of heat through a solid; with electricity, the flow of current through a conductor

conductor a material that will carry current; with heat, a material that will transmit heat

configuration shape or form

connecting rod the rod connecting the piston to the crankshaft

constant displacement relates to a pump that is arranged to always displace the same quantity, irrespective of pump speed

constant velocity at the same speed

constant-mesh gears gears that are always in mesh; they do not slide in or out of mesh

constant-velocity (C V) joint a universal joint designed to transmit drive without vibration; used particularly with front-wheel drive

contact points points of a switch or other device that are opened and closed to control current; the points in a distributor

contaminated affected by some foreign material or substance

continuity the state of being unbroken; with an electrical circuit, a continuous or unbroken circuit has continuity

contraction reduction in size due to cooling (this is the opposite of expansion)

control arm a suspension arm that controls the position of a road wheel

control cable an operating cable; a cable that operates the clutch

control valve a valve that controls the flow of fluid; an on-off valve

controller area network (CAN) a group of on board computers in communication with each other
convection the transmission of heat by currents in a liquid or gas
converter a device that can cause a change; a torque converter in an automatic transmission changes torque; a catalytic converter in the exhaust system changes liquid LPG to a vapour
convex curved outwards (*concave* is curved inwards)
coolant a mixture of water and chemicals used in the cooling system
core generally, the innermost part (*see also* radiator core)
core plug a plug that blanks off a hole in the engine block—the hole is used to remove the core sand after the part has been cast; the core creates voids in the casting for the water-jackets
corrode wear away or eat into a surface by chemical action; rusting of iron and steel is a common form of corrosion
corrosion inhibitor chemicals used to prevent corrosion in the cooling system
cotter a pin or wedge used for fastening (a cotter or split pin)
cotter pin split pin for use with a castellated nut
counter opposite to
counterbore a bored recess at the start of a hole to take the head of a bolt or pin
countergear a gear on the countershaft of a transmission
countershaft an intermediate shaft with gears or pulleys that receives motion from one shaft and transfers it to another
counterweight a mass attached to a moving part so that it will be in balance
coupling point with a torque converter, the point at which all the parts commence to rotate at the same speed, with no further torque increase
crack detection a method of locating cracks in components
crank the offset part of a crankshaft that carries the connecting rod
crank angle the angle through which the crank has turned; with EFI, a sensor registers this for timing purposes
crank case the lower part of the engine block that supports the crankshaft
crank case ventilation air arranged to flow through the crankcase to remove blow-by gases
crank case web a stiffener that is cast into the crankcase
cranking voltage the voltage available at the starter while it is actually cranking; this is less than battery voltage because of the load being applied
crankpin the bearing surface on the crankshaft that carries the connecting-rod bearing
crankshaft a cranked or bent shaft that is supported in the main bearings in the crankcase—it has a crank or throw for each connecting rod
creep with automatic transmissions, the tendency of the vehicle to move when a gear is selected, even though the engine is only idling
crescent pump an oil pump that has an internal toothed gear and an external toothed gear, with a crescent-shaped land between them
crossflow cylinder head a cylinder head with the intake valves on one side and the exhaust valves on the other
cross-hatch pattern the pattern of the marks produced on the cylinder walls by a cylinder hone
crossmember a member across the vehicle to which suspension or transmission parts are attached
crown wheel and pinion the final-drive gears in a rear axle; they provide a gear ratio of around 4:1 and also change the direction of drive
crush the height of a bearing insert above the parting face
cubic capacity the total volume of the cylinders of an engine
current rating the current that a fuse or other conductor is capable of carrying
cut-off solenoid a solenoid on the carburettor that cuts off the idle fuel passage when the ignition is switched off; it prevents the engine from running on; *see* dieseling
CV joint constant-velocity type of universal joint
cycle a series of events, such as the four strokes of an engine, which are repeated
cycle (refrigerant) the cycle of compressing and expanding the refrigerant in the system
cylinder the cylindrical hole in the engine block in which the piston operates
cylinder block a cast-iron or aluminium-alloy casting complete with the cylinders, water-jackets and crankcase; forms the major part of an engine
cylinder head a cast-iron or aluminium-alloy casting that is bolted to the top of the cylinder block; it contains the valves, valve ports and the combustion chambers
cylinder hone a hone with abrasive stones, used for finishing cylinder bores
cylinder liner an engine cylinder made as a separate part and then fitted to the cylinder block; also called a *cylinder sleeve*
cylinder-bore gauge a special dial gauge for checking wear of a cylinder

dashpot a small diaphragm in a container that is used to dampen or slow an action; a throttle dashpot closes the throttle valve slowly
data logger a device that plugs into the data link for recording live data
De Dion suspension a design of independent rear suspension (IRS) with open drive shafts between the differential assembly and the rear wheels
dead axle an axle that carries the wheel hubs but does not turn; live axles, such as those in a rear-axle housing, turn with the wheel
decal a label, with information, which is attached to a vehicle
deceleration slowing down; opposite to acceleration
dedicated only of one particular type
dedicated test equipment test equipment designed for a particular make or model of vehicle
de-energise cut off an electric current to demagnetise a coil
deep-cycle battery a battery that can be drained until it is flat and recharged without damage to the battery
deflection change in direction
defogger a heater attached to the rear window to remove fogging which occurs under certain weather conditions
deform change shape
deionised water water that has been treated to make it suitable for use in cooling systems and batteries
delivery valve the valve at the outlet of a diesel injection-pump element
delta windings arrangement of alternator stator windings which, when drawn as a diagram, form a triangle
demagnetise remove the magnetism from a magnet or piece of steel
density mass per unit volume
deposits particles of carbon that are deposited on the combustion chamber
desiccant granules, in the receiver-dryer of an air conditioner, which remove moisture from the refrigerant
detent spring-loaded ball or plunger that fits into a groove
detergent a cleaning agent which is included in engine-lubricating oil
detonation noise caused by the last part of a fuel charge burning too fast, and exploding; this causes a knock or 'ping'
device a switching device that uses transistors
Dexron a particular type of automatic transmission fluid
diagnosis method of locating problems
diagnosis chart a chart that sets out procedures for locating problems
diagnosis codes codes that are displayed by test instruments when used with EFI and engine management systems
diamond dresser a small industrial diamond set into a tool; used for dressing grinding stones
diaphragm a flexible division (usually rubber) between two chambers of a control unit; differences in pressure move the diaphragm
diaphragm spring the special type of spring used as part of a clutch assembly
die tool for cutting a thread; also a metal form for pressing thin metal to shape
diecasting a casting produced in a metal mould; other castings are produced in a sand mould
diesel engine compression-ignition engine based on a design by Dr Diesel
dieseling also called run-on; term used when a petrol engine tries to continue to run after the ignition switch is turned off—ignition is from heat, not from a spark
differential arrangement of gearing in a final drive that allows the driving wheels to turn at different speeds
digital relates to instruments that display numbers

digital display the numbers shown on the liquid crystal panel of an instrument
digital processor a computer
diode an electronic component that allows current to flow in one direction, but not the other
dip switch switch for changing the headlamps between high and low beam
direct current (dc) electric current that flows constantly in the one direction, compared with alternating current (ac), which is constantly reversing its direction
direct ignition a system that has an ignition coil for each cylinder or pair of cylinders; there is no distributor—coil output goes directly to the spark plugs
direct injection in a diesel engine, where the fuel is injected directly into the main combustion chamber; *see* indirect injection
discharge (battery) electrical energy being taken from the battery, compared with charge or charging, where energy is put back into the battery
discharge nozzle the nozzle, in a carburettor, that discharges fuel
discolouration change in colour; can be due to heat or foreign matter
displacement amount of air displaced from the cylinder when the piston moves from the bottom to the top of the cylinder
dissipate spread
distillate fuel used in a diesel engine
distilled water water purified by boiling and condensing for use in batteries; same as deionised water
distortion unwanted change of shape
distributor (ignition) the unit of the ignition system that delivers high voltage to each spark plug in the correct firing order
distributor-type pump a diesel injection pump that has a single plunger and an arrangement for distributing fuel to the cylinders (an in-line pump has a separate plunger for each cylinder)
dog clutch a type of clutch; the dog teeth of the clutch engage when two parts are slid into mesh
dog teeth small gear teeth on a synchromesh gear
dongle a piece of external hardware that plugs into a computer to run software
dowel pins small metal pins used for aligning two parts; the pins are fixed in one part and are fitted into holes in the other
downdraft (carburettor) a carburettor mounted vertically so that the air flows downwards
downshift changing from a higher to a lower gear
drag link part of the steering linkage attached to the pitman arm
draw (current) the current required to operate an electrical component
dribble drops from the end of a diesel injector nozzle which does not cut off cleanly after injection
drive by wire a system of operating the throttle valve on the intake manifold electronically through an accelerator pedal sensor rather than a cable or linkage
drive gear a gear that rotates another gear; the other gear is the driven gear
drive line the components that carry the drive from the engine through to the driving wheels
drive shaft a shaft between the final drive and a driving wheel; a shaft between the transmission and the rear axle (propeller shaft)
drop-forged a part that has been formed to shape by forging a red-hot blank
drum brakes brakes with shoes and a drum
dual fuel able to run on petrol or gas
dual-fuel engine an engine able to run on either petrol or gas
duel-clutch transmission two multi-plate wet clutches each driving a separate input shaft to give rapid gear changes
duel-mass flywheel a two-piece flywheel that dampens crankshaft vibrations
duo-servo applies to an arrangement of brake shoes that self-energise
duty cycle percentage of time a cycling component is switched on
dwell *see* cam angle
dynamic balance a tyre or other part that is in balance when it is rotating
dynamometer a machine for measuring engine power and torque output

