# Automobile Engineering

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He is currently engaged in organising training programmes for technical teachers and supervisory skills development training programmes for industry. He is also involved in developing curricula for high technology courses at diploma and post diploma levels.

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He has also published articles in national and international journals. He is an active member of Institution of Engineers (India).

Presently he is actively engaged in writing books.

# Automobile Engineering

*Developed at*
**Technical Teachers' Training Institute**
**Bhopal**


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# Foreword

The last one decade has witnessed a phenomenal growth in the population of automobiles in India. It is said that the civilisation of a country can be measured in terms of the number of automobile vehicles. It has been timely for the authors to come up with a book on Indian automobiles. The book has touched upon various issues like the adequacy of technology, the various constraints which were coming earlier in the way of growth and also the future trends of the industry. The book will be beneficial to all those who would like to delve deeper into the subject. In the current context, Prof. K.K. Jain's and Mr. R.B. Asthana's work is just in time, especially when the Indian automobiles are poised for a great leap into the international market.

The salient features of the book are:

- In-depth treatment of engine with maintenance aspects and troubleshooting.
- Fuel systems for various models and supercharges of I.C. engine have been specially given for beginners in automobile study.
- Transmission of power from engine to wheel has an objective role to play in modern-age cars. Distinct characters, which are based on design of transmission, of many vehicles have been dealt with.
- Modern automobile's special features are for passenger comfort, and its suspension system takes the lead over old generation cars, the reasoning for which could be very well understood.
- In this computer age, automobile's electrical systems are more sophisticated and use computer technology for different electrical components. This has been kept in mind.
- Service aspect of any automobile is important in making it a success. How to maintain a vehicle at its optimum performance level has been covered adequately.

A very good attempt has been made to put down all the parameters of automobile engineering in this text.

I am sure that this book will prove useful for students as well as practising engineers.

I wish all the best to the authors.

**Dr K Kumar**
Director (Engineering)
Maruti Udyog Ltd.

# Preface

Automobile Industry has witnessed a phenomenal growth in India in the post independence period. Rapid industrialisation of the country has resulted in an unprecedented advancement in the technological processes and improvement in the efficiency of structures, machines and transport vehicles under various operating conditions. To cope with the advances in the automobile engineering field, the engineers and technicians engaged in the field must understand the various constructional and working details of the components used in different vehicles. They are also expected to understand repair, and maintenance of automobiles in the country.

A large number of automobiles consisting of four-wheelers and two-wheelers are manufactured by various companies in India and abroad. Different manufacturing companies provide detailed information in their catalogues and service manuals. However, there are very few books on automobile engineering which deal with the components, designs and processes adopted by the automobile manufacturers in India. The present textbook endeavours to provide relevant information on various types of components used in the Indian automobile industry and thus fulfils a long felt need of students, teachers and professional in the field.

One of the salient features of the book is its practical approach in dealing with the subject. It deals with in detail, aspects like fault diagnosis and maintenance of various assemblies of vehicles, troubleshooting and remedial measures among others. The authors have pooled in their technical knowledge and experience in the industry and educational sector in developing this book.

The book deals with the latest technology used in different models and presents comparative data on Indian vehicles with suitable illustrations.

It is our hope that this book, will be of immense value to the technical teachers, students as well as professional in the field. We look forward to receiving invaluable suggestions from the users and experts in the field. This textbook could be improved further on the basis of these erudite suggestions.

**TTTI, Bhopal**

# Acknowledgements

Many books on Automobile Engineering are available in the country, but most of them do not specifically deal with the Indian automobiles. Looking at the advancements in the Automobile Industry in India, Shri B R Jain, Ex-Chairman, Board of Governors, TTTI, Bhopal motivated the authors to write a book on Automobile Engineering based on Indian vehicles for students, teachers and professionals working in the industry. The authors wish to express their sincere gratitude to him.

While preparing this book the material made available by various organisations and individuals in the form of manuals, catalogues and brochures on current practices has been extensively referred to. The permission for the same was given by M/s Maruti Udyog Ltd, M/s Hindustan Motors Ltd., M/s The Premier Automobiles Ltd., M/s Mahindra & Mahindra Ltd, M/s Tata Engineering and Locomotive Company Ltd., M/s Hyundai Motors India Ltd., M/s Daewoo Motors India Ltd., etc. The authors wish to express their thanks for the help and guidance in this endeavour, to all the organisations which permitted them to use their technical material.

The authors wish to thank Shri D Guha, formerly Superintendent, Bhilai Technical Institute, Bhilai Steel Plant, for inspiring them to write this book. In completing this book the contributions made by the following experts, Late (Prof.) N L Jain, Formerly Director of Technical Education, Madhya Pradesh, Prof S M Pandey, Formerly Head of the Mechanical Engineering, Department, Government Engineering College, Jabalpur and Dr A D Telang, Professor, Mechanical Engineering, Department, MACT, Bhopal had been of immense value.

Special thanks are also due to Mr S Majumdar, Manager (Service Deptt.), Maruti Udyog Ltd., Prof. P P Prabhu, Principal, Father Agnel Technical College, Bandra, Mumbai and Dr N K Banthiya, Formerly Head of the Mechanical Engineering & Continuing Education Department, TTTI Bhopal for having taken pains to edit the text materials.

The authors are grateful to Late (Prof.) S A Balu and Prof. R K Mani both Ex-Principals of TTTI, Bhopal for providing invaluable support while collecting the data for the book. They are extremely grateful to Prof. P C Jain, Principal, TTTI, Bhopal for his continued inspiration in completing the book as well as providing valuable guidance and support during the project.

The authors thank all the colleagues and supporting staff of TTTI Bhopal who have helped them in the completion of this book. Special thanks are due to the faculty and supporting staff of Mechanical Engineering Department of TTTI, Bhopal for their cooperation and assistance at various stages of this project.

**K K Jain**
**R B Asthana**

# Contents

# 1

# Introduction

**Objectives**

After studying this chapter, you should be able to:

- Explain the automotive vehicles and their historical development.
- Describe the types of automotive vehicles.
- Draw the layout of some common automotive vehicles.
- Explain the functions of the main components and assemblies of some common automotive vehicles.
- List the name of manufacturers of Indian automotive vehicles.
- State the technical specification of Indian automotive vehicles.

## 1.1 INTRODUCTION TO AN AUTOMOBILE

An *automobile* is a self-propelled vehicle driven by an internal combustion engine and is used for transportation of goods and passengers on ground.

In general, the modern automobile is essentially a transportation equipment unit. It is made up of a frame supporting the body and certain power developing and transmitting units. These are further supported by tyres and wheels through springs and axles. An engine supplies the power, which is delivered by the transmission system to the wheels through the clutch or fluid coupling.

## 1.2 HISTORY OF THE AUTOMOBILE

Nicolas Cugnot, a French artillery officer, designed and built the world's first self-propelled road vehicle. In 1769, Cugnot constructed a crude three-wheeled steam tractor for handling canon. It attained a speed of about two and half mph for 15 minutes only.

The saga of the modern day car really began as early as 1860. In that year Jean Etienne Lenoir, a Belgian inventor, built the first practicable gas engine, and which subsequently became the model from which all other internal-combustion engines developed. In that first engine, however, the mixture of coal gas and air was not compressed before ignition, and as such it was inefficient.

The next milestone in the history of the automobile, was in 1876 when Count Nikolus Otto, a German engineer, first successfully applied the four-stroke principle that had been proposed by the Frenchman Beau da Rochas. The four-stroke cycle enabled the charge to be compressed, which gave a significantly better performance. At about the same time, gasoline—a distillate of petroleum later to be known also as petrol came into use instead of coal gas.

In 1880, German and French efforts resulted in an internal combustion engine vehicle which was used to carry fruits. The present-day automobile developed from this vehicle. In 1883, Gottlieb Daimler and Carl Benz Daimler, working with Wilhelm Maybach, produced his first engine and it created a sensation by running at more than four times the speed of Otto's engines. On the other hand, Benz started with the objective of making his own self-propelled vehicle, and in 1885 installed his first engine at the back of a tricycle. Within a year or so, Daimler and Benz were building cars for sale. In 1895, Panhard and Daimler in France had the engine placed in the front of a chassis, hooked up to a sliding gear transmission, and incorporated the brake pedal, clutch and accelerator.

The Locomotives Act 1865, framed in Britain for steam-driven traction engines, set an overall speed limit of 4 mph in open country and 2 mph in towns and villages. Cars had to be preceded by a man carrying a red flag to warn the drivers of horse-drawn vehicles. Although the flag was abolished in 1876, the man was still required by law until 1896.

In 1908, Ford started his model with an initial run of 20,000 vehicles, an output unheard of at that time. This was the period when the designers' chief objective was to make his vehicle run in mass production, at the lowest possible price. In 1920 there was a gradual change and refinement in automobile design. By that time the spark-ignition gasoline engine was to be the power plant of the modern motor vehicle. Water-cooled engines were almost universal. The sliding gear transmission had established itself predominantly. The poppet valve was used in almost every engine design. Engines were all located in the front of the chassis.

Substantial progress has been made after the second world war in every car feature. The designers during this time tried to produce a vehicle which not only functioned at all times under all conditions, but which was also comfortable to ride and easy to operate. The increased life of tyres, brakes, independent front wheel suspension, heating and ventilation, improved engine design. Safety and exhaust emission were the additional features. However, this is not an end. Further research and development efforts continue and are focussed to produce a better, cheaper, safer and in the future, computer controlled vehicles.

## 1.3 INDIAN AUTOMOBILES

In the pre-Independence days cars used to be imported into India and it was later, when car manufacture was started in the country with foreign collaborations. Car manufacturing companies such as Hindustan Motors, Premier Automobiles and Standard Motors, could not contribute much to improve the design and manufacture of new cars. It used to be often remarked that we are perhaps the only country in the world still producing cars with the 50's technology. Chronologically, Hindustan Motors was the first to set up shop in 1946, in the eastern region while Premier Automobiles entered the industry the following year. Mahindra and Mahindra arrived, in 1949 to produce jeeps in the western region, while in 1950, Standard Motors was established to produce passenger cars in the southern region. The industrial giant, Tata introduced a plant for the manufacture of commercial vehicles in 1954, at Jamshedpur.

The production of all these cars was far below the nation's demand. In 1980, Hindustan Motors produced only 21,572 cars, Premier Automobiles 8,729, while Standard motors produced only 6 cars.

The complacency of these manufacturers and the silence of the consumers was finally broken in 1973, the period of the oil crunch, viz. the oil crisis. It was finally in this period that the small car concept came into being and Maruti took shape. In 1982, Maruti was established in collaboration with Suzuki.

Maruti however, was not the country's first small car. In the last decade, the Banglore-based Sipani Automobiles Ltd. brought out the Badal/Dolphin based on technology from the Reliant Motor Works, England. Though only a limited number of cars are produced each year despite the licensed capacity of 3000, these cars are the only fibre-glass body automobiles in the country.

New models introduced by various companies in recent years have been: The Hindustan Motors Contessa, a very highly priced car, which has a 69 Vauxhall body over an Ambassador engine; The Standard 2000 which has a 2000 cc and a body designed by Austin/Rover, again a very highly priced car. The Premier 118 NE, with a Nissan 1200 cc petrol engine and a Fiat 124 body, Peugeot 309 with 1360 cc petrol engine are manufactured by Premier Automobile. Maruti 800, Maruti Van with 800 cc petrol engine, Maruti Gypsy with 970 cc petrol engine, Maruti 1000, Maruti Zen with 993 cc engine, and Maruti Esteem with 1300 cc petrol engine are the models of Maruti Udyog Ltd., Tata Sierra, Tata Estate with 1948 cc diesel engine are multi-purpose cars and again highly priced cars introduced by Telco. Recently, new small car models introduced by various companies in the Indian market have been Daewoo's Matiz with 796 cc petrol engine, Hyundai's Santro with 999 cc petrol engine, Fiat's Uno with 999 cc petrol and Telco's Indica with 1405 cc petrol and diesel engine.

## 1.4 TYPES OF AUTOMOBILES

Numerous types of automobiles are available in the world. Automobiles are classified in the following ways based on their load capacity, fuel used, the suspension system used, the body system, etc.

### 1. Purpose

| | |
|---|---|
| • Passenger vehicle | Car, Station wagon, Jeep, Bus |
| • Goods vehicle | Truck, Pick-up |
| • Special purpose | Ambulance, Fire engine, Army vehicles, Concrete mixer, etc. |

### 2. Load Capacity

| | |
|---|---|
| • Light duty vehicle | Car, Jeep, Scooter, Motor cycle, etc. |
| • Heavy duty vehicle | Bus, Truck, Tractor, Coach |

### 3. Number of Wheels and Axles

| | |
|---|---|
| • Two wheeler | Motor cycles, Scooters, Mopeds |
| • Three wheeler | Tempo, Auto-rickshaws |
| • Four wheeler | Car, Jeep, Bus, Truck, etc. |
| • Six wheeler | Buses and Trucks have six tyres out of which four are carried on the rear wheels for additional traction. |
| • Six axle wheeler | Shaktiman, Dodge (10 tyres) vehicle |

### 4. Fuel Used

| | |
|---|---|
| • Petrol vehicle | Car, Jeep, Motor-Cycle, Scooter |
| • Diesel vehicle | Car, Truck, Tractor, Bus, Bulldozer. |

| | |
|---|---|
| • Steam vehicle | Steam road roller |
| • Electric vehicle | Fork lift, Battery truck |

### 5. Suspension System Used

| | |
|---|---|
| • Conventional | Leaf spring |
| • Independent | Coil spring, Torsion bar, Pneumatic |

### 6. Type of Automobile Body System

- Two door sedan
- Hard top
- Four door sedan
- Station wagon
- Convertible
- Van

### 7. Drive of the Vehicles

- Right hand drive
- Left hand drive
- Front wheel drive
- Rear wheel drive
- Single wheel drive
- Two wheel drive
- Four wheel drive
- Six wheel drive

## 1.5 LAYOUT OF AN AUTOMOBILE

Before we begin our study of the various components of automobiles, let us first look at the complete automobile in Fig. 1.1, examine its component parts, and find out how these parts work together with the engine.

Figure 1.1 shows the position of the main components of an automobile. It consists of the engine located at the front of the vehicle followed by a clutch, gearbox, propeller shaft, universal joint, differential, rear axle, etc. Various other parts of the vehicle shown in the layout are: steering wheel, battery, air-cleaner, alternator, headlamp, fan, radiator, distributor, carburettor, tie rod, exhaust pipe, silencer, tail pipe, fuel tank, shock absorber, brake, back light, wheel and tyres. The layout also consists of rear leaf spring suspension system.

## 1.6 MAJOR COMPONENTS OF THE AUTOMOBILE

The major components which are used in an automobile are:

1. *The engine or power plant* which is the source of power. It converts the explosive power of fuel and air mixture into rotating power to drive the automobile.
2. *The frame* The automobile frame is made of steel members known as a "chassis-frame". It supports the engine, wheels, car body and other component parts.

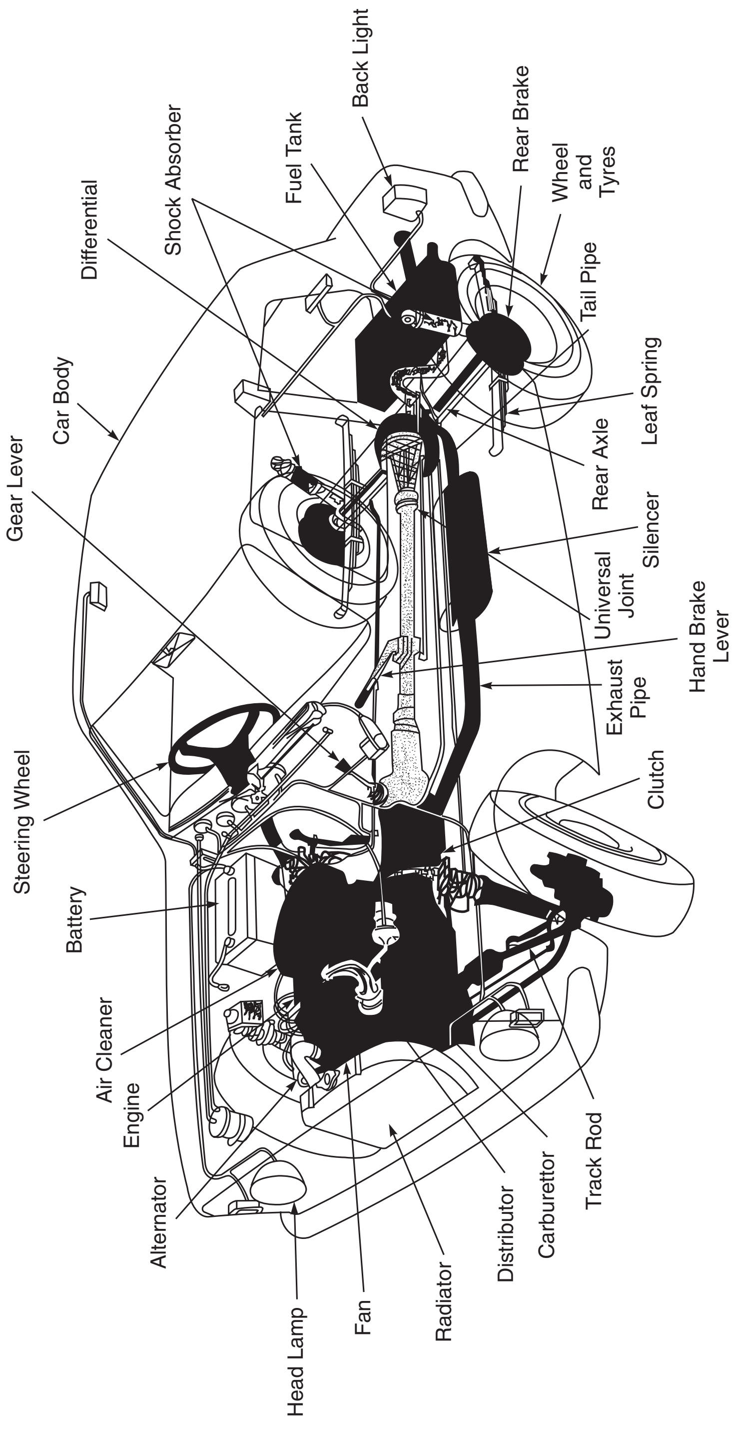



**Fig. 1.1** Layout of an Automobile

3. *The power train* which carries power from the engine to the car wheels. The power train includes the clutch, transmission, drive shaft (propeller shaft), differential, axles and wheels.
4. *The steering system* of the automobile is used for changing the direction of the automobile.
5. The brake system is used to stop the automobile.
6. *The car body*.
7. *The car body accessories*, which include lights, heater, radio, windshield, wipers, convertible top, raiser and so on.

## 1.7 FUNCTIONS OF THE AUTOMOBILE COMPONENTS

### 1. Engine

The engine is a power generator/power plant or a motor, which provides power to drive the automobile.

In most automobile engines, the explosive power of the mixture of air and gasoline drives the pistons. The pistons turn a crankshaft to which they are attached. The rotating force of the crankshaft makes the automobile's wheels turn.

Some automobiles are powered by another kind of engine, known as the rotary valve, rotating combustion engine or Wankel engine. The rotary valve engine also draws in a mixture of air and fuel, which is then compressed and burnt. A motor revolving in an elliptical chamber is connected to a shaft, which finally drives the rear wheels. In most automobiles, the engine is mounted at the front end of the car, with the clutch and gearbox immediately behind it; the engine, clutch and gearbox are assembled into a single unit.

A number of systems are necessary to make an engine work. A lubrication system is needed to reduce friction and prevent engine wear. A cooling system is required to keep the engine's temperature within safe limits. The engine must be provided with the correct amount of air and fuel by a fuel system.

The mixture of air and fuel must be ignited inside the cylinder at just the right time by an ignition system. Finally, an electrical system is required to operate the cranking motor that starts the engine and to provide electrical energy to power engine accessories.

### 2. Lubrication System

An engine has many moving parts which eventually develop wear, as they move against each other. The engine circulates oil between these moving parts to prevent the metal-to-metal contact that results in wear. Parts that are oiled can move more easily with less friction and hence power loss due to friction is minimized. The secondary function of a lubricant is to act as a coolant and also as a sealing medium to prevent leakages. Finally, a film of lubricant on the cylinder walls helps the rings in sealing and thus improves the engine's compressions.

### 3. Cooling System

Due to the combustion of fuel with air inside the cylinder, the temperature of the engine parts increases. This increase of temperature directly affects the engine performance and the life of the engine parts. The cooling system keeps the engine operating at an efficient temperature. Whatever the driving conditions, the system is designed to prevent both overheating and overcooling.

### 4. Fuel System

The main function of the fuel supply system is to provide fuel to the carburettor or injection system at a rate and pressure sufficient to meet engine demands under all conditions of load, speed and gradients encountered by the vehicle. The fuel system must also have enough reserve fuel for several miles of vehicle operation.

### 5. Ignition System

The purpose of the ignition system is to provide assistance for the combustion of fuel either by a high voltage spark or self-ignition in each of the engine's cylinders at the right time so that the air-fuel mixture can burn completely.

The fuel supplied to the combustion chamber must be ignited to deliver power. In a spark-ignition engine an electric spark is used for this purpose. The compression-ignition engine does not require a separate ignition system because the ignition is affected by compression of the mixture to a high pressure.

### 6. Electrical System

The engine's electrical system provides energy to operate a starting motor and to power all the accessories. The main components of the electrical system are a battery, an alternator, a starting motor, ignition coil and heater.

### 7. Frame

The frame provides a foundation for the engine and the body of the vehicle. The frame is constructed from square or box-shaped steel members strong enough to support the weight of the body and other components.

The automobile frame is usually made up of a number of members welded or riveted together to give the final shape. The engine is mounted on the frame with rubber pads which absorb vibrations and also provide damping of these vibrations. Absorption and damping of vibrations protects passengers from discomfort caused by shocks.

The frame is supported on wheel axles by means of springs. This whole assembly is called the chassis.

### 8. Suspension System

The function of the suspension system is to absorb vibrations due to the up and down motion of wheels, caused by the irregularities in the road surface. The springs, connecting linkages, and shock absorber comprise the suspension system of a vehicle. The suspension system is of two types:

(i) Rigid system
(ii) Independent system

In the rigid system, the road springs are attached to a rigid beam axle. It is mostly used in the front axle of commercial vehicles and in the rear axle of all types of vehicles.

The independent system does not have a rigid axle. Each wheel is free to move vertically without any reaction on its mating wheel. The independent system is mostly used in small cars.

## 9. Power Train

The power train carries the power that the engine produces to the car wheels. It consists of the clutch (on cars with a manual transmission), transmission (a system of gears that increases the turning effort of the engine to move the automobile), drive shaft, differential and rear axle (Fig. 1.2).

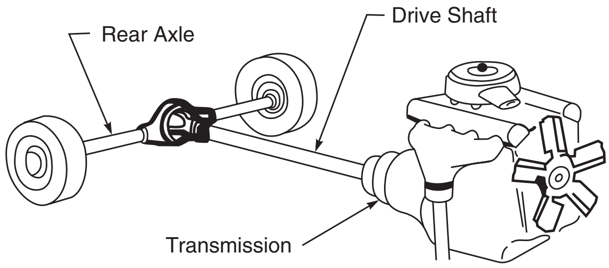



**Fig. 1.2** Power Train

## 10. Clutch

A clutch is required with the manual transmission system to temporarily disconnect the engine from wheels. Such disengagement of the power train from the engine is essential while changing the gear ratio or while stopping the vehicle.

## 11. Transmission

The main function of the transmission is to provide the necessary variation to the torque applied by the engine to the wheels. This is achieved by changing the gearing ratio between the engine output shaft and the drive shaft.

## 12. Drive Shaft

The drive shaft or propeller shaft connects the gearbox and the differential unit. The drive shaft has universal joints at its ends.

## 13. Differential

The function of the differential is to split the power received from the propeller shaft to the rear axle shaft. It allows the rear wheels to be driven at different speeds when the vehicle takes a bend or falls into a ditch.

## 14. Axles

Axles are the shafts on which road wheels are mounted. The road wheels are provided with the required drive through these axles.

## 15. Wheels

The automobile wheels take the load of the vehicle and also produce tractive force to move the vehicle. The wheels are also used for retardation and for stopping the vehicle.

## 16. Steering System

The steering system is used for changing the direction of the vehicle. The major requirements in any steering mechanism are that it should be precise and easy to handle, and that the front wheels should have a tendency to return to the straight-ahead position after a turn. A gear mechanism, which is known as steering gear, is used in this system to increase the steering effort provided by the driver. This system makes the vehicle steering very easy as the driver does not have to put in much effort. Vehicle steering is not only required on a curved road but also while maneuvering on the busy traffic roads. The steering system allows the vehicle to be guided, i.e. to be turned left or right. Figure 1.3 shows a simplified diagram of the steering system.

## 17. Braking System

Brakes are required for slowing down or stopping a moving vehicle. The braking system is essential for the safety of passengers, and passers-by on roads. The braking system may be operated mechanically or hydraulically. 95 per cent of the braking systems in use today are of the hydraulic type.

All brakes consist of two members, one rotating and the other stationary. There are various means by which the two members can be brought in contact, thus reducing the speed of the vehicle. Figure 1.4 shows the simplified layout of a hydraulic braking system.

The major components of the braking system are: brake pedal, master cylinder, wheel cylinders, brake drum, brake pipe, brake shoes, brake packing plant and linkages. As the load on the vehicle

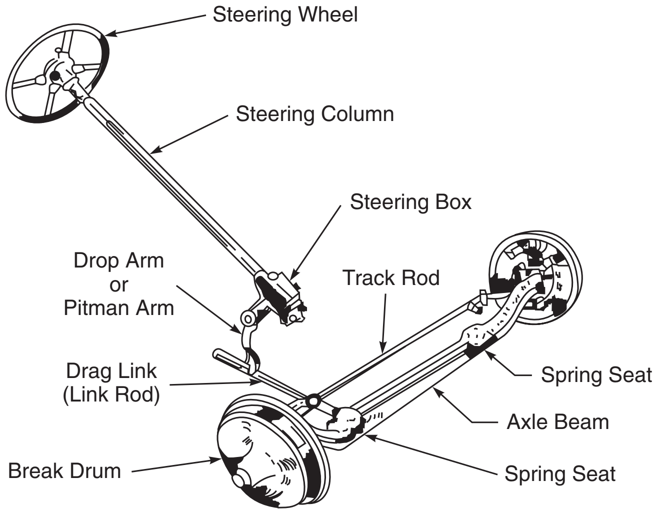



**Fig. 1.3** Steering System

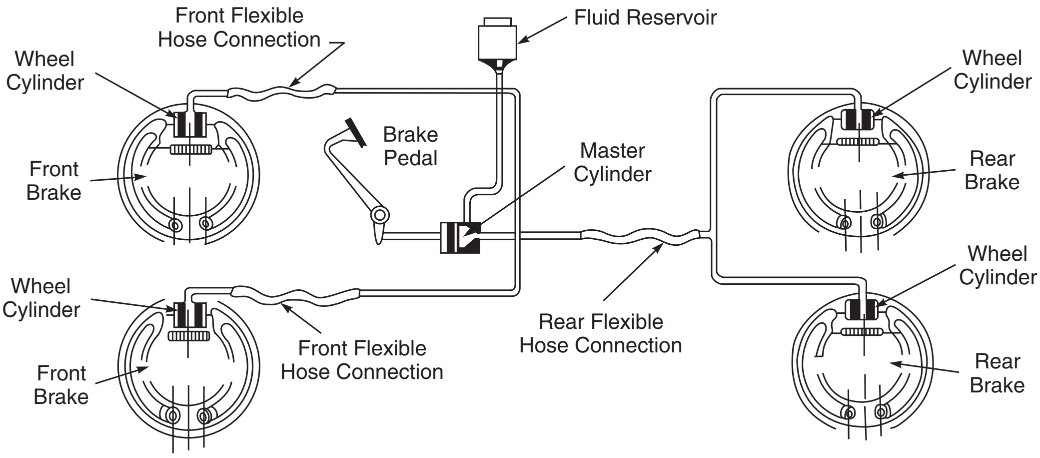



**Fig. 1.4** Hydraulic Brake System

and the vehicle speed has increased according to recent trends, in modern days, the importance of the brake system has also increased and power brakes are now being preferred. Power brakes utilize vacuum and air pressure to provide most of the brake-applying effort.

## 18. The Car Body

The main purpose of the bodywork is to provide accommodation for the driver and passengers, with suitable protection against wind and weather. The degree of comfort provided depends upon the type of car and its cost.

The body on the first automobiles was little more than a platform with seats attached. It gradually developed into a closed compartment complete with roof and windows. The modern automobile body is constructed of sheet steel formed to the required shape in giant punch presses. Most of the body components are welded together to form a light rattle-free unit.

Automobiles may also be classed on the basis of their body style (Fig. 1.5).

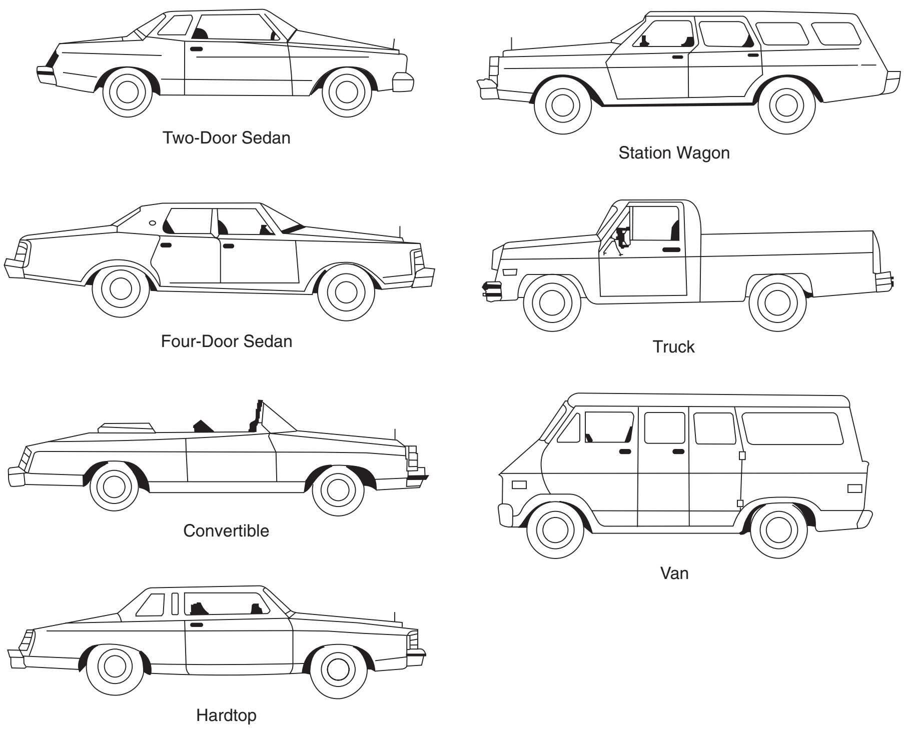



**Fig. 1.5** Automobile Body System

## 19. Accessories

The modern automobile uses a wide variety of accessories to make driving safer and more comfortable. Typical examples are self-starter driving and signalling lights such as headlights, tail lights, brake lights, parking lights, windshield wipers, horn, indicators, radio, heating and air conditioning system, power steering, etc.

## 1.8 MANUFACTURERS OF MOTOR VEHICLES IN INDIA

In India we have the following vehicles and engines being manufactured at present.

### 1. Passenger Cars

| | |
|---|---|
| 1. Premier Automobiles Ltd., Bombay | Fiat, NE 118, Peugeot 309 |
| 2. Hindustan Motors Ltd., Calcutta | Ambassador, Contessa |
| 3. Maruti Udog Ltd., Gurgaon | Maruti 800, Omni 800, Gypsy, Maruti 1000 cc, Maruti Zen, Maruti Esteem |
| 4. Standards Motor Products of India Ltd., Madras | Standard 1000, Standard 2000 |
| 5. Sipani Automobiles | Dolphin |
| 6. Mahindra & Mahindra Ltd., Bombay | Jeep Universal (Petrol & Diesel) |
| 7. Telco, Poona | Indica (Petrol & Diesel) |
| 8. Hyundai Motor India Ltd. | Santro (Petrol & Diesel) |
| 9. Daewoo Motor India Ltd. | Matiz |

### 2. Commercial Vehicles (Light Duty Vehicles)

| | |
|---|---|
| 1. Allwyn Nissan | Cabstar |
| 2. Hindustan Motors Ltd., Calcutta | Trekkar Petrol and Diesel and 1 ton portor |
| 3. Bajaj Tempo Ltd., Poona | Tempo Janseat-3 wheels and Tempo Viking and Matador- 4wheels. |
| 4. DCM Toyota | DCM Toyota Dyna |
| 5. Swaraj Mazda | T-3500 |
| 6. Standard Motors, Madras | Standard-20 Commercial vehicle |
| 7. Premier Automobiles Ltd., Bombay | LD-170 N |
| 8. Mahindra &Mahindra Ltd., Bombay | FC-160 P(Petrol), FJ 460 D (Diesel)& NC 665 DP (Diesel) |
| 9. Telco, Poona | Telco 407 |

### 3. Heavy Duty Vehicles

| | |
|---|---|
| 1. Tata, Engg. Locomotive Co., Jamshedpur | Tata Trucks & Buses in the range of 5 to 9 tonnes and 3- axle 10 tonnes Dumpers. |
| 2. Ashok Leyland Ltd., Madras | Comet Bus & Trucks and Beaver Hipod Jump Trucks in the range of 5 to 16-tonnes. |
| 3. Hindustan Motors Ltd., Calcutta | Hindustan Truck and Buses in the range of 5, $7\frac{1}{2}$ and 12 tonnes. |
| 4. Premier Automobiles Ltd., Bombay | Dodge and Fargo Trucks and buses |

### 4. Motor Cycles and Scooters

| | |
|---|---|
| 1. Enfield India Ltd., Madras | Bullet 350 cc Mini Bullet 198 cc |
| 2. Ideal Jawa (India) Pvt. Ltd., Mysore | Yezdi 250 cc and colt 60 cc. |

| | |
|---|---|
| 3. Escorts Ltd., Faridabad | Rajdoot 350 cc, 175 cc and Yamaha Rx 100. |
| 4. Hero-Honda | Hero-Honda (CD-100) |
| 5. TVS-Suzuki, Madras | TVS-Suzuki AX 100 |
| 6. Bajaj Auto Ltd., Bombay | Bajaj 150 cc., Bajaj Chetak, Bajaj Super, KB-700 |
| 7. A.P. Scooters Ltd., Hyderabad | Vespa PL-170 |
| 8. Kinetic Honda, Pithampur, Indore | Kinetic Honda |
| 9. Lohia Machine, Kanpur | Vespa XE, Vespa-NV |
| 10. Kelvinator, India | Avanti XE 100 cc |
| 11. Maharashtra Scooters | Priya 150 cc |

## 5. Mopeds

| | |
|---|---|
| 1. Enfield India Ltd., Madras | Silver plus 50 cc and Explorer 50 cc |
| 2. Kelvinator India | Avanti vip 2 and vip 3 |
| 3. Kinetic Engg. Pvt. Ltd., Poona | Luna Spark, Kinetic Spark and Kinetic Swift |
| 4. Kirloskar Chatge Patil, Kolhapur. | Pizzaz and Laxmi |
| 5. Majestic Auto | Hero Majestic |
| 6. Shree Chamundi | Sportif |
| 7. Sundaram Clayton | TVS |

## 6. Tractors and Three Wheelers

| | |
|---|---|
| 1. Eicher Tractors Ltd., Faridabad | Eicher Tractors |
| 2. Escorts Ltd., Faridabad | Escorts 3036,3350 and Junior Escorts |
| 3. Escorts Tractors Ltd., New Delhi | Ford Tractors 3600 |
| 4. Gujarat Tractor Corpn. Ltd., Baroda | Hindustan HWD 50 |
| 5. HMT, Pinjore | Zetor 2511, 3511, 4511 & 5711, 5911 |
| 6. Mahindra & Mahindra, Bombay | International B 275, 444 & 500 |
| 7. Punjab Tractors, Mohali. | Swaraj 720, 724, 735 and 855 |
| 8. Tractors & Farm Equipment Ltd | Massy Ferguson Tractors-MF 1035, Delux 245 |
| 9. Bajaj Auto Ltd., Pune | Tempo 3 wheeler |
| 10. Automobile Products of India | Auto rickshaw Ltd., Bombay |

**Table 1.1** Technical Details of Various Indian Vehicles

| *Name of vehicle* | *Engine* | | | | | | *Weight (kg)* | *Fuel tank capacity (litre)* |
|---|---|---|---|---|---|---|---|---|
| | *No. of cylinder and arrangement* | *Capacity (cc)* | *Maximum output* | *Maximum torque* | *Bore x stroke (mm)* | *Compression ratio* | | |
| Ambassador (Petrol) | 4 in-line | 1817 | 75 HP @ 5000 rpm | 13.8 kgm @ 3000 rpm | 84 x 82 | 8.5 : 1 | 1104 | 42 |
| Ambassador (Diesel) | 4 in-line | 1489 | 36 HP @ 4000 rpm | 8.5 kgm @ 2250 rpm | 73 x 88.9 | 23 : 1 | 1200 | 54 |

*Contd.*

*Contd.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Fiat (Padmini Premier) | 4 in-line | 1089 | 47.5 BHP @ 5000 rpm | 8.0 kgm @ 3000 rpm | 68 x 75 | 7.3 : 1 | 1050 | 38.25 |
| Maruti 800 | 3 in-line | 796 | 39.5 BHP @ 5500 rpm | 6 kgm @ 3000 rpm | 68.5 x 72 | 8.7 : 1 | 910 | 27.165 |
| Maruti Gypsy | 4 in-line | 970 | 68 BHP @ 5500 rpm | 7.5 kgm @ 3000 rpm | 65.5 x 72 | 8.8 : 1 | 1450 | 40 |
| Mahindra Jeep (CJ3B) | 4 in-line | 2199 | 72 BHP @ 4000 rpm | 15.7 kgm @ 2000 rpm | 79.37 x 111.12 | 7.4 : 1 | 1043 | 40 |
| Maruti Zen | 4 in-line | 993 | 50 BHP @ 6500 rpm | 7.2 kgm @ 4500 rpm | 72 x 61 | 8.8 : 1 | 910 | 35 |
| Daewoo Matiz | 3 in-line | 796 | 52 BHP @ 6000 rpm | 7.3 kgm @ 3500 rpm | 68.5 x 72 | 8.5 : 1 | 800 | 35 |
| Hyundai Santro | 4 in-line | 999 | 55 PS @ 5500 rpm | 8.4 kgm @ 2500 rpm | 66 x 73 | 8.9 : 1 | 776 | 35 |
| Telco Indica (Petrol) | 4 in-line | 1405 | 60 PS @ 5500 rpm | 10.5 kgm @ 2500 rpm | 75 x 95 | 9 : 1 | 980 | 37 |
| Telco Indica (Diesel) | 4 in-line | 1405 | 53.5 PS @ 5000 rpm | 8.5 kgm @ 2500 rpm | 75 x 95 | 22 : 1 | 980 | 37 |
| Fiat Uno | 4 in-line | 999 | 45 PS @ 5250 rpm | 7.2 kgm @ 3500 rpm | 70 x 64.9 | 9 : 1 | 795 | 35 |
| Maruti Esteem (MPFI Engine) | 4 in-line | 1298 | 85 BHP @ 6000 rpm | 106 Nm @ 3000 rpm | 74 x 75.5 | 960.2:1 | 890 Kg | 40 |
| Maruti Wagon R | 4 in-line | 1061 | 62 BHP @ 6000 rpm | 8.4 Kgm @ 3500 rpm | 68.5 x 72 | 9.2 : 1 | 810-840 Kerb Weight | 35 |
| Maruti Alto (Lx) | 3 in-line | 796 | 45 BHP @ 6000 rpm | 62 Nm @ 3000 rpm | 68.5 x 72 | 9.260.2:1 | 740 Kg | 35 |
| Maruti Alto (Vx 1.1) | 4 in-line (MPFI Engine) | 1061 | 62 BHP @ 6000 rpm | 82 Nm @ 3500 rpm | 68.5 x 72 | 960.2:1 | 750 Kg | 35 |
| Maruti Baleno | 4 in-line (MPFI Engine) | 1590 | 94 BHP @ 6000 rpm | 132 Nm @ 3000 rpm | 75 x 90 | 960.2:1 | 975 Kg | 51 |

**Table 1.1** (Contd.)

| *Name of vehicle* | *Transmission* | | *Steering* | | *Brakes* | *Tyre size* |
|---|---|---|---|---|---|---|
| | *Type* | *Gear box* | *Type* | *Turning radius (M)* | | |
| Ambassador (Petrol) | Manual | Five speed all synchromesh | Rack & pinion | 5.4 | Drum on all four wheels | 5.90 x 15-6PR |
| Ambassador (Diesel) | Manual | Four speed synchromesh on 2nd , 3rd and 4th | Rack & pinion | 5.4 | Drum on all four wheels | 5.90 x 15-6 PR |

*Contd.*

*Contd.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Fiat (Padmini Premier) | Manual | Four speed synchromesh on 2nd , 3rd and 4th | Worm and roller | 5.25 | Drum on all four wheels | 5.20-14 |
| Maruti 800 | Manual | Four speed all synchromesh | Rack & pinion | 4.4 | Disc in front wheels and drum on rear wheels | 4.50-12-4 PR<br>4.50-12-6 PR |
| Maruti Gypsy | Manual | Four speed all synchromesh | Rack & pinion | 5.7 | Disc in front wheels and drum on rear wheels | F78 - 15 |
| Mahindra Jeep (CJ3B) | Manual | Three speed synchromesh on 2nd, and top | Worm and roller | 5.3 | Drum on all four wheels | 6.00-16 |
| Maruti Zen | Manual | Five speed all synchromesh | Rack & pinion | 4.5 | Disc in front wheels and drum on rear wheels | 145/70 R13 |
| Daewoo Matiz | Manual | Five speed all synchromesh | Rack & pinion power assisted | 4.5 | Disc in front wheels and drum on rear wheels | 145/70 R13 |
| Hyundai Santro | Manual | Five speed all synchromesh overdrive on 4th and 5th | Rack & pinion power assisted | 4.4 | Disc in front wheels and drum on rear wheels | 155/70 R13 |
| Telco Indica (Petrol) | Manual | Five speed all synchromesh with overdrive on five | Rack & pinion power assisted | 4.9 | Disc in front wheels and drum on rear wheels | 155/70 R13 |
| Telco Indica (Diesel) | Manual | Five speed all synchromesh with overdrive on five | Rack & pinion power assisted | 4.9 | Disc in front wheels and drum on rear wheels | 155/70 R13 |
| Fiat Uno | Manual | Five speed all synchromesh with overdrive on five | Rack & pinion | 4.7 | Disc in front wheels and drum on rear wheels | 145/80 R13 |
| Maruti Esteem | Manual<br>Automatic | 5 speed all synchromesh, 1 reverse<br>3 speed automatic, 1 reverse | Rack and Pinion | 4.8 | Booster assisted ventilated disc in front wheels and booster assisted drum on rear wheels | 155/80 R13 |
| Maruti Wagon R | Manual | 5 speed all synchromesh | Electronic power steering | 4.6 | Booster assisted disc in front | 145/70 R13 |

*Contd.*

*Contd.*

| | | | | | | |
|---|---|---|---|---|---|---|
| | | with two overdrive gears | | | wheels and booster assisted drum on | |
| | Automatic | 3 speed | | | rear wheels. | |
| Maruti Alto (LX, VX 1.1) | Manual | 5 speed all synchromesh | Power steering | 4.6 | Booster assisted disc in front wheels and booster assisted drum on rear wheels. | 145/80 R12 |
| Maruti Baleno | Manual | 5 speed all synchromesh 1 reverse | Rack and pinion with hydraulic power assisted | 4.9 | Ventilated disc in front wheels and drum on rear wheels | 165/80 R13 |

## Review Questions

1. Describe briefly the development of the automobile industry in India.
2. What are the main components used in an automobile?
3. Give the various functions of the suspension system of a vehicle.
4. Differentiate between independent and rigid suspension systems.
5. What is power train and why is it essential in an automobile?
6. Draw a diagram of the steering system and label the various parts.
7. Why is a brake system essential in an automobile?
8. Draw and explain the layout of a hydraulic brake system?
9. What is the purpose of a differential in the transmission system?
10. Write short notes on
    (i) Clutch
    (ii) Car body
    (iii) Lubrication system

# 2 Automobile Engines

## Objectives

After studying this chapter, you should be able to:

- Describe the classifications of automobile engines.
- State the use of different types of engines.
- Write the advantages and disadvantages of vertical and horizontal engines.
- Give reasons for using single-cylinder two-stroke air-cooled petrol engine on two wheelers.
- Give reasons for using multi-cylinder diesel engine for commercial vehicles.

## 2.1 INTRODUCTION

Automobiles are designed keeping in view the requirements of users. Significantly, the engines used in automobiles must be light in weight and their fuel consumption must be minimum. These are the two main considerations which have led engineers to develop various types of automobile engines.

## 2.2 CLASSIFICATION OF AUTOMOBILE ENGINES

Automobile engines are classified on the following basis.

### 1. Number of Cylinders

An engine may be a single-cylinder engine or a multi-cylinder engine. In a single-cylinder engine there is only one cylinder, whereas in a multi-cylinder engine there are more than one cylinders. The pistons of all the cylinders are connected to the common crankshaft. Therefore engines may be:

| | |
|---|---|
| • Single-cylinder | Cylinder may be vertical or horizontal |
| • Multi-cylinder | Cylinders may be vertical or inclined to vertical plane. |

### 2. Cylinder Arrangement

**(i)** ***In-line Cylinder Engine*** The in-Line cylinder engine is a multi-cylinder engine, with all the cylinders arranged in one straight line. Each cylinder has an independent crank.

**(ii)** ***V Cylinder Engine or V Engine*** The V cylinder engine has two cylinders inclined at 90° to each other as shown in Fig. 2.1. The connecting rods are connected to a common crank pin. There is a common crank for both cylinders.

**(iii)** ***V-8 Engine*** In the V-8 engine design there are two blocks inclined at 90° to each other and each block has four cylinders.

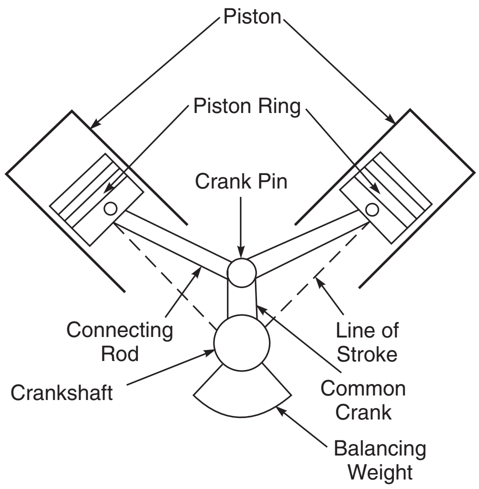



**Fig. 2.1** V Engine

## 3. Valve Arrangement in Cylinder Head Assembly

**(i)** ***T-head Engine*** In the T-head engine the valves are arranged as shown in Fig. 2.2. The suction valve (SV) and the exhaust valve (EV) are on the cylinder block in opposite directions.

**(ii)** ***F-head Engine*** In the F-head engine one valve is in the cylinder block and the other valve is in the cylinder head as shown in Fig. 2.3.

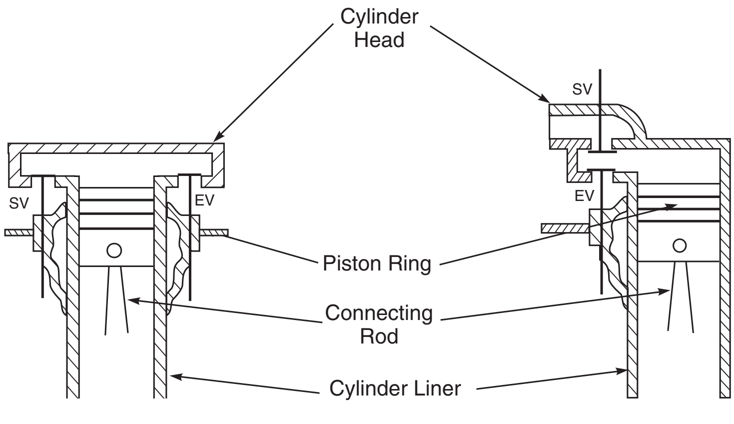



**Fig. 2.2** T-Head

**Fig. 2.3** F-Head

**(iii)** ***L-head Engine*** In the L-head engine the suction and exhaust valves are arranged side by side in the cylinder block as shown in Fig. 2.4.

**(iv)** ***I-head Engine*** In the I-head engine the suction and exhaust valves are arranged in the cylinder head as shown in Fig. 2.5.

**(v)** ***Overhead Engine*** In the overhead engine the suction and exhaust valves are arranged in the cylinder head. The cylinder head has a hemispherical shape as shown in Fig. 2.6. The difference between the I-head and overhead valve engines is that the I-head valves are actuated by push rods whereas the overhead valves are actuated by the cams located above the cylinder head.

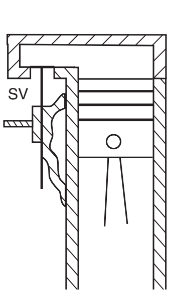



**Fig. 2.4** L-Head

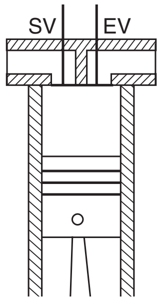



**Fig. 2.5** I-Head

## 4. Cooling Methods

**(i) *Air-cooled Engines*** Air-cooled engines have fins to radiate heat into the surrounding air. The fins are made triangular in shape as they increase the cooling surface area. These fins are made of aluminium, which is a good conductor of heat. Air-cooled engines run at higher temperatures because air is not a good conductor of heat. Figure 2.7 shows an air-cooled engine.

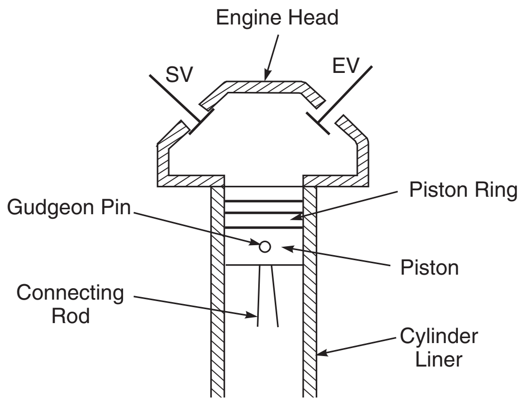



**Fig. 2.6** Overhead Engine

**(ii) *Water-cooled Engines*** Water-cooled engines require circulation of water. All automobile engines, which are water-cooled, are fitted with radiators as shown in Fig. 2.8. The radiator offers resistance to the flow of air through the passages in between the small diameter tubes carrying hot water. Therefore

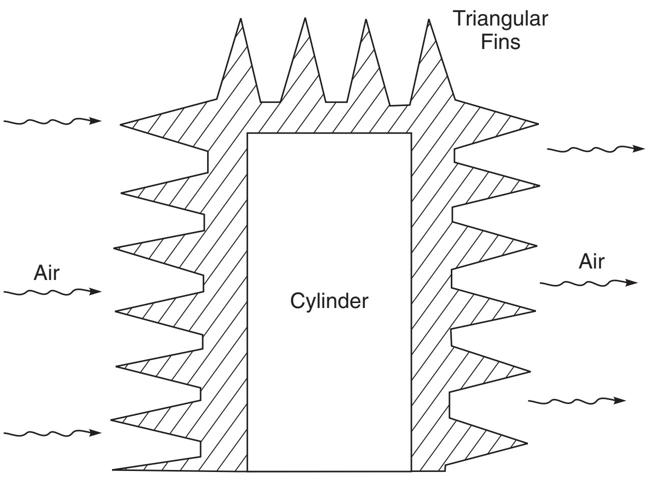



**Fig. 2.7** Air Cooled Cylinder

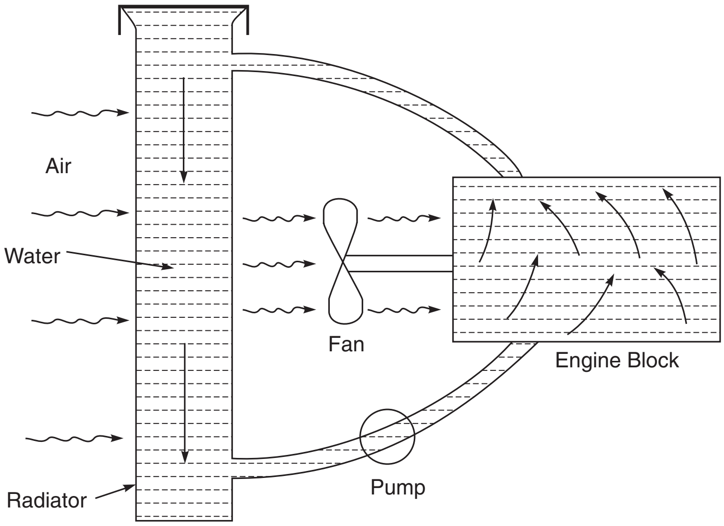



**Fig. 2.8** Water Cooling System (Schematic)

an induced draught fan is provided at the back of the radiator. This fan creates the pressure difference required to get an increased flow of air. Similarly, to get pressure difference and to overcome the resistance in the water flow at the jackets of the engine, a water pump is provided which draws water from the radiator and forces it into the water jacket of the engine. Water is not allowed to rise to a higher temperature, as at higher temperatures scale formation takes place. Scale formation causes local heating due to poor cooling as scales are bad conductor of heat. Such local heating may lead to detonation, which may damage engine parts. (Refer to Chapter 9 for more details on detonation).

### 5. Fuel Used

**(i) *Gasoline Engine*** In the gasoline engine, gasoline (petrol) is used as fuel. A mixture of gasoline and air is prepared outside the cylinder and an electric spark plug is used to initiate combustion of the compressed charge.

**(ii) *Diesel Engine*** The diesel engine utilizes a compressed mixture of air and diesel prepared inside the cylinder as fuel. The heat of compression is utilized to initiate combustion of the mixture.

**(iii) *Gas Engine*** In the gas engine combustible gases are used as fuel. These engines are not commonly used in automobiles.

### 6. Thermodynamic Cycles

Engines may be classified as following based on the thermodynamic cycle used:

(i) Constant volume combustion cycle engine, which is also called *Otto cycle engine.*
(ii) Constant pressure combustion cycle engine, which is also called *Diesel cycle engine.*
(iii) *Mixed cycle engine* which has partial combustion at constant volume and partial combustion at constant pressure.

### 7. Mechanical Cycles

**(i) *Two-stroke Cycle Engine*** The two-stroke engine its completes thermodynamic cycle in two strokes of the piston (one revolution of the crank).

**(ii) *Four-stroke Cycle Engine*** The engine which completes its thermodynamic cycle in four strokes of the piston (two revolutions of the crank) is a four-stroke cycle engine.

### 8. Ignition System

**(i) *Spark Ignition Engine*** A spark ignition engine is either a gasoline engine or a gas engine. The electrical energy required to produce spark in the spark plug is obtained either from a battery or a magneto.

**(ii) *Compression Ignition Engine*** Compression ignition engines are diesel engines in which air is highly compressed to raise its temperature and initiate combustion when diesel fuel is injected.

### 9. Lubrication Systems

Three systems for lubricating the moving engine parts are used:

(i) Petrol lubrication system
(ii) Wet sump lubrication system
(iii) Dry sump lubrication system

Petrol lubrication system is also known as mist lubrication system. This system is used in two-stroke cycle gasoline engines. The wet sump lubrication system is of two types: *splash lubrication* and *pressure lubrication* system. These systems are used in four-stroke cycle automobile engines. Dry sump lubrication system is used in heavy-duty engines.

## 2.3 USE OF ENGINES

1. Two-stroke cycle gasoline engines with petrol lubrication are used in light duty automobiles like mopeds, scooters etc.
2. Two-stroke cycle diesel engines with pressure lubrication are used in medium duty automobiles like tempos etc.
3. Four-stroke cycle gasoline and diesel engines with splash and pressure lubrication are used in heavy duty automobiles like trucks, buses, delivery vans etc.
4. Cars are provided with four-stroke gasoline engines with splash and pressure lubrication systems.
5. The inline engine is vertical, i.e. the stroke of the pistons is vertical. Such inline vertical engines are used in cars, buses, trucks etc.
6. V-engines have cylinders at 90° and are used in heavy duty motor cycles, which are designed for long run.
7. Single-cylinder horizontal engines are used in scooters and mopeds. This engine is so located that the cylinder head is towards the front of the scooter or moped.

## 2.4 MERITS AND DEMERITS OF VERTICAL AND HORIZONTAL ENGINES

Horizontal and vertical engines are identified by the line of stroke. If the line of stroke of an engine piston is vertical, then it is a vertical engine. The line of stroke of the horizontal engine is horizontal.

In a reciprocating type of engine, primary and secondary forces of the reciprocating parts exist. These forces act along the line of stroke and depend on the crank position. These primary and secondary forces combine together and give maximum force to the engine crank when the crank is at TDC. Note that the primary and secondary forces increase with the square of the crank rpm.

### 1. Merits of Vertical Engine

The vertical engine has vertical stroke of the piston. The crankcase is at the bottom and stores lubricating oil for splash lubrication (Refer Chapter 10).

The lubricating oil which dribbles from the bearings and other engine parts is collected in the crankcase and then reused after filtering.

The weight of the piston is carried by the crank. Therefore the weight of the piston does not wear the cylinder liner during motion.

### 2. Demerits of Vertical Engine

In a vertical engine, the primary and secondary forces caused due to inertia of the reciprocating parts, combine together and produce tensile dynamic stresses on the foundation bolts. This gives vertical vibrations to the vehicle chassis frame, which can be felt by the passengers sitting in the vehicle. Also, the foundation bolts may get fatigue failure.

### 3. Merits of Horizontal Engine

Since the stroke of the engine piston is horizontal in a horizontal engine, the inertial forces of the reciprocating parts, i.e. primary and secondary forces combine together and give an impulse to the chassis frame of the vehicle. If the cylinder head is towards the front of the vehicle, then a driving impulse is obtained from the engine.

It should be clear that when the piston is at BDC, then the impulsive force is the difference (not sum) between the primary and the secondary forces. When the piston is at TDC, both these forces combine together and increase the impulsive force. The net result is that the excessive impulsive force slides the engine forward on a smooth floor, when the running engine is placed on the floor. Thus an engine having horizontal stroke tends to push forward the moped or the scooter by its impulsive forces.

### 4. Demerits of Horizontal Engine

The crankcase cannot be used for storing lubricating oil for splash lubrication. Therefore petrol lubrication system is used in the two-stroke cycle engine and pressure lubrication system is used in four-stroke cycle horizontal engine.

In the horizontal engine, weight of the piston is carried by the cylinder liner. This causes excessive wear at the lower side of the piston and cylinder liner where the cylinder liner gives support to the piston.

The lubricating oil, which dribbles from the bearings does not return to the crank case but is thrown out by centrifugal forces. This cause more consumption of lubricating oil in a horizontal engine.

## 2.5 REASONS FOR USING SINGLE-CYLINDER TWO-STROKE AIR-COOLED PETROL ENGINE ON TWO-WHEELERS

Following are the reasons:

1. A two-stroke cycle engine is more compact than a four-stroke cycle engine for the same amount of power handled. Therefore a two-stroke cycle engine is preferred over a four-stroke cycle engine in a two-wheeler as it requires less space.
2. Two-wheelers, i.e. scooters, mopeds and motor cycles, are light duty vehicles to carry one or two passengers. A single cylinder engine develops enough power to carry such loads.
3. A petrol engine runs at a lower compression ratio than a diesel engine. Therefore, the weight—power ratio of a petrol engine is less than a diesel engine.
4. A lighter engine (two-stroke cycle petrol engine) makes the vehicle (two-wheeler) lighter. Hence for the same tractive force, a two-wheeler gives higher acceleration.
   (Force = mass $\times$ acceleration)
5. An air-cooled engine does not require water, radiator and a water circulating pump. Therefore the weight-power ratio of an air-cooled engine is decreased.

From the reasons stated, it is seen that an engine required for a two-wheeler is compact in size, lighter in weight, and capable of giving higher acceleration and generating sufficient power to carry load.

However two-stroke cycle petrol engines do not give higher thermal efficiency than a four-stroke cycle petrol engine. This means that a two-stroke cycle petrol engine consumes more petrol per horse power hour than a four-stroke cycle engine. However the total fuel consumption per 100 kilometres is lesser in case of two-stroke engines because work done is lesser.

(Work done = Force $\times$ Distance moved. Force required to propel a two-wheeler is very small being light in weight).

## 2.6 REASONS FOR USING MULTI-CYLINDER DIESEL ENGINE FOR COMMERCIAL VEHICLES

Trucks and buses are commercial vehicles and use multi-cylinder diesel engines. The reasons for the use of multi-cylinder engines are:

1. A multi-cylinder engine develops more power. A commercial vehicle needs greater force to propell the vehicle because it carries greater loads.
2. A diesel engine runs at a higher compression ratio (about 22) and at such high compression ratios the thermal efficiency of a multi-cylinder engine is higher than an Otto cycle petrol engine. This means that a diesel engine gives better fuel economy per kilometre.
3. A multi-cylinder engine has a greater swept volume and also its surface volume ratio is increased. This results in greater engine output (power) and also better cooling which is essential for the protection of engine parts like cylinder head, cylinder liner, piston etc. The lubricating oil is also prevented from partial oxidation.
4. In a multi-cylinder engine, vibrations are decreased due to balancing of the crank.

## 2.7 MERITS AND DEMERITS OF TWO-STROKE AND FOUR-STROKE CYCLE ENGINES

### 1. *Merits of Two-Stroke Cycle Engines*

(i) Two-stroke cycle engines are compact and occupy less space for the same output.

(ii) A lighter flywheel is required in a two-stroke cycle engine.
(iii) Its weight to power ratio is less.

**2. *Demerits of Two-Stroke Cycle Engines***

(i) Its specific fuel consumption is more, i.e. it consumes more fuel per horsepower hour. This also means that its thermal efficiency is less than a four-stroke cycle engine.
(ii) A two-stroke cycle engine runs at higher temperature because of poor cooling. This is due to the fact that only one cycle is completed per revolution (crank rotation) and less time is available for cooling. This factor may lead to detonation in a two-stroke cycle petrol engine.

**3. *Merits of Four-Stroke Cycle Engines***

(i) The specific fuel consumption of a four-stroke cycle engine is less, i.e. it gives better economy in fuel consumption. This also means that its thermal efficiency is more than a two-stroke cycle engine.
(ii) It can be supercharged.
(iii) It runs cooler because it gets sufficient time (three strokes, i.e. 540° crank rotation) for cooling thus preventing detonation.

**4. *Demerits of Four-Stroke Cycle Engines***

(i) The weight to power ratio of a four-stroke cycle engine is greater than a two-stroke cycle engine.
(ii) It needs a heavier flywheel to minimise fluctuations in cyclic speed.
(iii) It occupies more space because it has a larger cylinder diameter for the same output (power).

## 2.8 ADVANTAGES OF A MULTI-CYLINDER ENGINE FOR THE SAME POWER

If a single cylinder and a multi-cylinder engine develop the same power, then it indicates that their stroke volumes (swept volumes) are also the same. For the same crank speed and the same piston stroke, the single cylinder engine has a larger cylinder bore. A larger cylinder bore leads to two disadvantages:

- Poor cooling of the cylinder walls.
- Increased vibrations and stresses. The weight of the piston in the single cylinder engine increases primary and secondary forces on the engine bearings. These forces are not balanced and cause vibrations.

Therefore the advantages of a multi-cylinder engine are:

1. Temperature stresses are reduced as the multi-cylinder engine has more cooling surface area due to smaller cylinder bore.
2. The intensity of vibration is sufficiently reduced as the primary and secondary forces are balanced.

## Review Questions

1. On what basis are automobile engines classified?
2. List the types of common cylinder arrangements in automobile engines.
3. Describe an I-head valve arrangement.
4. Describe an overhead valve arrangement.
5. List the merits and demerits of vertical and horizontal engines.
6. What are two ways of cooling an engine? Explain briefly.
7. Differentiate between two-stroke and four-stroke cycle engines?
8. List the advantages of a multi-cylinder engine.
9. Why are single-cylinder two-stroke air-cooled petrol engines used in two-wheelers?
10. Give reasons for using multi-cylinder diesel engines in commercial vehicles.

# 3

# Engine Construction

**Objectives**

After studying this chapter, you should be able to:

- List the main components of an engine.
- Explain the construction and functions of cylinder block, crankcase, and cylinder head.
- Describe the classification and constructional features of the parts of piston assembly.
- Explain the construction and function of connecting rod and its bearing.
- Describe the function of camshaft.
- Explain the construction and function of timing gear.
- Describe the construction and function of valve.
- Give reason for using sodium cooled valve for high performance engine.
- Explain valve timing and port timing.
- Know the construction and function of flywheel.
- Explain the construction and function of manifolds.

## 3.1 INTRODUCTION

The reliability of an automobile engine depends on the proper construction of the engine components. The constructional details depend on the stresses and the function of the components.

Figure 3.1 shows the main components of an engine. The comparative data of the constructional features of engines in some Indian vehicles is provided in Table 3.1.

## 3.2 CYLINDER BLOCKS

All the major engine components, are installed on or in the engine block. These components including the cylinder bores, are machined very precisely. They must be thick enough to contain the pressure of the burning fuel mixture. A tight fit must be ensured between the cylinder base and the piston rings to enable the piston rings to seal the combustible gas. If the cylinder becomes oval due to wear some of the gas escapes through the piston rings. The gas which leaks through the piston rings is called blow-by (Fig. 3.2). Blow-by reduces the efficiency of an engine. The finishing on the cylinder walls also affects the ring seal. The cylinder walls are machined to provide a very

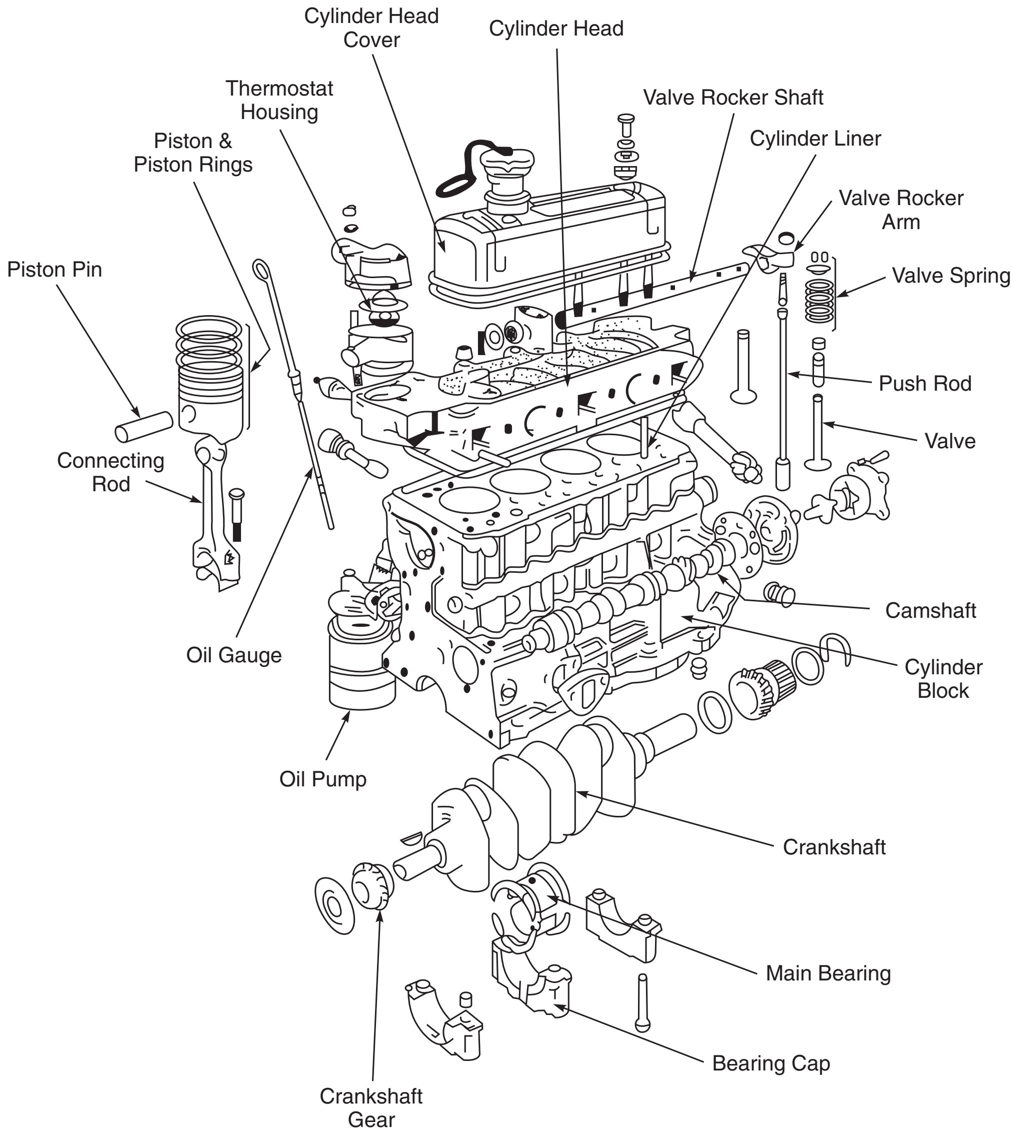



**Fig. 3.1** Main Components of an Engine

smooth finish. Special grinding stones produce small groves in the cylinder walls, which collect oil. These grooves help to lubricate the piston rings and piston skirts.

Previously, most cylinder blocks were made of cast iron or grey iron as the material was easy to machine. Aluminium pistons wear very well against cast iron cylinder walls. The main disadvantage of iron being is its weight, engine blocks are now being cast from lightweight aluminium. An aluminium block weighs much less than a cast iron block. An aluminium piston skirt rubbing against an aluminium cylinder wall wears very quickly. Most aluminium cylinder blocks are fitted with steel or ductile iron cylinder bore liners.

## 3.3 CYLINDER LINER

The cylinder liner is a sleeve in which the piston of an engine reciprocates. The life of a cylinder between its re-bores depends on two main factors:

(i) Abrasion, and (ii) Corrosion

Abrasion depends on the atmospheric condition and the efficiency of the air filter and oil filter. Dusty atmospheric air is more harmful as it increases abrasion in the cylinder.

Corrosion of the cylinder is caused due to the corrosive products of combustion, which are formed after burning of fuel with air. Corrosion is accelerated at low cylinder temperature due to acid bearing moisture on the cylinder walls.

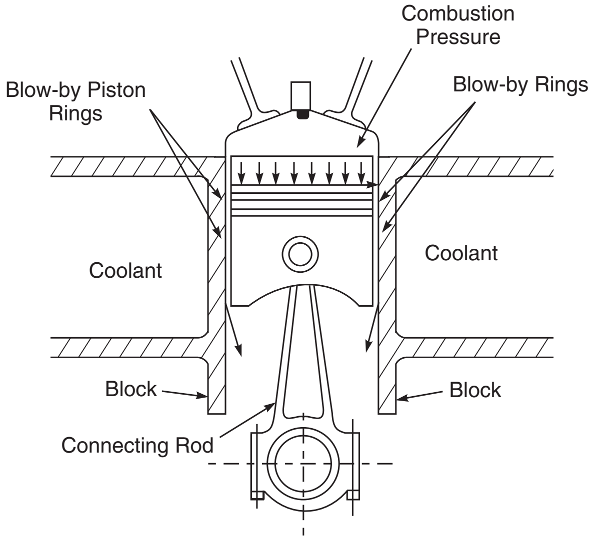



**Fig. 3.2** Blow-by in an IC Engine

The use of separate barrels or sleeves, which are known as cylinder liners, provides a long life to the cylinder. These cylinder liners are made of superior material and are fitted in the cylinder block. The liners are removable and can be replaced when worn or damaged. The liners should have good wear resistance and the ability to retain oil to lubricate the surface between the walls and the piston rings.

### Materials for Cylinder Liners

For cylinder liners nickel-chromium iron has been popularly used. The nickel-chromium iron used contains carbon 3.5%; manganese 0.6%; phosphorous 1.5%; sulphur 0.05%; silicon 2%; nickel 2%; and chromium 0.7%.

To increase the wear resistance, the liners are hardened by heating to 855°C–865°C for 30 to 40 minutes and then quenched in oil. By such heat treatment, the life of the liners is increased to three times as compared with grey iron or cast iron cylinders.

### Types of Liners

The cylinder liners or sleeves are of two types:

1. Dry liners
2. Wet liners

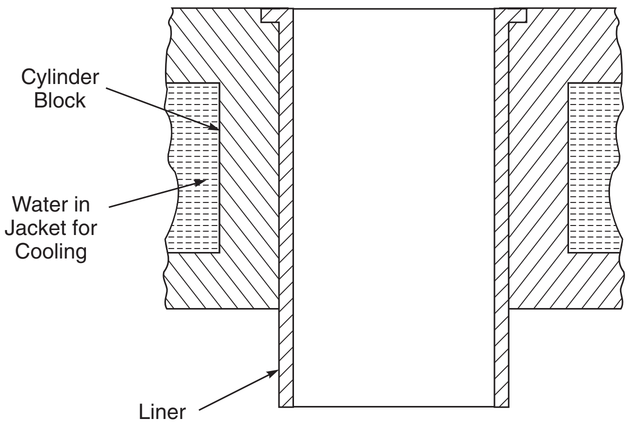



**Fig. 3.3** Dry Liner

**1. *Dry Liners*** Dry liners are made in the shape of a barrel having a flange at the top as shown in the Fig. 3.3.

The flange keeps the liner in position in the cylinder block. The liner fits accurately in the cylinder. The perfect contact of the liner with the cylinder block is necessary for the effective cooling of the liner. Also, the gas pressure, piston thrust and impact loading during combustion are resisted by the combined thickness of the liner and the cylinder. Therefore, dry liners are thinner having wall thickness varying from 1.5 mm to 3 mm and are used mostly for reconditioning worn liners. The dry liners are not in direct contact with cooling water.

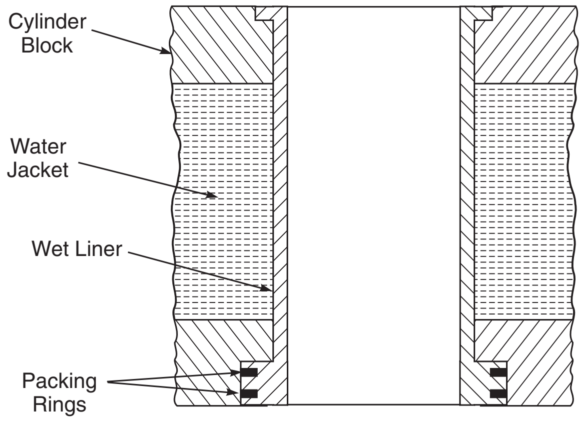



**Fig. 3.4** Wet Liner

**2. *Wet Liners*** Figure 3.4 shows a wet liner. A wet liner is so called because the cooling water comes in contact with the liner. This liner is provided with a flange at the top, which fits into the groove made in the cylinder block. To stop leakage of cooling water in the crankcase, the lower end of the wet liner is sealed with the help of sealing rings or packing rings.

As the wet liner has to withstand gas pressure, thrust and impact loading, the wall thickness of the liner is increased and is made more than that of the dry liner. Generally, the wall thickness of the wet liner ranges from 3 mm to 6 mm. The outside of the liner is coated with aluminium so that it is protected from rust. The wet liner is better cooled than the dry liner. It is easily removable when it is worn-out or damaged.

### Comparison of Dry and Wet Liners

1. A wet liner can be easily replaced whereas a dry liner requires special tools because it is tight-fitted in the cylinder block.
2. A wet liner is properly cooled as it comes in direct contact with the cooling water, whereas a dry liner does not come in direct contact with the cooling water. Hence the working temperature of a dry liner is more than a wet liner.
3. A wet liner needs leak proof joints, so that the cooling water does not leak into the crankcase, whereas a dry liner has no such requirement.
4. A wet liner does not require accurate finishing on the outside, whereas a dry liner needs accurate finishing.
5. Finishing may be completed in a wet liner before assembly, whereas a dry liner needs finishing after assembly.

## 3.4 CRANKCASE

The crankcase supports the cylinders and the crankshaft and is an important structure in the internal combustion engine. It also functions like a housing and protects the engine parts against dust, water and splashing mud. The crankcase stores lubricating oil required for lubricating the engine parts.

The size of a crankcase is sufficiently large as it accommodates the revolving crankshaft with the connecting rod. Various accessories like carburettor, fuel pump, generator, water pump, air cleaner, starting motor, fan, oil filter, oil body of cooler, etc. are also mounted on the crankcase. The crankcase not only gives support to the engine parts and engine mountings, but also withstands the loads caused by piston thrust, gas pressure, primary and secondary forces and couples, etc. Therefore the crankcase must be strong to withstand these loads and pressures.

When the cylinder block and the crankcase are cast together in one unit, grey cast iron is used because it has rigidity, low cost and high wear resistance.

### Types of Crankcases

The cylinder block and the upper part of the crankcase form an integral cast. Thus a crankcase is usually divided into an upper and a lower section. The lower section is known as the 'oil pan' and acts as a reservoir for the storage of lubricating oil. The lubricating oil is splashed due to the rotation of the crank and is also pumped to the engine bearings, thus lubricating the various engine parts. For cooling the lubricating oil, fins or ribs are provided on the outside of the oil pan. These fins also increase the strength of the oil pan.

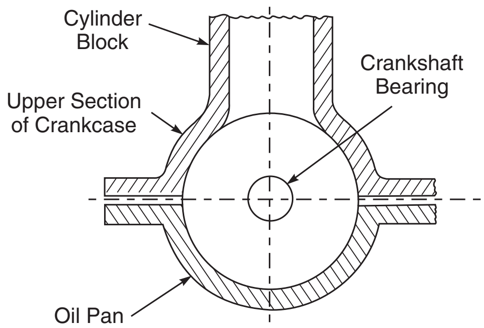



**Fig. 3.5** Crankcase

The joints between the upper section of the crankcase and the oil pan may be either on the level of the crankshaft axis or below this axis. In Fig. 3.5, the assembly of the upper section of the crankcase with the oil pan has been shown.

The main forces acting on a cylinder block are due to:

1. Gas pressure including force of explosion, and
2. Inertial forces due to reciprocating masses.

Both these forces act along the connecting rod, i.e. line of stroke. These forces tend to lift the cylinder blocks from the crankcase.

Therefore in the case of a single cylinder engine having crankcase joint on the axis of the crankshaft, resisting forces are induced in the threads of the retaining bolts used at the joints.

Note that the angularity of the connecting rod results in the horizontal forces on the cylinder walls and the crankshaft bearing. Decreasing the length of the connecting rod increases the side forces. In case of a multi-cylinder engine, the resulting stresses are divided between more number of bolts. In case of 90° V-type engines, the component of stresses are equally divided in vertical and horizontal directions. Therefore the crankcase is split through the crankshaft axis. Such assembly makes the crankcase lighter because the oil pan size is increased which is usually made of aluminium alloy.

To minimise the resisting forces in the bolts used in the crankcase joint, the upper section of the crankcase is further extended below the axis of the crankshaft. The extension is from 50 mm to 75 mm below the crankshaft. This decreases the size of the oil pan, but the crankcase rigidity is increased in the vertical direction. The upper section of the crankcase takes up the force of explosion, whereas the oil pan bolts take only inertial forces.

A four-stroke cycle engine needs a heavier flywheel than a two-stroke cycle engine. Therefore the crankcase of the four-stroke cycle engine is more robust than the two-stroke cycle engine. An engine following mixed cycle has a high compression ratio and large force of explosion and therefore needs a stronger crankcase.

## 3.5 CYLINDER HEAD

The space (volume) enclosed by the piston at TDC, the cylinder block and the cylinder head is known as the clearance volume. This is the combustion chamber. The design of combustion chamber is changed to improve the combustion quality of fuel. Different designs of combustion chambers have been considered in Chapters 5 and 6.

The various types of cylinder heads and the valve arrangements have been shown in Fig. 2.2 to 2.6. The cylinder heads of T-type and F-type are used with inferior fuels having lower octane number (Chapter 5) because these heads run at cooler temperatures. Since the quality of gasoline has now improved and its octane number has also increased, the cylinder heads of T-type and F-type are not in common use today. In modern automobile engines, cylinder heads of I-type and over-head valve type are commonly used. These cylinder heads reduce cooling losses and the engine efficiency is also increased.

Under the heading 'Types of Combustion Chambers' (in Chapter 5, para 5.6), different designs of cylinder heads have been considered.

## 3.6 GASKETS

The gasket is a piece of soft sheet or spongy sheet having similar holes and cuts as in the cylinder head and cylinder block so that the packing (gasket) placed between the cylinder block and cylinder head does not interfere with the flow of gases or water or bolts passed. The gasket prevents leakages and ensures tight fit joints. Sealing action is provided by the elastic deformation of the gasket material. The material of the gasket must be able to withstand high pressure and temperature.

### Types of Gaskets

The types of gaskets which are frequently used in automobile engines are:

**1.** ***Copper-asbestos Gasket*** In the copper-asbestos gasket, asbestos sheet is covered by thin copper plates on both sides so that the asbestos remains in combined form.

**2.** ***Steel-asbestos Gasket*** The steel-asbestos gasket has thin steel sheets on both sides covering the asbestos sheet.

**3.** ***Single Sheet Rigid or Corrugated Gasket*** Only a single sheet or corrugated sheet of soft metal like copper or lead, etc. is used in the single sheet rigid or corrugated gasket.

**4.** ***Stainless Steel Gasket*** In the stainless steel gasket a thin sheet of stainless steel is used. These gaskets are used as cylinder head gaskets between the cylinder block and the cylinder head. Usually, these gaskets are coated with a special varnish, which melts and seals the leakages when the cylinder head is hot.

**5.** ***Cork Gasket*** The cork gasket is used for the oil pan in the crankcase and rocker cover where high pressure on the gasket is not needed.

**6.** ***Rubber Gasket*** The rubber gasket is also used in place of the cork gasket in the crankcase holes.

## 3.7 PISTON

A piston of an internal combustion engine is in the form of an inverted bucket shape and it is free to slide in the cylinder barrel. The gas tightness is secured by means of flexible piston rings, which are in the grooves of the piston. These grooves are cut in the upper part of the piston.

A piston of an internal combustion engine serves three functions:

1. It forms a moveable wall of the combustion chamber.
2. It transmits turning force to the crankshaft via the connecting rod.
3. It functions like a crosshead and transmits side thrust, which is due to the angularity of the connecting rods, to the cylinder walls.

The piston must possess the following qualities:

1. It must be strong enough to withstand high pressure caused due to the combustion of fuel.
2. It must be very light in weight to have minimum primary and secondary forces, which are caused due to the inertia forces of the reciprocating masses. A light piston permits higher speed of the crank.
3. The piston material must be a good conductor of heat so that detonation is suppressed, and higher compression ratio is possible to get fuel economy.

It is interesting to know that an engine having a piston and cylinder head of aluminium alloy can be used at a compression ratio of 6.3 and it gives more power and fuel economy than a similar engine having a cast iron piston and cylinder head at a compression ratio of 5.3 as shown in Fig. 3.6. This is due to the improved thermal efficiency, which is due to the better thermal conductivity of aluminium alloy. Apart from the qualities mentioned previously, the piston must meet the following requirements:

1. The piston operation must not be noisy.
2. The piston must be of less coefficient of expansion.

It has been found by experiments that the maximum temperature produced is in the centre of the piston head, and the temperature decreases towards the edge of the piston head, and also decreases rapidly down side of the piston. Most of the heat is passed into the cylinder block at the ring belt, and some temperature drop takes place from the skirt.

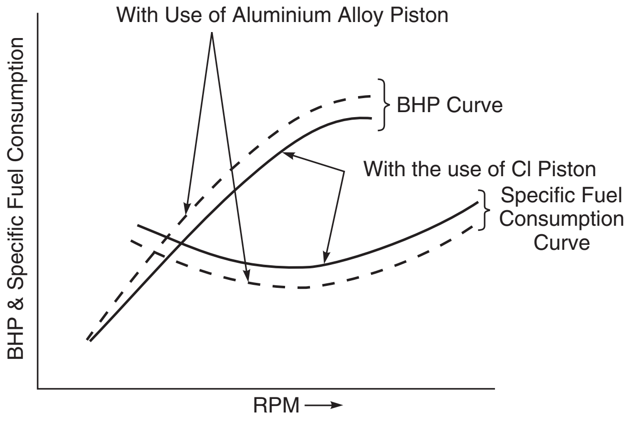



**Fig. 3.6** Variation of BHP and Sp. Fuel Consumption with the Use of Aluminium Alloy and CI Piston

In early years, cast iron pistons were used because of their strength and excellent wearing qualities. However, cast iron has lesser heat conductivity than aluminium alloy and consequently cast iron pistons run hotter than aluminium alloy pistons. Figure 3.7 shows the construction of a piston and the experimental results of piston temperature have been compared between cast iron pistons and aluminium alloy pistons.

In Fig. 3.7, an aluminium alloy piston with a 'T' slot skirt has been shown. 'A' is the head or crown of the piston. In this type of piston, the head grooves are cut to fit the piston rings 'B'. The piston skirt 'C' functions like a bearing and guiding surface in contact with the cylinder walls. In modern pistons, the length of the skirt is 0.75 to 0.8 times the piston diameter, and the overall length of the piston is from 1.0 to 1.1 times the piston diameter. It is seen that longer skirts do not reduce the rate of cylinder wear. However, piston slap is reduced in pistons with longer skirts because of the effective bearing surface provided. In Fig 3.7, 'D' indicates the bosses inside the skirt. These bosses are for fitting the gudgeon pin 'E' which is across the diameter of the skirt. There is an oil scraper ring 'F' which prevents excess oil from reaching the combustion chamber. In some modern pistons the oil ring is provided below the gudgeon pin or the piston pin.

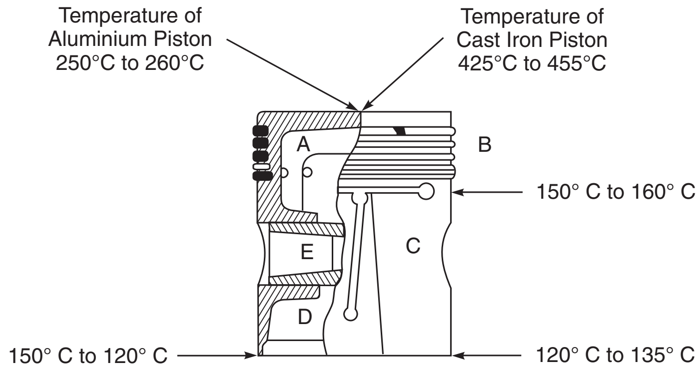



**Fig. 3.7** Piston Temperatures at Various Stages

## 3.8 PISTON RINGS

Piston rings are those rings which are fitted in the grooves provided in pistons. The piston rings perform three functions:

1. The piston rings seal the passage inside the cylinder so that gases cannot leak from one side of the piston to the other side. Any leakage of gases directly affects power and fuel consumption. In case of leakage, power is decreased and fuel consumption is increased.
2. They provide a path for conducting heat from the piston head to the cylinder walls. Thus piston rings help in reducing the piston temperature.
3. The crankcase oil, which is used for engine lubrication and is splashed by the crank, is prevented from passing into the combustion chamber. Piston rings scrap the excess oil from the cylinder walls and only a thin film of oil is left to lubricate the piston rings. The lubricating oil which leaks and passes into the combustion chamber, not only increases the consumption of lubricating oil but also gets carbonized. The carbonized lubricating oil is a hard substance which acts as an abrasive material between the piston rings and the cylinder walls. This causes rapid wear of the cylinder.

Piston rings are not completely closed and are provided with a gap at the ends. The gap allows the rings to fit over the piston and lets the rings expand without breaking. When the piston and piston rings expand with excessive heat, the ring gap becomes smaller as shown in Fig. 3.8. Generally, there are two forms of gaps provided in piston rings:

(a) straight or normal gap
(b) diagonal or scarf gap

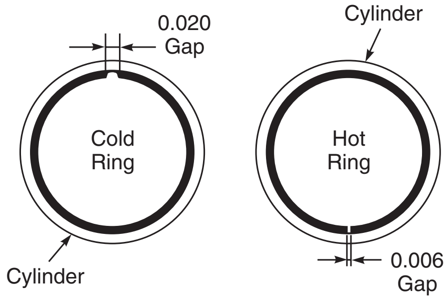



**Fig. 3.8** Piston Ring Expansion

Two types of piston rings are widely used:

1. Compression ring
2. Oil control ring

The compression ring serves two purposes, viz.

(i) to seal the combustion chamber and
(ii) to provide a path for heat transfer from the piston to the cylinder walls. This provides effective cooling.

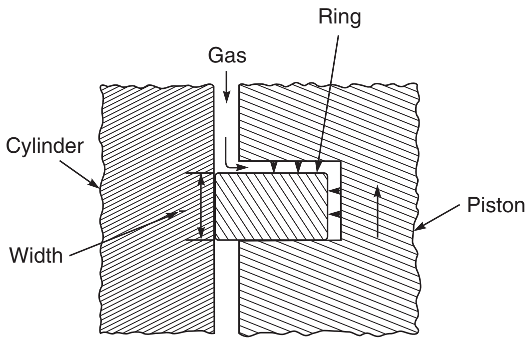



**Fig. 3.9** Piston Ring with Rectangular Section

An oil control ring is similar to a compression ring, but has a circumferential groove on its outer circumference. The function of the oil control ring (or oil ring) is to strip some of the lubricating oil from the cylinder walls and return the oil to the crankcase through radial passages in the oil ring.

Two compression rings and one oil ring are used in most passenger car engines. Compression rings are available in many cross-sections as shown in Fig. 3.9 to Fig. 3.12. Almost all modern compression rings have bevelled edges and a built-in twist. The twist is not visible to the unaided eye and is provided to force the opposite edges of the ring against the ring groove. An increased sealing pressure results from the twist.

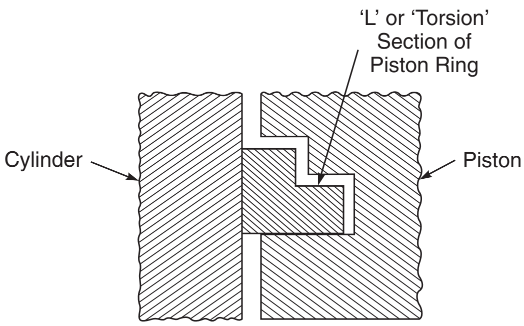



**Fig. 3.10** L Shaped Section of the Piston Ring

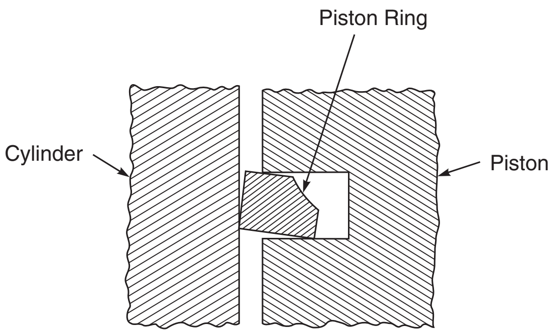



**Fig. 3.11** Twist Ring

The sectional view of an oil control ring is shown in Fig. 3.13. The groove or slot cut on the circumference of the oil ring is also shown clearly. Radial holes are drilled in the oil ring so that oil collected in the ring groove can pass in the piston ring groove. Other holes are drilled in the wall of the piston as shown in the figure. The oil collected in the groove can easily pass into the crankcase through these holes.

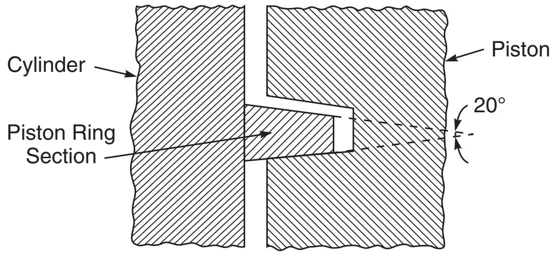



**Fig. 3.12** Keystone Section

The main problem with the grooved oil control ring is that the lubricating oil is pumped to the combustion chamber above the piston and the quantity of the pumped oil increases with the engine speed and increased compression ratio. The reason for the increase in the quantity of the oil pumped to the combustion chamber is that at higher engine r.p.m., the gas blow increases during compression and expansion stroke. This is due to ring fluttering, i.e. ring vibration. Many oil rings are made of three parts, two rails that do the scraping and one that expands and forces the rails against the cylinder.

Piston ring materials have changed from plain cast iron to materials such as peartitic and modular iron as well as steel. Piston rings may be coated with chromium or molybdenum materials.

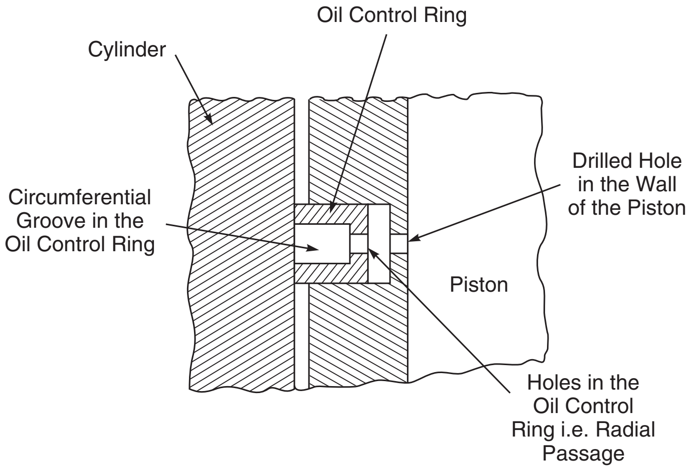



**Fig. 3.13** Oil Control Ring

### Piston Ring Joints

The oil control and compression rings usually butt together with a joint called a butt gap. Some piston rings for automotive use have an angle type or sealed type gap (Fig. 3.14.).

Since piston rings fit in ring grooves with some clearance they tend to rotate in the piston grooves. In a two-stroke cycle engine, the ends of the rotating ring could move into a cylinder part and cause breakage. Most two-stroke cycle pistons therefore, have a pin in the piston groove that prevents the ring from rotating.

## 3.9 PISTON PIN

A piston pin is also known as a wrist pin because of its similarity in construction with human hand and arm joint. A piston pin is a link for connecting the piston and the connecting rods. Since the piston pin reciprocates with the piston, its weight is minimised by making it hollow, so that inertia

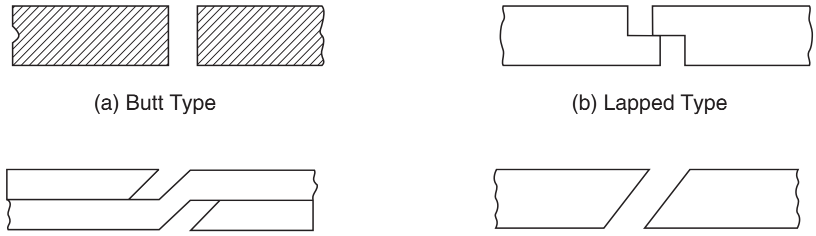



**Fig. 3.14** Types of Ring Joints

forces at piston TDC are decreased. The piston pin is fitted in the bosses which are in the piston. The small end of the connecting rod is accommodated in between the piston bosses.

Figure. 3.15 shows the assembly of the piston, the piston pin and the connecting rod.

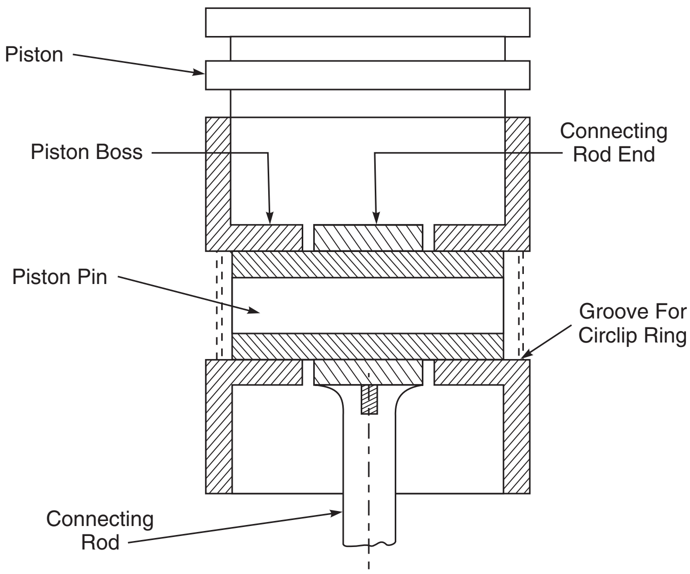



**Fig. 3.15** Assembly of Piston and Connecting Rod by a Piston Pin

In the figure the piston pin is in a floating state and its axial movement is restricted by fitting snap rings or circlip rings, which are inserted in the grooves made at the entrance of the piston boss. The construction of a circlip ring has been shown in Fig. 3.16. The ends of the circlip ring are pressed and inserted in the piston boss, and then released in the groove made for this ring.

Piston pins are made of casehardening steel, either plain carbon steel, nickel steel or chrome-nickel steel. The pins are designed to work as bearing journals.

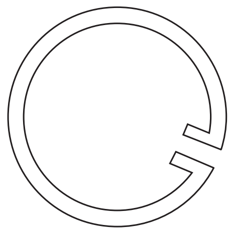


**Fig. 3.16** Circlip Ring

## 3.10 CONNECTING ROD

The connecting rod is a link, which connects the reciprocating piston and the rotating crank. Most connecting rods are made of medium-carbon steel which has 0.35% to 0.45% carbon. However, the connecting rods heavy-duty engines are made of chrome-nickel and chrome-molybdenum steel. The connecting rods are drop-forged.

The length of the connecting rod is expressed in terms of the piston stroke. As the length of the connecting rod increases, the side thrust due to its angularity on the cylinder wall decreases and thus, cylinder wear decreases. However, the longer connecting rod makes the engine more bulky, heavy and costly. For this reason the length of connecting rod is reduced. Moreover, investigations have shown that the length of the connecting rod is not the primary factor for increasing wear on the cylinder walls.

The high-pressure gas behind the piston rings causes maximum wear when the piston is at TDC. The other reason for reducing the length of the connecting rod is that the buckling tendency decreases with the decrease in its length. This means that the shorter connecting rod can take more thrust. Calculations have shown that the stresses in the connecting rod are four times as great in the plane of rotation than at right angles. This implies that the connecting rod must be stronger in the plane of rotation. Therefore, the connecting rod in constructed as an I-section with the web provided in the plane of motion.

The end of the connecting rod connected to the piston pin is called the 'small end' because its size is smaller. The other end of the connecting rod attached to the crank pin is called the 'big end'. To lubricate the small end bearing of the connecting rod, the connecting rod is drilled through the shank. Lubricating oil is passed through this drilled hole under pressure. Thus the bearing at the piston pin is flooded with oil.

Aluminium alloy is also used in the manufacture of the connecting rod. The lighter the connecting rod and the piston, the greater is the resulting power. Vibrations are also reduced in a lighter connecting rod and piston.

There are two types of small end and big end bearings. The small end of the connecting rod may have split eye, or solid eye. In Fig. 3.17, different types of small ends and big ends have been shown. Figure 3.17 (a) shows the split eye of the small end of the connecting rod. The gudgeon pin is fitted in this eye and clamped with the pinch bolt. Thus the gudgeon pin remains fixed in the eye of the connecting rod. In Fig. 3.17 (b), the solid eye of the small end of the connecting rod has been shown. A phosphor bronze bush is tightly fitted in this eye. The gudgeon pin floats in the bush fitted in the eye. The axial movement of the gudgeon pin (wrist pin or piston pin) is restricted by the circlips fitted on both the ends in the piston bosses, as shown in the figure. The big end of the connecting rod may be split at right angles to the length of the connecting rod as shown in Fig. 3.17(a). The split of the big end is essential for the assembly of the connecting rod on the crank pin. In Fig. 3.17(b), the split is given at an angle of 45° to the length of the connecting rod. It has been calculated that such angularly split big end head reduces the load on the cap bolts. Therefore the bolts can be made somewhat smaller in diameter.

It should be clear that the bolts used in the big end head are excessively stressed in both tension and bending. Therefore proper material and design is needed. A properly tightened nut is one that applies a tension load to the bolt that is equal to or greater than the external load to be supported in service. When this condition is fulfilled the bolt cannot fail due to fatigue.

## 3.11 CRANKSHAFT

The crankshaft is an important part of the engine which converts the reciprocating motion of the piston into rotary motion. This rotary motion of the crankshaft is used to rotate the shaft of a machine to get work. The motion of the piston is transmitted to the crank by the connecting rod.

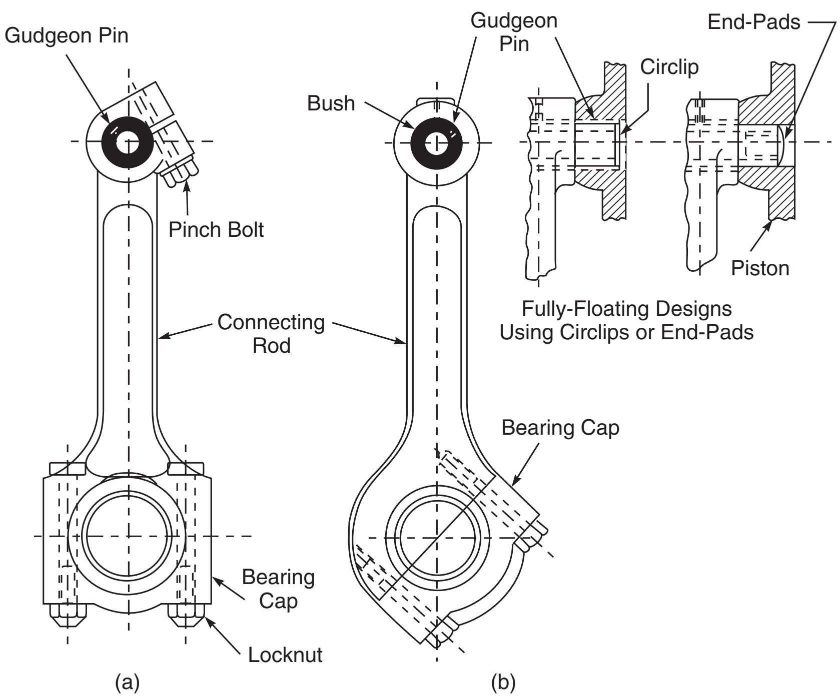


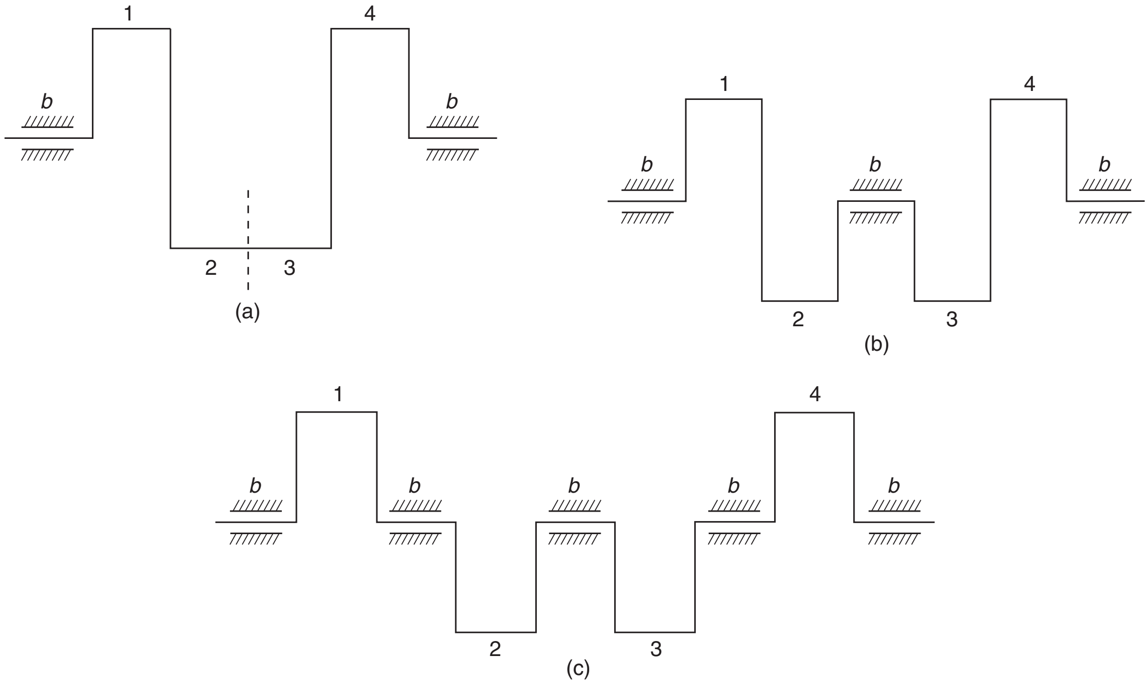

**Fig. 3.17** Connecting Rod

The crankshaft is subjected to torsional and bending stresses and is supported on the crankcase structure on large bearings. These crankshaft bearings are known as main bearings. The main bearings and the crankpin bearings are made large so that the load is distributed evenly. The load on the main bearings due to centrifugal force is reduced or even made zero by providing suitable counter weights.

The number of bearings in a crankshaft varies depending on the dynamic load on it. For example, a four-cylinder engine crank may have two, three or five bearings. In Fig. 3.18 a crankshaft for a four-cylinder engine has been shown. The numbers 1,2,3,4 represent the cylinder cranks and 'b' is the position of bearings. In Fig. 3.18 (a), two bearings are provided whereas in Fig. 3.18 (b), three bearings are provided. In Fig. 3.18 (c), five bearings are provided in the same four-cylinder engine crank. Obviously, as the number of crank bearings are increased, the length of the crankshaft is increased and the rigidity of the crankshaft is also increased. This means that a four-cylinder engine having only two bearings gives a very compact arrangement but requires a very stiff crankshaft having large diameter pins and greater frictional losses at the big ends. However, a four-cylinder engine having five bearings, does not require a crankshaft with large diameter pins. Such crankshafts with five bearings require correct alignment of all the bearings. In practice, three bearings are used in a four-cylinder engine crankshaft.

A crankshaft is composed of crankpins, crank arms, crank journals, and driving ends. Generally, cranks are made of medium carbon steel and forged in a single piece.

The physical properties of the material are restored by suitable heat treatment, consisting of normalizing, reheating and quenching.




1-2-3-4 are Cranks
*b* - Bearing for Crank Support

**Fig. 3.18** Bearings in Crank

### Crankshafts for Multi-cylinder Engines (Firing Order)

To achieve better balancing of the dynamic (primary and secondary) forces and their couples, the multi-cylinder engines have even number of cylinders, i.e. 4 cylinder, 6 cylinder, 8 cylinder engines. In Fig. 3.19, the crank arrangement of a four-cylinder engine has been shown. Cranks 1 and 2 are the mirror images of cranks 3 and 4 with respect to the plane AB. The firing orders are arranged at an interval of

$$\frac{360 \times 2}{4} = 180°$$

in case of a four-stroke cycle four-cylinder engine.

In Fig. 3.20, the crank arrangement for a six-cylinder engine has been shown. From the figure it is obvious that the cranks 1-2-3 are the mirror images of the cranks 6-5-4 respectively. The firing orders are arranged at an interval of

$$\frac{360 \times 2}{6} = 120°$$

in case of a four-stroke cycle six-cylinder engine.

## 3.12 BALANCE WEIGHT

In an internal combustion engine, a single cylinder engine cannot be perfectly balanced due to its reciprocating parts. Multi-cylinder engines (six-cylinder engines) can be perfectly balanced. The

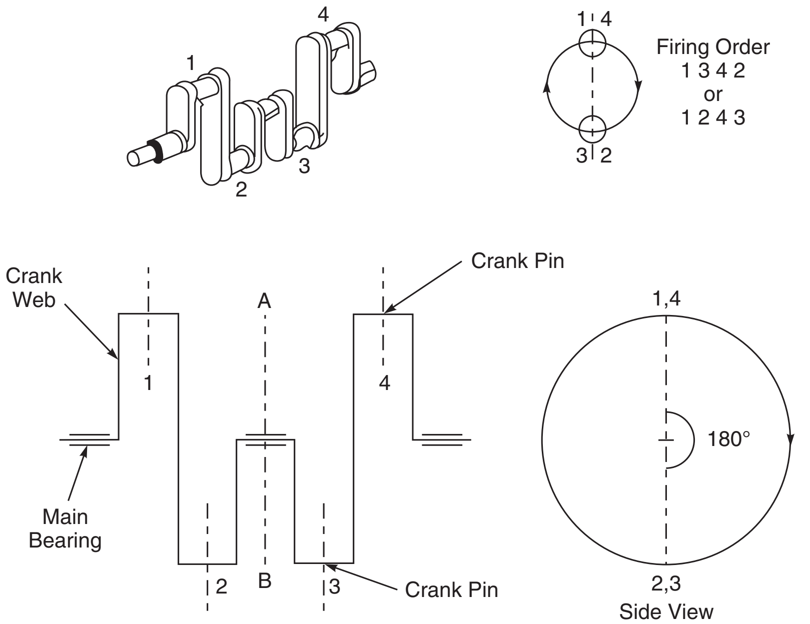



**Fig. 3.19** Four Cylinder Crank Arrangement

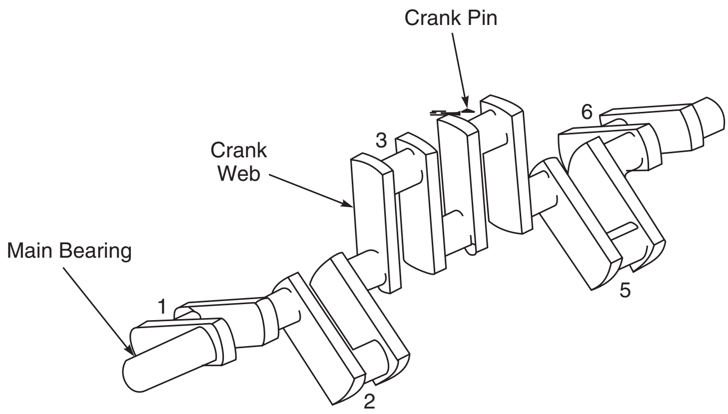



**Fig. 3.20** Crank for 6-cylinder Engine

reciprocating parts causing inertia forces in one cylinder are balanced by the inertia forces of the reciprocating parts in the other cylinder.

The revolving masses like crank pin, and big end of the connecting rod are balanced by providing counter weights at the opposite direction of the crank.

In Fig. 3.21, a crankshaft with a counter weight at the opposite side of the crank pin has been shown. The weight arm product of the counter weight is equal to the weight arm product of the revolving masses.

## 3.13 VIBRATION DAMPER

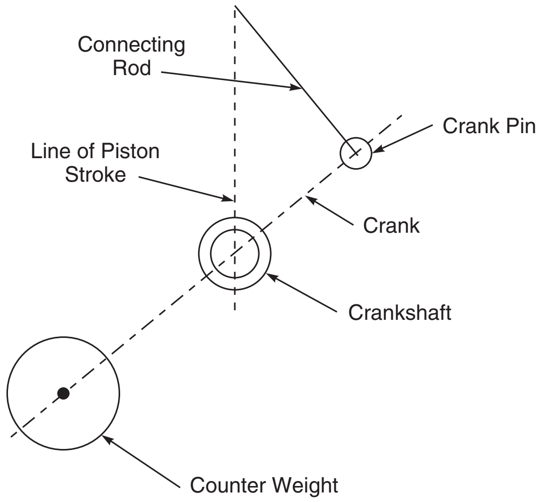



**Fig. 3.21** Balance Weight

Torsional vibrations are produced in an internal combustion engine depending on the thermodynamic cycle of the engine. In the four-stroke cycle, there is one power stroke, which gives energy, and the remaining three strokes require energy. This variation in energy generates torsional vibrations.

Torsional vibrations impose additional stresses on the crankshaft varying in intensity along the length of the shaft. These stresses are repetitive and they induce fatigue. One of the serious effects of torsional vibrations is that the drives to the camshaft and accessories are subjected to increased stresses and rapid wear consequently.

A vibration damper functions by resisting the acceleration and retardation. For this purpose two types of vibration dampers have been developed:

1. Rubber-hysteresis type of damper
2. Viscous type of damper

The rubber-hysteresis damper is based on the principle that when a mass of rubber is deformed, energy is absorbed and heat is generated due to molecular friction within the rubber. This phenomenon is known as hysteresis.

An alternative damper is the viscous type which, though more expensive than the rubber type, is extremely reliable. This damper consists of an annular fly wheel sealed in a metal casing. The space between the two is filled with a silicone fluid of high viscosity. Since the casing rotates and oscillates with the crankshaft, while the flywheel tends to maintain a steady-state motion, there is a considerable viscous drag in the fluid between the two; thus energy of vibration is dissipated as heat.

## 3.14 CAMSHAFT

The camshaft receives the drive from the crankshaft. A camshaft consists of cams. Components like a fuel pump, a lubricating oil pump, a water pump, a generator, an ignition unit, and a fan are driven by the camshaft. An air compressor, a governor and a magneto are also driven by the camshaft. Either gear drive or chain drive may be used between the crankshaft and the camshaft. The camshaft driving gears located at the forward end of the engine are subjected to great stresses, when the crankshaft has torsional vibrations. In such cases heavier gears and heavier chains are useful to withstand these abnormal stresses.

It has been experienced that a non-metallic gear on a camshaft gives noiseless drive. Usually, bakelite is used to mould gears with helical teeth. Bakelite has a considerable degree of elasticity (about 20 times as great as that of steel), and it can also withstand greater loads than a cast iron gear at high speed. It is interesting to note that bakelite has about 75% mechanical strength of cast iron under static load, but at high speed the working stress of bakelite is greater than cast iron.

It is also found that a spoked non-metallic gear on a camshaft is more flexible than a solid-web gear and therefore, the non-metallic (celoron) gear can withstand greater shock load without injury.

In a four-stroke cycle engine, the camshaft has to revolve at half the crank speed. This means that all the cams fitted on the camshaft have to operate once in every two revolutions of the crankshaft. The engine valves, fuel pump, ignition unit, etc. have to operate at a definite position of the crankshaft. For this reason there must be proper timing between the crankshaft and the camshaft. The gears on the crankshaft and the camshaft are known as timing gears.

Figure 3.22 shows the part meshing of the crankshaft gear and the camshaft gear. Circle marks are indicated on the teeth as shown.

The material used in camshafts is copper-chromium-iron with high carbon and some silicon. This is known as high carbon high copper chrome silicon cast steel.

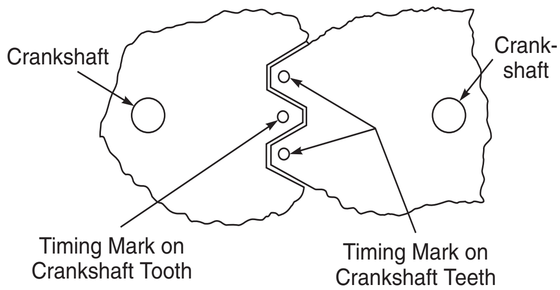



**Fig. 3.22** Timing Gears

## 3.15 VALVES

The valves used in an engine following four-stroke cycle are mushroom-shaped with a conical seating surface. In Fig. 3.23, the assembly of a value has been shown. The valve head rests in the cylinder head on conical seating, the angle of the cone being 45°. The valve stem passes through a guide, which has a plain hole. The valve guide is fitted in the cylinder head casting. The valve is closed and pressed on its seat by a spring or springs coiled in opposite directions as shown in Fig. 3.23. There are valve collets split in two or three parts. The valve collet is pressed on its seat by a spring retainer which provides seating for the springs as shown in the assembled sectional view. Thus the gas pressure on the valve head assists the springs in pressing the valve firmly on its seat.

The heads of the valves are subjected to the high temperature of the burning gases, and therefore the value must be highly temperature-resistant. The valve seat also should not scale or corrode. Failure of a valve may arise from any one of the following causes:

1. Higher-lift of cams and stronger springs
2. Higher maximum speed of the engine associated with spring surge
3. Heat of the burning gases.

The valves in the modern engine are made of special alloy steels which are capable of retaining their mechanical strength at high temperatures and are able to resist the corrosive and erosive effects of the high temperature and high velocity of cylinder gases.

The material for the inlet valve does not pose much of a problem because the temperatures encountered by the valve not attain high values. Chromium-nickel-molybdenum steel containing 0.35 to 0.65 percent chromium, 0.35 to 0.75 percent nickel and 0.12 to 0.25 per cent molybdenum is generally used. In addition to this, carbon and manganese are also added.

### Valve Materials

The exhaust valves, which run at high temperatures, are made of silicon-chromium alloy steel. However, these days the exhaust valve is made of austenitic. Austenitic is better than silicon-

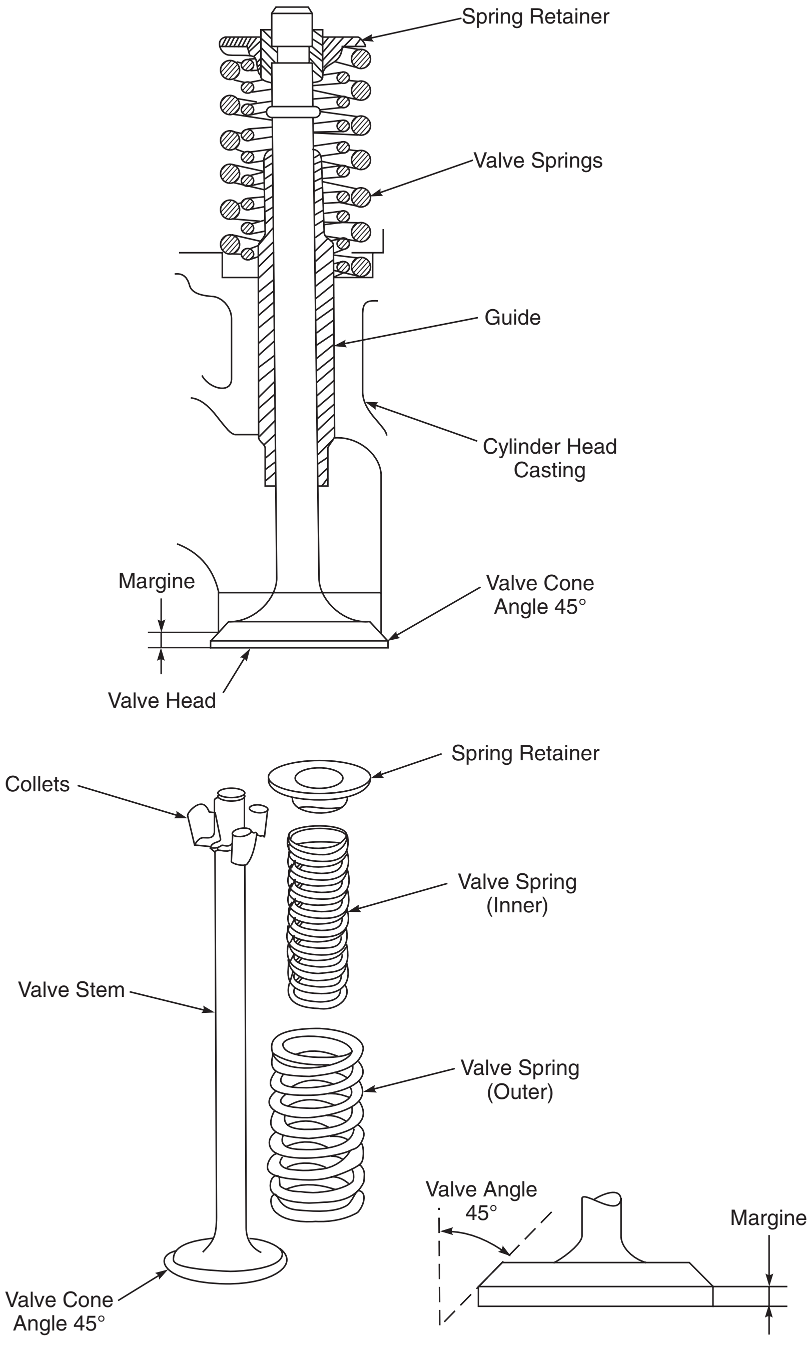



**Fig. 3.23** Valve Assembly

chromium steel as far as impact value, hot hardness, and resistance to oxidation and corrosion are concerned. Austenitic contains a high percentage of chromium and nickel.

## Valve Cooling

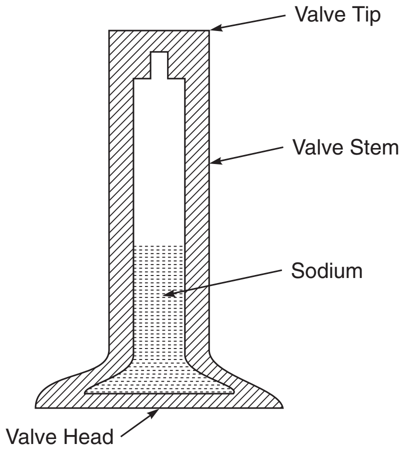



**Fig. 3.24** Sodium Cooled Valve Head and Stem

An engine valve having a fairly wide steel seat gets cooled because the wide valve seat helps to lower the temperature of the valve head. The heat absorbed from the burning gases by the valve head has only two paths through which it can be released:

1. to the valve stem and to the valve guide and hence into the cylinder head and jacket.
2. to the valve seat directly into the head and jacket. The wider seat allows more percentage of heat to pass through and the valve temperature is lowered.

Large valves of heavy-duty engines are provided with sodium cooling to lower the temperature of the valve. Sodium has low specific gravity (0.97), high specific heat, low melting point (70°C) and high boiling point (880°C). Figure 3.24 shows a sodium-cooled valve. The stem diameter is made somewhat larger and half the hollow stem is filled with sodium. The metallic sodium cools the stem and the head of the valve. Experimental results show that a valve head without sodium cooling attains a maximum temperature of about 750°C, whereas under similar conditions the sodium-cooled valve attains a maximum temperature of about 620°C. Sodium-cooled valves are expensive, therefore they are not widely used in automobile engines. Under high temperatures, metallic sodium in the valve stem melts and as the valve moves back and forth, heat is mechanically transferred to the valve's stem as the molten sodium is thrown violently from one end of the chamber to the other. The heat passes to the valve guide and then into the cylinder head. These sodium-cooled valves are sometimes furnished with an inner lining of copper, which has four times the heat conductivity of the valve.

## Valve Mechanism

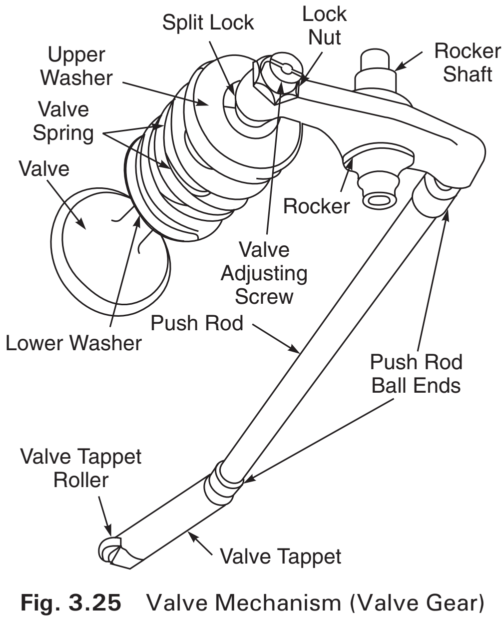



**Fig. 3.25** Valve Mechanism (Valve Gear)

Figure 3.25 shows the valve operating mechanism. The poppet valves are lifted from their seats by means of cams and the valves are closed by springs. The lifting and droping of the valve must be gradual so that the valve gear operates without noise.

In Fig. 3.25, the cam follower is connected to a push rod. The cam follower may be a roller or a flat or in some cases a lever. The cam in the camshaft lifts the follower. The follower pushes the push rod to actuate a lever, which is known as a rocker arm. This rocker arm depresses the valve stem against the valve springs and lifts the valve from its seat.

In an engine the exhaust valve stem is heated more and so expands more than the cylinder barrel. Therefore it is essential to provide some clearance in the valve gear (valve operating mechanism) when the engine is cold and the valve is seated on its seat.

If no clearance is provided then the valve is quickly destroyed. The leakage of gases in case of nature failure also lowers the engine performance.

To have some clearance in the valve operating mechanism a valve adjusting screw is provided as shown in Fig. 3.25. The clearance between the valve tip and the rocker arm is measured by a feeler gauge when the valve is seated on its seat. The clearance is recommended by the manufacturer of the engine for best performance of the engine. After setting the valve clearance, the adjusting screw is finally locked in its position by a lock nut as shown in the figure.

In some valve designs, 'Automatic Zero Clearance' tappets are provided. This device functions on the hydraulic principle and keeps the valve clearance zero at all temperatures. Lubricating oil is pumped to take up the volume of the clearance between the tappet and the valve. On heating the engine, the valve clearance is reduced. The valve stem pushes the plunger in the hydraulic device. The lubricating oil leaks under pressure through the clearance between the plunger and its barrel. In normal conditions, this clearance between the barrel and the hydraulic plunger is always filled with viscous oil and the valve clearance is entirely taken up by the oil column below the plunger. Hydraulic tappets of this type give silent operation, eliminating the need for valve adjustment when the engine is cold. Also the life of the valve is increased.

It is important to note that in an automobile engine the cylinder heads are made of aluminium. The valve seat is provided separately. This is known as an inserted valve seat. The inserted seats are made of heat-resistant materials similar to the valves.

In the L-head engine, side valves are provided. To actuate these valves, rocker arms are not needed and the cam pushes the push rod directly to lift the valve from its seat. Figure 3.26 shows the assembly of the side valve of an engine. To give valve clearance, the adjusting screw is provided at the top of the valve tappet. The gap between the valve tip and the tappet is measured by a feeler gauge and then locked by a lock nut, as shown in Fig. 3.26. If the distance between the cam and the valve is less, then the push rod is eliminated.

## Multiple Springs in a Valve

Breaking of valve springs is common due to surges. To avoid these breakages, two springs, each of different stiffness and coiled in opposite directions are used. The springs are coiled in opposite directions so that they do not get entangled during valve operation. If one spring breaks due to a surge, the other will continue to close the valve rapidly at higher engine speed. Therefore the closing of the valve lags behind the instantaneous engine speed at high valves of speed. The cylinder thus affected continues to function, though with some loss of power at high speed. If the valve has only one spring, then the cylinder completely fails to develop power on the failure of the spring due to a surge.

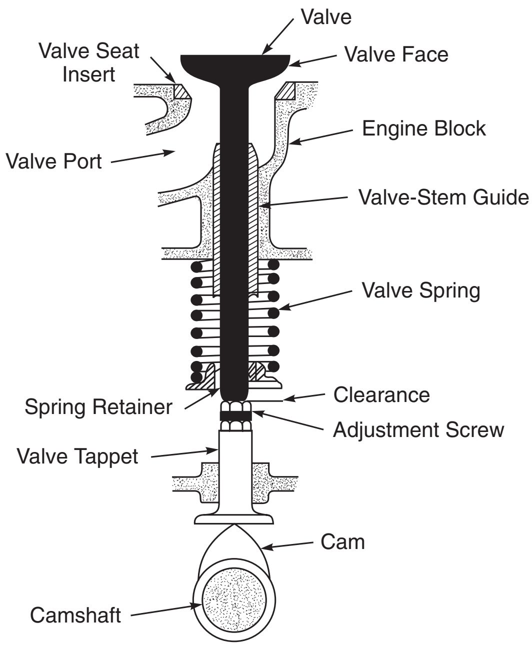


**Fig. 3.26** Side Valve Mechanism

## Valve Timing

Valve tming of an engine represents the crank position when the valve is operated. To make the valve operate without noise, it is essential that the valves must be operated very slowly during their opening and closing. If the inlet valve begins to open at the beginning of the suction stroke, the effective valve opening during a considerable part of the inlet stroke would be so small that the incoming charge would be seriously throttled. Such action of the valve increases pumping losses and reduces power of the engine. Therefore the suction valve and the exhaust valve begin to open before the start of the suction (inlet) and the exhaust strokes respectively. Similarly, the incoming fresh gases and the out-going burnt gases have inertia, and the advantage of their flow inertia is taken by closing the inlet valve after the suction stroke and closing the exhaust valve after the exhaust stroke as shown in Fig. 3.27.

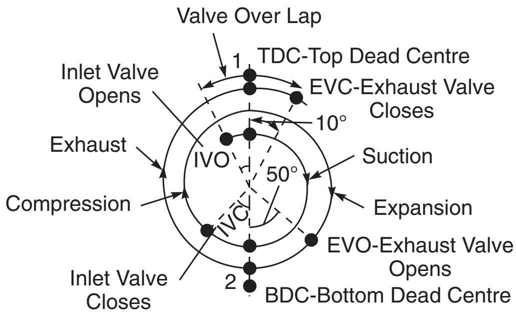



**Fig. 3.27** Valve Timing

In the valve timing diagram of Fig. 3.27, the inlet valve begins to open at 'IVO' about 25° before TDC. The suction valve (inlet valve) remains open during the suction stroke and closes at 'IVC' about 35° after BDC. Thus the suction valve remains open for about 25° + 180° + 35° = 240° of crank rotation. At the end of the suction stroke when the piston is at BDC, the flow of fresh charge continues due to its inertia. This action of the fresh charge packs more charge in the cylinder and the cylinder is naturally supercharged, and develops more power. Compression of the fresh charge continues up to the point (1), when the piston reaches TDC. After the combustion of the fresh charge, the expansion stroke begins and the exhaust valve begins to open at 'EVO' about 50° before BDC. At the beginning of the exhaust stroke, the exhaust valve is sufficiently opened and thus the throttling of the burnt gases is avoided. The exhaust stroke begins at the point (2), when the piston is at BDC. The exhaust valve closes at 'EVC' about 10° after TDC. Thus the exhaust valve remains open for about 50° + 180° + 10° = 240°.

In the valve timing diagram (Fig. 3.27) the suction stroke starts at the point (1) when the piston is at TDC. At the same position of the crank the exhaust stroke ends. This means that the suction valve opens at 25° before TDC of the piston and the exhaust valve closes at 10° after TDC of the piston. Thus for the crank rotation of 25° + 10° + 35° = 70°, both the valves remain open. Such overlapping in the opening of the valves reduces the percentage of residual gases due to flow inertia or momentum of the burnt gases flowing through the exhaust valve under high velocity. Partial vacuum created by the out-going burnt gases increases the scavenging effect in the clearance volume of the engine.

Valve timing directly affects volumetric efficiency and thus engine power is also affected. Some useful pressure is lost by opening the exhaust valve before BDC, that results in losses in work, but late opening of the exhaust valve increases the throttling loss. The throttling loss is greater than the work obtained by late opening of the exhaust valve. Therefore, early opening of the exhaust valve is more advantageous.

## 3.16 PORT-TIMING DIAGRAM

A port-timing diagram is drawn for a two-stroke cycle engine in which ports are provided as shown in Fig. 3.28.

The exhaust port 'E' in the figure is being uncovered by the piston. This event is shown in Fig. 3.29, by the point 'EPO' when the exhaust port is opened. Obviously, the exhaust port would be covered at the same piston position during its return stroke. Therefore the exhaust port opens at about 80° before BDC and also closes at about 80° after BDC. These events have been shown by the points 'EPO' and 'EPC' respectively in Fig. 3.29. Similarly, the transfer port 'T' is opened at about 60° before BDC and also closed at 60° after BDC.

The opening and closing of the transfer port 'T' have been shown by the points 'TPO' and 'TPC' respectively in Fig. 3.29. Thus, the below down of the burnt gases takes place at the point 'EPO'. Crankcase scavenging continues from 'TPO' to 'TPC', i.e. for 60° + 60° = 120° of crank rotation. From Fig. 3.29 it is obvious that useful pressure is lost when the exhaust port 'E' is opened about and 80° before BDC, and also the compression ratio is decreased because compression starts only after the closing of the port 'E'. These factors reduce engine efficiency.

The inlet port 'I' is not opened or uncovered in the cylinder. Therefore, the opening and closing of the inlet port are not shown in Fig. 3.29. The inlet port 'I' in the crankcase can be drawn by showing the opening and closing of the port when the piston approaches TDC.

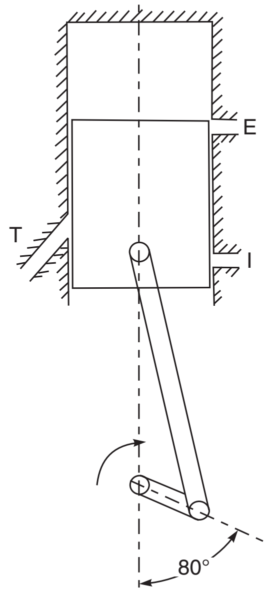



**Fig. 3.28** Two-stroke Cycle Engine

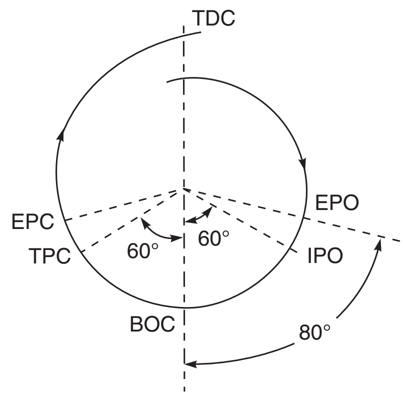



**Fig. 3.29** Port Timing Diagram

## 3.17 FLYWHEEL

The function of the flywheel is to absorb the torsional vibrations (in impulse) transmitted to the crankshaft by the combustion of the gases and to release the energy during the other three strokes in a single cylinder four-stroke cycle engine. Thus a flywheel drives the piston over the dead points and the idle strokes. In an automobile, a lighter flywheel is required because the engine carries a dynamic load. For example, a car, when it is in motion, serves as a store of energy, which tends to prevent speed fluctuation. In fact, a fairly lighter flywheel is desirable so that it gives better response to the throttle operation. This means that the engine must rapidly accelerate and retard as the throttle valve is opened or closed.

A flywheel stores kinetic energy to supply it during idle strokes. The proportion of the stored energy in a flywheel decreases with an increase in the number of cylinders. In a four-cylinder engine about 40% of the energy of the cycle is temporarily stored. This part of the total energy is not stored in the flywheel but some of it is utilized in accelerating the reciprocating engine parts. Besides this, the rotating parts other than the flywheel also absorb energy like a flywheel. This reduces the proportion of the excess energy of the cycle, which must be stored in the flywheel. In a six-cylinder engine, the proportion of the energy which must be absorbed and returned by the moving parts, amounts to about 20%. Thus the greater the number of cylinders, the smaller the flywheel capacity required per unit of piston displacement. In a multi-cylinder engine, power strokes overlap. As a result, the power stroke of one cylinder helps the compression stroke of the other cylinder. However, the flywheel has the greatest inertia even in a multi-cylinder engine. In a V-8 engine, the polar moment of inertia of the flywheel is about seven times that of the crankshaft and of the parts rotating with it.

The capacity of storing energy of a flywheel increases with the increase in the flywheel diameter. The flywheel need not be heavy. In an automobile, a higher crank speed increases the centrifugal force on the rim of the flywheel, and there is a danger of the flywheel bursting. Hence a smaller flywheel diameter is preferred.

In an automobile engine, the disc-type flywheel is used because it gives greater safety against bursting, and also the flywheel functions as the member of the friction clutch. Usually, a ring gear is also provided on the rim of flywheel to provide self-starting of the engine.

## 3.18 MANIFOLDS

The passages in the cylinder head leading to or from the valves are called ports. The system of pipes, which connect the intake ports of various engines, is called the inlet manifold. If the exhaust ports are similarly connected to a common exhaust system, then this system of piping is called the exhaust manifold.

The purpose of designing an inlet manifold is for the qualitative or quantitative distribution of charge in the cylinders. In the equal quantitative distribution design of the inlet manifold, all the cylinders of the engine receive the same mass of charges per cycle. Whereas in the qualitative distribution arrangement, all the cylinders of the engine receive the same air-fuel mixture, i.e. the same proportion.

To ensure equal quantitative distribution, the resistance to the gaseous flow from the carburettor to all the cylinders must be the same. Naturally, the resistance to flow is greater in case of cylinders located away from the carburettor. This resistance to the flow can be minimised by suitable design so that the manifold resistance is reduced. In case of engines having six or less cylinders, the cross-section of the inlet manifold is made substantially equal to that of the valve port. However in case of an eight-cylinder engine, dual carburettors and dual manifolds are provided and the cross-section of each branch of the manifold is made 75% to 80% that of the inlet valve port. In case of an updraft manifold, the area of the inlet manifold section is not made too large because the reduced velocity of air in the manifold cannot carry the partly vapourized fuel which is in suspension in air. In the idle stroke, the fuel droplets fall back on the carburettor and the air filter. Therefore, in an updraft carburettor, the inlet manifold must be small in diameter to induce high velocity at low speeds of the engine. Higher velocity of air carries the suspended fuel droplets against the force of gravity. In case of the downdraft carburettor, such difficulty with the inlet manifold does not arise.

For equal quantitative distribution, the inlet manifold for a multi-cylinder engine is so designed that there is a single division zone and it must be close to the carburettor so that if condensation of the fuel takes place beyond this point, the condensate cannot get into any cylinder other than the one for which it was intended. This means that just after the carburettor, a separate passage for each cylinder must be provided. However, such design is not possible in a multi-cylinder engine, which is required to develop maximum power. In a racing vehicle a separate carburettor can be adjusted to deliver the best possible mixture to its particular cylinder or cylinders.

Figure 3.30 shows the flow of the air-fuel mixture in a manifold. There are two cylinders A and B, of which cylinder A is under the intake process. The intake manifold carries the uniform (homogeneous) mixture before the entrance in the cylinder A. However, as the homogeneous mixture of air and fuel reaches the division zone, i.e. the bend leading to cylinder A, the inertia of

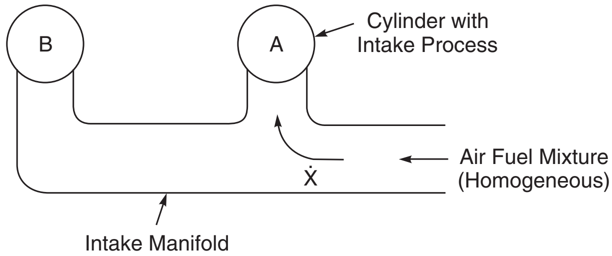



**Fig. 3.30** Mixture Flow in Manifold

the heavy fuel particles does not allow the change in direction on the curved path (bend of pipe) leading to cylinder A. The result is that cylinder A receives a leaner mixture of air and fuel. Cylinder B receives a higher percentage of the fuel, which includes the share of cylinder A. The heavy fuel particles which were intended for cylinder A are collected at the point X as shown in Fig. 3.30, and these fuel particles are passed to cylinder B.

The design given in Fig. 3.30 is not satisfactory and it indicates that the dividing action should take place before the bend in the inlet manifold, which is not possible in a multi-cylinder engine. The other remedy is that the charge (air-fuel mixture) must be heated before it enters the branches of the manifolds. This heat can be supplied either by preheating the air before it enters the carburettor, or by heating that portion of the wall, where any unevaporated fuel collects. For such heating, the heat of exhaust gases can be utilised. Preheating of air is not recommended because it decreases the volumetric efficiency of the engine cylinder and causes loss of power. Exhaust heat must not be applied too near the carburettor because the evaporated fuel in the float chamber causes vapour lock in the carburettor that stops the flow of the fuel through the jets.

In modern design in cold countries, exhaust jacketed inlet manifolds are used. In a multi-cylinder engine the down draft carburettor is located at the middle of the length of the engine and the exhaust gases are passed through the jacket provided on the inlet manifold. Temperature control is essential to maintain volumetric efficiency and to get proper distribution of homogeneous mixture. Generally, a thermostatic spring is used to regulate the valve which by-passes the exhaust gases.

In Fig. 3.31, an eight-cylinder in-line engine has been shown. Experiments have shown that if one carburettor is used in an eight-cylinder engine, then it develops 65 HP at 3400 rpm. The same engine develops 85 HP at 3800 rpm with a dual manifold carburettor. A dual manifold carburettor has two carburettors with a common float chamber cast in one unit. In the Fig. 3.31, two inlet manifolds have been shown. The manifold no. I supplies charge to the inner four cylinders 3, 4, 5 and 6; whereas the other manifold supplies charge (air-fuel mixture) to the outer cylinders 1, 2, 7 and 8 as shown in the figure. At the bottom of this dual manifold, the exhaust pipe is fitted with a temperature control thermostat valve. Thus the problem of distribution is reduced to that of a four-cylinder engine. The advantage of this design is that no section of either manifold carries a flow greater than the maximum rate of flow into one cylinder. In Fig. 3.32, the crank diagram for an eight-cylinder in-line engine has been shown. The numbers 1,2,3, represent cylinder crank numbers and I, II represent the manifold number as given in the Fig. 3.31. The sequence of induction in the respective cylinders has been written and the charge supplied by the respective manifolds is shown below it. From Fig. 3.31 and Fig. 3.32, it is obvious that the manifold connecting cylinders 1 and 2, 3 and 4, 5 and 6, 7 and 8 carries charge to supply only one cylinder. It must be clear that interval of inlet valve opening is 90° of crank rotation. Such a design permits a smaller section of the inlet manifold.

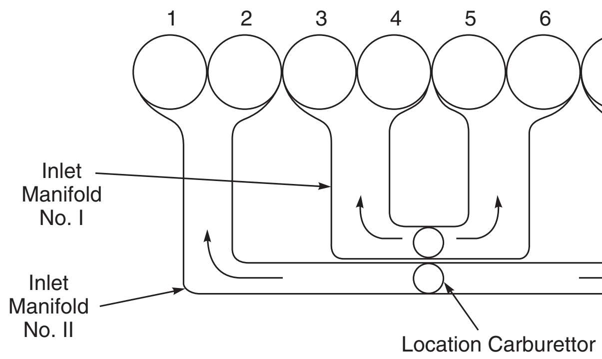



**Fig. 3.31** Dual Manifold

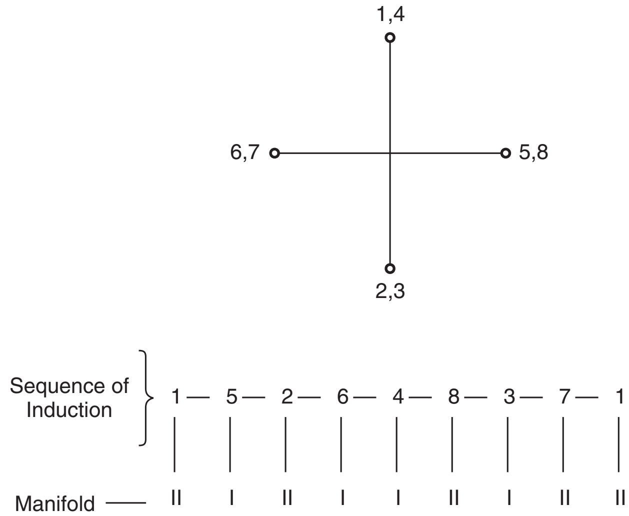



**Fig. 3.32** Crank Diagram for 8-cylinder Inline Engine

In the case of the exhaust manifold it is required that the expansion should take place as quickly as possible after the gases have left the cylinder. Therefore the branches of the exhaust manifold are generally made of about the same section as the valve port. The cross-section of the trunk of the manifold is made two to three times as large as the branch section of the exhaust manifold. Refer Fig. 3.33. In this figure the exhaust manifold has been shown with a branch section from the cylinder and trunk section.

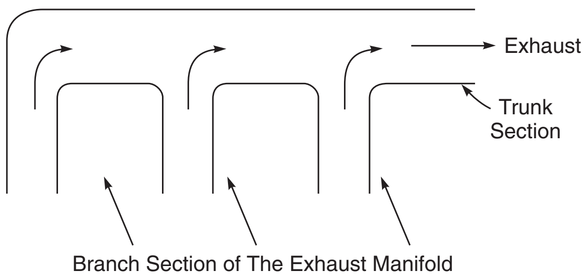



**Fig. 3.33** Exhaust Manifold

**Table 3.1** Comparative Data of Constructional Features of Engines of Some Indian Vehicles

| *S. No. Item* | *Maruti 800* | *Jeep Gypsy* | *Hindustan Ambassador* | *Premier Padmini* | *Jeep (Mahindra) Universal* | *Santro Epsilon Engine* | *Maruti Esteem* | *Maruti Baleno* | *Maruti Zen* |
|---|---|---|---|---|---|---|---|---|---|
| 1. No of cylinders & arrangements | 3 in line | 4 in line | 4 in line | 4 in line | 4 in line | 4 in-line | 4 in-line | 4 in-line | 4 in-line |
| 2. Firing order | 1,3,2 | 1,3,4,2 | 1,3,4,2 | 1,3,4,2 | 1,3,4,2 | 1,3,4,2 | 1,3,4,2 | 1,3,4,2 | 1,3,4,2 |
| 3. Bore | 68.5mm | 65.5mm | 73.02mm | 68mm | 79.3mm | 66mm | 74mm | 75mm | 72mm |
| 4. Stroke | 72mm | 72mm | 88.9mm | 75mm | 111.12mm | 73mm | 75.5mm | 90mm | 61mm |
| 5. Cubic Capacity | 796cc | 970cc | 1489cc | 1089cc | 2199cc | 999cc | 1298cc | 1590 | 993cc |
| 6. Compression ratio | 8.7:1 | 8.8:1 | 7.2:1 | 7.3:1 | 7.4:1 | 8.9:1 | 960.2:1 | 960.2:1 | 8.8:1 |
| 7. Cylinder liner | No separate rate cylinder liner | No cylinder liner | No cylinder liner, originally | Originally, no separate cylinder liner | No cylinder liner | No cylinder liner | No cylinder liner | No cylinder liner | No cylinder liner |
| 8. Piston | Cast aluminium alloy cum concave skirt | Aluminium alloy concave crown split skirt | Aluminium alloy oval tapered split skirt | Aluminium alloy ground T-slot | Aluminium Alloy cam grounded | Cast aluminium alloy | Cast aluminium alloy | Cast aluminium alloy | |
| 9. Compression Rings | 2 | 2 | 3 | 1 | 2 | 2 | 2 | 2 | 2 |
| 10. Oil Control Rings | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| 11. Gudgeon pin connection | Fully floating | Fully floating | Clamped in connecting rod. | Fully floating | Clamped in connecting rod. | Semi floating | Fully floating | Fully Floating | Fully floating |
| 12. No. of crank-shaft main bearings | 4 | 5 | 3 | 3 | 3 | 5 | 5 | 5 | 5 |
| 13. No. of Camshaft bearings | 4 | 5 | 3 | 3 | 3 | 5 | 5 | 5 | 5 |

*Contd.*

*Contd.*

| *S. No. Item* | *Maruti 800* | *Jeep Gypsy* | *Hindustan Ambassador* | *Premier Padmini* | *Jeep (Mahindra) Universal* | *Santro Epsilon Engine* | *Maruti Esteem* | *Maruti Baleno* | *Maruti Zen* |
|---|---|---|---|---|---|---|---|---|---|
| 14. Camshaft drive | Grooved Rubber belt drive | Grooved Rubber belt drive | Chain | Chain | Single helical gear | Cogged belt drive | Grooved belt drive | Grooved belt drive | Grooved belt drive |
| 15. Valve Type | Poppet | Poppet | Poppet | Poppet | Poppet | Poppet | Poppet | Poppet | Poppet |
| 16. Valve Mechanism | Overhead | Overhead | Overhead | Overhead | Overhead inlet and side exhaust | Single over-head cam (SOHC) | Single over-head cam (SOHC) | Single over-head cam (SOHC) | Single over-head cam (SOHC) |
| 17. Valve seat | Originally no separate valve seat insert is fitted. | Originally no separate valve seat insert is fitted. | Originally no separate valve seat insert is fitted | Cadmium steel insert. | Eatonite E.M.S 58. insert for exhaust is fitted. | No separate valve seat | No separate valve seat | No separate valve seat | No separate valve seat |
| 18. Valve seat angle | 45° | 45° | 45° | 45° | 45° | | | | |

## Review Questions

1. List the main components of an automobile engine.
2. Explain the meaning of blow-by in an IC engine.
3. What is a cylinder liner? What is the difference between a dry-liner and wet-liner?
4. What are the different types of crankcases?
5. What are the two types of cylinder designs in use?
6. What is the purpose of the oil pan?
7. Describe the function of the cylinder head gasket.
8. What are the types of gaskets used in automobile engines?
9. What is the purpose of the piston?
10. Explain why pistons need to be light in weight.
11. What are the spaces between the piston ring grooves called?
12. Where is the piston skirt located?
13. What are the three functions performed by piston rings?
14. What is the purpose of compression rings?
15. What is the purpose of the oil control ring?
16. Why is the oil ring inner spacer slotted?
17. What is an end gap?
18. What is the function of the joints in a piston ring?
19. Give reasons for providing joints in a piston ring.
20. Describe the function of a connecting rod and crankshaft.
21. What is the purpose of the spurt hole in the connecting rod?
22. State the function of a vibration damper. How does it work?
23. What is the purpose of the camshaft?
24. Draw an engine valve and name its different parts.
25. Differentiate between a valve seat and a valve face.
26. What is a valve retainer?
27. Explain how the valve spring works to close the valve.
28. What is the necessity for a valve clearance?
29. Why is the intake valve of the gasoline engine opened before top dead centre of the exhaust stroke?
30. Why is the exhaust valve opened during the power stroke?
31. State the two purposes of the flywheel.
32. What is the purpose of manifolds?

# 4

# Engine Maintenance and Troubleshooting

**Objectives**

After studying this chapter, you should be able to:

- State the reasons for preventive maintenance.
- List the basic areas normally serviced as part of preventive maintenance.
- Describe the steps in disassembling an engine for service.
- Explain the main service procedures for reconditioning an engine.
- List the steps for reassembling an engine after service.

## 4.1 INTRODUCTION

In the previous chapters, we have examined the construction and operation of various engine components. In this chapter we will look at repair, service procedures for engine and trouble-shooting of components. We will begin with areas of preventive maintenance. These are very important service operations designed to prevent wear or failure of automobile parts. The manu-facturers of different vehicles detail the procedure of engine assembly and disassembly in their service manual. The servicing procedure for the Maruti car engine has been provided in this chapter.

## 4.2 PREVENTIVE MAINTENANCE

Taking care of your car is a lot like taking care of your teeth. Some people visit the dentist only when they have toothache. The dentist then examines the problem and either repairs, removes or replaces the damaged tooth. Other people visit the dentist once a year whether their teeth hurt or not. The dentist then cleans and inspects the teeth. This is preventive maintenance. Preventive maintenance involves inspecting and replacing parts before they become problems.

There are good reasons for performing preventive maintenance. Safety is greatly increased by changing worn parts. For example, if the fan belt breaks, the water pump will not turn and the engine will overheat. Overheating damages the cylinders, pistons, heads, valves, head gaskets and possibly other parts as well. To avoid this serious damage of engine parts, the faulty or broken belt should be replaced. Preventive maintenance is also cheaper. It is regularly required for high performance of the engine. The parts changed in a regular tune-up keep horsepower at the rated levels. Fuel mileage is increased dramatically through preventive maintenance.

Preventive maintenance is known by several names. Many people simply call it a tune-up. Most shops have a series of services done at specified kilometres. Manufacturers specify the service operations to be carried out every several thousand kilometres to keep warranties in effect as shown in Table 4.1. No matter what the service is called, all of them are some forms of preventive maintenance.

## 4.3 ENGINE MAINTENANCE

As a technician, a large part of your time will be spent on routine engine jobs such as changing oil, inspecting belts and setting the ignition timing. Also important are the regular inspection of the cooling system and overall servicing and regular tune-ups. All are part of preventive maintenance and a very important part of your job. The preventive maintenance schedule for Maruti engines is provided in Table 4.1.

### 1. Cleanliness

A large part of engine maintenance is cleanliness. A clean engine and compartment runs better and longer than a dirty engine. Leaks and broken parts are also easier to spot on a clean car. You can keep a new engine clean by washing it periodically with detergent and water. Be careful to keep water out of the distributor, carburettor and other control components. If the engine is excessively dirty, use a water-soluble grease emulsifier to clean it.

### 2. Oil and Filter

The most important part of engine maintenance is checking the oil and changing the oil. The level of engine oil can be seen on the dipstick, which has index marks, as shown in Fig. 4.1, identifying the low and full level of oil required for the engine.

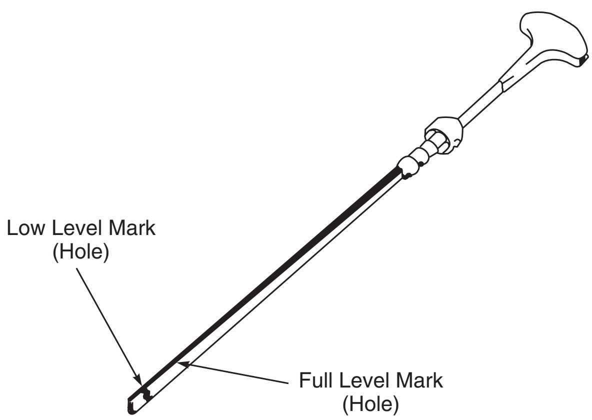



**Fig. 4.1** Dipstick

Many manufacturers suggest changing the oil after every 5000 to 10,000 km.

**Table 4.1** Preventive Maintenance Schedule (*Courtesy:* Maruti Udyog Ltd.)

| *Interval* | *Free services* | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Maintenance service operation* — *Km (x 1.000)* | *0.5-0.8* | *2.0-2.5* | *5.0-5.5* | *10* | *15* | *20* | *25* | *30* | *35* | *40* | *45* | *50* | *55* | *60* | *65* | *70* | *75* | *80* |
| **ENGINE** | | | | | | | | | | | | | | | | | | |
| 1. Water pump drive belt (tension wear) | A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | R | A | 1 | 1 | 1 | 1 | 1 | 1 | R |
| 2. Engine coolant (level. leakage) | 1 | 1 | 1 | 1 | 1 | R | 1 | 1 | 1 | R | 1 | 1 | 1 | R | 1 | 1 | 1 | R |
| 3. Engine oil (level. leakage) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | A PI GRADE SC<br>API GRADE SF | | | | | Replace at an interval of 5,000 km.<br>Replace at an interval of 5,000 km. | | | | | | | | | | | | |
| 4. Cooling system hoses and connections (leakage. damage) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5. Engine oil filter (leakage) | 1 | 1 | 1 | R | 1 | R | 1 | R | 1 | R | 1 | R | 1 | R | 1 | R | 1 | R |
| 6. Engine bolts (All cylinder head and manifold fixing) | - | - | T | - | T | - | T | - | T | - | T | - | T | - | T | - | T | - |
| 7. Engine mounting (loose. damage) | - | - | 1 | - | T | - | T | - | T | - | T | - | T | - | T | - | T | - |
| 8. Valve clearance | - | - | A | - | - | A | - | - | - | A | - | - | A | - | - | - | A | - |
| 9. Camshaft liming belt (damage. wear) | - | - | 1 | - | - | 1 | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 |
| 10. Exhaust system, (noise. leakage or otherwise defective) | - | - | 1 | - | - | 1 | - | 1 | - | 1 | - | 1 | - | 1 | - | 1 | - | 1 |
| 11. Positive Crankcase ventilation System (Hoses. Connections and valve) | - | - | 1 | - | - | 1 | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 |
| **IGNITION** | | | | | | | | | | | | | | | | | | |
| 1. Ignition wiring (damage, deterioration) | - | - | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 |
| 2. Distributor cap and rotor (wear deterioration) | - | - | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 |
| 3. Spark plugs (clean and adjust the gap) | - | - | 1 | R | - | R | - | R | - | R | - | R | - | R | - | R | - | R |
| 4. Distributor breaker point | - | - | 1 | R | - | R | - | R | - | R | - | R | - | R | - | R | - | R |
| 5. Ignition timing | - | A | A | A | - | A | - | A | - | A | - | A | - | A | - | A | - | A |
| 6. Distributor advance | - | - | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 |

*Contd.*

*Contd.*

**CLUTCH AND TRANSMISSION**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Clutch pedal (play) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2. Clutch slipping (or excessive damage) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3. Transmission oil (level, leakage) | 1 | 1 | 1 | 1 | 1 | R | 1 | 1 | 1 | R | 1 | 1 | 1 | R | 1 | 1 | 1 | r |

**NOTE**
**A- ADJUST** **T-TIGHTEN TO THE SPECIFIED TORQUE**
**B- REPLACE OR CHANGE** **I- INSPECT AND CORRECT OR REPLACE IF NECESSARY**
**L- LUBRICATE**

To help engine longevity, change the oil at the intervals specified by the manufacturer. Do not go beyond the manufacturer's recommended oil-change requirements. The oil filter cannot keep the oil perfectly clean as it does not filter out the moisture or acid.

Use a good quality, manufacturer-recommended oil. Maruti recommends the following oils given in Table 4.2 to be used as engine oils.

**Table 4.2** Engine Oils

| *Hindustan Petroleum* | *:* | *Super engine oil 20 W – 40 (SC Grade)* |
|---|---|---|
| Indian Oil | : | Servo Super 20W – 40 (SC Grade) |
| | : | Servo Superior Multigrade 20 W – 40 (S F Grade) |
| Indrol | : | Castrol Super 20W – 50 |
| | : | Castrol GTX 20 W – 50 (S F Grade) |
| Bharat Petroleum | : | Bharat Actuma T-Multigrade oil 20 W – 40 W |
| | : | Bharat Automol Super F-Multigrade 20 W – 40 W oil (S F Grade) |

### 3. Air Filter

The air cleaner sits atop the carburettor or the fuel injection unit. Air cleaners are classified on the basis of principles of filtration and the nature of filtering material. The air cleaners generally used are of the following types—dry type and wet type.

Figure 4.2 shows the exploded view of an air cleaner. In the air cleaner case, a dry-type air cleaner element is provided for filtering out the dirt and dust being drawn from air into the engine for combustion. A damaged element must be replaced with a new one, since it allows dust particles to enter the engine if used as it is. Dust particles can cause wearing of the engine inner parts and this further results in decreased output and increase in fuel consumption.

The wet type air cleaner consists of a filtering element, generally a wire mesh coated with an oil film. The air passes through this element, and the dust particles of the air adhere to the oil film. This type of air cleaner should be cleaned periodically, about every 8000 km, by washing the wire mesh in petrol or paraffin. After drying it properly, it should be coated with engine oil, allowed to drain and again fit for working.

## 4. Coolant Level

The coolant is an antifreeze, a lubricant and a corrosion inhibitor.

To check the coolant level, lift the hood and look at the "see through" water reservoir tank. It is not necessary to remove the radiator cap to check the coolant level.

***Note***

- *Do not remove the reservoir tank cap while the coolant is boiling, and*
- *Do not remove the radiator cap while the engine and radiator are still hot.*
- *Scalding fluid and steam can be blown out under pressure if either cap is taken off too soon.*

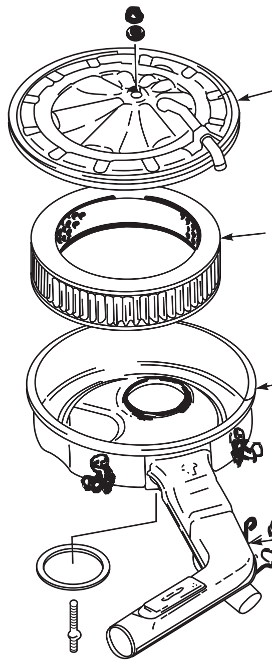



**Fig. 4.2** Exploded View of Air Cleaner (*Courtesy:* Maruti Udyog Ltd.)

When the engine is cool, check the coolant level in the reservoir tank. A normal coolant level should be between "Full" and "Low" marks on the reservoir tank. If the coolant level is below the "Low" mark, remove the reservoir tank cap and add the proper amount of coolant to the tank to bring the level up to the "full" mark.

The average amount of time for replacing the coolant is between one and two years because the additives wear out and become corrosive. The coolant, usually a 1 : 1 mixture of antifreeze (ethylene glycol) and water is used in the cooling system of the automobile.

The long-term reliability and cooling capacity of the engine cooling system depends much on the quality of the cooling water used. Use of hard water and water high in acid concentration will foul up the cooling circuit by scale formation and also promote rusting. For such reasons river water, well water and seawater is not fit to be used as an engine coolant. Distilled water is ideal for the cooling system, but is a luxury in most cases.

## 5. Brake Fluid

Maintaining the brake fluid level in the master cylinder could save a life. If there is an unseen leak in the brake system, the fluid will escape. When all the fluid is gone, so are the brakes. Accidents can be avoided by checking the brake fluid during periodic maintenance. If fluid level is lower than the minimum level, refilling becomes necessary. The reservoir should be filled with one of the brake fluids given in Table 4.3.

**Table 4.3** Brake Fluids

| *Brake fluid* | *Specification* |
|---|---|
| Indian oil | Servo Brake fluid super HD |
| Hindustan Petroleum | HP Superduty Brake fluid |
| Indrol | Castrol Brake fluid crimso |

The brake fluid must be changed every two years.

## 6. Battery

The automobile battery has been described in detail in Section 21.11. In this section, we shall concentrate on the maintenance of the battery. The first step in checking the battery is to look for damage. Check for a cracked case and dirt on top of the battery and the battery carrier hold-down clamp. Clean the battery with water and baking soda solution. Baking soda neutralizes the battery acid. Keep caps on tight when washing.

The next step in checking is to remove the battery caps and determine if the electrolyte (acid) is at the correct level. Usually, this level is marked with a triangle section in the filler neck.

Also check the battery cables each time the hood is opened. Check for corrosion and wear around the insulation and the clamp. The battery should be checked periodically every six months, for specific gravity of battery and also electrolyte against correct values of 1.28 at 27°C.

## 7. Drive Test

Upon completion of all the periodical checks, there are a number of other checks which should be carried out before driving the car or vehicle.

**(i)** ***Engine Start*** Check to ensure that the engine is free from abnormal noise and abnormal vibrations.

**(ii)** ***Clutch*** The following checks should be carried out in case of the clutch:

- The clutch should be completely released when depressing the clutch pedal.
- No slipping of the clutch should occur when releasing the pedal and accelerating, and
- The clutch itself should be free from any abnormal condition.

**(iii)** ***Foot Brake*** The following checks must be carried out when depressing the brake pedal while driving:

- The brake must work properly
- It should be free from noise, and
- The braking force is applied equally on all wheels.

**(iv)** ***Parking Brake*** It should be ensured that the parking brake is fully effective when the car is stopped on a slope and the brake lever is pulled all the way.

**(v)** ***Gear-shift Lever*** The gearshift lever should be checked for smooth shifting to all positions and for good performance of transmission in any position.

**(vi)** ***Steering*** Checks should be carried out to ensure that the steering wheel is free from instability, or abnormal heavy feeling while driving.

**(vii)** ***Meters and Gauge*** The speedometer, odometer, fuel meter and temperature gauge should operate accurately.

**(viii)** ***Oil Pressure and Charging Indicator Lights*** The charging indicator lights should stay off while the engine is operating. If either of them is on during engine operation, it means that something is wrong with the engine lubrication system or the charging system and consequently immediate inspection is necessary.

**(ix)** ***Body, Wheels and Power Transmitting System*** The body, wheels and power transmitting system should be free from abnormal noise and vibrations or any other abnormal condition.

## 4.4 DISMOUNTING THE ENGINE

To prepare for engine overhauling, it is necessary to disconnect the unit from the vehicle. The procedure for dismounting the engine is as follows:

1. Disconnect negative and positive cords from the battery terminals and remove the battery with battery insulation tray. After this has been done, remove the battery bracket.
2. Remove engine hood, front grill, bumper upper member lock, and upper member; remove the head light unit and then the lower grill panel.
3. Remove the battery insulator from the battery tray.
4. Disconnect the radiator fan thermo-switch lead wire at the coupler.
5. Disconnect the radiator fan lead wire at the coupler.
6. Disconnect the radiator outlet hose from the outlet pipe and drain the cooling water.
7. Disconnect the radiator inlet hose from the thermostat cap.
8. Remove the radiator and reserve tank from the body.
9. Pull off the ignition coil high-tension cord from the distributor.
10. Disconnect the lead wire from the distributor terminal.
11. Disconnect the lead wire and positive (+) battery cord from the starter motor.
12. Disconnect the negative (–) battery cord from the transmission case.
13. Disconnect the clutch cable from the clutch release lever and the transmission case.
14. Disconnect the back light switch lead wire at the coupler.
15. Release the transmission breather hose from its clamp.
16. Disconnect the speedometer cable from the transmission case.
17. Disconnect the coupler and lead wire from the alternator terminals.
18. Remove the air cleaner case.
19. Disconnect the choke wire from the carburettor body.
20. Disconnect the accelerator wire from the carburettor body.
21. Disconnect the carburettor solenoid lead wire at the coupler.
22. Disconnect the fuel return hose from the carburettor body.
23. Disconnect the fuel pump inlet hose from the fuel pump.
24. Disconnect the lead wire from the water temperature gauge.
25. Disconnect the lead wire from the oil pressure gauge.
26. Disconnect the heater inlet and outlet hoses from the heater unit. (In case of car heater).
27. Hoist the car.
28. Disconnect the exhaust centre pipe from the exhaust manifold.
29. Disconnect the gearshift control shaft from the transmission case.
30. Disconnect the extension rod from the transmission case.
31. Remove the transmission drain plug-using special tools (Hexagon socket) and drain the transmission oil.
32. Disconnect the drive shafts (left and right) from the differential side gear snap rings.
33. Draw out the drive shafts (right and left) from the differential side gears.
34. Set a piece of wire across the hook on the inlet manifold and the transmission case so that using a chain block can lift the engine.
35. Remove the transmission left side mounting and mounting bracket.

36. Remove the nuts securing the engine mounting (front and rear) to make the engine ready for removal.
37. Take down the engine with transmission.

## 4.5 ENGINE DISASSEMBLY

Engine disassembly is carried out in a sequence, which is outlined in the following paragraphs. In the sequence presented it is assumed that the engine is out of the vehicle. Some of the operations of the procedure are also applicable separately with the engine in the vehicle.

During the disassembly operations the engine should be mounted in a suitable engine repair stand. If an engine repair stand is not available, disassembly operations should be performed in a careful manner to prevent accident and damage to engine parts.

***Note*** *If the engine is being disassembled because of possible valve failure, check the valve tappet clearance before disassembly. Improper valve clearance could be the possible cause of valve failure, indicating a need for frequent valve checks and adjustments.*

1. Remove the starter motor, the engine front side mounting bracket and the clutch housing the lower plate, and loosen the transmission securing bolts after removing the radiator outlet pipe.
2. Take off the transmission from the cylinder block.
3. Remove the drain plug and drain out the engine oil.
4. Remove the clutch cover and clutch disc.
5. Remove the distributor assembly.
6. Remove the fuel pump.

***Note*** *When removing the fuel pump, engine oil in the distributor gear case may come out. So place waste or receiver under the fuel pump.*

7. Take down the distributor case.
8. Take down the alternator.
9. Remove the alternator-mounting stay.
10. Ease out the water pump pulley.
11. Remove the crank pulley with special tools (flywheel holder).
12. Remove the outside cover on the timing belt.
13. Remove the timing belt tensioner after removing a part of the tensioner spring from the water pump-securing bolt.
14. Remove the timing belt.
15. Remove the camshaft timing belt pulley, with special tools (camshaft lock holder).
16. Similarly remove the crankshaft timing belt pulley.
17. After removing the pulley key, take out the timing belt guide.
18. Take down the timing belt inside cover.
19. Remove the alternator bracket.
20. Remove the water pump case.
21. Take off the exhaust manifold cover and the exhaust manifold.
22. Remove the oil filter with special tools (oil filter wrench).

23. Draw bypass hose from the intake manifold.
24. Take down the inlet manifold with the carburettor.
25. Remove the water inlet pipe.
26. Take off the cylinder head cover.
27. Loosen the valve adjusting screws fully. Leave the screws in place.
28. Loosen the rocker arm shaft securing screws.
29. While drawing out the rocker arm shaft, separate the valve rocker arms and the rocker arm springs.
30. Remove the camshaft thrust plate, and draw the camshaft out towards the distributor gear case side.
31. Remove the cylinder head.
    (i) Use the valve lifter and attachment to compress the valve spring in order to free the valve cotter pieces for removal. In this way, remove the valve spring and the valves (see Fig. 4.3).
    (ii) Remove the valve stem oil seal from the valve guide and then the valve spring seat (see Fig. 4.4).

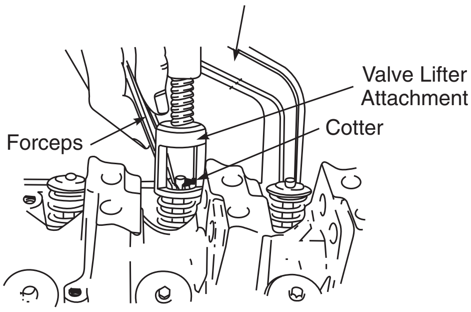



**Fig. 4.3** Removing Valve Spring and Valves

***Note*** *Do not reuse the oil seal once disassembled. Be sure to use a new oil seal when assembling.*

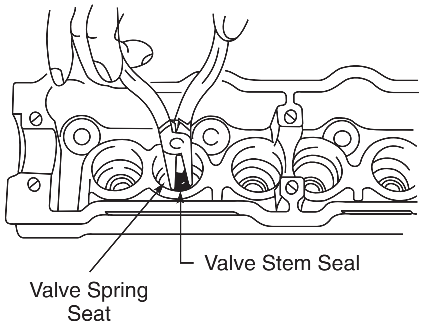



**Fig. 4.4** Removing Valve Stem Seal

    (iii) Using the valve guide remover, drive the valve guide out from the combustion chamber side to the valve spring side as shown in Fig. 4.5.

***Note*** *Do not reuse the valve guide once disassembled. Be sure to use a new valve guide (Oversize) when assembling.*

32. Remove the flywheel, using the flywheel holder.
33. Take down the oil pan.
34. Remove the oil pump strainer.
35. Remove the three connecting rod caps.
36. Install the guide hose over the threads of the rod bolts. This is to prevent damage to the bearing journal and the cylinder wall when removing the connecting rod.
37. De-carbon the top of cylinder bore, before removing the piston from cylinder.
38. Push the piston and the connecting rod assembly out through the top of the cylinder bore.

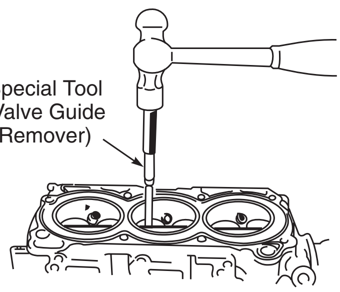



**Fig. 4.5** Removing Valve Guide

***Note***

- *Before pushing the piston out, scribe the cylinder number on its crown.*

- *Be sure to identify each bearing cap for its connecting rod by using the cylinder number. Set the cap and rod aside in combination.*

(i) From each piston, ease out the piston pin circlips, as shown in Fig. 4.6.

(ii) Force the piston pin out as shown in Fig. 4.7.

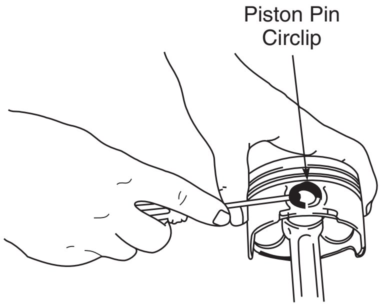



**Fig. 4.6** Removing Piston Pin Circlips

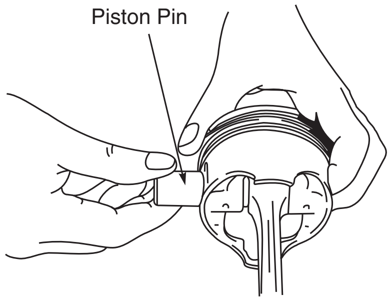



**Fig. 4.7** Removing Piston Pin

39. Remove the oil pump case.

(i) Remove the oil pump gear plates and take out the inner and outer gear as shown in Fig. 4.8.

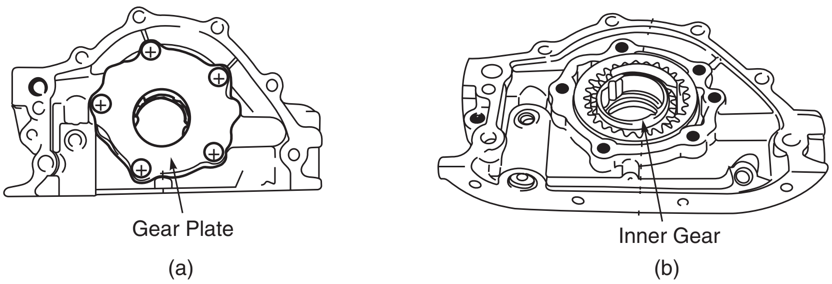



**Fig. 4.8** Removing Gear Plate and Inner Gear

40. Remove the oil seal housing
41. Remove the crankshaft-bearing caps and take out the crankshaft.

## 4.6 INSPECTION OF ENGINE COMPONENTS

The inspection procedures detailed in the following paragraphs cover the complete overhaul of the engine with the unit taken out of the vehicle.

Before commencing the inspection and repair operations, the following instructions should be kept in mind.

(i) During and immediately after disassembly, inspect the cylinder block and head for evidence of water leakage or damage and after washing them clean, inspect more closely.

(ii) Wash all disassembled parts clean, removing grease, slime, carbon and scales. Be sure to de-scale the water jackets.

(iii) Use compressed air to clean internal oil holes and passages.
(iv) Do not disturb the set combinations of valves, bearings and bearing caps etc.

## 1. Cylinder Head

The cylinder head should be properly examined in the following manner:

(i) Remove all carbon from the combustion chambers.

***Note*** *Do not use any sharp-edged tool to scrape off the carbon. Be careful not to scuff or nick the metal surfaces when de-carboning. This applies to valves and valve seats, too.*

(ii) Check the cylinder head for cracks in the intake and exhaust ports, combustion chambers, and the head surface.
(iii) Check flatness of the gasketed surface (Fig. 4.9 and 4.10).

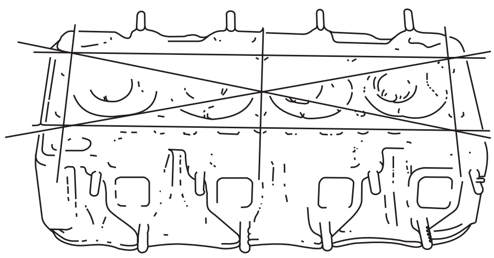


**Fig. 4.9** Locations for Measurement of Distortion of Cylinder Head

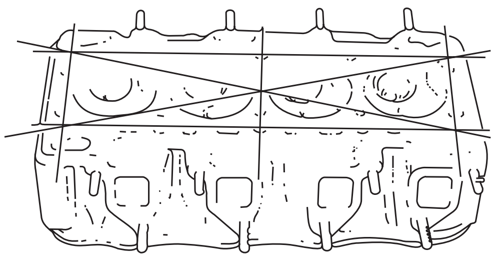


**Fig. 4.10** Surface Measurement of Cylinder Head

Using a straight-edge and thickness gauge, check the surface at a total of eight locations. If the distortion limit of 0.05 mm is exceeded, correct the gasketed surface plate using an abrasive paper of about # 400 (waterproof silicon carbide abrasive paper). Place the paper over the surface plate and rub the gasketed surface to grind off the uneven spots. Should this fail to reduce the thickness gauge readings to within the limit, replace the cylinder head.

Leakage of combustion gases from the gasketed joint often occurs due to a warped gasketed surface. Such leakage results in a reduced power output.

(iv) Check flatness of the manifold seating faces (Figures 4.11 and 4.12).

Check the seating faces of the cylinder head for manifolds, using a straight-edge and thickness gauge, in order to determine whether these faces should be corrected or the cylinder head replaced.

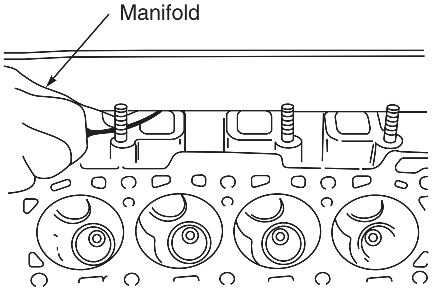



**Fig. 4.11** Measuring Surface of Intake Manifold Seating Face

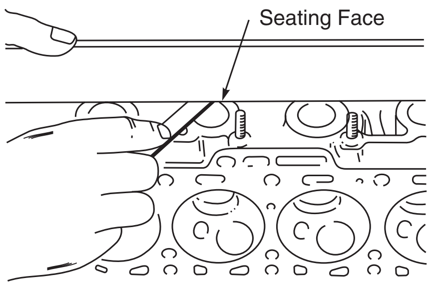



**Fig. 4.12** Measuring Surface of Seating Face

## 2. Rocker Arm (Figure 4.13)

**(a)** ***Adjusting Screw*** If the tip of the adjusting screw in the rocker arm is badly worn, replace the screw. The arm must be replaced if its cam-riding face is badly worn.