earth the body and engine of the vehicle; an electrical connection to either of these parts
earth (electrical) the body and engine of the vehicle; an electrical connection to either part
earth-return system an electrical circuit that uses the body and engine earth as a conductor for part of the circuit
eccentric two circles, one within the other, but with different centres; off-centre; a part of a shaft that is off-centre and used to change rotary motion to reciprocating motion; similar to a cam
eccentricity the property of being off-centre, or being worn out of round
effective stroke the part of a plunger stroke where pumping actually occurs
efficiency output compared with input, expressed as a percentage; the ability to produce results
electrical energy energy in electrical form; the capacity to do work electrically
electrode (spark plug) spark plugs have a centre electrode and an earth electrode
electrode (welding) a flux-coated rod that is used for arc welding
electrodeposit to electroplate; to deposit metal from an anode to a cathode
electrodes for spark plugs, two small wires of alloy steel which provide an air cap for the spark
electrolyte mixture of sulphuric acid and distilled water in a battery
electromagnet a magnet produced by a current passing through a coil of wire wound on a soft-iron core
electromagnetic switch switch contacts operated by an electromagnet; a relay
electromotive force (EMF) voltage; the force providing voltage
electron a negative-charged part of an atom
electronic having semiconductor components, e.g. diodes, transistors
electronic control a control unit with electronic components; a computer
electronic fuel injection (EFI) fuel injected by spray and controlled by an electronic control unit
electronic ignition an ignition system that uses sensors and transistor switching instead of breaker points
electronic regulator a voltage regulator that uses transistors and other electronic components electronic switching
electroplate a thin coating of chromium or nickel as an electrodeposit
emission controls devices that reduce emissions from the engine and fuel system
emissions chemicals in the exhaust and fuel vapour that cause pollution of the atmosphere
emulsion a mixture of water and oil that forms a milky fluid; also used to denote a mixture of air and fuel
emulsion tube a tube, in a carburettor, that causes air to be mixed with fuel
end thrust force along a shaft (axially)
end-float same as end-play
end-play end movement of a shaft or other part; axial movement; clearance between two parts
energise to pass a current through the windings of an electromagnetic coil
energy capacity to do work
engine breathing the intake of air or air–fuel mixture into the engine
engine capacity the volume of the cylinders of an engine
engine flare an increase in engine speed during an upshift of an automatic transmission
engine management electronic control of all the operating systems of an engine
engine-speed sensor a sensor that produces an electric pulse related to engine rpm; the sensor sends a signal to the electronic control unit
Environment Protection Authority (EPA) a state government authority with the responsibility of administrating environment protection legislation
epicycle gears *see* planetary gears
equivalent being equal to
ethylene glycol chemical used as an antifreeze in cooling systems
evacuation removing air to create a vacuum
evaporate change to a vapour
evaporative controls emission controls that prevent the escape of fuel vapour
evaporator component of an air conditioner that turns liquid into gas
excite electrically, to energise a coil
exciter diodes field diodes of an alternator; these direct current to excite the rotor windings so that the alternator will start to charge
exhaust emissions harmful chemicals in the engine's exhaust
exhaust gas gases formed by combustion; they include water vapour, carbon dioxide, carbon monoxide, nitrous oxides and unburnt hydrocarbons
exhaust gases gases from combustion; they include water vapour, carbon dioxide, carbon monoxide, nitrous oxides and unburnt hydrocarbons

exhaust system the exhaust manifold on the engine, the exhaust pipes, catalytic converter and the mufflers
exhaust-gas analyser an instrument for analysing the content of gases in the exhaust system
exhaust-gas recirculation (EGR) a form of emission control where some exhaust gas is recirculated back into the engine
expansion an increase in size of a solid, liquid or gas due to heat, such as of the burning gases in the engine's cylinders during the power stroke
expansion plug *see* core plug
expansion rate the rate at which expansion takes place in relation to changes in temperature
extreme-pressure lubricant special gear oil for use in rear axles and some transmissions

fail-safe system a system that is arranged so that it will remain in a safe condition if some part of it should fail
farad unit of capacitance; relates to an electrical capacitor
Faraday's law a basic law for generating electricity; it says simply that voltage is induced in a conductor if it moves to cut a magnetic field
fatigue weakness in metal caused by repeated stress; fatigue failure due to prolonged and repeated stress
fatigue (metal) failure caused by a repeated stress
fault finding *see* diagnosis
feedback information fed back into a system to allow it to make adjustments for itself
feeler gauge thin strips of hardened steel of accurate thickness used for measuring clearances
feeler strip a strip of thin metal of accurate thickness, similar to a feeler gauge
ferrous metal metal containing iron; non-ferrous metals have no iron
fibreglass a mixture of glass fibres and resins, which is light and tough when cured; used for some special car, truck and bus bodywork
field (magnetic) area of magnetic lines of force around a magnet
field coil a coil that produces a magnetic field; the field windings of a starter or motor; the rotor coil of an alternator
field diode a diode that supplies current to the rotor of an alternator
filament a fine thread; the fine wire of an electric light bulb that produces light when heated
fillet a curved section of an angle joint; provides reinforcement and prevents a stress rise; designed to remove a sharp angle
filter fine material or device designed to remove impurities; fuel filter, oil filter and air cleaner
filtration the process of filtering to remove unwanted material
final drive the gearing, including the differential, that drives the rear axle shafts or transaxle
finished size the accurate size to which a part is machined
fire to ignite the air-fuel mixture charge
firewall body panel at the back of the engine; also referred to as a bulkhead
firing impulses impulses produced by the cylinders during the power strokes
firing order the order in which the engine cylinders are fired (have their power stroke) for example, 1, 3, 4, 2
fit how two parts fit together; tightness or clearance between the parts
flame propagation progressive burning of the fuel charge in the combustion chamber
flank the lower part of a gear tooth
flasher vehicle turn signal
flasher unit the unit of a turn-indicator circuit that causes the lamps to flash
float bowl the part of a carburettor that holds the supply of fuel
floating axle way in which an axle shaft is supported in the rear axle; these are: semi-floating, three-quarter-floating and full-floating
flooding (carburettor) excess fuel due to overchoking or excess fuel in the float bowl
fluid coupling a coupling that transmits torque by means of fluid (oil) in the coupling
flux (magnetic) the area of magnetic lines of force around a magnet; same as field
flyweight a weight that moves outwards under centrifugal force as it rotates; used with distributor advance mechanisms and governors
focal point the position, or point, at which a bulb is in focus
focus the position of a bulb in relation to its reflector
foot pound measure of torque (imperial measurement); one pound at a radius of one foot
footprint (tyre) the area of a tyre that is in contact with the road
force anything that has an influence on a body; for example, pushing force and pulling force
four-stroke the common engine operating cycle
fracture break
frame the chassis or main structural body parts of a vehicle
free play free movement between parts, like that between gear teeth
freewheel not driving; a device that drives in one direction and is free in the other
freewheel hub a special hub, fitted to the front wheels of a four-wheel-drive vehicle, that allows the hub to be disconnected from the drive
frequency the number of times something occurs, or the rate at which something occurs
fretting damage caused by two dry parts rubbing together
friction resistance to movement
friction elements the clutches and brakes of an automatic transmission
friction loss the loss of power caused by the friction within an engine or other machine
fuel charge the charge of air–fuel mixture in a cylinder
fuel consumption the fuel used by a vehicle, stated in litres per 100 kilometres
fuel gallery a fuel pipe to which the injectors of an EFI engine are connected
fuel injection a fuel system where injectors are used to spray fuel into the manifold or engine
fuel line a pipe or hose that carries fuel
fuel mixture combustible mixture of air and fuel
fuel rail *see* fuel gallery
fulcrum a point about which a lever operates
full lock the front wheels turned in one direction as far as they will go
full-wave rectification the process of rectifying the current from all three phases of an alternator
fuse an electrical protection device that blows if overloaded
fuse rating the current that a fuse is designed to carry
fusible link a type of fuse that will carry high current
fusion melting; becoming liquid by heating; two pieces of metal joined by melting together

galling term used to describe a type of damage to a bearing
galvanometer basic electrical measuring instrument consisting of a magnet and a coil
gap space between two electrodes or contacts; air gap; spark plug gap
gas-filled relates to shock absorbers that have nitrogen gas instead of air
gasket sealing material between two surfaces
gassing giving off gas, as in a battery which gives off hydrogen gas while charging
gas-tight seal a seal that resists the pressure of combustion gases
gauge a temperature gauge that is operated by electromagnetic coils
gear ratio ratio of the number of teeth in meshing gears, for example, 4:1—this is also the ratio of the number of turns that a small gear makes to one turn of a larger one
gear set two or more gears that work together
gear train more than two gears in mesh—a simple gear train has separate gears; compound gears have some gears joined together
gearing planetary gearing that combines two simple planetary gear sets
generation the production of electrical energy, for example with an alternator
generator a device for producing electrical energy; a generator (alternator) generates lots of energy, while a signal generator produces only a little energy
glow plug a heating plug used with some diesel engines for easy starting
go and no-go gauge a measuring gauge with two sizes; one is a little oversized and the other a little undersized
governor a controlling device; it can be used to limit engine speed, or control gearshifts of an automatic transmission
governor pressure the pressure from a hydraulic governor of an automatic transmission
graduated accurately marked with measurements
granulate to break up into small grains

grommet a rubber insert fitted to a hole through which an electrical cable passes
ground *see* earth
ground (battery) the negative terminal of the battery is connected to the body and the engine so that it provides a ground or earth with negative electrical potential
gudgeon pin another name for the piston pin that connects the piston to the connecting rod

half-shaft a term sometimes used for a rear-axle drive shaft
half-wave rectification the process where only half the voltage of a three-phase alternator is rectified
Hall effect the principle of one type of signal generator used for electronic ignition
hand wheel a control wheel of a machine, that has a handle for the operator
harmonic balancer a balancer on the front of the engine to dampen torsional vibrations
headlamp aimer equipment for aiming headlamps
heat conductivity the conducting of heat through a solid
heat exchanger a device for transferring (exchanging) heat. Heat is transferred from a hot to a cold source or vice versa; the radiator of the cooling system is the best-known example
heat range (spark plug) the temperature range over which a spark plug is designed to operate
heat sink a metal base in which diodes and transistors are mounted; it absorbs heat from the component to prevent it from being damaged by overheating
heat transfer the transfer of heat from a hot body to a colder one
heat treatment treatment given to metal by heating and cooling to make it harder or tougher
helical spiral-shaped; coiled
helical gear teeth cut on an angle; if the angle were taken far enough, it would form a helix
helix a spiral
hemispherical shaped like half a sphere
hertz (Hz) frequency stated in cycles per second
high range the higher gear ratio of a transfer case of a four-wheel-drive vehicle
high tension high voltage produced by the ignition coil
high-energy ignition an electronic ignition system that produces high voltage
honing finishing a cylinder with a hone fitted with abrasive stones
Hooke's joint a basic design of universal joint
horizontally opposed relates to an engine in which the cylinders are horizontal and opposite each other
horsepower a unit of the power of an engine; superseded by kilowatt for the metric system
hot spot localised area with a high temperature
hot-wire sensor a type of airflow sensor used with EFI
hub centre of a wheel; or the part of the suspension that carries the bearings and mounting flange for the wheel
humidity moisture in the air
hunting (engine) at idle, a regular increase and decrease in speed
hybrid vehicle uses two or more methods of power to drive the wheels. Usually a combination of an internal combustion engine and electric motor
hydraulics use of liquids to transfer power
hydrocarbon (HC) a compound consisting of hydrogen and carbon atoms; the basis of most automotive fuels
hydrogen (H) a colourless gas that combines with oxygen to form water
hydrometer an instrument that uses a float for measuring relative density; it is used for measuring the density of battery electrolyte to determine the state of charge of the battery
hygroscopic ability to absorb moisture from the air
hypoid a type of bevel gearing used in final drives
hypoid gears a design of spiral bevel gears used in rear axle final drives

idle engine running at low speed
idle cut-off solenoid the solenoid of a carburettor that is used to cut off the idle fuel and prevent engine run-on
idle port the port in a carburettor that discharges idle mixture
idle-mixture screw a screw adjustment for engine idle
idler arm arm of a steering linkage that transfers motion
idler gear a gear in a gear train that transfers motion but has no effect on the gear ratio; the reverse idler gear in a transmission
ignite to set on fire
igniter an electronic control that triggers off the spark to ignite the fuel charge
ignition firing of the fuel charge in a cylinder by a spark from the spark plug; in a diesel engine, ignition by the heat of compression
ignition coil an induction coil that produces the high voltage for the spark plugs
ignition timing the time at which the spark occurs at the spark plugs; setting the ignition system so that the spark occurs at the correct time
impact bump or collision
impeller a rotor with blades; part of a pump, such as in a water pump; e.g. the impeller of a turbocharger; the impeller of a torque converter
impregnated saturated with something
indirect injection the type of fuel injection for a diesel engine that has a precombustion chamber in the cylinder head
induction the process of inducing electricity from one conductor to another; also relates to the intake system of an engine
induction stroke the stroke of a piston that takes in the charge; with a diesel, the stroke of a piston that takes in air
inductive pulse generator a signal generator that induces a small electrical pulse in a coil
inertia laziness; a reluctance to move
inhibitor chemical that prevents or delays an action, for example, corrosion inhibitor
inhibitor switch a switch that allows an automatic transmission to start only in the P or N positions
injection pump the pump of a diesel engine that delivers fuel to the injectors
injector a device used with diesel engines and electronic fuel injection to produce a spray of fuel
in-line cylinders cylinders that are one behind the other
in-line engine engine with all its cylinders in a straight line
in-line pump a diesel injection pump with a pumping element for each cylinder of the engine
input shaft the shaft that carries the drive from the clutch to the transmission
input signal a signal sent to an electronic control unit by a sensor
instrument cluster a group of instruments on an instrument panel
insulated return an electrical system or circuit that uses cables to complete the circuit instead of the metal parts of the vehicle (earth return)
insulation material that will not conduct electric current; for heat, material that resists heat
insulator (electrical) a material that will not carry an electrical current
insulator (heat) a material that does not readily transfer heat
intake stroke *see* induction stroke
integral being of one piece, being a part of
integrated circuit an electronic component that incorporates a number of smaller components
intercooler *see* heat exchanger
interference fit a pin that is a tight fit in a hole
interlock a device to prevent two gears being selected at once
intermediate gear a gear located between two other gears; an idler gear
intermittent does not occur all the time; not regular
internal gear a gear with internal teeth used with a planetary gear set
internal teeth gear teeth on the inside of a gear
ion an electrically charged particle
ionise air becomes ionised when it conducts electricity (spark or arc)
isolator switch *see* inhibitor switch
iso-octane a reference fuel rated at 100 octane

jacking points locations on a vehicle that are specifically designed for lifting and hoisting
jackshaft an intermediate shaft sometimes used between the crankshaft and the camshaft
jerk-type pump another name for an in-line injection pump
jet a small hole or orifice for supplying a measured quantity of air, fuel or oil; carburettor jet

jet well in a carburettor, a hole or hollow that contains fuel in which a jet is immersed
jig a locating or holding device
joule (J) unit of energy or work
journal part of a shaft with a surface to take a bearing
journal overlap an arrangement of the crankshaft journals that gives a rigid shaft
judder vibration of clutch or brake caused by an on-off action
jumper leads heavy cables used to connect batteries for emergency starting

Karman vortex a design of airflow sensor used with some electronic fuel-injection systems
key a metal insert in a shaft used to drive a gear or pulley
keyless entry a method of operating the car doors and security system using a remote wireless communication device
keyway the groove to carry a key
kickdown a forced downshift of gears in an automatic transmission
kilopascal (kPa) unit of pressure
kilowatt (kW) unit of power; used for measuring engine power
king pin large pin on which the stub axles of a front beam axle pivot
knock an engine noise caused by worn bearings or other parts; also used for detonation; *see* detonation
knock sensor a sensor used to pick up detonation and signal this to the electronic control unit, which adjusts the spark
knocking (engine) noises caused by worn or loose bearings, pistons, or other engine parts
knocking (fuel) detonation; noise caused by the sudden burning of the last of the fuel charge
knuckle the part of the suspension that carries the wheel spindle and pivots for steering
knurling a process that raises the metal of a shaft or the metal around a hole in a particular pattern