**(b)** ***Rocker Arm Spring*** Visually examine each rocker-arm spring for any evidence of breakage or weakening. Be sure to the replace the springs found in bad condition.

**(c)** ***Rocker Arm Shaft***

**(i)** ***Wear*** Check the rocker arm shaft for wear and, as necessary, replace them. The extent of wear is determined on the basis of two readings, one taken on the rocker-arm ID, and the other taken on the shaft diameter as shown in Fig. 4.14 (see Table 4.4).

**(ii)** ***Deflection (Fig. 4.15)*** Set the rocker-arm shaft between two V blocks, and measure its deflection by using a dial gauge. If the measured deflection exceeds specified limit of 0.12 mm, replace the shaft.

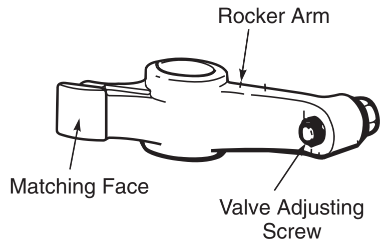



**Fig. 4.13** Valve Rocker Arm and Adjusting Screw

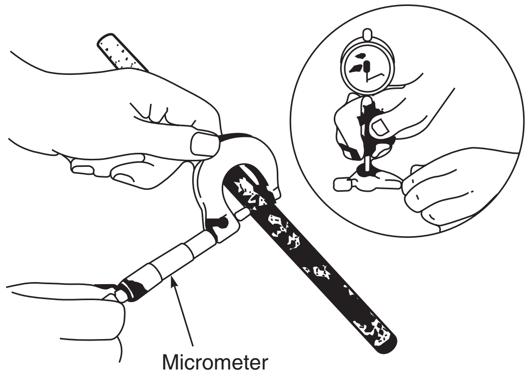



**Fig. 4.14** Measuring Rocker Arm ID and Shaft

**Table 4.4** Rocker Arm Measurements

| *Item* | *Standard* | *Limit* |
|---|---|---|
| Rocker arm ID | 14.985–15.005 | mm |
| Rocker arm shaft diameter | 14.965–14.980 | mm |
| Arm to shaft clearance (inlet and exhaust) | – | 0.07 mm |

## 3. Camshaft

A noisy engine or an engine not producing enough power frequently has an excessively worn-out camshaft or a camshaft which is bent or bowed. The wearing often occurs on the cams and journals of the camshaft.

**(a)** ***Cam Wear (Fig. 4.16)*** Using a micrometer, measure the height of each cam. If the measured height is below its limit (Table 4.5), replace the camshaft.

**Table 4.5** Cam Height

| *Cam height (H)* | *Standard (mm)* | *Limit (mm)* |
|---|---|---|
| Inlet cam. | 36.152 | 36.100 |
| Exhaust cam. | 36.152 | 36.100 |
| Pump drive cam | 33.300 | 33.000 |

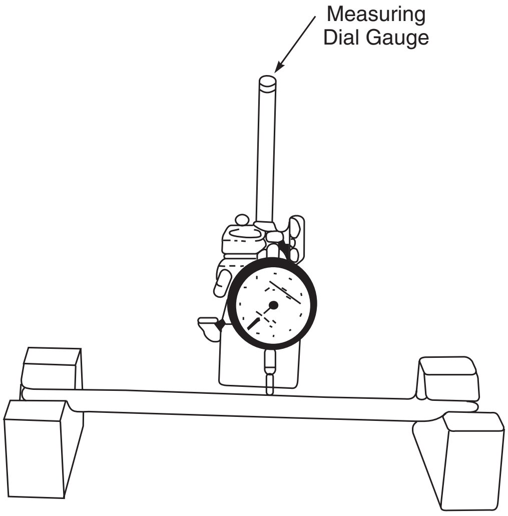



**Fig. 4.15** Measuring Shaft Deflection

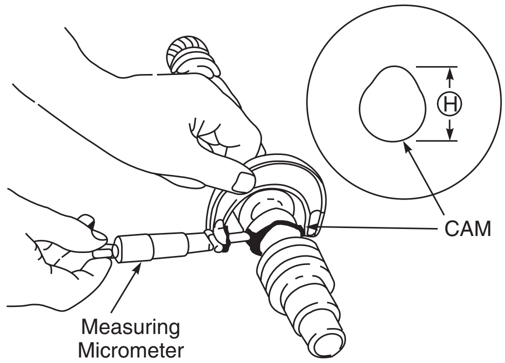



**Fig. 4.16** Measuring Cam Height

**(b) *Deflection (Fig. 4.17)*** Set the camshaft between two V blocks, and measure its deflection by using a dial gauge. If the measured deflection exceeds the specified limit of 0.10 mm, replace the camshaft.

**(c) *Journal Wear*** Check the camshaft journals and the camshaft housings for pitting, scratches, wear or damage.

If any wear is found, replace the camshaft or the cylinder head.

Using a micrometer, measure the journal diameter in two directions at four places to obtain four readings on each journal, and check the journal bores with a cylinder gauge as shown in Figs 4.18 and 4.19 producing four readings on each. From these readings, compute the radial clearance (journal clearance).

If the computed radial distance exceeds specified limits (Table 4.6), replace both the camshaft and the cylinder head.

**(d) *Thrust Clearance (Figure 4.20)*** Using a thickness gauge measure the thrust clearance. If the measured clearance exceeds specified limit (Table 4.7), replace the thrust plate or camshaft.

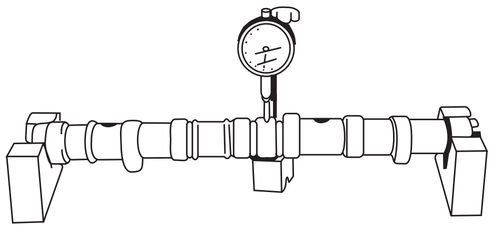


**Fig. 4.17** Measuring Camshaft Deflection

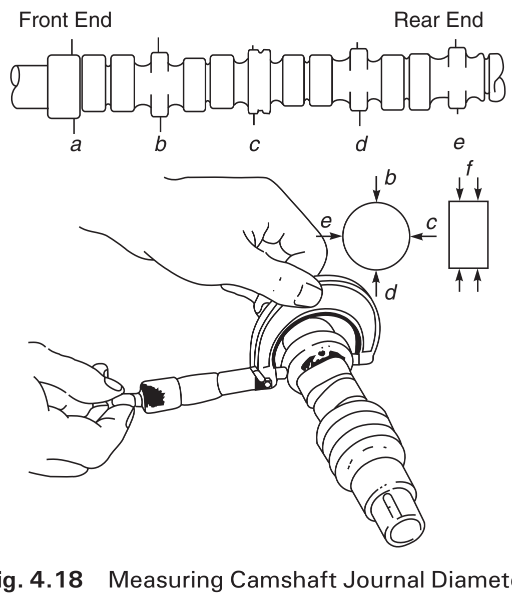



**Fig. 4.18** Measuring Camshaft Journal Diameter

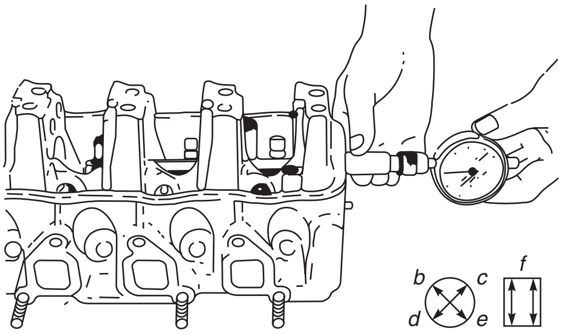



**Fig. 4.19** Measuring Journal Bore Diameter

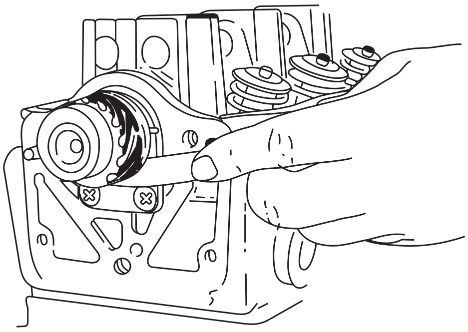


**Fig. 4.20** Measuring Thrust Clearance

**Table 4.6** Journal Diameter

| *Place* | *Journals Diameter (mm)* | *Journal bore Diameter (mm)* |
|---|---|---|
| (a) | 43.425–43.450 | 43.500–43.516 |
| (b) | 43.625–43.650 | 43.700–43.716 |
| (c) | 43.825–43.850 | 43.900–43.916 |
| (d) | 44.025–44.050 | 44.100–44.116 |
| (e) | 44.225–44.250 | 44.300–44.316 |
| Journal Clearance | Standard (mm)<br>0.050–0.091 | Limit (mm)<br>0.11 |

**Table 4.7** Thrust Clearance

| *Thrust* | *Standard* | *Limit* |
|---|---|---|
| Clearance | 0.05–0.15 mm | 0.30 mm |

## 4. Valve Guides

Using a micrometer and bore gauge, take diameter readings on valve stems and guides to check the stem-to-guide clearance. Be sure to take readings at several places along the length of each stem and guide as shown in Fig. 4.21. If the clearance exceeds the limit (Table 4.8), replace the valves and the valve guide.

If the bore gauge is not available, check the end deflection of the valve stem with a dial gauge.

Move the stem end in directions 1 and 2 to measure the end deflection (see Fig. 4.22).

If the deflection exceeds its limit (Table 4.9), replace the valve stem and valve guide.

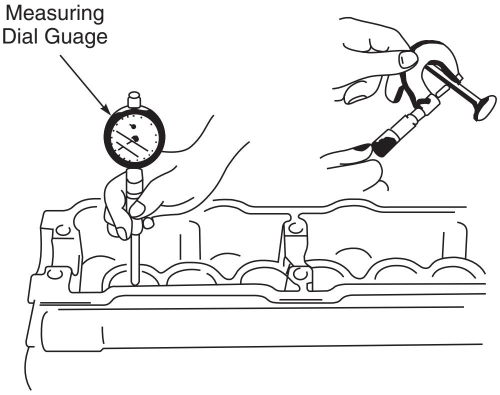



**Fig. 4.21** Measuring Valve Stem Diameter and Valve Guide Internal Diameter

**Table 4.8** Valve Stem and Valve Guide Diameter

| *Item* | | *Standard* | *Limit* |
|---|---|---|---|
| Valve Stem diameter | In | 6.965-6.980 mm (0.2742–0.2748 in.) | — |
| | Ex | 7.000-7.015mm (0.2756–0.2761 in) | — |
| Valve guides ID | In | 7.000-7.015mm (0.2756-0.2761 in.) | — |
| | Ex | 7.000-7.015mm (0.2756-0.2761 in) | — |
| Stem to guide clearance | In | 0.020-0.050mm (0.0008-0.0019 in.) | 0.07 mm (0.0027 in.) |
| | Ex | 0.035-0.050 mm (0.0014-0.0025in) | 0.09 mm (0.0035 in.) |

**Table 4.9** Valve Stem End Deflection

| *Valve stem end deflection limit* | *Inlet* | *0.14 mm (0.005 in.)* |
|---|---|---|
| | Exhaust | 0.18 mm (0.007 in.) |

## 5. Valves

Valves used in engines should be examined in the following manner:

(i) Remove all carbon from the valves.
(ii) Inspect each valve for wear, burn or distortion at its face and stem and as necessary, replace it.
(iii) Measure the thickness of the valve head (Fig. 4.23). If the measured thickness exceeds the prescribed limits (Table 4.10), replace the valve.

**Table 4.10** Valve Head Thickness

| *Valve* | *Standard* | *Limit* |
|---|---|---|
| Inlet | 1.0 mm (0.039 in.) | 0.6 mm (0.023 in). |
| Exhaust | 1.2 mm (0.047 in.) | 0.7 mm (0.027 in). |

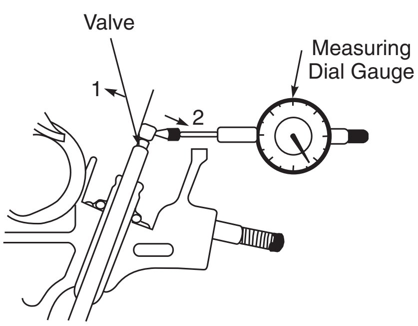



**Fig. 4.22** Measuring Valve End Diameter

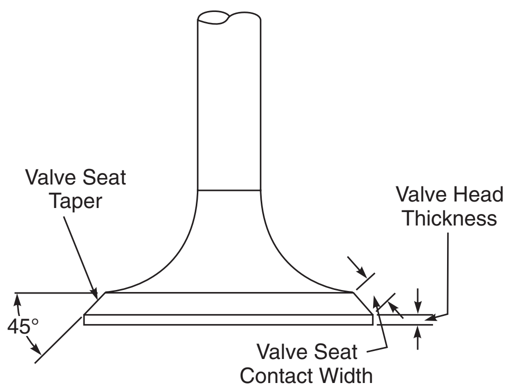



**Fig. 4.23** Valve Head Thickness

(iv) Inspect the valve stem end face for pitting and wear. If any pitting or wear is found the valve stem end may be re-surfaced, but not so much as to grind off its chamfer. When it is worn so much that its chamfer is gone, replace the valve (Refer Fig. 4.24).

(v) Check each valve for radial runout with a dial gauge and a V block. To check runout, rotate the valve slowly. If the measured runout exceeds the limit, i.e. 0.08 mm/0.003 in., replace the valve.

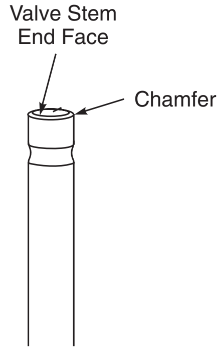



**Fig. 4.24** Valve Stem End Face

**(a) *Seating Contact Width*** Produce a contact pattern on each valve in the usual manner, that is, by giving a uniform coat of red-lead paste to the valve seat and by rotatingly taping each seat with the valve head. The valve lapper (the tool used in valve lapping) must be used for this purpose (Fig. 4.25).

The pattern produced on seating face of each valve must be a continuous ring without any break, and the width of pattern must be within the following specification (Table 4.11).

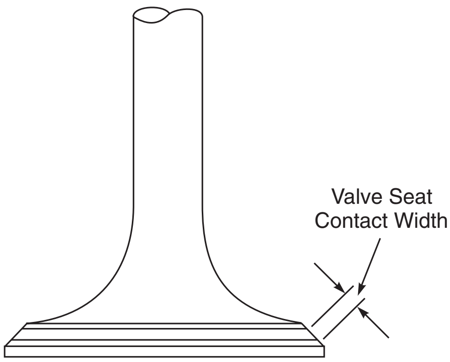



**Fig. 4.25** Valve Seating Contact Width

**(b) *Valve Seat Repair*** A valve seat not producing a uniform contact with its valve or showing seating contact that is off the specified width must be repaired by regrinding or by cutting and regrinding and finished by lapping.

**Table 4.11** Valve Seating Contact Width

| | | |
|---|---|---|
| Standard seating width revealed by contact pattern on valve face | Inlet<br>Exhaust | 1.3-1.5 mm<br>(0.0512-0.0590 in.) |

**(c) *Exhaust Valve Seat*** A valve seat cutter is used to make three cuts for the exhaust valve in the order illustrated in Fig. 4.26. Three cutters must be used: the first for making the 15° angle, the second for making the 75° angle and the third for making the 45° seat angle. The third cut must be made to produce the desired seat width.

**(d) *Intake Valve Seat*** The cutting sequence for the intake valve seat is the same as for the exhaust valve seats but the second angle is different as shown in Fig. 4.27.

**(e) *Valve Lapping*** Lap the valve on the seat in two steps, first with a coarse size lapping compound applied to the face and the second with a fine size compound, each time using a valve lapper according to the usual lapping method (Figs 4.28 and 4.29).

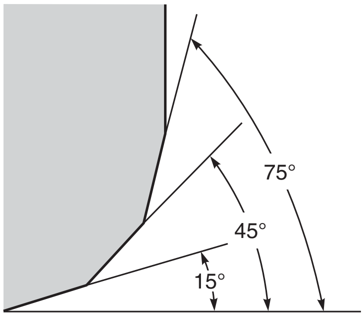



**Fig. 4.26** Valve Seat Angles for Exhaust Valve

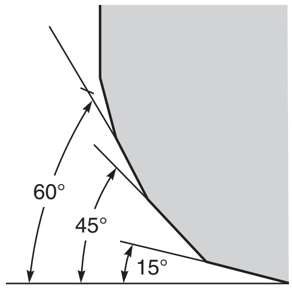



**Fig. 4.27** Valve Seat Angles for Intake Valve

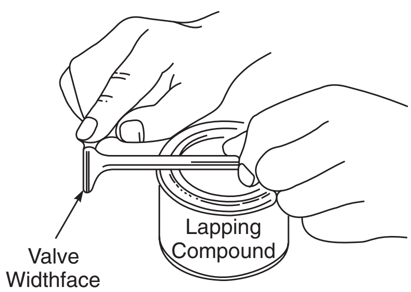



**Fig. 4.28** Apply Lapping Compound to Valve Width Face

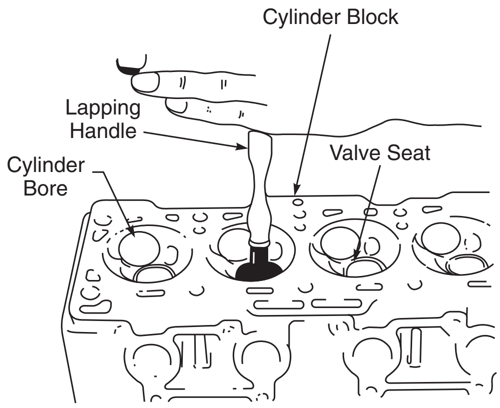



**Fig. 4.29** Lapping for Valve Seats

***Note***

- *After lapping, wipe the compound off the valve face and seat, and produce a contact pattern with a red-lead paste. Check to be sure that the contact is centered width wise on the valve seat and that there is no break in the contact pattern ring.*
- *Be sure to check and, as necessary, adjust the valve clearance after re-installing the cylinder head and valve mechanism.*

## 6. Valve Springs

Inspection of valve springs is carried out in the following manner.

(i) Referring to data given in Table 4.12, ensure that each spring is in sound condition, free of any evidence of breakage or weakening. Remember, weakened valve springs can cause chatter, not to mention the possibility of reducing the power output due to gas leakage caused by decreased seating pressure. Figure 4.30 shows the measuring of the free length of spring.

(ii) Spring squareness (Fig. 4.32).

**Table 4.12** Valve Spring Length

| *Item* | *Standard* | *Length* |
|---|---|---|
| Valve spring free length | 48.9 mm | 47.6 mm |
| Valve spring preload | 23.6-27.6 kg for 40 mm | 22 kg for 40 mm |

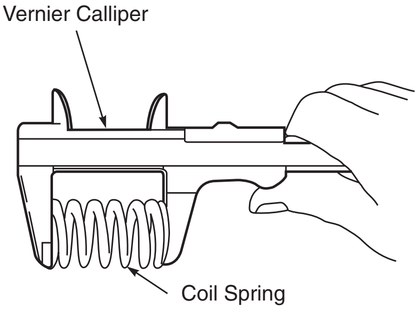



**Fig. 4.30** Measuring Free Length of Spring

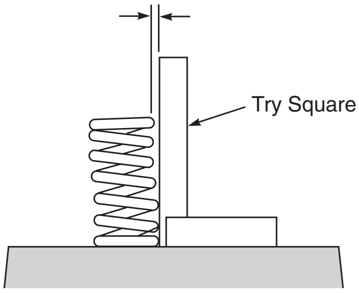



**Fig. 4.31** Measuring Spring Squareness

Use a square and surface plate to check each spring for squareness in terms of the clearance between the end of the valve spring and the square. Valve springs found to exhibit a clearance larger than the limit of 2.0 mm, must be replaced.

## 7. Cylinder Block

The following checks should be carried out in case of a cylinder block:

(a) Distortion of gasketed surface

Using a straightedge and a thickness gauge, check the gasketed surface for distortion and if the flatness exceeds the prescribed limit of 0.05 mm, correct it.

(b) Honing or reboring cylinders

(i) Inspect cylinder walls for scratches, roughness or ridges, which indicate excessive wear. If the cylinder bore is very rough or deeply scratched, or ridged, rebore the cylinder and use an oversize piston.

(ii) Using a cylinder gauge, measure the cylinder bore in thrust and axial directions at the three positions as shown in Fig. 4.32 and Fig. 4.33.

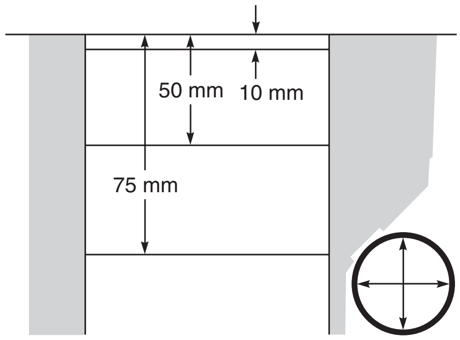



**Fig. 4.32** Positions to be Measured

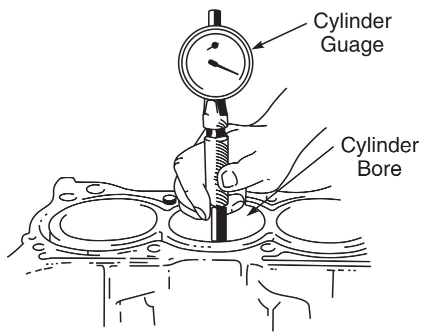



**Fig. 4.33** Measuring Cylinder Bore

If any of following conditions are noted, rebore the cylinder.

1. Cylinder bore diameter exceeds limit (Table 4.13).
2. Cylinder measurements at two positions exceeds taper limit (Table 4.13).
3. Difference between the thrust and axial measurements exceeds the out-of-round limit.

**Table 4.13** Cylinder Block Measurements

| | |
|---|---|
| Cylinder bore dia. limit | 65.520 mm |
| Taper and out of round limit | 0.10 mm |

***Note*** *If any one of three cylinders has to be rebored, rebore the three to the same next oversize. This is necessary for the sake of uniformity and balance.*

## 8. Pistons

The following points should be noted while inspecting pistons:

(i) Inspect the piston for faults, cracks or other damages. Damaged or faulty pistons should be replaced.

(ii) Piston diameter

As indicated in Fig. 4.34, piston diameter should be measured at a position 30 mm, (1.18-inch) from the piston skirt end in the direction perpendicular to the piston pin (see Table 4.14).

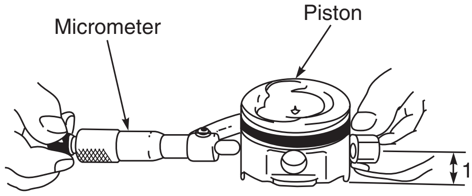



**Fig. 4.34** Measuring Piston Diameter

(iii) Piston clearance

Measure the cylinder bore diameter and the piston diameter to find their difference, which gives the piston clearance. Piston clearance should be within the specified limit of 0.04. If the piston clearance does not match the specifications, rebore the cylinder and use an oversize piston.

(iv) Ring groove clearance

Before any checking is carried out, ensure that the piston grooves are clean, dry and free of carbon.

Fit the new piston ring into the piston groove, and measure the clearance between the ring and the ring land by using a thickness gauge as shown in Fig. 4.35.

If the clearance does not match the specifications, replace the piston. For specifications refer to Table 4.15.

**(a)** ***Piston Rings*** To measure the end gap, insert the piston ring into the cylinder bore as shown in Fig. 4.36 and then measure the gap by using a thickness gauge.

If the measured gap does not meet the specifications shown in Table 4.16, replace the ring.

**Table 4.14** Piston Diameter Measurements

| | |
|---|---|
| Piston diameter | |
| Standard | 65.460-65.475mm |
| Oversize : 0.25 mm | 65.710-65.725 mm |
| 0.50 mm | 65.950-65.995 mm |

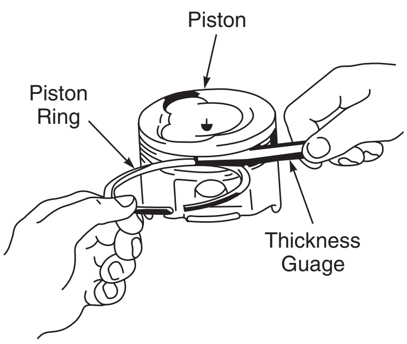



**Fig 4.35** Measuring Ring Groove Clearance

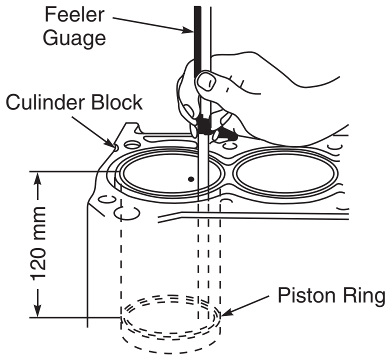



**Fig 4.36** Measuring Piston Ring End Gap

**Table 4.15** Ring Groove Clearance

| | | *Standard* | *Limit* |
|---|---|---|---|
| Ring Groove Clearance | Top | 0.03 -0.7 mm | 0.12 mm |
| | 2nd | 0.02-0.06 mm | 0.10 mm |

***Note:*** *Decarbon and clean the top of cylinder bore before inserting piston ring.*

**Table 4.16** Piston Ring End Gap

| | | *Standard* | *Limit* |
|---|---|---|---|
| Piston ring end gap | Top ring 2nd ring | 0.15-0.35 mm | 0.7 mm |
| | Oil ring | 0.30-0.90 mm | 1.8 mm |

**(b) *Piston Pin***

(i) Check the piston pin, the connecting rod small end bore and the piston bore for wear or damage, paying particular attention to the condition of the small end bore bush. If the pin, connecting rod small end bore or piston bore are badly worn or damaged, replace the pin, connencting rod or piston.

(ii) Piston pin clearance

Check the piston pin clearance in the small end. Replace the connecting rod if its small end is badly worn or damaged or if the clearance exceeds the limits shown in Table 4.17.

**Table 4.17** Piston Pin Measurements

| | *Standard* | *Limit* |
|---|---|---|
| Pin clearance in small end | 0.003-0.016 mm | 0.05 mm |
| Small-end bore | 16.003-16.011 mm | |
| Piston pin dia. | 15.995-16.000 mm | |

## 9. Connecting Rod

The following checks should be carried out in case of a connecting rod:

**(a) *Big End Side Clearance*** Check the big end of the connecting rod for side clearance, with the rod fitted and connected to its crank pin in the normal manner. If the measured clearance is found to exceed its limit (Table 4.18), replace the connecting rod.

**Table 4.18** Big End Side Clearance

| *Item* | *Standard* | *Limit* |
|---|---|---|
| Big-end side | 0.10-0.20 mm | 0.30 mm |

**(b) *Connecting Rod Alignment*** Mount the connecting rod on the aligner to check it for bow and twist and if limit is exceeded (Table 4.19), replace it.

**Table 4.19** Connecting Rod Alignment

| | |
|---|---|
| Limit on bow | 0.05 mm |
| Limit on twist | 0.10 mm |

## 10. Crank Pin and Connecting Rod Bearings

Inspection of the crank pin and the connecting rod bearings is carried out in the following ways:

(a) Inspect the crank pin for uneven wear or damage. Measure the crank pin for out-of-round or taper with a micrometer. If the crank pin is damaged, or the out-of-round or taper is out of limit, replace the crankshaft or regrind the crank pin to the undersize bearing (Refer to Table 4.20).

**Table 4.20** Crank Pin and Connecting Rod Bearing Measurements

| *Connecting rod bearing size* | *Crank pin diameter (mm)* |
|---|---|
| Standard twist | 37.985-38.000 |
| 0.25 mm Undersize | 37.735-37.750 |
| Limit on twist | 0.50 Undersize |
| Out-of-round and taper limit | 0.01 |

(b) Rod Bearing:

Inspect the bearing shells for signs of fusion, pitting, burns or flaking and observe the contact pattern. Bearing shells found in defective condition must be replaced.

Two kinds of rod bearings are available: the standard size bearing and the 0.25-mm undersize bearing.

(c) Rod Bearing Clearance:

(a) Before checking the bearing clearance, clean the bearing and the crank pin.
(b) Install the bearing in the connecting rod and the bearing cap.
(c) Place a piece of gaging plastic along the full width of the crank pin as contacted by the bearing (parallel to crankshaft), avoiding the oil hole.

(d) Install the rod-bearing cap on the connecting rod. When installing the cap, be sure to point the arrow mark on the cap to the crankshaft pulley side, as shown in Fig. 4.37. After applying engine oil to the rod bolts, tighten the cap nuts to the specified torque (Table 4.21). Do not turn the crankshaft with the gaging plastic installed.

**Table 4.21** Torque for Rod Bearing Cap Nuts

| Tightening, torque for | N-m | g-mm | Ib-ft |
|---|---|---|---|
| rod bearing cap nuts | 28-32 | 2.8-3.2 | 20.0-24.0 |

(e) Remove the cap using a scale on the gaging plastic envelop, and measure the gaging plastic width at the widest point (clearance) as shown in Fig. 4.38.

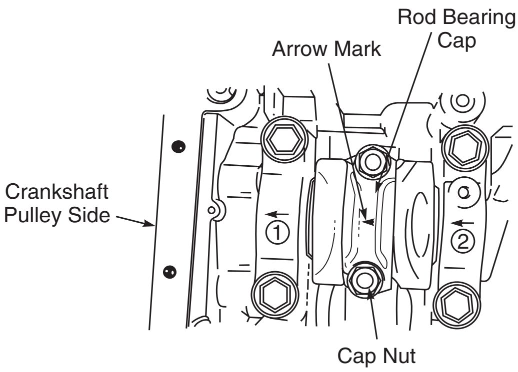



**Fig. 4.37** Installing Bearing Cap

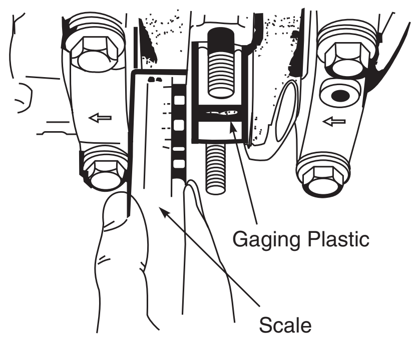



**Fig. 4.38** Measuring Rod Bearing Clearance

If the clearance exceeds its limit (Table 4.22), use a new standard size bearing and remeasure the clearance.

(f) If the clearance cannot be brought to within its limit even by using a new standard size bearing, regrind the crank pin to undersize and use a 0.25 mm undersize bearing.

**Table 4.22** Bearing Clearance

| | *Standard* | *Limit* |
|---|---|---|
| Bearing clearance | 0.020-0.040 mm | 0.080 mm |

## 11. Crankshaft

The following points should be noted when inspecting a crankshaft:

(i) Crankshaft Runout (Figure 4.39)

Using a dial gauge, measure the runout at the centre journal. Rotate the crankshaft slowly. If the runout exceeds the limit of 0.06 mm, replace the crankshaft.

(ii) Crankshaft Thrust Play (Fig. 4.40)

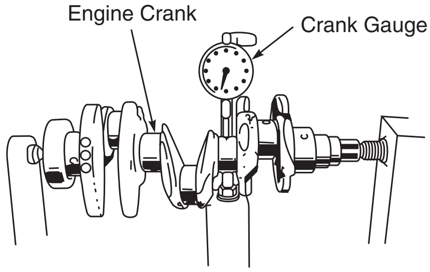



**Fig. 4.39** Measuring Runout

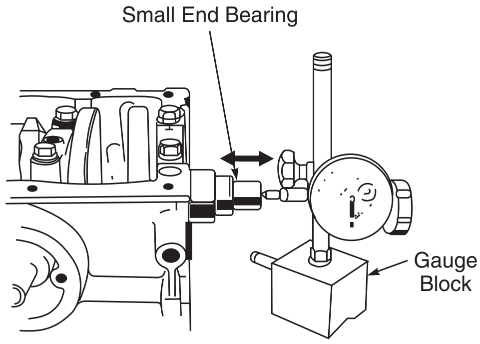



**Fig. 4.40** Measuring Thrust Play of Crankshaft

Measure the crankshaft thrust play with the crankshaft set in the cylinder block in the normal manner, that is, with the thrust bearing and the journal bearing caps installed. Tighten the bearing caps bolts to the specified torque (Table 4.23).

**Table 4.23** Torque for Main Bearing Cap Bolts

| | | | |
|---|---|---|---|
| Tightening torque for | N-m | kg-mm | Ib-ft |
| main bearing cap bolts | 43-48 | 4.3-4.8 | 32.25-36 |

Use a dial gauge to read the displacement in the axial (thrust) direction of the crankshaft.
If its limit is exceeded (Table 4.24), replace the thrust bearing with the new standard one or with the oversize to obtain the standard thrust play.

**Table 4.24** Crankshaft Thrust Play and Thrust Bearing Measurements

| *Item* | *Standard mm* | *Limit mm* |
|---|---|---|
| Crankshaft thrust play | 0.13-0.28 | 0.35 |
| Thickness of crankshaft thrust bearings | Standard | 2.500 |
| | Oversize: 0.125 | 2.563 |
| | Oversize 0.250 | 2.652 |

(iii) Out-of-round and taper (uneven wear) of journals (Fig. 4.41)

An unevenly worn crankshaft journal shows up as a difference in diameter at a cross-section or along its length (or both). This difference, if any is determined by taking micrometer readings.

If any one of the journals is badly damaged or if the amount of uneven wear in the sense explained in the proceeding paragraph exceeds its limit, regrind or replace the crankshaft.

Limit on out of round and taper 0.01 mm

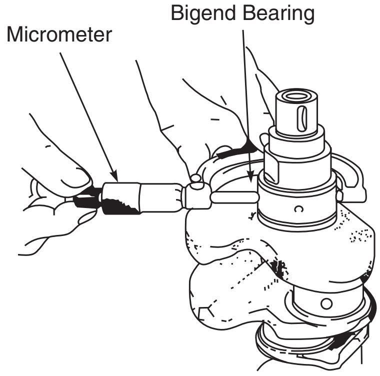



**Fig. 4.41** Checking Uneven Wear

### 12. Main Bearings

The main bearings should be checked for pitting, scratches, wear or damage. If any wear or damage is found, both the upper and lower halves are replaced. One half of the bearing is never replaced without replacing the other half.

(i) Main Bearing Clearance (Fig. 4.42)

Check main bearing clearance by using a gaging plastic according to the following procedure:

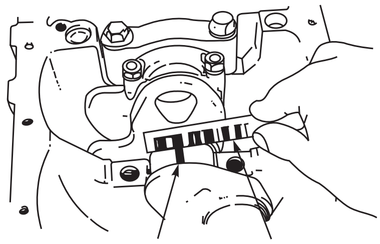



**Fig. 4.42** Measuring Main Bearing Clearance

(a) Remove the bearing and the main caps.
(b) Clean the bearings and the main journals.
(c) Place a piece of gaging plastic along the full width of the bearing (parallel to the crankshaft) on the journal, avoiding the oil hole.
(d) Install the bearing cap as previously specified and evenly tighten the cap bolts to the specified torque. The bearing cap must be torqued to specifications in order to assure the proper reading of clearance (Table 4.25).

**Table 4.25** Bearing Clearance

| Bearing Clearance | Standard | Limit |
|---|---|---|
| | 0.02-0.04 mm | 0.06 mm |

***Note*** *Do not rotate the crankshaft while the gaging plastic is installed.*

(e) Remove the cap, and using a scale on the gaging plastic envelop, measure the gaging plastic width at its widest point. If the clearance exceeds its limit, replace the bearing. Always replace both the upper and lower inserts as a unit.

A new standard bearing may produce the proper clearance. If not, it will be necessary to regrind the crankshaft journal for the use of 0.25 mm undersize bearing.

After selecting the new bearing, recheck the clearance.

### 13. Rear Oil Seal

Carefully inspect the oil seal for wear or damage (Fig. 4.43). If its lip is worn or damaged, replace it.

### 14. Flywheel

The flywheel (Fig. 4.44) is inspected for the following conditions:

(i) If the ring gear is damaged, cracked or worn, replace the flywheel.
(ii) If the surface in contact with the clutch disc is damaged, or excessively worn, replace the flywheel.
(iii) Check the flywheel for face runout with a dial gauge. If the runout exceeds the limit of 0.02 mm, replace the flywheel.

## 4.7 ENGINE REASSEMBLY

Engine reassembly is the reverse process of engine disassembly as far as sequence is concerned. However, there are many reassembling steps that involve certain measures necessary for

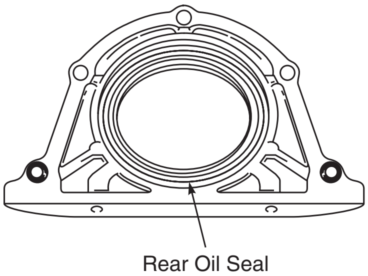



**Fig. 4.43** Rear Oil Seal

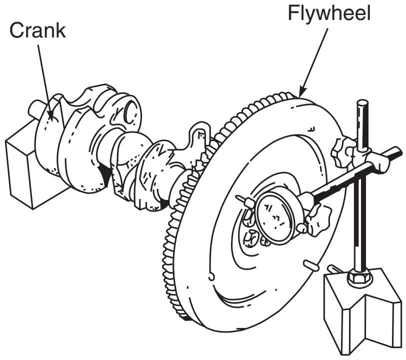



**Fig. 4.44** Measuring Runout

restoring the engine as close to the factory assembled condition as possible. Some of these steps involved are:

(a) Be sure to oil the crankshaft journals, journal bearings, thrust bearings, crank pins, connecting rod bearings, pistons, piston rings and cylinder bores.
(b) Journal bearings, bearing caps, connecting rods, rod bearings, rod bearing caps, pistons and piston rings form a set of combinations. Do not disturb such combinations and make sure that each part goes back where it came from, when installing.
(c) There are many running clearances. During the course of engine reassembly be sure to check these clearances, one after another as they occur.
(d) Gaskets, 'O' rings and similar sealing members must be in perfect condition. For these members, use replacement parts in stock.
(e) The tightening torque is specified for important fasteners, bolts and nuts in the main of the engine and other components. Use torque wrenches and constantly refer to the specified values given in the manufacturer's service manual.

### 1. Crankshaft

(i) Install main bearing to cylinder block; (Fig. 4.45). Between two halves of the main bearing one side has the oil groove. Install this half with the oil groove on the cylinder block, and the other half without the oil groove on the bearing cap.
(ii) Figure 4.46 shows the installing of the thrust bearing on the cylinder block between the second and third cylinders. The sides of the oil groove must face the crank webs.
(iii) Install crankshaft on the cylinder block.
(iv) When fitting the crankshaft-bearing caps to journals after setting the crankshaft in place, be sure to point the arrow mark to the crankshaft pulley side as shown in Fig. 4.47. Fit them sequentially in ascending order 1, 2, 3, 4 and 5 starting from the pulley side.

Gradual and uniform tightening is important for bearing cap bolts. Make sure that the four caps become equally tight progressively till the specified torque is attained. The tightening torque for bearing cap bolts as recommended by Maruti ranges from 4.3 kg-m to 4.8 kg-m.

***Note*** *After tightening the cap bolts, check to ensure that the crankshaft rotates smoothly when turned by hand.*

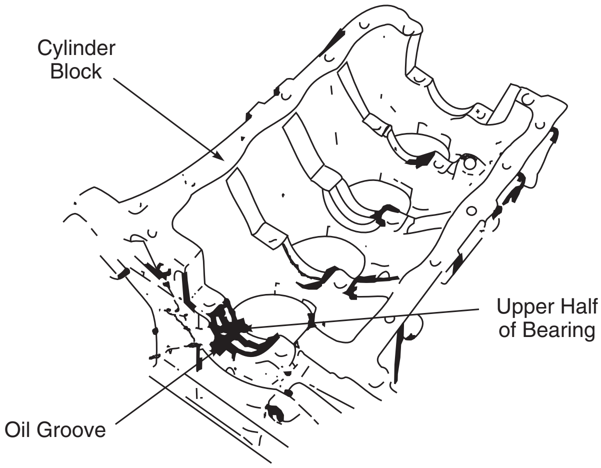



**Fig. 4.45** Installing Bearing Half with Oil Groove

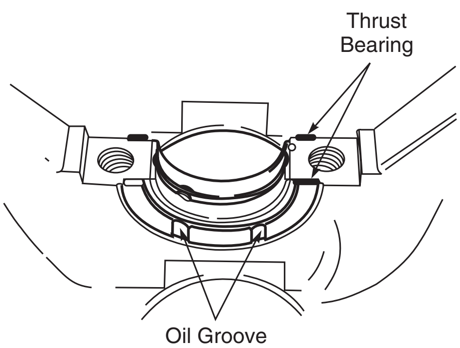



**Fig. 4.46** Installing Thrust Bearing

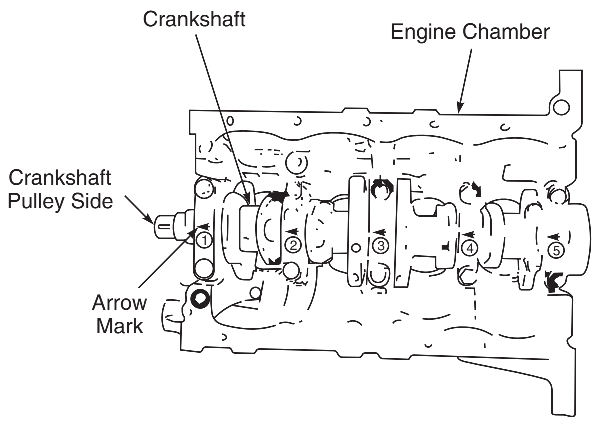



**Fig. 4.47** Installing Main Bearing Caps

## 2. Oil Seal Housing

In case of the oil seal housing first install a new gasket. Apply lithium grease to the oil seal lip portion. After installing the oil seal housing, the gasket edges might bulge out. If so, cut off the edges to make the input seam flat and smooth using a sharp knife.

## 3. Oil Pump

Reassemble the components of the oil pump assembly according to the following procedure:

(i) Wash, clean and then dry all disassembled parts.
(ii) Apply a thin coat of engine oil to the inner and outer gears, the oil seal lip portion and inside the surface of the oil pump case and plate.
(iii) Install the outer and inner gear on the pump case.
(iv) Install the gear plate.
(v) After installing the plate, ensure that the gears turn smoothly by hand.

Installation of oil pump is carried out in following steps.

(i) Install the two oil pump pins and the oil pump's gasket onto the cylinder block. Use a new gasket.

(ii) To prevent the oil seal lip from becoming damaged or upturned when installing the oil pump onto the crankshaft, fit the oil seal guide to the crankshaft and apply engine oil to it.

(iii) Install oil pump to the crankshaft and the cylinder block. After installing the oil pump, ensure that the oil seal lip is not upturned.

## 4. Piston and Piston Rings

For reassembling the piston and piston rings the following points should be noted:

(i) Position of the piston relative to the connecting rod

The arrow on the crown points to the crankshaft pulley side and the oil hole is on the inlet port side. Fit the connecting rod to the piston as indicated in Fig. 4.48 inserting the piston pin in the piston and the connecting rod. Finally, install the piston pin circlip.

(ii) Install piston rings on the piston.

(a) As indicated in Fig. 4.49, the first and second rings are marked 'RN', 'T' or 'R' respectively. When installing these piston rings on the piston, direct the marked side of each ring towards the top of the piston.

(b) When installing the oil ring, install the spacer first and then the two rails.

(c) After installing the three rings, distribute their end gaps as shown in Fig. 4.50.

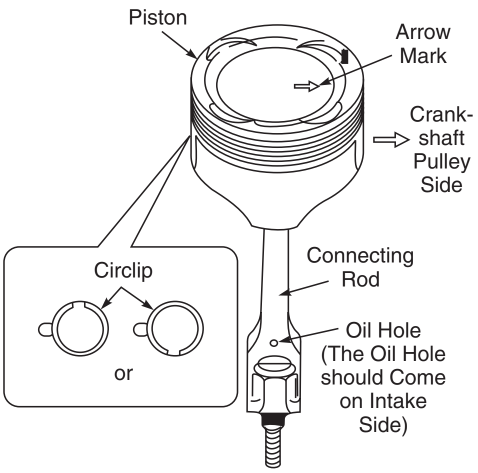



**Fig. 4.48** Fitting Connecting Rod to Piston

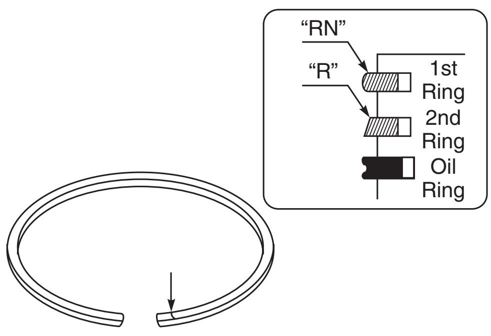



**Fig. 4.49** Installing Piston Ring

## 5. Connecting Rods

In the connecting rod, two stoppers determine the position of each big-end bearing cap relative to the big end. At the time of installing these caps, be sure to locate the stopper of the cap in the direction of stopper.

After fitting all three big-end bearing caps, start tightening them uniformly, making sure to equalize the tightness between the right and left on each cap.

Special care should be taken when installing the connecting rod that the studs on the rod do not hit the crankshaft journal. The stud may be covered with a rubber hose or special aluminum guides.

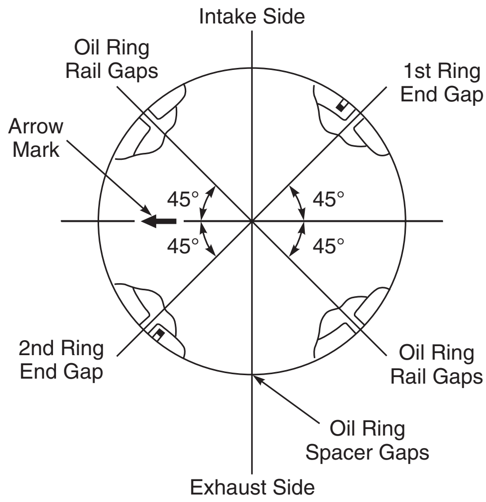



**Fig. 4.50** Piston Ring End Gaps Positions

## 6. Flywheel

The most important step in the installation of the flywheel is to check that the locating pin is studded in the crankshaft.

## 7. Cylinder Head

Reassembling the cylinder head involves the following steps:

(i) Before installing the valve guide into the cylinder head, ream the guide hole with a special tool (12 mm reamer) to remove burns and make it truly round.

(ii) Install valve guide to the cylinder head

Heat the cylinder head uniformly at a temperature of 80° C to 100° C (176° F to 212° F) so that the head will not be distorted. Drive the new valve guide into the hole with special tools. Drive in the new valve guide until the special tool (valve guide installer) makes contact with the cylinder head. After installing, make sure that the valve guide protrudes by a length of 14.0 mm from the cylinder head (see Fig. 4.51).

(iii) Ream the valve guide bore with a special tool (7 mm reamer)

(iv) After reaming, clean the bore.

(v) Install valve spring seat on the cylinder head.

(vi) Install valve spring seat to the cylinder head.

(vii) Install a new valve stem seal in the valve guide (Fig. 4.52).

After applying engine oil to the seal and the spindle of the valve stem seal installer (special tool), fit the oil seal to the spindle, and then install the seat in the valve guide by pushing the tool. After installation, ensure that the seal is properly fixed to the valve guide.

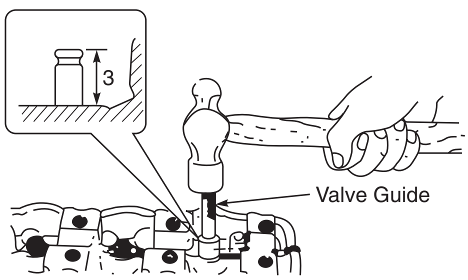



**Fig. 4.51** Valve Guide Installation

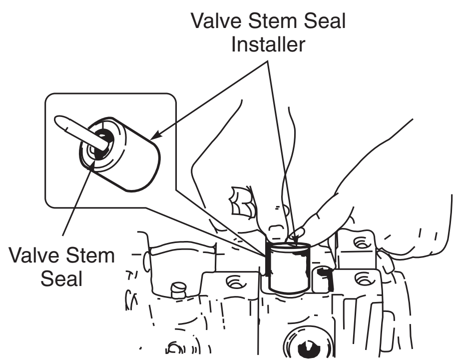



**Fig. 4.52** Valve Stem Seal Installation

***Note***

- *Do not reuse the oil seal once disassembled. Be sure to install a new oil seal.*
- *When installing, never tap or hit the special tool with a hammer or anything else. Install the seal in the guide only by pushing the special tool with hand. Tapping or hitting the special tool may cause damage on the seal.*

(viii) Install valve on the valve guide

Before installing the valve in the valve guide, apply engine oil to the stem seal, valve guide bore, and the valve stem.

***Note*** *Be sure to distinguish between inlet valve and exhaust valves. The difference is in their diameter and make.*

(ix) Install valve spring and spring retainer.

Each valve spring has a top end (large-pitch end) and a bottom end (small-pitch end). Be sure to position the spring in place with its bottom end (small pitch end) towards the valve spring seat side as shown in Fig. 4.53.

(x) Using a special tool (valve lifter), compress the valve spring and fit two valve cotters into the groove provided on the valve stem (see Fig. 4.54).

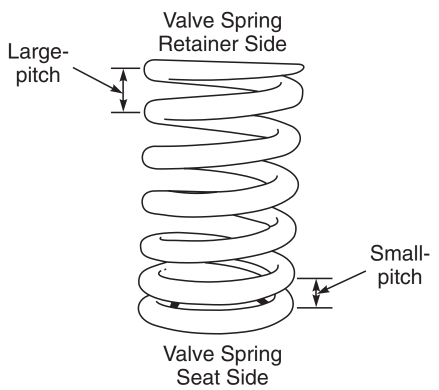



**Fig. 4.53** Installing Valve Spring

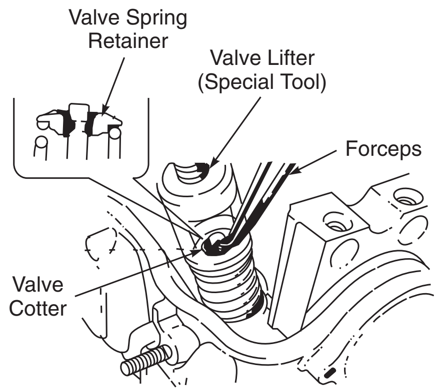



**Fig. 4.54** Valve Cotter Installation

## 8. Camshaft

The camshaft is assembled into the cylinder head from the distributor gear case side. Before inserting it be sure to oil its journals. Be careful not to leave out the thrust plate when installing the camshaft. After setting this shaft in place, with its thrust plate properly fitted, turn the shaft by hand to be sure it rotates smoothly.

## 9. Rocker-arm Shafts

The assembly of rocker-arm shafts is carried out in the following steps:

(i) Apply engine oil to the rocker-arms and the rocker-arm shafts.

(ii) The two rocker-arm shafts are identical, there being no need to distinguish between the two. Inlet valve rocker arm shaft, rocker arms and rocker arm spring from camshaft timing belt

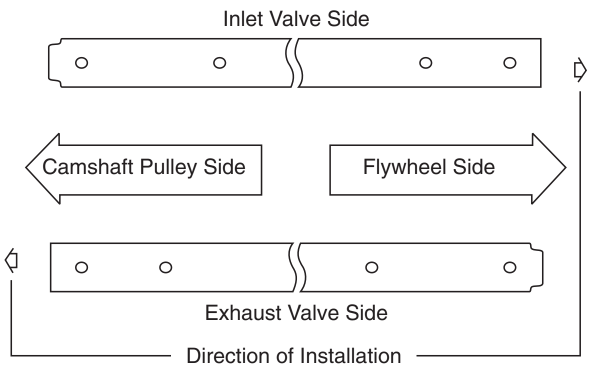



**Fig. 4.55** Installation of Rocker Arm Shaft

pulley side. Exhaust valve rocker arm shaft, rocker arm and springs from distributor case side (see Fig. 4.56).

***Note*** *When installing the rocker arm shafts, be sure to have valve-adjusting screws loosened fully but do not remove them.*

### 10. Camshaft and Crankshaft Lining Belt Pulleys

The camshaft and the crankshaft lining belt pulleys have a dot mark punched on one side. Install the pulley with this dot mark facing out (towards the timing belt outside cover) and the dot mark matching with the arrow mark on the timing belt outside cover as shown in Fig. 4.56.

### 11. Timing Belt

***Note*** *When installing the timing belt, match the arrow mark on the timing belt with the rotating direction of the crankshaft.*

(i) Timing belt, tensioner spring—With two sets of marks aligned, install timing belt on two pulleys in such a way that the drive side of belt is free from any slack, and then hook the tensioner spring to the water pump belt (see Fig. 4.57).

(ii) Now rotate the crankshaft pulley by one complete turn. The alignment of the two pulleys should be as shown in Fig. 4.58.

The other parts and accessories may now be installed on the engine. Torque the cylinder heads after installing a new gasket. The proper torque and tightening sequence chart (Fig. 4.59 is an example) is available in the service manual. The intake manifold and oil pan bolts also often have a particular tightening sequence.

Before engine startup, an engine prelubricator should be used to fill the lubrication system galleries and oil filter. This is very important for the life of engine bearings. The lag between starting the engine and getting oil to the bearings may shorten bearing life.

After the engine is prelubricated and all accessories are installed, start it. Watch closely for oil or coolant leaks. Oil consumption in new engines or after installation of new rings is often higher than normal until the rings become seated. That period of engine operation which is required before blow-by and oil consumption level off is referred to as the break-in period. Different piston ring manufacturers specify different break-in procedures.

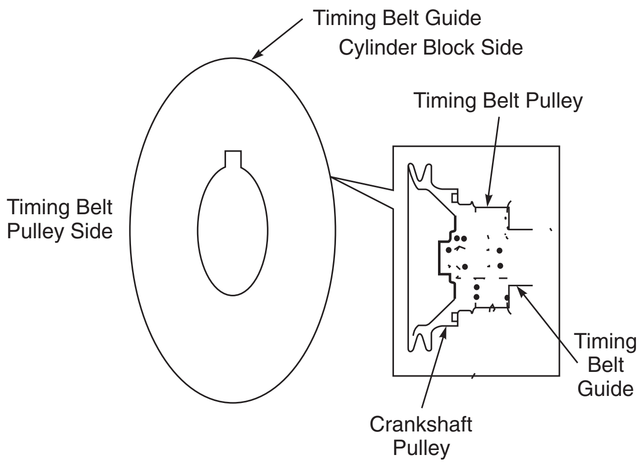



**Fig. 4.56** Installing Timing Belt Guide

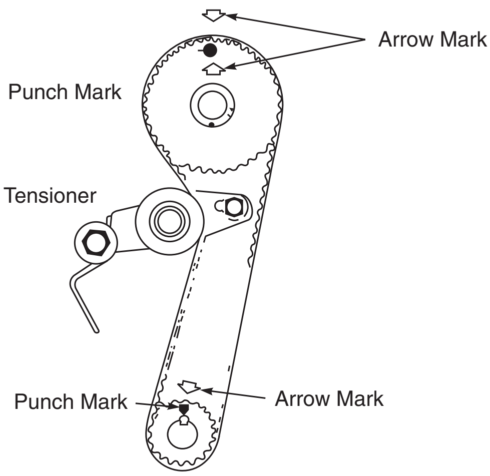



**Fig. 4.57** Aligning Timing Marks

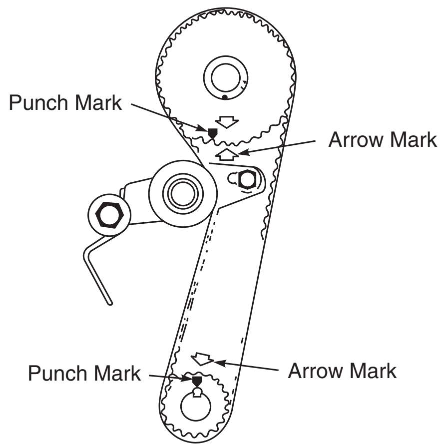



**Fig. 4.58** Aligning Timing Marks

Ring seating consists of the mating of the ring face with the cylinder wall throughout the complete stroke of the ring. This is done by wearing off the very slight irregularities of the ring face and the cylinder wall. The break-in period has been reduced as rings and cylinders have been produced with greater accuracy. Ring and engine manufacturers have not been able to duplicate the nearly perfect mating surfaces made by the engine. For this reason, all new and rebuilt engines require a certain amount of running for maximum oil control.

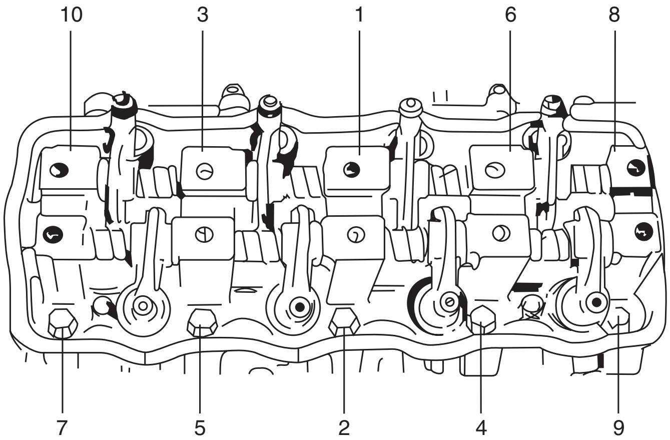



**Fig. 4.59** Tightening Sequence of Cylinder Head Bolts

**Table 4.26** Troubleshooting of an Engine

| *Trouble* | | *Cause* | *Remedy* |
|---|---|---|---|
| 1. Poor starting | | **Starter will not run** | |
| | (a) | Main fuse blown off | Replace |
| | (b) | Contact not closing in main switch, or this switch open-circuited | Repair or replace |
| | (c) | Run-down battery | Recharge |
| | (d) | Defective magnetic switch of starter | Replace |
| | (e) | Loose battery terminal connection | Clean and Tighten |
| | (f) | Defective brushes in starter | Replace |
| | (g) | Loose battery cord connection | Replace |
| | (h) | Open in field or armature circuit of starter | Repair or replace |
| | | **Not sparking** | |
| | (a) | Defective spark plug | Adjust gap, or replace |
| | (b) | High tension cord short-circuited (grounded) | Repair or replace |
| | (c) | Cracked rotor or cap in distributor | Replace |
| | (d) | Burnt contact breaker points | Replace |
| | (e) | Breaker contact gap out of adjustment | Adjust gap |
| | (f) | Contact not closing positively in main switch, or this switch open-circuited. | Replace |
| | (g) | Loose or blown fuse | Set right or replace |
| | (h) | Improper ignition timing | Adjust |
| | (i) | Defective ignition coil | Replace |
| | | **Faulty intake and exhaust system** | |
| | (a) | Carburettor out of adjustment | Adjust |
| | (b) | Fuel pump not discharging adequately | Replace |

*Contd.*

*Contd.*

| | | | |
|---|---|---|---|
| | (c) | Clogged fuel filter | Clean, or replace |
| | (d) | Defective choke mechanism | Repair or replace |
| | (e) | Loose intake manifold | Tighten |
| | (f) | Dirty and clogged carburettor | Adjust |
| | (g) | Float level out of adjustment | Clean or replace |
| | (h) | Clogged fuel hose or pipe | Clean or replace |
| | (i) | Not enough fuel in the tank | Refill |
| | (j) | Malfunctioning fuel cut solenoid valve | Check solenoid valve for proper operation and replace if necessary |
| | | **Abnormal engine internal condition** | |
| | (a) | Ruptured cylinder head gasket | Replace |
| | (b) | Improper valve clearance | Adjust |
| | (c) | Weakened or broken valve spring | Replace |
| | (d) | Loose manifold, permitting air to be drawn in. | Tighten and as necessary, replace gasket. Replace worn rings and pistons and rebore as necessary |
| | (e) | Broken valve timing belt | Replace |
| | (f) | Poor valve seating | Repair or replace |
| | (g) | Wrong kind of engine oil | Replace |
| | (h) | Burnt valves | Replace |
| | (i) | Sticky valve stem | Correct or replace and guide. |
| 2. Not enough power | | **Inadequate compression** | |
| | (a) | Improper valve clearance | Adjust |
| | (b) | Valves not seating tight | Repair |
| | (c) | Valve stems tending to seize | Replace |
| | (d) | Broken or weakened valve spring | Replace |
| | (e) | Piston rings seized in grooves, or broken | Replace |
| | (f) | Worn pistons, rings or cylinders | Replace worn parts and rebore as necessary |
| | (g) | Leaky cylinder head gasket | Replace |
| | | **Improperly timed ignition** | |
| | (a) | Improper ignition timing | Adjust |
| | (b) | Defective spark plug | Adjust gap or replace |
| | (c) | Breaker point gap out of adjustment | Adjust or replace |
| | (d) | Leaks, loose connection or disconnection of high tension cord | Connect or replace as necessary |
| | (e) | Malfunctioning ignition timing advances | Replace |
| | | **Fuel system out of order** | |
| | (a) | Clogged carburettor jets | Disassemble and clean |
| | (b) | Defective fuel pump | Repair or replace |

*Contd.*

*Contd.*

| | | | |
|---|---|---|---|
| | (c) | Clogged fuel filter | Replace |
| | (d) | Malfunctioning choke system | Adjust or replace |
| | (e) | Float level out of adjustment | Adjust |
| | (f) | Clogged fuel pipe | Clean or replace |
| | (g) | Clogged fuel tank outlet | Clean |
| | (h) | Loose joint in fuel system | Tighten |
| | | **Abnormal condition in air intake system** | |
| | (a) | Air cleaner dirty and clogged | Clean or replace |
| | (b) | Poor returning motion of choke valve | Repair, adjust or replace |
| | | **Overheating tendency of engine** | |
| | (a) | (Refer to the section entitled "over-heating") | |
| | | **Others** | |
| | (a) | Dragging breakes | Repair or replace |
| | (b) | Slipping clutch | Adjust or replace |
| 3. Engine hesitates (Momentary lack of response as the accelerator is depressed. Can occur at all car speeds. Usually most severe when first trying to make the car move, as from the stop sign). | | **Abnormal condition in electrical systems** | |
| | (a) | Defective spark plug or plug gap of adjustment | Replace or adjust gap |
| | (b) | Cracked rotor or cap in distributor resulting in leakage | Replace |
| | (c) | Deteriorated ignition coil, or crack resulting in leakage | Replace |
| | (d) | leaky high-tension cords | Replace |
| | (e) | Ignition timing out of adjustment | Adjust as prescribed |
| | (f) | Breaker contact point gap too large | Adjust as prescribed |
| | (g) | Defective condenser | Replace |
| | | **Abnormal condition in fuel system** | |
| | (a) | Improper adjustment of float level | Adjust |
| | (b) | Clogged carburettor jets | Clean |
| | (c) | Malfunctioning accelerator pump | Check and replace as necessary |
| | (d) | Inadequately discharging fuel pump | Replace |
| | | **Abnormal condition in engine** | |
| | (a) | Loss of compression pressure due to leaky cylinder head gasket | Replace |
| | (b) | Compression pressure too low because of worn pistons, rings, cylinders or burnt valves | Replace and rebore as necessary |
| 4. Surges (Engine power variation under steady throttle or cruise. Feels like the car speeds up and down | | **Fuel system out of order** | |
| | (a) | Clogged fuel filter | Replace |
| | (b) | Kinky, leaky or damaged fuel hoses and lines | Check and replace as necessary |
| | (c) | Malfunctioning fuel pump | Check and replace as necessary |
| | (d) | Leaky manifold and carburettor gaskets | Replace |
| | (e) | Improper float level | Adjust |
| | | **Ignition system out of order** | |
| | (a) | Improper ignition timing | Adjust |

*Contd.*

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| | | | |
|---|---|---|---|
| with no change in the accelerator pedal.) | (b) | Malfunctioning ignition timing advancers (mechanical and vaccum) | Check or replace |
| | (c) | Leaky or loosely connected high tension cord | Check and repair or replace |
| | (d) | Defective spark plug (excess carbon deposits, improper gap, burnt electrodes, etc.) | Check and clean, adjust or replace |
| | (e) | Cracked rotor or cap in distributor | Replace |
| | (f) | Breaker contact points out of adjustment or defective | Adjust or replace |
| | (g) | Defective condenser | Replace |
| 5. Dieseling (Engine continues to run after ignition switch is turned off. It runs unevenly and may make knocking noise.) | | Malfunctioning fuel cut solenoid valve in carburettor | Check solenoid valve for proper operation and replace as necessary |
| 6. Improper engine idling (erratic idling) | | **Abnormal condition in ignition system** | |
| | (a) | Defective spark plug | Adjust or replace |
| | (b) | Leaky or disconnected high tension cord | Connect or replace |
| | (c) | Worn distributor terminals | Adjust |
| | (d) | Improper ignition timing | Replace |
| | (e) | Cracked cap in distributor, leakage inside | Replace |
| | | **Abnormal condition in fuel system** | |
| | (a) | Clogged carburettor jets | Clean |
| | (b) | Incorrect idle adjustment | Adjust |
| | (c) | Clogged air cleaner element | Clean or replace |
| | (d) | Leaky manifold, carburettor or cylinder head gaskets | Replace |
| | (e) | Improper float level | Adjust |
| | (f) | Malfunctioning choke system | Replace |
| | (g) | Malfunctioning fuel cut solenoid valve | Replace |
| | | **Others** | |
| | (a) | Loose connection or disconnection of vaccum hoses | Connect |
| | (b) | Leaky cylinder head gasket | Replace |
| | (c) | Low compression | Previously outlined |
| | (d) | Loose carburettor and intake manifold bolts and nuts | Tighten bolts and nuts |
| | (e) | Leaky carburettor and intake manifold gaskets | Replace |
| 7. Abnormal detonation | | **Abnormal condition in ignition system** | |
| | (a) | Spark plugs tending to overheat | Change plug heat valve |

*Contd.*

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| | | | |
|---|---|---|---|
| | (b) | Improper ignition timing | Adjust |
| | (c) | Loose connection in high-tension or low tension circuit. | Tighten |
| | (d) | Defective breaker contact points | Replace |
| | | **Abnormal condition in fuel system** | |
| | (a) | Clogged fuel filter and fuel lines | Replace or clean |
| | (b) | Clogged carburettor jets | Clean |
| | (c) | Improper adjustment of float level | Adjust |
| | (d) | Malfunctioning fuel pump | Replace |
| | (e) | Air inhaling from intake manifold and carburettor gaskets. | Replace |
| | | **Abnormal condition in engine** | |
| | (a) | Excessive carbon deposit on piston crowns or cylinder head | Clean |
| | (b) | Blown cylinder head gasket, resulting in low compression pressure | Replace |
| | (c) | Improper valve clearance | Adjust |
| | (d) | Valves tending to seize | Replace |
| | (e) | Weakened valve springs | Replace |
| 8. Overheating | | **Abnormal condition in ignition system** | |
| | (a) | Improper ignition timing | Adjust |
| | (b) | Wrong heat value of spark plugs | Change heat value |
| | (c) | Breaker point gap out of adjustment in distributor | Adjust as prescribed |
| | | **Abnormal condition in fuel system** | |
| | (a) | Float level set too low | Adjust |
| | (b) | Clogged jets in carburettor | Clean |
| | (c) | Loose inlet manifold | Tighten |
| | | **Abnormal condition in cooling system** | |
| | (a) | Not enough coolant | Refill |
| | (b) | Loose or broken water pump belt | Adjust or replace |
| | (c) | Erratically working thermostat | Replace |
| | (d) | Poor water pump performance | Replace |
| | (e) | Leaky radiator cores | Repair or replace |
| | | **Abnormal condition in lubrication system** | |
| | (a) | Clogged oil filter | Replace |
| | (b) | Clogged oil strainer | Clean |
| | (c) | Deteriorated oil pump performance | Replace |
| | (d) | Oil leakage from oil pan or pump | Repair |
| | (e) | Improper engine oil grade | Replace with proper |
| | (f) | Not enough oil in oil pan | Replenish |

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| | | | |
|---|---|---|---|
| | | **Others** | |
| | (a) | Dragging brakes | Repair or replace |
| | (b) | Slipping clutch | Adjust or replace |
| | | **Crankshaft noise** | |
| 9. Abnormal Engine noise | (a) | Worn-down bearings, resulting in excessively large running clearances | Replace |
| | (b) | Worn connecting-rod | Replace |
| | (c) | Distorted connecting rods | Repair or replace |
| | (d) | Worn crankshaft journals | Repair by grinding, or replace crankshaft |
| | (e) | Worn crankpins | Repair by grinding or replace crankshaft |
| | | **Noise due to pistons, rings, pins or cylinders** | |
| | (a) | Abnormally worn cylinder bores | Rebore to next oversize or replace |
| | (b) | Worn pistons, rings or pins | Replace |
| | (c) | Pistons tending to seize | Replace |
| | (d) | Broken piston rings | Replace |
| | | **Others** | |
| | (a) | Excessively large camshaft thrust play | Replace |
| | (b) | Excessively large crankshafft thurst clearance | Adjust as prescribed |
| | (c) | Valve clearance too large | Adjust as prescribed |
| | (d) | Not enough engine oil | Replenish |
| 10. High fuel consumption | | **Abnormal condition of ignition system** | |
| | (a) | Improper ignition timing | Adjust |
| | (b) | Leak or loose connection of high tension cord | Repair or replace |
| | (c) | Defective spark plug (improper gap, heavy deposits, and burnt electrodes, etc.) | Clean, adjust or replace |
| | (d) | Cracked distributor cap or rotor | Check and repair or replace |
| | (e) | Malfunctioning mechanical and vaccum advancers in distributor | Check and repair or replace |
| | (f) | Breaker point gap maladjusted | Adjust or replace |
| | | **Abnormal condition in fuel system** | |
| | (a) | Improper float level | Adjust |
| | (b) | Fuel leakage from tank, pipe or carburettor | Repair or replace |
| | (c) | Malfunctioning carburettor choke system | Repair or replace |
| | (d) | Dirty or clogged carburettor jets | Clean |
| | (e) | Clogged air cleaner element | Clean or replace |
| | | **Abnormal condition in engine** | |
| | (a) | Low compression | Previously outlined |
| | (b) | Poor valve seating | Repair or replace |
| | (c) | Improper valve clearance | Adjust |

*Contd.*

*Contd.*

| | | | |
|---|---|---|---|
| 11. Excessive engine oil consumption | | **Oil leakage** | |
| | (a) | Loose oil drain plug | Tighten |
| | (b) | Loose oil pan securing bolts | Tighten |
| | (c) | Deteriorated or broken oil pan sealant | Replace sealant |
| | (d) | Leaky oil seals | Replace |
| | (e) | Blown cylinder head gasket | Replace |
| | (f) | Improper tightening of oil filter | Tighten |
| | (g) | Loose oil pressure switch | Tighten |
| | | **Oil pumping (Oil finding its way into combustion chambers)** | |
| | (a) | Sticky piston ring | Remove carbon rod and replace rings |
| | (b) | Worn piston ring groove and ring | Replace piston and ring |
| | (c) | Improper location of piston ring gap | Reposition ring gap |
| | (d) | Worn pistons or cylinders | Replace pistons and rebore as necessary |
| | | **Oil leakage along valve stems** | |
| | (a) | Defective valve stem oil seals | Replace |
| | (b) | Badly worn valves or valve guide bushes | Replace |

## Review Questions

1. State three reasons for preventive maintenance.
2. Why is a clean engine better from a preventive maintenance point of view?
3. How much dirt does it take to ruin an engine if the dirt is inside the engine?
4. How does most dirt enter an engine?
5. Write the first step in changing engine oil.
6. Explain why hard water causes problem in the cooling system.
7. How often does the coolant need to be changed?
8. How often does the filtering element need to be cleaned?
9. List the visual checks made to locate battery trouble.
10. Explain the preventive maintenance schedule. List the advantages.
11. List general checks/precautions to be observed by the driver before starting and taking off vehicle.
12. List the steps to be taken when removing an engine.
13. Why should all the disassembled parts be promptly examined when they have been removed from the engine?
14. How would you remove a valve guide using the tool shown in Fig. 4.6?
15. List the several causes for reboring cylinder.
16. Describe how camshaft deflection is measured and the working of the camshaft journal.
17. What checks and measurements must be made before installing piston rings on the piston?
18. Explain how piston ring groove is measured.

19. List the steps to be taken to check the main bearing clearance by using plastic strip.
20. List the visual inspection you must make when checking a crankshaft.
21. Give reasons for measuring crankshaft runout.
22. List the steps for reassembling an engine after servicing.
23. List the steps to be taken to install a crankshaft.
24. How would you check the service ability of a valve guide?
25. List the visual checks and preparations to be made prior to resurfacing the valve seat.
26. List the activities to be carried out before placing the cylinder head in position.
27. Describe the procedure of fitting the connecting rod to the piston.
28. List the checks and measurements you must make when installing a rocker-arm and a rocker-arm shaft.
29. State the precautions to be taken when installing a timing belt.
30. Why is it important to follow the tightening sequence (as given in manufacturer's service manual) for the cylinder head bolts?

# 5

# Combustion Process in Petrol Engines

**Objectives**

After studying this chapter, you should be able to:

- Enumerate the properties of petrol.
- Explain the combustion process in a petrol engine.
- Describe normal combustion and abnormal combustion with the help of suitable sketches.
- Explain how detonation leads to pre-ignition.
- Describe the function and constructional details of different types of combustion chambers.

## 5.1 INTRODUCTION

The air-fuel mixture is supplied to a petrol engine during its induction (suction) process. Heat obtained from the combustion of this mixture is converted into mechanical work by the engine. In this chapter the mechanism of combustion of fuel in an Otto Cycle engine is discussed.

## 5.2 PROPERTIES OF PETROL (GASOLINE)

A crude oil form the oil wells is refined by distilation process by utilizing the fact that the boiling points of various hydrocabons differ and this results in the separation of the different constituents, such as, natural gas, liquefied petroleum gas (LPG), gasoline, etc. Gasoline is the lightest liquid petroleum fraction. All material boiling up to 200°C are generally considered as gasoline (petrol).

Petrol must possess the following properties.

### 1. Volatility

The air-fuel mixture supplied to the engine is prepared in the carburettor. Petrol absorbs heat from air and evaporates. Therefore petrol must be volatile at low temperatures. If petrol is not highly volatile, then the starting of a petrol engine would be difficult. Highly volatile fuel evaporates in the fuel line or in the fuel pump and creates vapour lock that stops the supply of the fuel (petrol). Fuel having low volatility tends to condense in the inlet manifold or in the cylinder. The condensed petrol in the cylinder mixes with the lubricating oil and dilutes it. If this condensed petrol passes into the crankcase, then the crankcase oil gets diluted. This is generally known as crankcase dilution.

Therefore volatility of petrol must be studied with respect to the atmospheric temperature. Highly volatile petrol helps in starting the engine from cold, but a warm engine needs less volatile petrol.

### 2. Anti-Knock Property

Petrol used in engines must not 'pink' in the combustion chamber. *The abnormal combustion of petrol in the combustion chamber is known as detonation or pinking*. This results in loss in power and increase in fuel consumption. If the abnormal combustion of petrol continues for a long time, then it harms the engine parts and the engine may completely fail to develop power. To ensure the anti-knock property of petrol, impurities from petrol are removed. Sometimes chemicals (dopes) are added to attain this anti-knock property in petrol.

### 3. Sulphur Content

Sulphur is the most undesirable constituent in petrol. During the combustion process, sulphur combines with oxygen and forms sulphur dioxide ($SO_2$). Under high temperature and pressure, the $SO_2$ is converted into $SO_3$. Hydrogen already present in petrol, forms $H_2O$ (water) with oxygen during the process of combustion. $H_2O$ which is water vapour, combines, with $SO_3$ and forms $H_2SO_4$ (sulphuric acid) which is corrosive on condensation. This acid corrodes the engine parts and thus the life of the cylinder liner, piston and the valves is reduced. Therefore petrol must be free from sulphur.

### 4. Gum Deposits

Gum is a Sticky substance, which is formed due to the oxidization of certain constituents present in petrol. Gum is deposited on the piston rings, the valves, and other places in the cylinder, and prevents the parts from functioning properly. Deposition of gum reduces the performance of the engine.

The tendency of gum deposition in petrol increases under the following conditions:

(a) Petrol is stored for long time.
(b) Petrol is stored in a copper vessel. Copper acts like a catalytic agent.
(c) When petrol is exposed to sunlight.

### 5. Non-corrosive

Petrol must be non-corrosive. Petrol must not contain dirt, dust and other compounds which are corrosive.

Corrosion tends to cause pitting on the valve seat faces. As a result, the hot gases start to leak through, evolving lot of heat to the channels locally, thereby, lowering the compression. In engines with cast iron heads run by liquid petroleum gas (LPG), a deposition of protecting film of adequate thickness results on the sitting faces, avoiding such a situation.

## 5.3 OCTANE NUMBER

Octane number is an index which measures the combustion quality of petrol. Octane number is assigned to petrol used in Otto engines. A higher octane number of petrol indicates that the petrol has anti-knock property under certain conditions.

To determine the octane number of petrol, two reference fuels—iso-octane and normal heptane are mixed in a certain proportion by volume. For example, if the mixture of the reference fuels contains 80% iso-octane and 20% normal heptane by volume, then this mixture has an octane number equal to 80. Thus fuels with different octane numbers are prepared by mixing iso-octane and normal heptane in various proportions. To assign a rating to the sample petrol bought from market, an engine having a variable compression ratio is used. All the conditions are kept constant while the sample petrol is used at various compression ratios. In Fig. 5.1 a curve 'A' shows the relationship between compression ratio and thermal efficiency when iso-octane is used as fuel. It has been shown experimentally that if normal heptane is added to iso-octane, then the mixture starts pinking, i.e. the engine undergoes rough running beyond a certain compression ratio and the thermal efficiency also starts to drop. The compression ratio at which the mixture of iso-octane and normal heptane gives maximum thermal efficiency is known as *the highest useful compression ratio* for that mixture. The highest useful compression ratio is written as HUCR. HUCR increases with increase in the octane number of the fuel.

To provide a rating for the sample petrol, its HUCR is found in the variable compression ratio engine. In Fig. 5.1, HUCR of the sample petrol is shown by the point 'B'. After this, the mixture of the reference fuels is used under similar conditions and the mixture, corresponding to the same HUCR, i.e. point 'B', is obtained.

This means that the sample petrol has the same combustion quality as this mixture of the reference fuels. If the reference fuel has 60% iso-octane and 40% normal heptane, then the sample petrol has an octane number equal to 60.

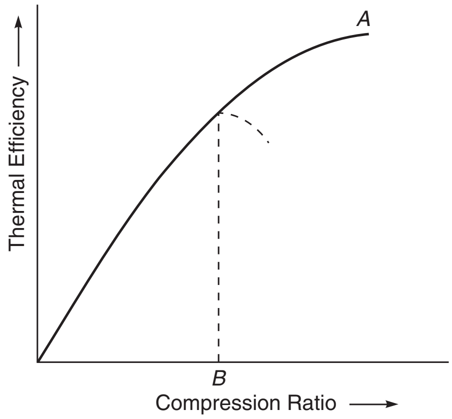



**Fig. 5.1** HUCR

It must be clear that a petrol engine, which detonates with petrol having an octane number equal to 55, can have its detonation supressed with petrol of octane number 60. If the petrol engine performs well with fuel having an octane number equal to 55, then the performance of the engine cannot be improved by using petrol of octane number 60.

## 5.4 OCTANE RATINGS

Octane rating of gasoline is a measure of its resistance to detonation in the engine. An octane rating is not indicative of the energy in gasoline, the quality of gasoline, or whether the gasoline contains lead.

There are three ways of designating the octane rating of gasoline.

### 1. Research Octane Number (RON)

The research octane number is determined by testing gasoline in laboroatory engines running at low speed with wide-open throttle. This gives the gasoline a high octane rating such as 100 for premium and 94 for regular.

### 2. Motor Octane Number (MON)

Motor Octane Number or MON is determined by testing the gasoline in an engine running at full throttle with high engine speed. This gives the gasoline a lower octane rating such as 92 for premium and 86 for regular.

### 3. Antiknock Index

The antiknock index is also called the Road Octane Number. It relates to the actual performance of gasoline in cars. This is the newest rating system and is the number that you are most likely to see on the pumps at service stations. Road octane number is found by adding together the RON and MON for gasoline and then dividing by 2. The mathematical expression is:

$$\text{Road octane number} = \frac{\text{RON} + \text{MON}}{2} \qquad \text{(Eq. 5.1)}$$

The typical road octane number for gasoline is about 96 for premium and 90 for regular.

In practice, some engines require a higher-octane gasoline than that for which they were designed. This is because all engines, even of the same model cannot be manufactured exactly alike. For example, most engines of one model will run satisfactorily on a gasoline with an octane rating of 87. However, a few engines will require a slightly higher or a lower octane rating. After the engines are in use, the variations in their octane requirements grow even wider. This is because cars are driven and maintained in different ways. Many engines need a higher-octane gasoline, as they grow older.

### Motor Spirit

87 octane and 93 octane motor spirits meeting IS: 2796-1971 specifications are used for spark ignition in the engine of automobiles. These are refined to a high level of quality to meet critical areas of performance and possess appropriate stability, good volatility characteristics and anti-knock qualities to suit the climatic conditions and vehicle design aspects. A comparison between these two motor spirits is presented in Table 5.1.

**Table 5.1** Motor Spirits

| *TEST* | *87 Octane Number* | *93 Octane Number* |
|---|---|---|
| Colour | Orange | Red |
| Distillation recovery up to | | |
| • 70° C % vol. | 10 min | 10 min |
| • 125° C % vol. | 50 min | 50 min |
| • 180° C % vol. | 90 min | 90 min |
| Final boiling °C | 215 max. | 215 max. |
| Residue % vol. | 2 max. | 2 max. |
| Oxidation Stability | 360 min. | 360 min. |
| Residue on evaporation mg/100 ml unwashed | 4 max. | 4 max. |
| Reid vapour pressure at 38°C kgf/ $Cm^2$ | 0.70 max. | 0.70 max. |
| Copper strip corrosion (3 hrs at 50° C) | Not worse than No.1 | Not worse than No.1 |
| Sulphur % wt. | 0.25 | 0.25 |
| Lead Content | 0.56 | 0.80 |

## 5.5 COMBUSTION PROCESS IN PETROL ENGINE

At the end of the compression stroke in petrol engines, spark is produced at the spark plug gap. The charge molecules in between the spark plug gap are heated to initiate combustion. Thus the flame is initiated at the spark plug gap and the homogeneous mixture in the combustion chamber sustains the progress of a definite flame across the combustion chamber.

Since the charge (mixture of air and fuel) has a certain delay period of the order of fractions of a second, some ignition advance about 5 to 10 degrees of crank rotation is usually given. This means that spark is produced 5 to 10 degrees of the crank rotation before TDC of the piston.

In Fig. 5.2, the combustion process in a spark-ignition engine has been shown. The flame initiated at the spark plug gap, advances to the other side of the combustion chamber. As the flame front advances, it burns the charge. The flame travels with the speed of sound. The temperature and pressure in the burned space increases and push the unburned charge, which is the remaining charge in the space 'a' as shown in Fig. 5.2. Thus the remaining charge at 'a' is adiabatically compressed and its temperature is raised. If the charge has a greater delay period, then before auto-ignition of the charge at 'a', the flame front reaches the end and burns the remaining part of the charge in the normal way. Such normal combustion in the spark-ignition engine gives a normal rate of rise of pressure and the engine runs smoothly.

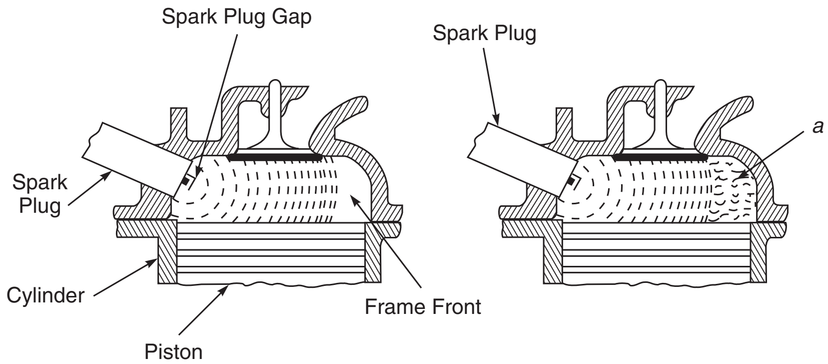



**Fig 5.2** Combustion Process in SI Engine

In case the portion of charge at 'a' has a lesser delay period, auto-ignition takes place even before the flame front reaches it. Such abnormal combustion starts at various points in the combustion chamber and as a result pressure waves start from various points. This abnormal combustion produces a sudden rise in pressure which produces a sound like explosive shells. This phenomenon of combustion is known as 'pinking'. Figure 5.3(1) shows normal combustion and abnormal combustion is shown in Fig. 5.3(2). The charge attains a pressure of 150 kg/cm$^2$ in abnormal combustion and detonation (pinking) takes place simultaneously.

Figure 5.4 shows the P-V diagram for normal combustion in a SI engine in terms of an average cycle. Before the pressure reaches the point 3 in the normal combustion cycle (average cycle), the end portion of the charge reaches of pressure indicated by the point 2. At point 2 violent combustion takes place and the pressure reaches the point 3 as shown in Fig. 5.4. The pressures difference between the normally burned charge and the abnormally burned charge, generates high-pressure waves, which strike the cylinder walls and are reflected back. This rapid release of energy causes vibration of the engine structure.

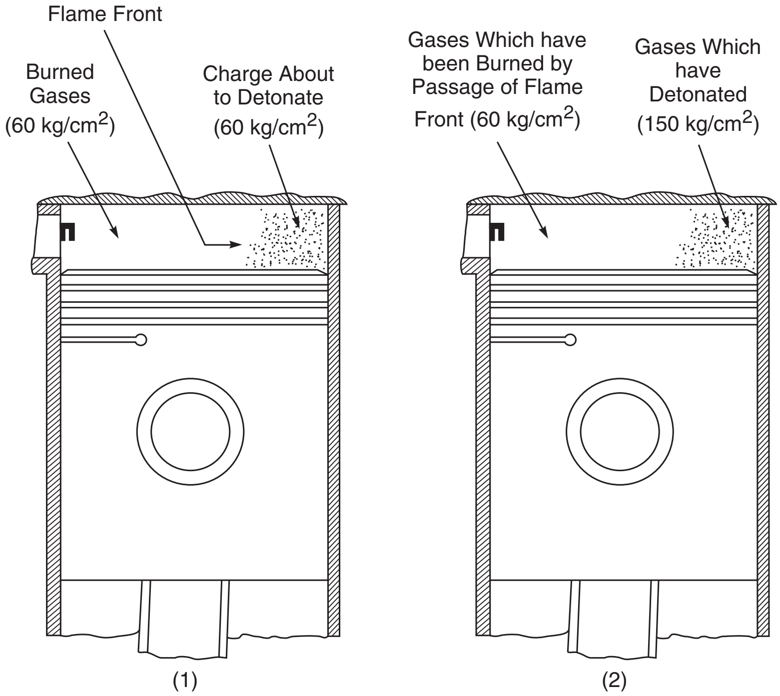



**Fig. 5.3** Pinking

The tendency towards detonation is aggravated or reduced by the form of the combustion chamber and the position of the spark plug, as well as by the compression ratio.

If heat dissipation is not quick during the abnormal combustion of the end portion of the charge, then heat accumulates on the cylinder walls and leads to pre-ignition. When ignition of the charge takes place before the predetermined time, then it is called pre-ignition. Pre-ignition increases pressure over the piston head and the energy is absorbed.

In Fig. 5.5, the normal cycle is shown by the dotted line. When the cylinder is heated due to abnormal combustion (detonation), ignition of the charge starts from the point 'x' before TDC. The combustion curve xy depends on the charge. Obviously, the area in the P-V diagram is decreased due to pre-ignition. Finally, the engine stops after pre-ignition.

It must be clear that the engine may detonate and then pre-ignition might occur. However, pre-ignition does not lead to detonation and pre-ignition cannot be sustained for a long time.

## 5.6 TYPES OF COMBUSTION CHAMBERS

Combustion chamber is an endorsed area where combustion takes place. It is formed by cylinder head, valves, spark plug, head gasket; cylinder walls, piston and piston rings.

The basic requirements of a combustion chamber are to ensure:

1. Power output
2. Smooth running
3. Fuel economy

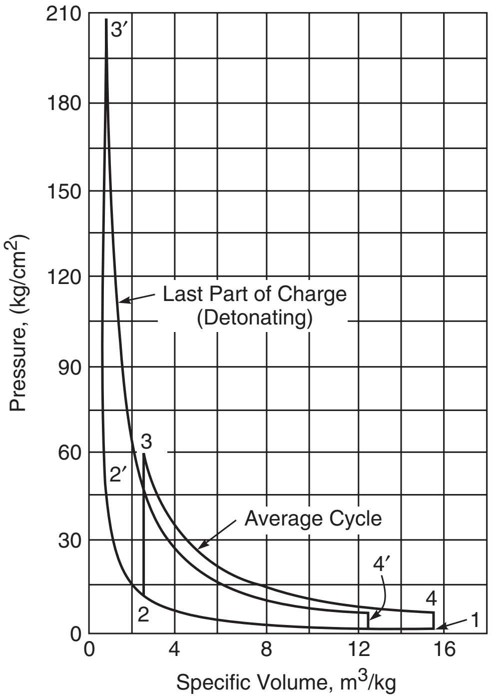



**Fig. 5.4** P-V Diagram for Combustion

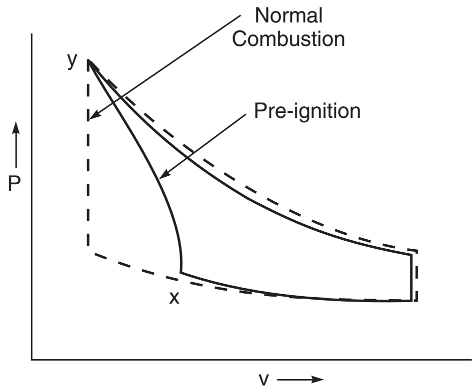



**Fig. 5.5** Pre-ignition

To accomplish the objectives, the combustion chamber must fulfill the following characteristics-

(i) High compression ratio
(ii) High volumetric efficiency
(iii) Free from detonation (pinking)
(iv) Low surface to volume ratio

To achieve these characteristics, different types of combustion chambers have been developed. Some of the designs used in common practice are given in the following paragraphs:

Figure 5.6 shows the T-head combustion chamber. The T-head combustion chamber has a high surface to volume ratio and it increases cooling losses, which reduce engine power and thermal efficiency.

Figure 5.7 shows the L-head combustion chamber. It has a suction valve (S), and an exhaust valve (E) side by side in the cylinder block.

The L-head combustion chamber is an improvement over the T-head combustion chamber. The surface to volume ratio is decreased, and turbulence is created over the valves during the compression stroke. The disadvantage of this combustion chamber is that the end part of the charge is near the exhaust valve which promotes detonation. Moreover, the volumetric efficiency of the engine is reduced due to change in the

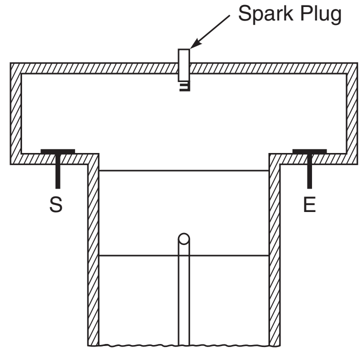



**Fig. 5.6** T-head Combustion Chamber

direction of gases during the suction and exhaust processes. If the spark plug is located near the exhaust valve, then pinking can be avoided. However, fuel economy is not obtained due to the high surface to volume ratio. High turbulence over the valves tends to form a homogeneous mixture of air and fuel.

In Fig. 5.8, the F-head combustion chamber has been shown. The F-head combustion chamber is an improvement over the L-Head combustion chamber. The suction valve is located in the cylinder head and also the size of the suction valve is increased to get more volumetric efficiency. The exhaust valve (E) is located in the cylinder block. Turbulence is created over the exhaust valve (E) during the compression stroke and heat is absorbed by the fresh charge. This reduces the delay period of the charge and combustion occurs almost at TDC of the piston. At the same time, detonation is avoided as the end portion of the charge is situated in a narrow cavity over the piston head and at the cool suction valve. Note that the spark plug is above the exhaust valve. This heats the spark plug and may lead to pre-ignition. The main disadvantage of the F-head combustion chamber is that the surface area per unit volume is more and hence fuel economy is not obtained.

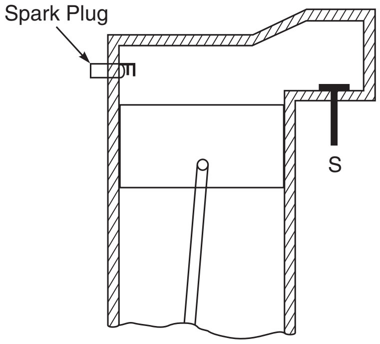



**Fig. 5.7** L-head Combustion Chamber

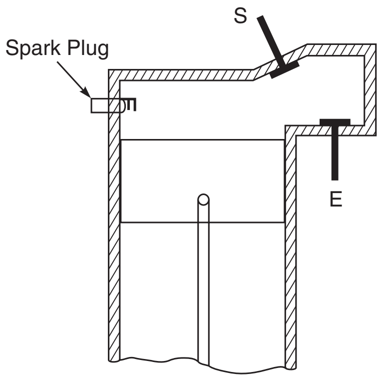



**Fig. 5.8** F-head Combustion Chamber

In Fig. 5.9, the I-head combustion chamber has been shown. The suction and exhaust valves are located in the cylinder head. The valves are vertical and therefore it is easy to operate them with simple push rods and rocker arms. The I-head combustion chamber has a lesser surface volume ratio than the F-head combustion chamber. Therefore the cooling losses are reduced.

In Fig. 5.10, another type of the I-head combustion chamber has been shown. This design permits the use of larger valves unlike the design given in Fig. 5.9. Therefore this engine has a greater volumetric efficiency. However, as the clearance volume is increased, the compression ratio decreases and the specific fuel consumption is increased for this engine.

In Fig. 5.11, a Rover engine has been shown. In this engine, a domed piston crown has been utilised. This design decreases the clearance volume, thereby increasing the compression ratio. Hence fuel economy is

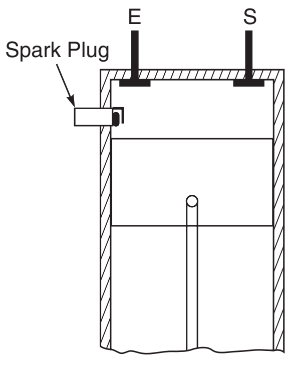



**Fig. 5.9** I-head Combustion Chamber (i)

higher. The Rover engine has a compression ratio of 7.5. Detonation is automatically suppressed because the end portion of the charge is in a narrow cavity where the surface to volume ratio is more and the charge readily cools under the inlet (suction) valve.

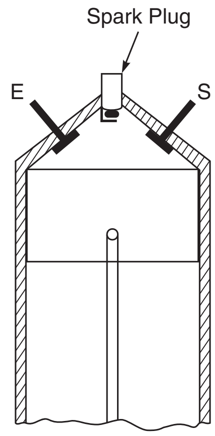



**Fig. 5.10** I-head Combustion Chamber (ii)

The Rover engine combustion chamber shown in Fig. 5.11 has the suction valve in the cylinder head and the exhaust valve in the cylinder block. Therefore it is an F-head combustion chamber. This design permits a large valve head and therefore the volumetric efficiency is increased. The end portion of the charge is in a cooler place and hence detonation is avoided. The normal flame reaches the end of the charge more quickly by increasing the turbulence within the cylinder. As shown in Fig. 5.11, the mixture is forced out from the cavity below the suction valve into the combustion space at

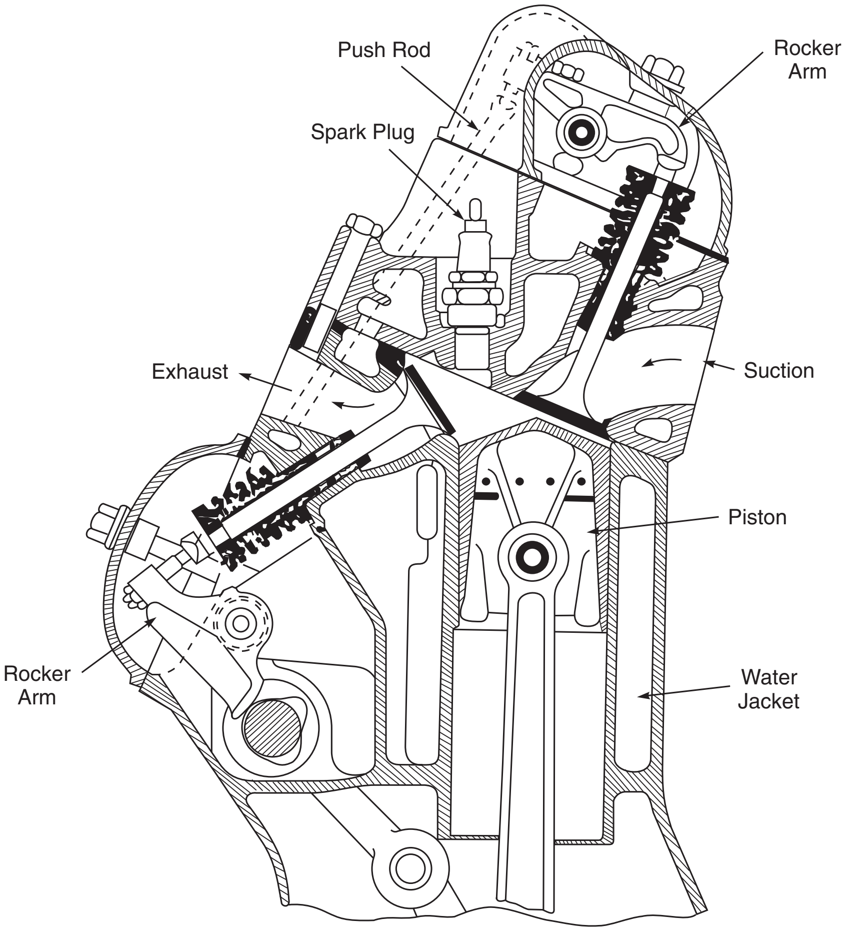



**Fig. 5.11** Wedge of Combustion Chamber (Rover Engine)

the end of the compression stroke. This creates turbulence which accelerates flame propagation and the combustion period is shortened.

Based on the principle montioned in the previous paragraph, valve in the I-head combustion chamber is designed as shown in Fig. 5.10. This design shown in Fig. 5.12, reduces the clearance volume and increases the compression ratio. The spark plug is located at the centre of the cylinder. The outer portion of the piston crown is fairly close to the cylinder head; turbulence is created at the end of compression stroke. Turbulence reduces the combustion period. If petrol is blended with methanol, then a high compression ratio can be used.

The wedge type combustion chamber shown in Fig. 5.13 is also designed based on the same principle. The suction valve (S) is located in the cylinder head and the exhaust valve (E) is located in the cylinder block. Spark plug is located near the exhaust valve. The narrow portion of the wedge combustion chamber accommodates the last portion of the charge.

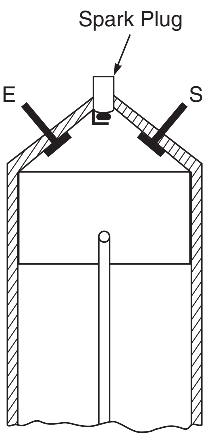



**Fig. 5.12** Combustion Chamber for High Speed Engine

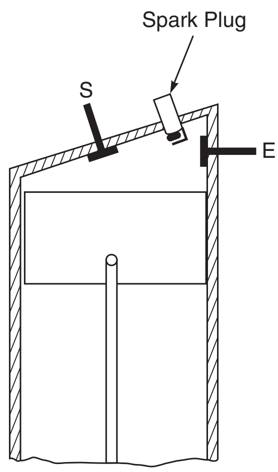



**Fig. 5.13** Wedge Type Combustion Chamber

## Review Questions

1. What are the basic properties of ideal gasoline?
2. What is octane number? How is it determined?
3. What is HUCR? Explain it briefly.
4. What is the effect of high sulphur content on the performance of an SI engine?
5. How do gums affect engine operation?
6. What is pinking and how does it affect engine performance?
7. Describe normal and abnormal combustion with the help of suitable diagrams.
8. Explain how detonation leads to preignition.
9. Describe the function of a combustion chamber and the constructional details of different types of combustion chambers.

6

# Combustion Process in Diesel Engines

**Objectives**

After studying this chapter, you should be able to:

- Understand the properties of diesel fuel.
- Explain the combustion process in compression ignition engines.
- Define the term diesel knock and explain how delay period influences diesel knock.
- Explain the different types of CI combustion chambers.
- Describe the various methods of fuel injection.
- Justify the use of heater plug in case of pre-combustion method.
- Differentiate between direct injection and pre-combustion method.

## 6.1 INTRODUCTION

The process of combustion in a diesel engine is different from that in a petrol engine. The heat generated in the combustion chamber is utilised to perform work. However, 100% of the heat is not utilised to perform work. The percentage of heat that is utilised for work depends on many factors, and out of them, form (shape and size) of the combustion chamber is very important. In this chapter, various forms of combustion chambers and the process of combustion are discussed.

## 6.2 PROPERTIES OF DIESEL FUEL

The properties required in diesel fuel are different from those required in petrol. The desirable properties of diesel fuel are:

### 1. Viscosity

Viscosity indicates the internal resistance between the fuel molecules. Fuel is injected in the combustion chamber. Highly viscous diesel fuel is not finely atomised and requires more injection pressure, whereas the less viscous diesel fuel is well atomized, but causes more wear in the injection unit and leaks through the clearance. This means that the injection pressure and the degree of atomisation of the injected fuel depend on diesel viscosity. The injection units (injectors and fuel pumps) are designed considering the viscosity of diesel.

### 2. Sulphur Content

The presence of sulphur in diesel fuel reduces the self-ignition temperature of diesel. Due to the sulphur content, the injected fuel starts burning at a lower temperature in the combustion chamber. The quantity of sulphur should not exceed 0.5%, which is the desirable quantity of sulphur in diesel fuel. Excess sulphur increases wear due to acidic corrosion and the formation and deposition of carbonaceous materials over the piston rings. Burned sulphur forms $SO_2$ which reacts with lubricating oil and forms gum, varnish and hard substances.

### 3. Volatility

Diesel fuel must be volatile at the cylinder temperature. The heavy ends of diesel which evaporate at a higher temperature are partially burned and leave carbon deposits. Such carbon deposits in the cylinder cause cylinder wear and problems with the spraying of fuel from the injector if carbon is deposited over the injector orifice.

### 4. Ignition Quality

The diesel fuel must have a good ignition quality. Ignition quality of diesel is ascertained from its ignition lag. Ignition lag is the time interval between the entrance of the fuel particle in the combustion chamber and its subsequent ignition. It has been found that a fuel particle takes a certain time (about 1/1000 of sec) to ignite. This time interval is known as the ignition lag. The lesser time the ignition lag, the better the ignition quality of diesel fuel.

The ignition quality of diesel, is indicated by its cetane number. This cetane number is determined by comparing the mixture of reference fuels (cetane and methyl naphthalene) to the sample diesel fuel in a variable compression ratio engine. When the sample diesel fuel and the mixture of the reference fuels give the same combustion quality, the diesel fuel is assigned a cetane number equal to the percentage of cetane in the reference fuel mixture. For example, if the combustion quality of the sample diesel fuel is the same as the mixture of 85% cetane and 15% methyl naphthalene, then the sample diesel fuel is assigned a cetane number of 85.

The higher the cetane number, the lerser the ignition lag and the better is the fuel.

### 5. Free from Water and Sediments

The injection unit is fitted very precisely to minimise diesel leakage under high pressure. Any sediment such as dust damages the injection units (fuel pump assembly and injector assembly). Due to the viscosity of diesel, these sediments do not settle down in the tank.

## 6.3 COMBUSTION PROCESS IN CI ENGINE

The term CI engine means "Compression Ignition" engine. This engine works on the principle of compression of air in a cylinder so that the temperature of air becomes greater than the self-ignition temperature of the diesel fuel, which is injected into the cylinder. The injected fuel (diesel) enters the combustion chamber in the form of fine spray and ignites. Such burning of fuel does not require a spark plug to initiate combustion as in the case of a petrol engine. Therefore, it is essential to compress air to a high compression ratio to produce compression ignition of the injected fuel (diesel).

To understand the combustion process in a CI engine, the pressure-crank diagram must be drawn.

Figure 6.1 shows the pressure-crank diagram for a diesel engine. The position of the piston when it is at TDC is indicated by 0° crank position. The dotted curve shows the motoring curve which means that it represents the rise and fall of pressure in the cylinder when fuel is not injected. At the point 'A' in the diagram, diesel is injected. Since the fuel has a certain delay period, it does not ignite till the crank rotates and the air pressure rises to that indicated by point B. The crank rotation from the point A to B is due to the delay period or ignition lag of the diesel fuel.

The delay period is the time interval given in seconds. If the delay period is 1/1000 second, and the crank rotates 1500 times per minute (i.e. 1500 rpm), then the crank rotates 9° during the delay period. This delay period is due to:

(i) The physical delay period when the fuel absorbs heat and evaporates, and
(ii) The chemical delay period when there is a pre-flame chain reaction before combustion.

At point B, the combustion of injected fuel (during delay period) starts and the pressure in the cylinder increases. The injection of fuel starts at point A and continues for some degrees of crank rotation. If the delay period is long, then more diesel is accumulated during this period. Once the flame is established, the temperature of the cylinder rises rapidly and all the accumulated fuel suddenly ignites in a blast producing a rapid rise of temperature and pressure. This is rapid uncontrolled combustion. In Fig. 6.1, the curve from B to C represents uncontrolled rapid combustion. At point C all the accumulated fuel burns completely. The fuel which is futher injected burns as it enters the cylinder (combustion chamber). This is due to the increased temperature and pressure in the cylinder. Therefore further combustion of fuel after point C is controlled by the rate of injection of the fuel. Hence the process of combustion from point C to D is called controlled combustion.

In case the bigger droplets are left in the combustion chamber, these droplets continue to burn even after the injection has stopped. In Fig. 6.1, injection stops at point D but after-combustion continues between D and E. At point E combustion of fuel (diesel) ends.

Thus, the combustion process of diesel in a CI engine is divided into four stages:

1. Delay period, (from A to B)
2. Rapid uncontrolled combustion (from B to C)
3. Controlled combustion (from C to D) and
4. After burning (from D to E)

As soon as the first droplet of injected fuel enters the combustion chamber which is under high temperature and pressure, chemical reaction starts so slowly that the time and place where ignition occurs is not fixed. The ignition of any droplet of injected fuel occurs when the local circumstances such as temperature, pressure and mixing of fuel with air make combustion possible. The point to be emphasised here is that combustion of fuel in a CI engine is dependent on local conditions and does not depend on the spread of flame from one point to the other. Therefore the combustion rate is affected by the state and distribution of fuel in the combustion chamber.

In a CI engine, combustion begins with auto-ignition, and the process is quite heterogeneous. This means that at some or at many locations, the flame appears and later on the entire area may explode or burn because of accumulation of fuel in the chamber during the delay period. It should be noted that the burning droplet only radiates heat and not flame. Flame propagation is only possible if the region of combustible mixture is continuous.

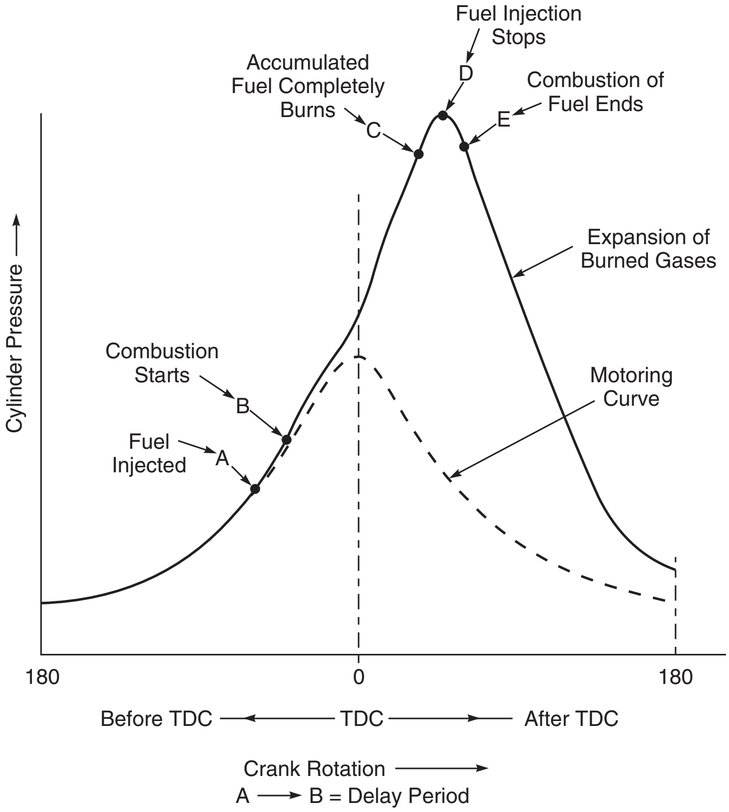



**Fig. 6.1** Pressure-crank Diagram for CI Engine

The name ignition delay is assigned to the time consumed by both the physical and chemical delays. It should be realised that exact division of the delay period into two parts is impossible due to the complexity of the process. The delay period is influenced by:

(a) the density and temperature of the compressed air in the cylinder.
(b) the atomisation, penetration and spray characteristics of the injection system.
(c) the properties of fuel, such as volatility and viscosity which are affected by spray characteristics.
(d) the turbulence of air which promotes mixing.

## 6.4 DIESEL KNOCK

Any factor which increases the cylinder temperature reduces the delay period, which also reduces diesel knock. The quantity of fuel accumulated during the delay period is responsible for the violent combustion that is called diesel knock. This means that the following factors encourage diesel knock because these factors reduce the cylinder temperature:

1. Lower compression ratio
2. Lower inlet air temperature
3. Lower cooling water temperature

4. Increase of humidity in atmosphere, and
5. Too early advance of injection from an optimum position

Diesel fuel having a lower cetane number has a greater delay period, hence it tends to knock. The following qualities of diesel promote diesel knock.

1. Longer ignition lag (lower cetane number)
2. High self-ignition temperature
3. Low volatility
4. High viscosity (This causes poor atomisation)

The following characteristics of a running CI engine increase its knocking tendency:

1. *Increasing air turbulence of the compressed air* The fuel droplets are stripped of their outer surface due to turbulence to form a homogenous mixture.
2. *Increasing the speed of the engine* A higher cam speed injects more fuel during the delay period which promotes knocking. If knocking is suppressed, then it is due to the increased turbulence with the increase in the engine speed. Cooling time is then reduced.
3. *Decreasing the injection pressure* This gives bigger size of droplets which take more time to evaporate and mix with air. Thus, the delay period is increased and more fuel is accumulated which produces diesel knock.
4. *Increasing the rate of injection* This factor depends on the design of the cam profile which operates the fuel pump. Increasing the rate of injection during the delay period accumulates more fuel during the delay period.

## 6.5 TYPES OF CI COMBUSTION CHAMBERS

The main purpose of a CI engine combustion chamber is to provide a proper mixture of air and fuel in a very short time. To achieve this, efforts are made either to direct air to fuel or to direct the fuel towards air in a short time.

There are three methods used for producing the air swirl (air movement) for the proper mixing of fuel with air.

1. During suction process
2. During compression process
3. During partial combustion process

The combustion chamber in which suction stroke is used to create the air swirl, is known as "*open combustion chamber*".

The combustion chamber in which compression stroke is used to create air swirl is known as *turbulence combustion chamber* or *swirl combustion chamber*.

The combustion chamber in which partial combustion is used to create swirl turbulence is known as the *pre-combustion chamber*, *the air-cell combustion chamber* or *energy-cell combustion chamber*.

## 6.6 OPEN COMBUSTION CHAMBER

In the open combustion chamber fuel is directly sprayed (injected) in the combustion chamber. Therefore it is also called *direct injection combustion chamber* or the *plain combustion chamber* and is shown in Fig. 6.2.

In the four-stroke cycle engine, the inlet air enters through a valve in the head. The valve and passageway (port) are designed to provide tangential entry to the inlet air, or else the masked (shrouded) inlet valve is used as shown in Fig. 6.3. The mask over the valve gives a rotary swirl to the flowing air entering the cylinder during the suction stroke. The rotary movement of the air persists during compression stroke. This rotary movement of air is reinforced by the shape of the piston head as shown in Fig. 6.2. Turbulence is created over the piston head in the circular channel provided over the piston heads. A fuel nozzle is located in the centre of the chamber with four or more orifices. The jets of fuel are directed towards air for combustion. The turbulence or air swirl over the piston head does not greatly disturb the direction of the fuel spray, but tends to strip the fuel particles and carry them away from the jet. The orifices in the nozzle are so located that the spray pattern fits the combustion space without impinging on the cylinder walls or piston head. The spray must contain a mixture of droplet sizes so that various degrees of penetration along with gradual vapourisation are obtained.

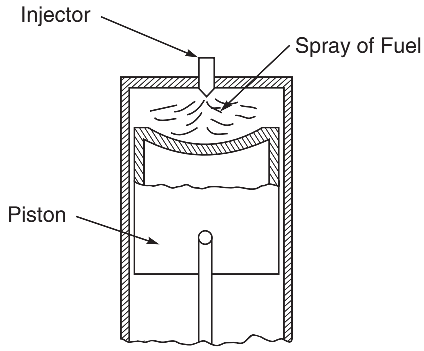



**Fig. 6.2** Open Combustion Chamber

In Fig. 6.4, other designs of the open combustion chamber have been shown. As the piston reaches TDC, the air trapped between piston and the cylinder head is forced radially inward and increases the swirl rotative velocity at the time of injection.

This final action of collecting air at the centre is known as the squeezing of air. Turbulence induced on the suction stroke and on the compression stroke is called *primary turbulence*. Once combustion is initiated, turbulence may be increased by the exploding nature of the process.

The turbulence obtained by the combustion of fuel, is called *secondary turbulence*. The working of the open combustion chamber depends upon primary turbulence.

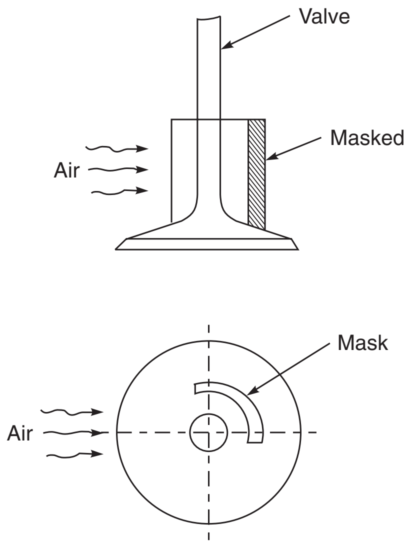



**Fig. 6.3** Masked or Shrouded Inlet Valve

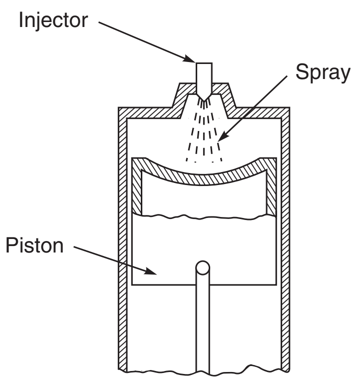



**Fig. 6.4** Open Combustion Chamber

The open combustion chamber has a high thermal efficiency because a compact combustion chamber has minimum surface to volume ratio which reduces cooling losses. Since excess air is supplied, the combustion temperature is low and in the diesel cycle, thermal efficiency approaches the standard efficiency as the percentage of air increases. The compact combustion chamber gives easy starting because the compression temperature is high. If this engine run at low speeds, then a cheaper fuel of lower cetane number can be used because a large quantity of fuel cannot be injected during the delay period. For these reasons, open combustion chamber engines have become popular.

The main demerit of the open combustion chamber engine is that the direct combustion of fuel over the piston head transmits direct thrust over the engine bearings. The injection pressure must be high to get good atomisation and distribution of fuel. The problem of fuel injection is complicated with variable speed operation because the fuel velocity in the injection unit is given by

$$V = \sqrt{2gH}$$

This means that the fuel velocity is proportional to $\sqrt{H}$, where $H$ is the pressure head. Thus injection pressure varies as the square of the engine speed. At lower engine speed, dribbling of fuel takes place and the orifices become clogged.

## 6.7 PRE-COMBUSTION CHAMBER

Figure 6.5 shows the pre-combustion chamber. In this type of engine the clearance volume is divided into two parts by a restricting passageway. For this reason, this design is also called a *divided combustion chamber*. The volume of the pre-combustion chamber varies from 25% to 40% of the total clearance volume. At the end of the compression stroke, fuel is injected into the pre-combustion chamber where the initial shock of combustion occurs without affecting the piston and bearings. Since limited air is available in the pre-combustion chamber, partial combustion of fuel takes place and the pressure is increased. The partially burned charge is expelled through the restricted passage with high velocity. This secondary turbulence enables the unburned charge to

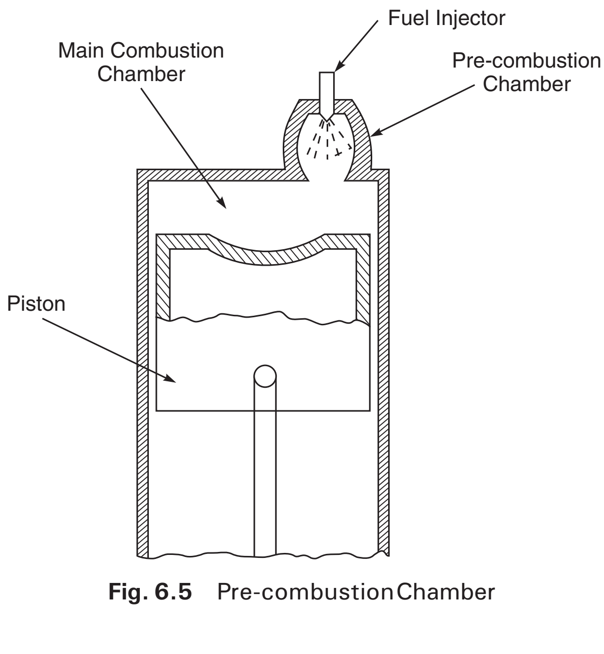



**Fig. 6.5** Pre-combustion Chamber

find more air in the main combustion chamber and complete the combustion. During expansion stroke, the charge in the pre-combustion chamber is drawn in the main combustion chamber.

The pre-combustion chamber engine has been developed chiefly for high speed engines. Its design overcomes some of the limitations of the open combustion chamber. The merits of the engine are:

1. For rapid mixing of air and fuel, extremely high velocity of air or swirl is obtained through the throat (restricted passage) of the pre-combustion chamber. Thus the spray characteristic is not the important factor in the divided combustion chamber as in the case of the open chamber design.
2. The pre-combustion chamber in which partial combustion takes place, is so stiff that much higher pressures and higher rates of pressure rise can be tolerated, than can be allowed in the main combustion chamber over the piston head.
3. The mixing process is accelerated by the early stages of the combustion process in the pre-combustion chamber.
4. The pre-combustion chamber has certain hot spots due to partial insulation from the cooling medium. These hot spots in the pre-combustion chamber reduce the delay period as compared to that with the open combustion chamber engine. The stainless steel inserts at the restricted throat of the pre-combustion chamber function as the hot spots, as these inserts are loosely fitted. These inserts are heated only while the engine is running. Therefore it is essential to cut off the pre-combustion chamber while cold starting, otherwise starting of this engine is very difficult.
5. The engine having a divided combustion chamber is not sensitive to the quality of fuel. Therefore a wide range of fuels even of lower cetane numbers can be used without affecting the engine performance.
6. Its maintenance cost is very low because
   (i) low injection pressure reduces stresses in the injection equipment.
   (ii) low pressure in the main combustion chamber reduces load on the bearings.
   (iii) simple hole nozzle is used which does not become clogged as the multi-hole nozzle.

The demerits of the divided combustion chamber engine are:

(i) The engine is more expensive.

(ii) Cold starting is difficult as the clearance volume is increased and the cooling surface area is also increased. Therefore glow plugs or other auxiliary devices are required.
A glow plug is like a spark plug in appearance, but it has a resistance wire in place of the spark gap. This wire is heated to incandescence for starting purpose by means of electric current from a storage battery.

(iii) Increased cooling surface area increases cooling losses, which reduces thermal efficiency. The high turbulence or jet of hot gases entering the main combustion chamber scour away the cool layer of stagnant gas clinging to the combustion chamber. This factor promotes cooling losses.

(iv) Pumping loss is increased due to pumping work through the restricted neck (passage) of the pre-combustion chamber, during compression stroke.

The pre-combustion chamber requires limited maintenance, therefore, it is widely used in farm equipment.

## 6.8 TURBULENCE COMBUSTION CHAMBER

The turbulence combustion chamber is designed to create a high turbulence during compression stroke. Increased turbulence is used to strip the fuel droplets to form a homogeneous mixture. The turbulence combustion chamber has been shown in Fig. 6.6. This is also a divided type combustion chamber. In the turbulence chamber 50% to 90% of the compressed air is forced by the piston. The fuel injector is located in the turbulence chamber such that the spray of the fuel is crossed by the produced swirl (whirling motion of air). This combustion chamber has all the advantages as that of the pre-combustion chamber. However, the action within the turbulence chamber is as follows:

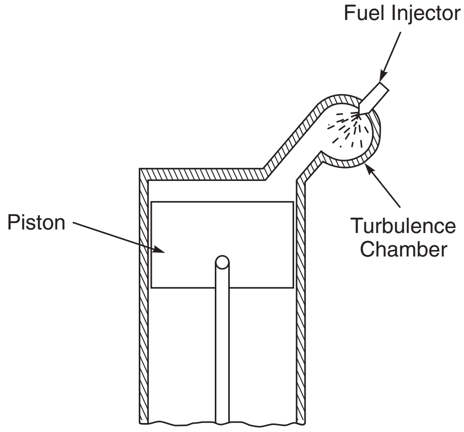



**Fig. 6.6** Turbulence Combustion Chamber

On the compression stroke, air is pumped at high velocity through the restricted passage into the chamber, thus causing a high turbulence within the chamber. As the piston approaches TDC the injector discharges fuel into the chamber at a relatively low pressure. Combustion then causes the pressure to rise, forcing the fiery droplets of air and gases at high velocity into the combustion area. Although this causes a high turbulence within the main combustion chamber, burning nevertheless is controlled by the dependency of combustion on injection.

Controlled burning means that combustion catches up with injection and then progresses with it. The turbulence chamber design is becoming more popular as emission and mileage concerns increase.

## 6.9 AIR CELL COMBUSTION CHAMBER

The air cell combustion chamber is similar to an open combustion chamber. The difference being that an air cell is attached in this combustion chamber as shown in Fig. 6.7. In the operation of the engine, the sequence of events is similar to the open combustion chamber and the turbulence combustion chamber. During the compression stroke, air is forced in the air cell. During the expansion stroke air is expelled from the air cell in the cylinder due to the difference of pressure. The discharge of air from the air cell creates a light secondary turbulence which helps to complete the combustion.

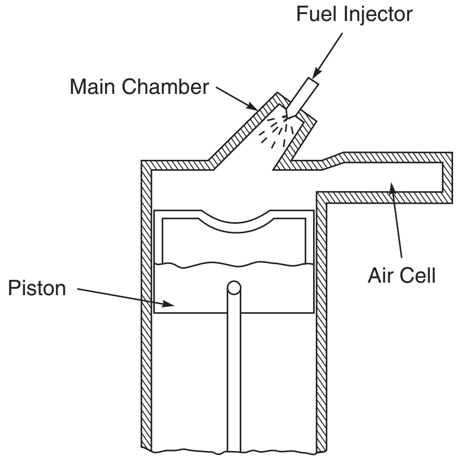



**Fig. 6.7** Air Cell Combustion Chamber

## 6.10 ENERGY CELL COMBUSTION CHAMBER

In Fig. 6.8, the sectional elevation and plan of an energy cell combustion chamber has been shown. The design of this combustion chamber is a combination of the pre-combustion chamber and the air cell chamber. The energy cell combustion chamber is also known as the *Lanova Combustion Chamber*. Its working principle is similar to the pre-combustion chamber.

There is a single hole nozzle, which injects fuel towards a small pre-combustion chamber (energy cell combustion chamber) which is on the opposite side of the cylinder as shown in the Fig. 6.8. About 60% of the injected fuel which is in the form of the core (poorly atomized) passes across the main combustion chamber and enters the energy cell. This energy cell has about 10% of the clearance volume. The walls of the energy cell combustion chamber run hot. Therefore the fuel reaching the energy cell combines almost immediately with the small amount of air in the cell. The resulting explosion forces the burning fuel out into the main combustion chamber at a high velocity. The blast from the minor cell is directed against the final portions of the fuel spraying from the nozzle. This action produces a mixture of fuel and burning gas in the main combustion chamber which is shaped such that the burning fuel stream splits and forms two vertices for rapid mixing with the air. As the piston moves down in the expansion stroke, the pressure difference between the cell and the cylinder permits the blowing of air from the cell to the cylinder. The discharge from the major cell picks up the fuel in the minor cell and passes into the main chamber (cylinder).

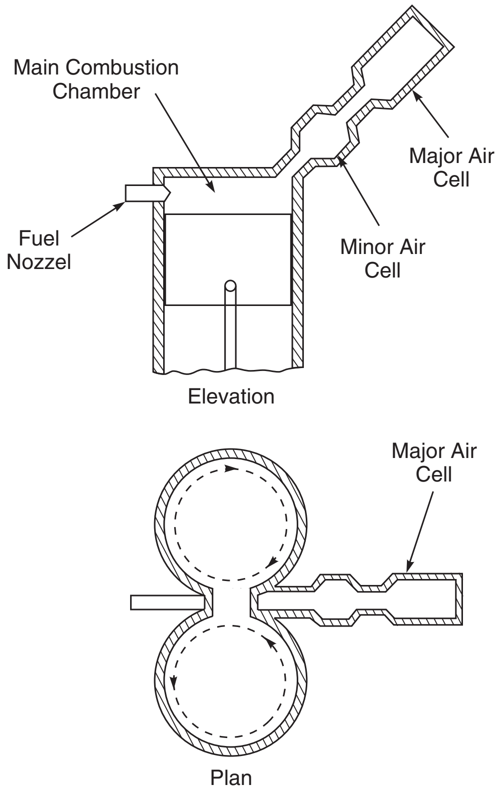



**Fig. 6.8** Energy Cell Combustion Chamber

Obviously, the major cell discharges air only after initiating combustion of fuel. This discharge is similar as in the case of the pre-combustion chamber. The action of the major air cell is accelerated by a narrow neck between the major and minor cells. The blow off from the minor cell is prolonged because small-restricted holes are provided at the outlet of the minor cell.

Cold starting of this engine is easy since the fuel is injected through the main chamber (cylinder) where the air is hot and fine particles catch flame. In comparison to an open combustion chamber, the duration of combustion in the energy cell combustion chamber is longer and the turbulence is also higher. As the combustion continues even during the expansion stroke, its full advantage is not obtained and it causes greater fuel consumption compared to that in an open combustion chamber. However, the energy cell engine is knockless and does not over-stress the engine parts and bearings. This engine has a smooth performance at variable speeds. The energy cell engine is well suited for high speed operation because the time for blowing charge from the cell is constant and in seconds. During this period, the crank rotates more at its high speed and the cylinder pressure is assisted by the cell.

## Review Questions

1. What are the main properties of fuel for a CI engine?
2. Discuss the role of viscosity as a property of diesel fuel in the performance of a CI engine.
3. Explain the combustion process in CI engine with the help of a pressure-crank diagram.
4. Define diesel knock and explain how delay period influences the diesel knock.
5. State the different types of CI combustion chambers. List the merits and demerits of an open combustion chamber.
6. What are the main differences between a pre-combustion chamber and an energy cell combustion chamber.
7. List the main advantages of an energy cell combustion chamber over an open combustion chamber.
8. List the merits and demerits of a pre-combustion chamber.

7

# Fuel System for Petrol Engine

**Objectives**

After studying this chapter, you should be able to:

- Describe the fuel system used for petrol engines.
- Explain the function and constructional details of 3-way cock.
- Explain the working of mechanical fuel pump.
- Describe the function of an electrically operated fuel pump.
- Describe the function of gauge type filter.
- Explain carburation and mixture quality for an auto engine.
- State the properties of air-fuel mixture.
- Explain the construction and working principle of carburettor used for automobiles.
- Explain the function of the throttle valve.
- Describe the working of the following mixture-control devices:
  - Suction controlled device.
  - Mechanical control device.
  - Air bleed device.
- Describe the types of inlet manifold and methods of vapourisation.
- Explain the working of dry and wet types of air cleaner.

## 7.1 INTRODUCTION

In a petrol engine (gasoline engine), the combustible mixture of air and petrol is prepared outside the cylinder. Petrol is highly inflammable. Also a combustible mixture requires a certain air-fuel ratio which is within the limits of combustibility. This requires proper handling of petrol in an automobile and a device which can supply the required air-petrol ratio to the engine at various conditions. A petrol engine needs a richer mixture while starting and a leaner (weaker) mixture while normal running. Such requirements of a petrol engine must be fulfilled before the charge (air-fuel mixture) enters the cylinder. In this chapter handling of fuel and the preparation of the air-fuel mixture are discussed in detail.

## 7.2 FUEL SYSTEM FOR PETROL ENGINE

The fuel system for a petrol engine comprises a fuel tank, fuel gauge, fuel pump and filter, air filter and carburettor.

In an automobile, petrol is stored in a tank known as the fuel tank. It is essential to know the quantity of petrol available in the fuel tank. Hence, a fuel gauge is provided which indicates the fuel level (petrol level) in the fuel tank.

In Fig. 7.1, the layout of a fuel system has been shown. There is fuel gauge attached to the fuel tank. The fuel level indicator is battery-operated. Therefore the fuel level indication is placed away from the fuel tank, in front of the operator (driver) in a car. In a two wheeler such arrangement is sometimes provided. A three-way cock is also provided which stops the normal supply of petrol to the engine when a limited quantity (about 0.5 litre) of petrol is left in the fuel tank. This quantity of petrol left in the fuel tank is known as *Reserved Fuel* which is used in emergency and is often enough to reach the nearest fuel filling station.

Figure 7.1 also shows a fuel pump with a fuel filter. The fuel pump may be operated either mechanically or electrically. This fuel pump is so designed that it maintains constant petrol pressure in the float chamber attached to a carburettor. When the float chamber is full, the fuel pump automatically stops and that also stops the supply of petrol to the carburettor.

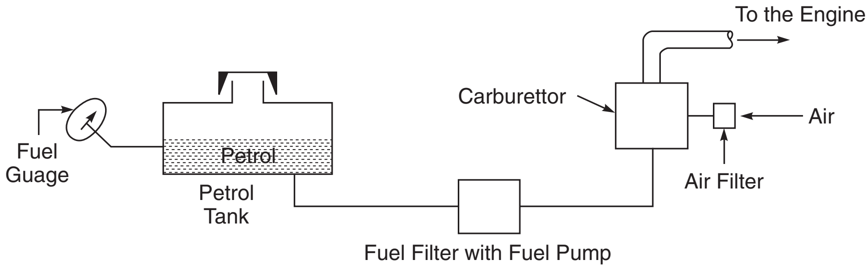



**Fig. 7.1** Layout of Fuel System

In the carburettor there is a float chamber which contains petrol at constant level. Fresh air from the atmosphere enters the carburettor where air mixes with fuel and forms a combustible mixture. This charge containing air and fuel is inducted in the engine cylinder during its suction stroke.

The air filter traps or arrests dust particles which are suspended in atmospheric air.

In a four-stroke cycle petrol engine, the combustible charge supplied by the carburettor enters the cylinder through the inlet port fitted with a valve known as the suction valve. Whereas in a two-stroke cycle engine, charge enters through the crankcase.

## 7.3 GRAVITY FEED SYSTEM

In two wheelers, fuel is supplied to the carburettor by the fuel tank located at the upper level of the carburettor. The fuel is fed by the action of gravity through a pipe. This system of fuel feed is cheaper because it does not require a fuel pump. The fuel filter is provided at the entrance to the carburettor. Further precaution is taken by designing a large sized float chamber so that dust particles in petrol settle down or precipitate in the float chamber and do not enter the fuel nozzle of the carburettor. The main disadvantage of the gravity feed system is that the fuel pressure entering the float chamber does not remain constant but changes with the petrol head in the fuel tank. When the fuel tank is full, the petrol head is $H_1$, and when reserved petrol is left in the fuel tank, then the petrol head is $H_2$ as shown in Fig. 7.2.

$$\text{Petrol pressure } P = H \times w \tag{7.1}$$

where

$P$ is the pressure in kg/cm$^2$

$H$ is the head of fuel in cm

$w$ is the specific weight in kg/cm$^3$

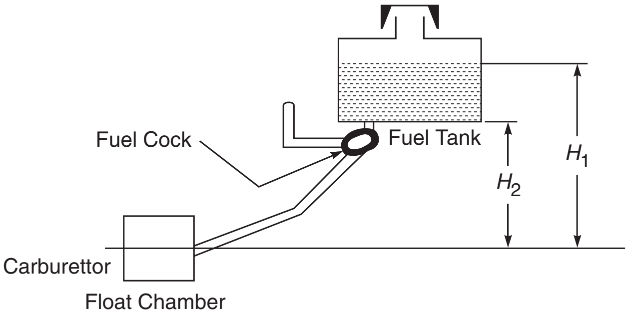



**Fig. 7.2** Gravity Feed System

Therefore when the fuel tank is full with petrol, pressure on the float $<P_1 = H_1\ w>$. Since $H_1$ is greater than $H_2$, $P_1$ is also greater than $P_2$, the pressure on the float when the tank is not full. This means that the float valve is pushed down with greater force and more fuel (petrol) enters the float chamber. This increases the petrol level in the float chamber as well as in the nozzle of the carburettor. The carburettor supplies richer mixture than when reserved petrol is left in the fuel tank. At the 'reserved petrol' condition, the carburettor supplies leaner (weaker) mixture. In Fig. 7.3, details of a float chamber are shown. At $H_2$, petrol pressure on the float valve is reduced and it is closed earlier keeping a lower petrol level in the float chamber. Thus fuel consumption in the feed system is increased when the fuel tank is full.

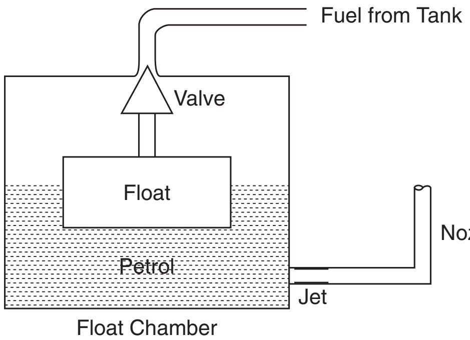



**Fig. 7.3** Float Chamber

In Fig. 7.4 (a), the basic function of a fuel cock used in a two wheeler in which gravity feed system is used has been shown. The fuel cock body has three holes A, B and C. The hole A is connected to a tube which is inside the fuel tank. This tube in the fuel tank allows petrol to flow to the carburettor through the hole A. Until the fuel level in the tank reaches upto the tip of the tube, the supply of fuel continues to the carburettor. When the level of fuel reaches the tip of the tube, the supply of fuel (petrol) to the carburettor stops.

There is a cover plate inside the body of the fuel cock. This cover plate has a slot which connects the holes A and C. Fuel can pass from hole A to hole C. Hole C is connected to the pipeline leading to the carburettor. As explained previously, when the fuel level reaches the tip of the tube inside the fuel tank, the supply of fuel stops. Then the cover of the cock is turned so that the slot in it connects hole B to hole C and the reserved fuel in the fuel tank starts flowing to the carburettor. The vehicle driver becomes cautious and tries to reach the petrol filling station before the petrol in the fuel tank is completely exhausted. Further rotation of the cover does not connect A or B to C. The supply of petrol to the carburettor stops.

In Fig. 7.4 (b), the assembly of a three-way fuel cock has been shown. The inlet and outlet are shown in the assembly. Between the body of the cock and the cover plate, a fiber washer having similar holes A, B and C is placed to avoid leakage of petrol. On the back of the cover plate a coil spring is placed. This spring keeps the cover plate pressed against the fiber washer. Such an assembly makes the fuel cock leak-proof.

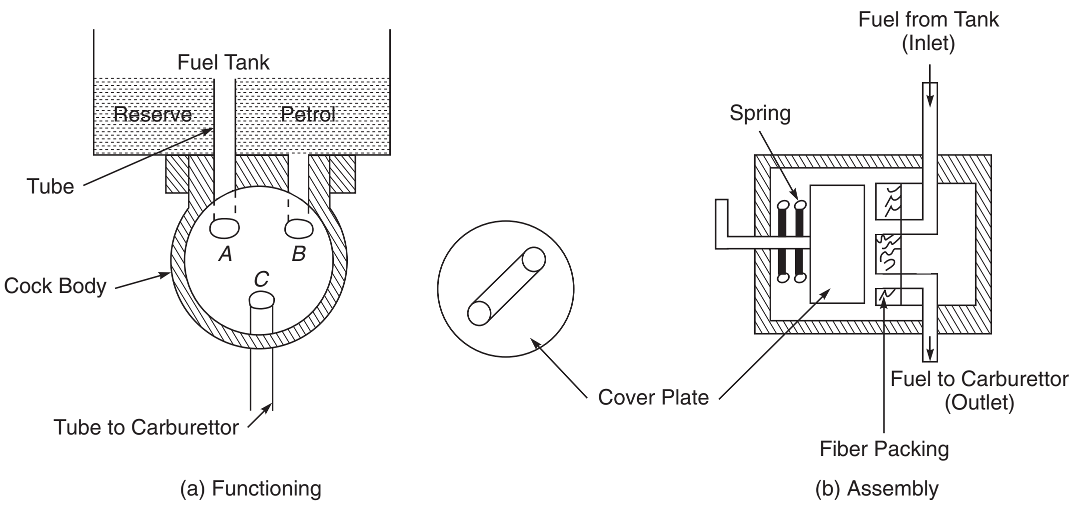



**Fig. 7.4** Three Way Fuel Cock

## 7.4 FUEL PUMPS

The fuel feed system of petrol in a four wheeler is not based on the action of greavity. Instead fuel pumps are used. Generally, two types of fuel pumps are used:

1. Mechanically operated fuel pump.
2. Electrically operated fuel pump

### 1. Mechanically Operated Fuel Pump

Figure 7.5 shows a mechanical fuel pump which is operated by a cam or an eccentric. There is a diaphragm which is connected to a pull rod. A rocker arm which is operated by an eccentric pulls the diaphragm via the pull rod. Thus, the diaphragm is actuated by the eccentric. When the diaphragm is pulled down pressure above the diaphragm drops and petrol is drawn through the inlet port. On the return stroke of the diaphragm, petrol is pumped through the outlet port. The outlet of the fuel pump is connected to the float chamber of the carburettor. This sequence of pumping action continues until the float chamber receives petrol upto the level that closes the float valves.

When the float valve is closed, pressure is developed in the pipe line connecting the pump and the float chamber. This pressure of petrol is also communicated over the diaphragm. Under this condition, force applied by petrol pressure over the diaphragm is equal to the spring force below

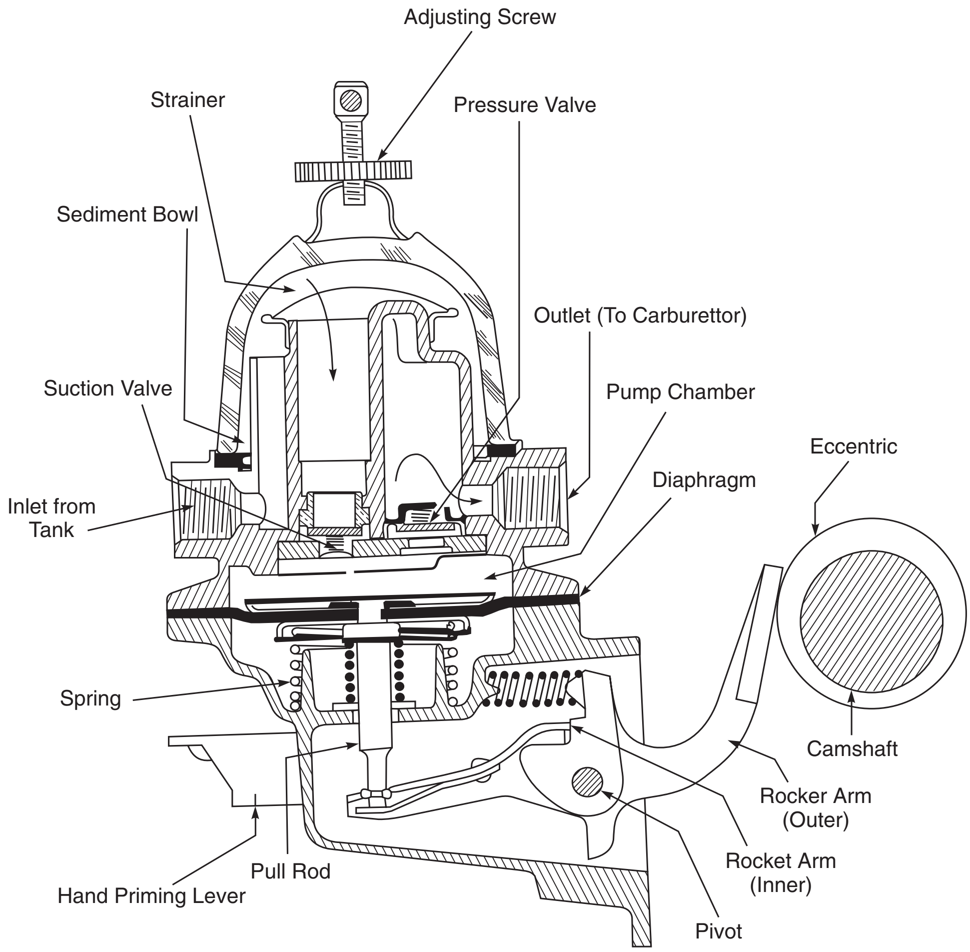



**Fig. 7.5** Mechanical Fuel Pump

the diaphragm. Thus the fuel pump stops functioning automatically when fuel is not required in the float chamber. As soon as the petrol level goes down in the float chamber, the float valve is opened and the supply of petrol from the fuel pump starts. The mechanical fuel pump is located at the lowest level so that suction of fuel is avoided and the fuel flows under gravity upto the fuel pump. Also, the fuel pump must be located at the place where cooling is more effective. This is necessary to avoid vapour lock in the fuel pump.

Referring Fig. 7.1, we can see that the layout of the mechanical fuel pump is similar to the layout of a petrol feed system for a petrol engine used in a four wheeler (car).

The petrol tank is located at the rear side of the car so that the petrol tank is away from the heat of the engine. The fuel pump is placed at the lower level of the fuel tank to avoid vacuum in the fuel pump. This is essential to avoid vapour lock in the fuel pump because petrol evaporates quickly when it receives heat under low pressure.

The disadvantage in the mechanical type of fuel pump is that it functions only when the engine runs. This creates starting problem if there is no petrol in the float chamber of the carburettor. This problem can be solved to some extent by providing a hand priming lever on the fuel pump. The car driver has to operate this hand priming lever which gives reciprocating motion to the diaphragm and petrol is supplied to the carburettor.

## 2. Electrically Operated Fuel Pump

The electric fuel pump is operated by electric current supplied either from a battery or from a dynamo (generator). Figure 7.6 shows the basic working principle of an electric fuel pump. A diaphragm provides the pumping action which reciprocates as the armature behind it experiences a pull from the solenoid and similarly experiences a push from the spring. This action of the fuel pump feeds petrol to the float chamber. The solenoid is energized when the breaker points make contact and the electric circuit is completed. The upward movement of the armature transmits motion through a bronze rod which is located at the center of the solenoid and connected to a lever. The upward motion of this rod pushes the lever which disconnects the breaker points and the current is interrupted. This demagnetizes the solenoid and the armature is pushed back by the spring, consequently pushing the diaphragm and producing the delivery stroke.

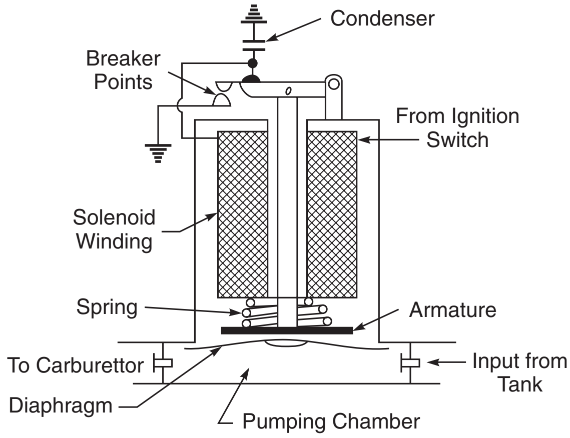



**Fig. 7.6** Electric Fuel Pump

When the float chamber is full and the float valve is closed, the developed fuel pressure over the diaphragm keeps the diaphragm pressed and the breaker points are left open. This stops the supply of current and energy is saved. Thus, petrol supply is automatically cut off when petrol is not needed in the float chamber and the electric energy is saved.

The advantage of the electric fuel pump is that it starts operating as soon as ignition switch is turned on and the fuel pump can be located at any convenient place away from the engine. The trouble only starts when the car battery is discharged or any connection becomes faulty.

## 7.5 PROPERTIES OF AIR–FUEL MIXTURE

The fuel (petrol or gasoline) used in automobiles is obtained from different oil fields. The percentage of oxygen in air differs from place to place and also from time to time. However, it has been found that about 15 kg of air is required to burn 1 kg of fuel. The oxygen present in air and the hydrocarbons present in petrol chemically combine during the process of combustion in this proportion. This air-fuel ratio (15:1) is the chemically correct air-fuel ratio, and is also known as the *stoichiometric mixture*. If the percentage of fuel (petrol) is increased, i.e. the percentage of air is decreased, then the mixture becomes rich. For example, air-fuel ratio 12:1 is a rich mixture because the stoichiometric mixture is 15:1. Similarly, if the percentage of fuel is less, i.e. the percentage of air is more than in the stoichiometric mixture, then the mixture is known as 'weak' or 'lean' mixture. For example, air-fuel ratio 20:1 is a weak mixture.

The combustion quality of these different air-fuel ratios changes. The products of combustion (burned gases), temperature of burned gases, etc. also change. The combustion quality of a mixture is indicated by the rate of combustion or the manner of flame propagation in the combustion chamber.

In Fig. 7.7, a curve has been drawn to show the relation between flame propagation, i.e. the rate of burning in the combustion chamber and the different air-fuel ratios. The figures on the x-axis represent the percentages of air in various mixtures.

Here the air-fuel mixture is chemically correct. "90" means 90% air in comparison to the air required for stoichiometric mixture. This mixture is 'rich' due to shortage of air.

Similarly, 110 represents 110% of air in comparison to the air required for stoichiometric mixture. This mixture is 'lean' due to excess of air.

From experiments it has been found that maximum flame propagation takes place when the air-fuel mixture is slightly rich, i.e. about 90% air when compared to the air in stoichiometric mixture (Flame propagation depends on other factors also, e.g. temperature, compression ratio, percentage of residual gases, atmospheric air condition, etc.).

Maximum flame propagation is shown at point C in Fig. 7.7, and not at point D which is at 100% air. Note that flame propagation reduces as the air-fuel mixture becomes weak or rich. At points A and B where the air-fuel mixture is too rich and too lean (weak) respectively, flame propagation completely stops. These limits at the points A and B are known as *limits of combustibility*. This means that excessively rich and lean mixtures do not catch flame. The limits of combustibility are not definite and depend on the properties of fuel and the conditions of the combustion chamber. For example, a non-combustible weak mixture of air and fuel at a lower cylinder temperature becomes a combustible mixture if the cylinder temperature is increased.

A rich mixture dissociates and absorbs heat that reduces cylinder temperature during the combustion process. This reduces the mean effective pressure, hence the engine power is reduced.

A curve between the engine horse power and mixture strength has been drawn in Fig. 7.8. 100 represents 100% air to get a chemically correct mixture. Similarly, 85 represents 85% of air with respect to the chemically correct mixture. This mixture is a rich mixture due to shortage of air. 120 represents 120% of air with respect to the chemically correct mixture and is a lean mixture due to the excess air present in it. From experiments it has been found that the engine develops maximum power when the air-fuel mixture is slightly rich (about 85% air than the air required for stoichiometric mixture). For this mixture all air is consumed and maximum heat is generated to perform work. Further enrichment of the mixture reduces power due to incomplete combustion of fuel caused by the shortage of air. If 120% air is available, then power is reduced due to the excess air which absorbs the heat of combustion. From Fig. 7.9, it is clear that the engine has maximum ther-

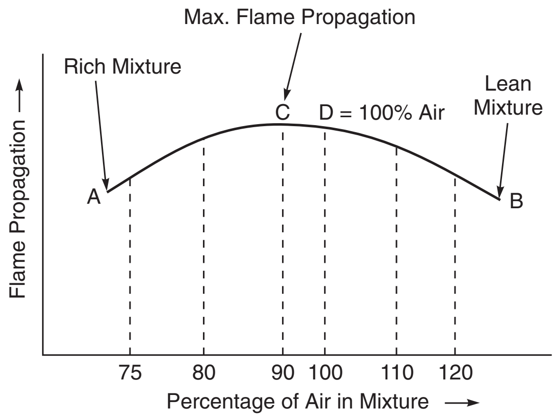



**Fig. 7.7** Combustion Quality of Charge

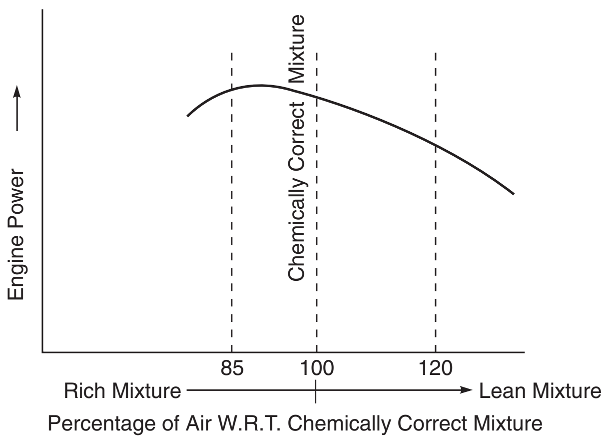



**Fig. 7.8** Horse Power-mixture Strength Relation Curve

mal efficiency when the mixture contains about 120% air with respect to the chemically correct mixture. This mixture is lean (weak) due to the excess air in it. For this mixture strength all fuel is consumed. This is due to non-uniform mixture (heterogeneous mixture) in the combustion chamber.

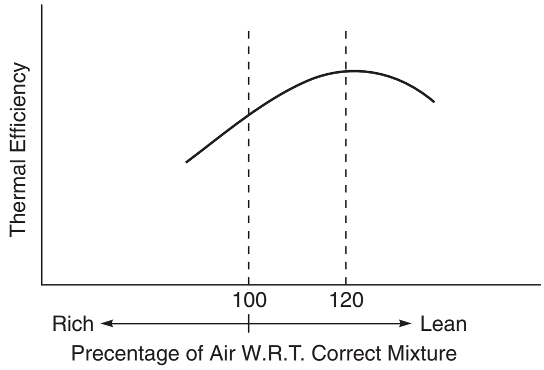



**Fig. 7.9** Effect on Thermal Efficiency

## 7.6 ENGINE REQUIREMENTS

Figure 7.10 shows, a curve drawn to illustrate the different mixture requirements of the engine at various loads. When the engine runs without load, i.e. at idle speed, the engine requires a richer mixture (not more fuel consumption) due to the following reasons:

1. On no load (idle speed), the throttle valve that absorbs work is almost closed. This consumes fuel as work is done against vacuum.
2. The volumetric efficiency is reduced. This increases the percentage of residual gases (burnt gases) and dilutes the fresh charge. The fuel molecules in contact with the burned gases are a part of waste.
3. The mixture supplied is heterogeneous.
4. At starting when the cylinder temperature is low, most of the heat of combustion passes to the engine parts.

As the load increases, the throttle valve is opened. This reduces the residual gases in the combustion chamber and the engine requires a lesser fuel air ratio.

After 20% load, the engine needs a leaner mixture because the throttle valve is sufficiently opened, volumetric efficiency is increased, mechanical efficiency is increased, the air-fuel mixture becomes more homogeneous, and the percentage of residual gases decreases.

After 80% load, the power jet is opened which supplies more fuel. The throttle valve is almost fully opened, and the excess fuel in the air-fuel mixture (of greater proportion of fuel) consumes all the air available. Engine temperature is increased as such cooling losses also increase. Engine power increases, and the percentage of residual gases reduces. Therefore a richer mixture is needed to develop more power.

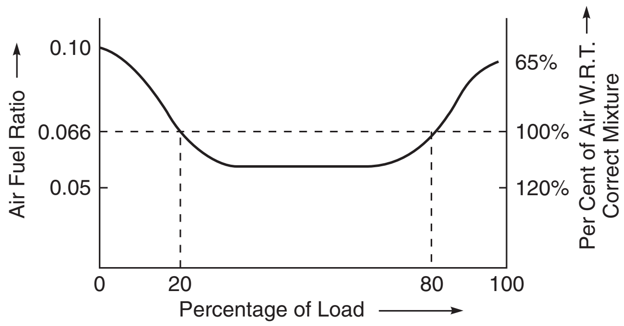



**Fig. 7.10** Mixture Requirements of the Engine on Loads

## 7.7 SIMPLE CARBURETTOR

To carburize means to combine an element with carbon. Therefore, a carburettor is a unit which by the process of carburization supplies a combustible mixture of vapourized fuel and air. The simplest method to get a mixture of air and fuel is to vapourize the liquid fuel in a stream of air. In a carburettor, Bernoulli's principle is utilized for converting the pressure energy of the air stream into kinetic energy.

Figure 7.11, shows a simple carburettor. There is a float chamber which supplies fuel to the fuel nozzle through a fixed fuel jet at constant level. In the figure, a U-tube manometer has been used to observe the changes in venturi depression due to the flow of air through the venturi neck. The venturi depression $(\nabla h)$ increases with the increased velocity of air through the venturi neck. The difference of pressure pulls the fuel from the float chamber and sprays it into the air stream. It is obvious that the force causing the flow of fuel from the float chamber is due to the venturi depression. Further, the venturi depression increases with the increase in air velocity. This means that flow of fuel increases with the increase in air velocity through the venturi neck. As long as the densities of air and fuel remain constant, the air-fuel ratio also remains constant. However in practice, the air flow through the venturi is due to the suction process of the engine. This suction reduces air density. Therefore the air-fuel ratio which was chemically correct at the normal engine

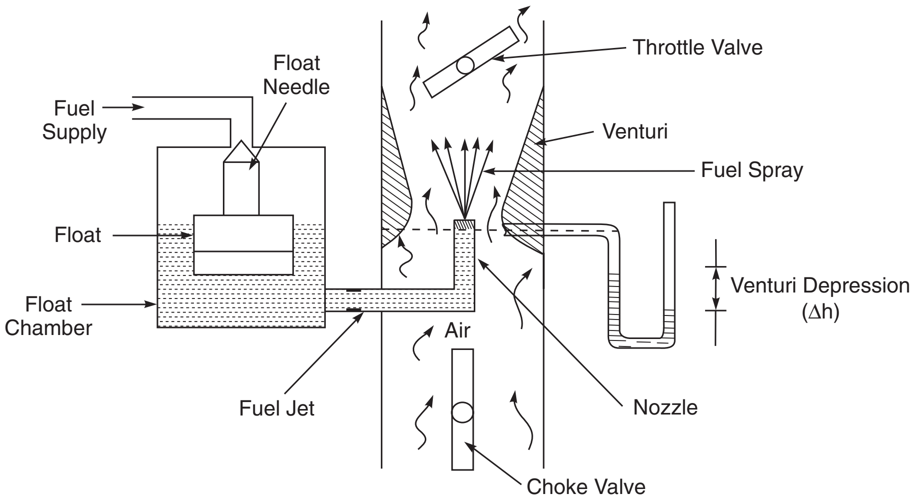


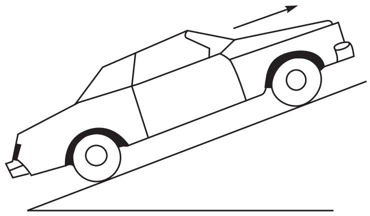

**Fig. 7.11** Simple Carburettor

speed, becomes 'richer' at the higher engine speeds, and 'leaner' (weaker) at lower engine speeds. Such a change in the air-fuel ratio creates practical difficulties with a simple carburettor. In Fig. 7.12 (a), a car is shown going up a gradient. Due to the load on the engine its speed is decreased. This means that the rate of flow of air through the venturi is decreased and the carburettor supplies a weaker mixture, whereas the engine needs a richer mixture to develop more power to go up the hill.

In Fig. 7.12 (b), a car is shown descending the hill. Since there is no load or the load is decreased, the engine runs faster and this increases the rate of flow of air through the venturi. This action in the venturi increases depression and pulls more fuel. Also the density of air is decreased which makes the mixture richer, hence developing more power. However, the engine needs a weaker mixture because there is no load on the engine.

The proceeding discussion indicates that a simple carburettor provides a leaner mixture when the vehicle ascends a hill and a richer mixture when the vehicle descends the hill. However, the engine requirements are completely different.

This is the main drawback in a simple carburettor. Thus modern carburettors are developed to fulfill different engine requirements.


(a) Car Moving Up Hill

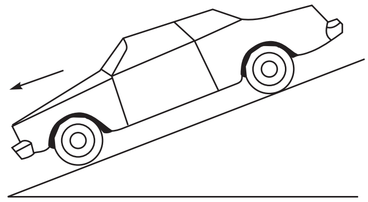

(b) Car Moving Down Hill

**Fig. 7.12** Varying Engine Loads

## 7.8 THROTTLE VALVE

In Fig. 7.11, a throttle valve has been shown above the venturi. The throttle valve controls the quantity of charge passing to the engine cylinder. A wider opening of the throttle valve permits a greater flow of charge to the engine cylinder and the closing of the throttle valve chokes the passage. The flow area is reduced, and thus a lesser quantity of charge passes to the cylinder. This means that the engine speed is controlled by operating the throttle valve. Note that the operation of the throttle valve only controls the flow area and not the air-fuel ratio. It is the venturi depression ($\nabla h$ in Fig. 7.11) which controls the air-fuel ratio and also affects air density which is responsible for the preparation of a leaner mixture or a richer mixture in the carburettor.

In Fig. 7.13, experimental curves are drawn for fuel and air discharge through a fixed jet and a venturi for different openings of the throttle valve. The flow of fuel (petrol) follows the parabolic curve, whereas the flow of air does not follow the parabolic curve due to change in air density during the suction process. In this case, the carburettor is set to supply 15 kg of air, and 1 kg of petrol at the throttle opening 'x'. This means that the carburettor supplies the air-fuel mixture in the ratio of 15:1 (chemically correct mixture or stoichiometric mixture) for the throttle opening 'x'. For a smaller opening of the throttle valve, the mixture prepared is lean, and for a wider opening the mixture is rich.

This shows that during idling (engine running without load), the throttle valve is almost closed and the mixture supplied by the simple carburettor is so lean that it is beyond the limits of combustibility (*Sec.* 7.5). Therefore it is not possible to run an engine on idle speed with a simple carburettor.

In short, it can be concluded that a simple carburettor working satisfactorily for throttle opening 'x' (Fig. 7.13) fails to supply the required mixture when:

1. Vehicle is going up hill.
2. Vehicle is going down hill.
3. Vehicle is not moving but the engine is running (idling of the engine).

It is difficult to start a petrol engine with a simple carburettor.

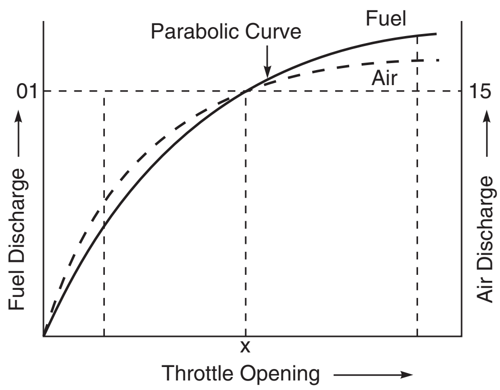



**Fig. 7.13** Effect of Throttle Opening on Air-fuel Ratio

## 7.9 MIXTURE CONTROL DEVICES

Generally three devices are used to get control on the mixture strength.

### 1. Suction Control Device

In Fig. 7.14, a suction control device has been shown. Air entering the carburettor, enters the pipe from entrance A. The pressure over the fuel level is the air pressure at A. The pipe A-B has a control valve which controls the air flow from A to B. The pipe opens at B in the float chamber. Pipe B-C has a small orifice to provide a restricted flow of air from the float chamber to the end of pipe C which opens at the venturi neck. In a simple carburettor the mixture becomes richer if the atmospheric pressure is reduced, because air density is consequently reduced. Clogging of the air filter also makes richer mixture.

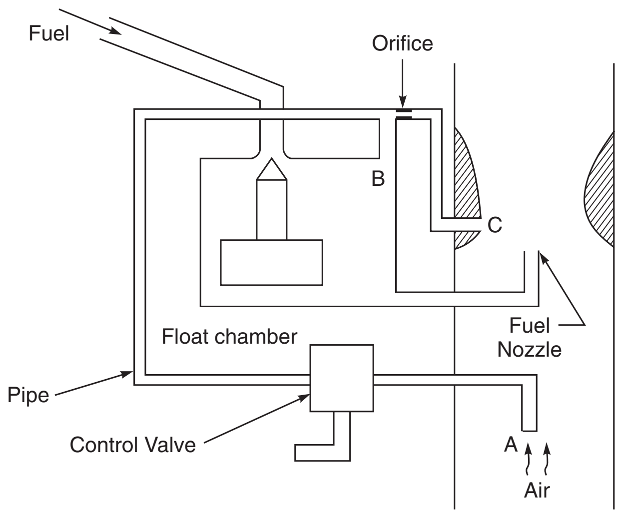



**Fig. 7.14** Suction Control Device

There is a control valve in the pipe line A-B. This control valve controls the flow of air from A to B. On complete opening of the control valve, the pressure at A is equal to the pressure at B and air leaks to the opening C through a narrow orifice. The pressure difference between B and C causes the flow of fuel from the float chamber to the fuel nozzle. When the control valve is completely closed, then pressure at B is the pressure at C. Since there is no pressure difference between B and C, the flow of fuel from the float chamber to the fuel nozzle is stopped. Thus by properly regulating the control valve, the flow of fuel to the fuel nozzle is regulated to get the required air-fuel ratio.

### 2. Mechanical Control Device

Figure 7.15 shows a mechanical control device. The figure shows a rod having a needle which is tapered as per design. The downward movement of the needle reduces the flow area for the fuel (petrol). This controls the quantity of the fuel passing to the fuel nozzle. The movement of the rod is controlled by the throttle valve through some mechanism. When the throttle valve is widely

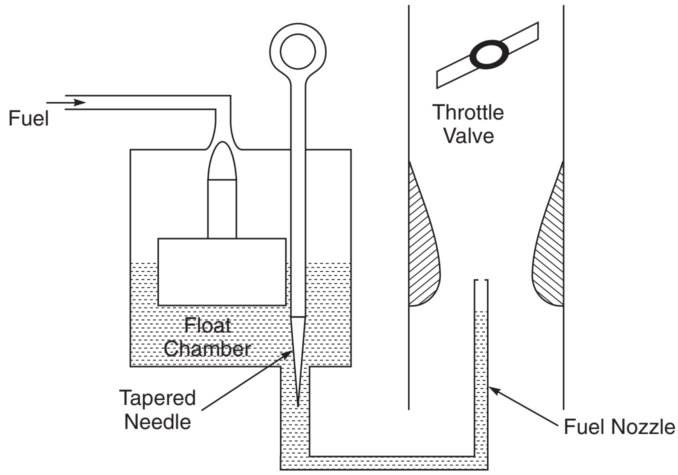



**Fig. 7.15** Mechanical Control Device

opened, greater venturi depression is created which reduces air density. Hence the mixture is not enriched due to the downward movement of the tapered needle.

## 3. Air Bleed Device

An air-bleed device is shown in Fig. 7.16. There is a vent pipe in the mechanical device one end of which is opened in air and the other end is in the fuel nozzle as shown in the figure. When the throttle valve is widely opened, more fuel is sucked in by the increased venturi depression (Fig. 7.11) and the level of the fuel (petrol) in the nozzle goes down. The end of the vent pipe (air bleeder) in the nozzle is opened to atmospheric air and air bleeds or flows out from this end. Thus the enrichment of the charge is avoided. The other air bleeding device is known as a compensating device (Fig. 7.17). In this device a separate nozzle is provided which is connected to a tube known as a compensating well which stores some quantity of fuel. It should be noted that fuel is supplied from the float chamber through a very narrow restricted jet which is known as a compensating jet. When the throttle valve is suddenly widely opened, a flat spot is avoided by the supply of fuel from the compensating well, and when the compensating well is empty, air starts bleeding through

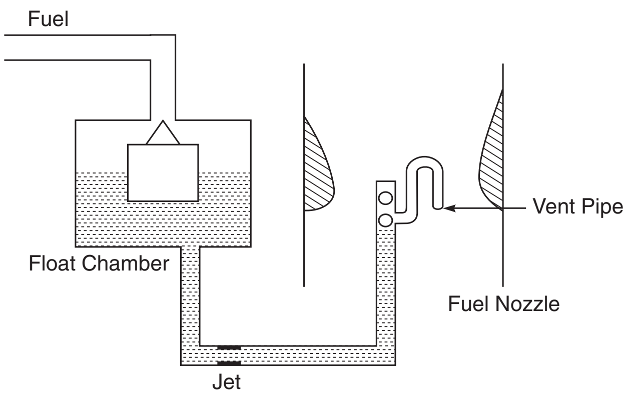



**Fig. 7.16** Air Bleed Device

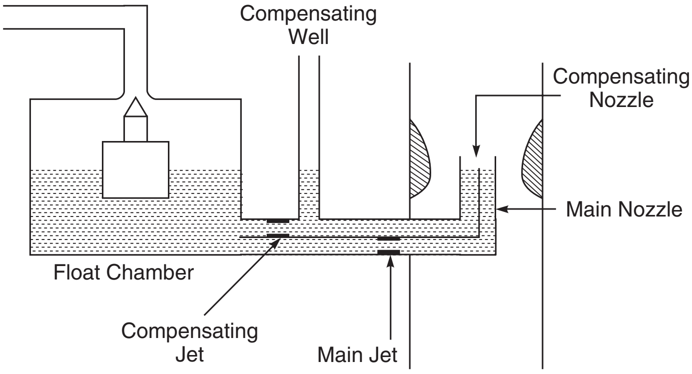



**Fig. 7.17** Compensating Device

the compensating nozzle. On closing the throttle valve, fuel is again stored in the compensating well due to the difference in levels. This device is very successful because it prevents the weakening of the mixture at the beginning of the throttle opening and also prevents enrichment of the mixture if the throttle valve remains open for a longer time.

## 7.10 TYPES OF INLET MANIFOLDS

We have already studied about manifolds in detail in Chapter 3, Section 3.18. Here we shall concentrate on the types of inlet manifolds. Inlet manifolds are of two types:

(a) Inlet manifolds without exhaust jackets
(b) Inlet manifolds with exhaust jackets.

For evaporation of petrol, a large amount of heat is required. If the atmospheric air temperature is high, then the heat content in the atmospheric air is utilized to evaporate petrol. The air temperature reduces and in some cases the air temperature goes below 0°C. The moisture in the atmospheric air starts condensing and freezing in the carburettor or in the manifolds.

To avoid this difficulty of icing either in the carburettor or in the inlet manifold, an exhaust jacket is provided in which hot exhaust gases are passed to make the inlet manifold hot. Care should be taken that the temperature of the inlet manifold is not excessive so that partial oxidization of the fuel does not occur. A bimetallic strip is attached to a control valve which is located at the entrance of the exhaust gases in the exhaust jacket pipe. At low temperatures, the bimetallic strip contracts and opens the valve which in turn opens the entrance of the jacket. The exhaust gases keep the inlet manifold heated so that the petrol is easily evaporated. If the exhaust temperature is greater, then the bimetallic strips get heated and expands. This closes the valve and the exhaust entrance is also closed.

The flow resistance in the inlet manifold directly increases with the increase in length, and also increases with the square of the gas velocity. Therefore to minimise the flow resistance in the inlet manifold, the inlet manifolds are made shorter in length and greater in diameter to reduce gas velocity.

## 7.11 AIR CLEANER

The air cleaner is a device which arrests the dust particles carried by the air entering the carburettor. If these dust particles are not arrested, then they enter the cylinder and act as an abrasive between the piston and the cylinder walls. This causes cylinder wear.

To avoid wearing of the cylinder, air cleaners are used. Air cleaners are of two types –

1. Dry Type Air Cleaner.
2. Wet Type Air Cleaner.

## 1. Dry Type Air Cleaner

The dry type air cleaner consists of a specially treated paper element. Dust particles are arrested by this paper and the filtered air passes to the cylinder. After a certain period or (kilometer run) the filter paper is taken out from the unit and cleaned.

The filter paper is usually replaced after 40,000 km. The element should not be rinsed in petrol.

## 2. Wet Type Air Cleaner

The wet type air cleaner is also known as oil bath type air cleaner. The wet type air cleaners are suitable where extremely dusty conditions are anticipated. In general, the oil wetted mesh filter is used in this type of air cleaner. In Fig. 7.18 (a), an oil bath type of air filter has been shown. Air does not enter directly in the wet air cleaner, but passes through the annular passage provided in between the shell and top cover. Air enters the cleaner and moves down. At the bottom of the cleaner, the moving air stream almost touches the oil surface and leaves the heavy dust particles in the oil bath. The air tends to flow upward carrying some drops of oil into the filter element which is an oil wetted metallic mesh. The dust particles impinge on the oil surface and are trapped. Dust particles which are not directly precipitated by the oil are trapped on the oil-wetted metallic mesh and washed back by the excess oil. Finally, the dust particles are dropped into the oil sump. Clean air passes out of the filter element into the carburettor.

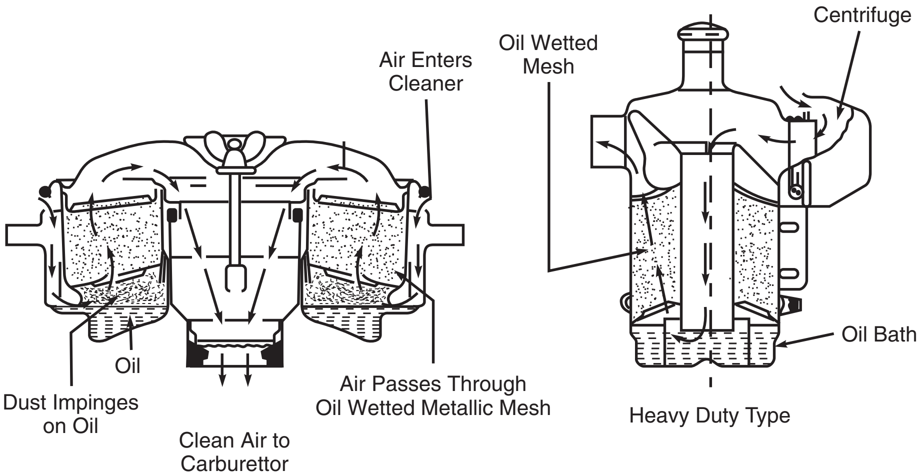



**Fig. 7.18** Types of Air-cleaner

Figure 7.18 (b) shows the 'Heavy duty type' air cleaner. Such air filters are used in tractors or in jeeps which are used on dusty roads. In the heavy duty type filter there is a centrifuge around the filter. Most of the dust is removed by centrifugal action in the centrifuge. After the removal of dust, the air passes through the main oil bath cleaner. The filter should be cleaned every 1500 kilometers in dusty areas, otherwise it is normally cleaned after every 4,000 kilometres.

The air cleaners are usually provided with an air silencer as shown in Fig. 7.19. The air silencer contains a number of sound damping passages and resonating chambers. As shown in the figure, air enters from one end of the silencer and follows the path as shown by arrows.

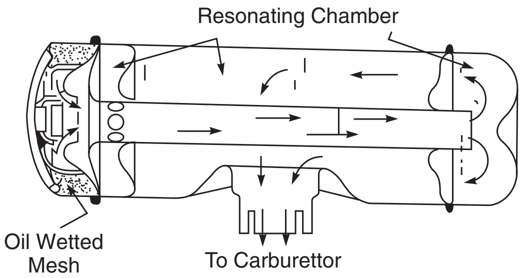



**Fig. 7.19** Air Silencer

## 7.12 WORKING OF POPULAR MAKES OF CARBURETTORS USED IN INDIAN VEHICLES

**Table 7.1** Popular Carburettors Used In Indian Vehicles

| | |
|---|---|
| Ambassador Car | - S.U.H.S. 2 semi-down draught type and solex down draught M 32 PBIC. |
| Premier Padmini Fiat Car | - Solex M 32 PBIC and solex M 32 BIC. down draught type. |
| Maruti Car | - Solex 2-barrel down draught and solex M 32 PBIC. |
| Mahindra Jeep | - Cartex YF - 938 SD - down draught (Petrol)and solex M 32 PBIC |

### 1. S.U. Carburettor (HS type)

The S.U. carburettor is of the automatically expanding choke type in which the size of the main air passage (or choke) over the jet and the effective area of the jet, are variable according to the degree of throttle opening. This automatic regulation of the size of the choke over the complete throttle range gives an approximately constant air velocity over the jet (sometimes called a constant vaccum carburettor) which is sufficient to ensure good atomization at all speeds, making multiple jets necessary.

Figures 7.20 and the 7.21 show the exterior and sectional views of the S.U. (H.S. type) carburettor fitted in Ambassador cars having 1760 cc engines.

This type of carburettor consists of a single jet in which a tapered needle operates. The area of the throat is varied by means of a piston which slides up and down.

The movement of the piston causes the movement of the tapered needle. The needle is fastened to the bottom of the piston. When the piston moves upward, more air can pass through the throat. At the same time, the needle moves up in the jet, increasing the effective size of the jet. Thus more fuel flows and mixes with the air passing through. When the piston moves downward, the needle also moves down into the fuel jet. This reduces the operating size of the jet opening and limits the amount of fuel that can flow. The piston and tapered needle work together to provide a properly proportioned mixture of air and fuel for different operating conditions of the engine.

The piston is raised or lowered in response to the movement of the throttle valve (Fig. 7.21). When the throttle valve is closed to the idling position, intake manifold vaccum is cut off from the throttle body. The piston spring pushes the piston down to its lowest position. A small amount of air flows around the throttle valve and through the venturi. It produces just enough vaccum at the venturi to cause the fuel jet to deliver enough fuel for idling. When the throttle valve is opened, intake-manifold vacuum enters the throttle body. This vacuum draws air from the space above the piston, acting through the vacuum port in the lower part of the piston. The piston is raised by the vacuum, partly compressing the piston spring. The oil damper reservoir that is part of the piston

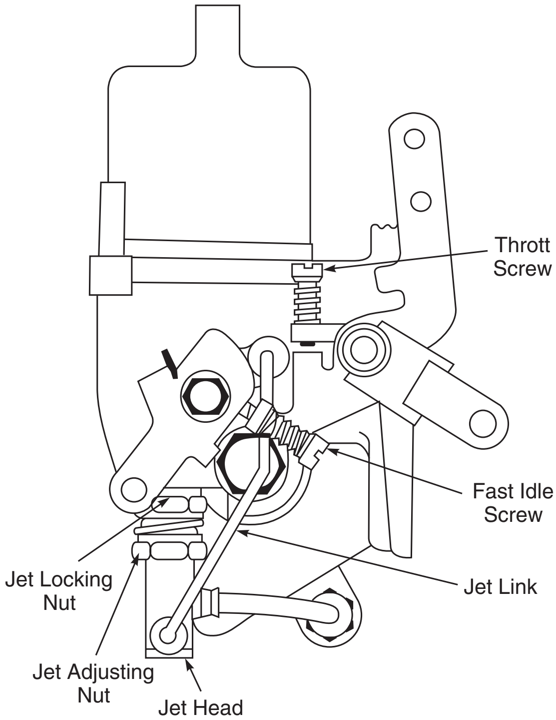



**Fig 7.20** Exterior View of a S.U. (H.S. Type) Carburettor (*Courtesy:* Hindustan Motors Ltd.)

acts like a tiny shock absorber. It prevents excessive movements of the piston as the throttle valve is moved and vacuum conditions change.

## 2. Solex Carburettor

The Solex carburettor is manufactured in India by M/S. Carburettor Limited, Madras. The Solex carburettor gives better performance and is most reliable. It is used in most of the vehicles like Premier Padmini, Ambassador, Standard, Jeep CJ-3B and also used in most foreign cars. The exploded view of the solex carburettor M 32 PBIC is shown in Fig. 7.22. The names of the different parts of the carburettor are provided in Table 7.2.