lambda (λ) the quantity of air entering the intake divided by the quantity of air necessary for complete combustion
lambda sensor an oxygen sensor fitted in the exhaust system which provides feedback to the electronic control unit of an EFI system
laminated layered; one or more layers of materials joined together
laminated core a number of pieces of soft iron which form the core of an ignition coil or of an electromagnet
laminations layers
land raised metal beside a groove, such as the lands of a piston beside the grooves for the piston rings
lapping rubbing parts together with an abrasive paste to obtain a seal or fit
lash free movement; clearance
lash adjustment adjustment of the clearance between the tip of the valve stem and the rocker arm (or other valve-operating mechanism); valve-clearance adjustment; tappet adjustment
latent heat hidden heat; heat applied and absorbed by a liquid or gas as it continues to boil
lateral sideways
layshaft another name for a transmission countershaft
lead oxide an exhaust emission from leaded petrol
leaded petrol petrol containing tetraethyl lead (no longer available)
leading first or front
leaf spring a flat piece of spring steel
leak-off pipe a pipe on a diesel injector that returns a small amount of fuel to the tank
left-hand rule a rule that shows the direction of rotation of an electric motor
legislation laws passed by state or federal parliament
lens glass or plastic, in front of the headlamps, that concentrates the rays of light to form a beam
lift amount of movement, particularly movement caused by a cam limited-slip
lift pump a pump in a diesel fuel system that takes fuel from the tank and delivers it to the injection pump on the engine; a supply pump
light sensor an electronic component that is sensitive to light
light-emitting diode (LED) a diode that produces light
limited-slip differential a differential where action is controlled to prevent a driving wheel from spinning
line fuse a fuse, in its own holder, fitted to a cable ahead of a component
line pressure the pressure in the hydraulic system of an automatic transmission; also called *control pressure*
live axle an axle that rotates with the wheel
live wire a wire which has voltage, or is carrying an electric current
L-Jetronic system a Bosch electronic fuel-injection system on which many other systems are based
lobe the high part of a cam
lock-up clutch the clutch in a torque converter of an automatic transmission
lock-up converter a torque converter with a lock-up clutch
longitudinal lengthwise; parallel with the centreline of the vehicle
loop conductor a wire shaped into a circle
loops turns of wire that make up an electrical coil
low range the low gear ratio of the transfer case of a four-wheel-drive vehicle; low gear of a transmission
low tension low voltage; battery voltage; the voltage on the primary side of an ignition system, compared with high tension on the secondary side
lubricant anything that reduces friction, usually oil or grease but can be a dry lubricant such as graphite or talc
lubrication supplying oil or grease to parts to reduce friction
lug an extended part; also refers to operating an engine under heavy load at too slow a speed
lugging operating an engine under load at too slow a speed

magnet magnetised steel that attracts ferrous metals; electromagnet produced by a coil carrying an electric current
magnetic clutch a clutch, of an air-conditioning compressor, that is operated by an electromagnet
magnetic field the area of magnetic lines of force around a magnet
magnetic fuel gauge a fuel gauge that is operated by electromagnetic coils
magnetic polarity the north and the south poles of a magnet magnetic temperature
magnetise turn into a magnet
mainshaft the main shaft in a transmission; also called the output shaft
major thrust the side of a piston that takes the thrust from the reaction of the connecting rod during the power stroke
mandrel a shaft that is used to support a part, or on which a cutting or grinding tool is mounted
manifold a number of pipes joined together; a pipe with a number of branches
manifold gauge set a set of gauges for checking the pressures in an air-conditioning system
manifold vacuum the vacuum (low pressure) in an intake manifold; actually, a negative pressure or pressure below atmospheric; a partial vacuum
manometer an instrument for measuring vacuum or low pressure; a U-tube with mercury or water
MAP sensor a sensor for determining the intake manifold pressure
master cylinder the cylinder operated by the driver in a hydraulic brake or clutch system
master switch a switch that controls other switches
MAT sensor a sensor for determining intake manifold temperature
material safety data sheets (MSDS) information provided by the manufactures of hazardous materials mechanical efficiency the efficiency of a machine—there are internal losses, due mainly to friction, which reduce the mechanical efficiency
mating surfaces surfaces, of parts, that are assembled together
matter anything that exists
mechanical efficiency the efficiency of a machine or an engine; the output compared with the input, expressed as a percentage. The efficiency is reduced by internal losses, mainly friction
mechanical energy energy produced by mechanical means
micrometer a precision measuring instrument
micron a unit of length equal to one-thousandth of a millimetre
micro-processor a computer; the control unit of an EFI system or an engine management system
micro-switch small switch that is operated by a small movement
minor thrust the side of the piston that takes the thrust on the compression stroke; *see* major thrust
misalignment (connecting rod) where a connecting rod is bent or twisted

misfire when a spark plug misses a spark, or a charge does not fire properly; often abbreviated to 'mis'
mixer (gas) component for mixing air and gas in a gas fuel system
mixture combustible air and fuel mixture for the engine
mixture correction a system of a carburettor that corrects the air–fuel mixture at wider throttle openings; *see* air-bleed correction
mixture setting the setting or adjustment of the idle-mixture screw in a carburettor
mode manner or system; the way in which something is done
modulator a control to vary or delay an action or pressure
modulator valve a valve in a hydraulic system used to modify or vary pressure
molecule a very small particle consisting of atoms
molybdenum a rare silver-white metal, used in alloys; its sulphides are used, with grease, as a lubricant
molybdenum disulphide a lubricant that is added to grease; it has an affinity for metals and adheres to metals under high pressure
momentum the tendency of a moving object to keep moving; its momentum is related to its mass and its speed
monitor to check or oversee; a display unit of an electronic instrument
monoblock a cylinder block with its cylinders and crankcase cast in one piece
motor electric motor; sometimes incorrectly used in relation to an engine
mould a shape formed in sand into which metal is poured to produce a casting
MP3/4 a format of compressing and storing data (usually music)
muffler a chamber in the exhaust system that reduces the energy in the exhaust gases and so reduces exhaust noise
multipin connector an electrical connector with a number of pins or terminals
multiplate clutch a clutch with a number of discs, used in automatic transmissions
multipoint injection electronic fuel injection, with an injector for each engine cylinder
mutual induction voltage induced into one coil from another

naturally aspirated when an engine does not have a supercharger or turbocharger; it 'breathes' by piston action only. Turbocharged engines have air or air–fuel mixture forced into the cylinders
needle a valve with a tapered end, used in a carburettor
needle bearings small-diameter roller bearings, sometimes caged and sometimes loose
needle valve a valve with a tapered end which seals on a conical seat
negative (electrical) the negative battery terminal; the body and engine at negative potential
negative pressure pressure below atmospheric; a partial vacuum
neutral transmission with no gear engaged
neutral switch *see* inhibitor switch
neutron particle of an atom without an electrical charge
newton unit of force
newton metre (Nm) unit of torque
nickel a hard, silvery metal used in alloys
nitrous oxides (NOx) oxides of nitrogen occurring in engine exhaust emissions
non-ferrous metal a metal that contains no iron (a ferrous metal is one with iron)
non-ferrous metals metals that do not contain iron
non-return valve a one-way valve to control liquids or gases
nozzle part of the carburettor that discharges fuel; part of an injector that discharges a spray of fuel into the combustion chamber

octane rating a rating of petrol based on its ability to resist knocking
odometer the part of a speedometer unit that registers the kilometres travelled
ohm unit of electrical resistance
oil consumption the amount of oil used or burnt in the engine
oil cooler a cooler that transfers heat from the engine oil to the cooling system
oil filter a container with an element that prevents impurities from circulating through the engine with the oil
oil gallery the main passage in the crankcase for the engine oil
oil jet a jet that directs cooling oil up into the piston head
oil pressure oil under pressure that is circulated by the oil pump
oil pressure sender a sender in the lubricating system that registers oil pressure
oil-bath air cleaner that uses oil to trap dust particles
oil-control ring a piston ring that is used to control the amount of oil on the cylinder wall
on-board diagnostics a function of the ECU that records faults and data that can be displayed as codes to assist in diagnosing faults
one-way clutch a clutch with rollers or sprags that drives or holds in one direction and releases in the other
open chamber a combustion chamber, of a diesel engine, which is mainly in the piston head; there is no pre-combustion chamber
open circuit an electrical circuit that is 'open' due to a broken or disconnected wire, or due to a faulty connection or switch
open-circuit voltage the voltage of the battery when it is not under any load
opposed cylinders cylinders that are opposite each other
optical sensor a sensor that uses light-sensitive diodes to provide a signal
orifice a small hole or opening, often of a specified size
O-ring a ring of rubber of circular section, used in a groove as a seal
oscillations regular backwards-and-forwards, swinging movement, or up-and-down movement
oscilloscope an instrument (cathode ray oscilloscope) that produces traces or patterns of voltage on a screen. Used as a test and diagnostic instrument for the ignition system
oscilloscope pattern traces of the voltage of an ignition system or other electrical component, shown on an oscilloscope screen
Otto cycle the operating cycle of a four-stroke engine
output shaft the shaft that carries the drive from a trans-mission; the mainshaft of a transmission
output signal a signal sent from the central control unit to a system component
overdrive a gear in a transmission that provides a speed increase; often the fourth gear of an automatic transmission, or the fifth gear of a manual transmission
overhead camshaft a camshaft that is mounted on top of the cylinder head
overinflation a tyre at too high a pressure
overlap the short period during which an intake valve and an exhaust valve are both open
overrunning clutch another name for a one-way clutch; it locks one way, but overruns in the other
oversize larger than standard (undersize is smaller than standard)
oversteer where the vehicle is over-responsive and tends to move into the curve (*see also* understeer)
oxidation of oil deterioration of engine oil due to oxygen from the air being mixed with the oil
oxidise affect by oxygen from the air; the oxygen on exposed metal causes rust and corrosion
oxygen a gas in the air that is essential to life; also needed for combustion; gas used with acetylene for gas welding
oxygen sensor a sensor in the exhaust system for measuring the oxygen content of the exhaust gases; *see* lambda sensor

Panhard rod a stabilising rod of a rear suspension
parking pawl a latch, in an automatic transmission, that engages with a gear when P is selected
particulates particles of solid and semisolid substances in the exhaust gases
parting line the joint between a connecting-rod cap and the connecting rod, or similar parts; also called the *parting face*
Pascal's principle basic principle of hydraulics which states that pressure applied to a liquid can be transmitted throughout the liquid without loss
pawl pin or lever that is engaged with a gear or other part as a lock
PCV valve valve used in the crankcase-ventilating system
peen to form an end on a rivet with the ball end of a hammer
penetrating oil oil used to lubricate tight or corroded parts
pent roof dome-shaped combustion chamber, similar to a hemispherical combustion chamber
permanent-magnet motor an electric motor with permanent magnets for fields (other motors have electromagnetic fields)

petrol a light hydrocarbon fuel
petrol injection *see* fuel injection
petroleum jelly a light petroleum grease without additives
phase a stage or part; for an alternator, relates to its stator windings, which are three-phase windings
photochemical smog visible pollution from the reaction of exhaust emissions, air and sunlight
pickup coil a coil of a pulse generator in which a small voltage is induced
piezoelectric a means of producing voltage by compressing certain types of quartz
pilot a guide
pilot shaft a guide shaft used for aligning parts
pinging detonation; *see* knocking (fuel)
pinion a small gear that drives a larger one; the pinion of rear-axle gears
pintle a type of diesel injector nozzle with a shaped pin on the end of its needle
piston basically, a hollow plug that operates in a cylinder; an engine piston; a piston in a hydraulic system
piston displacement the volume displaced by a piston on its downstroke; the volume of the cylinder
piston slap a knock caused by a piston with excess clearance in its cylinder
pitch the distance between the crests of the threads of a bolt; the distance between the centres of the teeth of a gear; the spacing between holes or bolts
pitman arm arm on a steering-box shaft to which the steering linkage is attached
pitting small irregular-shaped holes caused by corrosion—with exhaust valve faces it is caused by heat or burning; with gear teeth, by wear and loading
pivot turn; a shaft, pin or ball on which a part turns
planet carrier the carrier on which the pinions of a planetary gear set are mounted
planetary gears gears that consist of a sun gear, planetary pinions and carrier, and a ring gear; also known as *epicyclic gears*
Plastigage a plastic strip that is used for measuring the clearance of crankshaft bearings
platinum a highly durable material sometimes used for spark-plug electrodes
plenum chamber an air chamber associated with the intake manifold of an EFI engine; swirl chamber
plug gap gap between the spark plug electrodes
plug lead common term for a spark plug cable
ply (tyre) a layer of rubberised fabric in a tyre casing
pneumatic by means of air; pneumatic tyres are inflated with air
points breaker points of a distributor; contact points of a switch or relay
polarity electrical positive and negative; the polarity of a battery; the north and south poles of a magnet
pole a magnetic pole (north or south); the field pole of a starter or motor. An armature that rubs on the pole shoes, due to worn bearings, is said to *pole*
pollution (air) harmful substances discharged into the atmosphere
poppet valve a valve, with a head and stem, that operates against a seat; an engine valve
porosity being porous
porous full of minute holes which allow liquid or gas to pass through
port an opening; the intake and exhaust ports in a cylinder head
positive terminal the live battery terminal
potential electrical pressure; voltage–potential difference is the difference in voltage between a positive and a negative battery terminal
potentiometer an electrical component with an adjustable resistance that is used to vary voltage
power the rate of doing work; the power of an engine is stated in kilowatts
power brakes brakes with a booster to assist with applying the brakes
power diodes the diodes of an alternator that rectify the stator current; large diodes that can carry heavy current
power flow the flow of power through a transmission or other torque-transmitting unit
power impulses impulses produced in the crankshaft by the power strokes
power mode a condition that can be selected for an automatic transmission that has electronic control; used where power is needed (economy mode is used for normal driving)
power steering steering that is assisted by hydraulic pressure
power stroke the working stroke of an engine during which the piston is forced downwards by the expanding gases of combustion
power take-off a mounting on a transmission or transfer case where a winch or other power-operated equipment can be fitted
precombustion chamber a small auxiliary combustion chamber of a diesel engine
preheat applying heat in advance; carburettor manifolds are heated so that the air–fuel mixture is preheated before it enters the engine
pre-ignition same as *dieseling*. Firing of the charge in the cylinder before the spark occurs at the spark plug. Occurs when hot carbon or another hot spot in the combustion chamber causes the charge to ignite; this occurs before, or without the aid of, a spark from the spark plug
preload initial load placed on a bearing during adjustment
pre-programmed tables or data that is permanently stored in a computer memory
press fit when parts that are a tight fit require pressing to assemble, such as some piston pins in their pistons
pressure cap radiator cap with a valve that maintains a pressure in the cooling system
pressure plate the cast-iron plate of the clutch assembly that holds the clutch disc against the flywheel
pressure-regulator valve a valve that regulates the pressure in a hydraulic system; also called a *relief valve*
pressure-relief valve a valve that opens when a specified pressure is reached; also called a relief valve
primary first, or first stage; applied to brakes, the primary shoe; applied to transmissions, the primary shaft (secondary is the second stage)
primary circuit the low-tension or low-voltage circuit of an ignition system
primary stage the first stage
primary throttle valve the throttle valve in the primary section of a carburettor
priming pump a hand-operated pump, in a diesel fuel system, which is used to fill and bleed the system
printed circuit printed conductors on an insulated panel to which small electrical or electronic components are attached
propane petroleum gas used for fuel
propeller shaft the drive shaft between the transmission and the rear axle; also to the front axle on some four-wheel drives
proton the positive-charged part of an atom
protrusion part of a component that extends beyond or above another part
PT fuel system a fuel injection system used on Cummins diesel engines
pull-in windings windings of a starter solenoid that pull the plunger in (hold-in windings are then used to hold the plunger in)
pulse (electrical) a small voltage from a pulse generator which is used as a signal to an electronic control unit
pulse generator a device used to produce a small electrical pulse signal
pumping element a pumping unit of a diesel injection pump
purge clean out; the charcoal canister is purged of petrol vapour when the purge valve is open
pushrod rod used with overhead valves to transfer cam movement to the rocker assembly on top of the cylinder head; engines with pushrods are sometimes referred to as pushrod engines

quartz halogen bulb a headlamp bulb with a quartz envelope which is filled with halogen gas
quench cooling a heated object in water or oil to reduce its temperature
quench area a cool area of a combustion chamber on which some of the air–fuel mixture could condense

race part of a bearing; inner or outer race
rack a shaft with gear teeth
rack-and-pinion a steering box with a rack operated by a pinion on the steering shaft
radial from the centre
radial tyre tyre with cords that run in a radial direction
radiation (heat) transmission of heat, across space, by rays
radiator a heat exchanger that gives up heat to the cooler air passing through its core
radiator core the centre part of the radiator, with the cooling fins
radius a straight line from the centre to the circumference of a circle
radius rod a rod on the suspension that acts like a radius with one end moving in an arc