The solex carburettor is the *down draught type carburettor*. The performance of this carburettor is controlled by five circuits: Float circuit, low speed circuit, high speed circuit (normal running), accelerating pump circuit and choke circuit (starter). These circuits are shown in Fig. 7.23, and are described in brief as follows:

***Float Circuit*** The float circuit consists of a float, a float toggle assembly, a needle valve assembly and the filter plug assembly (see Fig. 7.23). The level of petrol in the float chamber is controlled by means of the float and the needle valve. The correct setting of the level is determined by three main factors, namely the weight of the float, the size of the needle valve and the thickness of the fiber washer fitted under the needle valve. In this circuit, petrol is fed through the banjo inlet, and is filtered by a built-in filter before passing through the needle valve assembly to the float chamber.

***Low Speed Circuit*** For slow running, the feeding of the engine is ensured by the pilot jet(g) and the air bleed(u) (Fig. 7.23). Petrol is drawn from the main jet well which in turn is metered by the pilot

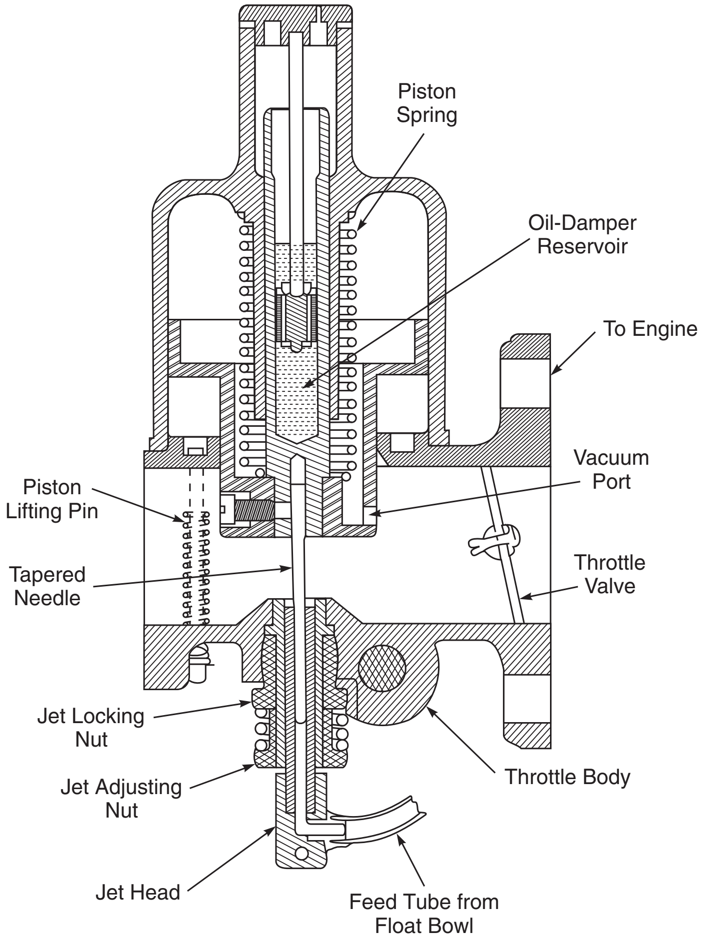



**Fig 7.21** Sectional View of a S.U. (H.S. Type) Carburettor (*Courtesy:* Hindustan Motors Ltd.)

jet(g). For correct setting under idling it is necessary to use both means of adjustment, i.e. the volume control screw(w) for mixture strength and the slow running screw for speed (not shown in figure).

***High Speed Circuit (normal running)*** The fuel for part throttle and full throttle operation is supplied through the high speed circuit. Fuel is provided by the main jet ($G_g$) and the air by the choke tube(k) (Fig. 7.23). As the throttle is slowly opened, air velocity in the choke tube(k) begins to rise, thus creating a depression across the spraying orifice. The correct balance is automatically ensured by the air entering through and being calibrated by the air correction jet(a). Underneath the air correction jet, there is a tube for emulsification with lateral holes(s), the calibration of which should not be altered.

***Accelerating Pump Circuit*** For rapid acceleration, extra quantity of fuel is required by the engine which is supplied through the pump injector (i) (Fig. 7.23). When the throttle valve is suddenly opened, the accelerating pump is actuated by the pump operating lever and the pump control rod which in turn is connected to the throttle spindle. Petrol is drawn into the pump non-return inlet valve($P_n$) where the petrol is filtered by a fine filter ($F_f$). The inward movement of the diaphragm supplies petrol under pressure which is metered by the pump jet($G_p$) and fed into the engine through the injector(i). The quantity of petrol supplied to the engine can be altered by adjusting the pump control rod nut(N).

***Choke Circuit (Starter)*** While starting, petrol is drawn from the float chamber through the starter petrol jet and supplied to the progressive choke (starter). The operation of the starter is by the rotation of the starter disc valve which is connected to the dashboard choke control by means of a lever and a flexible cable. The weakening of the choke(starter) mixture is spread over the whole movement of the choke. When the choke lever is pulled out fully, the richest mixture is delivered. As the choke lever is pushed in, the mixture is progressively weakened until, when the lever is fully in, the choke(starter) is completely out of action.

General instructions for starting the engine under different conditions:

***(a) Starting the Engine When Cold***

(i) Pull the starter control right out

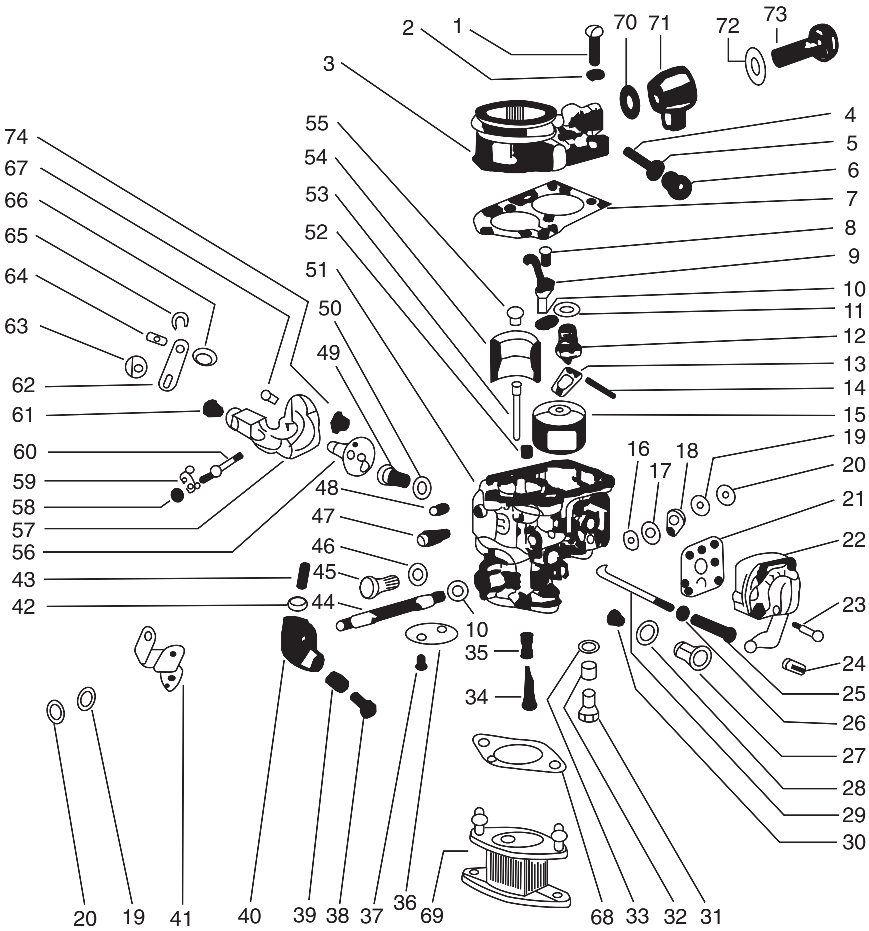
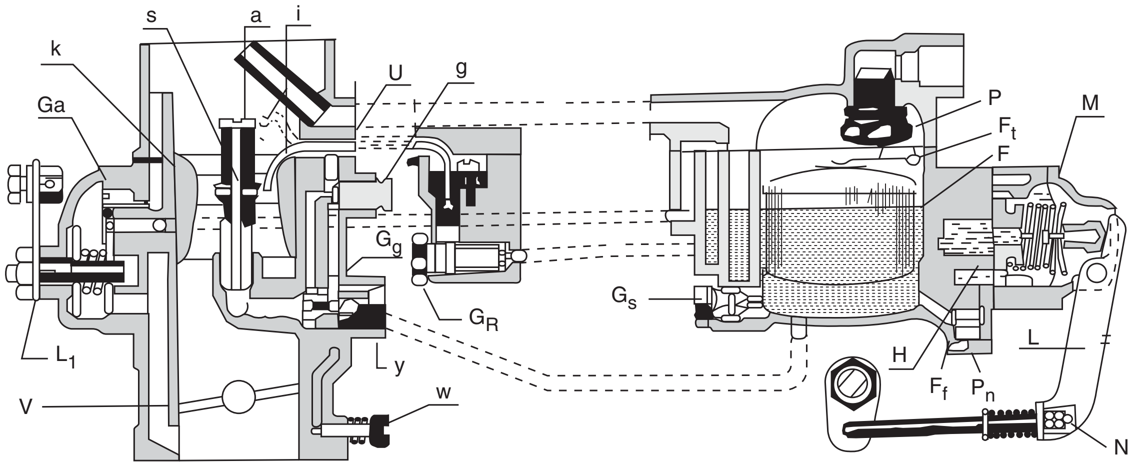



**Fig. 7.22** Solex Carburettor M 32 PBIC Exploded View
(*Courtesy:* Mahindra and Mahindra Ltd.)

**Table 7.2** Solex Carburettor M 32 PBIC

| | |
|---|---|
| 1. Float chamber cover assembly screw | 38. Slow running adjustment screw |
| 2. Spring washer | 39. Spring for slow running adjustment screw |
| 3. Float chamber cover sub-assembly | 40. Abutment plate |
| 4. Filter gauze | 41. Throttle lever assembly |
| 5. Washer for filter plug | 42. Throttle stop screw nut |
| 6. Filter plug | 43. Throttle stop screw |
| 7. Float chamber cover gasket | 44. Throttle spindle |
| 8. Pump injector assembly fixing screw | 45. Pump jet |
| 9. Pump injector assembly | 46. Washer |
| 10. Pump injector assembly gasket | 47. Pilot jet |
| 11. Washer | 48. Choke tube fixing screw |
| 12. Needle valve | 49. Starter petrol jet |
| 13. Float toggle | 50. Washer |
| 14. Float toggle spindle | 51. Main body sub-assembly |
| 15. Float 12.5 gms | 52. Pilot air-bleed |
| 16. Sealing washer | 53. Emulsion tube |
| 17. Throttle spindle washer | 54. Choke tube |
| 18. Intermediate lever | 55. Air correction jet |
| 19. End nut retaining washer | 56. Choke (starter) valve assembly |
| 20. Throttle spindle end nut | 57. Choke (starter) cover |
| 21. Pump body gasket | 58. Nut for outer cable bracket |
| 22. Accelerating pump assembly | 59. Clip for outer cable |
| 23. Pump body fixing screw | 60. Stud for outer cable bracket |
| 24. Pump control rod adjusting nut | 61. Choke (starter) cable clamp screw |
| 25. Pump control rod spring | 62. Choke (starter) lever |
| 26. Control rod spring retaining washer | 63. Choke (starter) spindle end nut |
| 27. Pump control washer | 64. Choke (starter) cable swivel screw |
| 28. Main jet holder | 65. Circlip |
| 29. Washer | 66. Choke (starter) cable swivel |
| 30. Main jet | 67. Choke (starter) cover fixing screw |
| 31. Pump inlet value | 68. Flange gasket |
| 32. Pump filter gauze | 69. Flange adaptor sub-assembly |
| 33. Washer | 70. Washer |
| 34. Volumes control screw | 71. Banjo |
| 35. Spring for volume control screw | 72. Banjo washer |
| 36. Throttle | 73. Banjo bolt |
| 37. Throttle fixing screw | 74. Starter air jet |




| | | | | | |
|---|---|---|---|---|---|
| a | Air correction jet | g | Pilot Jet | P | Needle Valve Assembly |
| F | Float | H | Pump Valve | $P_n$ | Pump Non Return Valve |
| $F_t$ | Float toggle | i | Pump Injector | s | Emulsion Tube |
| $F_f$ | Fine Filter | k | Choke Tube | U | Pilot Air Bleed |
| $G_a$ | Starter Air Jet | L | Pump Lever | V | Throttle |
| $G_g$ | Main Jet | $L_1$ | Starter Lever | W | Volume Control Screw |
| $G_p$ | Pump Jet | M | Pump Membrane | y | Main Jet |
| $G_s$ | Starter Petrol Jet | N | Control Unit | | |

**Fig. 7.23** Solex Carburettor

(ii) Switch on and operate the electric starter without depressing the acceleration.

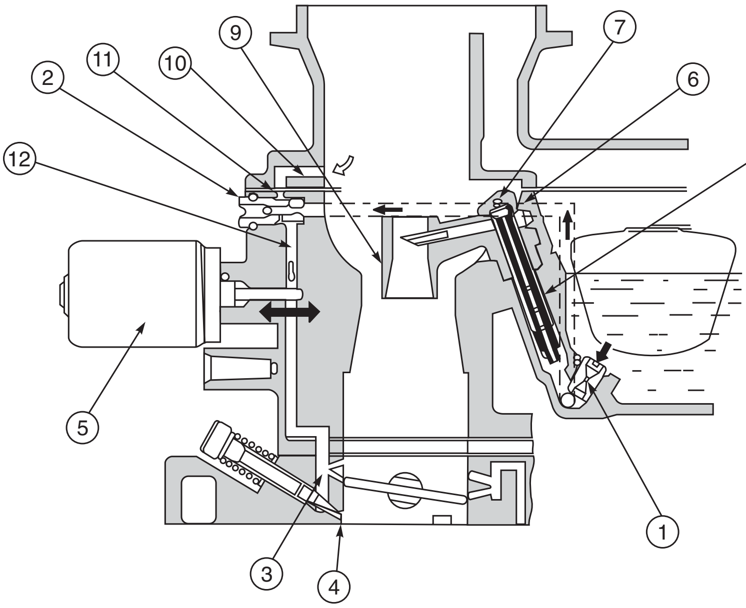
(iii) As soon as the engine starts running, push in the starter control knob half-way. This will provide a 'fast' idling and prevent stalling in the first mile or so. Push in the dashboard control right home as soon as possible to prevent unnecessary use of rich mixture.

***(b) Starting the Engine When Warm*** If the engine is warm, start with the starter control in half-way position.

***(c) Re-starting the Hot Engine*** While restarting a hot engine the starter control must not be used. If the engine cannot be started in the normal way, the acceleration pedal should be pressed slightly during the next attempt.

## 3. Maruti Solex Carburettor

The solex carburettor fitted to Maruti engines differs from the solex carburettor mentioned earlier in this Chapter. The Maruti Solex carburettor is a *two-barrel down draft type having a primary system and a secondary system.* The primary system operates under normal driving condition, and the secondary system operates under high speed and high load driving conditions. In the primary system, a choke valve is incorporated. The exploded view of this type of carburettor is shown in Fig. 7.24. The preformance of the Maruti Solex carburettor is controlled by the following circuits-float chamber circuit, slow speed circuit, high speed circuit, acceleration power circuit and fuel return system. Brief descriptions of the different circuits are given in the following paragraphs:




| | | |
|---|---|---|
| 1. Primary Main Jet | 5. Solenoid Valve | 9. Inner Venturi |
| 2. Primary Slow Jet | 6. Main Air Hole No. 2 | 10. Slow Air Hole No. 2 |
| 3. Bypass Port | 7. Main Air Hole No. 1 | 11. Slow Air Hole No. 1 |
| 4. Idle Port | 8. Primary Bleed Pipe | 12. Slow Mixture Passage |

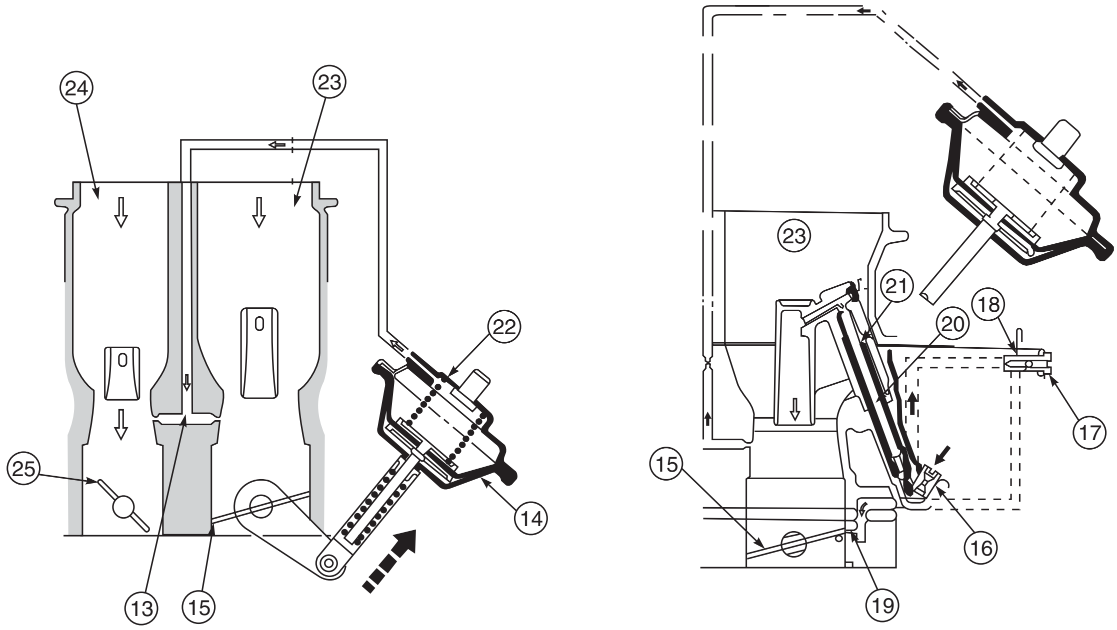
**Fig. 7.24** Exploded View of Maruti Solex Carburettor

***Float Chamber Circuit*** The float chamber with its needle valve is a vessel receiving the fuel from the fuel pump and holding it up to a certain constant level. The float responds to the up-and-down movement of the fuel surface and actuates the needle valve.

***Slow Speed Circuit*** When the engine starts to run, the fuel in the float chamber flows out through the main jet (1) and reaches the pilot (slow) jet (2) (Fig. 7.24). There the incoming fuel is metered and mixed with the air metered at the two pilot (slow) air holes (10 and 11). This air-fuel mixture is sprayed out from the bypass port (3) and the idle port (4). During idling, the mixture is spread out mainly from the idle port (4) and mixed with the air flowing into the main bore. Thus the air-fuel mixture can be made leaner or richer by tightening or loosening the idle mixture adjusting screw respectively.

***High Speed Circuit (Primary Circuit)*** When the accelerator pedal is depressed from the idle speed position (wider opening of the primary throttle valve), the fuel in the float chamber is metered at the primary main jet (1) and flows into the primary bleed pipe (8) (Fig. 7.24). There, it is mixed with the air metered at the two primary main air holes (7 and 6). This air-fuel mixture is sprayed out into the inner venturi (9) through the primary main nozzle.

***Secondary Circuit*** When the primary throttle valve opens wider than in the primary circuit (above 40°), a boost pressure about 7 mm Hg develops in the primary venturi. The boost pressure, being transmitted through the hole (13) provided in the primary venturi, surpasses the spring force in the depression chamber and pulls up the diaphragm (14) as shown in Fig. 7.25.




13. Vacuum Hole
14. Diaphragm
15. Secondary Throttle Valve
16. Secondary Main Jet
17. Secondary Pilot Jet
18. Secondary Pilot Air Hole
19. Bypass Port
20. Bleed Pipe
21. Secondary Main Air Hole
22. Depression Chamber
23. Secondary Side
24. Primary Side
25. Secondary Throttle Valve

**Fig. 7.25** Secondary Circuit

In accordance with this movement of the diaphragm, the secondary throttle valve (15) opens as they are inter-locked by way of the rod and lever. In this state, the fuel which has passed through the secondary main jet (16) reaches the secondary pilot jet (17). There it is metered and mixed with the air which is metered at the secondary pilot air hole (18). This mixture is sprayed out of the bypass port (19).

When the boost pressure in the primary venturi gets higher and a boost pressure also develops in the secondary venturi, the secondary throttle valve opens wider (more than about 5°). In this state, the fuel metered at the main jet (16) and the air metered at the secondary main air hole (21) are mixed in the bleed pipe (20). Then this air-fuel mixture is sprayed out into the secondary venturi.

***Acceleration Power Circuit*** The main device of the acceleration power circuit is an accelerating pump (Fig. 7.26) for making the carburettor respond without delay to the accelerator pedal when it is depressed abruptly while the engine is running in its low speed range or is idling. The actuating lever of this pump is linked to the primary throttle shaft so that, as the primary throttle valve opens quickly, the pump lever pushes up the diaphragm, thereby closing the suction ball valve and opening the discharge ball valve. Consequently, the fuel in the pump is forced out of the pump nozzle into the primary venturi.

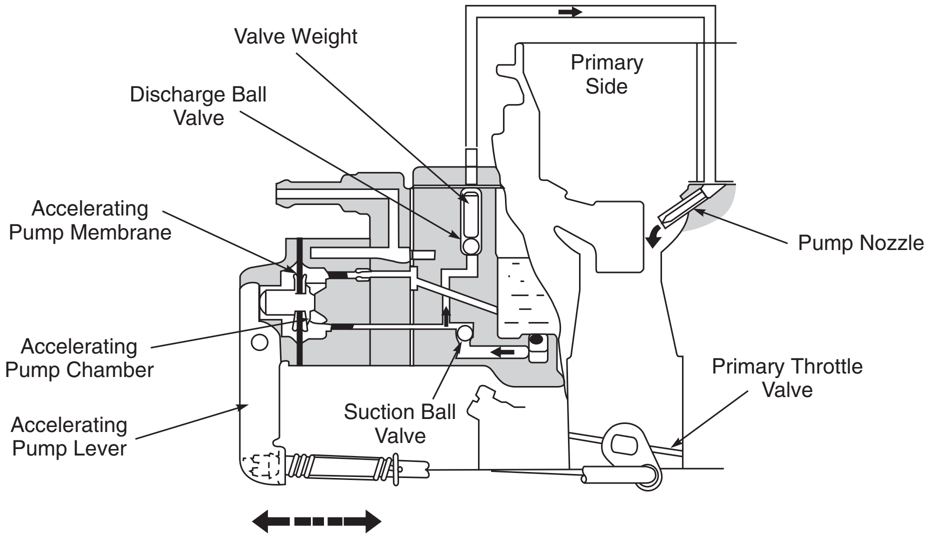


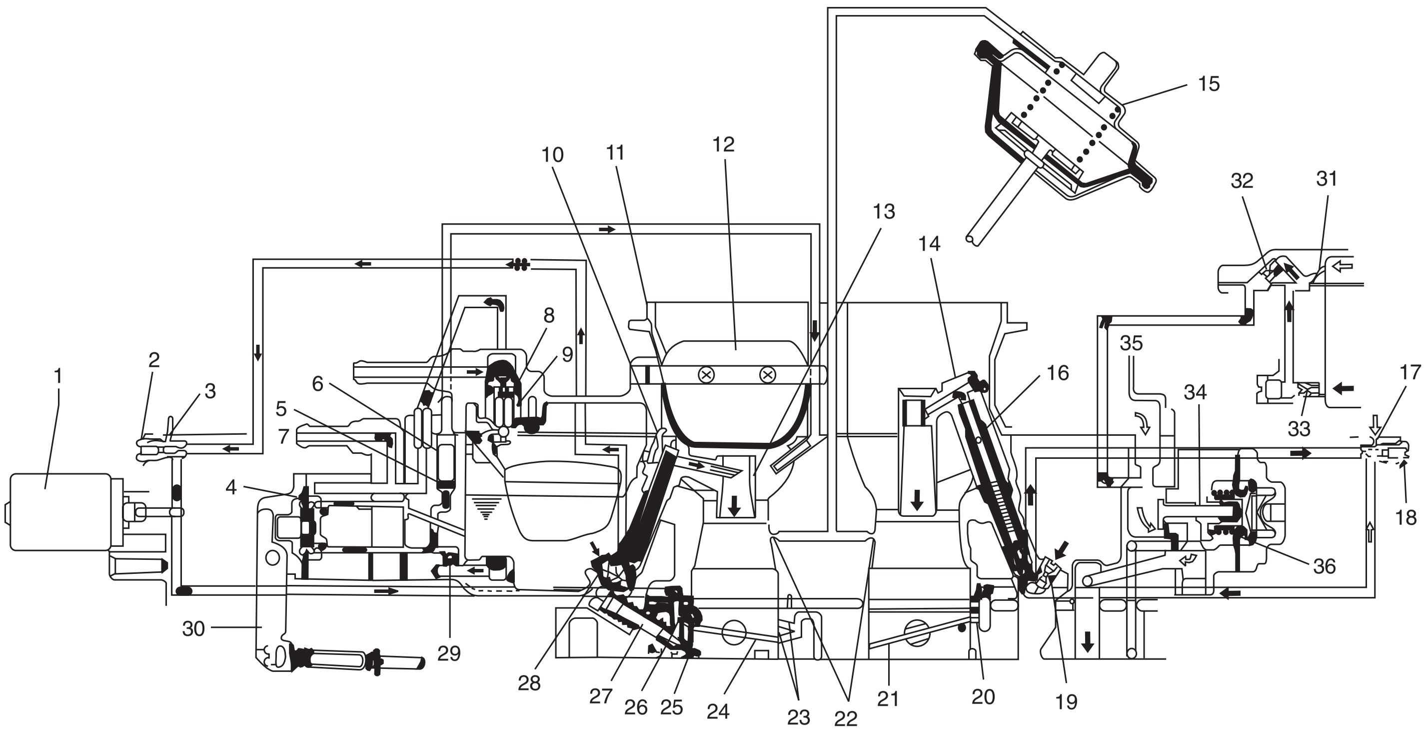

**Fig. 7.26** Acceleration Power Circuit

With the acclerator pedal released, the diaphragm is set back to the original position with the pump spring. In this state, the fuel in the float chamber opens up the suction ball valve and enters the pump chamber.

***Solenoid Valve*** The main function of the solenoid valve is to prevent engine run-on (the engine not stoping ignition key turned off). With the ignition key turned on, current flows in the solenoid coil which generates a magnetic force. The force pulls the needle valve and opens the passage for the slow mixture. On the other hand, with the ignition key turned off, the magnetic force disappears and the needle valve is brought back to the original position with the spring in the solenoid valve. The closed passage cuts off the slow mixture, thus preventing engine run-on.

***Fuel Return System*** A fuel return circuit is provided in Maruti Solex carburettor in order to avoid *vapour locking* of fuel. When the fuel level rises in the float chamber, its float valve closes; and as the level falls, the valve opens. With the valve closed, the incoming fuel (delivered under pressure by the pump) finds its way through the side hole provided in the top part of the float valve anchoring point and flows through the passage drilled out through the float chamber wall and around the acceleration pump chamber back to the fuel tank filler. This arrangement allows the fuel pump to keep on delivering fuel. For this reason, the incoming fuel for the float chamber is always cold and cools the acceleration-pump chamber by flowing past its chamber, thereby suppressing the conditions leading to vapour locking.

The complete circuit diagram of the Maruti Solex Carburettor is shown in Fig. 7.27. The names of the different parts and circuits are given in Table 7.3.



Fuel

Air

Fuel and Air Mixture

1. Fuel cut solenoid
2. Primary pilot
3. Primary pilot air hole
4. Accelerating pump membrane
5. Discharge well valve
6. Weight
7. To fuel tank (fuel return)
8. Needle valve
9. Needle valve seat
10. Primary main air hole no. 2
11. Primary main air hole no. 1
12. Choke valve
13. Primary inner venturi
14. Secondary inner venturi
15. Depression chamber
16. Secondary main air hole
17. Secondary pilot air hole
18. Secondary pilot jet
19. Secondary main jet
20. Secondary bypass port
21. Secondary throttle valve
22. Depression chamber hole
23. Induction air port
24. Primary throttle valve
25. Idle port
26. Primary bypass port
27. Idle mixture adjusting screw
28. Primary main jet
29. Suction ball valve
30. Accelerating pump lever
31. Air hole
32. Coasting mixture
33. Coasting fuel jet
34. Coasting valve
35. Air horn
36. Membrane

**Fig. 7.27** Maruti Solax Carburettor

**Table 7.3** Troubleshooting of a Fuel System

| *Trouble* | | *Cause* | *Remedy* |
|---|---|---|---|
| 1. Engine will not start | (a) | Starting mixture too weak | Check the size of the starter petrol jet against specification. Checks for air leaks and that the throttle has returned to idling position. |
| 2. Engine fires but will not continue running | (a) | Volume of starting mixture insufficient | Starter petrol jet and air jet smaller than specified. Check and fit correct sizes of starter petrol jet and air jet. |
| 3. Engine will not idle | (a) | Air leaks | Check joints between carburettor and mani fold and engine. Check for worn throttle spindle. |
| 4. Engine misfires at idling speed | (a) | Pilot jet smaller than specified | Fit pilot jet as specified and adjust volume control screw as necessary. |
| 5. Engine "hunts" at idling speed | (a) | Pilot jet larger than specified | Fit pilot jet of specified size and adjust idling speed adjustment screw as necessary. |
| 6. Engine top speed insufficient | (a) | Correction jet larger than specified | Fit correction jet as specified |
| | (b) | Main jet smaller than specified | Fit main jet as specified. |
| | (c) | Fuel supply restricted | Check fuel pump pressure. Check for blockage in fuel supply pipe. |
| 7. Engine knocks and overheats. | (a) | Mixture too weak (Main jet smaller than specified) | Fit main jet of specified size. |
| 8. Heavy fuel comsumption. | (a) | Air cleaner choked | Clean air cleaner thoroughly. |
| | (b) | Bi-starter disc valve not closing completely | Check for sufficient travel in the dashboard control wire. Check that spring is holding the disc valve flat against casting. |
| | (c) | Carburettor flooding internally | Check that the float is not leaking. Shaking the float will show whether there is petrol inside. Needle valve may be worn or not moving due to the presence of gum; wash thoroughly in methylated spirit. |
| | | | Check correct size of valve assembly and number and thickness of fibre washers used. Check lift pump pressure. If excessive it will force needle off the seating. Vent hole to atmosphere may be blocked; clear it thoroughly. |
| | (d) | Jet setting not to specifications | Check and alter where necessary. |
| 9. Poor acceleration | (a) | Accelerator pump is not functioning. | Check that valves are free, diaphragm spring is sound, passages (air and petrol) are clear. |
| | (b) | Pump jet smaller than specified. | Fit pump jet of specified size. |

**Table 7.4** Troubleshooting of a Fuel Pump

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. No suction at the inlet No fuel supply | (a) Leak in the fuel line between the tank and pump inlet. | Check and rectify. |
| | (b) Filter chamber cover gasket damaged or missing | Change or fit the filter chamber cover gasket. |
| | (c) Valve sticking to the valve seat | Blow compressed air at the inlet. |
| | (d) Valve plate assembly not screwed in properly in its place or valve plate washer is damaged. | Make sure that the valve plate washer is good. Tighten the valve plate screws. |
| | (e) Pump filter completely clogged | Open out the filter chamber cover and clean it. |
| | (f) Valve sealing quality is lost | Change the valve plate assembly only with washer. |
| 2. Reduced delivery of petrol | (a) Weak diaphragm | Change diaphragm. |
| | (b) Weak diaphragm spring | Change diaphragm spring. |
| 3. Delivery pressure not sufficient | (a) Weak diaphragm | Change diaphragm. |
| | (b) Weak diaphragm spring | Change diaphragm spring. |
| 4. Diaphragm leak | (a) Diaphragm layers punctured | Change the diaphragm assembly completely as a unit. |
| | (b) Diaphragm layers, rotating in between the upper and lower diaphragm metallic washers | Change the diaphragm assembly completely as a unit. |
| | (c) Diaphragm soldering affected as a unit | Change the diaphragm assembly completely. |
| 5. Breakage of the main lever | (a) Due to wrong assembly of the pump on the engine block | While assembling the pump, ensure that the main lever does not go underneath the cam. |

## Review Questions

1. List two purposes of the fuel system.
2. State the purpose of the fuel pump.
3. What operates the fuel pump?
4. How does the fuel pump work?
5. Explain the function of a fuel cock used in a two wheeler in which a gravity feed system is used.
6. List the types of fuel pumps. Explain with a figure the working of an electric fuel pump.
7. What is the ideal fuel-air mixture?
8. How is an increased quantity of the fuel-air mixture carried to the cylinder?
9. State the purpose of an air bleed.
10. What has the venturi to do with the operation of a carburettor?

11. Why is the carburettor fitted in a petrol engine?
12. Describe the working of a simple carburettor with the help of a neat sketch.
13. List the different types of air cleaners. Describe a wet type air cleaner.
14. What is the intake manifold and where is it connected?
15. What can cause trouble in the fuel system?
16. What may cause stumbling on an acceleration?
17. Mention the reasons for the carburettor supplying excess fuel in slow speed.

8

# Fuel Injection Equipment for Diesel Engine

**Objectives**

After studying this chapter, you should be able to:

- State the fundamental requirements of a fuel injection system in a diesel engine.
- Describe the function of a fuel injection-pump for diesel engine.
- Justify delivery valve function as an anti-dribble device.
- Explain the operation of a pump plunger in relation to its barrel.
- State the different types of injections.
- Explain the details of various types of governors for controlling engine speed.
- Justify the need for a governor in a CI engine

## 8.1 INTRODUCTION

In the case of a diesel engine, fuel is supplied through hot compressed air in the combustion chamber. The time available for the combustion of fuel when the piston is at TDC is very short (about 1/1000 of a second). During this period the liquid fuel has to absorb heat for evaporation and find air for combustion. To meet these requirements, the fuel has to be atomized into fine particles so that the heat-absorbing area is increased for immediate evaporation. To spray fuel in atomized form into the hot compressed air requires special equipment. In this Chapter, operations of such equipment have been discussed.

## 8.2 FUEL INJECTION SYSTEM

A fuel injection system in a diesel engine has to satisfy the following fundamental requirements:

1. To spray the correct quantity of fuel as required, depending on the load.
2. To inject the fuel at the correct time in the cycle.
3. To inject the quantity of fuel at such rate that constant pressure combustion is obtained.
4. The sprayed fuel must be atomized such that the fuel gets depression and penetration.
5. Starting and ending of injection must be sharp without dribbling.

In Fig. 8.1, the layout of the fuel injection system has been shown. The fuel injection pump has a small plunger and a small stroke. The movement of the plunger cannot create sufficient vacuum to suck fuel from the fuel tank. Therefore an auxiliary fuel pump is used to lift the fuel above the level of the injection pump. Usually a fuel filter of sufficiently large capacity is fitted above the level of the injection pump. A small quantity of fuel entrapped in the pump is compressed by the fuel injection plunger and pressure is developed to inject fuel in the combustion chamber which is under air pressure.

Figure 8.1 also shows a fuel tank (diesel tank) with a fuel gauge. There is a fuel pump which takes fuel from the fuel tank and delivers it to the fuel filter which is located above the level of the injection pump. Pressure is developed in the injection pump and the fuel under pressure flows from the injection pump to the fuel injector. The fuel injector has either a single hole nozzle or a multi-hole nozzle. A jet of fuel passes through this hole at high velocity and atomizes.

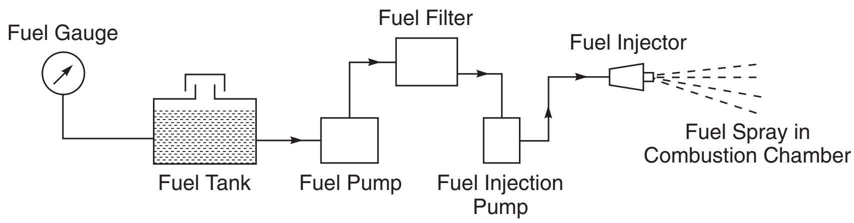



**Fig. 8.1** Layout of Fuel Injection System

## 8.3 FUEL INJECTION PUMP FOR DIESEL ENGINE

Figure 8.2 shows the assembly of a diesel fuel pump. As seen in the figure, there is a fuel pump element having a helical groove in the plunger. The plunger reciprocates up and down with the help of a cam, which is driven by a camshaft.

The return stroke is obtained from a return spring. The fuel pump element consists of a plunger and a barrel. The position of the barrel is fixed and locked with a screw. The plunger moves up and down and can also be rotated by a pinion. The rack shown in the figure is attached to a governor which changes the position of the rack and the pinion. As a result, the helix position of the plunger is changed with respect to the barrel. The barrel has an inlet port and a bypass port (spill port). When the plunger is at BDC, fuel enters in the barrel. When the plunger starts moving up with the help of the cam, the excess fuel spills out through the inlet port and the bypass port. At a certain position of the plunger on the way to TDC, both inlet and bypass ports are covered by the plunger and a small quantity of the fuel is entrapped in the barrel. Further movement of the plunger increases the pressure over the entrapped fuel. At the set pressure, the pressurized fuel flows from the injection fuel pump to the injector.

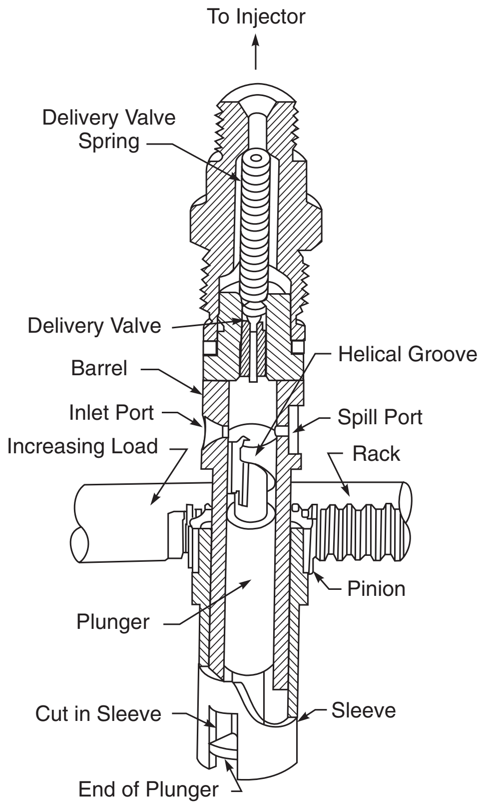



**Fig. 8.2** Diesel Injection Pump-element Assembly

The quantity of the fuel to be injected in the combustion chamber is decided by the position of the helical groove cut in the plunger. The moment the spill port is uncovered by the helical groove, fuel under pressure is spilled out in the annular groove and the pressure is released. The result is that the fuel injection is stopped.

In Fig. 8.3, two positions of the plunger have been shown. When the plunger is at the bottom of the stroke, the fuel enters in the barrel through the inlet port.

The inlet port and the bypass port (spill port) are connected by an annular groove as shown in Fig. 8.3. At a certain upward stroke of the plunger, the bypass port is uncovered by the helical groove of the plunger and the delivery of the fuel (fuel injection) ends. The movement of the plunger continues depending on the design of the cam. Here it should be clear that though the beginning of fuel injection is fixed, the timing of the end of injection changes depending on the position of the helical groove.

In Fig. 8.4, the position of the plunger has been shown, which can be changed by rotating the plunger with the rack and pinion arrangement. This can be understood by locating the position of the vertical slot. In Fig. 8.4, the annular groove and other components are not shown to provide a clearer understanding. From the figure it is obvious that the bypass port is uncovered earlier than shown in Fig. 8.3. This means that the delivery of fuel ends earlier and less fuel is injected in the combustion chamber. This condition of the plunger is highly suitable when the load on the engine is reduced. The regulation of the plunger is automatic and it maintains a constant engine speed.

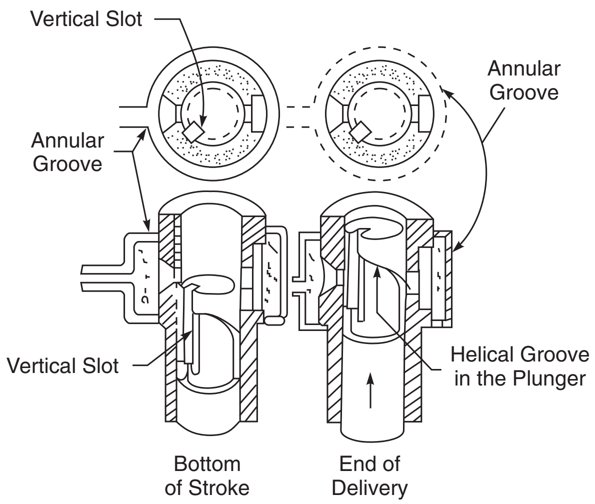



**Fig. 8.3** Maximum Delivery

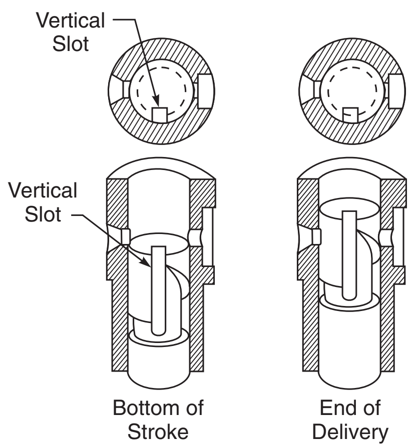



**Fig. 8.4** Normal Delivery

In Fig. 8.5, the position of the plunger has been shown changed by further rotation of the plunger by the governor. At excessive engine speed, the governor pulls the rack towards left and rotates the pinion (Fig. 8.2) which rotates the plunger. In Fig. 8.5, the vertical slot of the plunger is facing the spill port. This means that the fuel in the barrel spills out as the port remains uncovered during the upward stroke of the plunger. Since the fuel is not injected in the combustion chamber, the thermodynamic cycle is not initiated.

In Fig. 8.6, an enlarged view of the helical groove cut in the injection pump plunger has been shown. In this design, the injection of fuel starts at constant crank position, but the end of fuel

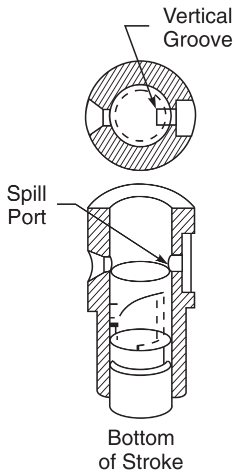



**Fig. 8.5** Zero Delivery

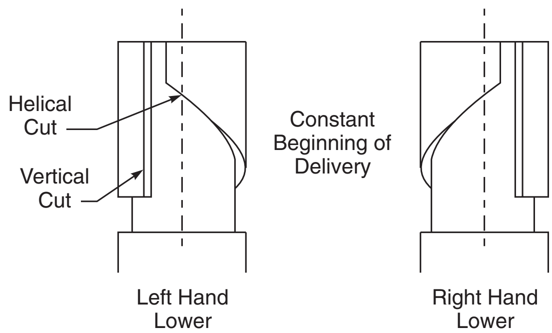



**Fig. 8.6** Helical Cut in Plunger

injection changes, increasing with the increase in load. On load, the engine rpm decreases and the governor changes the position of the rack and pinion which rotates the plunger such that the effective stroke of the plunger to inject more fuel is increased. In this design automatic injection advance is not possible.

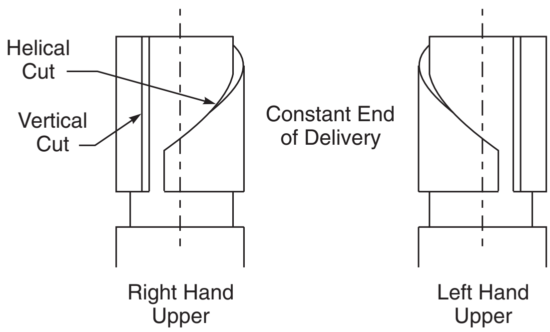



**Fig. 8.7** Helix with Automatic Advance

In Fig. 8.7, a change in the design of the helical cut is shown. The effective stroke to inject more fuel increases with the increase in load. In this design injection advance increases with the increase of the effective plunger stroke for the injection of fuel. The end of injection remains constant.

As shown in Fig. 8.8, helical cuts are provided at the upper and lower edges of the groove. This design provides injection advance with load; also the injection is prolonged with the effective stroke.

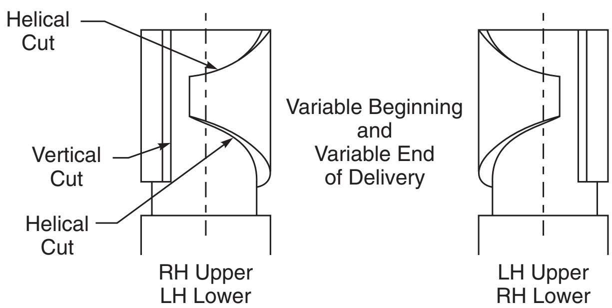



**Fig. 8.8** Helix at Both Ends

In Fig. 8.9, the delivery valve of an injection pump has been shown. The assembly of the delivery valve in closed and open positions are also shown. This valve is located at the outlet of the injection

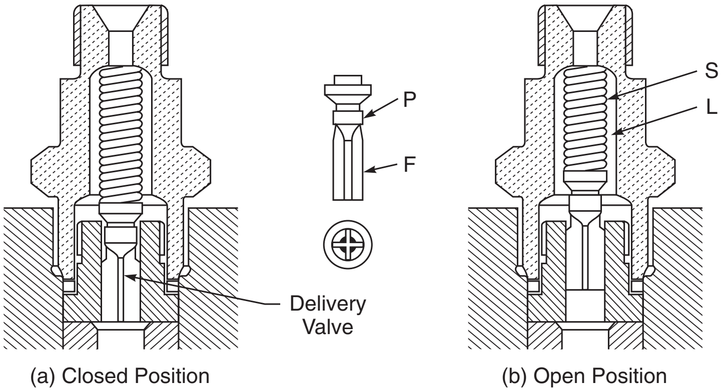



**Fig. 8.9** Delivery Valve

pump. The design of the delivery valve allows the maintenance of high pressure in the delivery pipe, and also stops the fuel injection abruptly thus avoiding dribbling of the fuel in the combustion chamber.

When the pressure rises in the barrel element of the pump, the delivery valve is forced upward against the spring force S. In the delivery valve there is a piston P above the flutes F as shown in the figure. Due to the piston P, the flow of fuel does not begin until the flutes are uncovered as shown in the figure (open position). Fuel under pressure flows from the pump to the injector through the discharge line L.

When the pressure falls, the spring S pushes back the delivery valve to its seat. At the same time the relief piston P moves down into the housing as shown (closed position). Such movement of the piston P in the housing increases the volume of the discharge fuel pipe, and the fuel pressure is abruptly decreased causing the injection valve to snap shut. Thus low pressure injection which gives rise to dribbling of fuel is avoided. It should be clear that the seating of the delivery valve does not entirely reduce the fuel pressure, and the residual pressure in the pipeline is not enough to open the injection valve in the injector. The residual pressure in the fuel line enables the fuel injection pump to increase the pressure quickly on the next injection stroke.

## 8.4 DIESEL INJECTOR

The purpose of an injector is to atomize or to divide the fuel into fine droplets and to direct the spray such that every fuel particle finds sufficient air to burn completely. Poor atomization and distribution reduce efficiency and the combustion time is prolonged. The main element in an injector is a nozzle. Figure 8.10 shows the assembly of a nozzle. There is a valve which is spring-loaded. The spring force over the valve is adjustable. Due to the spring force, gases of the cylinder cannot enter the injection system.

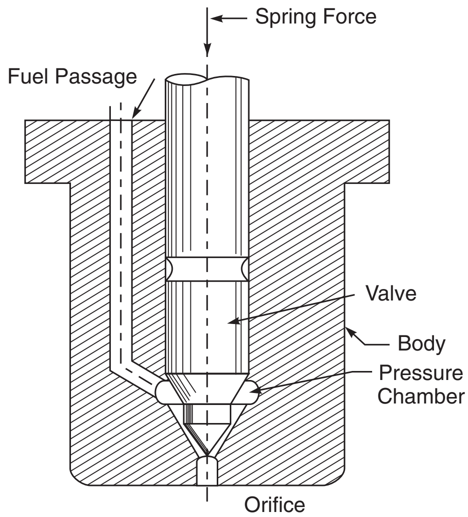



**Fig. 8.10** Nozzle

There is a pressure chamber or gallery which receives fuel under pressure from the fuel injection pump. The fuel pressure acts on the inclined part of the valve surface and the resultant force acts vertically up against the spring force. When the resultant force acted upon by the fuel pressure is greater than the spring force, the valve opens and fuel under pressure flows at a very high velocity into the combustion chamber through the opening of the orifice.

During the flow of the fuel, fuel undergoes atomization. The degree of atomization depends on the pressure difference between the fuel pressure and the combustion chamber pressure. This means that the fuel dribbles at the end of the stroke of the plunger in the injection fuel pump, i.e. at the end of injection when the fuel pressure sufficiently reduces. However, dribbling of the fuel is avoided by the design of the piston P in the delivery valve (Fig. 8.9). The piston P in the delivery valve increases the volume of the injection pipeline (explained in Sec. 8.3) resulting in a sudden pressure drop at the nozzle. This action causes the nozzle valve to close instantly by the spring force thus stopping the spray without dribbling. The residual pressure reduces the time lag between the end of the last injection and the beginning of the next injection.

### Spray Formation

When a jet of fuel comes out from the nozzle of the injector at very high velocity, then the solid stream of fuel is torn away by the resistance offered by air in the combustion chamber, and the fuel is drawn into drops by surface tension. The first droplets are quickly slowed down by the resistance of air. The fuel droplets also provide viscous drag to the air molecules leaving a partial vacuum behind them. The result is that the core of the spray moves ahead and the process of atomization continues until all the fuel is atomized.

The atomization of fuel is essential for increasing its surface to volume ratio so that the droplets are quickly evaporated. The combustion of fuel depends on the availability of air. When the fuel droplets are finely atomized, they lose their kinetic energy. Also the distance to which the droplets penetrate the combustion chamber is lessened. It is for this reason that highly atomized fuel droplets around the fuel injector do not burn completely due to lack of air.
Spray formation is affected by the following factors:

1. *Injection Pressure* An increased injection pressure is obtained by the initial compression of the spring located over the valve of the nozzle. Increasing the injection pressure increases the degree of atomization, i.e. fine atomization.
2. *Orifice Diameter* Increase in the orifice diameter reduces the degree of atomization. This means that the penetration distance increases with the increase in the nozzle orifice diameter.
3. *Fuel Velocity* Increased viscosity of the fuel increases the internal resistance and a greater injection pressure is required to get the same amount of atomization. Or at the same injection pressure, the degree of atomization is decreased and the size of droplets is increased for increased fuel viscosity.
4. *Design of Nozzle Valve* The nozzle valve which is extended into the orifice, produces a hollow cone spray which has less penetration due to fine atomization. Such nozzles are used in the precombustion chamber in which deep penetration is not desirable.

A multihole nozzle has an orifice of very small diameter, offering high resistance and producing a bushy spray in the vicinity of the nozzle. Such nozzles need air swirl in the combustion chamber for better dispersion. The relative motion of the fuel droplets and air also help in better combustion of fuel because the combustion products surrounding the fuel droplets are removed and replaced with fresh air. In the multihole nozzle, the orifices of smaller diameter are generally clogged by carbon particles which either deform the spray or completely close the orifice. It is difficult to remove these carbon particles lodged in the orifices.

### Types of Injectors

Mainly, the injectors are of two types:

1. Open injector nozzle
2. Closed injector nozzle

There is no valve in the open injector nozzle. If a valve is provided, then it is actuated by some mechanism. In case of diesel injection, the open injector is provided with a ball type non-return valve to prevent the compression pressure from forcing the fuel back to the pump. The injection of fuel commences when the pressure in the fuel is sufficient to overcome the pressure in the combustion chamber and the resistance in the pipe line. The injection stops when the pressure falls below this value and the non-return valve closes the passage.

The disadvantages of the open type injector are:

(i) The injection period is sensitive to the diameter and the length of the delivery pipe.
(ii) The pressure surges in the pipeline cause secondary injection and the fuel dribbles.

In the closed injection nozzle, there is a valve which is operated by the hydrostatic pressure acting on the annular area as shown in Fig. 8.10. When the hydrostatic pressure required to lift the valve is greater than the spring force, the valve opens, and fuel is injected. When the valve lifts the pressure is operated over the entire projected area of the valve stem, and the valve does not close until the pressure has fallen to somewhat below the pressure required for its opening.

In Fig. 8.11, a closed type injector has been shown. There is a pintle type nozzle N. The spindle H transmits the spring force to the nozzle. The spring force is made adjustable by the screw S,

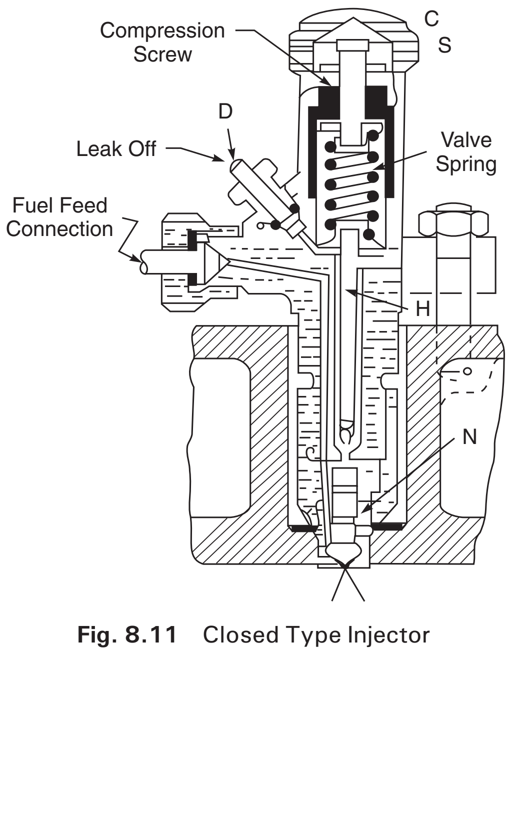



**Fig. 8.11** Closed Type Injector

having a lock nut. The cap C is provided for the protection of the screw. The fuel which leaks from the valve and its body is collected and returned to the supply pipe through the tube D.

The projection at the bottom of the valve is known as the pintle. This pintle protrudes through the orifice and may be conical or cylindrical in shape. The pintle nozzle is a self cleaning nozzle and gives fine atomization (shown in Fig. 8.12).

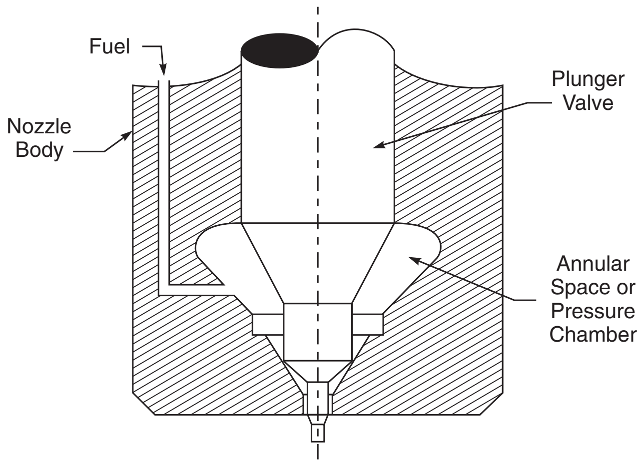



**Fig. 8.12** Pintle Nozzle

## 8.5 GOVERNOR

The main function of a governor is to regulate the supply of fuel through some mechanism so that the engine speed remains within its range. On an increased load, the engine speed drops. The governor which is set for a particular engine speed operates a mechanism such that more fuel is injected to increase the engine power. When the load decreases, the engine speed increases. The governor in this case operates the mechanism to reduce the supply of fuel in the engine.

Without a governor, the engine speed increases at lighter loads and the dynamic stresses damage the engine parts. Therefore a governor is essential to keep the engine speed within limits.

There are three types of governors:

1. Torque Control Governor (Mechanical Governor).
2. Pneumatic Governor.
3. Hydraulic Governor.

In Fig. 8.13, a torque control mechanical type governor has been shown. AB is a floating lever. The accelerator pedal is attached at the end A, and the governor control rod is attached at the end B. To the floating lever AB, a rack is attached as shown in the figure. Any movement of the floating lever AB pulls or pushes the rack to operate the mechanism in the fuel injection pump. The attached governor gets its drive from the engine crank.

On increased loads, the engine crank rpm reduces and the end B of the floating lever moves towards left. The rack is pulled to inject more fuel in the engine and the engine rpm increases. Similarly on decreased loads, the engine crank rpm increases and the end B of the floating lever moves towards right. The rack is pushed to inject less fuel into the engine and the engine rpm is decreased.

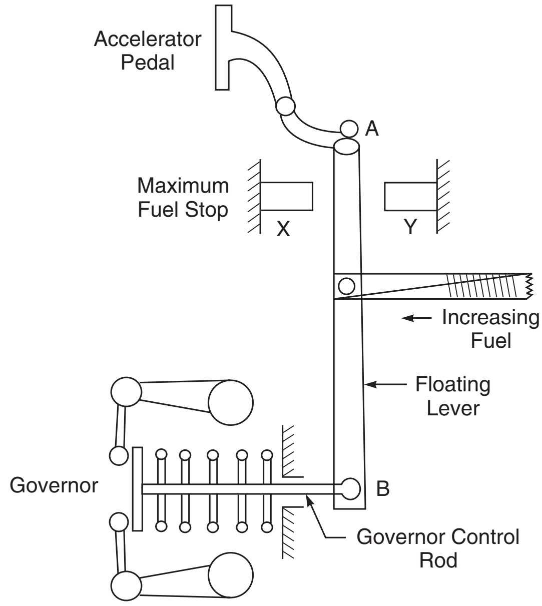



**Fig. 8.13** Torque Control Governor

During idling the floating lever is in contact with the stop Y. The engine has maximum speed when the floating lever touches the stop X has shown in the figure.

In case of a pneumatic governor, the engine manifold pressure is communicated over a piston head. The piston moves due to the change in manifold pressure. The movement of the piston operates a mechanism to control the fuel which in turn controls the engine speed.

In case of the hydraulic governor, a gear pump is used to pump fluid at constant pressure which depends on the pump speed, i.e. engine speed. As the engine speed changes, the pump speed also changes and the fluid pressure is affected. Such a change in the fluid pressure operates a mechanism to control the fuel and hence control the engine speed.

**Table 8.1** Troubleshooting of a Nozzle

| *Trouble* | *Cause* | *Remedies* |
|---|---|---|
| 1. Nozzle does not buzz (Note that delay types may not on test rig) | (a) Valve binding or seat leakage | Remove, clean, refit and test nozzle, replace. |
| | (b) Cap nut distorted | Replace, correct torque loading. |
| 2. Lead-off excessive | (a) Excessively worn valve and bore | Replace nozzle assembly. |
| | (b) Dirt between face of nozzle and holder | Strip, clean and refit. |
| | (c) Slack nozzle cap | Tighten to correct torque loading. |
| 3. Blued nozzle | (a) Excessive tightening of holder. | Remove, fit new seal washer, correct torque loading. |
| | (b) Excessive cap loading | Correct loading. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | (c) Engine over heating | Locate cause and correct. |
| 4. Injection pressure too high | (a) Spring tension too great | Adjust and test. |
| | (b) Valve seized | Replace valve and nozzle or clean. |
| | (c) Blocked nozzle holes | Clean with correct tools. |
| 5. Injection pressure too low | (a) Spring tension inadequate | Adjust and test. |
| | (b) Spring broken | Fit new spring and adjust. |
| 6. Nozzle drip | (a) Valve sticking | Strip, clean, refit or replace. |
| | (b) Carbon deposits | |
| 7. Distorted spray | (a) Holes partly blocked | Clean with correct tools. |
| | (b) Carbon at valve tip | Clean nozzle. |
| | (c) Pintle damaged | Replace nozzle assembly. |

## Review Questions

1. Why do some injection pumps use as an upper-helix plunger?
2. State the purpose of a delivery valve.
3. Identify the inspection or checkpoints of the barrel and plunger type delivery valve assembly.
4. State the function of a nozzle.
5. List the different types of nozzles. Explain with a figure the working of the pintle nozzle.
6. Differentiate between an open injector nozzle and a closed injector nozzle.
7. How many types of governors are used in injection systems? Explain the working of a mechanical governor.
8. Differentiate between a pneumatic governor and a hydraulic governor.

# 9

# Cooling System of Engines

**Objectives**

After studying this chapter, you should be able to:

- Explain the purpose of the engine cooling system.
- Describe the operation of an air cooling system.
- Describe the operation of a water cooling system.
- Identify and explain the purpose of the main parts of a water cooling system.
- Explain the construction and functions of different types of radiators.
- List the additives used in cooling water.

## 9.1 INTRODUCTION

When fuel is supplied to an engine for combustion then the heat generated increases the engine temperature. It has been observed that the properties of metals change if the temperature is raised beyond certain limits and that increased temperature damages the engine. Hence it is essential to control the rise in temperature by providing certain means for cooling the engine in automobiles. This chapter discusses the various methods of cooling employed in engines.

## 9.2 COOLING SYSTEM

The cooling systems control the engine temperature by dissipating heat into the atmospheric. About 30% of heat is lost by the cooling system and only 10% of heat is lost by radiation. About 25% to 30% of heat is used to perform work. The rest of the heat is lost through the exhaust gases and the cooling medium.

Lubricating oil is also affected by the heat of combustion. Its viscosity decreases with the rise in temperature which increases the friction losses. The heat of friction is carried away by the cooling medium and the exhaust gases.

There are two types of cooling systems:

1. Direct cooling, i.e. air cooling.
2. Indirect cooling, i.e. water cooling.

### 1. Air Cooling

In case of the air cooling system or the direct cooling system, air is brought in contact with the engine parts. However, the specific heat of air is low (0.24), and therefore a large amount of air is needed to cool the engine parts. Also air is not a good conductor of heat and it carries heat by the convection method only. It is for this reason that the air contact area is increased by providing fins as shown in Fig. 9.1.

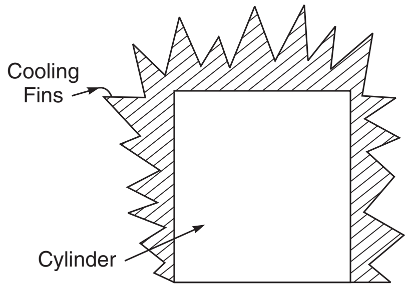


**Fig. 9.1** Air Cooling

As shown in the figure, fins are provided over the cylinder. In an automobile, such air-cooled engines are exposed to the atmosphere for cooling by the draughts obtained due the motion of the vehicle. In case of scooters in which engines are covered, air blowers are used to force the cool air over the fins. The fins are made of aluminium which is a good conductor of heat and the shape increases the surface area for cooling. Due to inertia a certain time elapses before the heat begins to flow from the cylinder to the cooling fins. Since the heat is not quickly dissipated due to the characteristics of air, the cylinder temperature is higher in air-cooled engines than in water-cooled engines.

***Advantages of Air Cooling***

1. The air cooling system is lighter in weight, i.e. less weight-power ratio.
2. It does not require a radiator and a water pump.
3. No antifreezes agents are required as in water-cooled engines.
4. No salt and mud deposits are formed in water-cooled engines.
5. Air-cooled engines are cheaper.

***Disadvantages***

1. The engine is not cooled efficiently and so runs hot.
2. Due to non-uniform cooling, temperature stresses are developed in the engine parts.
3. Engines are noisier.
4. It needs an impeller to blow air over the fins. This impeller is noisy and it absorbs more power in case of scooters, in which engines are covered.

### 2. Water Cooling

The water cooling system is an indirect cooling system. Water is cheap and easily available. Its specific heat being greater than that of air, water can absorb more heat than air. Water absorbs heat and dissipates it into the atmospheric air. Therefore, the same water can be circulated by a pump and used again.

Figure 9.2 shows a water cooling system. Water is forced by a water pump in the water jacket of the engine. Hot water comes out from the jacket of the engine and is passed into the radiator. The vertical radiator tubes are brought in contact with the atmospheric air. Water passing through these tubes gets cooled and is collected at the bottom of the radiator. The water pump recirculates water through the water jacket of the engine.

There is also a fan which is driven by the engine or electrically as in a modern car. The fan draws air and blows it over the engine parts. Thus the partial vacuum created behind the radiator, increases the pressure difference across the radiator and more air flows through the narrow gaps between the radiator tubes. Thus the quantity of air passing through the radiator is increased. This air drawn by the fan is blown over the engine body and the engine temperature is reduced.

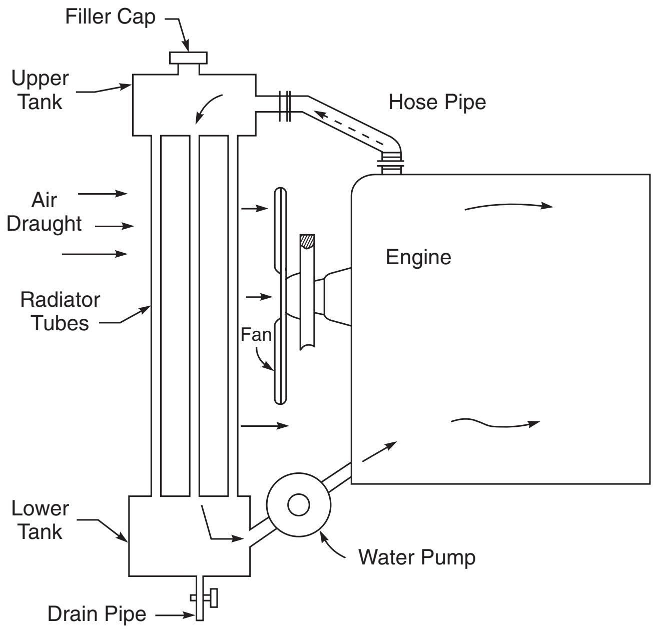



**Fig. 9.2** Water Cooling

The forced circulation of water does not allow its temperature to rise to the boiling point. Scale formation takes place in boiling water. Scales are the deposits of salts and mud and are a bad conductor of heat. Therefore scale deposition leaves hot spots in the combustion chamber which may lead to detonation and pre-ignition in a petrol engine. Hence forced circulation of water is essential in the engines.

***Advantages of Forced Cooling***

1. Forced cooling reduces the size of the radiator. Therefore a smaller radiator is needed.
2. Water under pressure is forced into every corner of the water jacket. Therefore no hot spots are left in the combustion chamber.
3. This system gives a rapid cooling effect.
4. Scale formation does not take place.
5. Pressurised cooling has an advantage that its boiling temperature is increased and its heat absorption capacity is also increased.

## 9.3 PARTS OF COOLING SYSTEM

Figure 9.3 shows the cooling system of Maruti 800.

The cooling system consists of the following main parts:

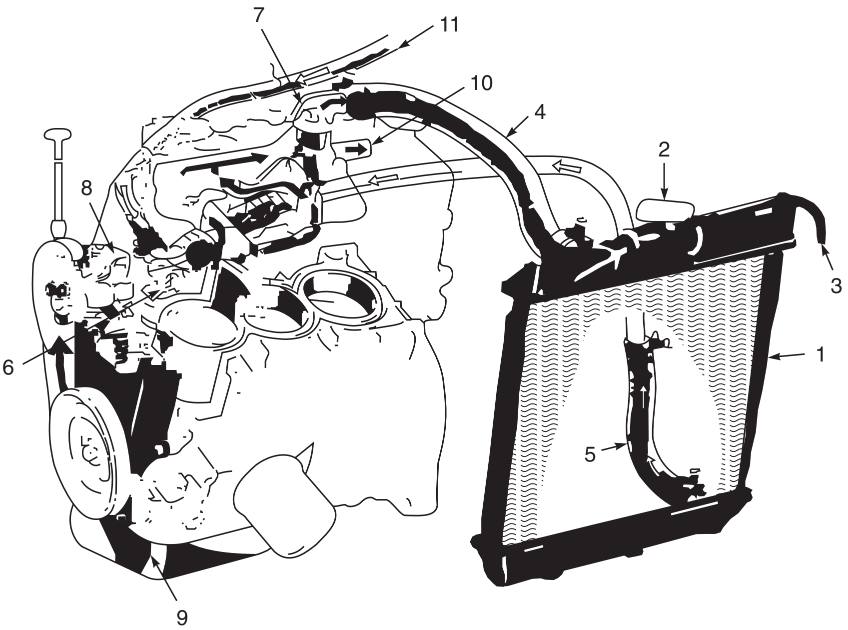
- Water jacket
- Water pump
- Thermostat
- Fan and fanbelt
- Radiator and radiator cap

A tube and pin type of radiator is used in this system. The circulation of cooling system is briefly explained as follows:

During engine warm-up (thermostat closed) the water pump discharges coolant into the water jacket chamber adjacent to cylinder No.1. The coolant then flows through the cylinder block and the cylinder head. The coolant then returns to the water pump through the intake manifold, the bypass hose, and the water intake pipe. During normal temperatures (thermostat open), the coolant takes the same route but is now allowed to flow past the thermostat, the inlet hose and the radiator, and then back to the water pump through the outlet hose and the water intake pipe.

## 9.4 WATER JACKET

The water jacket is the space inside the engine through which water is circulated for cooling the hot parts of the engine. Therefore the water jacket is a hollow space in the engine.




| | | |
|---|---|---|
| 1. Radiator | 5. Radiator Outlet Hose | 9. Water Pump Belt |
| 2. Radiator Cap | 6. Water Intake Pipe | 10. Heater Inlet Hose (Optional) |
| 3. To Reservoir Tank | 7. Thermostat | 11. Heater Outlet Hose (Optional) |
| 4. Radiator Inlet Hose | 8. Water Pump | |

**Fig. 9.3** Cooling System (*Courtesy:* Maruti Udyog Ltd.)

### Water Pump

The water pump is a centrifugal pump driven by the crank through a belt. The water pump is shown in Fig. 9.4. It takes water from the bottom of the radiator and forces it into the water jacket for circulating water in the engine. Figure 9.5 shows the exploded view of a Fiat water pump. The pump is made watertight by a special rubber seal encased in a metal shell, and provided with a spring which presses the seal against the front face of the impeller shaft bush. The seal is press fitted in the pump body so that no water can leak between the seal and the pump body even after a long period and without any adjustment being necessary.

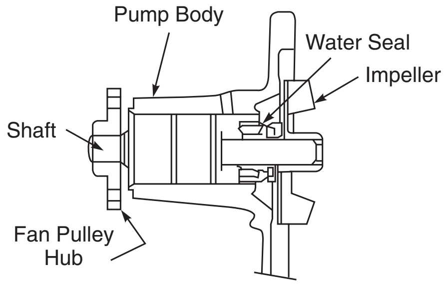



**Fig. 9.4** Water Pump (*Courtesy:* Maruti Udyog Ltd.)

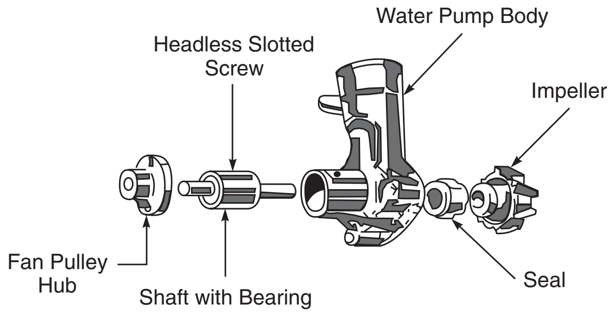



**Fig. 9.5** Water Pump Components (*Courtesy:* The Premier Automobiles Ltd.)

## Thermostat

A thermostat valve is used in the water cooling system to regulate the circulation of water in the system. The continuous circulation of water is necessary for maintaining the normal working temperature of the engine parts during different operating conditions. Two types of thermostat are used in automobile vehicles:

1. Bellows type
2. Pellet type

Figure 9.6 shows the working of the Bellows type thermostat. When water temperature is low, the thermostat having air inside, contracts and closes the valve. Thus cold water is not circulated and the heat lost by cooling is reduced. When the engine runs and the water in the jacket is sufficiently warmed then the hot water heats the thermostat. The thermostat expands and pushes off the valve from its seat. The water which is under pressure in the jacket starts flowing through the radiator and the water pump. Thus the thermostat permits the hot water to flow and eventually cool. This saves heat loss through the cooling medium.

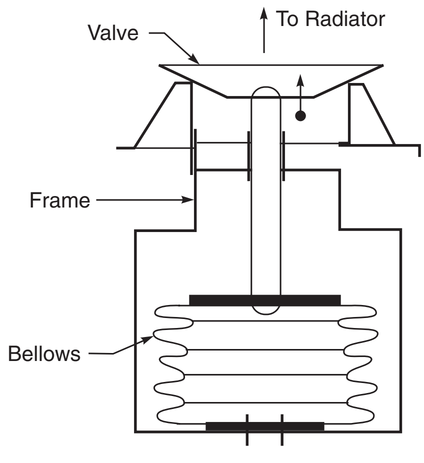



**Fig. 9.6** Bellows Type Thermostat

The most recent trend in the automotive industry is to use the wax pellet type of thermostat. A wax pellet type of thermostat fitted in a Maruti engine is shown in Fig. 9.7. The temperature sensitive material in the thermostat is placed in a metal case and it expands when heated and contracts when cooled. When the pellet is heated and it expands, the metal case pushes down the valve and opens it. As the pellet is cooled, its contraction allows the spring to close the valve. Thus the valve remains closed while the coolant is cold, preventing the circulation of coolant through the radiator. The Maruti thermostat is designed to open at a temperature of 82°C.

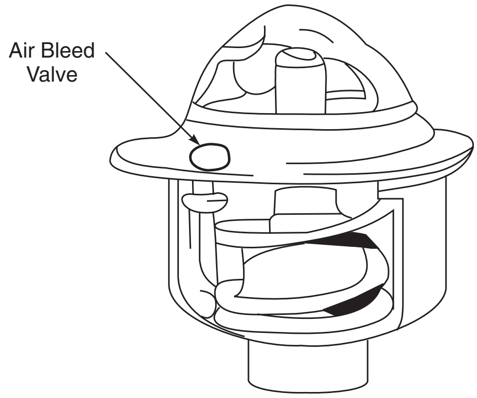



**Fig. 9.7** Wax Pellet Type Thermostat

## Fan and Fanbelt

A fanbelt of V-section gives drive to a fan from the crankshaft pulley. The fan is placed behind the radiator to force air over the engine body. This creates a pressure difference between the front and the rear of the radiator, and the rate of flow of air through the radiator is increased. Such increase in the air flow provides effective cooling for the water circulated through the radiator.

In excessively cold weather, the water in the radiator and in the jacket must not freeze otherwise the radiator or other engine parts may be broken or damaged. To avoid such damages, an antifreeze mixture is added to water so that the water freezing point of water is lowered. The antifreeze mixtures commonly used are—wood alcohol, denatured alcohol, glycerine, ethylene glycol, propylene glycol, mixtures of alcohol and glycerine, etc. Out of all these mixtures, alcohol must be added frequently because alcohol evaporates quickly.

## Radiator

A radiator is a device which is used as a heat exchanger between the hot water and atmospheric air. Radiators are essentially used in heavy duty automobiles for cooling the automobile engines. Water, which is forced by a pump into the water jacket of the automobile engine, is sent to the radiator, from where water is passed through the tubes of the radiator which dispel the heat to the air which flows round the tubes. Thus a radiator is a device which permits the cooling of water through the transfer of heat to the atmospheric air.

**1. *Location of Radiator*** The radiator is located in front of the automobile engine so that it gets the advantage of the air draught obtained by the motion of the vehicle. The other advantage of having the radiator in front of the engine is that the pipes required to connect the radiator to the engine are of smaller length. This reduces the losses, and less power is needed to circulate the cooling water through the water jacket of the engine and the radiator. Since a greater mass of air is needed to cool the water which is passing through the tubes of the radiator, a fan is used to create the pressure difference across the radiator. This increases the flow of atmospheric air between the water tubes of the radiator. This air fan is driven by a belt and the power required for driving it is obtained from the engine crank.

Figure 9.2 shows the location of a radiator. By placing the radiator in front of the engine, the air-draughts required for cooling are made readily available.

There is also a water pump driven by the crank. A common belt connecting the air fan and the water pump transmits drive from the engine crank. The water sump draws water from the lower tank of the radiator and pumps it into the water jacket of the engine. The hot water at the outlet of the engine is passed into the upper tank of the radiator. A hose pipe is used for this purpose as shown in the Fig. 9.2. Hot water passes down to the lower tank through the radiator tubes. During this flow, atmospheric air comes in contact with these radiator tubes and cools the water.

Since air has poor specific heat ($C_p$ = 0.24) and is a bad conductor of heat, effective cooling is obtained by providing an increased cooling surface area. This is obtained by providing metal fins between the radiator tubes.

**2. *Types of Radiators*** Basically, radiators are of two types:

(i) Tubular type, and
(ii) Cellular type

In the tubular type core, the upper and lower tanks (Fig. 9.2) are connected by a number of tubes arranged in series. These vertical tubes carry hot water from the upper tank to the lower tank. While water passing through these tubes, heat is transferred to air which flows through the core. Between the water tubes or water channels there are spacers which provide additional indirect radiation which helps in the rapid cooling of hot water. Different designs of the tubular type core have been shown in Fig. 9.8.

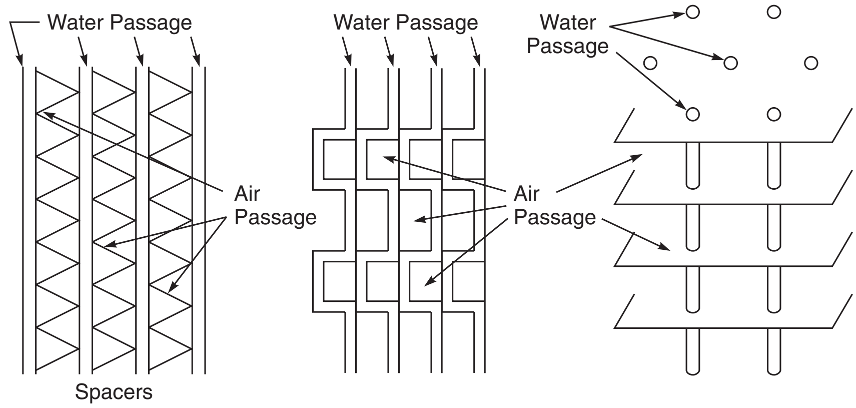



**Fig. 9.8** Types of Tubular Core

The tubular type core increases resistance to air flow through the core. Therefore a stronger fan is needed to overcome this resistance caused by the water tubes. An advantage of this type of core is that it has fewer soldered joints and hence is more robust than the cellular type core. For this reason, the tubular type core is preferred for use in heavy vehicles in which the radiator is subjected to very severe stresses.

The disadvantage of this type of core is that if one of the tubes is clogged, the cooling effect of the entire tube is lost.

The cellular type of core is also known as the air tube cellular core. This type of radiator consists of a number of horizontal tubes which carry atmospheric air. The space between the tubes is used for the flow of hot water which is to be cooled. Thus the cellular core is composed of a large number of individual air cells which are surrounded by water. Due to its appearance, the cellular type of core is also known as the *honey comb* radiator.

The ends of the tubes are expanded into hexagonal shape and then soldered together. The spacing of the tubes depends on the dimensions of the expanded ends. This spacing is provided for the flow of water from the upper tank to the lower tank. In Fig. 9.9, the expanded ends of the cellular tubes have been shown.

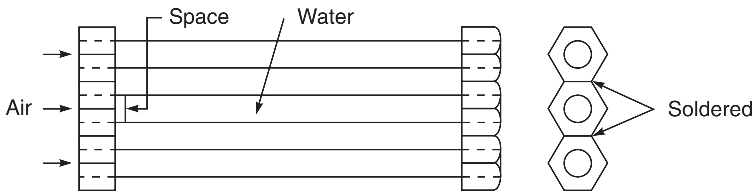



**Fig. 9.9** Cellular Tubes

Figure 9.10 shows the assembly of the ends of the cellular tubes. In this core all the metal sheet is in contact with water at the outer side and with air on the inside. Thus 12 to 25 per cent more heat is transferred per unit area of the sheet used in comparison to the core in which only a part of the area comes in contact with air.

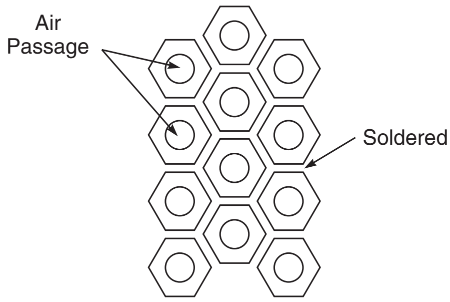



**Fig. 9.10** Assembly of Cellular Tubes

The cellular core type of radiator is best adapted for use where air speeds are high and low weight is the primary consideration. Therefore the cellular type radiators are preferred in racing cars. However, the higher cost has limited the general use of this type of radiators in the field of automobiles.

The chief advantages of cellular radiators are:

(a) The cellular rediator provides better cooling.
(b) It does not require stronger fans.
(c) Air resistance is minimised.
(d) The clogging of the passage for water flow does not give rise to serious problems.
(e) It is light in weight.

The disadvantages are:

(a) Its initial cost is more.
(b) It is not robust due to the various joints.

**3. *Material for Radiators*** Radiator cores are made of copper or brass. Copper has high thermal conductivity and good resistance to corrosion. Due to its property of ductility, it is easy to work with in the press. Brass is stronger than copper and also cheaper. Due to these properties of copper and brass, copper is used to form the core of the radiator, whereas brass is used to make the upper and lower tanks of the radiator. Brass is also resistant to corrosion. The side members of the radiator are made of pressed steel.

## 9.4 COOLING WATER ADDITIVES

When a vehicle is in operation having pump circulated water in the cooling system, there is practically no chance of freezing of water. However, freezing may occur when the car is parked in a place or area where temperatures are below freezing point. When water freezes, it expands approximately ten percent in volume. Expansion of water on freezing usually results in damage to the radiator, the cylinder block or the cylinder heads. Therefore it is essential to prevent freezing of water in cold climate. To prevent freezing, various mixtures are added to water in winter to lower the freezing point of water below freezing atmospheric temperatures. The ideal requirements for an antifreeze mixture are:

1. The antifreeze should be harmless to all parts of the cooling system.
2. It should easily dissolve in water.
3. Its cost must be reasonable.
4. Its boiling point must be high and it should not evaporate.
5. It must be stable and should not decompose. It must also not react with raw water.

The antifreezes that are employed to prevent the freezing of the coolant are:

1. Methyl, ethyl, and isopropyl alcohol
2. A solution of alcohol and water
3. Ethylene glycol
4. A solution of water and ethylene glycol.

The percentage by volume of anti-freeze used in solution with water depends on the atmospheric temperature. If the temperature drops below the freezing point of the antifreeze solution, the solution does not freeze to a solid but forms a slush. The water particles freeze but the antifreeze solution remains in liquid form which produces the slush. The slush formed does not crack the cylinder block or damage the radiator, but it clogs the small the passages of the radiator tubes and passages in the water jacket. This directly affects water circulation and causes overheating of the engine.

Alcohol is more volatile and readily evaporates. Therefore the antifreeze solution requires constant (periodic) additions of alcohol. For this reason, the alcohol mixture must be checked frequently.

**Table 9.1** Cooling System Data of Some Indian Vehicles

| *S. No.* | *Make of Vehicles* | *Component Part* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *Type of cooling system* | *Engin Coolant temperature sensor* | *Type of radiator* | *Capacity in Litre.* | *Water pump* | *Thermo state* | *Anti-freeze mixture* |
| 1. | Ambassador | Water cooling | - | Tube & fin | 8 | Centrifugal | Metal bellows type | Ethylene glycol type |
| 2. | Premier Padmini | Water cooling | - | Tube & fin | 4.5 | Centrifugal type | Metal bellows type | Natural glycerine or dena tured alcohol |
| 3. | Maruti 800 | Water cooling | - | Tube & fin | 3.6 | Centrifugal type | Wax pallet type | Ethylene alcohol |
| 4. | Jeep Mahindra | Water cooling | - | Cellular tube & fin | 10 | Centrifugal type | Choak type | Methyl alcohol |
| 5. | Maruti Gypsy | Water cooling | - | Tube & fin | 4 | Centrifugal type | Wax pallet type | Ethylene glycol |
| 6. | Ashok Leyland | Water cooling | - | Tube & fin | 25 | Centrifugal type | Bellow type | Ethylene glycol |
| 7. | Tata Truck | Water cooling | - | Tube & fin | 13 | Centrifugal type | Bellow type | Ethylene glycol |
| 8. | Santro | Water cooled pressurized, forced circu-lation with one electrical fan | Thermistor type | Pressurized corrugated fin type | 6 | Centrifugal type impeller | Wax pallet type with jiggle valve | Ethylene glycol |
| 9. | Wagon R | Water cooled | Thermistor type | Tube and fin type | 3.5 | Centrifugal type impeller | Wax pallet type | Ethylene glycol |
| 10. | Balleno | Water cooled | Thermistor type | Tube and fin type | 4.2 | Centrifugal type impeller | Wax pallet type | Ethylene glycol |

**Table 9.2** Troubleshooting of a Cooling System

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. External leakage | (a) Loose hose clamp | Inspect and tighten clamps. Replace if necessary. |
| | (b) Defective rubber hose | Replace defective hose. |
| | (c) Broken radiator | Remove radiator and solder seams. Test radiator for possible leaks before installation. |
| | (d) Worn or damaged water pump seal | Remove and replace water pump seal. |
| | (e) Damaged gaskets, or dry gasket, if engine has been stored | - Inspect for leak at water pump and cylinder head.<br>- Replace gasket as required. |
| | (f) Warped cylinder head | - Resurface or replace cylinder head and gasket.<br>- Tighten bolts securely and in sequence. |
| | (g) Cracked cylinder head | Replace cylinder head and tighten as per specification. |
| | (h) Cracked cylinder block | Replace cylinder block. |
| 2. Internal leakage | (a) Blow cylinder head gasket | Check cylinder head for warpage and replace gasket and torque the cylinder bolts securely in sequence. |
| | (b) Cracked cylinder wall | Replace cylinder block. |
| | (c) Loose cylinder head bolts | Tight cylinder had bolts securely and in sequence. |
| | (d) Sand holes or porous condition (cylinder block) | Replace the cylinder block. |
| 3. Poor circulation | (a) Restricted radiator core | Drain and reverse flush radiator. |
| | (b) Restricted water jacket | Drain system, disconnect radiator hoses, and reverse flush cylinder block. |
| | (c) Low coolant level | Refill radiator to recommended level. |
| | (d) Collapsed radiator hose | Replace radiator. Check clamps for fatigue. Replace, if necessary. |
| | (e) Water pump defective | Remove and recondition water pump. |
| | (f) Fan belt loose | Check driving surface of fan. If belt is frayed or greasy on the sides or bottom, replace and adjust. |
| | (g) Scales in cylinder block | Use the cooling system cylinder to correct this condition. After correction, use a rust resister in the system to prevent recurrence. |
| 4. Corrosion | (a) Impurities in water | Drain and flush radiator and cylinder block until clean. Refill system with mineral free clean water and add rust resistor. |
| | (b) Failure to use rust resister in system | See above (a) |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | (c) Improper draining and service | When draining the system make sure that the drain cock in the cylinder block is open. In severe cases of restrictions, remove the drain cock to allow the large particles of sediment to be washed out. |
| | (d) Air leaks in the system | - Tighten all hose connections securely.<br>- Check for possible leaks in the cylinder head gasket.<br>- Inspect water level in system. If necessary, fill system to required level. |
| 5. Overheating | (a) Poor circulation | Refer to 3. Poor circulation. |
| | (b) Radiator core air passage plugged | Thoroughly clean the passages of radiator cores with air pressure from the engine side. |
| | (c) Obstruction in front of radiator | Remove any obstruction that may block entry of air to radiator. |
| | (d) Incorrect ignition timing | Check ignition timing and adjust as required. |
| | (e) Incorrect valve timing | Check valve timing and adjust as required. |
| | (f) Low oil level | Inspect condition of oil. Drain if necessary and refill to proper level. |
| | (g) Clogged, defective muffler or exhaust pipe | Check exhaust system for restriction and check parts for damage or rust. |
| | (h) Engine labouring on grades | To avoid engine lugging or labouring on grades, drive in lower gear as needed. |
| | (i) Excessive engine idling. | Avoid excessive engine idling. |
| | (j) "Stop" and "go" | Watch temperature indicator during excessive "stop" and "go" driving to avoid engine overheating. |

## Review Questions

1. Why is it important to remove excess heat from the engine?
2. State the purpose of the cooling system.
3. Name different methods for cooling engines.
4. What are the troubles occurring in cooling systems?
5. State the advantages of a forced cooling system.
6. Describe the various parts of a water cooling system.
7. Describe the purpose of the thermostat.
8. Explain the pellet type of thermostat.
9. Explain the purpose and operation of the water pump.
10. Describe the purpose of a radiator.
11. What are the two types of antifreeze commonly used in Indian vehicles?
12. Why is it so important to protect the engine against freezing?