Ravigneaux (gearing) a name for compound planetary gearing
reach the length of the threaded part of a spark plug
reaction force opposing force; an opposite force to an action
ream finishing a hole or bush to size with a reamer, usually to take a pin
reamer a tool for accurately finishing a hole to size
rebore to bore a worn cylinder oversize
receiver-dryer a component of an air-conditioning system
reciprocating motion backwards and forwards movement in a straight line
recirculating-ball type of steering box that uses balls between the nut and the worm
recovery station equipment used to evacuate the refrigerant from an air-conditioning system and to store it so that it can be reclaimed
rectification changing alternating current to direct current
rectifier electrical device that changes alternating current to direct current; diodes as used in an alternator
rectifying diodes the main diodes of an alternator which change AC to DC
recycled materials that can be re-used
reduction gear gears that provide a gear ratio
reduction-type starter a starter that has reduction gearing
reed valve a thin metal valve that opens or closes a hole
refraction the change in speed of waves as they pass through different mediums causing them to change direction e.g. light passing through glass
refrigerant the gas in an air conditioner
regulator a means of controlling and reducing pressure
regulator (electrical) unit used with an alternator to limit the alternator voltage
relay an electromagnetic switch
release bearing the thrust bearing that releases the clutch; also called a throwout bearing
relief valve valve in a system that opens when a specified pressure is reached (similar to a regulator valve); a safety valve to relieve excessive pressure
reluctor the rotating part of a sensor used with electronic ignition
resistance (electrical) opposition to current flow; in a circuit, resistance causes voltage drop
resistor electrical component that resists current flow; a poor conductor of electric current
resonance an echo or vibration
resonator a muffler in the exhaust system
retainer a device to hold a part in place or prevent it from coming loose; can be a circlip, snap ring, pin, washer or a cover bolted in place
retard (ignition) alter the ignition timing so that the spark occurs closer to top dead-centre
retreading reconditioning a tyre by moulding on a new tread
rheostat a variable resistance used to control current in a circuit
rich (fuel) too much fuel in the air–fuel mixture
right-hand rule a basic rule for alternators
rigid axle an axle that extends from one side of the vehicle to the other
rigidity stiffness
rim edge; the outer part of a wheel
ring gap the gap between the ends of a piston ring
ring gear the gear on the flywheel, or driving plate of an automatic transmission, with which the starter pinion engages
ring ridge a ridge at the top of an engine cylinder where the piston ring does not travel and so there is no wear
rocker arm lever or arm that operates the valves in the cylinder head
roller clutch *see* one-way clutch
roller-cell pump a pump with rollers that is used with EFI fuel systems
rolling radius (tyre) the distance from the wheel centre to the road surface; this is less than the nominal radius of the tyre because of the spread on the rim and the bulge on the road
Rootes a type of supercharger
rotary engine engine that has a rotor instead of pistons
rotary valve a cylindrical valve that opens and closes ports as it turns
rotating field a magnetic field that is rotating; the field produced by an alternator rotor
rotor the central part of an alternator; the device, in a distributor, that rotates to distribute the spark; the term is also used for other rotating parts
running-in a period of operating a new vehicle or parts under moderate conditions; allowing parts that operate together to obtain a working finish
run-on *see* dieseling and pre-ignition
runout a wheel, hub, or other rotating part that does not run true, for example, a bent wheel

SAE oil grade a system of grading oil by its viscosity
safety rim beads in the wheel rim that hold the bead of the tyre in place if it suddenly deflates
safety valve a valve that opens to relieve a build-up of pressure
sand core a solid shape made of sand used in a mould during casting; it forms a core for spaces where metal is not wanted
sand mould a shape formed in sand into which molten metal is poured to produce a casting
sandblast a blast of sand used for cleaning parts, spark plugs in particular
scan tool a hand-held diagnostic tool for electronic systems
scavenging clearing the exhaust gases from the cylinder; in some two-stroke diesels, by means of a blower
scoring damage in the form of scratch marks or grooves on a surface
scuffing damage similar to scoring, but to a lesser degree
sealant compound used for sealing joints
sealed bearing a bearing that is lubricated and fitted with seals during manufacture
seat the part against which a valve rests and seals when it is closed; a rest or mounting
secondary second, or following; coming after the primary; secondary circuit of an ignition system; secondary brake shoe
secondary circuit the high-tension section of the ignition system that delivers the voltage to the spark plugs
sector shaft a shaft in a steering box with teeth in the form of a sector (part) of a gear
sediment matter that settles in the bottom of a liquid; dust and moisture in the bottom of a filter
sedimenter filter for removing water; used with diesel engines
segmental made of a number of parts; for example, segmental oil rings
seize when two parts which work together become locked due to lack of lubrication, or because of corrosion
selective fit selecting a part to provide the correct fit with a mating part, for example, a pin to suit a hole or a thrust washer for correct end-play
selector shaft shaft in a transmission for selecting gears
self-diagnosis a facility, built into an electronic control unit, that identifies faults which occur in the systems that it controls
self-energising a brake shoe that has a wedging action which assists braking
self-locking nut a nut with a nylon insert that is tight on the thread to prevent the nut from loosening
semiconductor an electrical component that conducts under certain conditions, but not under others; a diode
semi-elliptic refers to springs that are shaped like a half-ellipse
sender unit a unit that 'sends' an electrical current to operate a gauge on the dash; used with fuel and temperature gauges
sensors devices that create input signals for an electronic control unit
sequential one after another
series one after the other; in an electrical circuit, components can be connected in series
serrations notches or teeth
service limit (wear) the limit to which a part can be worn and still be considered to be serviceable; specification for maximum wear
serviceable a part in good condition and suitable for use
servo (brakes) a piston and cylinder in the hydraulic system of an automatic transmission that is used to apply a brake band; the self-energising action of brakes
shackle the connection between a leaf spring and the subframe
shift duration time taken for an automatic transmission to make a gear change
shift pattern the road speeds at which upshifts and downshifts occur in an automatic transmission
shift point road speed at which a change of gear occurs
shift quality firmness and duration of automatic gear shift

shim a thin piece of steel, or washer, fitted between parts and used to adjust clearance or preload

shimmy front wheels wobbling from side to side

shock absorber hydraulic damper used to reduce spring oscillations

short common name for an electrical short circuit

short circuit an electrical fault that causes a circuit to become shorter than it should be

short motor the engine block, complete with pistons, but without the cylinder head and accessories

shred to cut into small strips

shrink fit relates to a part that is expanded by heat so that it fits over another part; when it cools, it shrinks firmly into place

shunt a bypass electrical circuit; a circuit or component in parallel

shunt coil a coil wired in parallel, particularly with an instrument

side thrust (piston) the thrust on the sides of a piston due to the angularity of the connecting rod; *see* major thrust and minor thrust

side valves valves in the cylinder block at the side of the cylinders; not used now for motor vehicle engines

sight glass a small window in the top of the receiver–dryer of an air conditioner through which the flow of refrigerant can be seen

signal an electrical pulse produced by a signal generator

signal generator a device to generate an electrical signal for an electronic control unit; *see* generator

silencer muffler in the exhaust system

silicon crystals crystals that absorb moisture

silicone oil an oil with special properties used in hydraulic couplings

Simpson (gearing) an arrangement of two planetary gear sets with a common sun gear

simultaneous all at once

single-barrel relates to carburettors, which can have one, two, or four barrels

single-point injection an EFI system where the injector is located in the throttle body

sintered small particles of bronze fused together; this gives a porous material which is used for bushes and filters

sintered metal small particles of bronze fused together to give a porous material; used for bushes and filters

slave cylinder the actuating cylinder of a hydraulic clutch control

sliding gear a transmission gear that slides into mesh with another gear

sliding joint a joint with slip splines, such as the splined joint of a propeller shaft

slip rings the pickup rings of an alternator rotor against which the brushes rest

sludge thick black sediment in the sump formed from oxidation of the oil and contamination; found in an engine in worn condition

small end the smaller (upper) end of a connecting rod; the lower end is referred to as the big end

smog a term derived from the words 'smoke' and 'fog'; the visual effects of air pollution

snap ring a spring ring that fits into a groove to retain a bearing or shaft

sodium a metal that can combine with other chemicals to form salts, for example sodium chloride; these salts are often found in solution

solar of the sun

solder an alloy of lead and tin; to join parts by soldering

solenoid an electromagnetic coil with a movable soft-iron core which is moved when the coil is energised; movement of the core is used to operate a switch or hydraulic valve

solvent a liquid that is used to thin or dissolve other materials; solvent used as a cleaner

spark advance the number of degrees before top dead-centre at which a spark occurs at a spark plug

spark gap a gap across which a spark jumps; spark plug gap

spark plug device for igniting the fuel charge in the combustion chamber

spark -ignition engine a petrol engine that has spark plugs for ignition, compared with a diesel engine which uses compression ignition; *see* compression ignition

specific gravity the ratio of the density of a substance to that of water; the specific gravity of the electrolyte of a battery is checked to determine its state of charge

specifications measurements, clearances, adjustments etc. which are provided by the manufacturer

spherical shaped like a sphere; like a ball

spider the cross of a universal joint; the cross-shaft that carries the differential pinions in some differentials

spigot a small end of a shaft

spill kit an emergency-response kit to deal with liquid spills

spill port a port in the pumping element of a diesel in-line injection pump

spill-timing a method of timing a diesel in-line injection pump

spindle shaft on which the hub of a wheel is mounted

spiral bevel gears bevel gears with a spiral-toothed pinion

splines teeth and grooves in a shaft and its mating part which allow them to be joined together

spongy (brak es) soft brake pedal due to air in the system

spool valve a valve in a hydraulic system that has grooves and lands

sports mode similar to power mode that can be selected with some automatic transmissions

sprag clutch a type of one-way clutch

sprock et a toothed wheel used with a chain drive

sprung mass the mass of the vehicle that is carried by the suspension; the remaining parts make up the unsprung mass

spur gear a gear with straight external teeth

square engine an engine in which the bore and stroke are of the same dimension

squish the squeezing or squashing action on the air or air–fuel mixture when the piston is almost at top dead-centre of a compression stroke; occurs particularly with some designs of diesel combustion chambers