10

# Lubrication System of Engines

## Objectives

After studying this chapter, you should be able to:

- Comprehend the necessity of lubrication system in an automobile engine.
- Example the terms friction and viscosity.
- Describe the properties of lubricating oil.
- List the purposes of additives for lubrication oil.
- Justify the use of low viscosity oil for engine lubrication.
- Classify the lubricating oil to be used by their SAE numbers at different temperatures.
- Understand the different lubrication systems.
- Explain the main parts of lubrication systems.
- Describe the purpose of crankcase ventilation.

## 10.1 INTRODUCTION

The force required to rub two surfaces has to overcome the opposing friction loss between the surfaces. Friction generates heat and some part of the energy applied in rubbing the two surfaces is thus lost. To prevent losses in the applied mechanical energy, it is essential to reduce friction. Certain fluids may be applied to the rubbing surfaces to minimize function. Such fluids which minimize friction are called lubricants. Hence the main purpose of a lubricant is to save mechanical energy.

In an automobile, fuel energy is converted into mechanical energy by the engine. For maximum utilization of this mechanical energy for driving the automobile, all the rubbing surfaces must be lubricated. Special systems are designed in automoblies to lubricate the engine parts.

## 10.2 FRICTION

The force which resists motion is called friction. When two surfaces slide with constant velocity due to tangential force, then the ratio of the tangential force to the normal force which holds the two surfaces together is called *dynamic coefficient of friction*.

The coefficient of friction between two dry surfaces tends to be constant and independent of the load, speed and contact areas of the surfaces, but varies with the material and the surface finish.

This friction between the dry surfaces is known as *solid friction*. When a fluid or a lubricant is placed between the surfaces, then the friction between the layers of the fluid (lubricant) is called *fluid friction*.

## 10.3 MECHANISM OF LUBRICATION

Figure 10.1 shows an inclined surface AB and a stationary surface which is horizontal. Both these surfaces are separated by a lubricant. If the inclined surface AB is moved in the direction as shown in the figure, then the layers of the lubricant are compressed at the corner A of the surface where the sectional area is less. Thus a wedge is built up and the molecules of the lubricant (fluid) cannot escape from this wedge in a short time. This results in developing a fluid pressure under the inclined surface AB. The magnitude of the fluid pressure is shown separately in the figure. This fluid pressure sustains load on the inclined surface AB.

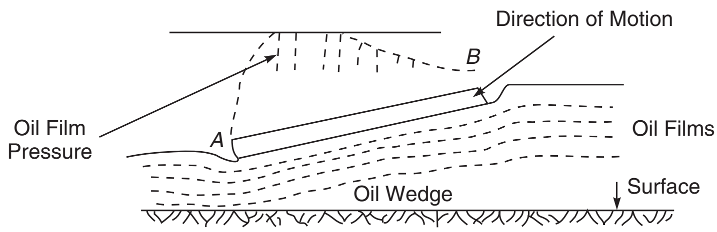



**Fig. 10.1** Wedge Action

If the surfaces are not inclined to each other and are parallel, or the inclined surfaces do not have relative motion, the fluid pressure could not be developed and the load on the surface AB could not be supported by the lubricant. This indicates that it is essential to build up a wedge to sustain load on the moving surface.

The fluid pressure developed under the surface AB due to the wedge action of the fluid is known as *hydrostatic pressure* and it is influenced by the following factors:

1. *Relative velocity of the surfaces* Higher relative velocity increases hydrostatic pressure.
2. *Viscosity of the lubricant* Higher viscosity of the lubricant increases hydrostatic pressure.
3. *Geometric configuration of the surfaces* Plain surfaces develop a greater hydrostatic pressure.

## 10.4 FUNCTIONS OF LUBRICATING OIL

A lubricating oil performs the following functions:

(a) Lubricating oil reduce friction between the moving parts. This saves energy, i.e. reduces losses.
(b) It functions like a cooling medium. The engine piston is cooled by the lubricant.
(c) It reduces noise between the striking surfaces. A highly viscous lubricant is more effective in reducing noise.
(d) Lubricating oil seal a joint to make it gas-leak proof. Gas leakage is stopped by the film of the lubricant in between the piston and cylinder.

## 10.5 VISCOSITY

If the sliding surfaces are separated by a layer of lubricant, then the force of friction is produced by the sliding of the layers of lubricating oil over each other. This means that viscosity is an indication of the friction between the layers of the lubricating oil. This fluid friction is due to the molecular attraction in the fluid. Therefore the fluid friction is influenced by

(i) the area of the layer sliding.
(ii) viscosity (molecular attraction or internal resistance).
(iii) rate of sliding of the layers, i.e. velocity of the layers, and
(iv) the thickness of the fluid layer. The lesser the thickness of the film (fluid layer), the more the fluid friction.

## 10.6 PROPERTIES OF LUBRICATING OIL

Lubricating oils are obtained by refining crude petroleum. The properties of the lubricants are dependent upon the crude oil from which they are derived, and the extent of refining. Some additives are added to improve the properties of lubricants. The important properties are:

**(a) *Viscosity*** Viscosity is the measure of the internal resistance of the lubricant and it is regarded as lubricant friction. Highly viscous oils offer more resistance between the layers of the oil while sliding. Such highly viscous lubricants can maintain a film of the lubricant even under thrust. For rating the viscosity of lubricants, SAE (Society of Automotive Engineers) has adopted a process under the specified standard conditions and allotted SAE numbers. These SAE numbers are related to fluid friction. For example, SAE 60 oil is more viscous and offers more resistance than SAE 30 oil. As a test of viscosity, the lubricant which flows more slowly on the same inclined surface has more viscosity. The highly viscous lubricant absorbs more energy to move the engine parts whereas the low viscous lubricant fails to maintain the film of the lubricant between the moving parts and the parts run dry. This means that a highly viscous lubricant offers more viscous resistance (viscous friction) which absorbs energy, whereas a low viscous lubricant offers dry resistance (dry friction). Therefore proper selection of a lubricant is essential.

**(b) *Viscosity Index*** The viscosity index indicates the change in viscosity with the change in temperature. Normally, viscosity of a lubricant decreases (becomes thin oil) as the temperature of the lubricant increases. This shows that an engine having such lubricant has viscous friction during starting when the engine temperature is low, but the same lubricant offers dry friction when the engine temperature is high. This quality of a lubricant is not desirable. In general, the viscosity index is a number which indicates the relative resistance of a given lubricant to changes in viscosity with changes in temperature. A lubricant having viscosity index equal to 30 has a lower resistance and its viscosity readily changes with an increase in temperature than the lubricant having a viscosity index equal to 50. Therefore a high viscosity index lubricant is preferred for an engine.

To improve the viscosity index, high molecule polymers are added to the lubricant. A high viscosity index lubricant will have good starting characteristics and satisfactory operation at high speed and heavy load conditions.

**(c) *Pour Point*** Pour point is an important property of lubricants which are used in cold countries where atmospheric temperatures reach subzero levels. The temperature at which the lubricant stops flowing or loses its fluidity under test conditions is known as the pour point. To improve the pour point of the lubricant, i.e. to retain fluidity of the lubricant at low temperatures, some chemicals are added which are known as *pour point depressants*. Two pour point depressants (i) Santopour, and (ii) Acryloid are commonly used. These pour point depressants tend to prevent the formation of wax at lower temperatures and provide easy starting of the engine. Mechanical agitation lowers the pour point.

**(d) *Flash Point*** Flash point is the temperature at which a lubricant gives off sufficient vapours to form a combustible mixture with air. The flash point of a lubricant in an auto engine varies from 175°C to 250°C. Any lubricant which has a lower flash point must not be used in the auto engine.

The term *flash point* must not be confused with *fire point*. The temperature at which an oil continues to burn after the flammable vapour-air mixture is ignited, is termed as the fire point. Flash point is at a lower temperature than the fire point.

**(e) *Carbon Residue*** Generally, low grade lubricants decompose at high temperatures and leave carbon as a residue. The lubricant must not leave carbon in the engine parts even at high temperatures. This can be determined in a laboratory by heating, igniting and burning 10 gm of the sample under specified conditions. The percentage of oil in carbon is determined. This carbon residue test indicates the type of crude oil from which the lubricant was refined and the refining process used to obtain the lubricant.

**(f) *Stability*** Some lubricants tend to break down at high temperatures and form gummy deposits which stick on piston rings and bearings. Other lubricants tend to form sludge in the presence of water. Sludge changes the viscosity of the lubricant and tends to clog the oil passages. Stability of a lubricant can be improved by refining methods and the ventilation of the crankcase.

**(g) *Oiliness*** The property of a lubricant in adhering to the bearing surface is called oiliness. For oiliness, no quantitative scale or unit has been adopted. It should be clear that oiliness and viscosity are in no way related. Therefore the property of oiliness becomes ineffective if the engine parts are loaded with the lubricant.

Some lubricants have the property of clinging to a metal surface due to molecular attraction. This means that a thin layer of lubricant will be present even under extreme conditions. Oiliness helps to protect bearings' surfaces during the starting of the engine before the build up of hydrostatic pressure in bearings.

**(h) *Corrosiveness*** The lubricating oil should not be corrosive and it should protect the surface against corrosion. This means that the lubricant should not retain any mineral acid or alkali that are employed in the refining process.

**(i) *Detergency*** Detergency means the act of cleaning. Therefore a lubricant which has the property of detergency acts to clean the engine deposits. The term *detergent* is used for cleaning and dispersing the small particles of dirt. A detergent is not used to clean and purge a dirty engine, but it is used to keep a clean engine free from sludge and other deposits. Certain additives like aluminium naphthenate, calcium phenyl stearates, etc. are added in a lubricant to improve the property of detergency.

**(j) *Foaming*** When minute bubbles of air are trapped in a lubricant, then it is known as foaming. All lubricants foam to some extent due to the violent mechanical agitation that occurs in a running engine. The action of foaming accelerates oxidation and reduces the mass flow of the lubricant to the bearings, thereby reducing the oil pressure. In addition to this, foaming may cause abnormal loss of oil through the breather. Silicon polymers are the most effective anti-foam agents to reduce the foaming tendencies of lubricants.

## 10.7 ADDITIVES FOR LUBRICANTS

During refining, undesirable compounds present in oil are removed. However, during this process, the desirable compounds which are essential for effective lubrication are also removed. On the other hand, if the refining process is changed to save the essential compounds, the lubricant may sludge badly and suffer a progressive increase in viscosity. This means that a well refined lubricant is not sufficiently strong to work in an engine. For this reason, modern lubricants are highly refined and then tempered or seasoned by the addition of certain chemicals to establish the desired properties. The additives used by various refiners are not known exactly due to trade secret.

In general, *Regular Motor Oils* are suitable for use in combustion engines under moderate operating conditions. *Premium Motor Oils* are suitable for more severe conditions. *Heavy Duty Motor Oils* are suitable for both diesel and gasoline engines under heavy duty and high speed services. Additives for oiliness and film strength are not usually found in engine oils because pressure lubrication system is used in auto engines. Generally, the additives are certain oil soluble organic compounds, containing inorganic elements such as phosphorus, sulphur, amine derivatives and metals.

Normal engine operation subjects the lubricating oil to high temperatures and the presence of oxygen, particularly in the cylinders, resulting in the oxidation and decomposition of the lubricant. The oxidized and decomposed oil forms acids, lacquers and sludge. The ability of the lubricant to resist oxidation is called "stability".

Oxygen is present in the crankcase and the gases of combustion that blow by the piston rings, react with the lubricating oil in the crankcase under high temperature and form acids, lacquers and sludge. Lacquer is a hard, dry, and lustrous, oil insoluble deposit which is usually found on the piston skirt, piston and piston ring. These lacquers cannot be removed without a solvent. These materials coagulate with carbon, oil, water and foreign materials in the crankcase and form a black muddy mixture called sludge. Sludge can be removed by wiping.

It is important to note that animal oils (such as lard and fish oils) and vegetable oils (such as castor oil) have oiliness and viscosity, but they are not chemically stable under high temperature and they tend to form gums. (Gum is a highly viscous liquid or a solid which has the property of sticking to surfaces).

The following additives are used to improve the quality of a lubricant, to work under different operating conditions of an engine.

**(a) *Oxidation and Corrosion Inhibitors*** The oxidation process, in a lubricating oil is slow below temperatures of 95°C, but the process becomes rapid at higher temperatures. Oxidation creates sludge, varnishes and acids. The additives used as oxidation and corrosion inhibitors are sulphur and phosphorus compounds of unsaturated hydrocarbons, or amine and phenal derivatives. These compounds have a greater affinity for oxygen than the hydrocarbons of the lubricant. Usually, breathers are provided in an engine to remove some of the gases of combustion that have blown by the piston rings. Such crankcase ventilation helps in preventing the formation of sludge and lacquer.

**(b) *Detergent Additives*** Detergent additives improve the property of an oil by keeping the oxidation products such as, carbon, water, dirt and other insoluble compounds in suspension or dispersion in the oil. By keeping the insoluble compounds dispersed, the tendency of the compounds to settle and stick to the metal surfaces forming sludge and lacquer is decreased. Some of the chemical compounds used as additives are—aluminium naphthenate, calcium phenyl stearates, calcium alkyl salicylates, metal salts of cetyl phenol, and alkaline earth metal petroleum sulphates. Their physical action is similar to the action of soap in keeping dust and oil suspended in water.

**(c) *Anti-Foam Additives*** Silicone polymers are used to avoid foaming in lubricants.

**(d) *Pour Point Depressants*** The formation of wax governs the pour point of the lubricant. Removal of wax from a lubricant lowers the pour point. However, this removel proces is expensive and also the removal of wax changes other properties of the lubricant. For these reasons, additives are preferred for dewaxing as a means for obtaining low pour points. High molecular weight compounds are added to depress the pour point. Addition of 0.25 to 1.5 per cent of paraflow lowers the pour point of a lubricant from 0°C to below –20°C. It is interesting to note that paraflow itself has a pour point of –5°C. Paraflow does not change any other characteristic of the lubricant. The probable action of this additive is to coat the surfaces of the wax crystals and prevent growth. The other two pour depressants available commercially are Santo pour and Acryloid.

**(e) *Viscosity Index Improvers*** High molecule polymers are added to lubricating oils to increase their viscosity index. A high viscosity index oil will have good starting characteristics and it will also provide satisfactory operation at high speed and heavy and load conditions. Note that lubricants with a high viscosity index can meet the requirements of a winter oil and also of a summer oil.

***(f) Oiliness and Film-strength Agents*** The additives used to increase film strength are organic sulphur, chlorine, and phosphorus compounds. Oiliness additives are used for running in new engines and for rust prevention. Addition of some percentage (about 2%) fatty oil improves oiliness.

## 10.8 IMPORTANCE OF LOW VISCOSITY OIL

A low viscosity oil offers lesser resistance to flow in a pipeline. A lubricant having low viscosity fails to maintain a film of lubricant between surfaces, and under load the thin film of the lubricant may rupture. Such conditions give rise to solid friction. However, in modern engines the pressure lubrication system is used, in which the lubricating oil is pumped between the surfaces for lubrication. Therefore, a film of the lubricant is automatically established in between the surfaces. Since a low viscosity oil is used in pumping the lubricant, power consumed by the pump is sufficiently reduced. Therefore, a low viscosity oil saves engine power in the system of lubrication that overcomes the ill-effects of low viscosity oil.

High viscosity lubricants increase fuel consumption and decrease the engine brake horse power, but allow less blow-by of the gases into the crankcase by sealing the clearances. The proper viscosity of the lubricant for an engine is best determined by experience. The oils used for gear lubrication are known as *EP lubricants*. (EP means extreme pressure). These lubricants permit greater loads than can be carried with ordinary mineral oil of the same viscosity. EP oil are composed of blends of mineral and fixed oils (vegetable or animal oils), and have a slight amount of sulphur or chloride compounds.

In automotive service, the use of light oil having low viscosity gives boundary lubrication when the engine speed is low, and gives pressure lubrication when the speed is high. This is avoided by shifting to a lower gear in the gear box.

## 10.9 LUBRICATION IN AUTOMOBILE ENGINES

If higher SAE (highly viscous) lubricants are used in automobile engines, then the following results are noted:

1. Consumption of the lubricant is decreased.
2. Temperature of bearings is increased.
3. Oxidation of the lubricating oil is decreased.
4. Engine wear is not affected.

Highly viscous oils provide better sealing of the piston rings and also the crankcase oil is not contaminated by the gases of combustion as they cannot blow by the piston rings. Lower grades of oil contain a higher per cent of volatile compounds that may be lost by vapourization. Once the engine reaches its operating temperature, the properties of the lubricating oil cylinder lubrication are offset by the increased temperature. Thus the SAE 60 lubricating oil operates at a higher temperature than the SAE 10 lubricating oil. The reason being that the viscous friction in the viscous oil (SAE 60) increases the oil temperature and its viscosity is reduced, whereas the lower viscous oil has no viscous friction and its temperature does not increase due to viscous friction (internal friction). Therefore the operating viscosities remain the same. These conditions occur more in case of journal bearings than in the case of piston rings and cylinder lubrication.

The viscosity of the lubricant should not be too low, otherwise it passes into the combustion chamber and burns, thereby increasing the consumption of the lubricant. A satisfactory oil consumption is difficult to define because the operational conditions and the wearing of engines cause considerable variation. Engine operation at high speeds usually causes an increase in the consumption of lubricating oil, and the consumption further increases when the engine is warm.

Lubricating oils should be changed whenever their condition deteriorates because such oils harm the engine. An analysis of the deteriorated lubricant reveals the exact condition of the lubricant. For automobile engines, the period of oil change is decided by the hours of service as well as the distance travelled. If the automobile engine is subjected to extreme variations in temperature, humid climates, and frequent starting, then the lubricating oil may require changing even though the distance travelled is less. This is due to the contamination of lubricant from the condensation of moisture and fuel vapour. In general, 1500 km to 5000 km of engine run can be attained without much deterioration in the lubricant. Frequent changes of oil results in lower consumption of the lubricant and engine service is extended because mechanical wear and deposits are minimised.

## 10.10 CLASSIFICATION OF LUBRICATING OILS

Lubricating oils are normally classified according to their viscosity. The SAE (Society of Automative Engineers) method of assigning numbers to different lubricating oils is in universal use. Two temperatures are used as references in assigning SAE numbers to oils –18°C (0°F) and 99°C (210°F). The lubricants referred to –18°C are winter oils and are graded as 5W, 10W, 20W. They are good for engine used in cold climates. Whereas the lubricants referred to 99°C are graded as SAE 20, 30, 40, and 50 and work satisfactorily in normal and hot climates. These numbers are merely for classification of lubricants according to their viscosity and do not indicate qualities of the lubricant such as stability, oiliness etc.

Multigrade lubricants are developed with the help of additves. For example, SAE 20W/50 indicates that the lubricant has a viscosity equal to that of SAE 20 W oil at –18°C (0°F) and a viscosity equal to SAE 50 at 99°C (210°F).

SAE grades refer solely to viscosity and not to the quality of oil. For this reason, the American Petroleum Institute (API) adopted another system and divided crankcase oil into three classes:

1. Regular type
2. Premium type
3. Heavy duty type

This classification depends upon the properties of lubricants and the operating conditions under which the lubricants are used. The grades of the lubricants do not refer to the severity of the engines. For example, diesel engines are more severe than gasoline engines. For this reason, API has developed a new classification based on the severity of the engine service. For gasoline engines, five grades of lubricants are recommended. The service ratings are SA, SB, SC, SD and SE. Similarly for diesel engines, four grades of lubricants are recommended and they are — CA, CB, CC and CD. The letter S stands for spark ignition engines, and C stands for compression ignition engine. The rating A is for light duty service, and the severity of services increases towards rating D or E.

It should be noted that the viscosity rating (SAE) refers to the thickness of the lubricant and highly viscous oils (higher SAE number) may not be good for heavy duty service.

In modern automobile engines, low viscous lubricants, SAE 10 and 20 are used for the entire range of operating temperatures below 32°C (90°F). Use of these lighter lubricants has made possible smaller bearing clearances and closer piston fits. The chief advantage with such a thin lubricant is that it provides easy cold engine starting and its consumption is low.

## 10.11 LUBRICATION SYSTEM

In a lubrication system, the engine bearings are lubricated in two ways:

(i) The lubricating oil is delivered into the oil hole which is provided above the bearing and allowed to drain from there to the bearing surface. This is the principle of the *splash system.*

(ii) The lubricating oil is fed directly to the bearing surface under pressure. This is the *pressure lubrication system*.

The lubrication systems in engines may be classified as?

1. Petrol lubrication system
2. Wet sump lubrication system
3. Dry sump lubrication system.

### 1. Petrol Lubrication System

The petrol lubrication system is also known as the *mist lubrication system*. This system is used in two-stroke cycle engines in which the crankcase is used to charge the cylinder. Two to three per cent of lubricating oil is added in the petrol tank where it mixes with the petrol. In the carburettor, the gasoline (petrol) is evaporated and the lubricating oil is left in the form of mist. The lubricant mist is carried into the cylinder by the stream of charge to lubricate the piston rings and the cylinder. Some droplets of the lubricant impinge (strike) on the engine parts and lubricate the main bearings and the connecting rod bearings which are in the crankcase.

The two-stroke engine is sensitive to the type of the lubricant mixed in petrol. The mixture of petrol and lubricating oil influences the exhaust smoke, corrosion, bearing life, ring and cylinder bore wear, and may cause ring sticking and spark plug fouling. Therefore only the recommended lubricating oil must be added for petrol lubrication.

The advantage of the petrol lubrication system is that the system does not require extra units like pump, filters, etc. Therefore the initial cost of the engine is reduced.

The disadvantages of this system are:

(a) The droplets of the lubricating oil when partially burnt leave gum deposits over the piston head (crown), piston rings and the exhaust port. Such deposits reduce the engine efficiency.
(b) The acidic vapours of the lubricant results in the corrosion of bearings.
(c) When the throttle valve is a closed for idling, there is a shortage of the lubricating oil which may result in overheating and piston seizure if idling is continued for a long time.
(d) The burning of the lubricating oil in the combustion chamber increases the oil consumption, which in turn increases the running cost of the automobile.
(e) Since there is no control over the proper mixing of the lubricating oil and gasoline, the engine may be over-oiled or under-oiled for most of its running time.

It is claimed that 2T oil is a self mixing oil in petrol and forms a homogenous mixture. Additionally, it does not have any undesirable effects on the engine parts.

Some manufacturers use a separate lubricating oil injector which injects oil into the stream of charge. This system avoids oil-starvation of the lubricating oil and the engine is neither under-oiled nor over-oiled.

The lubrication system of some Indian vehicles is given in Table 10.2.

## 2. Wet Sump Lubrication System

The bottom portion of the crankcase where lubricating oil is stored is called the sump. In the wet sump lubrication system, lubricating oil is stored in the sump. The various types of the wet sump lubrication system are:

(i) Splash system
(ii) Modified splash system
(iii) Full pressure system

***Splash Lubrication System*** Figure 10.2 shows a splash lubrication system. There are splash troughs under all the connecting rod heads. An oil pump delivers the lubricant to these troughs. Thus, the oil pump takes the lubricating oil from the sump and maintains a constant level of lubricant in the troughs. In some installations, an oil pressure gauge is provided on the dash board.

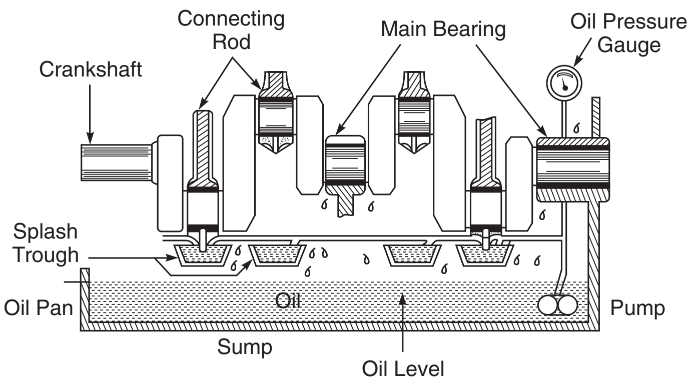



**Fig. 10.2** Splash System

Each connecting rod cap is provided with a splash or dipper which dips into the oil in the trough below it on each revolution of the crankshaft, and splashes the lubricating oil over the whole interior of the crankcase, into the pistons and the exposed portion of the cylinder walls. To lubricate the connecting rod bearing a hole is drilled through the connecting rod cap directly in front of the dipper. To lubricate the main bearings and the crankshaft bearings, oil pockets are provided over the bearings to catch the splashed oil. Any oil caught in these pockets is drained into the bearings.

***Advantage of the System*** The only advantage of the splash lubrication system is that the system is simple. However, the system is costly. In some designs the pressure gauge is removed to reduce the engine cost.

***Disadvantages of the System*** The splash lubrication system has the following disadvantages:

(i) The energy required to splash the lubricating oil is not fully utilized to lubricate the engine parts. Most of the engine energy is lost in splashing the oil over the interior of the crankcase and the oil returns to the sump without lubricating the parts.

(ii) Perfect lubrication of a bearing is a matter of chance. Some bearings are over-oiled and some bearings are under-oiled.

(iii) The upper piston ring, and the overhead valves and valve guides are not lubricated by this system.

(iv) The mist of the lubricating oil in the crankcase comes in contact with air, water vapour and the gases of combustion that have blown by the piston rings. The lubricant readily deteriorates and clogs the holes of the bearings.

(v) The unfiltered lubricating oil is splashed again and again. This reduces the life of the bearings.

(vi) At high speed, small droplets of the lubricant which are suspended in air in the crankcase are carried away by air through the breather holes. This increases oil consumption.

The splash lubrication system is used in small light duty engines.

***Modified Splash Lubrication System*** This modified form of the splash lubrication system is used in engines in which the bearing loads are higher. An oil pump supplies lubricating oil under pressure to the main and camshaft bearings. There are nozzles which direct the stream of the lubricating oil against the dippers on the connecting rod bearing cups. The crankpin bearings receive the lubricating oil from the dipper through the slots cut in the lower ends of the connecting rods.

The other engine parts are lubricated by the splash or spray of the lubricating oil thrown up by the dipper (see Fig. 10.3).

***Full Pressure Lubrication System*** The full pressure lubrication system is used in large engines and many automotive engines which are designed for heavy duty. This system keeps the bearings cool. The full pressure system supplies a continuous flow of oil that maintains the bearings at a relatively low temperature. Figure 10.4 shows the full pressure lubrication system. In this system, there is an oil pump which supplies oil under pressure and forces oil through the drilled passages to all the bearings. The drilled holes in the connecting rods permit the lubricating oil to flow from the connecting rod bearings (big end bearings) to the piston pins. The cylinder walls, piston and piston rings are lubricated by the oil spray from around the piston pin bearings and the connecting rod bearings (big end bearings). In this design, holes are drilled in the upper part of the connecting rod bearings so that oil under pressure is sprayed on the cylinder walls and the underside of the pistons.

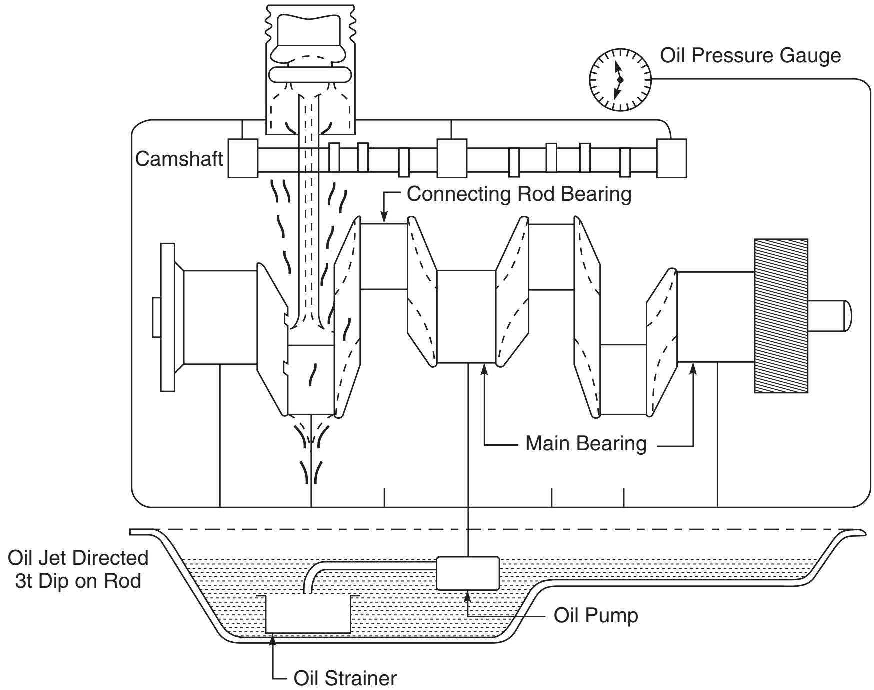



**Fig. 10.3** Modified Splash System

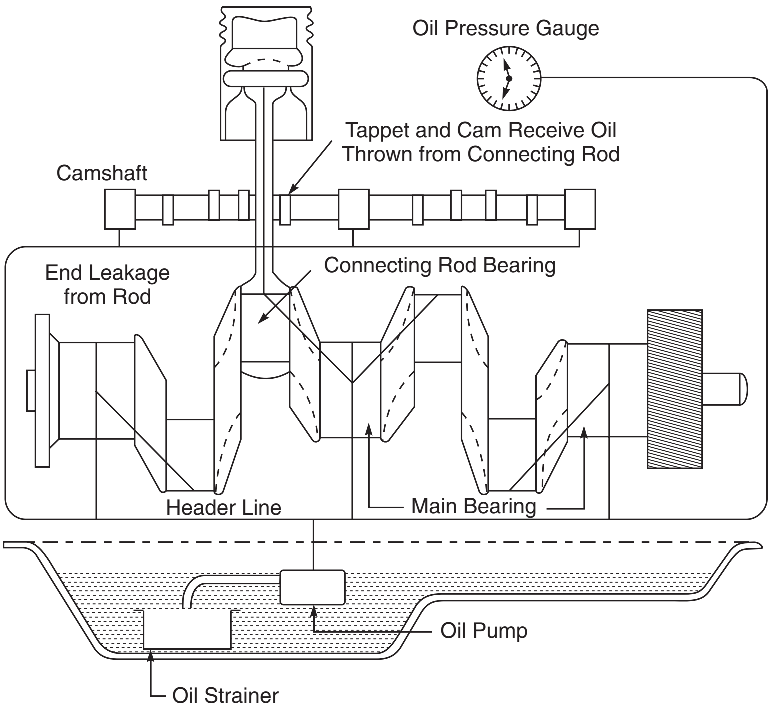



**Fig. 10.4** Full Pressure System

In Fig. 10.5, a schematic diagram of the wet sump pressure lubrication system has been shown with the following basic components.

1. Oil pump (gear pump)
2. Strainer
3. Pressure regulator with a spring loaded valve
4. Oil filter

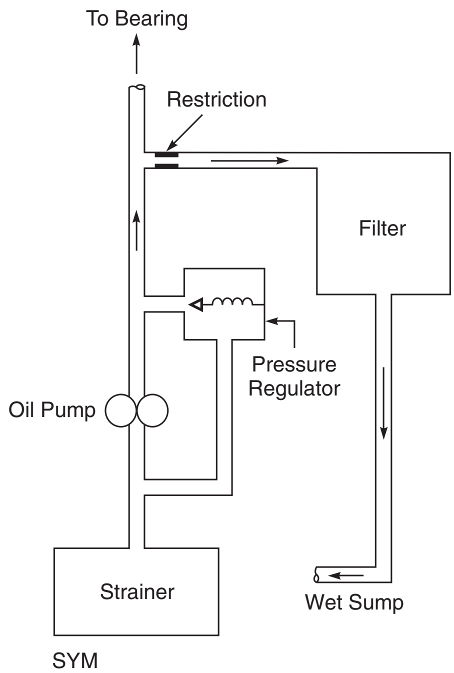



**Fig. 10.5** Schematic Diagram of Wet Sump Pressure Lubrication System

### 3. Dry Sump Lubrication System

The dry sump lubrication system is used in heavy duty engines. In this system, the sump is kept dry and the oil collected in the sump after lubrication is taken out for filtering and cooling, then again pumped onto the bearings. Figure 10.6 shows the schematic diagram of a dry sump pressure lubrication system. There is a scavenging pump which extracts the sump oil and feeds it to an oil filter. The filtered oil is collected in a storage tank. The other pressure pump feeds this oil to an oil cooler which is a heat exchanger. Here, viscosity of the oil is increased. The pressure relief valve (PRV) is parallel to the oil filter and is essential for flow of the lubricant in case the oil filter is choked or clogged. Lifting of the relief valve gives a signal to the operator, but the flow of the lubricant continues. Another pressure relief valve (PRV) in parallel to the pressure oil pump which functions like a safety valve so that excess oil pressure is relieved by the leakage of oil through the relief valve.

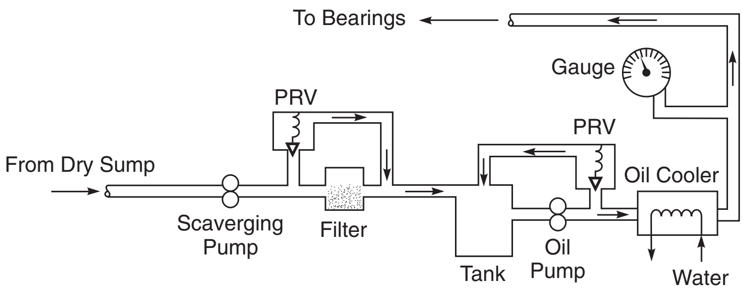



**Fig. 10.6** Schematic Diagram of Dry Sump Pressure System

It should be noted that the oil pressure (hydrostatic pressure) generated within the bearing has no relation to the oil pump pressure. The reason being that in film lubrication it does not matter how oil enters the bearing as long as there is a sufficient quantity of oil. This dry sump pressure system supplies a continuous flow of oil, which helps to maintain the bearing at a relatively low temperature. Excess flow of the lubricating oil increases power consumption for running the pumps. The scavenging pump has a greater capacity than the oil pump.

## Parts of a Lubrication System

The main parts of a lubrication system are described in the following sections.

***Gear Oil Pump*** In automobile engines, gear pumps are commonly used for pressure lubrication. Figure 10.7 illustrates the basic principle of a gear pump. The pump consists of a casing in which two spur gears or helical gears are fitted. One of the gears is keyed to the driving shaft and gets drive from the engine while the other gear meshes with the driving gear. The lubricating oil enters the pump casing from the side where the meshing teeth separate. The space between the adjacent teeth and the casing wall is filled with the lubricating oil. Thus the oil between the teeth is mechanically carried to the opposite side of the housing (casing) and leaves through the delivery (outlet) port. On the opposite side, the meshing teeth engage and push out the oil from the space between the teeth. Thus the volume of oil delivered depends on the tooth space and the face width of the gear. Actual delivery of the lubricant reduces due to the leakages from gaps.

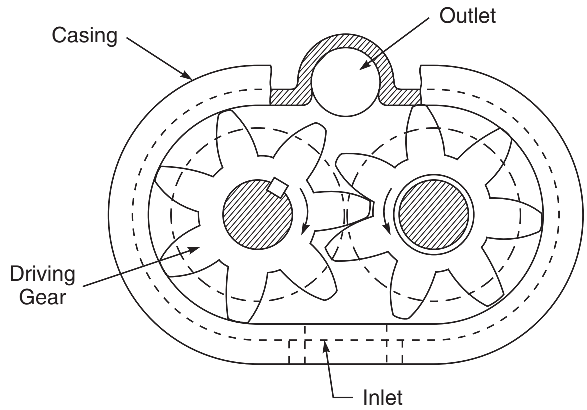


**Fig. 10.7** Illustration Principal of Gear Pump

***Relief Valve*** A relief valve in the force — feed system automatically maintains the constant pressure at which it is set. In Fig. 10.8, the pressure relief valve has been shown. The unit consists of a spring-loaded valve in the bypass passage from the delivery side of the pump to the inlet side. When the oil pressure exceeds the set pressure then the valve opens and allows some of the oil to return to the inlet side of the pump. This relieves delivery pressure in the system.

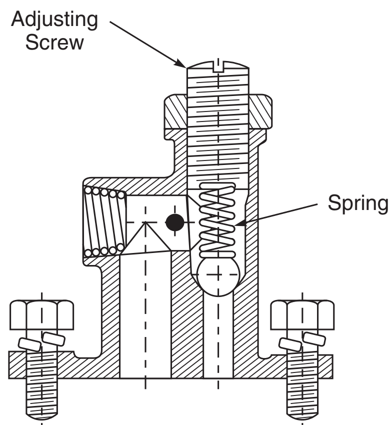


**Fig. 10.8** Pressure Relief Valve

***Oil Filter*** An oil filter consists of a closed bag of filtering cloth. This filter bag is placed within a steel shell so that the dirty oil enters the shell at its one end and passes through the filter bag leaving the shell at the other end. Any dirt in the oil is filtered out and adheres to the outside of the filter bag. It is also possible that the layer of sediment deposited on the surface of the filter bag acts as mother filter and the effectiveness of the filter increases with time. However, this also increases the resistance to the flow of oil. For this reason the old filter must be replaced by a new one as per recommendations of the manufacturer.

The job of the filter is to remove the abrasive particles which cause wear of the surfaces. Filters also prevent sludge deposits from passing into the bearings.

***Oil Level Gauge*** In an automobile engine the bottom of the crankcase which contains lubricating oil is known as the oil sump. To measure the quantity of oil in the sump, a device known as the oil level gauge is used. A rod which is used as an oil level gauge is called a *dip-stick gauge*. So the dip-stick is a measuring rod that extends through a hole provided in the upper part of the crankcase, to the bottom of the sump. The lower portion of the dip-stick has two marks for maximum and minimum levels of lubricating oil in the oil sump. The quantity of oil above the mark Max increases viscous resistance in the splash lubrication system because the lower part of the connecting rod dips more inside the oil. The quantity of lubricating oil below the mark Min fails the lubrication system due to shortage of oil.

For measusing the quantity of lubricating oil in the sump, the dip-stick is taken out from the crankcase and then cleaned with a piece of cloth. After this, the dip-stick is placed in its position and then drawn out to see the oil level mark. The oil level must not be above the Max mark and below the Min mark on the dip-stick.

## 10.12 CRANKCASE VENTILATION

The dilution of lubricating oil in the crankcase is due to water vapour and other products of combustion, i.e. gases which blow-by from the cylinder. If the lubricating oil or fuel contains an appreciable amount of sulphur, then sulphuric acid is formed. This results in the corrosion of engine parts in the crankcase. Crankcase corrosion occurs particularly when the engine is stopped and the crankcase is allowed to cool. If the blow-by gases which are in the crankcase are not removed, then they react with the lubricating oil and promote the formation of oil sludge.

Crankcase ventilation is employed in all automatic engines to minimize such dilution. If a stream of fresh air is allowed to pass through the crankcase, then a considerable proportion of the blow-by products may be removed from the crankcase. The breather holes and oil filler holes are suitable inlets for fresh air. Therefore these holes are preferably provided near the forward end of the crankcase. An outlet opening is then provided near the rear side of the crankcase. The outlet from the crankcase should be located at the point where air is comparatively quiescent and does not hold much oil in suspension. By passing the ventilating air through the valve chamber, the loss of oil is minimized and the valve mechanism is well lubricated. It is possible to connect the crankcase outlet to the air cleaner so that the ventilating air which contains unburnt fuel gases and water vapour are drawn into the cylinder during the intake (suction) stroke of the piston. Thus, the fuel gases get another chance to burn. However, this scheme is not popular because it is believed that corrosion might be promoted by recirculating these vapours through the engines.

## 10.13 LUBRICATION CHART

Figure 10.9 shows a typical lubrication chart supplied by the vehicle manufacturer M/s Hindustan Motors Ltd. It shows the location of all the places that require lubrication, and the frequency of checking or renewal needed. Hindustan Motors Ltd. recommend the following type and grade of lubricants for their Ambassador cars (Table 10.1).

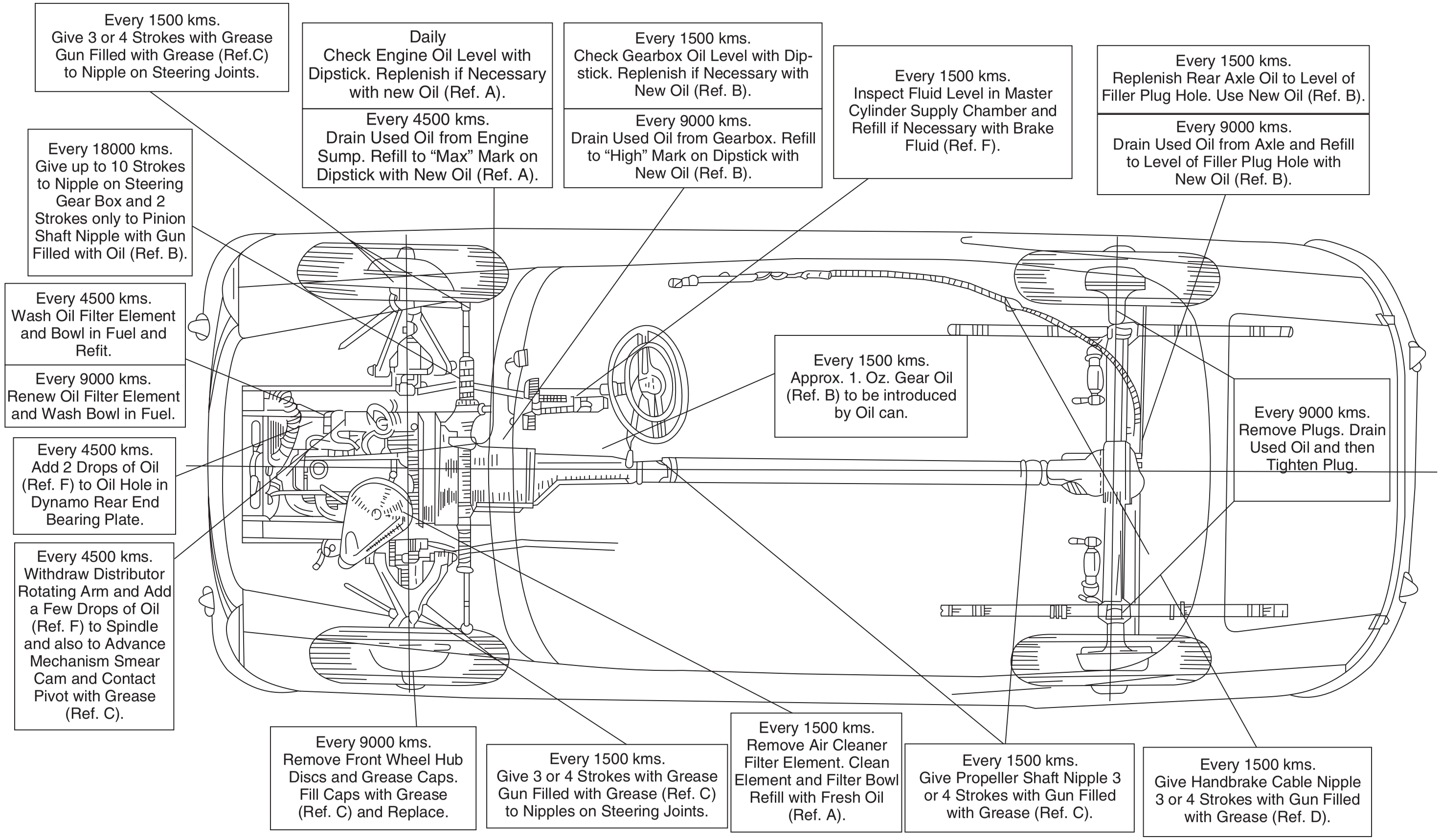



**Fig. 10.9** Lubrication Chart of Ambassador Car

**Table 10.1** Lubrication Chart

| | *Component* | | *Climatic Conditions* | *Type and Grade of Lubricant* |
|---|---|---|---|---|
| 1. | Engine and air cleaner | (a) | Tropical-temperature down to 32°F | Caltex RPM Motor oil SAE 30 HD |
| | | (b) | Extreme cold down to 10°F | Caltex RPM motor oil SAE 20 HD |
| | | (c) | Arctic-consistently below 10°F | Caltex RPM Motor oil SAE 10/10 W |
| 2. | Gearbox, steering gear box and differential | (a) | Tropical and temperature down to 10° F | Caltex Universal Thuban 90 |
| | | (b) | Extreme cold below 10°F | Caltex Universal Thuban 90 |
| (c) | Wheel hubs, fan bearings, chassis greasing (nipples), cables and control points | | All conditions | Caltex Marfak 2 HD |
| (d) | Oil can and carburettor | | All conditions | Caltex RPM Motor oil SAE 20 HD |
| (e) | Upper cylinder lubrication | | All conditions | Caltex upper cylinder lubricant |
| (f) | Brake fluid | | All conditions | H.P. hydraulic brake fluid HD |
| (g) | Battery terminals and earthing points | | All conditions | Petroleum jelly |

**Table 10.2** Lubrication System of Some Indian Vehicles

| *S.No.* | *Make of the Vehicle* | *Type of Lubrication system* | *Oil pump* | *Oil Filter* | *Oil Pressure ($kg/cm^2$)* |
|---|---|---|---|---|---|
| 1. | Ambassador | Wet sump (pressure type) | Eccentric | Full flow with paper element | 3.5 |
| 2. | Premier Padmini | Wet sump (pressure type) | Gear type | (i) Full flow (ii) Bypass cartridge type | 2.5 |
| 3. | Maruti 800 | Wet sump (pressure type) | Internal Gear type | Full flow cartridge | 3.0 |
| 4. | Jeep Mahindra | Wet sump | Gear type (pressure type) | Full flow | 4.0 |
| 5. | Maruti Gypsy | Wet sump (pressure type) | Internal Gear type | Full flow cartridge type | 4.5 |
| 6. | Ashok Leyland Comet Passenger | Wet sump (pressure type) | Gear type | Full flow | 4.2 |
| 7. | Tata Truck | Wet sump | Gear type (pressure type) | Full flow | 4.2 |
| 8. | Santro | Forced circulation system | Gear type driven by crankshaft | Full flow cartridge type with relief valve | 1.5 |
| 9. | Maruti Baleno | Wet sump (pressure feeding type) | Trochoid type | Full flow cartridge | 3.3 |
| 10. | Maruti Wagon R. | Wet sump (pressure feeding type) | Internal gear type | Full flow cartridge | 3.3 |

## Review Questions

1. What is the necessity of lubrication in an engine?
2. What are the important properties of a lubricant? Explain them briefly.
3. Define the term viscosity.
4. Differentiate between a viscosity rating of SAE 30 and SAE 40.
5. Enlist the different types of additives used and explain their functions.
6. What effect do detergent additives have on the lubricant?
7. Describe different lubricating systems of an engine.
8. Explain the working of the full pressure lubrication system with the help of a neat sketch.
9. What are the causes of low oil pressure?
10. What are the causes of high oil consumption?
11. Explain how an oil pump works.
12. Why is a relief valve used in the lubrication system?
13. How is it possible to remove harmful liquids from the lubricating oil through a crankcase ventilator?

# 11

# Supercharging of IC Engines

**Objectives**

After studying this chapter, you should be able to:

- State the purpose of supercharging.
- State three methods used for increasing air capacity for combustion of fuel in a gasoline engine.
- Describe the effect of supercharging on power and thermal efficiency.
- List the merits of supercharging in relation to high compression ratio method.
- Give the advantages of supercharging in a petrol engine and diesel engine
- Explain the effect of supercharging on mechanical efficiency and fuel consumption of an engine.
- Describe supercharging of a two-stroke engine.
- Explain different types of superchargers.

## 11.1 INTRODUCTION

It has been observed that power generation of an automobile engine depends on fuel consumption, and fuel consumption can only be increased by feeding more air to the engine cylinder. This means that air consumption by an engine is directly related to the engine power. The air supplied to the engine depends on the swept volume of the engine. Therefore, more air has to be pumped into the cylinder to get more power. The process which forces more charge into the cylinders than can be drawn in by natural piston action is known as *supercharging*.

The power of an engine falls off with an increase in altitude the decrease being due to the decrease in the density of air. At an altitude of 5500 meters, an engine draws in only about half as much charge per cycle as that at sea level, and the engine then develops less than half as much power. By supercharging an engine at high altitude, it is possible to keep the power constant as that at sea level.

A supercharged engine has low weight-power ratio. This means that a small supercharged engine develops more power. A supercharger increases the pressure of the air-fuel mixture received from the carburettor before it enters the engine. Thus a supercharger forces the mixture into the cylinder at a pressure higher than that of the atmosphere. The higher weight of charge develops more power.

## 11.2 PURPOSE OF SUPERCHARGING

The purpose of supercharging can be stated as:

1. To reduce the weight per horse power of the engine.
2. To reduce the space occupied by the engine.
3. To maintain the power of the engine even at high altitudes.
4. To improve power in a racing car.
5. To improve combustion efficiency due to the formation of a homogeneous mixture.

## 11.3 EFFECT OF SUPERCHARGING

The following effects are observed in supercharged engines:

1. A supercharger produces better mixing of the air-fuel mixture. The turbulent flow helps in additional mixing of the fuel and air particles.
2. The temperature of the charge is raised as the charge is compressed in the supercharger. This is beneficial so far as the vaporisation of fuel is concerned. However, the higher temperature tends to lessen the density of the charge. Also the chances for detonation are highly increased. In a diesel engine, knock is suppressed due to the rise in temperature of the charge (air).
3. Power is required to drive the supercharger. This power is usually supplied by the engine. Therefore, some of the gain in power due to supercharging is utilised by the supercharger.

## 11.4 METHODS OF INCREASING AIR CAPACITY

There are three methods which are generally used to increase air supply for the combustion of fuel in a gasoline engine:

1. *Increasing the piston displacement* This increases the cylinder size and weight of the engine. Increasing the cylinder diameter introduces cooling problems due to the decrease in surface to volume ratio. This condition does not occur in the case of supercharging.
2. *Running the engine at high speeds* Proper valve timing and design of suction manifold increase natural supercharging. This is due to the inertia of charge entering the cylinder. This is the case of natural supercharging without a supercharger.
3. *Increasing the density of the charge* This is done so that the cylinder is packed with a greater mass of charge. This is the case of supercharging with a supercharger.

Natural supercharging by increasing the engine speed is rarely used. Increasing the piston speed increases fluid friction as the square of the speed, and also increases mechanical friction losses caused by the dynamic forces (primary and secondary forces) on the crank bearings. These losses absorb engine energy and the effective gain due to natural supercharging is very small.

For supercharging, the engine with a supercharger is commonly used.

## 11.5 SUPERCHARGING AND THERMAL EFFICIENCY

The process of supercharging increases the compression pressure. If the engine cylinder is not designed for such pressures, then it gets damaged. To derive the advantages of supercharging an engine, it is essential to redesign the engine parts so that the parts can withstand the high stresses caused by the increased pressures. Usually, the clearance volume is increased. This accommodates the increased quantity of charge packed by the supercharger, and also the compression pressure is controlled. The combustion pressure is not higher than in the engine with natural induction having the same compression pressure. However, the greater heat generation in the supercharged engine increases pressure at all points of the power stroke except at the beginning. This results in increased power in the supercharged engine in which the compression pressure is controlled by increasing the clearance volume. Increasing the clearance volume, decreases the compression ratio and reduces thermal efficiency. Refer to Fig. 11.1. In this figure, the effect of supercharge ratio on the engine power and efficiency has been shown. The results are plotted from an engine which has a compression ratio of 6 when it is un-supercharged. The clearance volume is increased with the increase in ratio of supercharge so that the compression pressure remains the same in the cylinder when the piston is at TDC. In the Fig. 11.1, when the supercharge ratio is 1, it indicates that the engine is not supercharged and the engine has a compression ratio of 6. When the supercharge ratio is 6, it indicates that the engine is supercharged and the engine has a compression ratio of 1 which means no piston stroke occurs. In this condition, both power and efficiency are zero. Therefore, in every case the total compression ratio (in the supercharger and the engine cylinder) remains the same, i.e. 6. The results of Fig. 11.1 have been plotted for the case where compression takes place in the engine alone, to that where it takes place in the supercharger alone.

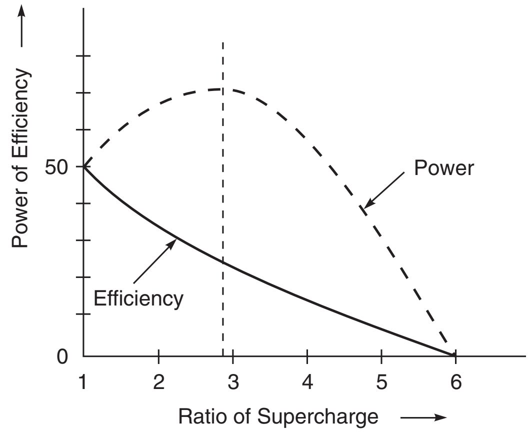



**Fig. 11.1** Effect of Supercharge Ratio on Power and Efficiency

It is interesting to note that the thermal efficiency is maximum without supercharger. The power developed by the engine increases with an increase in the supercharge ratio nearly 2.5 or 3 times when compression is nearly equally divided between the supercharger and the engine cylinder. The maximum power developed by the engine is nearly 145 percent of the power developed without the supercharger. The engine thermal efficiency is only 30%, as compared with 51.2% for the unsupercharged engine.

Thus the conclusion is that supercharging of a gasoline engine is recommended when the engine power is more important than economy. For example, racing cars which are designed for challenging top speeds, are fitted with superchargers. Public cars are not fitted with superchargers because these cars are designed for maximum economy. Moreover, the partial throttle closing to control the engine speed, nullifies the effect of supercharging. Supercharging is advantageous when engines are operated in high altitudes. The loss in air density at higher altitudes is compensated by a supercharger. In such a case, a supercharger is a charge restoring device than a supercharging device.

## 11.6 MERITS OF SUPERCHARGING IN RELATION TO HIGH COMPRESSION RATIO METHOD

The power output can also be increased by increasing the compression ratio. A higher compression ratio increases the thermal efficiency of the engine. Therefore engine power is increased by increasing the engine compression ratio. However, the increased compression ratio leads to an increase in the maximum cylinder pressure at the end of combustion. This means that the engine cylinder must be more robust to be able to withstand the combustion pressure.

In a gasoline engine, compression temperature also increases with the compression ratio and leads to detonation. Therefore superior gasoline of higher octane number is needed to get improved power from the engine by increasing the compression ratio. In such an engine, the rate of increase of maximum cylinder pressure is more than the rate of increase of brake mean effective pressure. Since the engine parts must be built strong enough to withstand this pressure, the disadvantages of increased weight and other difficulties soon overcome the advantages of improved thermal efficiency and engine power. For this reason, gasoline engines are run at a lower compression ratio.

For a given maximum cylinder pressure, more power can be obtained by supercharging as compared to that obtained by the increase in compression ratio. In a supercharged engine the rate of increase of maximum cylinder pressure and maximum temperature are lower, than the rate of increase of brake mean effective pressure. Therefore mechanical and thermal loads are lower in a supercharged engine. The power output of a gasoline engine is limited by detonation when the engine is supercharged at the fixed compression ratio.

## 11.7 METHODS OF INCREASING POWER IN AN ENGINE AT FIXED ENGINE SPEED

There are two methods for increasing power in a gasoline engine which has a fixed swept volume and which runs at a fixed speed.

1. *By providing more fuel* Providing more fuel increases the maximum combustion pressure and the mean effective pressure. Work done or power developed by the engine is increased. The theoretical efficiency is not affected, but the actual efficiency depends on the air-fuel ratio and the homogeneity of the mixture. An over-rich mixture cannot develop more power due to incomplete combustion of fuel. It has been found that 110% of the theoretically ascertained quantity of fuel in an air-fuel mixture develops the maximum mean effective pressure. This is because all the air in the mixture is consumed by the fuel.
2. *By increasing compression ratio* In Section 11.6 it was shown that the increase in compression ratio increases the mean effective pressure. An increased compression ratio is obtained by reducing the clearance volume. The increased mean effective pressure increases engine power. This power is limited by the increased stresses in the engine parts. The increased compression ratio also increases the expansion ratio which in turn increases the engine power.

## 11.8 SUPERCHARGING OF A PETROL ENGINE

A petrol engine consumes virtually all the air supplied to it, and the power developed depends almost entirely on the cylinder capacity, i.e. the breathing capacity of the engine. However, supercharging tends to lead to detonation and high thermal loading. The tendency for detonation can be reduced by lowering the compression ratio as explained in Section 11.5. Reducing the compression ratio reduces thermal efficiency. The increase in the maximum temperature of the cycle leads to loss of thermal efficiency and higher fuel consumption due to dissociation losses. The increased flame speeds make the petrol engine more sensitive to the fuel-air ratio and the engine cannot run on a weak mixture. Therefore rich mixtures are used to control detonation which further increase the specific fuel consumption of the engine. Knocking can be controlled in a supercharged engine by using inter-coolers of the charge before it is fed to the engine. Due to its poor fuel economy (Refer to Section 11.5), supercharging of a petrol engine is not very popular and it is used only when a large amount of power is needed or to restore the loss of density at high altitudes.

## 11.9 SUPERCHARGING OF A DIESEL ENGINE

The high inlet temperature and pressure produced by a supercharger leads to detonation in a petrol engine, but the same factors reduce the delay period of the diesel fuel and also suppress knock. The improved combustion characteristics resulting from supercharging has led to the process of supercharging being used in a diesel engine. Moreover, the high expansion ratio and the low fuel-air ratio in the supercharged diesel engine reduces the exhaust temperature. Due to the low temperature, these exhaust gases may be used in a gas turbine to run the supercharger. To derive power from the exhaust gases, fuel injection is controlled in order to utilize the extra amount of air. The indicated thermal efficiency of the diesel, engine is slightly negatively affected by supercharging but the mechanical efficiency is improved.

The supercharged diesel engine is not sensitive to the quality of fuel used. The process of supercharging increases the induction temperature which reduces the volumetric efficiency. However, the supercharger compensates for this loss by packing more air in the engine cylinder.

The degree of supercharging is limited by the thermal and mechanical loads on the engine. The thermal and mechanical loads on the engine are due to the high temperature and high pressure of the air obtained for supercharging the diesel engine. The load on the bearing is increased due to the increased pressure in the cylinder. Copper-lead bearings in the diesel engine can withstand the loads caused due to maximum cylinder pressure which are about 85 kg/cm$^2$, and which limit the supercharger pressure to about 2 atmospheres with a compression ratio of 15:1. Thus an increase in supercharging pressure in the cylinder decreases the reliability of the engine.

Therefore *durability, reliability* and *fuel economy* are the main considerations in limiting the degree of supercharging of a diesel engine.

## 11.10 MERITS OF SUPERCHARGERS

It is always possible to increase the power of an engine by increasing the density of air supplied to the engine. The power developed depends almost entirely on the breathing capacity of the engine. In general, the degree to which an engine may be supercharged is limited by

(i) detonation in a gasoline engine,
(ii) additional mechanical stresses in the gasoline and the diesel engine, and
(iii) cooling difficulties.

The power required to drive the supercharger depends upon the quantity of air handled, the pressure ratio, the initial temperature and the adiabatic efficiency during the supercharging process in the supercharger. The increase in the engine power due to supercharging is many times the power required to drive the supercharger. Therefore, the excess power of the supercharged engine is useful for external work.

A supercharger may be engine driven through gears, or exhaust-driven which is known as a turbo-supercharger. In case of the direct driven supercharger, the engine power reduces by an amount equal to the power drawn by the supercharger. Therefore additional fuel is used to produce this power. The turbo-supercharger is driven by the energy obtained from the exhaust gases. A small gas turbine is used for this purpose. In this case, the shaft output of the engine is not affected. Moreover, the exhaust energy which is normally wasted is utilised to drive the turbo-supercharger.

## 11.11 EFFECT OF SUPERCHARGING ON MECHANICAL EFFICIENCY

Due to the packing of more charge in the engine cylinder during supercharging, the gas load is increased which needs large bearings and robust components. Heavy load on the bearings increases the friction force. However, the increase in the brake mean effective pressure is much more than the increase in frictional forces. Therefore the mechanical efficiency of a supercharged engine is improved as compared to an un-supercharged engine. This mechanical efficiency increases with the increase in the degree of supercharging, but reduces with the increase in engine speed.

## 11.12 EFFECT OF SUPERCHARGING ON FUEL CONSUMPTION

The power required to drive the supercharger varies with different arrangements. If the supercharger is directly driven by the engine, then extra fuel is supplied to compensate for the loss of power which is required to drive the compressor. If a gasoline engine runs at part load, then the throttle valve is partially closed. In such conditions the effect of supercharging is neutralised. This results in a greater loss and the specific fuel consumption is increased. A highly supercharged gasoline engine needs a very rich mixture to avoid knock and pre-ignition. This also gives rise to higher specific fuel consumption.

The specific fuel consumption in a supercharged diesel engine is lesser than the un-supercharged diesel engine and is due to better combustion and increased mechanical efficiency.

Exhaust-driven superchargers do not require any power from the engine. On the other hand, a part of the exhaust energy is utilised for work which gives about 5% better thermal efficiency at full load when the throttle valve is fully opened. This lowers specific fuel consumption.

## 11.13 SUPERCHARGING OF A TWO-STROKE ENGINE

A two-stroke diesel engine needs excess air for scavenging the cylinder. About 40% of the total air delivered to the engine escapes through the exhaust port which helps in cooling the engine parts. Therefore a reasonable degree of supercharging is used when there is flow resistance through the exhaust port and manifold.

Thus it seems that the two-stroke engine provides a suitable field for the application of the turbo-supercharger.

## 11.14 TYPES OF SUPERCHARGERS

A supercharger is a device which increases the induction pressure of an engine and is connected between the carburettor and the induction manifold. Superchargers are of three types:

1. Centrifugal type supercharger
2. Roots air blower type supercharger
3. Vane type supercharger

### 1. Centrifugal Type Supercharger

In Fig. 11.2 a centrifugal type supercharger has been shown. A centrifugal type supercharger is relatively light and compact, and produces a continuous flow of air under pressure. The mixture of fuel and air enters the rotating impeller in a direction parallel to the shaft. The impeller (rotor) rotates in a close fitting casing at the speed of 10,000 to 15,000 rpm. Thus the impeller imparts high velocity to the mixture due to centrifugal action. The mixture leaves the impeller readily and enters the diffuser. In passing through the diffuser, the velocity of the mixture is reduced and the pressure is increased. At this stage, the density of charge is increased. After the diffuser the mixture passes to the volute casing. The volute casing (outer casing) leads the mixture to the engine cylinder through the inlet manifold.

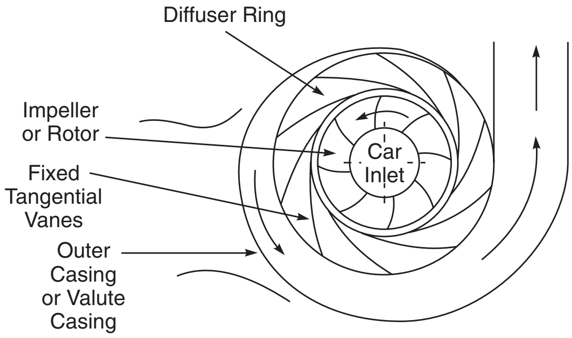



**Fig. 11.2** Centrifugal Type Supercharger

The centrifugal supercharger is simple and cheap. It has good efficiency in the range of pressure ratio of 1.5 to 3.0. The pressure ratio varies with the square of the speed. In the high efficiency range of operation, the pressure ratio remains constant but the volume flow changes. This makes the centrifugal supercharger unattractive for use in automobile engines because automobile engines are variable speed engines. The limited speed range of the centrifugal supercharger makes it suitable for constant speed type engines such as aircraft engines and water pump engines.

The disadvantage of the centrifugal supercharger is the occurrence of surge, which reduces the performance of the centrifugal supercharger due to severe pulsation of the delivery pressure. When the inlet valve of the engine closes and the outlet air flow is restricted, the pressure ratio of the supercharger increases in an attempt to counteract the restriction. The opposing characteristic to changes in the flow of air changes the performance of the supercharger and surges occur. At this stage the pressure ratio falls and does not oppose the restriction to flow. The higher pressure air in the delivery pipe surges back through the supercharger. Thus a high frequency surge of air, occurs back and forth in the supercharger.

In the supercharged gasoline engine, the supply of mixture is controlled by a throttle. When the throttle is closed far enough to reduce the inlet-manifold pressure below the atmospheric pressure, surge may occur in the centrifugal supercharger. This reduces the efficiency of the compressor.

The impeller of this supercharger is run at speed ranging from 10,000 to 30,000 rpm, and at such tremendous speeds, the centrifugal and inertia forces on the impeller are very great. Therefore the materials whose tensile strength and weight ratio are the highest are suitable for impellers. Hence the impellers are made either of alloy steel, duralumin or magnesium. The housing is generally made of cast aluminium.

## 2. Roots Type Supercharger

In Fig. 11.3 a roots supercharger has been shown. The roots type supercharger consists of two rotors with two, three or more lobes in each rotor. The shafts are connected by gearing and rotate at the same speed. The rotors are made of such dimensions that they rotate in the housing with a slight clearance, and also have a clearance between them. Air enters the space between the rotor lobes at inlet and is carried around the rotors to the discharge port. There is no compression in this process. Compression of air takes place only when the discharge port is opened and the air is pushed. The movement of the impeller (lobes) causes only displacement and not compression. Therefore the force on the impeller is constant during the inlet and discharge processes.

An ideal roots supercharger has no leakage. However in practice, the volume inducted into the displacement is less than that theoretically calculated because of leakage between the lobes and the housing of the supercharger. This supercharger is suitable for the pressure ratio from 1.1 to 2.0.

The roots supercharger is simple, cheap, has good mechanical efficiency and does not require lubrication. The volumetric efficiency decreases rapidly with an increase in pressure ratio. The volumetric fficiency is nearly 80 to 90 percent when the pressure ratio is 1.5, but the olumetric efficiency is 50 to 60 percent at the pressure ratio of 3. The rate of delivery of air varies faster than the speed because the leakage decreases as the speed increases. The power absorbed by the roots supercharger increases in a greater proportion due to the turbulence caused by the right angle flow path.

When the roots blower is used in a two-stroke engine, then it is called a *scavenging blower*. The leakage of air is approximately proportional to the square root of the pressure difference and independent of the speed. Therefore volumetric efficiency increases with increased speed.

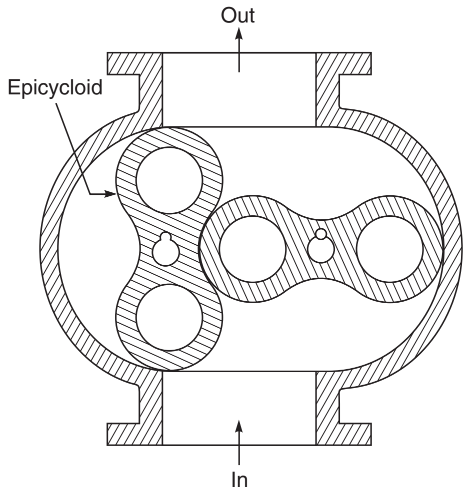



**Fig. 11.3** Roots Supercharger

## 3. Vane Type Supercharger

Figure 11.4 shows a vane type supercharger. It is also known as the *centric vane type supercharger*. It consists of an eccentric drum on which a number of vanes are mounted in such a manner that they can slide in the slots provided for them. Each slot carries one vanes. The vanes are pushed out by the springs which are at the inner side of the vane. (Springs are not shown in Fig. 11.4). The outer edge of the vanes remain in contact with the inner surface of the supercharger body. The drum is rotated by the power shaft. The vanes are carried round. Since the vanes are free for radial movement, the outer edges of the vanes remain in contact with the inner surface of the body. Thus a surface seal is obtained at the outer edge of the vanes, as well as where they pass through the revolving drum. In practice, actual contact is avoided by providing a very slight clearance. This avoids friction between the outer edge of the vanes and the inner surface of the body. The radial movements of the vanes are accurately controlled by their carriers (not shown). The space between

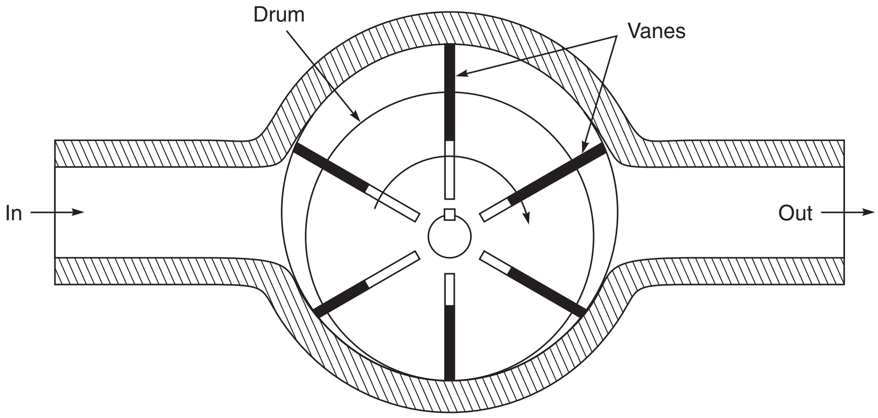



**Fig. 11.4** Vane Type Supercharger

the body and the drum goes on decreasing from the inlet to the outlet side. When the blades move out, air is induced between the space. Air is discharged when these spaces decrease near the exhaust side of the supercharger. Thus the air-fuel mixture (or air) entrapped between any two vanes goes on decreasing in volume and increasing in pressure as it reaches the outlet. Thus the flow at the outlet is pulsating and noisy. The speed of this supercharger is limited because of the radial motion of the vanes.

## Review Questions

1. State the purpose of supercharging.
2. Discuss the effect of supercharging on power and thermal efficiency.
3. What are the merits and demerits of superchargers?
4. Explain the effect of supercharging on fuel consumption of an engine.
5. How many types of superchargers are used in automobiles?
6. Explain the working of a centrifugal type supercharger.
7. Explain the following in brief:
   (i) Supercharging of a two-stroke engine
   (ii) Roots type supercharger
   (iii) Vane type supercharger.

# 12 Clutch

**Objectives**

After studying this chapter, you should be able to:

- State the purpose of providing clutch in vehicles.
- Describe the functions of a clutch.
- List the components of a clutch.
- Explain.
- Identify the different types of automotive clutches.
- Describe the construction of clutch automating mechanism.
- Explain how clutch linkage operates.
- Describe the construction details of automotive clutch.
- Know the use of automatic transmission devices.

## 12.1 INTRODUCTION

A clutch is a mechanism which connects or disconnects the transmission of power from one working part to another, i.e. the crankshaft and the gear box primary shaft.

The components concerned with the transmitting of engine power to the road wheels of a motor vehicle are the clutch, a gear box or automatic transmission, universal joints, propeller shaft, differential and the axles as well as bearings for the driving wheels.

## 12.2 FUNCTIONS OF A CLUTCH

Since it is not possible to permit direct drive of the vehicle under all conditions of speed, it is essential to have some device which can help in changing gears in order to obtain different vehicle speeds. To avoid damage to the transmission and jolting of the vehicle, the rotating engine is not connected directly to a stationary transmission shaft. A device known as clutch is used to disengage the drive from the engine to the gear box and subsequent re-engagement so that the engine takes the load gradually and smoothly. This is possible only if the clutch slips, i.e. it rotates and slides on the input shaft of the gear box instead of making a firm connection between the engine and the gear box.

Thus the different functions of a clutch are:

1. To permit engagement or disengagement of a gear when the vehicle is stationary and the engine is running.
2. To transmit the engine power to the road wheels smoothly without jolt/shock to the transmission system while setting the vehicle in motion.
3. To permit the engaging of gears when the vehicle is in motion without damaging the gear wheels.

The clutch may be manual or automatic, whatever the form, it must possess the following qualities.

1. It should consume minimum physical effort at the time of engagement and disengagement, i.e. should be easily operated.
2. It should be free from slip when engaged.
3. The wearing surfaces should have long life.
4. The clutch should be easily accessible and have simple means of adjustment.
5. Within the clutch, a suitable mechanism should be provided for damping of vibration and elimination of noise produced during transmission. Further, the clutch must also be designed to absorb the shock of engaging two shafts running at different speeds and to absorb small torque irregularities.

## 12.3 MAIN PARTS OF A CLUTCH

The principal parts in a typical clutch are the driving members, the driven member (clutch plate) and the operating members.

One driving member consists of a cover which carries a cast iron pressure plate or driving disc, the pressure springs and the releasing levers.

The entire assembly is bolted to the flywheel and rotates with it at all times. The flywheel acts as a second driving member; the flywheel and the pressure plate grip the driven member between them under the action of the pressure springs. The driven member consists of a disc or plate which is free to slide lengthwise on the splines of the clutch shaft but which drives the shaft through those splines. The clutch disc carries friction material on both bearing surfaces.

The operating mechanism consists of the foot pedal, the linkage, the release or throw-out bearing, the release lever and the springs necessary to ensure proper operation of the clutch.

In Premier Padmini, the clutch is of the single plate spring-cushioned hub type, working dry with damper rings.

The clutch consists of the following parts as shown in Fig. 12.1.

1. *Pressure Plate* It is accurately machined and presses the driven plate against the flywheel.
2. *Driven Plate* It is provided with annular facings and a spring-cushioned hub, i.e. with springs and with two vibration damper rings. Its outer diameter is 184 mm.
3. *Release Levers* Release levers are provided with every lever mounted on an eye bolt locked on the cover by a nut and held in place by a retainment spring.
4. *Engagement springs* Six powerful springs force the pressure plate on driven plate.
5. *Sliding sleeve with thrust bearing* The sleeve controlled by a fork lever may slide until it presses with the thrust bearing on the release lever inner ends.
6. *Cover* The cover which is of pressed sheet steel, is fixed to the flywheel by six screws.

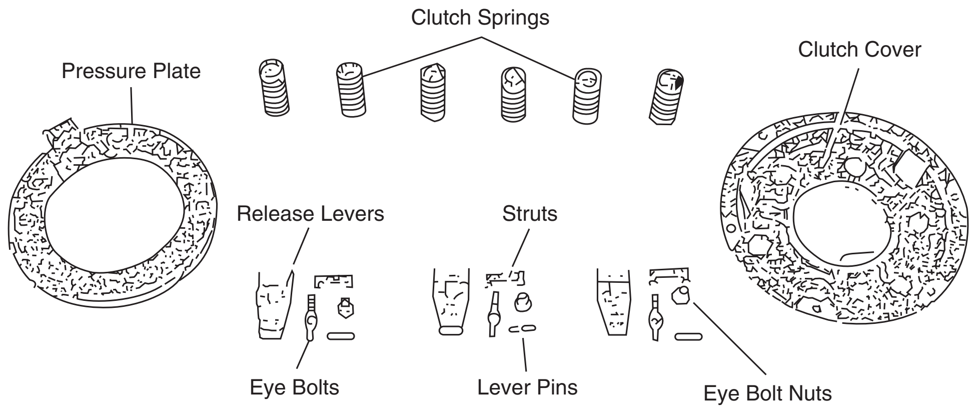



**Fig. 12.1** Clutch Components (*Courtesy:* The Premier Automobile Ltd.)

When the driver presses down on the clutch pedal to release the clutch, a suitable linkage moves the sleeve with the thrust bearing towards the engine. The thrust bearing presses on the release lever inner ends; the lever rocks and overcoming the spring load with its outer ends, pushes back the pressure plate thus disengaging the clutch. This action allows the flywheel and pressure plate to turn without transmitting power to the driven disc and the clutch shaft. Whenever the driver's foot is off the clutch pedal, the pressure plate springs push on the pressure plate and squeeze the disc against the flywheel and the engine is coupled to the transmission.

Hindustan Ambassador cars also use a single dry plate "Bore & Beck" type clutch consisting of a driven plate assembly (friction disc), a cover assembly and a graphite release bearing assembly. The clutch is operated mechanically using a 20 cm clutch friction disc. The driven plate assembly or the friction disc has a flexible centre in which the splined hub is indirectly attached to the clutch plate and transmits power and overturn through a number of coil springs held in position by retaining wires. Two friction facings are riveted to the clutch plate, one on each side.

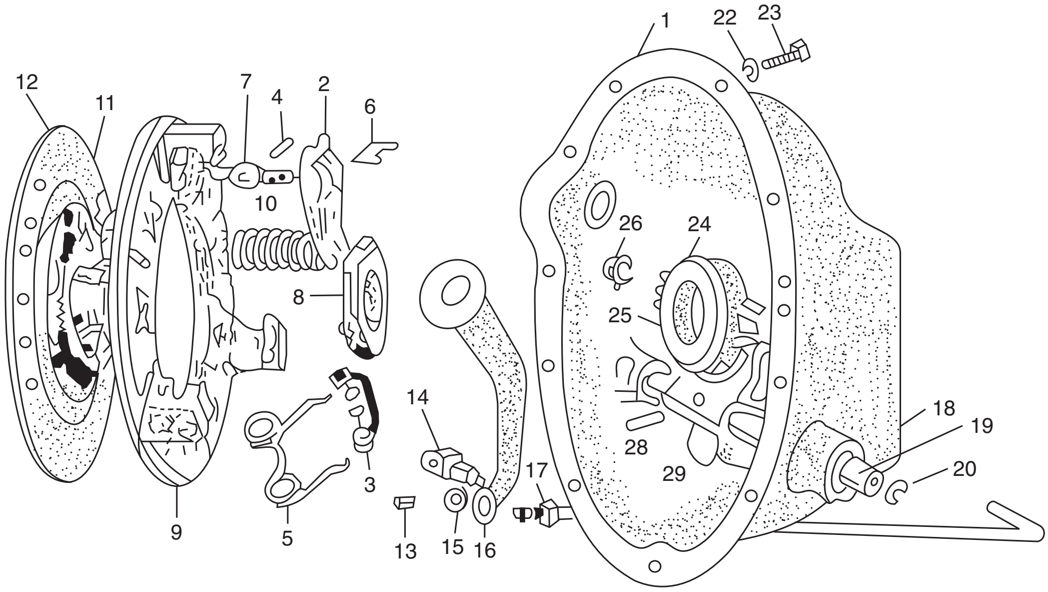
The cover assembly consists of a pressed steel cover and a CI pressure plate loaded by six thrust springs. Mounted on the pressure plate are three release levers which pivot on the floating pins retained by the eye-bolts. Anti-rattle springs load the release levers and the retainer springs connect the levers to the release lever plate. The release bearing consists of a graphite bearing shrunk into a bearing cup. Figure 12.2 shows the components of the clutch.

## 12.4 CLUTCH TYPES

The most widely used form of clutch is the friction type. This may be:

1. The *cone clutch* which is now only used in the synchromesh units of gear boxes, and in overdrives and some epicyclic gear boxes.
2. The *single plate clutch* (multi spring or diaphragm spring) which is used in most cars and small commercial vehicles.
3. The *multiplate clutch* which is used in motor-cycles, in some racing cars, tractors and also in special types of very heavy commercial vehicles.

The single and multi-plate friction clutches are usually dry types. The word "*dry type*" is used to distinguish these clutches from those that operate in a bath of oil known as the '*wet plate*' type.




1. Housing Clutch
2. Lever Release
3. Retainer Release Lever
4. Pin for Level
5. Spring (Anti Rattle)
6. Strut
7. Eyebolt
8. Plate Release Thrust
9. Plate Pressure
10. Spring Pressure
11. Plate Assembly (Clutch)
12. Lining
13. Dowel Clutch Assembly
14. Trunnion
15. Washer Anti-Rattle
16. Lever Fork Shaft
17. Nuts
18. Bush Fork Shaft
19. Shaft Clutch Fork
20. Circlip Fork Shaft
21. Connecting Rod
22. Washer
23. Bolt Clutch Cover
24. Release Bearing Assembly
25. Bearing Graphite
26. Retainer Bearing
27. Bush Fork Shaft
28. Taper Pin Clutch Fork
29. Fork Clutch

**Fig. 12.2** Components of Clutch (*Courtesy:* Hindustan Motors Ltd.)

In these clutches a cork-insert or phosphor-bronze plates are fitted between steel plates, all the plates being immersed in oil. Oil immersed clutches are however used in conjunction with, or as part of automatic transmission.

Other forms of clutch are also coming into use and generally form a part of the pre-selector, two-pedal or fully automatic transmission systems. These are the centrifugal and magnetic clutches, the fluid flywheel and the hydraulic torque converter.

## Single Plate Clutch

The single plate clutch is used in most automobiles for producing a quick disengagement and permitting change of gears with minimum effort. The clutch is of conventional design, having coiled pressure springs and three adjustable release levers. There are many designs of coil spring pressure plates, some using three large coil springs; others using nine or twelve smaller springs.

Another type of pressure plate uses a one-piece conical or diaphragm spring steel which is punched to give it greater flexibility. It claims following advantages over the coil spring type:

1. As the diaphragm itself acts as a series of levers, release levers are not needed.
2. Less effort is needed on the pedal to keep the clutch disengaged .
3. Operating load is practically uniform and constant on the driven plate.
4. Squeaks, rattles and vibrations are mostly eliminated.

### Multiplate Clutch

Multiplate clutches are used for large trucks and racing cars where high torque transmission is necessary but the diameter is limited. These are also used in automatic transmission and motor cycles. In this type of clutch a number of parallel discs of metal and friction material are arranged to transmit the drive. In comparison to the single plate type these are smoother and easier to operate. The increased number of plates/friction discs provide the increased torque carrying ability thus making it suitable for use in heavy commercial vehicles and special purpose military and agricultural vehicles. These clutches may be dry or wet.

### Multiple Wet Clutch

A multiple wet clutch consists of a number of thin plates made of steel fitted to the engine shaft and those on the gear shaft are made of phosphor bronze. These plates are immersed in a bath of oil and also have grooved surfaces for permitting the oil to flow through them. These grooves help to dissipate the heat generated during the engagement and release operations. The wet clutches are generally used in conjunction with or as a part of the automatic transmission.

### Multiple Dry Clutch

The multiple dry clutch has its different plates lined with a frictional material similar to that used in case of a single plate clutch.

Cork inserted multiplate clutches are used in motor cycles while those with metal plates are used in tractors or other light powered engine vehicles. To avoid scorching or changing of cork-inserts due to frictional heat, it is necessary to have the clutch oil-cooled.

### Centrifugal Clutch

The centrifugal clutch automatically disengages itself when the speed falls below and engages when the speed rises above a pre-set value. Centrifugal bob-weights are positioned in such a way (see Fig. 12.3) that the centrifugal forces exerted by them with the clutch rotation result in the release levers to be pivoted on their bearings. The clearance between the release levers and the bearing is reduced due to the outer end of the release lever moving towards the flywheel. This results in the proportionate increase of centrifugally generated pressure with the increase of engine speed. Therefore at low engine speeds only the spring pressure acts, while at high engine speeds the force generated by the weights supplements the spring pressure. Thus smooth and acceptable gear changes are obtained under varying conditions of load and speed.

### Semi-Centrifugal Clutch

The semi-centrifugal clutches are similar to the centrifugal clutches, only difference being that relatively lighter clutch pressure springs exerting low pressure at idling speeds can be used.

From Fig. 12.4 it can be seen that the release levers are provided with weights on its outer ends. These weights are forced outwards because of the centrifugal force when the clutch speed increases.

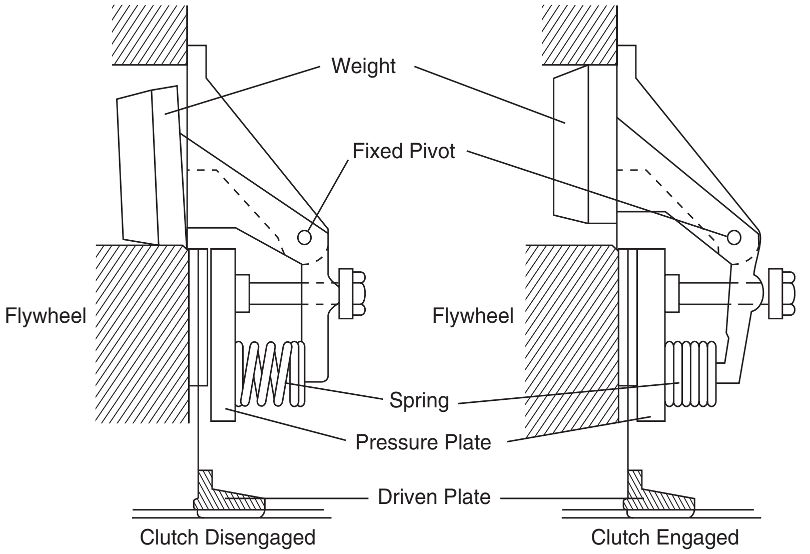



**Fig. 12.3** Centrifugally Operated Friction Clutch

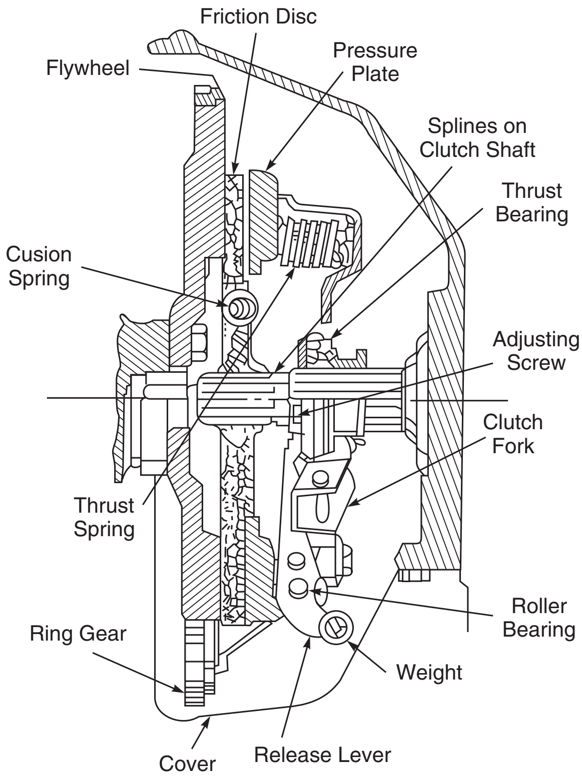



**Fig. 12.4** Semi-centrifugal Clutch

This way the release levers apply more pressure on the pressure plate, thus increasing the contact of the friction disc with the flywheel. This type of construction permits the use of light coil pressure springs and the clutch can operate without too much pressure.

### Free Wheel or One-way Clutch

The free wheel or one-way clutch is a device which transmits power in one direction only. This is fitted in transmission components just behind the gearbox so that transmission components beyond it can be overrun by components before it. With this arrangement, the engine can idle without having to disengage the gears and also helps in gear changing. While going downhill on a long steep road also the engine can overrun the transmission components so that no power is transmitted from the engine.

### Diaphragm Clutch

Figure 12.5 shows the cross-sectional view of the diaphragam clutch used in Maruti 800 manufactured in India by M/s Maruti Udyog Ltd. It is a dry single disc type clutch and the diaphragm spring is of a tapering finger type, which is a solid ring in the outer diameter part. The disc carrying six torsional coil springs is slidably mounted on the transmission input shaft with a serration fit.

The clutch cover is secured to the flywheel and carries the diaphragm spring in such a way that the peripheral edge of the spring pushes on the pressure plate against the flywheel (with the disc in between), when the clutch release bearing is held back. This is the engaged position of the clutch.

Depressing the clutch pedal causes the release bearing to advance and push in the tips of the tapering fingers of the diaphragm spring. When this happens, it acts like the release levers of a conventional clutch putting the pressure plate away from the flywheel. This interrupts the flow of drive from the flywheel through the clutch disc to the transmission input shaft. Figure 12.6 shows the components of this type of clutch.

### Automatic Clutches

Several automatic clutch designs have recently become available. Ferlec of French origin and the Smiths electroshift design have been used on certain Renault models and continental cars. It has a conventional type of friction disc. When battery current is supplied, an electromagnet in the flywheel operates the pressure plate which engages the disc thus transmitting engine torque.

Figure 12.7 shows the electroshift magnetic particle clutch which consists of two rotating members. One is attached to the engine and the other is attached to the gear box. A gap is provided between the two members. The torque is transmitted through this gap by means of magnetic particles. It may be mentioned that when the particles are magnetised by an external magnetic field, they tend to solidify, thus forming a solid connection between the engine and the gearbox. By the adjustment of this magnetic field, the slip to any degree can be conveniently obtained.

## 12.5 CLUTCH ACTUATING MECHANISM

The clutch linkage allows the driver to engage and disengage the clutch with a pedal. Two types of linkages are used, mechanical and hydraulic.

The mechanical clutch linkage has a system of levers that provides a force of approx. 40 lbs (180 N) at the clutch pedal to release the clutch. Clutch linkage transmits the force applied to the clutch pedal to the throw out or release bearing and provides the necessary leverage to make the

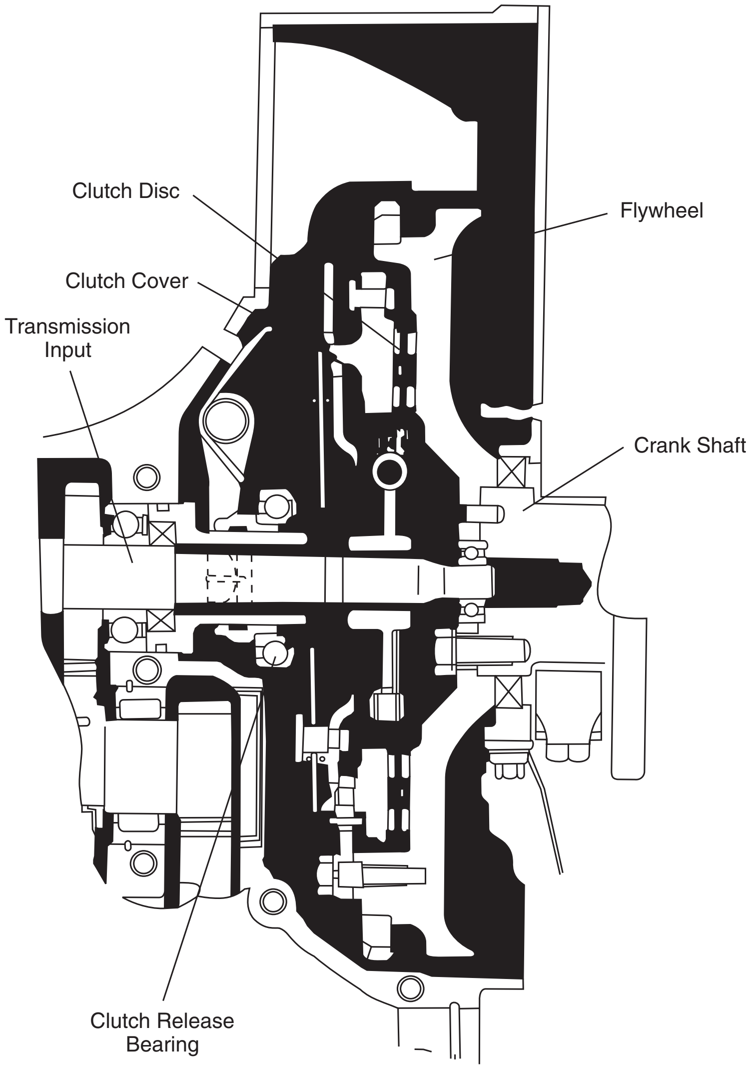



**Fig. 12.5** Cross-sectional View of Diaphragm Clutch (*Courtesy:* Maruti Udyog Ltd.)

clutch operation possible with a reasonable amount of foot pressure. In Fig. 12.8 the clutch pedal rotates about a pedal shaft, so that when it is depressed, it pushes a pedal rod backward causing in turn the torque shaft to transmit the backward motion through a fork rod to the end of a release-bearing fork. Since the fork is pivoted, the motion imparted to it by the fork rod causes the release bearing to move towards the flywheel to disengage the clutch.

When the clutch pedal is released, the pull back spring returns the release bearing linkage and the pedal to the engaged position.

Many compact automobiles use a cable instead of rods to pull on the clutch fork. The cable which may be routed through a small area is used where space is a problem.

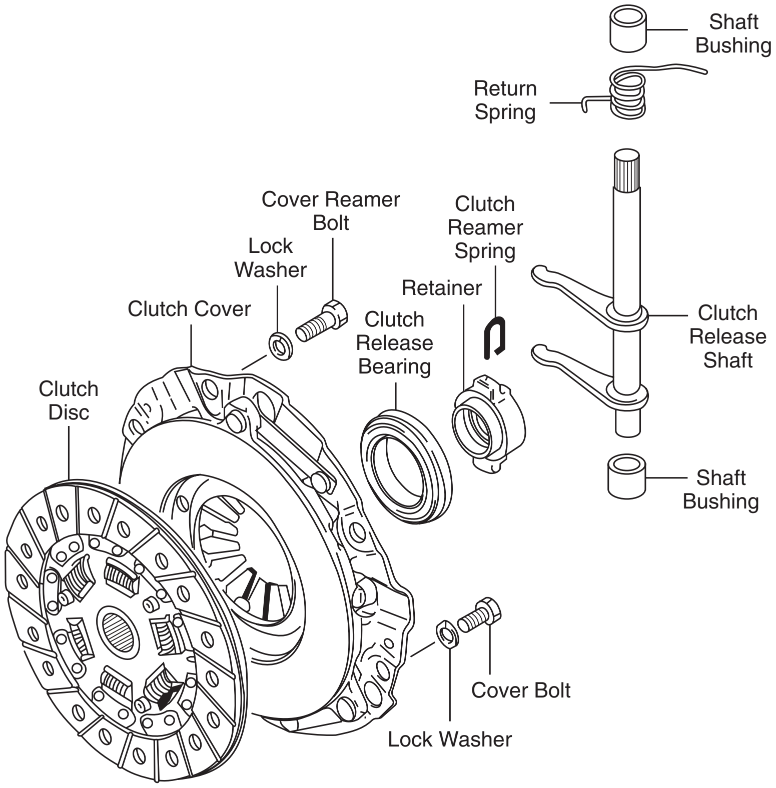



**Fig. 12.6** Clutch Component (*Courtesy*: Maruti Udyog Ltd.)

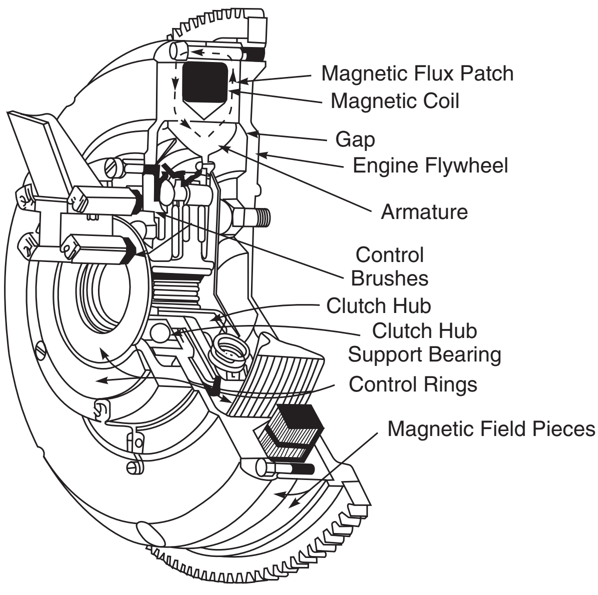



**Fig. 12.7** Magnetic Particle Clutch

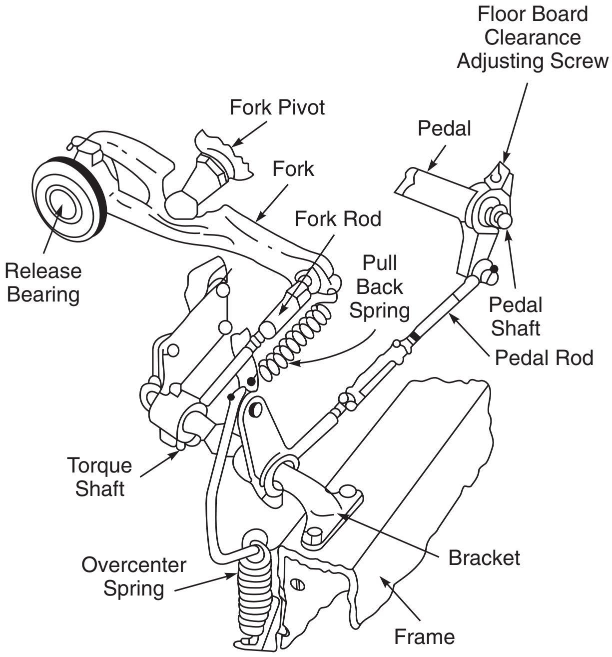



**Fig. 12.8** Clutch Linkage

### Hydraulic Clutch Linkage

Another way of getting motion from the clutch pedal to the pressure plate is through the use of hydraulic pressure. Figure 12.9 shows a master cylinder at the clutch pedal connected to a slave cylinder at the pressure plate release lever.

Standard-10 cars in our country are equipped with this type of clutch operation. The foot pedal, operating the piston in the cylinder produces hydraulic pressure, which is then transmitted through a tube to a slave cylinder containing the piston. This pressure moves the slave piston thereby releasing the clutch. This system has a distinct advantage in that complicated linkages, vibration and wear of linkages are eliminated.

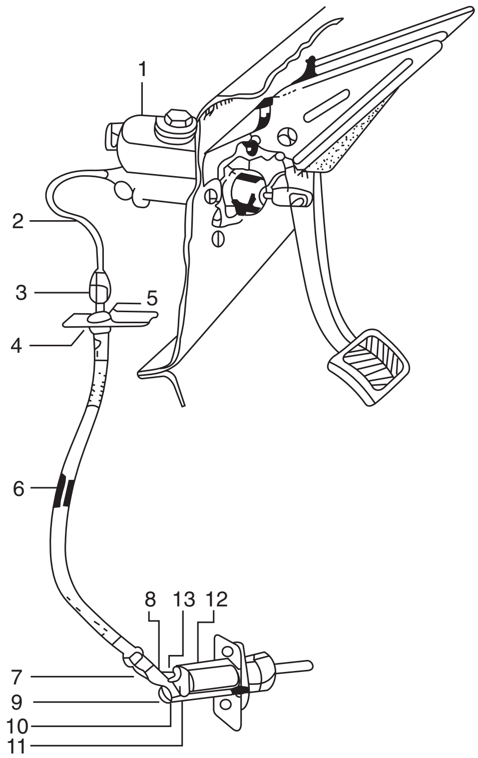
## 12.6 CLUTCH CONSTRUCTION

Single plate clutch of conventional design having coiled pressure springs and adjustable release levers (3 nos.) has been used in many automobiles equipped with synchromesh transmissions.

The clutch cover plate is bolted to the flywheel; three lugs on the pressure plate engage slots in the cover plate to transmit torque to the plate.

Pressure springs (only one shown in Fig. 12.10) are located between the cover plate and the pressure plate. The release lever is located so that its inner end is in position to be engaged by the clutch release bearing. The release lever is pivoted on a fulcrum which is bolted to the cover plate and is mounted in the pressure plate lug.

The outer end weight, an integral part of the release lever, is included so that at higher engine speeds where slippage may occur, the centrifugal force developed by the weight causes more pressure to be applied on the pressure plate. The faster the rotation of the clutch by the engine the




1. Master Cylinder Assembly
2. Bundy Pipe
3. Pipe Nut
4. Shake Proof Washer
5. Lock Nut
6. Hose Assembly
7. Gasket
8. Banjo
9. Banjo Bolt
10. Gasket
11. Gasket
12. Slave Cylinder Body
13. Bleed Screw

**Fig. 12.9** Hydraulic Actuation of Clutch

greater the pressure exerted against the clutch plate and the greater the torque transmitting ability of the clutch.

When the clutch is engaged the release lever is clear of the release bearing and the pressure spring causes the pressure plate to clamp the driven plate against the flywheel with sufficient force to transmit power from the engine without slippage. The power drive is from the flywheel to the cover plate, then to the pressure plate and finally to the driven member.

## 12.7 DRIVEN MEMBER (FRICTION OR CLUTCH DISC)

The driven member assembly is mounted with a free sliding fit on the transmission drive gear and is keyed to the gear by ten splines. The front end of the drive gear is piloted by a bushing pressed into a recess in the rear end of the engine crankshaft. The outer area is divided into segments which

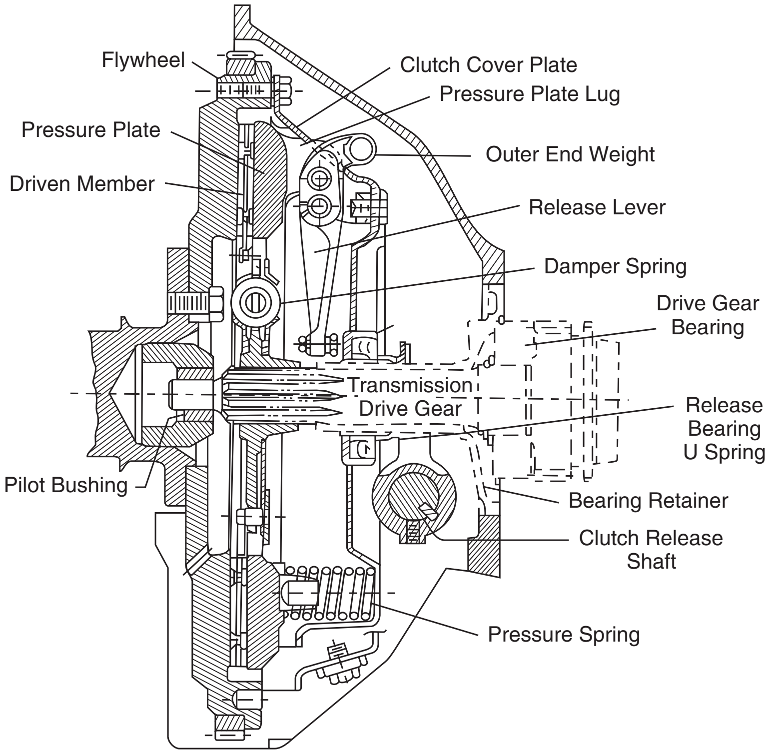



**Fig. 12.10** Single-Plate Clutch

are formed in low waves. These waves form a rippled-spring effect between the plate facings to cushion the engagement of the clutch. A moulded facing is riveted to each side of every plate segment. When the clutch is fully released the segments cause the facings to spread approximately .054 in. or 1.35 mm to assure full release of the driven member. Rattle-causing torsional vibrations of the engine are prevented by the use of coiled damper spring and the frictional dampening effect of moulded friction washers. The most commonly used facings are made of cotton and asbestos fibres woven or moulded together and mixed with resins. Copper wires are often woven or pressed into the material to give it additional strength.

The clutch disc usually has a flexible centre to absorb the torsional vibrations of the crankshaft. The flexible centre is made from steel compression springs placed between the hub and the steel plate. The springs allow the disc to rotate slightly in relation to its hub until the springs are fully compressed and relative motion stops. Then the disc can rotate slightly backward as the springs decompress. This slight backward and forward rotation allows the clutch shaft to rotate at a more uniform rate than the crankshaft and eliminate some of the torsional vibrations from the crankshaft.

As described earlier, the pressure plate assembly may contain a diaphragm spring or a number of coil springs. The springs are connected at one end to a steel cover and at the other end they are connected to a heavy flat ring with one ground contact surface, the pressure plate (see Fig. 12.11). The pressure plate and flywheel surfaces are usually machined and ground from nodular iron which contains enough graphite to provide some lubrication when the clutch is slipping during engagement.

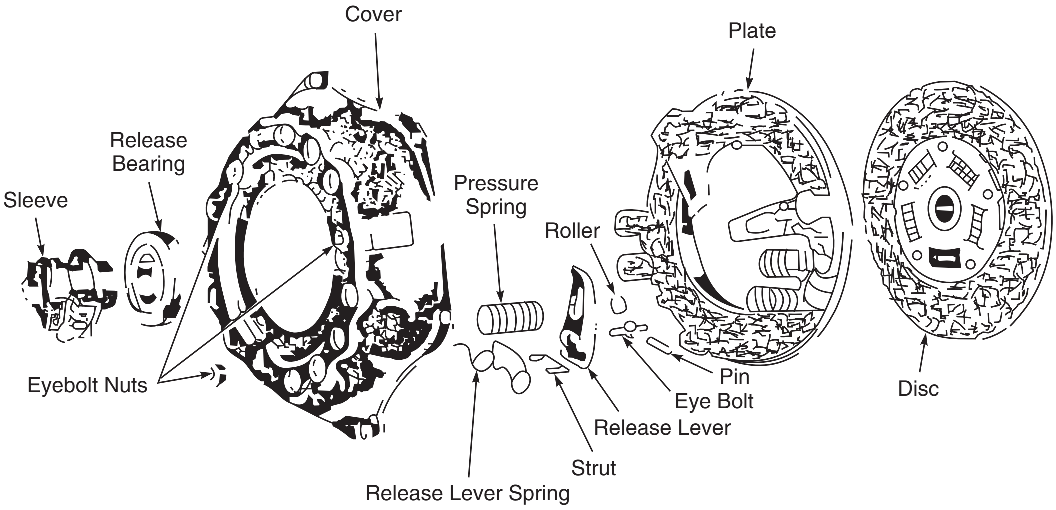



**Fig. 12.11** Clutch Assembly Showing Pressure Plate Dissembled

## 12.8 AUTOMATIC TRANSMISSION DEVICES

Automatic transmission helps to change the engine's rotational speed to the speed required at the driving wheels. It changes the gear ratios between the engine and the drive wheels to keep the engine operating in its most efficient range. It automatically shifts under the load demands.

### 1. Fluid Flywheel/Fluid Coupling

Fluid coupling is a hydraulic unit that replaces a clutch in a semi or fully automatic system, and transmits engine torque to a transmission system. Since the coupling is a major part of the engine flywheel assembly, it is also called a fluid flywheel or fluid-drive acting as an automatic clutch. In this drive the power flows through a fluid instead of through a mechanical device. The fluid drive consists of a driving and a driven member both bowl or half-doughnut shaped, immersed in a fluid contained in a casing. These units are mounted very closely with their open ends facing each other, so that they can be tuned independently without touching.

***Operation*** The driving unit (impeller) is linked to the engine crankshaft and sets the oil into motion when the throttle is opened. The force of the rotating, trapped oil impinges on the fins of the driven unit (the runner or turbine) and cause it to move. Thus the fluid transmits the engine power to the clutch-driving plate without any metal to metal contact. Figure 12.12 shows the simplified diagram of a fluid flywheel. It consists of a split housing driven by the engine. The turbine is attached to the gear box clutch shaft and it is inside the housing. It acts as a driven member. Both the driving (pump or impeller) and the driven member have radial vanes. When the driving member rotates with the engine, the fluid is thrown outwards under the action of centrifugal force. It circulates from the flywheel to the turbine vanes. Since the driving member carries around the fluid, it tends to rotate the turbine. As the speed of the driving member increases, the circulating fluid gains energy and the same is imparted to the turbine and causes it to turn. Thus power is transmitted from the impeller or pump to the turbine.

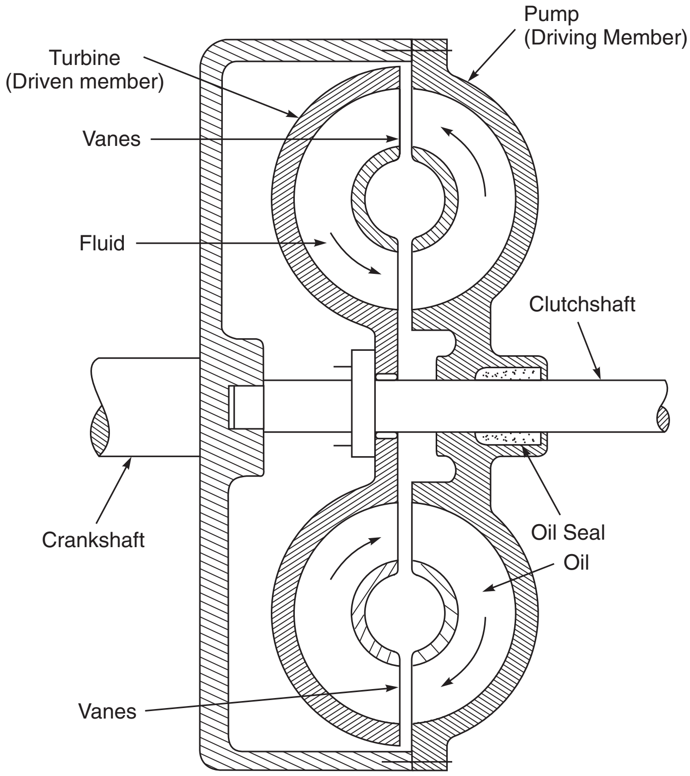



**Fig. 12.12** Fluid Flywheel

A fluid coupling always slips by about 2 to 4% when transmitting full load. It means that the turbine is always running slightly slower than the impeller and as such complete disconnection of the drive is not possible. Thus the fluid coupling is not suitable for ordinary gear box and is generally used with epicyclic gears to provide a semi or fully automatic gear box.

***Advantages***

The main advantages of a fluid coupling are:

1. Smooth transmission of power from engine to gears.
2. Elimination of clutch pedal.
3. Damping of the torsional vibrations of the crankshaft.
4. Less maintenance due to absence of friction surface.
5. During braking or coming down a hill, the transmission shocks are absorbed by the fluid.

The main disadvantage of fluid coupling is the presence of idling drag and that overloading of the fluid coupling not only slows down the turbine but also overloads the engine. Also the slip is greater at lower speeds (it is about 2% at max. efficiency).

## 2. Torque Converter

The torque converter is a special type of fluid wheel in which the vanes are curved. Its major parts are the pump, stator and the turbine. Figure 12.13 shows a simplified sectional view of a three

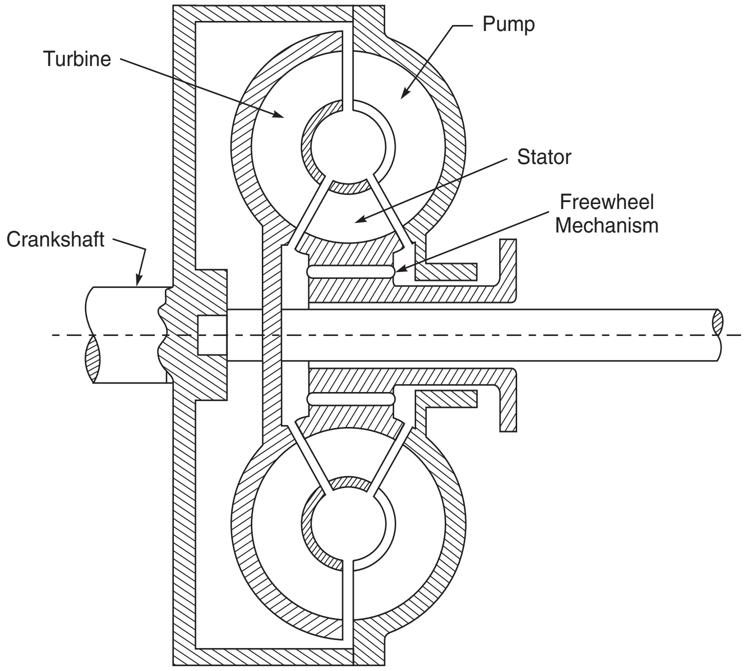



**Fig. 12.13** 3-Member Torque Converter

ember torque converter with the stator mounted on a free wheeling device. This allows the stator to run free when the torque members are turning at about the same speed. The pump and turbine are placed very close together and covered by a housing. The small space between these two wheels is filled with automatic transmission fluid.

***Operation*** When the engine is running, the pump rotates with the flywheel, the fluid thrown off the blades of the fast moving pump hits the blades on the turbine with sufficient force to make it rotate. As seen in Fig. 12.14, the input shaft of the transmission which runs through a hole in the centre of the turbine, is also forced to run. The faster the engine runs, the stronger the flow of oil from the pump to the turbine and the faster the shaft will run. When the engine slows down to idle speed, the fluid thrown off is unable to make the turbine rotate and the engine is automatically uncoupled from the power train.

The stator, located between the pump and turbine allows the torque converter to increase torque in addition to acting as a clutch. The stator has a series of curved blades or vanes. As oil thrown off the turbine hits the stator blades, they guide it back towards the pump which in turn redirects the oil back towards the turbine. This repeated process increases the engine's turning effort or torque. In many designs of torque converter, the torque is almost doubled. It is to be noted that the stator is needed only when the pump and turbine are turning at different speeds.

When they are turning at nearly the same speed, there is very little fluid flow to be redirected and thus no need for the stator. Actually for this reason, the stator is mounted on a reaction shaft that does not rotate, but is mounted on a shaft on the front of the transmission that goes into the torque converter. The stator is attached to the reaction shaft through a one-way roller clutch consisting of a number of spring loaded rollers which allow the stator to turn in one direction only. The stator is locked or unlocked to the reaction shaft by fluid flow conditions.

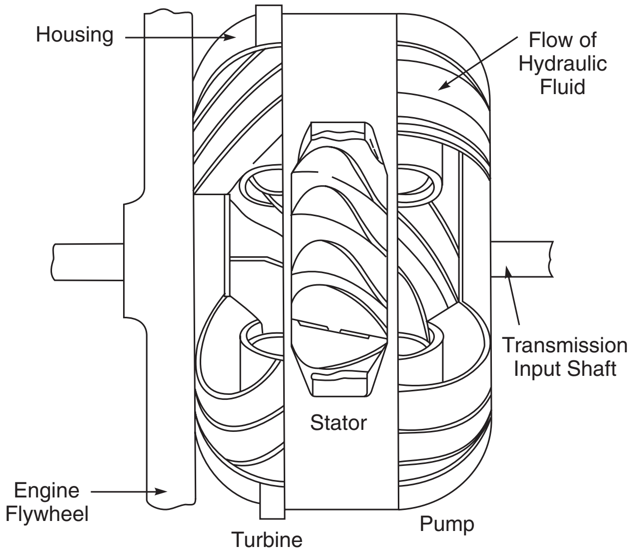



**Fig. 12.14** Torque Converter Operation

When the vehicle is accelerating from a stop, the fluid leaves the turbine at an angle to strike the stator squarely on the back of its blades. Pushing the stator in this direction locks up the one-way clutch and redirects oil back into the pump (Fig. 12.15).

As the vehicle nears cruising speed, the fluid leaves the turbine at a different angle so that it strikes the front of the stator blades. In this direction the stator clutch permits rotation, so that the stator rotates in the same direction as the pump and turbine. Thus as the turbine speed approaches the pump speed, the stator free wheels and is carried along with the rotating fluid mass.

Thus the torque converter increases engine torque a great deal when the difference in speed between the pump and turbine is great. When the difference is slight there is very little torque increase. As the speed of the turbine approaches the speed of the pump, the increase in torque falls off gradually till it becomes 1:1. At this stage, the fluid starts striking the back faces of the vanes in the stator thus making the stator turn and get out of the way of the fluid. Under these conditions, the converter simply acts as a fluid flywheel.

## 12.9 TROUBLESHOOTING/SERVICE PROCEDURES

Clutch problems generally fall into the following categories:

Clutch slippage, clutch drag, clutch related vibrations and noises, clutch chatter, etc.

**1. *Clutch Slippage*** Clutch slippage is a condition in which the engine over speeds (overrevs) but does not provide any power to the rear wheels. Slippage occurs when the clutch disc is not gripped firmly between the flywheel and the clutch cover pressure plate and rotates or slips between them at high torque. Clutch slippage can occur during initial acceleration or during gear shifts.

***Check Operation*** Drive the vehicle long enough to allow the clutch to warm up, listen for signs of overreving during shifting or acceleration.

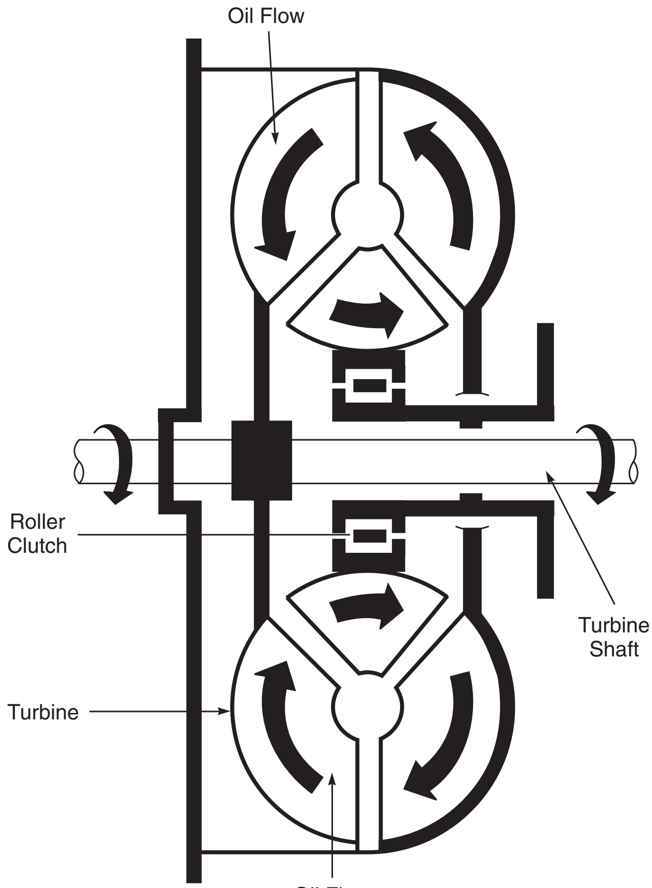



**Fig. 12.15** Cross-Section of Torque Converter Showing Oil Flow

**2. *Clutch Drag*** Clutch drag is a condition in which the clutch disc and the transmission clutch shaft do not come to a complete stop after the clutch pedal is pushed down (clutch disengaged).

Clutch drag can cause gear clash when shifting into reverse or hard/difficulty shifting.

***Check Operation*** Start the engine, depress the clutch pedal fully and shift the transmission into first gear. Shift the transmission into neutral but do not release the clutch pedal. Wait about 10 seconds and then shift transmission into reverse. If the shift is smooth with no gear clash, clutch operation is normal. If there is gear clash, raise the vehicle on hoist, check clutch linkage for binding, worn, broken or bent components. Lubricate or replace as necessary.

**3. *Clutch Pedal Pulsation*** This is rapid up and down (pumping) movement of the pedal without any noise. Movement is usually slight. Pulsation occurs when the release bearing first makes contact with the clutch cover release levers (clutch partially disengaged) or at any time the bearing is in contact with the release levers. It is usually caused by incorrect clutch release lever height or clutch housing misalignment.

***Check Operation*** Start the engine, slowly depress the clutch pedal until the release bearing first makes contact with levers. Continue to depress the clutch pedal while checking for pulsation until pedal is fully depressed.

**4. *Clutch Vibrations*** Clutch vibrations, different from pedal pulsations, occur at a relatively high engine speed (over 1500 rpm) regardless of clutch pedal position.

***Check Operation*** Raise the vehicle on a hoist and check whether any engine components such as exhaust manifold or valve cover touch the body or frame and cause vibrations.

If vibration continues, lower the vehicle, disconnect the accessory drive belts one at a time and check for vibration. If vibration is corrected after taking off a drive belt, the cause of vibration is the accessory driven by the belt or the belt itself.

If vibration continues, check the following—loose flywheel mounting bolts, excessive flywheel face runout, damaged crankshaft vibration damper, clutch cover imbalance.

**5. *Clutch Noises***

(i) Clutch throwout bearing noises are whirring, grating or grinding noises that occur when the clutch pedal is pushed down. These noises continue until the clutch pedal is fully released (clutch engaged) and the bearing is no longer in contact with the clutch cover release levers.

Throwout bearing noise is corrected by replacing the bearing and sleeve.

(ii) Clutch shaft or counterpart bearings noises—whirring, grating or grinding are noticeable when the clutch pedal is fully released and the transmission is in neutral.

To correct these noises, remove the transmission and replace the bearings:

(iii) Pilot bushing noises are squealing, howling or trumpeting noises most noticeable when the engine is cold. These occur during the first few inches of clutch pedal travel as the pedal is being released (partial clutch engagement) with the transmission in gear. They also occur in very cold weather when the pedal is fully pushed down (clutch disengaged) and the engine is started with the transmission in neutral.

To correct the noise, replace the bushing.

**6. *Clutch Chatter*** Clutch chatter can be described as a shaking or shuddering that is felt throughout the automobile. It usually develops when the clutch cover pressure plate first makes contact with the clutch disc and stops when the clutch is fully engaged.

***Check Operation*** Start the engine, push down the clutch pedal and shift the transmission into first gear. Increase the engine speed to 1200-1500 rpm and slowly release the clutch pedal. When the pressure plate first makes contact with the clutch disc, watch the clutch operation. Depress the clutch pedal and reduce engine speed. Shift the transmission into reverse and repeat. If there is no clutch chatter, increase engine speed to 1700-2200 rpm and repeat the test.

**7. *Preventive Maintenance*** Periodic lubrication of the clutch linkage and adjusting the clutch pedal free help in maintenance. The clutch linkage should be lubricated each time the vehicle has a chassis lubrication. All points of friction should be lubricated with engine oil. Some types of linkage with high-pressure gear fittings require lubrication with chassis grease.

**Table 12.1** Clutch Used in Some Indian Automobiles

| *S. No.* | *Make of the vehicle* | *Type of clutch* |
|---|---|---|
| 1. | Ambassador | Single, dry plate - 20.32 cm. dia. |
| 2. | Fiat 1100 | Single, dry plate - 18.40 cm. dia. |
| 3. | Premier Padmini | Single, dry plate - 18.40 cm. dia. |
| 4. | Fiat Uno | Single, dry plate. |
| 5. | Maruti 800 | Dry single Disc type |
| 6. | Jeep CJ-4, CJ-34 4 WD (Mahindra & Mahindra) | Single dry plate - 21.6 cm. dia. |
| 7. | Tata Mobile- 201 pick and Tata 608 | Single plate, dry 22.8 cm. dia.friction, diaphragm type |
| 8. | Ashok Leyland Comet | Single dry plate - 33 cm. dia. |
| 9. | Dodge (passenger) Forgo Model | Single dry plate - 27.94 cm. dia. |
| 10. | Royal Enfield, Bullet | Multiplate |
| 11. | Yamaha Rx-100 | Wet multiple disc type |
| 12. | Rajdoot 175 c.c. | Wet multiple disc type |
| 13. | LML Vespa | Wet multiplate |
| 14. | Luna | Automatic centrifugal clutch. |

## Review Questions

1. State the purpose of clutch.
2. Describe the two main functions of the clutch.
3. What types of automobiles usually have a manually operated clutch?
4. Why is the clutch placed between the flywheel and the transmission?
5. List the various units in the operating mechanism of the clutch assembly.
6. Give the purpose of the following:
   (a) Pressure plate
   (b) Driven plate
   (c) Torsional springs
   (d) Coil springs
   (e) Clutch disc
7. Explain the actions of the clutch during engagement and disengagement.
8. Explain the working of a single plate clutch.
9. Differentiate between:
   (a) single plate and multi-plate clutch.
   (b) wet and dry clutch
10. Explain the working and performance of a centrifugal clutch with a suitable sketch.
11. What is the difference between centrifugal and semi-centrifugal clutches?
12. Describe the principle of operation of free-wheel clutch.
13. Explain the working of a diaphragm clutch. How does it differ from a single-plate clutch?
14. What are the two common types of clutch linkages?

15. Describe the working of a fluid-flywheel.
16. What is a torque converter? How does it works?
17. What is a hydraulic clutch? How does it differ from ordinary clutches?
18. What is the difference between a fluid-flywheel and torque converter?
19. Describe clutch troubles and give reasons for each?

# 13

# Gear Box

## Objectives

After studying this chapter, you should be able to:

- Explain the meaning of terms such as air-resistance, rolling resistance and gradient resistance.
- State the use of different types of gear boxes in automobiles.
- Differentiate between sliding mesh and synchromesh gear box arrangements.
- Describe the function, with a suitable sketch, of dog clutch used in constant mesh gear box.
- Explain the importance of gear shifting mechanism in automobiles.
- Describe power flow through a three-speed gearbox.
- Describe the purpose and operation of the overdrive unit.

## 13.1 INTRODUCTION

It is common experience that a high torque is required at the driving wheels when a vehicle is starting from rest, climbing a hill or accelerating. Due to the variable nature of resistance because of load and gradient changes, it is imperative that the engine power should be available over a wide range of road speeds. For this purpose, a device called a transmission or gear set is provided to permit the engine crankshaft to revolve at a relatively high speed while the wheels turn at slower speeds. The gear set is enclosed in a metal box called a gear box. The gear box is fitted between the clutch and the rear axle and helps the road wheels to get the power of the engine in varying ratios. The driving force or tractive effort used must be equal to the total resistance of the forces opposing the motion of a vehicle and keeping it moving along a road at uniform speed. The moving vehicle has to overcome the following resistances:

1. Air or wind resistance,
2. Gradient resistance, and
3. Rolling resistance.

***Air Resistance*** is the aerodynamic drag experienced by the vehicle while moving and depends upon the frontal area of he vehicle speed and the speed of the vehicle. The expression

$$\text{Air resistance} \quad \frac{1}{2} \; P \; C_d A V^2$$

gives the air resistance where $C_d$ is the coefficient of drag. $A$ is the frontal area, $P$ is the density of air and $V$ is the vehicle speed and is of great significance in high speed vehicles.

***Gradient Resistance*** depends upon the weight of the vehicle and the steepness or the grade of the road. It is independent of the speed of the vehicle.

***Rolling Resistance*** is the resistance to rolling motion offered by the road over which the vehicle is moving. It is mainly the sum of the losses occurring due to the deformation of road and tyre and the losses occurring due to the dissipation of energy in the tyre. The factors which affect rolling resistance are mainly the inflation pressure of the tyre and tyre design. The effect of speed is rather negligible.

The total resistance to the motion of the vehicle is given by $R_t = R_a + R_g + R_r$, using suitable coefficients, this can be expressed as $R_t = W/100\ (G + x) + CAV^2$ where $W$ is the weight of the vehicle, $V$ is speed of the vehicle, $C$ is a constant and $G$ and $x$ represent the coefficients of gradient and rolling resistance. The power required to overcome this resistance is given by

$$P = WV/100\ (G + x) + CAV^3$$

Thus it can be seen that for a given vehicle:

(i) Total resistance increases as the gradient of the road increases, and

(ii) Power requirement becoms very high for high speeds (air resistance increasing as the cube of the speed) or at steep gradients.

It should be noted that the power available from the engine is directly related to the engine torque $T$ and the gear box ratio $g$. Assuming no loss in transmission, torque available at the wheel, $T_w = Txg$ and produces the driving force along the road. This driving force is known as tractive effort and the maximum amount which can be applied is limited by the coefficient of adhesion between the tyre and the road. The tractive effort also varies with vehicle speed as the engine torque varies with engine speed. Usually the speed of the engine is kept constant. To vary the speed of the road wheels relative to the engine, the gear box provides a number of varying ratios-usually three to four gear ratios are sufficient for passenger cars. Gear wheels of different sizes are provided for engaging or disengaging them for transmission of motion and power. A large gear meshed with a small gear will drive the small wheel at increased speed or vice-versa. The gear ratio is obtained by using the general formula.

$$\text{Gear ratio} = \frac{\text{No. of teeth on driver gear}}{\text{No. of teeth on driving gear}}$$

$$= \frac{\text{Speed of driving shaft}}{\text{Speed of driven shaft}}$$

The typical gear box ratio in a small car with a four-speed gear box is 3.5:1 in first, 2:1 in second, 1.4:1 in third and 1:1 in top. All these are multiplied by the axle ratio, which is taken as 4:1 to give the corresponding ratios between the engine speed and the road wheel speed.

## 13.2 TYPE OF GEAR BOXES

The following types of gear boxes are commonly used:

1. Sliding mesh type
2. Constant mesh type
3. Synchromesh type

### 1. Sliding Mesh Type Gear Box

The sliding mesh type gear box is the oldest and simplest type of gear box. As the meshing of gears takes place by sliding of gears on each other, it is known as the sliding mesh type.

The driving shaft of the gear box is known as the primary shaft or clutch shaft. The clutch gear rigidly fixed to the clutch shaft always remains connected to the driven gear of the countershaft or the layshaft. Three other gears are also fixed on the layshaft. Two gears are mounted on the splined mainshaft which can be slided or moved axially to mesh with the corresponding gears on the layshaft. A reverse idler gear mounted on another shaft always remains connected to the reverse gear of the layshaft.

A three-speed sliding mesh gear box along with the different positions of gears is shown in Fig. 13.1 and 13.2. It is to be noted that the layshaft carries two gear wheels for the three-speed and three gear wheels for the four speed gear box for transmitting the drive to give different gear ratios.

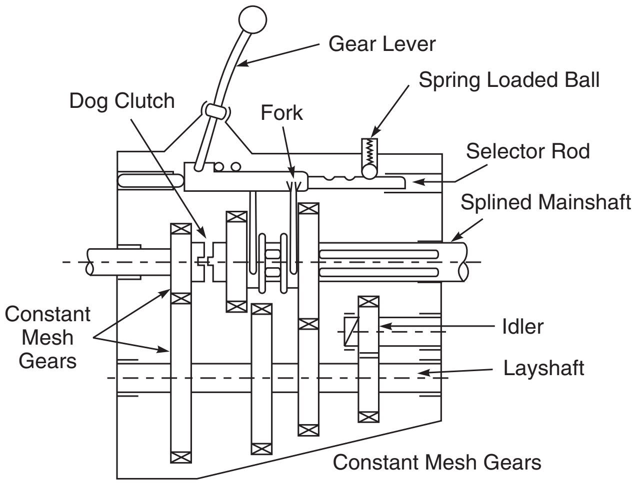



**Fig. 13.1** Three Speed Sliding Type Gear Box in First Gear

When the mainshaft is driven from the layshaft the gear reduction is provided by the first pair of gears which are always in mesh and known as the constant mesh gears. For changing the gear, the clutch is depressed and the gear lever moved till the selector pinion on the main shaft engages with its mating gear on the layshaft.

When the vehicle is in first gear the smallest gear on the layshaft meshes with the largest gear on the splined mainshaft, thereby producing maximum speed reduction and a corresponding increased torque for starting on gradients and hill climbing.

In the second gear, the second or smaller gear on the mainshaft is in mesh with the next larger gear on the layshaft. This produces less speed reduction and smaller torque increase.

In the third or top gear, the primary and main shafts revolve at the same speed without any change in torque. The main shaft is driven through a dog clutch in this gear.

In reverse gear, the speed reduction is usually same as that in the first gear. However, the direction of rotation of the main shaft is reversed by using an idler gear. When in neutral, the primary shaft is in connection with the layshaft. As the layshaft is not connected to the mainshaft, there is no power transmission to the wheels.

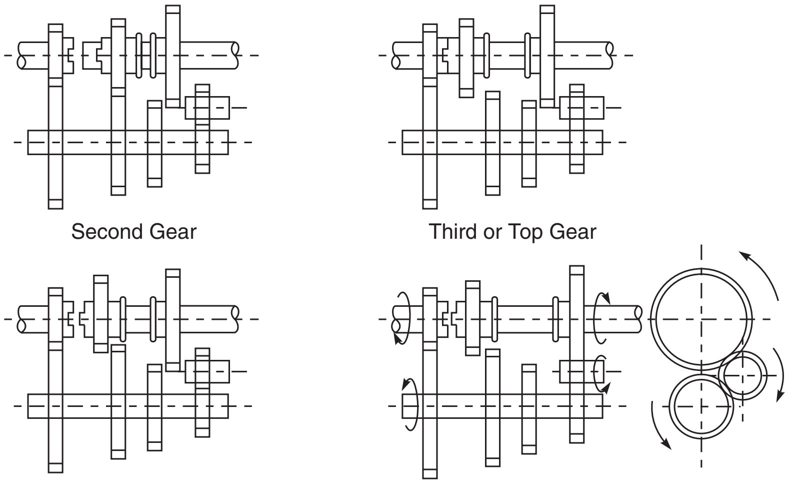



**Fig. 13.2** Different Positions of Gears for a Sliding Mesh Gearbox

## 2. Constant Mesh Gear Box

In the constant mesh gear box all the gears mesh with each other, all the time and this gives a silent or quiet operation. Gear changing is made easier by employing helical gears. The primary shaft which carries the clutch is splined and carries a gear that meshes with the largest layshaft gear.

The mainshaft has a number of gears that mesh with the gears on the layshaft. However, these gears being on bushes or ball/roller bearings are free to move on the mainshaft without transmitting any torque. All the gears on the layshaft are rigidly fixed with it.

When the left-hand dog clutch is made to slide to the left by means of the gearshift lever, it meshes with the clutch gear and the top speed gear is obtained (Fig. 13.3). When the dog clutch meshes with the second gear the second speed gear is obtained.

Similarly by sliding the right-hand dog clutch to the left and right, the first speed gear and reverse gear are obtained respectively. However, skillful handling is necessary on the part of the driver so that the speed of the locking dogs and respective pinion remain the same to effect a clash-free gear change.

## 3. Synchromesh Gear Box

Synchromesh gear boxes use synchronomesh gear devices which work on the principle that two gears to be engaged are first brought into frictional contact which equalises their speed after which they are engaged readily and smoothly. Two types of such devices are mostly used in vehicles, viz. pin type and synchronizer ring type. This gear box is similar to the constant mesh gear box and its main features are:

1. The mainshaft or output gears are free to rotate on bushes on the output shaft. The end of the mainshaft at the rear of the transmission is called the output shaft.
2. The output gears are locked to the shaft by the dog clutch of the synchronising hub when their speeds have been equalised by their cones.

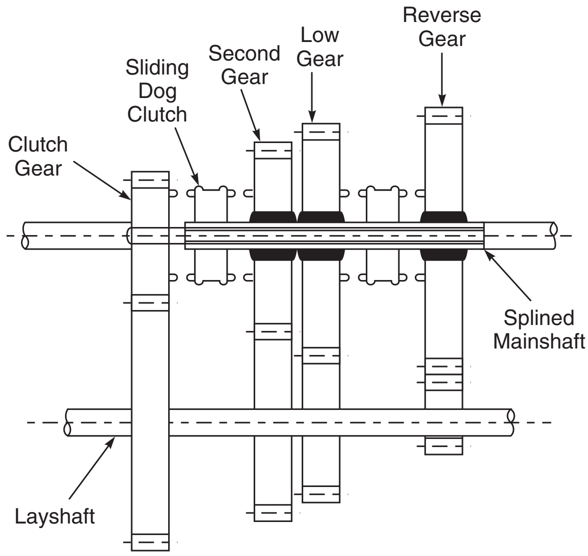



**Fig. 13.3** Constant Mesh Gear Box

## 13.3 THREE SPEED GEAR BOX

Figure 13.4 shows the layout of the box depicting the flow of power in the neutral position. The gears inside the box simply rotate without affecting the mainshaft. The power transmitted by the clutch rotates the main drive gear and countershaft drive gear as well as the second speed gears on the main and the countershafts being in constant mesh. Since the second speed gear on the mainshaft is loosely fitted, it does not drive the mainshaft. All the gears on the countershaft rotate without affecting the mainshaft.

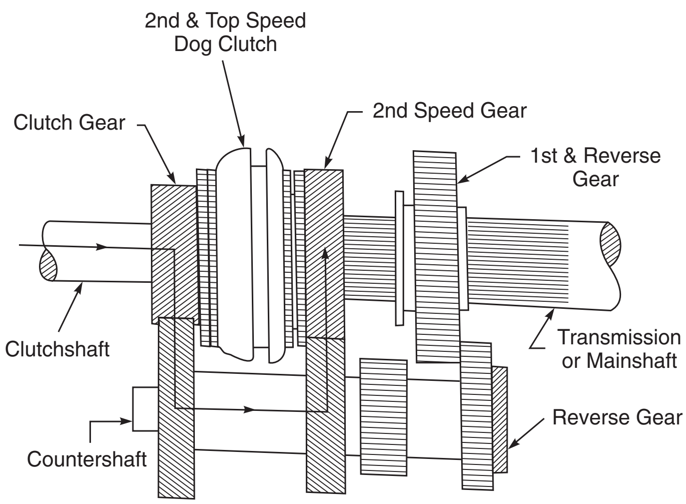



**Fig. 13.4** Layout of Three Speed Gear Box in Natural Position

The first gear portion is obtained by sliding the first and reverse gear to the left unit when its teeth mesh with that of the countershaft first gear. Drive is given to the countershaft from the clutch and the mainshaft is driven by the first gear. (See Fig. 13.5.)

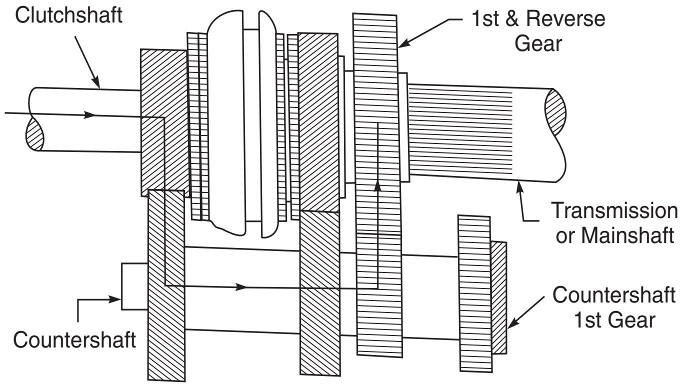



**Fig. 13.5** First Gear

For obtaining the second gear position (Fig. 13.6), the first gear is slided out of the mesh and then the dog clutch is moved to the right side making its internal teeth mesh with the external teeth of second speed gear. The dog clutch is splined with the mainshaft.

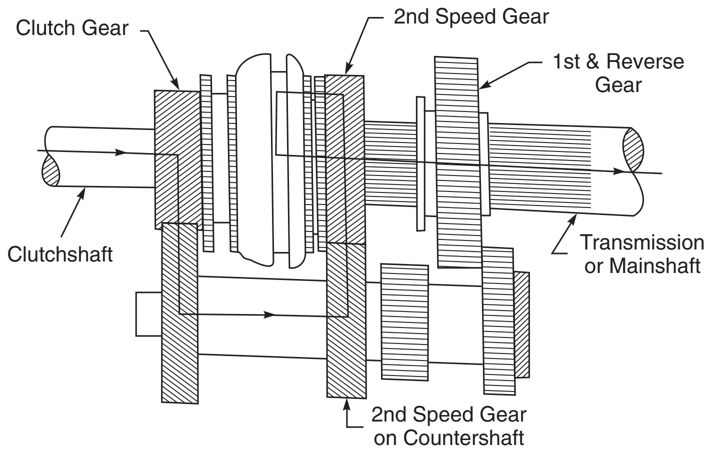



**Fig. 13.6** Second Gear

The third or top gear position is obtained by shifting the dog clutch to the left till its internal teeth mesh with the external teeth of the main drive gear. In this position the main shaft is locked with the clutchshaft making a direct drive (see Fig. 13.7).

Most of the cars today are equipped with four-speed gear boxes. Cars manufactured in our country have four forward and one reverse speed gear boxes. Commercial vehicles are invariably fitted with five speed gear boxes. Both gear boxes are discussed in Sections 13.9 and 13.10 respectively.

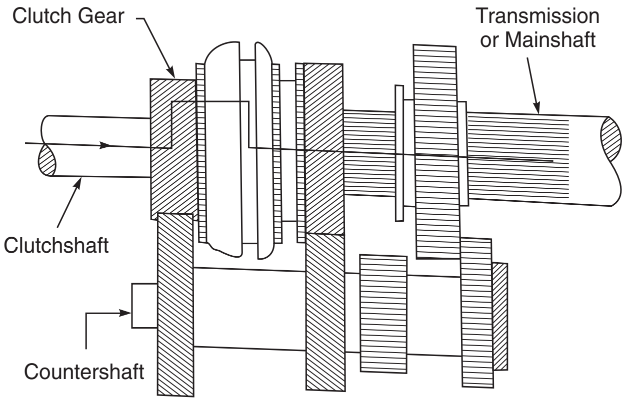



**Fig. 13.7** Third Gear

## 13.4 MERITS AND DEMERITS OF GEAR BOXES

The sliding mesh type gear box is still considered to be the simplest in design. Meshing of the gears takes place by the sliding of gears on each other, i.e. axially along the splined mainshaft to mesh with the corresponding gears on the layshaft.

Considerable skill is needed to make a gear change without damaging the gear teeth during meshing.

The constant mesh type marked a notable advance in gear box design by adopting a constant mesh of all the gears at all times. Further, the mainshaft gear is provided with dog clutches providing a means of locking the freely rotating mainshaft gears to the mainshaft for making an easier gear change.

There is considerable reduction of wear on the teeth of the reduction gears.

Skillful and timely hand and foot movements are required in order that the speed of the locking dogs and respective pinion are equal for a clash-free gear change. The driver has to match the speed of the gears to be engaged by double declutching.

The synchromesh gear box is considered the most advanced and has been adopted in most cars.

It enables rapid gear changes to be made without noisy engagement or clashing of teeth. It also simplifies shifting action for the driver as the synchronizer itself adjusts (i.e. either delays or accelerates) the members to be coupled so as to provide perfect dog teeth engagement. Thus matching of the gears is automatically done by the synchronizer resulting in smooth and silent coupling. It reduces the wearing of gear.

It has proved to be quite satisfactory for high speed cars.

## 13.5 GEAR SHIFTING MECHANISMS

The gear-shift lever, which is used for shifting the gears, is located either on the floorboard or on the steering column. The floorboard type is used in commercial vehicles, jeeps, vans etc. The steering column gear shift mechanism is used on all cars (except the earlier models prior to 1937, which also used floorboard type).

In order to make gear changing easier and select a particular gear train as well as bring it into operation, the gear shifting mechanism is used. It is also known as the *selector mechanism*. It consists of forks provided on the gear box to engage slots on the gear box. The tip of the gear lever is fitted into a slot in the top of the boss of the selector fork. The lever is given its free sideways movement either way in neutral position.

In case of steering column gear changes, the free movement is in up and down direction. The floorboard type of shifting mechanism is less costly as it requires less maintenance. The steering column type is easy to operate, the driver has to move his hand through a short distance and thus the front of the vehicle has more compartment space. However, it is difficult to learn to operate, has a complex mechanism, needs more maintenance and is costly to manufacture.

Figure 13.8 shows the steering column gear shift mechanism.

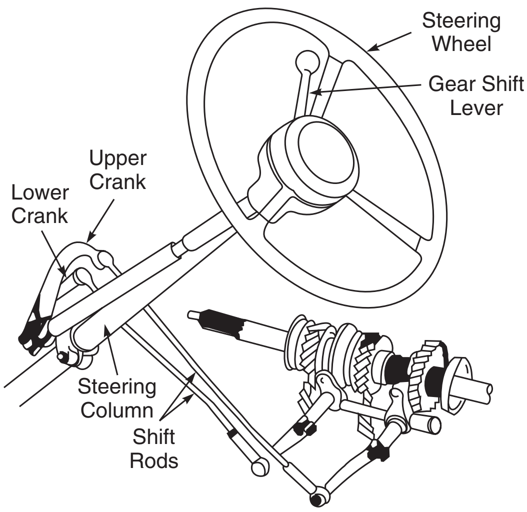



**Fig. 13.8** Steering Column Gear Shift Mechanism

Figure 13.9 shows the gear lever position for various speeds in case of a four-speed gear box for Ambassador car. It will be seen that the gear lever is moved axially upward and then moved radially forward or backward for obtaining the first or second gear. The gear lever is moved downwards from the neutral position and then moved radially forward or backward to obtain the

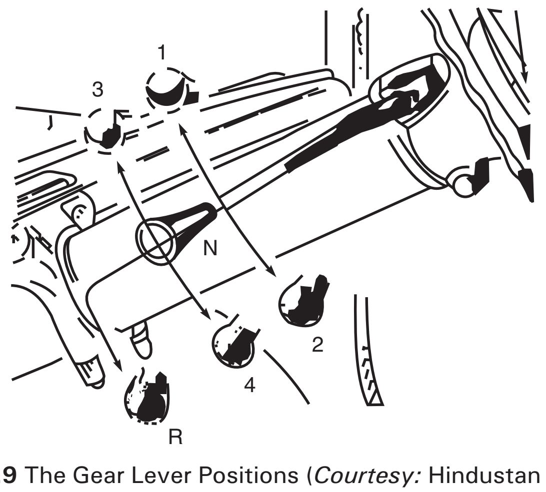



**Fig. 13.9** The Gear Lever Positions (*Courtesy:* Hindustan Motors)

third and fourth gear speed. To obtain reverse gear, the knob is moved outwards, the lever then pushed downwards in the neutral position to the extreme position. After this, the lever is moved backwards, thus engaging the reverse gear.

## 13.6 EPICYLIC GEAR BOX

The epicyclic gear box is also known as the sun and planet type gear box or the planetary gear box (Fig. 13.10). It uses no sliding dogs or gears to engage but different gear speeds are obtained by tightening the brake bands on the gear drums.

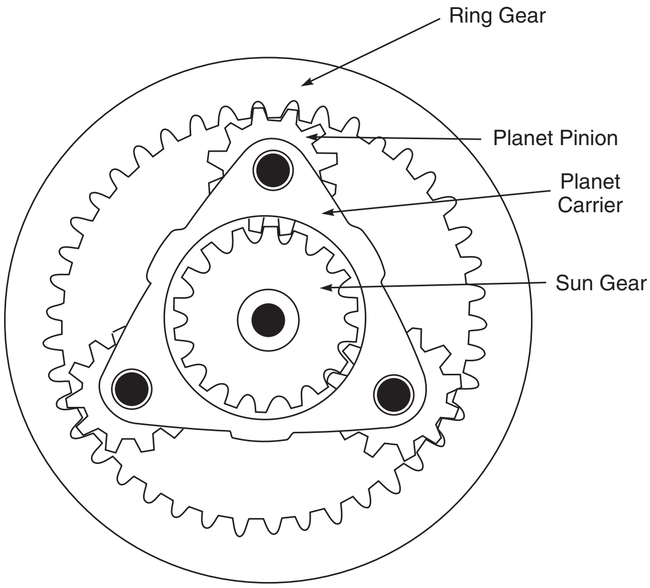



**Fig. 13.10** Planetary Gear Box

The sun gear which is at the centre remains in mesh with two or more planet wheels or pinions held together by a planet carrier. Surrounding the whole unit is a ring gear (also called annulus) whose inside teeth are also in mesh with the planets.

If any two members of the planetary system are locked up, the whole system (input and output) turns as a unit at a 1:1 ratio. Changes in gear ratio are made by holding one of the three components of the system and causing the others to rotate around it. A given epicyclic train can provide six ratios, depending upon which member is held stationary for reaction and which is used for input. Brake bands are used to hold the member.

## 13.7 GEAR REDUCTION

The gear reduction system reduces speed and increases torque by connecting the engine to the ring gear, holding the sun gear stationary and connecting the carrier to the rear wheels. Two possible speed reductions are:

(a) With the sun gear as the reaction member and the ring gear as the driving member, the ratio at the carrier which acts as the output member is $(R + S)/R$ where $R$ and $S$ are the number of teeth of the ring and sun gear.

(b) With the sun gear as the driving member and the ring as the reaction member, the gearing ratio at the carrier which acts as the output is (R+S)/S. The planet carrier rotates at a speed slower than that of the sun gear. Another two gear ratios are speed increasing ratios (overdrives) by driving firstly from the carrier to the sunwheel and secondly from the planet carrier to the ring gear. The rest of the two gear ratios are reversing ratios. One giving speed reduction by driving from the sunwheel to the ring gear and the other giving a speed increase by driving from the ring gear to the flywheel. Figure 13.12 shows the reverse position with the planet carrier held in from turning and the output taken from the ring gear.

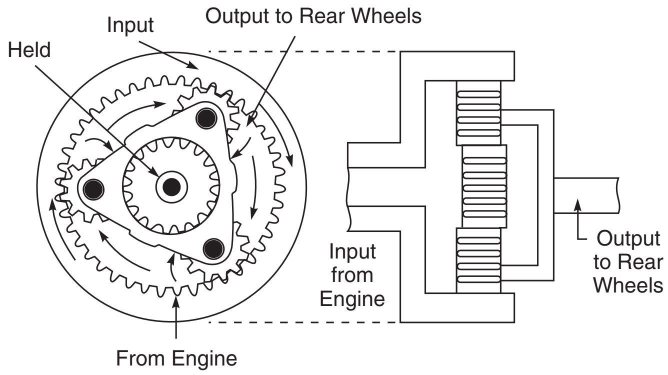



**Fig. 13.11** Planetary System in Reduction

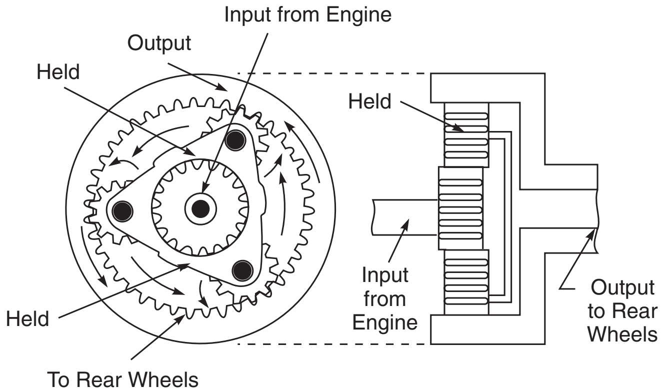



**Fig. 13.12** Planetary System in Reverse

Epicylic gear trains are popular for automatic transmission as the loads coming on gear teeth and bearings are much lower and consequently they are quieter in operation.

## 13.8 OVERDRIVE

The overdrive is a unit fitted behind the gear box to provide an extra gear (higher than top) which provides reduction in engine speed over the 1:1 ratio of fourth gear. In some cars the overdrive is also effective when the third gear is in use and thus adds to the driver's choice of gear ratios.

Most overdrives have an epicyclic gear arrangement that includes a hydraulically operated cone-clutch. When the driver selects the overdrive, the clutch locks to the outer casing and stops the sun wheel from turning. The planet carrier is then driven around the sun wheel and in turn drives the annulus (ring gear) at a slightly higher speed than itself.

Figure 13.13 shows the details of an overdrive unit.

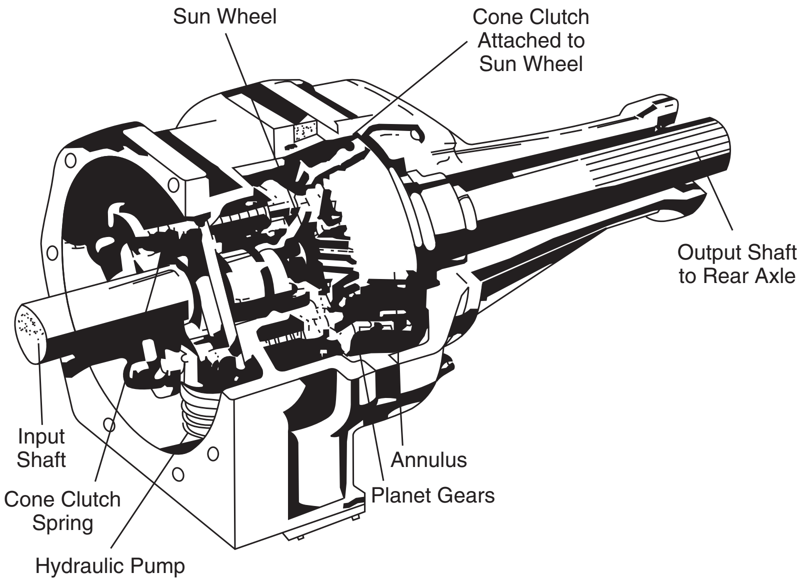



**Fig. 13.13** Overdrive Unit

The two main advantages of an overdrive are:

1. Engine life is prolonged as the engine turns slower for any given speed.
2. Fuel economy: When the engine turns slower it uses less fuel and the mileage is considerably increased.

Also most overdrives cut out automatically below a predetermined road speed.

Overdrives are controlled electrically or hydraulically by a dashboard or steering column switch.

## 13.9 MARUTI 800 GEAR BOX

The transmission system of Maruti 800 shown in Fig. 13.14 is fully synchronized and provides four forward speeds and one reverse speed by means of two synchronizers and two shafts the input shaft and the countershaft. The gears on both shafts (input and counter) are always meshed. The low speed synchronizer on the countershaft is engaged either with the low driven gear or second driven gear. The high speed synchronizer is engaged with either the third driven gear or top driven gear. The reverse idler gear is of clash-meshing type and is engaged with the low speed synchronizer sleeve on the countershaft and the reverse drive gear on the input shaft.

The transmission case is of two piece construction, consisting of an upper case and a lower case. The lower case has three fork shifting mechanisms built into it. The upper case houses the reverse shaft. Figure 13.15 shows the various components of a gear box.

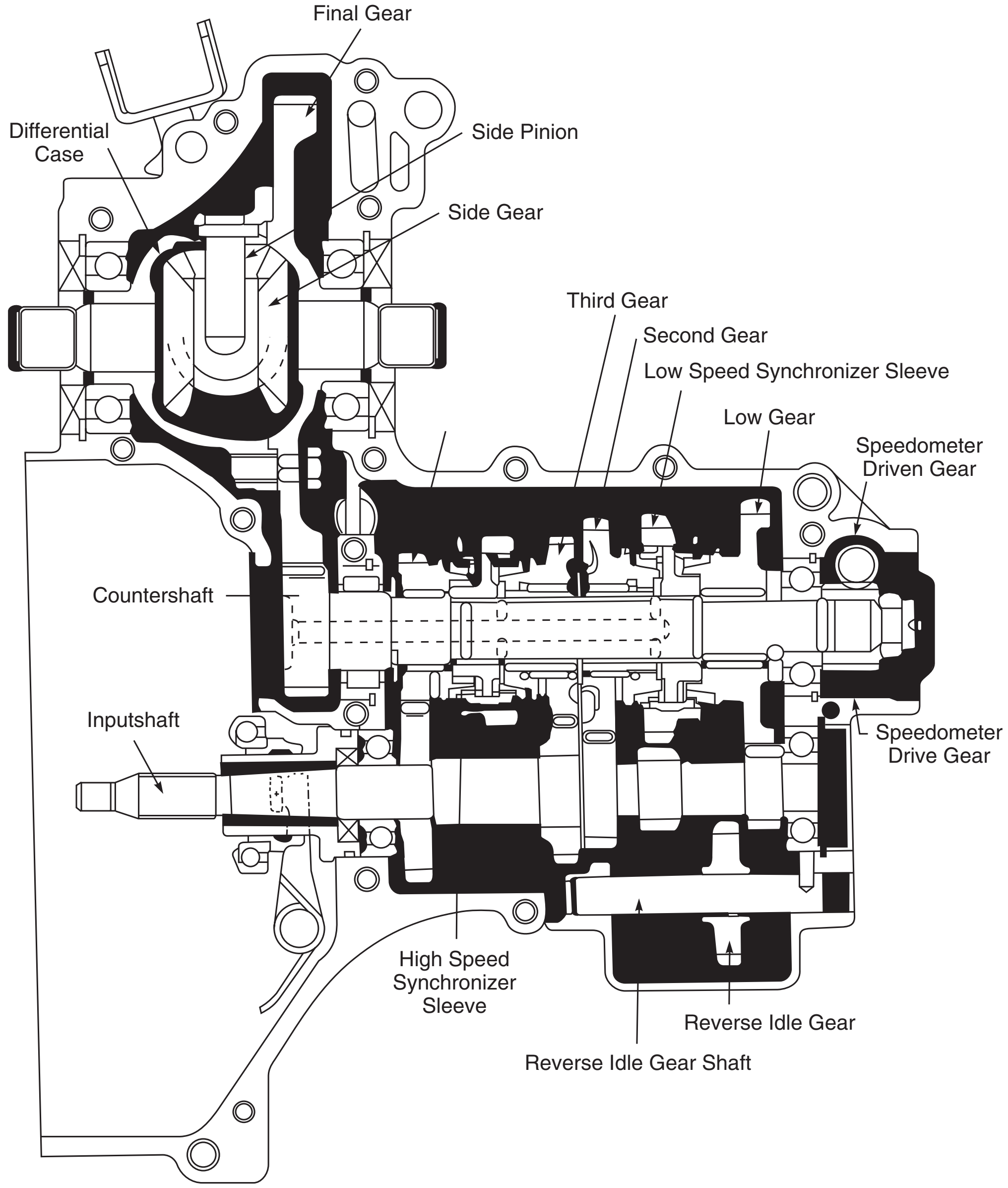
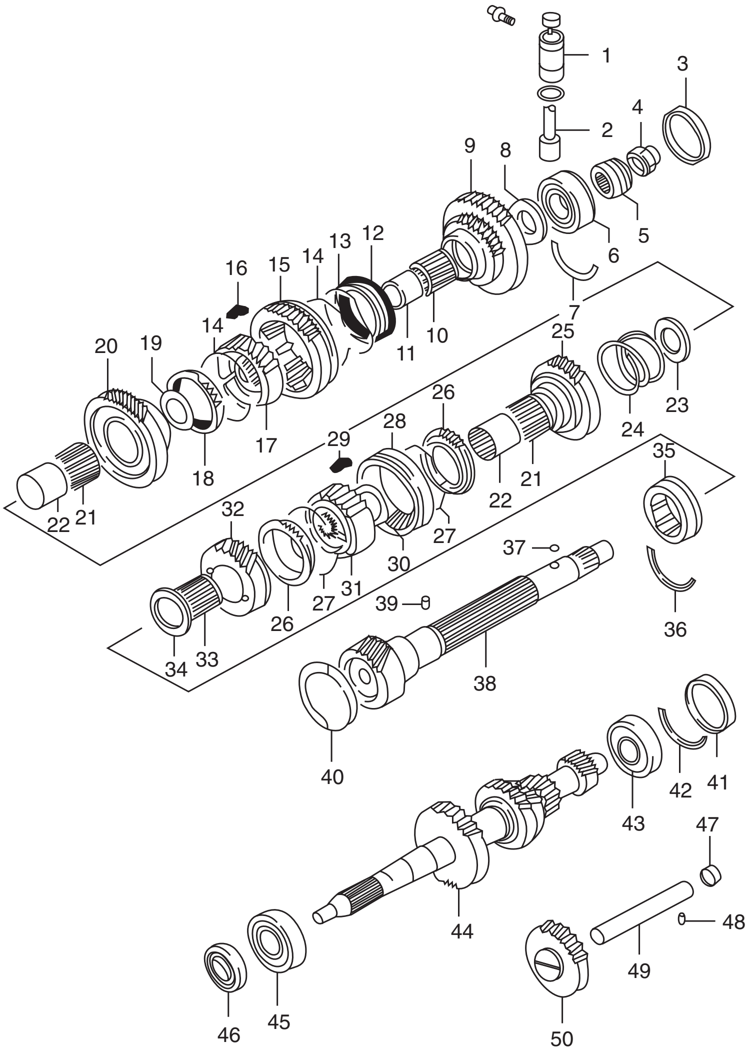



**Fig. 13.14** Transmission System (*Courtesy:* Maruti Udyog Ltd.)

### Flow of Drive through Transmission

In vehicles, transmission from engine to rear wheel flow through some forward and reverse gear which are explained as under.

**(1)** ***Low Speed Drive*** The low speed driven gear on the countershaft is free from this shaft and merely rotates around it, as driven from the low drive gear of the input shaft. Shifting the lever




| | | | |
|---|---|---|---|
| 1. Speedometer Driven Gear Case | 13. Synchronizer Ring Spring | 25. Third Gear | 38. Countershaft |
| 2. Speedometer Driven Gear | 14. Synchronizer Spring | 26. Synchronizer Ring | 39. Pin |
| 3. Countershaft Plug | 15. Low Speed Sleeve | 27. Synchronizer Spring | 40. Plug |
| 4. Nut | 16. Key | 28. High Speed Sleeve | 41. Plug |
| 5. Speedometer Drive Gear | 17. Low Speed Hub | 29. Key | 42. C Ring |
| 6. Bearing | 18. Synchronizer Ring | 30. Thrust Washer | 43. Bearing |
| 7. C Ring | 19. Thrust Washer | 31. High Speed Hub | 44. Inputshaft |
| 8. Thrust Washer | 20. Second Gear | 32. Top Gear | 45. Bearing |
| 9. Low Gear | 21. Needle Bearing | 33. Needle Bearing | 46. Oil Seal |
| 10. Needle Bearing | 22. Bush | 34. Thrust Washer | 47. Plug |
| 11. Bush | 23. Thrust Washer | 35. Bearing | 48. Pin |
| 12. Synchronizer Ring | 24. Spring | 36. C Ring | 49. Reverseshaft |
| | | 37. Steel Ball | 50. Reverse Idle Gear |

**Fig. 13.15** Various Components of a Gear Box (*Courtesy:* Maruti Udyog Ltd.)

into “low” causes the low-speed gear shifter fork to push the low-speed synchronizer towards the low driven gear and, through the dog teeth, mesh it with the gear, thus coupling the gear to the input shaft.

In this condition, the drive is transmitted through the low drive gear on the input shaft and the low driven gear on the countershaft to the final gear of the differential.

**(2)** ***Second Speed Drive*** Shifting the lever into “second” causes the same low-speed gear shifter fork to push the low-speed synchronizer in the other direction, that is towards the second driven gear and mesh it with this gear, thereby coupling the gear to the input shaft.

**(3)** ***Third Speed Drive*** Shifting the lever into “third” actuates the high-speed shifter fork to engage the high-speed synchronizer with the third driven gear on the countershaft. This gear, like the low and second driven gears, is free on the shaft and merely spins as driven by the third drive gear of the input shaft when the gearshift lever is in any other position.

In this condition, the drive is transmitted through the third drive gear on the input shaft and the third driven gear on the countershaft to the final gear of the differential.

**(4)** ***Top Speed Drive*** Shifting the lever into top causes the high-speed shifter fork, which is also used for the third speed, to mesh the top gear with the high speed synchronizer on the countershaft. In this condition, the drive is transmitted through the top drive gear on the input shaft and the top driven gear on the countershaft to the final gear of the differential.

***(5) Reverse Drive*** Shifting the lever into reverse causes the reverse gear shifter fork to mesh the reverse idle gear with the reverse gear on the input shaft and the low speed synchronizer sleeve on the countershaft. In this condition, the drive is transmitted through the reverse gear on the input shaft, reverse idle gear and low-speed synchronizer on the countershaft to the final gear of the differential.

Figure 13.16 shows the gear shift lever positions of the gear box used in Maruti 800 manufactured by M/s Maruti Udyog Ltd., in India. It will be seen that when the gear shift lever is in neutral position, the direct shift in either ‘top’ or ‘third’ is possible. If the gear shift lever is out of the above specified position, check the gear shift control shaft bushes for wear.

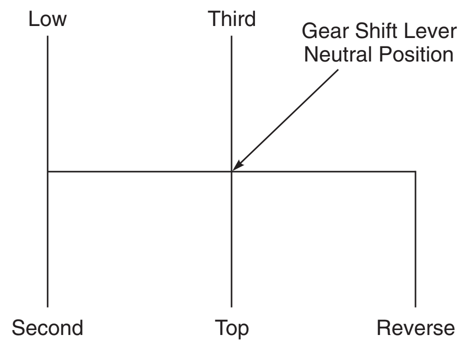



**Fig. 13.16** Gear Shift Lever Positions (*Courtesy:* Maruti Udyog)

If the bushes are free from wear and the gear shift lever is still out of position where it should be, check the low-speed select return spring or reverse select return spring, for deterioration, as shown in Fig. 13.17.

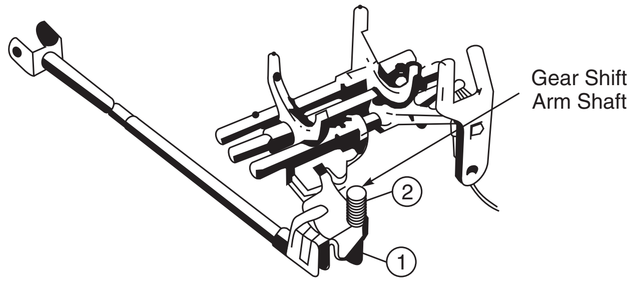



**Fig. 13.17** Checking of Gear Shift Control Shaft Bushes for Wear (*Courtesy:* Maruti Udyog Ltd.)

Figure 13.18 shows the exploded view of a gear shifting control system of a Maruti-800 car. The movement of the gear shift lever is transmitted by the control shaft to the transmission case, and the three fork shafts are actuated selectively to shift the gear.

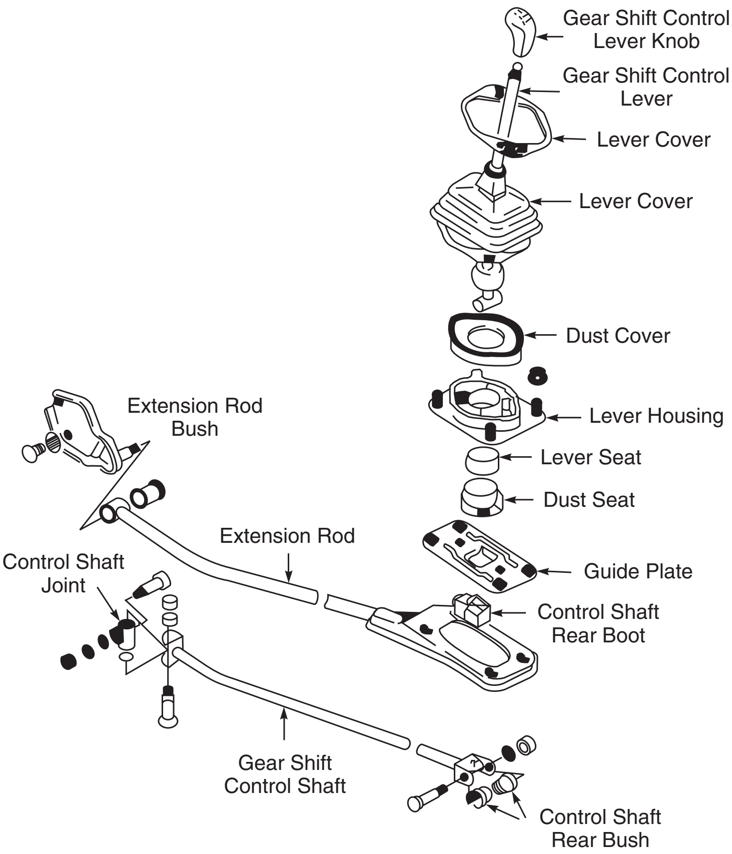



**Fig. 13.18** Exploded View of a Gear Shifting Control System of a Maruti 800 Car

## 13.10 FIVE-SPEED GEAR BOX

Figure 13.19 shows the sectional view of a GBC30 gear box assembly used in the commercial vehicle 1210 model of Tata manufactured in India by M/s. Tata Engineering and Locomotive

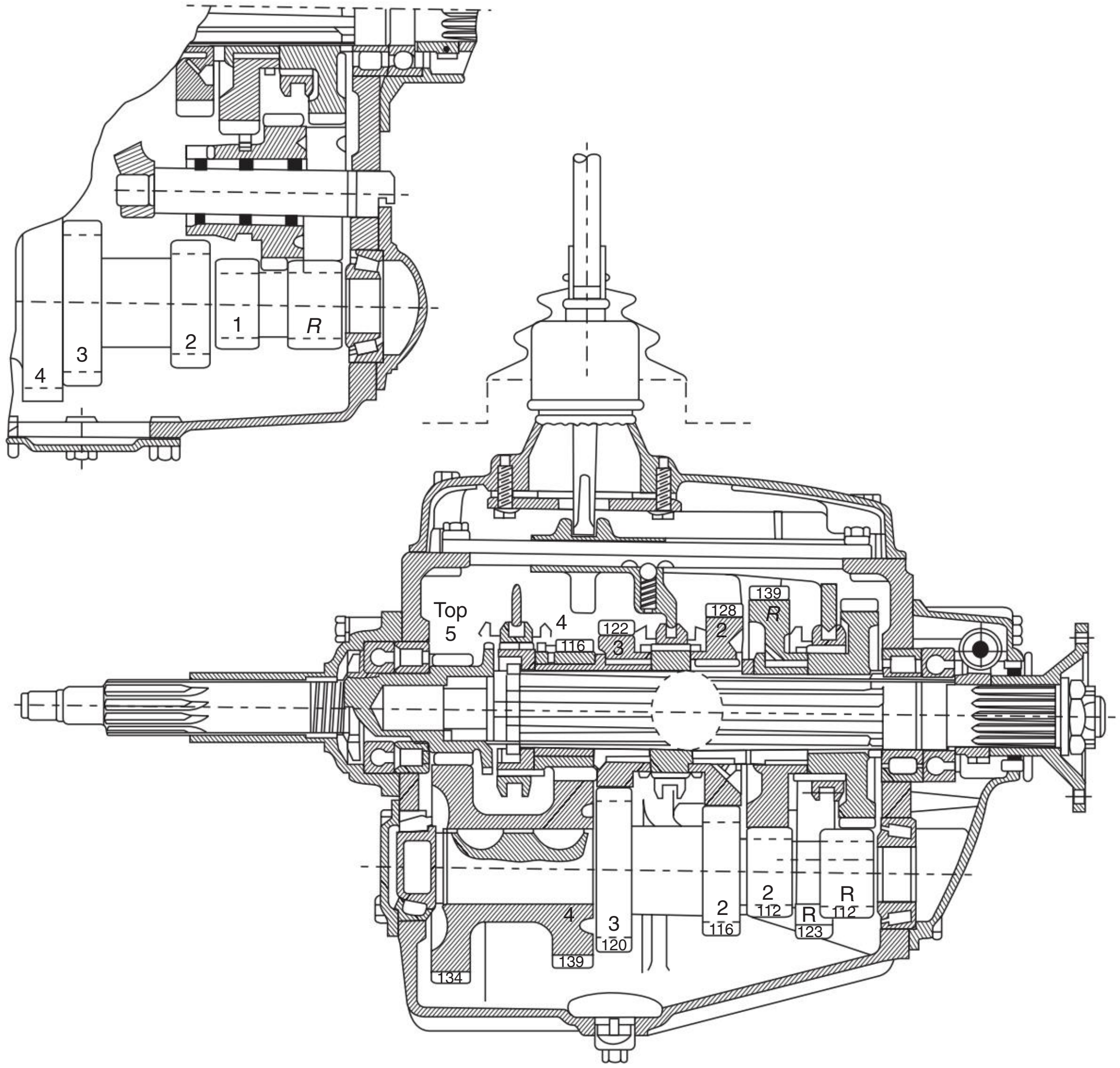



**Fig. 13.19** Section View of GBC 30 Gear Box Assembly (*Courtesy:* Telco)

Company Limited. It has five forward speeds and one reverse speed. The first, second, third and fourth gears are constant mesh, the fifth direct drive, and only the reverse is a sliding mesh.

The first and reverse gears on the countershaft, main shaft and reverse idler shaft are spur gears. The other gears on the countershaft, second, third and fourth speed gears on the main shaft and the drive shaft have helical teeth.

In the case of first, second, third and fourth gears, engagement is achieved by engaging the shifter sleeve in mesh with the engaging dogs of the helical gears on the main shaft. These four gears are normally free to rotate on the main shaft and are in constant mesh with the gears on the countershaft. These gears transmit power to the main shaft only when one of them is coupled to the engaging gear fixed on the main shaft by sliding the shifter sleeve on to the dog teeth of the concerned gear. The first, second and third speed gears on the main shaft are mounted on needle roller cages, whereas the fourth speed main shaft gear is directly mounted on the hub of engaging gear.

The gear engagements are effected by a gear shift lever which operates the shifter forks. The shifter forks move on the shifter shafts fixed to the gear housing. For the first to fourth speeds the shifter forks actuate the shifter sleeves into engagement with the dog teeth of the relevant gear, whereas for the reverse speed the shifter fork slides the reverse idler gear into engagement with the main shaft reverse gear. In neutral, the reverse idler gear is already in mesh with the counter-shaft reverse pinion. For the fifth gear the shifter sleeve directly couples the drive shaft with the main shaft. Out of the four gear shifter fork shafts, the one on the extreme right seen in the driving direction is for the reverse speed, and the others are in the following order: 1st, 2nd/3rd and 4th/5th.

The shifter forks are prevented from slipping out of their engaged or neutral position by means of a spring loaded ball sitting in the shifter shaft grooves.

On the rear end of the reverse shifter shaft a spacer is provided to arrest further movement of the reverse fork beyond that required for engagement.

The movements of the gear shift lever as marked on the knob are controlled by the slots in the guide plate. The shift lever also carries with it the interlocking plate having lugs which also slide in the slots of the guide plate. These lugs prevent simultaneous engagement of two gears at a time. The gear shift lever cannot be disengaged out of the reverse gear without a sidewise movement as indicated on the knob (Fig. 13.20).

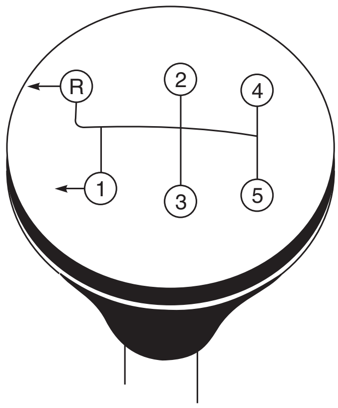



**Fig. 13.20** Gear Shift Lever Position (*Courtesy:* Telco)

The gearbox is fitted with a magnetic drain plug. Remove the chips collected around the magnet while changing the gear box oil.

The types of gear boxes used in some Indian vehicles is given in Table 13.1.

**Table 13.1** Gear Boxes Used in Some Indian Automobiles

| *S. No.* | *Make of Vehicle* | *Type of Gear Box* | *Gear Ratios* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | *I* | *II* | *III* | *IV* | *Top* | *Reverse* |
| 1 | Ashok Leyland Comet Passenger | Five speed and reverse | 698.8 : 1 | 4.308:1 | 2.655:1 | 1.605:1 | 1:1 | 6.343:1 |
| 2 | Tata mercedes Benz model 1210 | Five speed and reverse | | | | | | |
| | | (a) Synchromesh type | 8.82:1 | 4.785:1 | 2.736:1 | 1.663:1 | 1:1 | 8.29:1 |
| | | (b) Standard type | 7.37:1 | 4.23:1 | 2.49:1 | 1.56:1 | 1:1 | 7.15:1 |
| 3 | Dodge/Fargo | Four speed and reverse synchromesh for second, third and top. | 6.40:1 | 3.09:1 | 1.69:1 | – | 1:1 | 7.61:1 |
| 4 | Hindustan Ambassador mark II, III | Four speed and reverse synchromesh for second, third and top. | 3.807:1 | 2.253:1 | 1.506:1 | – | 1:1 | 3.807:1 |
| 5 | Fiat 1100, Premier, President and Padmini. | Four speed and reverse synchromesh for second, third and top. | 3.86:1 | 2.38:1 | 1.57:1 | – | 1:1 | 3.86:1 |
| 6 | Jeep CJ-3B | Three speed and reverse synchromesh for second and top. | 2.798:1 | 1.551:1 | – | – | 1:1 | 3.798:1 |
| 7 | Maruti 800 | Four forward all synchromesh and one reverse. | 3.585:1 | 2.166:1 | 1.333:1 | – | 0.999:1 | 3.365:1 |
| 8 | Maruti Gypsy | Four forword all synchromesh and one reverse. | 3.136:1 | 1.946:1 | 1.422:1 | – | 1.000:1 | 3.463:1 |
| 9 | Fiat Uno | Five speed all synchromesh with overdrive on five and one reverse. | 3.909:1 | 2.238:1 | 1.280:1 | 1.029:1 | 0.838:1 | – |
| 10 | Telco Indica (Petrol) | Five speed all synchromesh with overdrive on five and one reverse. | 3.420:1 | 1.950:1 | 1.360:1 | 0.950:1 | – | – |
| 11 | Hyundai Santro | Five speed all synchromesh overdrive on $4^{th}$ and $5^{th}$ and one reverse. | 3.833:1 | 2.105:1 | 1.310:1 | 0.919:1 | 0.784:1 | – |
| 12 | Daewoo Matiz | Five speed all synchromesh and one reverse. | 3.818:1 | 2.210:1 | 1.423:1 | 1.029:1 | 0.837:1 | – |
| 13 | Maruti Zen | Five speed all synchromesh and one reverse. | 3.416:1 | 1.894:1 | 1.280:1 | 0.914:1 | 0.757:1 | – |

**Table 13.2** Troubleshooting of Gear Box

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Hard shifting | (a) Defective clutch | Check and adjust clutch. |
| | (b) Defective clutch linkage or shifting linkage | Check and adjust pedal and/or shift linkage. |
| | (c) Insufficient lubricant or improper grade or quality | Fill to proper level with recommended oil for conditions. |
| | (d) Defective synchromesh | Repair or replace. |
| | (e) Worn or warped shaft rails | Replace. |
| | (f) Burred main shaft sliding gear splines | Remove burrs or replace. |
| | (g) Sliding gear tight on splines | Check and remove burr or replace. |
| | (h) Insufficient chamfer on gear teeth, or teeth are burred | Replace. |
| 2. Sticking of gear | (a) Defective clutch disengagement | Check and adjust clutch. |
| | (b) Insufficient disengagement of clutch shift linkage play | Check and adjust pedal and/or shift linkage. |
| 3. Repeated gear failure | (a) Improper driving habits | Driver training should stress on proper declutching and avoid clutch pedal riding to use the various available gear ratios. |
| | (b) Defective clutch | Check or overall and adjust the clutch. |
| | (c) Defective clutch linkage or shift linkage | Check and adjust pedal and/or shift linkage. |
| | (d) Insufficient lubricant or improper grade or quality | Fill to proper level with recommended grade oil. |
| 4. Noise in gear | (a) Worn gear, bearings or shafts | Replace. |
| | (b) Insufficient lubricant or improper quality or grade | Fill to proper level with recommended grade of oil. |

## Review Questions

1. Why is the gear box necessary in an automobile? Explain clearly.
2. List different types of gear boxes.
3. Explain the working of a three-speed sliding mesh gear box with the help of a diagram.
4. Describe the working of a synchromesh type of gear box.
5. Differentiate between three-speed and four-speed gear boxes. Where are these used?
6. State the merits and demerits of constant mesh type gear box.
7. What is an epicyclic gear box?
8. Describe the operation of planetary gears when the system is in speed reduction.
9. Describe the operation of planetary gears when the system is in reverse.
10. What is an overdrive unit? Mention its advantages.
11. Explain the working of a Maruti 800 car transmission System.
12. Explain the working of five-speed gear box.
13. Why do heavy duty vehicles (buses and trucks) need more than three forward speeds?
14. What are gear box troubles and their causes?