staggered offset; not in a line; alternate

stall test a test that can be used with some automatic transmissions; it checks the torque converter and the engine power

standard normal; original; the size of a shaft or bearing etc. as compared with one that is undersize or oversize

star windings an arrangement of alternator windings which, when drawn as a diagram, form a star shape

static balance a wheel where the mass is evenly distributed around its centre; when lightly mounted on a spindle, it will remain in any position in which it is placed

static electricity electricity generated by friction between two objects

stator the stationary windings and core of an alternator; a stationary part; one of the members of a torque converter

steering geometry the steering angles of the front wheels

steering knuckle the part of the front suspension that carries the wheel spindle and pivots during steering

steering linkage the rods that connect the front wheels together and to the steering box

stoichiometric ratio the theoretical ratio of the quantity of air needed for complete combustion of fuel; for petrol, this is 14.7 kg of air to 1 kg of fuel—for this condition, lambda (l) = 1.0

storage battery a battery that can be recharged, such as an automotive battery

stormwater rainwater

stress force applied; also used for the effect of a force that causes stress. Stress produces strain or change in shape

stress rise an increase in stress at a particular place

strok e movement of a piston from the top to the bottom of its cylinder, or from the bottom to the top

strut a type of independent suspension; McPherson strut

stub axle the end of a front beam axle that carries the wheel hub and swivels for steering

subframe reinforced parts of the bodywork that carry the suspension, engine and other parts

submerged jet a jet in a carburettor which is under the fuel

suction low pressure; low pressure created in the intake manifold by the movement of the pistons

sulphation formation of lead sulphate on the battery plates

sump container for engine oil; also called the oil pan

sun gear the central gear of a planetary gear set about which the other gears revolve

supercharger a type of pump that forces air into the cylinders of an engine, increasing the density. This puts more air into the cylinders to increase the volumetric efficiency; *see* turbocharger

surge chamber *see* plenum chamber
susceptible sensitive
suspension a system for supporting the body of the vehicle and absorbing road shocks
swage to close or compress a metal joint
sway bar a bar across the suspension which resists being twisted as the body leans on corners; also called a stabiliser bar
swept volume the volume of air or air–fuel mixture which is drawn into the cylinder during an intake stroke
swing axles the open-type drive shafts of an independent suspension of a rear-wheel-drive vehicle
swirl the spiral movement of the air–fuel mixture in a cylinder
synchromesh synchronising units on the gears of a transmission
synchronise bring to the same speed

tachometer an instrument for measuring revolutions per minute
tandem one behind the other
tandem (master cylinder) a master cylinder with two pistons
tappet part of an engine's valve train, also called a cam follower or valve lifter
taps (and dies) threading tools
telescopic a unit that has one part moving inside another
temper the degree of hardness of steel; act of hardening
tensile strength strength against stretching
tension pulling; stretching
tensioner a device for removing the slack from a belt or chain
terminal an electrical connection
thermal efficiency the efficiency of an engine in relation to the heat energy input compared with the mechanical output
thermal gauge a fuel or temperature gauge that has a thermostat for operation
thermistor electrical resistance unit that changes its resistance with temperature; used with an engine temperature gauge
thermo switch a switch with a bimetal blade that is operated by heat
thermo valve a vacuum valve that opens and closes according to temperature; operated by a bimetal blade or wax element
thermostat a valve, in the cooling system, that causes the coolant to bypass the radiator when cold
thermostatic affected by heat
thermostatic spring a spring that is affected by heat; it changes its shape according to its temperature
thermostatic switch switch with a bimetal blade that operates by heat
three-phase the voltage and current from the three stator windings of an alternator
throttle butterfly another name for the carburettor throttle valve
throttle body the lower part of a carburettor, or the component of an EFI system which has the throttle valve
throttle dashpot *see* dashpot
throttle stop a screw on the carburettor that adjusts engine idle speed
throttle valve the valve, in the throttle body, that is operated by the accelerator; controls engine speed and power
throttle-body injection an EFI system with one or two injectors in the throttle body; *see* single-point injection
throttle-position sensor a sensor, on the throttle body, which indicates the throttle opening
throw the crank or offset part of a crankshaft that carries the connecting rod or crankpin
throwout bearing *see* release bearing
thrust a force
thrust bearing a bearing that is capable of accepting a thrust
thrust washer a washer located where it will take a thrust load
tie rods the rods that connect a rack-and-pinion steering box to the steering arms at the wheels; on other linkages, the outer rods that connect to the steering arms
timing for ignition, having the spark occur at the correct time; for valves, having the camshaft correctly timed in relation to the crankshaft
timing belt a toothed belt that connects the crankshaft timing pulley to the camshaft timing pulley
timing chain a chain that connects the crankshaft sprocket to the camshaft sprocket
timing light a light for setting the ignition timing against marks on the crankshaft pulley
timing marks for ignition timing, the marks on the crankshaft pulley and engine; for valve timing, the marks on the crankshaft and camshaft sprockets, or on the crankshaft and camshaft timing pulleys
toe wheels not being parallel
toe-in the front of the wheels pointing inwards
toe-out the front of the wheels pointing outwards
toe-out-on-turns the inner wheel is arranged to turn through a greater angle than the outer wheel so that the wheels toe-out when on a turn
tolerance the amount of variation permitted in a dimension or adjustment, often specified as a plus or minus amount
tooth contact the way in which teeth of meshed gears contact each other; tooth markings when adjusting the crown wheel and pinion
top dead-centre (TDC) the top of a piston stroke
top overhaul overhaul of the cylinder head and valves
topping up adding oil, or coolant, so that the level is correct
toroidal ring shaped
torque twisting or turning force; the force produced by the engine and transmitted through the drive train to the driving wheels
torque converter a particular type of fluid coupling used with automatic transmissions; it acts as a coupling and can also increase torque about 2:1
torque multiplication an increase in torque within a torque converter
torque rod a rod, of a suspension system, that resists the torque reaction from the driving wheels
torque wrench a wrench for applying a specified torque to bolts or nuts
torsion twist or twisting
torsion bar a steel bar that acts as a spring when it is twisted; torsion bar suspension
torsional vibration vibrations in a shaft caused by twisting forces—this occurs with a crankshaft due to the power strokes
track the distance between the front wheels or the distance between the rear wheels (*see also* wheel track)
traction grip or friction between the tread of the tyres and the road
trade waste waste materials produced as a by-product of conducting a business
trailing following
trailing arm a rear-suspension arm with its front end attached to the subframe so that the wheel is trailing behind
tramp up-and-down motion of a wheel due to unbalance
transaxle transmission used with front-wheel drive that includes the final drive
transfer case a gearbox, attached to the transmission of a four-wheel-drive vehicle, that provides high and low ranges and drive to the front wheels
transformer an electrical device with coil windings; used to increase or decrease voltage
transistor an electronic component used for switching
transmission mechanical arrangement with gears that transmits and also increases torque
transverse across; a transverse engine is mounted across the vehicle
transverse engine an engine mounted across the vehicle, used with front-wheel drive
trouble shooting *see* diagnosis
trunnions bearings, usually used in pairs
tune-up a check and adjustment of the engine to restore or maintain performance
tungsten bulb a light bulb with a tungsten filament
tungsten steel an alloy steel containing tungsten
turbine a wheel with a number of blades or vanes against which oil or gas is directed to produce rotation
turbine engine an engine that uses a turbine rotor to produce power
turbocharger a supercharger that has a turbine, driven by exhaust gas, and a compressor to provide forced air for the engine
turbulence a swirling motion of a liquid or gas
turning circle the circle that a vehicle turns with the wheels on full lock
turns (coil) the windings of a coil
two-stage having two steps; two parts; in two operations
two-stroke engine that operates on a two-stroke cycle

undersize smaller than standard
understeer a condition where a vehicle is less responsive to steering and tries to keep wide on a curve (*see also* oversteer)
unit injector a type of diesel fuel injector

universal joint a flexible joint in a drive shaft that permits changes in the shaft angle
unsprung mass the parts of the vehicle that are not supported by the suspension
upshift change to a higher gear

vacuum zero pressure—in practice, pressures lower than atmospheric are referred to as a vacuum; negative pressure is a more accurate term
vacuum advance ignition-timing advance by a vacuum control on the distributor
vacuum control a control device that is operated by the engine intake manifold vacuum
vacuum delay valve a vacuum valve used with emission controls
vacuum diaphragm a diaphragm of a vacuum control; a vacuum control
vacuum gauge a gauge used to check engine manifold vacuum; it registers negative pressure
vacuum pump a pump used on diesel engines to provide vacuum for braking; a hand-operated pump for testing vacuum controls
vacuum servo a brake booster that uses intake manifold vacuum
valve a device to control the passage of liquid or gas; types of valves are poppet, flap, spool, ball and rotary
valve bounce relates to an engine valve that bounces on its seat after it closes, due to a weak valve spring
valve clearance valve lash; the clearance between the tip of a valve stem and the rocker arm; the clearance between a cam follower and the tip of a valve
valve grind reconditioning the valves and seats of a cylinder head
valve height *see* assembled valve height
valve lash *see* valve clearance
valve lifter *see* tappet
valve overlap the brief period during an engine cycle when the intake valve and the exhaust valve are both slightly open
valve rotator a device that causes an engine valve to rotate slightly when it opens
valve timing *see* timing (valves)
valve train the valve-operating mechanism from the camshaft to the valve stems
vane pump a pump that has vanes in a rotor within the pump body
vaporisation changing a liquid to a gas
vaporise to change from a liquid to a gas
vapour gaseous form of a substance that is normally a liquid, for example, water vapour or steam
vapour lock fuel in a fuel system that has changed to a gas by heat from the engine; this prevents normal liquid-fuel flow
variable-displacement pump a vane-type pump that can be varied in size to regulate its output
variable valve timing a method of advancing or retarding the camshaft in relation to the piston position
vehicle-speed sensor a sensor that transmits road-speed signals to a central control unit
velocity speed; stated in metres per second or kilometres per hour
V-engine an engine with two banks of cylinders at an angle
venturi a tube of a particular shape through which air flows – in a carburettor, the venturi is used to provide a low pressure at the fuel discharge nozzle
vernier a precision measuring instrument
vernier caliper precision measuring tool
viscosity a liquid's resistance to flow– viscosity changes with temperature; it decreases as the liquid is heated and increases as it cools
viscous coupling a coupling that uses silicone oil to transmit drive
volatility the tendency for a liquid to vaporise; petrol is very volatile because it readily turns to a vapour
volt unit of electrical pressure
voltage electrical pressure or potential
voltage drop the difference in voltage between two points in an electrical circuit; resistance causes voltage drop
voltage regulator an electronic device for limiting the maximum alternator voltage
voltmeter electrical instrument for measuring voltage
volumetric efficiency the amount of air that is actually taken into a cylinder, compared with the amount that could be taken in if the cylinder were completely filled
vortex a swirl or swirling motion

wander tendency of a vehicle to move away from a straight course
wastegate a control that regulates the flow of exhaust gases through a turbocharger to control its speed
wastegate actuator a control that opens and closes the wastegate valve of a supercharger
water pump the cooling-system pump that circulates the coolant
water-cooled refers to an engine that uses water, or a water mixture, as a coolant
water-jacket space around the cylinders and in the cylinder head that is filled with coolant
watt a unit of electrical power
waveform a trace produced on an oscilloscope by changes in voltage
wax element a pellet of wax that expands and contracts with changes in temperature
web reinforcing part of a casting, such as the crankcase webs, which are bridges of metal between the main bearings and the wall of the crankcase
wedge combustion chamber a combustion chamber that tapers to one side
welsh plugs *see* expansion plugs *or* core plugs
wet sleeve an engine sleeve that forms part of the water-jacket, and so is 'wet' by coolant against its outside
wheel aligner instruments or installed equipment used for carrying out a wheel alignment
wheel alignment the correct alignment of all four wheels of the vehicle; also used to indicate a wheel-alignment service
wheel balance balancing the wheels by adding weights
wheel track the distance between the centres of the tyres, measured across the vehicle
wheel wobble shimmy; wobble of the wheels from side to side due to unbalance of the tyre, or because of a steering fault
wheelbase the distance between the centre of a front wheel and the centre of a rear wheel with the steering straight ahead
wiring diagrams drawings of the wiring circuits of a vehicle, sometimes referred to as schematics
wiring harness a group of electrical cables in the wiring system
wishbone a suspension control arm (so named because of its shape) usually used with front suspension; the lower control arm of front coil suspension
witness marks wear marks that can be used for identification of how parts are fitted; also marks placed on parts for use when reassembling; identification marks
work effort applied or energy expended; the product of the force applied and the distance moved (simply, effort is force, work is effort applied, energy is stored work, and power is the speed at which work is done)
workhead the part of a machine that carries the work
working clearance the clearance between parts that allows them to work together and prevents them from binding
worm a thread-shaped gear used in steering boxes and also for speedometer drives
worm drive a drive with a type of thread meshed with a gear. used in wiper motors, steering boxes and some final drives
wrist pin the pin that connects the piston to its connecting rod; also called a piston pin or gudgeon pin

yield point the point beyond which stretched metal will not return to its original shape
yoke forked or U-shaped end of a rod or shaft that connects one part to another, for example, yokes of a universal joint

Zener diode a diode that will not conduct until a certain voltage is reached; it then breaks down and acts as a normal diode. Also called a breakdown diode; a diode used in a voltage regulator
zero nothing; point from which instruments are graduated
zinc a soft white metal used to prevent corrosion, as on zinc-plated bolts or parts
zone an area or division

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Common abbreviations

A	amps
ABS	antilock braking system
AC	alternating current
ADR	Australian Design Rules
AGM	absorbed glass mat (battery)
AT	automatic transmission
ATF	automatic transmission fluid
BDC	bottom dead-centre
BEM	body electronic module
BEV	battery electric vehicle
BHP	brak e horsepower
BMM	battery monitoring module
BMS	battery management system
BUS	bi-directional universal signalling
CAN	controller area network
CCA	cold cranking amps
CFC	chlorofluorocarbon
CO	carbon mono xide
CO_2	carbon dio xide
CPU	central processing unit
CTS	coolant/cylinder-head temperature sensor
CV	constant velocity
CVT	continuously variable transmission
DC	direct current
DIN	Deutsche Industrie Norman; a German industrial standard
DLC	data link connector
DMM	digital multi meter
DOHC	double overhead camshaft
DTC	diagnostic trouble codes
DVD	digital video disc
EBD	electronic brak eforce distribution
ECM	electronic control module
ECU	electronic control unit
EFI	electronic fuel injection
EGR	exhaust-gas recirculation/return
EMF	electromotive force
EMI	electromagnetic interference
EP	extreme pressure
EPA	Environment Protection A uthority
EPB	electronic parking brak e
EPROM	erasable programmable read-only memory
ESP	electronic stability program
EV	electronic vehicle
EX	exhaust
FCAT	forward collision advance technology
FCV	fuel cell vehicle
FCEV	fuel cell electric vehicle
FWD	front-wheel drive
GP	general purpose
GPS	global positioning system
H_2O	water
HC	hydrocarbon
HCU	hydraulic control unit
HD	heavy duty
HDC	hill descent control
HEV	hybrid electric vehicle
HFO	hydrofluoroolefin
HT	high tension
Hz	hertz or frequency
IC	integrated circuit
ICE	internal combustion engine
IG	ignition
IN	intak e or inlet
IPU	intelligent power unit
IRS	independent rear suspension
ISS	idle/stop start
j	joule
KAM	keep alive memory
km/h	kilometres per hour
kPa	kilopascals
LCD	liquid crystal display

LED	light-emitting diode
LFP	lithium ferro phosphate
LH	left hand
LIN	local interconnect network
LPG	liquefied petroleum gas
LT	low tension
MAF	mass air flow; the airflow through the throttle body
MAP	manifold absolute pressure; the actual pressure in the intak e manifold
MAT	manifold air temperature; the temperature in the intak e manifold
MG	motor/generator
MIL	malfunction indicator light
mm	millimetre
ms	millisecond
MP	multipurpose
MPI	multipoint injection
MSDS	material safety data sheet
MT	manual transmission
NGV	natural gas for vehicles
Nm	newton metre
NO_x	nitrous o xides
NTC	negative temperature coefficient (resistor)
O	oxygen
O_2	oxygen gas
OHC	overhead camshaft
OHV	overhead valve
OBD	on-board diagnostics
PCM	power control module
PCV	positive crank case ventilation
PEM	proton ex change membrane
PHEV	plug-in hybrid electric vehicle
PROM	programmable read-only memory
psi	pounds per square inch
PTC	positive temperature coefficient (resistor)
PTO	power tak e-off
R	resistance
RAM	random access memory; computer memory to which information is supplied, held or changed
RC	reserve capacity
RDC	radio data system
RF	radio frequency
RH	right hand
ROM	read-only memory; permanent memory of a computer where a program is stored
rpm	revolutions per minute
RWD	rear-wheel drive
SAE	Society of A utomotive Engineers
SAI	steering axis inclination
SOC	state of charge (battery)
SOH	state of health (battery)
SOHC	single overhead camshaft
SVR	sealed valve regulator
SW	switch
TBI	throttle-body injection
TC	traction/torque control
TCL	traction control
TCM	transmission control module
TCS	traction control system
TDC	top dead-centre
TPS	throttle-position sensor
TVRS	television and radio suppressed
TX	thermostatic expansion (valve)
V	volts
VDR	voltage-dependent resistor
VIN	vehicle identification number
VRLA	valve-regulated lead acid
VVT	variable valve timing
W	watts
W	wide-open throttle