# 14

# Propeller Shaft and Universal Joint

## Objectives

After studying this chapter, you should be able to:

- Describe the drive mechanism from gearbox to final drive in cars.
- Describe the constructional features of a propeller shaft.
- Identify the types of drive shaft in general use.
- Explain the purpose and operation of the universal joint.
- Identify the types of universal joints used in automobiles.
- Describe the purpose of centre bearing in propellers shaft drive.
- Describe how to service propeller shaft.
- Explain how to check a drive assembly.

## 14.1 INTRODUCTION

The earliest cars were an improvement over horse-driven carriages. They also had a feature derived from early bicycles and tricycles and that was the method of power transmission. For a number of years the earlier cars had chain drive for power transmission from the engine to the wheels. Although heavy, cumbersome, noisy and in need of continuous maintenance, it was used due to its reliability.

Although the Lanchester Brothers of Britain patented the propeller shaft transmission in 1887, Louis Renault of France perfected the use of this pioneer system in power transmission from the engine to rear axle in 1899. He not only used a shaft to transmit the drive from the engine to rear wheels, but also incorporated universal joints in it to allow for the movement of the rear suspension. He did this because he was using a live rear axle which he had already patented. It was adopted by small cars fairly quickly. However, larger models of cars started using it after sometime.

The Lanchester-Renault system of propeller shaft, universal joints and live rear axle is almost universally being used in cars and trucks albeit with some modifications to this day.

## 14.2 DRIVE MECHANISM FROM GEAR BOX TO FINAL DRIVE IN CARS

In conventional cars and trucks, except in cars with front wheel drives or in rear engine cars, the drive mechanism consists of a propeller shaft having universal joints at its two ends connecting the transmission output shaft of the gear box on one end and the differential input pinion at the other.

The propeller shaft, as the name suggests propels the vehicle. It is also sometimes called the drive shaft. It has to perform two important operations:

1. It has to receive the power from the gear box output shaft and without any change in speed transmit it to the input pinion of the differential for onward transmission to the rear axle and rear wheels.
2. It has to cope with the difference in line and level of the gear box output shaft and the differential input pinion shaft.

While the first function is simple since the propeller shaft is designed to bear the power and transmit it, it is the second function which is responsible for the constructional features of the propeller shaft.

While transmitting the power in accordance with the second requirement, two changes are taking place, since the rear axle moves up and down with reference to the gear box block. This is due to road irregularities.

1. The angle between the axis of the gear box output shaft and the propeller shaft axis changes continuously. Exactly in a similar manner, the angle between the propeller shaft axis and the differential input pinion axis changes.
2. To take care of these angle changes, Hooke's joints or universal joints/couplings as they are called, are fitted on both ends of the propeller shaft.
3. The effective length of the propeller axis changes. This happens since the horizontal distance between the gear box and the rear axle remains constant, while the propeller axis angular position changes.
4. For taking care of this the propeller shaft has splined ends on which the universal joints are fitted. This allows movement of the universal joints along the axis of the propeller shaft changing the effective length of the propeller shaft (Figs 14.1 and 14.2).

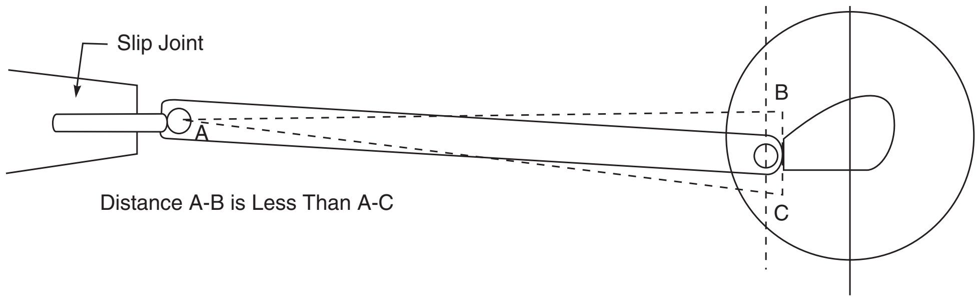



**Fig. 14.1** Changes in Propeller Shaft Length as the Rear Axle Moves up and Down

## 14.3 PROPELLER SHAFT (CONSTRUCTIONAL FEATURES)

Propeller shafts have to bear the driving and braking torques. When a front engine rear drive car starts from rest or is suddenly braked to slow down, the shock to the transmission is cushioned by the long propeller shaft which twists slightly and then untwists.

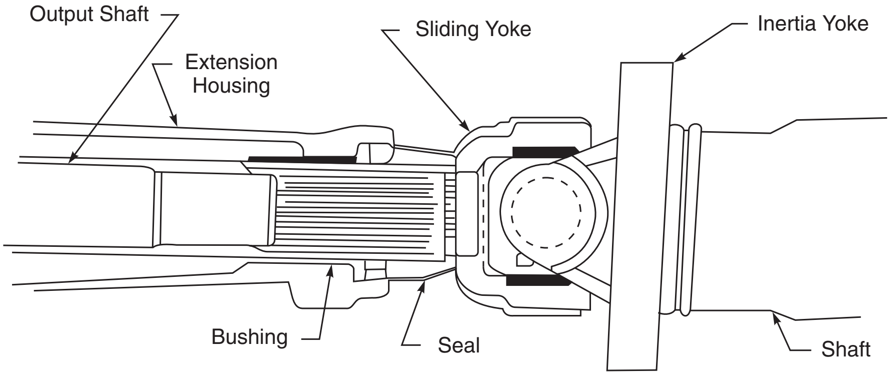



**Fig. 14.2** Slip Joint on the Transmission Output Shaft

Two types of construction have taken care of these forces:

## 1. Torque Tube Type Propeller Shaft

A torque tube is a large diameter tube fastened securely to the rear axle housing and completely enclosing the propeller shaft. The torque tube is fitted into a spherical ball and socket surrounding one universal joint at the transmission end. These two units carry their respective loads while allowing suspension flexibility. Thus while normal engine power transmission takes place through the propeller shaft, the braking and acceleration causing sudden torque are borne by the torque tube (Fig. 14.3).

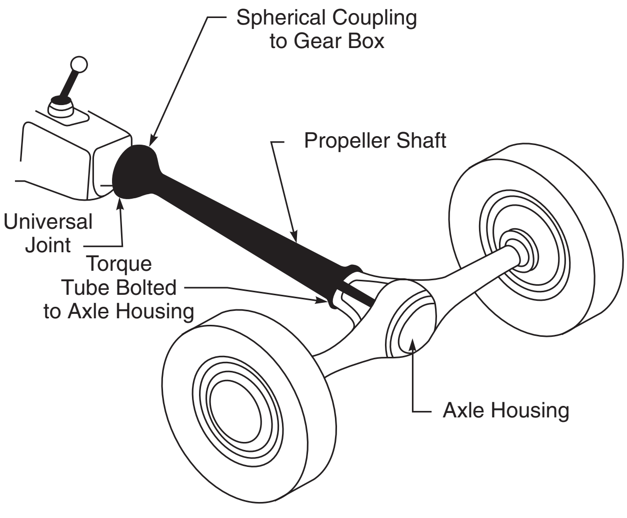



**Fig. 14.3** Torque Tube Type Propeller Shaft

This type of construction has been replaced in modern vehicles by the Hotchkiss drive.

## 2. Hotchkiss Type Propeller Shaft

In the Hotchkiss type, the driving and braking torques are absorbed through the front half of the rear leaf springs or through the links and arms when used with coil type springs. Thus while normal power is transmitted through the propeller shaft, acceleration and braking shocks are taken up by the leaf spring (by distortion) or by special links/frames in case of leaf springs (Fig. 14.4).

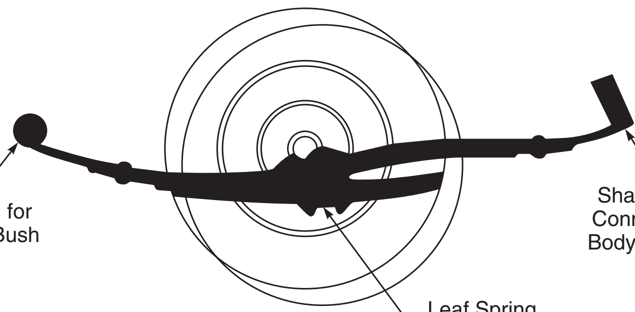



**Fig. 14.4** Hotchkiss Type Propeller Shaft

## 14.4 SHAFT

The propeller shaft is essentially a steel tube having forged steel universal joints at each end. Its only function is to deliver the transmission output torque to the differential input pinion. The shaft tube must be strong enough to transmit the power. However, oversize design is avoided since it increases the chances of imbalance, it is harder to straighten, tends to fan more air that may cause noise, requires more room under the pan and is more expensive (Fig. 14.5).

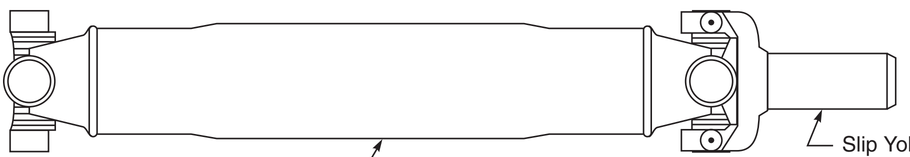



**Fig. 14.5** Propeller Shaft

The propeller shaft is so designed as to have its natural frequency or critical speed quite high, more than the normal running speed range. Since the natural frequency is proportional to its diameter and inversely proportional to the square of the length, the design necessitates a shorter and larger diameter shaft.

Imbalance in propeller shaft usually results in whirl which in action is similar to that of a rope being swung around in an arc while holding both ends. For this the shaft tubing is usually rolled from flat sheet stock, straightened within 0.010 in., and runout and balanced within 1/4 ounce inches. This keeps the centre of mass very nearly on the longitudinal axis centre to minimise whirl.

## 14.5 UNIVERSAL JOINTS

When power is being transmitted from one shaft to the other while the shaft axes are not co-linear but are intersecting, the coupling used is the universal joint. It takes care of the angularity of the two axes. However, while the power is transmitted the shaft speed of the driven shaft continuously varies even when the driving shaft is rotating at constant speed. This constructional feature requires

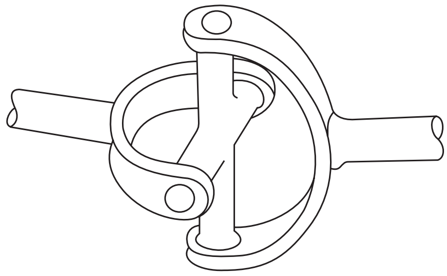


**Fig. 14.6** Simple Universal Joint

a pair of universal joints and an intermediate shaft (propeller shaft in this case), while the driver shaft (gear box output shaft) and the finally driven shaft (differential pinion shaft) are more or less parallel. In such a case, the angle between the gear box output shaft and propeller shaft and that between the propeller shaft and differential input shaft are equal to each other. Thus the speed variation between the gear box shaft and propeller shaft is corrected at the other end and the speed of the differential input shaft remains equal to the gear box shaft. The double universal joints thus do away with the variations in the propeller shaft speed. Figure 14.6 shows the simple universal joint.

Several types of universal joints are used in automobiles. Some of these joints are described in the following sections.

### 1. Hooke Universal Joint

Also known as the *cross and yoke type joint* or the *cardan universal joint*, the Hooke joint is the most commonly used with the Hotchkiss drive. It consists of two yokes pivoted on a central cross piece or "spider", formed by two pins intersecting at right angles.

The yokes, one on the input shaft and the other on the output shaft, are connected to the spider so that they are at right angles to each other. This kind of joint allows the shafts to rotate together, even when their axes do not form a straight line. Friction between the yoke and the spider is reduced by bearing caps containing needle roller bearings. These caps fit over the arms of the spider and are held in the yokes by circlips sprung into grooves (Fig. 14.7).

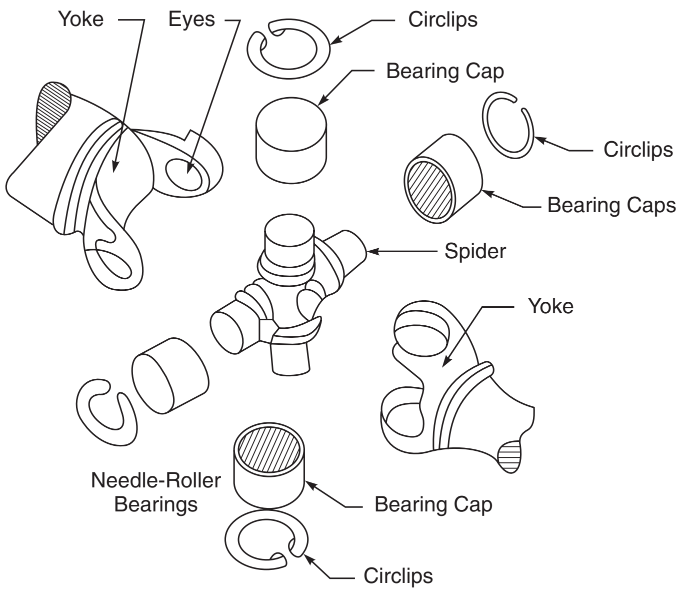



**Fig. 14.7** Hooke Universal Joint

In the latest versions of this type of universal joint, the bearing caps are packed with grease by the manufacturer and do not need periodic lubrication.

### 2. Double Cardan Universal Joint

The double cardan universal joint consists of two closely spaced cross and yoke joints with a special link yoke. The two joints work to reverse the non-uniform action and thus provide constant velocity. Yoke centres are maintained by a ball and socket centering device so that the joint working angle is the same in each joint half. This then forms a constant velocity joint.

The output velocity is uniform when the input velocity is uniform even though the joint centre link has the typical velocity increase and decrease action (Fig.14.8).

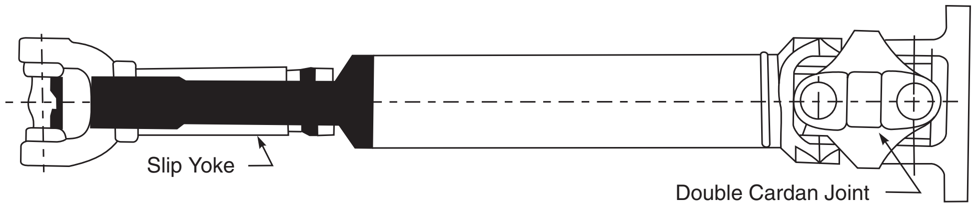



**Fig. 14.8** Double Cardan Universal Joint

Such constant velocity joints are more expensive but they produce minimum noise and vibration. These premium qualities are demanded by the buyers of luxury cars, even at extra cost.

### 3. Bendix-Weiss Universal Joint

The Bendix-Weiss universal joint is a constant velocity joint which also acts as a slip joint. It consist of two spiders, each having three or four arms. Each spider arm is located between the adjacent arms of the second spider. The motion of one set of spider arms is transferred to the other spider arms by steel balls wedged in grooves that are cut at an angle so that the balls always operate in a plane that bisects the joint's operating angle. Thus it operates as a constant velocity joint.

Bendix-Weiss joints are usually used on front wheel drive vehicles, where steering is another universal joint requirement.

### 4. Ball and Trunion Joint

The ball and trunion joint acts both as a universal joint and a slip joint. It allows axial movement within the joint, so no separate joint is necessary. The balls are mounted on a spider through needle bearings. Each ball fits into a partly cylindrical housing bore that runs in the axial direction. This provides a means to drive through the joint in a radial direction and allows slip in the axial direction.

Later developments in this type are a two ball and trunion joint and three ball and trunion joint. In the latter, the use of three equally spaced balls causes the joint to transfer constant velocity motion to the output shaft. This type of joint is ideal for the inside joint on front wheel drive vehicles because it eliminates the slip joint and transfers constant velocity motion.

## 14.6 CENTRE BEARING IN PROPELLER SHAFT DRIVE

As mentioned earlier, when the shafts are designed, it is checked that the natural frequency of the propeller shaft does not match its frequency at any speed. Critical propeller shaft speed varies as the diameter of the tube changes and inversely as the square of the length. Diameters are as large as possible and shafts are as short as possible to keep the critical speed frequency above the driving range.

Propeller shaft lengths over 60 in. between universal joints become a source of balancing problems. Shaft lengths are minimised by using long transmission extension housing and centre universal joints with two piece propeller shafts. When used the centre universal joint is supported by a centre support bearing that must be insulated from the vehicle chassis.

## 14.7 PROPELLER SHAFT PROBLEMS

Usually the problems that arise in propeller shafts are noise and vibrations which are the result of incorrect universal joint angles, unbalanced parts or loose or worn parts. They may also arise due to damaged propeller shaft tubes or material such as under coating sticking to the tube to cause unbalance.

***Checks*** The following checks should be made after a thorough visual inspection. Such an inspection gives many clues like damages to the shaft tube, loose joints etc.

1. Check the universal joint angles.
2. Check the propeller shaft runout.
   – Runout near the joint should be less than 0.01 in.
   – Runout in the centre of the shaft should be less than 0.015 in.
   – A bent propeller shaft results due to accident which should be replaced.

Check the shaft for unbalance. It may be done in a garage.

3. Check looseness of all joints/parts.
4. Check every 6000 miles that the four bolts holding the propeller shaft to the rear axle are tight.

***Servicing*** The propeller shaft and universal joint servicing should be done periodically. Proper cleaning and greasing of joints should be done carefully. In case the universal joints are fitted with grease nipples, grease them every 3000 miles.

**Table 14.1** Troubleshooting of a Propeller Shaft

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Vibration and noise | (a) Broken or worn bearing of universal joint spider | Replace. |
| | (b) Distorted propeller shaft | Replace. |
| | (c) Unbalanced propeller shaft | Replace. |
| | (d) Loose propeller shaft | Retighten. |
| 2. Noise occurring at standing, start or during coasting | (a) Worn or damaged universal joint | Replace. |
| | (b) Worn propeller shaft splines, due to lack of lubrication | Replace. |
| | (c) Loose propeller shaft | Retighten. |
| | (d) Loose flanged yoke of universal joint | Retighten. |

## Review Questions

1. What determines the minimum and maximum sizes of a propeller shaft?
2. What means are used to shorten the required propeller shaft length?
3. State the purpose of front and rear universal joints.
4. Name different types of universal joints in use. Which is the most popular?
5. Describe the following briefly:
   (a) Hooke universal joint
   (b) Double cardan universal joint
   (c) Bendix-Weiss universal joint
   (d) Ball and trunion universal joint.
6. What are the reasons for using a universal joint?
7. Why is a slip joint necessary with a propeller shaft transmission?
8. What are the problems in a propeller shaft? What is their effect on running?
9. What are the checks necessary in a propeller shaft servicing?
10. What problem symptoms are noticed during visual inspection?

# 15

# Rear Axle Assembly

## Objectives

After studying this chapter, you should be able to:

- List different types of rear axles.
- Explain the requirements of a final drive.
- Describe the purpose and operation of final drive.
- Identify the types of final drives used in automobiles.
- State the advantages of double reduction drive over single reduction drive.
- Describe the functions and operation of a differential.
- Identify the types of axle housings in general use.

## 15.1 INTRODUCTION

Rear axles form the last of the links in the power transmission chain. Power generated in the engine passes onto the gear box through a clutch. From the gear box it goes to the propeller shaft through universal joints and from the propeller shaft it goes to the rear axle to be ultimately delivered to the road wheels. Of course this statement applies to the vehicles which have rear wheel drives. As of today, all other vehicles except Maruti have rear wheel drive. The Maruti has front wheel drive.

There are three types of rear axles:

1. Live axle
2. Dead axle
3. Axleless transmission.

### 1. Live Axle

Live axle is one that either rotates or houses shafts that rotate, while a dead axle is one that does neither, but simply carries at its ends the stub axles on which the wheels rotate.

Live axles perform two functions:

(i) To act as a beam which, through the medium of the springs, carries the loads due to the weight of the carriage unit and its contents, and transmits these loads under dynamic conditions through the road wheels rotating on its ends to the ground. The dynamic loading is principally a result of the motions of the wheel and axle assembly over the ground and the reaction due to its mass, the flexibilities of the tyres and road springs and the mass of the carriage unit and its contents.

(ii) To house and support the final drive, differential and shafts to the road wheels, and to react the torques in both the input and output shafts. Most live axles are, therefore, of hollow construction and usually, though not necessarily, are of circular cross-section out board of the final drive unit.

## 2. Dead Axle

Normally all axles that do not transmit power like the front axle in a rear wheel drive are dead axles. In such a case even the presence of an axle is not necessary and the stub axles can be mounted on the independent suspension units as in the case of Premier or Ambassador cars.

However, in case of vehicles where the power transmission is through the rear axle, dead axles can be used for the rear axles, although such cases are less.

In case of dead axles for the rear axles, power transmission by chain is used by both the wheels separately from the output shafts of a differential mounted ahead of the rear axle.

An advantage of the dead axle arrangement is a considerable reduction in unsprung weight which improves both side and road holding. Incidentally, the suggestion that a rigid axle always holds its wheels perpendicular to the road is incorrect since a bump under one wheel tilts both the wheels equally relative to the road.

Another advantage of the dead axle arrangement is that the wheels remain in a fixed relationship to each other, either parallel or with a slight inward inclination towards the top, to resist rear-end drift when the vehicle is acted upon by centrifugal force while cornering.

One disadvantage is the shortness of the drive shafts and consequently large angles through which they move, which entails the use of fairly costly universal joints.

Another disadvantage is the fact that when one wheel alone rises, the contact points between the two tyres and the road move sideways, which momentarily produces a slight, but marked rear-end steering effect and therefore adversely affects stability and handling.

## 3. Axleless Transmission

Axleless transmission is one where the two wheels are mounted on two separate stub axles without having any axle joining the two wheels. For example, cars like Padmini and Ambassador having independent front suspension have axleless transmission in the front wheels.

Axleless power transmission, uses a differential mounted in the centre of the vehicle and then power is transmitted through the short propeller shafts with universal joints at the differential end and wheel ends. As mentioned in the preceeding paragraph, such arrangements are used with independent suspension. One such arrangement is shown in Fig. 15.1.

In these cases although the engine, clutch and gear box unit and the separate final drive unit are all carried on the frame or basic structure of the vehicle, universal or flexible joints are still used at the end of the propeller shaft to accommodate the slight differential movement that can occur between these two units because of deflections of both their flexible mounting and the structure of the vehicle. The forces on the mountings for the final drive unit are by far the largest problem owing mainly to reaction from the final drive torque.

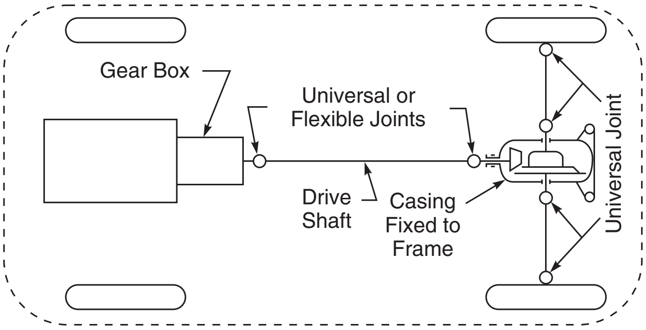



**Fig. 15.1** Arrangement of Power Transmission (Front Engine Rear Drive)

## 15.2 PURPOSE OF THE FINAL DRIVE

As the power generated in the engine of a car moves to its final destination, the wheels to their final stage, it is known as the *final drive*. It depends upon the position of the engine vis-a-vis the powered wheel as to how this transmission system final stage will be. In general the requirements of a transmission system are:

1. To provide for disconnecting the engine from the driving wheels.
2. When the engine is running, the connection to the driving wheels should be enabled smoothly without shock.
3. To enable the leverage between the engine and driving wheels to be varied.
4. It must reduce the drive line speed from that of the engine crankshaft to that of the driving wheels in a ratio of somewhere between 3:1 and 10:1 or more according to relative size of the engine, weight of the vehicle, type of the vehicle and the function it has to perform.
5. Turn the drive if necessary through 90° or perhaps otherwise realign it.
6. Enable the driving wheels to rotate at different speeds.
7. Provide relative movement between the engine and driving wheels.

Out of these seven points mentioned, the final drive performs functions 4,5 and 6. It depends upon the vehicle whether it is a car, truck or a bus, whether in a car it is a general passenger car or a racing car; according to the type of vehicle its transmission system will be decided. Also it will depend upon whether the car is a front wheel drive, rear wheel drive, or a four wheel drive. The transmission system also depends upon whether in the above drives the engine is mounted in the front or in the rear, whether it is mounted so that its crankshaft is along the axis of the car or placed across.

## 15.3 FINAL DRIVE REQUIREMENTS

The three functions performed by the final drive are therefore:

1. The final drive reduces the speed of the engine. As mentioned earlier, the engine speed is reduced within a range of 3:1 to 10:1 to the driving wheels. Part of this reduction is carried out in the gear box where different ratios of reduction are available for different gear positions. As the power enters the differential from the propeller shaft, the speed is reduced between 3:1 to 6.5:1 depending upon the requirement of the vehicle. Here there is only one setting for reduction.

2. When the final drive comes on the axle, the rotating wheels have to move at different speeds when the car negotiates a curve. Thus while turning, the inner wheel has to rotate at a lower speed as compared to the outer wheel since during turning, in the same time the outer wheel has to cover more distance. There is no problem in dead axles like the front axle since the wheels are free on stub axles. In the rear/driving wheels this condition is satisfied by the use of a differential.
3. Power comes through the propeller shaft which is in line with the axis of the car in a front engine rear wheel drive car which is the case in general. In such a case, the final function to be performed by the final drive is to turn the power through 90°. This is done by the gear and pinion assembly or what is commonly known as the crown wheel and pinion assembly between the propeller shaft and the differential.

However if the engine is mounted on the axle of the driving wheel, the power is transmitted without turning through 90° if the axle and crankshaft axles are the same. In such a case, it has to only realign the drive.

## 15.4 THE FINAL DRIVE

The functions of turning the drive from the propeller shaft through 90° to distribute it to the two wheels, and of reducing the speed of rotation, thus increasing the torque-is performed by the gearing carried in the final drive unit, usually housed in the back axle. For relatively small reductions —up to about 7:1, single stage gearing is used; but for greater reductions, two or even three stages may be required, and the gearing for one or more of these stages may be housed in wheel hubs. The terms single, double and triple reduction axles are therefore used.

The final drive, incorporating the action of reduction of speed and turning of drive through 90°, uses a gear drive. The first stage of reduction also the only one in single reduction drive uses three types of gear combinations such as Worm drive, Bevel and Hypoid Bevel final drive.

**(i) *Worm and Worm Wheel*** The worm and worm wheel gear combination has the following advantages:

(a) runs silently.
(b) low drive line when the worm is under slung.
(c) high ground clearance—when worm is over slung.
(d) ease of providing for a through drive to a second axle in tandem with the first.
(e) high reduction ratio in single reduction as high as 15:1.

Its main disadvantages are:

(a) sliding action of worm teeth generates lot of heat specially if gear ratio is high.
(b) heavy demands on lubricants.
(c) high cost of manufacture.
(d) low efficiency.

**(ii) *Bevel and Hypoid Bevel Final Drives*** The bevel and hypoid bevel final drives have the following advantages:

(a) low cost of manufacture.
(b) higher efficiency.
(c) low sliding friction.

Depending upon the vehicle requirements the following two reduction drives are used.

### 1. Single Reduction Live Axle

In the case of single reduction, the pinion coupled with or mounted on the propeller shaft after the universal joint, meshes with a corresponding crown wheel. This combination not only provides the reduction of speed but also turns the power through 90° as desired. The power transmission axle does not take the bending action of the car body. This is carried by the axle housing in which the axle is housed (Fig. 15.2). The figure shows an elementary single reduction unit without the differential.

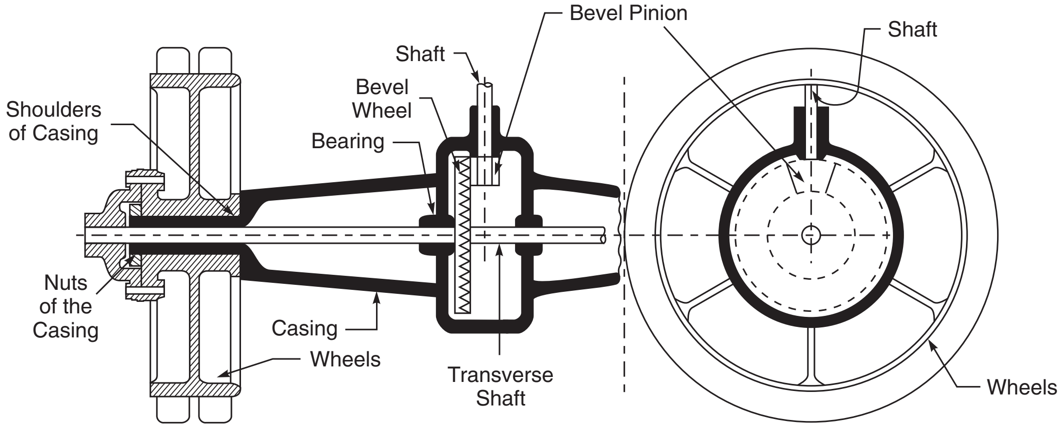



**Fig. 15.2** Single Reduction Live Axle

Most cars use a single reduction final drive since in their case the demands of high traction are not there. Double and triple reduction drives are only used in heavy traction vehicles.

### 2. Double Reduction Live Axle

For vehicles carrying heavy loads and requiring high torque like lorries, buses etc. double reduction drives are used. There are several reasons for double reduction drives to be used in such vehicles. For example,

(i) Such vehicles run at much lower speeds as compared to cars. Thus while cars run at speeds above 150 km/hr, lorries do not run above 75 to 120 km/hr.

(ii) These vehicles have large diameter wheels as compared to cars.

The reduction required in such vehicles is much larger, i.e. 5:1 to 10:1 as against 3.5:1 to 6:1 in case of cars.

If this large reduction is obtained in one stage, the gear ratio being very large either the pinion will be too small having very few teeth, or it will be too weak and inefficient or the crown wheel will be too large, reducing the ground clearance drastically.

There are two arrangements for the double reduction drive in general.

**1. *Both Steps at the Centre of the Axle*** In such an arrangement, the first step of reduction of speed and the turning of the direction of power is obtained with the usual arrangement like in the single reduction type. There is an intermediate axle for this purpose. After this, through another gearing the next step of reduction is obtained. Such an arrangement has been shown schematically in Fig. 15.3. In some cases the differential is also placed on the intermediate axle. In another arrangement, the first reduction between the propeller shaft and the intermediate shaft only changes the speed. While the second step of change of speed and the change in direction of power is obtained in second stage as shown in Fig.15.4.

**2.** ***One Step at the Centre of the Axle, the other at Road Wheels*** In this case, like in the case of single reduction of speed, the change in direction is carried out up to the differential. The second step of the change of speed is obtained between the differential axle and wheel axle by the help of a gear drive. This second reduction may be provided by a simple pinion and wheel or it may be provided by an epicylic gear train. The first type is shown in Fig. 15.5.

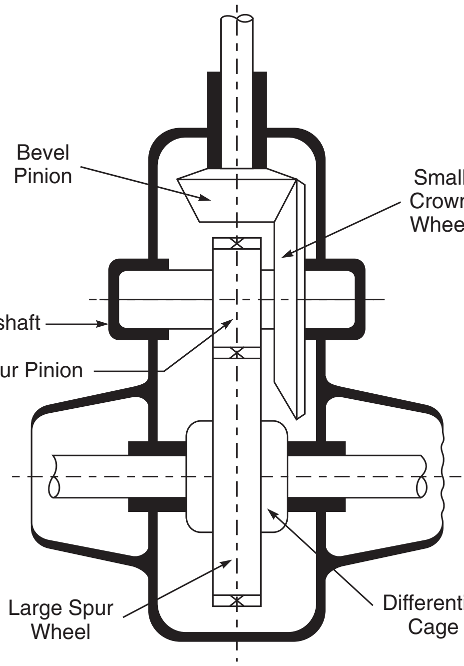



**Fig. 15.3** Arrangement for Reduction of Speed and Change in Direction of Power

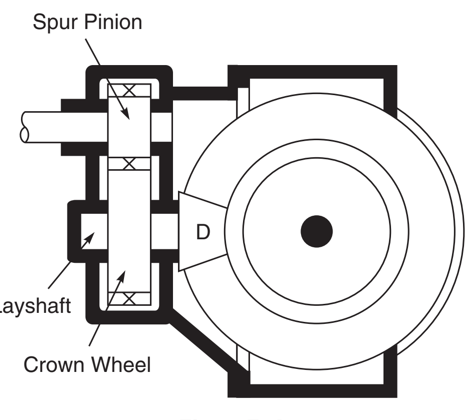



**Fig. 15.4**

## 15.5 THE DIFFERENTIAL

An important function of the final drive is to allow the flexibility of relatively different wheels on the same axle. When a vehicle negotiates a curve the path travelled by the inner wheel is shorter as compared to the outer wheel (Fig. 15.6). If now both the wheels are to move with the same speed, as for example in the case of wheels fixed rigidly to one axle, the inner wheel will skid causing tyre wear and affecting the control of the vehicle.

In case of dead axles like front axle, the wheels rotate freely on stub axles and they can rotate independent of each other but in case of power wheels like the rear wheels, this is not possible until an arrangement is specially made.

This arrangement is known as the *differential*. In this case the rear axle is split into two halves each half carrying one wheel. The power from the propeller shaft passes onto these two axles through a differential and the differential enables the rotation of one at a lower speed as compared to the other.

Schematically the working of a differential with bevel gear is shown in Fig. 15.7. The power from the propeller shaft pinion goes to the differential crown. Along with the crown, rotates the assembly of four bevel pinions. Two bevel gears are carried on individual half axles which are connected to the rear wheels.

When the shafts rotate in unison as on a straight road, the bevel pinions orbit with the bevel gears but do not turn about their own axle. It is the special feature of this system that when stationary, if one wheel is rotated in the clockwise direction the other wheel through the bevel gear assembly rotates in the anti-clockwise direction.

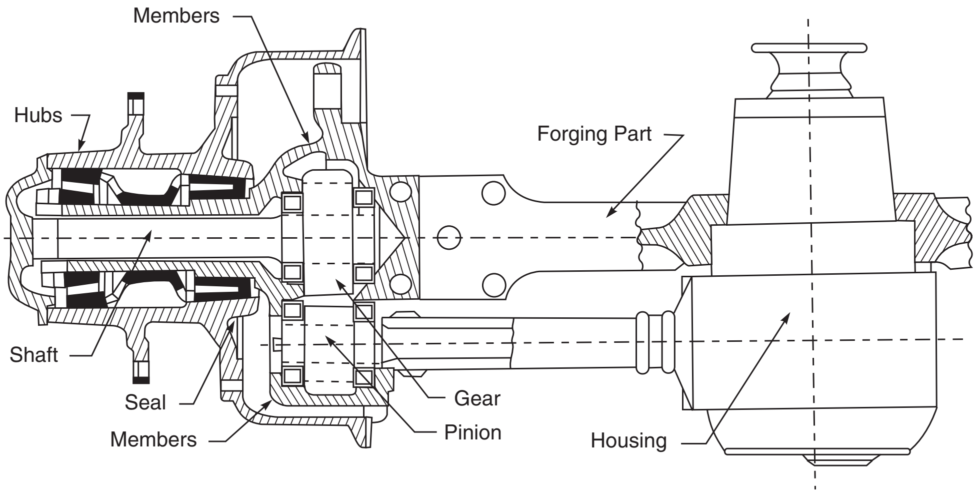


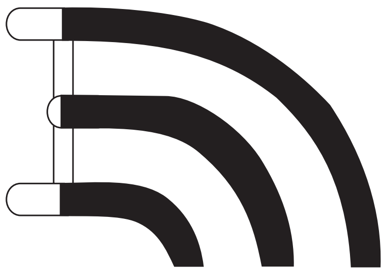

**Fig. 15.5**

Thus when power is being transmitted, and one shaft is stopped, the other can continue to rotate because as it does so its bevel gear makes the bevel pinions turn on their axles. This allows the pinions to orbit around the stationary gear.

If on a straight drive the wheels are rotating at $N$ rpm, and now if moving on a curved path, if the inner wheel turns at $N$-$n$ rpm the outer wheel will rotate at $N$+$n$ rpm. However with the differential there is also a disadvantage.

This is encountered when one of the wheels comes on a slippery surface where it can spin without grip. In such a case the other wheel on the firm ground will simply stop and the free wheel will rotate at double the speed. This is because the differential always applies equal torque (turning effort) to each road wheel. If one wheel is spinning doing no work, the other wheel will not do any work either. Also on rough surfaces, the wheel sometimes bounces free of the road and its speed increases. When it lands on the road surface again, it will immediately have to reduce its speed to the vehicle speed again. This gives the drive train a severe shock that could damage parts.

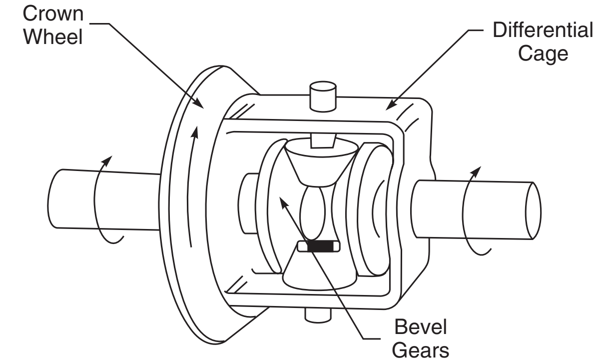
Travelling Straight Ahead Both Wheels Cover the Same Distance at the Same Speed



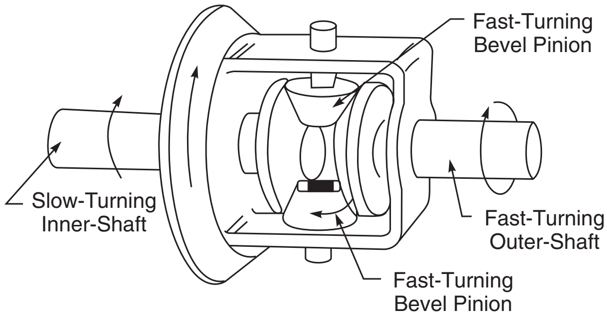
While Turning the Inner Wheel Covers Less Ground Than the Outer One. The Differential Lets Them Run at Different Speeds: the Crown Wheel Runs at Their Average Speed

**Fig. 15.6**

To overcome this disadvantage, limited slip differentials have been designed. They use either multiplate clutches or cone clutches and the outer wheel activated either by a torque differential or spring load. This effort is not very pronounced in case of turning but becomes effective when one wheel encounters a slippery surface.




**On the Straight** the Cage Rotates with the Crown Wheel; the Bevel Pinions, Orbiting but Spinning, Turn the Bevel Gears and with Them the Half-Shafts




**Taking a Bend** When the Inner Bevel Gear Turns more Slowly than the Crown Wheel the Outer Gear Driven by the Bevel Pinions, Turns Correspondingly Faster

**Fig. 15.7**

## 15.6 AXLE HOUSING

Most average-sized front engine cars with rear wheel drive are fitted with a rigid rear axle or beam axle. The half shafts and final drive assembly which includes the differential are enclosed by a rigid housing which contains bearings to support the rotating parts.

There are two types of these axles.

**1.** ***Banjo Type*** In the banjo axle, the axle is a single unit and the final drive assembly is carried in a separate casing which is bolted to the axle housing. The banjo construction shown in Fig. 15.8 is often used for the axle cases of the smaller and lighter vehicles.

**2.** ***Split Type*** In the split type axle arrangement a central housing contains the final drive and it is fitted with a tube on each side to carry the half axles and bearings.

Further classification of rear axles is based on the manner in which the half shafts and wheel hubs are supported. In all types the inner ends of the half shafts are connected to the gears of the differential.

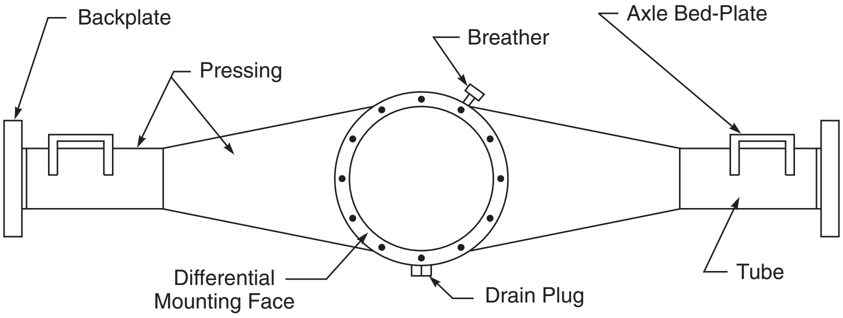



**Fig. 15.8** Banjo Axle Case

According to this classification, the rear axles are of three types:

- Semi floating axles
- Three quarter floating axles
- Fully floating axles.

***Semi Floating Axles*** In semi floating type of arrangement each half shaft is supported at its inner end by a bearing which also carries the final drive unit. At the outer end there is a bearing between the shaft and the inside of the axle housing. The half shaft has to withstand bending loads imposed by the weight of the car, as well as transmit torque. Figure 15.9 shows are such an arrangement.

***Three Quarter Floating Axle*** The three quarter floating axle arrangement also has a bearing inside the axle housing which carries the final drive unit, but the outer bearing is placed between the wheel hub and the axle housing, to support the weight of the car. The half shaft is subjected to a bending load only during cornering. Figure 15.10 shows a three quarter floating axle.

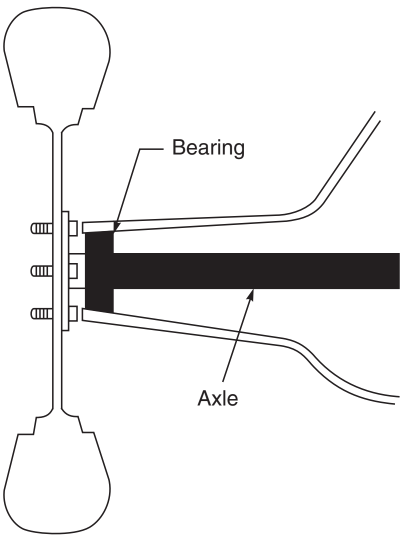



**Fig. 15.9** Semi Floating

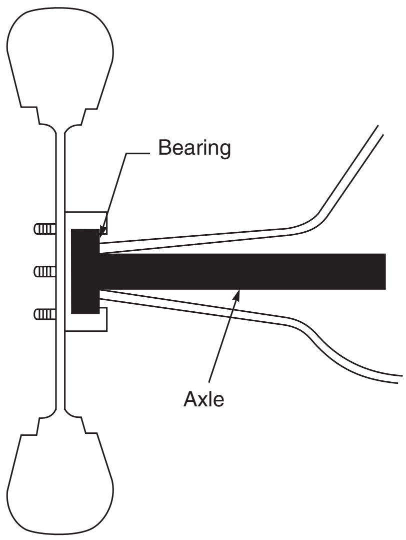



**Fig. 15.10** Three-quarter Floating

***Fully Floating Axle*** In a fully floating axle there are two bearings between each hub and the axle housing and these carry both the weight of the car and the cornering forces. This design is rarely used for cars.

## 15.7 MAINTENANCE OF REAR AXLE

In case of rear axle routine maintenance is limited to checking the oil level and topping up when necessary. Oil checks should be carried out every 3000 miles. It is not possible to drain some modern rear axles, but ensure when topping up the oil level that the axle is not overfilled. Too much oil can result in a blown seal and oil contaminated rear brakes.

Only indications of problems in the rear axle are abnormal noise or fluid leaks. These usually result from damaged oil seals, bearing failure and gear tooth wear in differentials.

## 15.8 TROUBLESHOOTING IN DIFFERENTIALS

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Breaking (case, gears, bearings, etc) | (a) Insufficient or wrong kind of gear oil. | Replenish or change. |
| | (b) Improperly shimmed side bearings or pinion bearings. | Adjust or replace. |
| | (c) Improper mesh of drive pinion with ring gear. | Adjust or replace. |
| | (d) Excessive backlash due to worn side gear thrust washer and pinion thrust washer. | Adjust or replace. |
| | (e) Distorted rear axle. | Replace. |
| | (f) Loose bolts securing ring gear. | Replace. |
| 2. Gear noise | (a) Maladjusted backlash between drive pinion and ring gear. | Adjust. |
| | (b) Damaged gear teeth or improper mesh of drive pinion and ring gear. | Replace or adjust. |
| | (c) Improper tooth contact in the mesh between drive pinion and ring gear. | Adjust. |
| | (d) Insufficient or wrong kind of gear oil. | Replenish or replace. |
| | (e) Ring gear wobbles when turning, or ring gear securing bolts are loose. | Replenish or retighten. |
| | (f) Broken or otherwise damaged teeth of side gears or differential pinion gears. | Replace. |
| 3. Bearing noise | (a) (Constant noise) Insufficient or wrong kind of gear oil. | Replenish or change. |
| | (b) (Constant noise) Damaged or worn bearings or worn parts. | Replace. |
| | (c) (Noise during coasting) Damaged bearings of rear drive pinion. | Replace. |
| | (d) (Noise during turning) Broken bearings on axle shafts. | Replace. |

## Review Questions

1. List the three requirements of the final drive.
2. Differentiate between a live and a dead axle.
3. Describe different types of live rear axles and explain their advantages and disadvantages.
4. Why must the rear wheels of an automobile move at different speeds when cornering?
5. Describe differential action in a standard differential assembly.
6. What are the two main gears in the differential?
7. How are the axles connected into the differential?
8. Why is a limited slip differential necessary?
9. What are the usual troubles in the final drive mechanism?

16

# Steering and Front Axle

**Objectives**

After studying this chapter, you should be able to:

- Explain the operation of steering gears.
- Describe the purpose and operation of the steering linkage.
- Explain the operation of steering wheel and column.
- Explain the function and construction of front axle.
- Draw the steering geometry.
- List and describe the different wheel alignment angles.
- Explain the principle of Ackerman Linkage.
- Describe the purpose and operation of power steering.
- Explain the meaning of terms-understeer and oversteer, slip angle, steering lock and turning radius.

## 16.1 FUNCTION OF THE STEERING SYSTEM

The function of the steering system is to enable the driver to control accurately the direction of the automobile by means of two major components: the steering gears, which multiply the driver's effort at the steering wheel, and the steering linkage which connects the gear box to the front wheels. The working of the system depends on proper alignment of the front wheel for directional control and ease of steering.

## 16.2 STEERING GEARS

Steering gears have two functions: to change the rotary motion of the steering wheel into straight line motion that will move the steering linkage and to provide a gear reduction that will make the automobile easier to steer. A small effort at the steering wheel is multiplied into a larger effort at the steering linkage. The amount of gear reduction is described as the *steering ratio*. A typical ratio of 16:1 means that in order to turn the front wheels by one degree the steering wheel has to be rotated 16 degrees. A light sports car with quick steering may have a ratio of 12:1, while a large heavy automobile may have a ratio of 20:1.

Several types of gears are used in steering gear boxes. Some of the most common types of steering gears are described in the next few sections.

## 1. The Worm and Nut Steering

In the worm and nut steering method the steering shaft ends in a square cut screw thread. A nut is made to work on these threads. The turning of the steering wheel moves this nut along the steering rod screw thread, and the nut activates a bell crank lever, pivoted (Fig. 16.1) in the steering box casing. The steering gear drop arm forms the other arm of this bell crank. The recirculating ball and worm type of steering gear box is developed on this type of steering gear box.

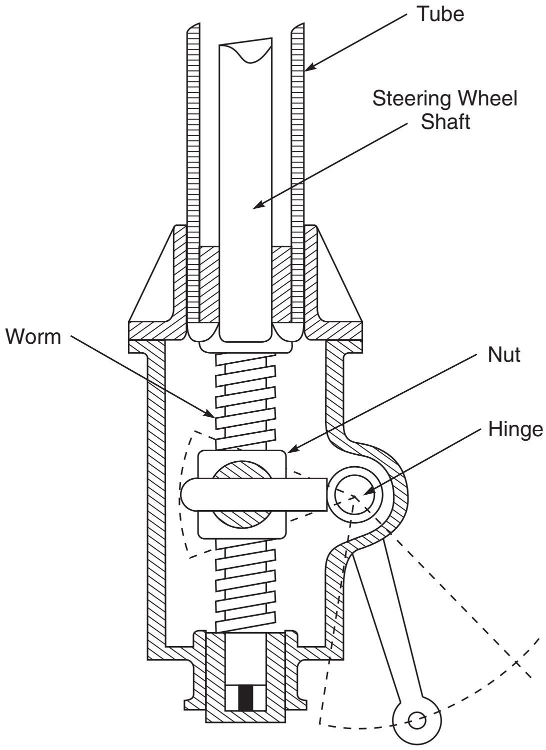



**Fig. 16.1** Worm and Nut Steering Gear

## 2. The Worm and Worm Wheel Steering

In the worm and worm wheel steering system there are square threads or worms on the steering rod end as before, but instead of working in a nut, it engages in a worm wheel. The drop arm (pitman arm) is keyed to the same shaft as the work wheel and works rigidly with it. Usually a square shaft is used for the worm wheel, so that as wearing of the worm sector occurs, the worm wheel can be turned round to a new position. The arc of movement of the drop arm is usually from 60 degrees to 90 degrees. Many makers provide only a sector of a wheel for this purpose. This gives a smaller and lighter mechanism but has no provision for worm and wheel teeth wear. Figure 16.2. (A) and (B) illustrate the principle of this type of steering. This system is most common in tractors.

## 3. The Worm and Roller Steering

In the worm and roller steering designs a single or double roller is mounted between two arms integral with the inner end of the cross-shaft, and this roller is meshed with the worm. The roller is free to turn on its shaft and moves in an arc, the correct mesh being obtained throughout its movement by the hour-glass shape of the worm. The worm is supported and located by two ball or taper roller bearings mounted in the case and its end float may be adjusted by shims placed between the outer bearing track and the end plate of the case. The roller shaft is eccentric and may be turned to compensate for wear between the roller and the worm. The upper end of the column is supported in the tube by a felt bush (Fig. 16.3).

## 4. Recirculating Ball Steering

Most large automobiles use a worm gear which look like a large bolt thread on the end of the steering shaft. Turning the steering wheel turns the worm gear, which causes a large nut in mesh with the large threads to move up and down the worm. The nut has teeth which mesh with the

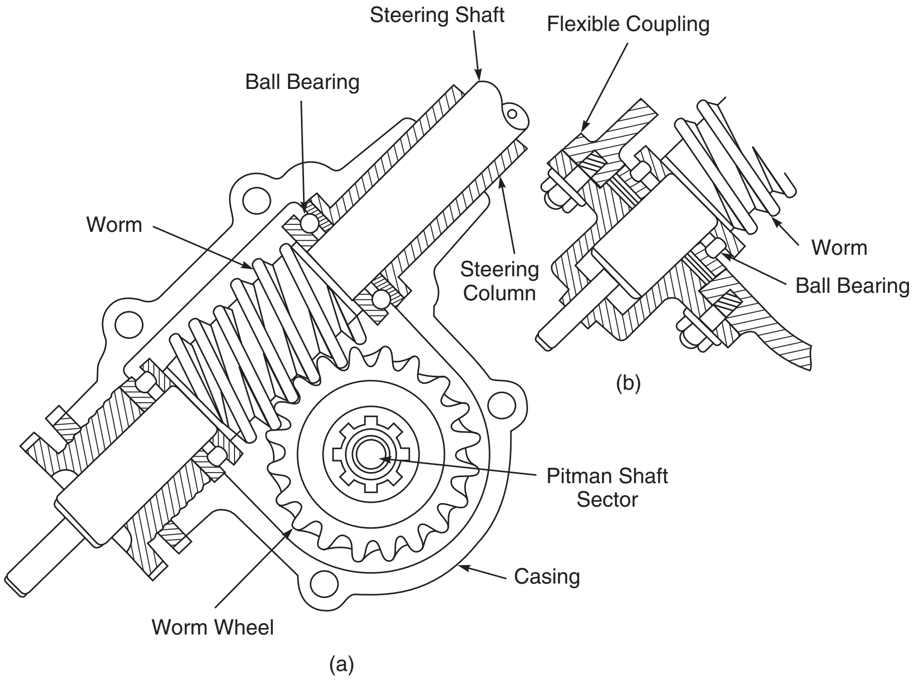



**Fig. 16.2** Worm and Worm Wheel Steering Gear

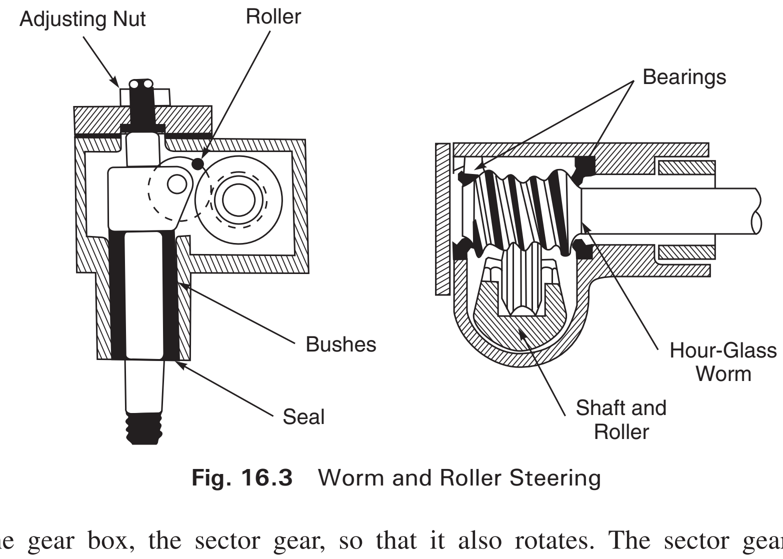



**Fig. 16.3** Worm and Roller Steering

other gear in the gear box, the sector gear, so that it also rotates. The sector gear, hooked to the steering linkage, completes the gear reduction process that increases the steering wheel's turning effort. To reduce friction and steering effort, small ball bearings may be used between the worm and nut. The bearings ride in the threads of the worm and mesh with the nut. Therefore, this type of steering unit is called a recirculating ball steering gear (Fig. 16.4).

### 5. Rack and Pinion Steering

Many small cars use a rack and pinion steering system in which the steering wheel and shaft are connected to a small pinion gear (Fig. 16.5). This gear is in mesh with teeth on top of a long bar, called a rack. Turning the steering wheel turns the pinion gear, which moves the rack back and forth. The rack is attached to the steering linkage that turns the wheels. The main advantage of this system is that it takes up very little space, making it especially suitable for compact vehicles.

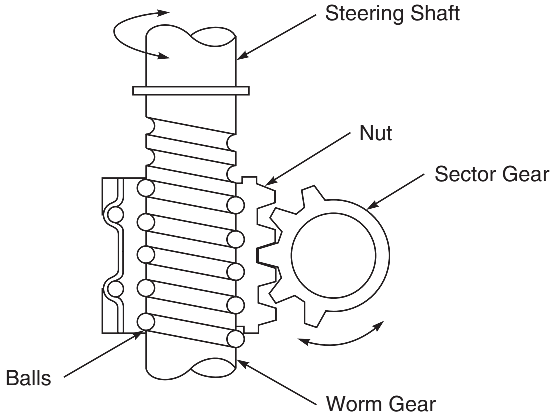



**Fig. 16.4** Recirculating Ball Steering Gear

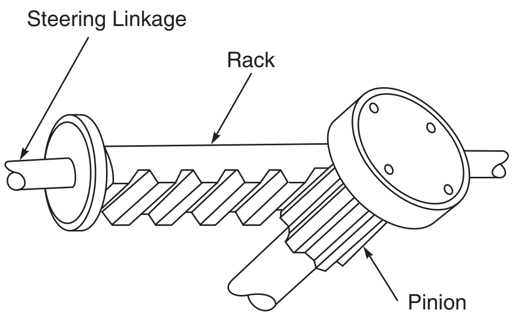



**Fig. 16.5** Rack and Pinion Steering

## 16.3 STEERING MECHANISMS USED IN SOME INDIAN VEHICLES

The steering mechanism increases the force transmitted from the steering wheel to the steering arm, thereby facilitating the turning of the steerable wheels.

In Maruti cars the steering mechanism is of the rack and pinion type. The ratios of the steering gear are as follows:

- Maruti 800 – 17:1
- Maruti 1000 – 18:1

The steering mechanism of the Maruti-800 car shown in Fig. 16.6 consists of two main components, the rack and the pinion. When the steering wheel is turned, the motion is transmitted to the steering shaft, the shaft joint and then the motion is further transferred to the rack and changed to linear motion. The force is then transmitted through the tie rods to the steering knuckles, which turn the wheels.

The rack and pinion type of steering system is also used in Ambassador cars (shown in Fig. 16.7).

In the CJ-3B and CJ-4 Mahindra and Mahindra Jeep, two types of steering assemblies were used in production, i.e. the cam and lever type up to 1967 and from 1968 onwards the Ex-cell-0 steering assembly RHD.

In Tata vehicles the steering system is of the worm and nut with recirculating ball type. As a matter of fact, it is an improved version of the worm and nut type of steering. In this type, steel balls are placed in the nut to act as threads.

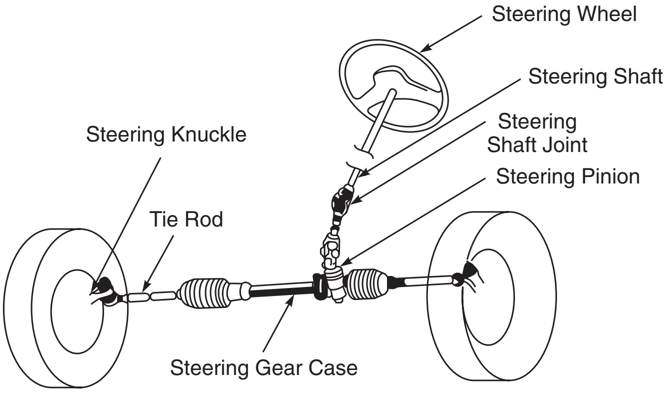



**Fig. 16.6** Rack and Pinion

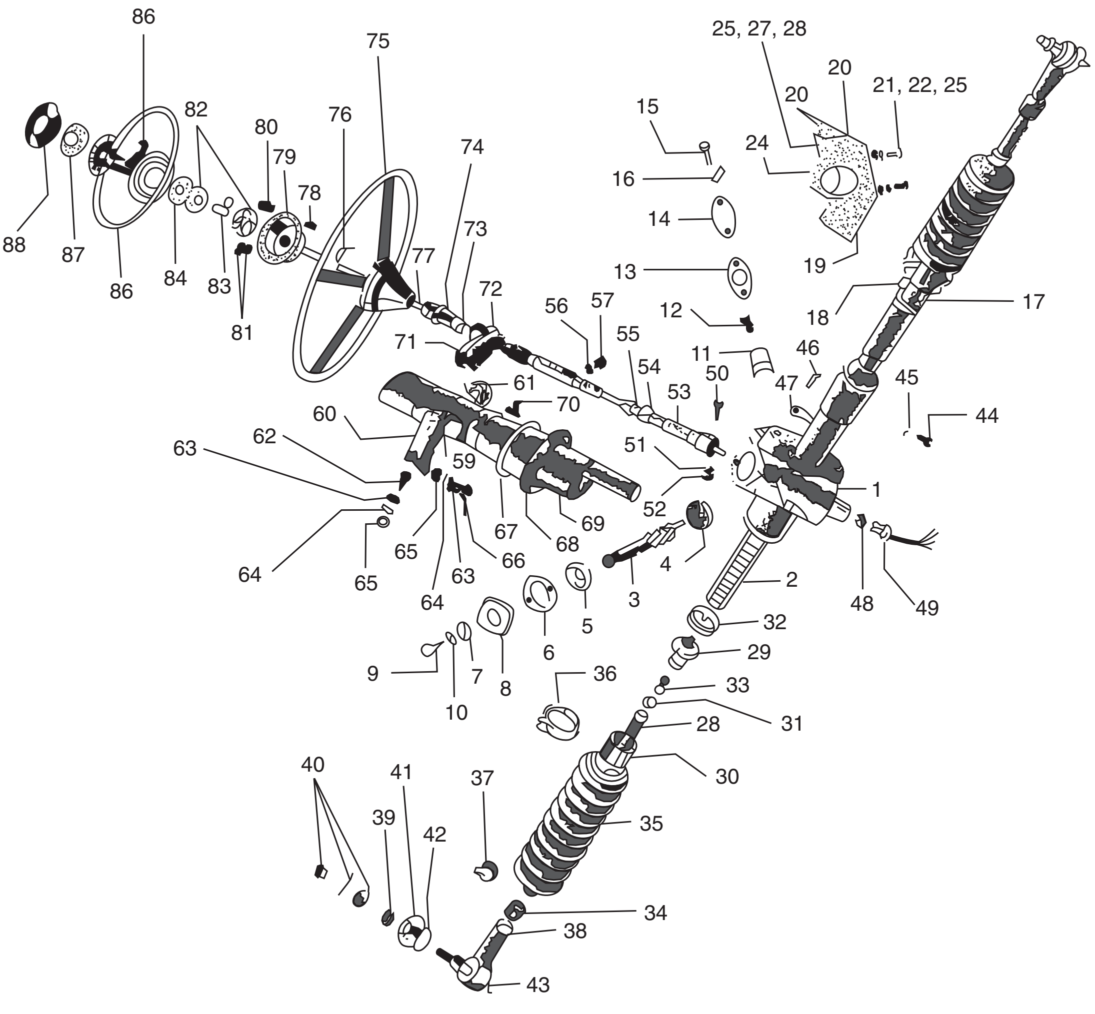



**Fig. 16.7** Steering Gear Components

**Legend for Fig. 16.7** Steering Gear Components

1. Assembly Housing-Steering-Rack
2. Rack-Steering Gear
3. Pinion-Steering Gear
4. Ball Bearing (Pinion Bottom)
5. Ball Bearing (Pinion Top)
6. Shim-Steering Rack Housing (.005" And .003")
7. Oil Seal-Pinion Upper
8. Cover-Steering Rack Housing
9. Hexagonal Head Screw
10. Spring Washer
11. Damper-Rack
12. Spring-Damper
13. Shim-Damper (.005" And .003")
14. Cover-Damper
15. Hexagonal Head Screw
16. Spring-Washer
17. Bearing Bush-Support End-Rack
18. Rivet
19. Mounting Rubber-Support End
20. Mounting Support End
21. Hexagonal Head Screw
22. Plain Washer
23. Spring Washer
24. Clamp-Support End
25. Hexagonal Head Screw
26. Spring-Washer
27. Plain Washer
28. Tie Rod
29. Ball Housing (Male)
30. Ball Housing (Female)
31. Ball Seat
32. Spring-Ball
33. Lock Washer-Male Housing
34. Lock-Nut-Tie Rod End
35. Rack Seal
36. Clip-Seal to Rack Housing
37. Clip-Seal to Tie Rod
38. Tie Rod End Assembly
39. Washer
40. Castle Nut with Pin or Nyloc Nut
41. Boot-Rubber-Tie Toe End
42. Retaining Ring-Rubber Boot
43. Greaser
44. Filler Plug
45. Gasket
46. Hexagonal Head Screw
47. Washer-Tab
48. Olive
49. Bolt-Hollow
50. Bolt-Steering Column to Pinion Clamping
51. Lock Washer
52. Nut
53. Steering Column
54. Bearing-Steering Column Bottom
55. Spring Clip-Bearing Retainer Bottom
56. Lock Washer
57. Nut Cap
58. Packing Strip-Bottom
59. Packing Strip-Top
60. Bracket Steering Column Support
61. Bracket Steering Column Support Lower
62. Screw-Steering Bracket to Rail
63. Plain Washer
64. Lock Washer
65. Nut-Hexagonal
66. Screw-Steering Bracket to Rail
67. Retainer Bottom Cover
68. Cover Bottom
69. Assy. Steering Column Tube
70. Screw Pan Sunk Tapping
71. Screw Counter Sunk Hd.
72. Flange Top Bracket
73. Bearing Steering Column Upper
74. Boss Top Bracket
75. Steering Wheel
76. Nut Steering Wheel
77. Stator Tube-Horn and Flasher Control
78. Screw Cover to Steering Wheel
79. Plate and Sleeve–Stator
80. Spring Horn Push Return
81. Ferrule for Spring (Rubber)
82. Switch
83. Rotor Flasher Switch
84. Contact-Horn (Bottom)
85. Ring-Horn Switch
86. Lever-Flasher Switch
87. Motiff
88. Tube-Stator

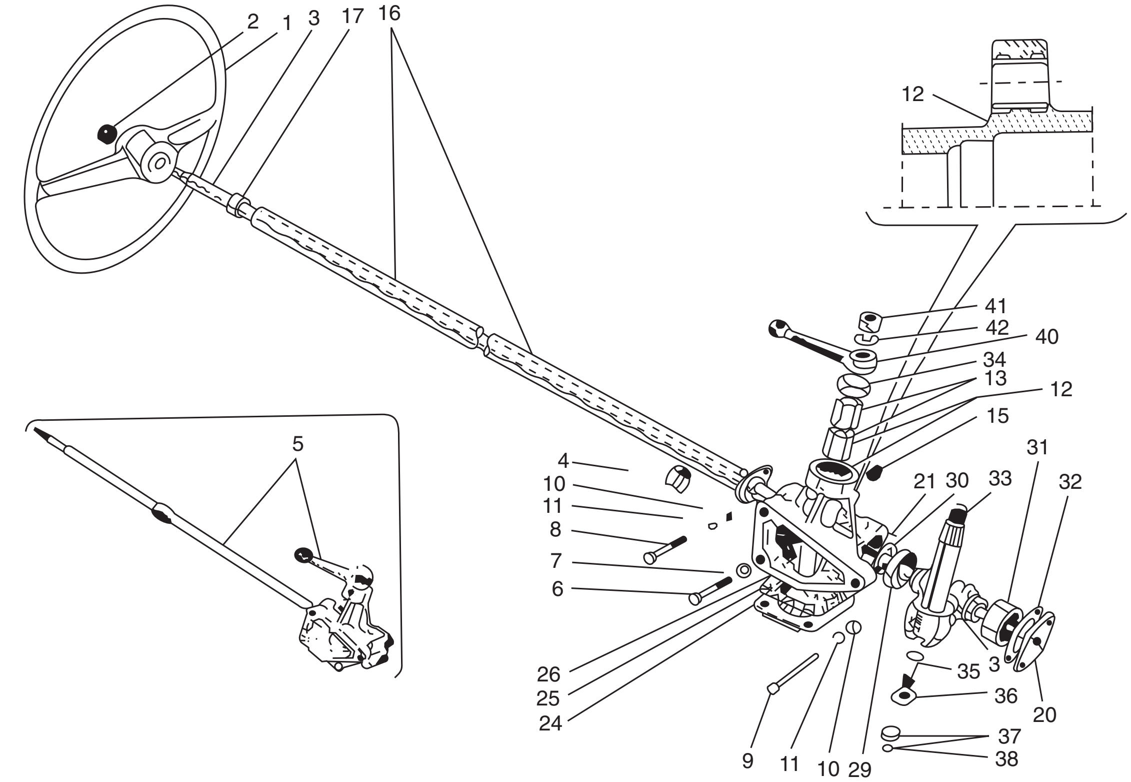
In the Maruti Gypsy, manufactured by M/s Maruti Udyog Ltd., the steering system is of the recirculating ball and nut type. The ratio of the steering gear is 15.6 to 18.6.

The Premium Padmini passenger car manufactured by M/s Premier Automobiles Ltd. is of the worm screw and roller type with a ratio of 16.4:1. This type of steering gear (Fig. 16.8) consists of:

(a) a pitman arm on the roller shaft and a relay lever pivoted in a support on the engine compartment rear wall.

(b) a link rod connecting the pitman arm to the relay lever.

(c) two symmetric side track rods connected to the relay lever and to the wheels through the knuckle arms on the steering knuckle pillars. Articulation of track rods is by the ball-and-socket heads.




| | | |
|---|---|---|
| 1. Steering Wheel assembly | 12. Steering Box Case | 31. Steering Worm Front Bearing |
| 2. Steering Wheel to Worm Shaft Nut | 13. Roller Shaft Bush | 32. Steering Worm Front Bearing Shim |
| 3. Steering Shaft with Worm | 14. Oil Filler Plug | 33. Steering Roller Shaft Assembly |
| 4. Steering Box Oil Seal | 16. Steering Column Jacket Assembly | 34. Roller Shaft Seal |
| 5. Steering Box Assembly | 17. Steering Column Inner Shaft Bush | 35. Roller Shaft Adjusting Screw |
| 6. Steering Box Bolt—Small | 18. Worm Cover Assembly with Tube | 36. Thrust Washer |
| 7.Steering Box Bolt Lock Washer | 21. Cover Screw | 37. Adjusting Screw Nut |
| 8.Steering Box Bolt—Medium | 24. Shaft Cover | 38. Oil Drain Plug |
| 9. Steering Box Bolt—Long | 25. Shaft Cover Gasket | 39. Steering Control Pitman Arm |
| 10. Steering Box Bolt Nut | 26. Cover Screw | 41. Nut |
| 11. Steering Box Bolt Nut | 30. Rear Bearing Cup | 42. Lock Washer |

**Fig. 16.8** Steering Gear and Steering Box

## 16.4 STEERING LINKAGE

The steering linkage transfers the side-to-side, or front-to-rear movement of the pitman arm into the left-to-right movement at the wheels. Figure 16.9 shows a typical example of this linkage.

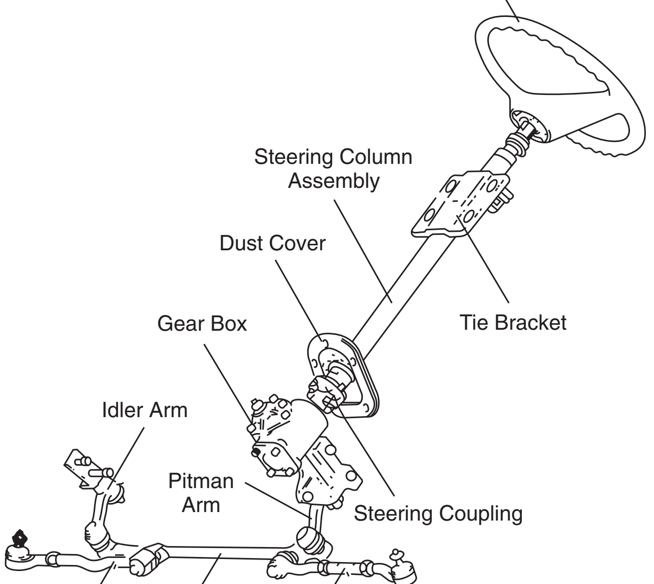



**Fig. 16.9** Steering Linkage

The steering linkage which connects the steering gear box to the front wheels, consists of a number of round rods. These rods, are connected with a socket arrangement similar to a ball joint, called a tie rod end. This tie rod end allows the linkage to move back and forth freely so that the steering effort will not interfere with the vehicle's up-and-down motion as the wheel moves over roads. The steering gears are attached to a relay rod which moves when the steering wheel is turned. The relay rod is supported at one end by its connection to the gear box and at the other end by an arm mounted to the automobile frame. The idler arm moves back and forth with the relay rod, connected at each end to a tie rod. The tie rods are attached to each wheel's spindle assembly so that movement of the steering wheel through the steering box and linkage results in the movement of the front wheels.

As the driver makes a left or right turn, the wheel on the inside of the turn travels through a sharper corner than the one on the outside because of the way the steering linkage is designed.

Servicing the linkage includes greasing the zerk fittings in the tie rod ends. Some newer cars do not use zerk fittings and need no lubrication. These fittings are sealed and lubed for life.

Some older cars came with greaseable tie rod ends and ball joints, but the joints had no zerk fittings installed. Where there is no zerk fitting, a small plug is threaded in. You must understand the plug, install a zerk fitting, lubricate with a grease gun, and reinstall the plug. Most shops will simply install the zerk fittings the first time they service the car.

Any wearing in the linkage is easy to spot. Look for movement in the system while a helper shakes the steering wheel back and forth. The car must be on the ground so that the tyres do not move. As the steering wheel is rapidly shaken, the linkage should follow. If part of the linkage moves but some of it does not, the worn part is where the two sections are joined. Also try shaking the linkage by hand. If it is loose enough to shake by hand, some of the parts in the linkage system need replacement.

There are many possible arrangements of the steering linkage depending on the location of the steering gear box and the front suspension layout. Figure 16.10 shows the different types of the linkage arrangements commonly in use.

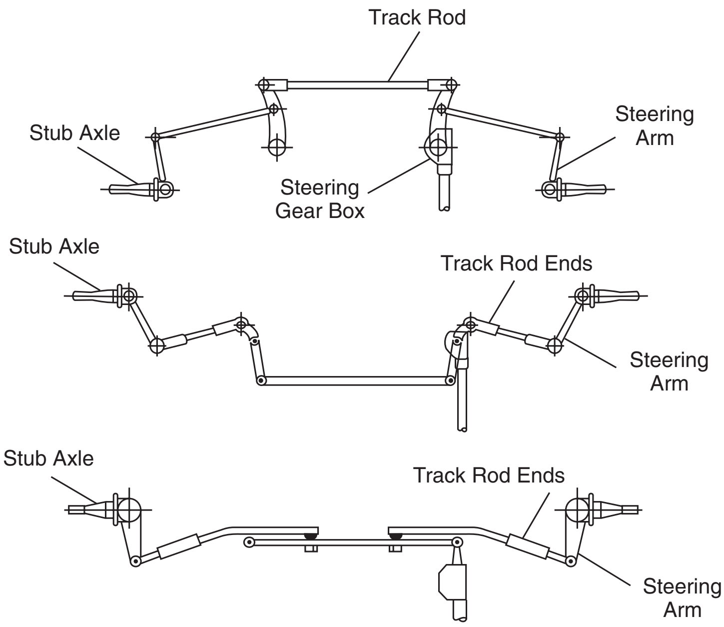



**Fig. 16.10** Different Types of Steering Linkage Arrangement

## 16.5 STEERING WHEEL AND COLUMN

The steering wheel comprises a hub with metal spokes and a rim fabricated as a single piece. The wheel rim diameter should be large enough to convert the driver rim pull into maximum input torque but is limited by the driver's comfort. The rim is elliptical in cross-section with finger indentions on the under-surface and is so dimensioned that a good grip is obtained.

In our country steering wheels have a fixed position, but in foreign countries, in some vehicles these wheels can be tilted and locked in any position to suit the driver.

The size of the steering wheel should be such that in case of an accident the impact load is transmitted to the driver's shoulders and not to his chest.

The steering column on today's car is designed to do more than just house the steering shaft. As the steering is closest to the driver, a number of controls are on it. These include the horn, lights, turn signals, windshield wipers and washers, ignition key and a variety of other devices. To help protect the driver, steering columns are designed to be a collapsible steering column. In such a steering, the shaft and the tube or column are made from two pieces that fit together like an extended telescope. During a collision, the column and shaft absorb the energy and the shaft collapses back into the column.

Figure 16.11 shows the exploded view of the steering wheel and column of the Maruti-1000 car.

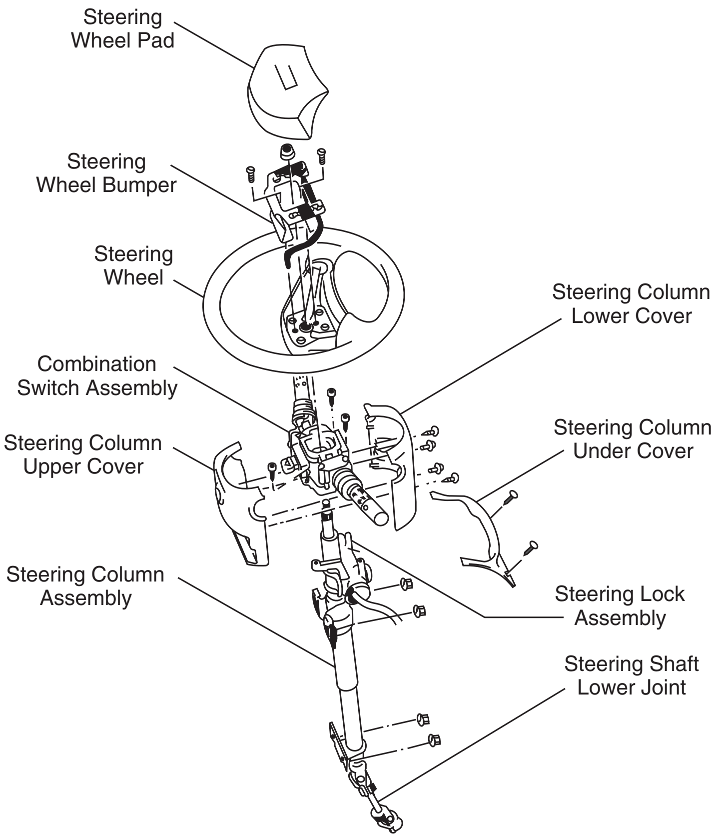



**Fig. 16.11** Steering Wheel and Column

## 16.6 FRONT AXLE

Before we discuss the steering system any further, it is essential to talk about the front axle. It is an axle over which the front wheels are mounted. In automobiles the front wheels are fixed to the chassis in two ways, i.e. either with the independent suspension system or with the help of axle beam with leaf spring. A typical axle beam is shown in Fig. 16.12.

### Functions of Front Axle

The front axle performs the following functions:

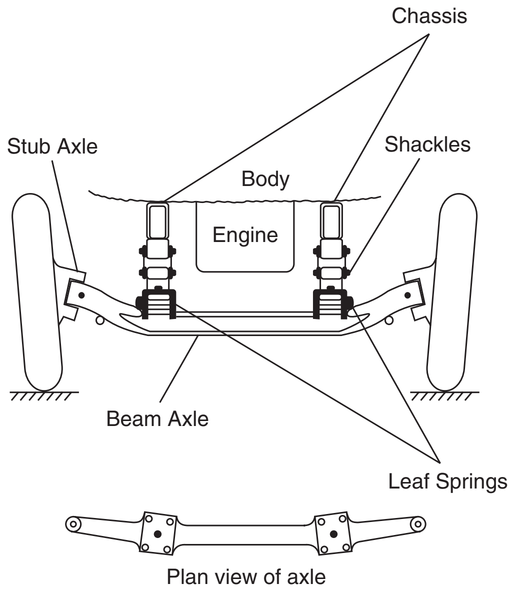



**Fig. 16.12** Front Axle Arrangements

1. It carries the weight of the front of the vehicle.
2. It carries the horizontal and vertical loads on bumpy roads.
3. If brakes are provided at the front wheels also, then the braking torque reaction causes twisting of the axle between the stub axle and the spring seat. Thus the front axle is subjected to bending stresses, and torsional stresses.
4. It works as a cushion through its spring for a comfortable ride.
5. In a four wheel drive it also transmits power to the road wheels.

### Construction of Front Axle

The front axle is a simple beam of steel. The section of the beam is changed depending on the stresses induced. When the front wheel is not braked, the axle beam is usually a simple forging of I-section with suitable seats for the attachment of the springs and with the ends suitably shaped to carry the stub axles. The I-section is adopted because it is best adapted to withstand the bending action to which the beam is subjected. However, when the front wheels are braked, the horizontal bending action becomes considerable. In this case a rectangular or a circular section may be more suitable than an I-section. Again, when the front wheels are braked, the portions of the axle beam between the stub axles and the spring seats are subjected to a twisting action, the torque reaction of the braking torque applied to the brake drums. A circular section is best adapted to withstand this twisting action. Hence when front wheel brakes are fitted, circular section may be used.

## 16.7 STEERING HEADS

Figure 16.13 to 16.15 show the different methods of pivoting the slub axles. The pivot pins or king pins hold knuckles to the proper axle and permit the necessary movement of the knuckles for steering.

There are three types of steering heads:

1. Elliot type
2. Reversed Elliot type, and
3. Lemoine type.

In the Elliot type of steering head (Fig. 16.13), the steering knuckle is inserted between the forked ends of the axle. In the Reverse Elliot type of steering head (Fig. 16.14), the steering knuckle is forked and the axle proper fits inside the fork. In the Lemoine type of steering head (Fig. 16.15), the L-shaped steering knuckle is attached with the axle end by a pivot. It is used in tractors.

The Reverse Elliot type of pivoting is most popular because:

(i) It is easier to manufacture.
(ii) Load exerted by the stub axle is equally distributed.
(iii) It is more adaptable for use with front brakes and also allows a simpler steering arrangement.

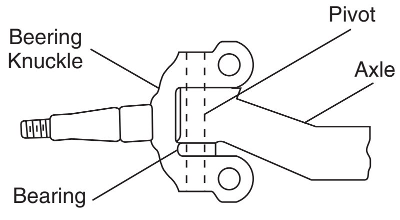



**Fig. 16.13** Elliot

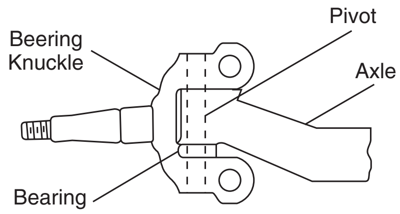



**Fig. 16.14** Reverse Elliot

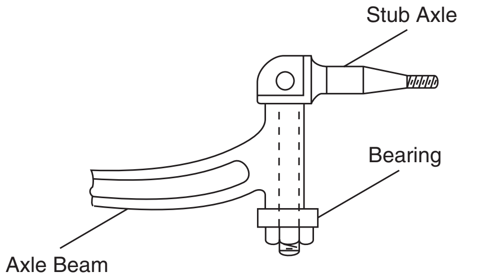



**Fig. 16.15** Lemoine Type Steering Head

## 16.8 STEERING GEOMETRY

Whenever two or more things such as support arms, are connected together they form angles in relation to each other. Since geometry is the branch of mathematics which deals with angles, therefore the study of the angles in the steering system is called *steering geometry*. It is important to know the name of each angle which is produced in steering geometry.

1. Caster angle
2. Camber angle
3. Angle of king pin inclination
4. Toe-in
5. Toe-out

**1. *Caster Angle*** Caster angle is the tilt, i.e. the inclination of the top axle or kingpin towards the front or rear of the car. If tilted towards the front it is positive caster(+) and if tilted towards the back it is negative (–) caster. The purpose of caster is to give a trailing effect to the front wheels. When the wheel trails the line of weight, that is, moves in the same direction as the vehicle, it is easy to steer a straight course (see Fig. 16.16(a)).

**2. *Camber Angle*** Camber angle is the outward or inward tilt of the wheel at the top. If tilted outward it is positive (+) camber and if inward it is negative (–) camber. The main purpose of the camber is to bring the road contact of the wheel more nearly under the point of the load and to throw the weight on the inner wheel bearings which are larger than the outer (see Fig. 16.16(b)).

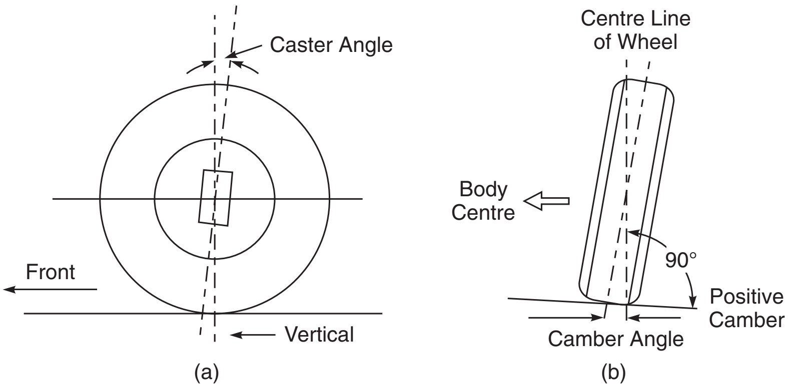



**Fig. 16.16**

**3.** ***King Pin Inclination*** The king pin is tilted in at the top towards the vehicle in order that the weight of the load will be thrown towards the tyre centre. The angle between the vehicle line and the kingpin centre line is known as kingpin inclination angle (Fig. 16.17).

**4.** ***Toe-in*** The wheels are closer together at the front than they are at the back. The purpose of toe-in is to offset the camber and prevent excessive tyre wear (Fig. 16.18).

**5.** ***Toe-out*** Toe-out is the spreading apart of the front wheels on turns. The purpose of toe-out is to give correct turning alignment and to prevent excessive tyre wear (Fig. 16.19).

The steering angles are all adjustable at the manufacture's specification and the procedure should be followed closely when checking and setting up front end alignment. Steering angles of some Indian automobiles are provided in Table 16.1. Table 16.2 lists the types of steering systems used in some Indian vehicles.

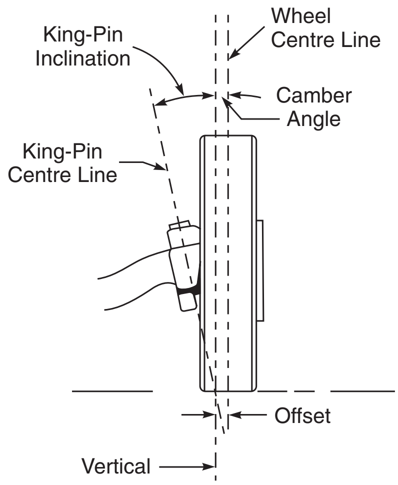



**Fig. 16.17**

## 16.9 WHEEL ALIGNMENT

Wheel alignment refers to the positioning of the front wheels and steering mechanism, that gives the vehicle directional stability, promotes ease of steering and reduces tyre wear to a minimum. A vehicle is said to have directional stability or control if it can run straight down a road, enter and leave a turn easily and resist road shocks.

Other factors, such as frame alignment, spring condition, positioning of rear axle and condition of the shock absorbers also affect steering, tyre wear and directional control and are sometimes included as part of wheel alignment.

***Front Wheel Alignment*** The front wheel alignment depends upon the following factors.

(i) Factors pertaining to steering geometry:

(a) Camber

(b) King pin inclination

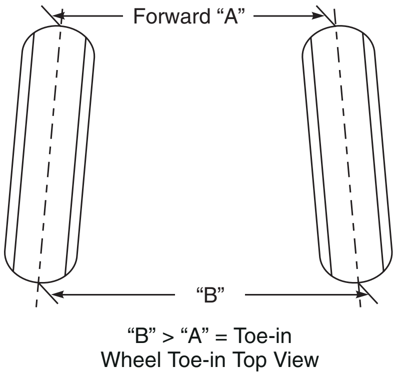



**Fig. 16.18**

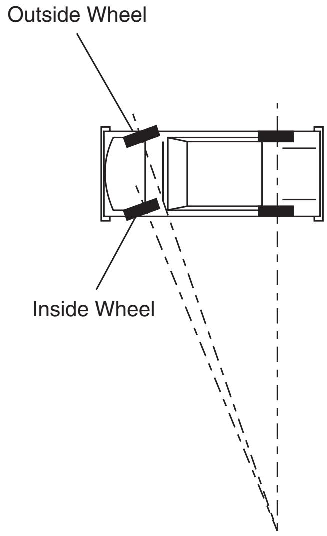



**Fig. 16.19** Toe-out on Turn

**Table 16.1** Steering Geometry Angles of Some Indian Automobiles

| *S.No.* | *Vehicle* | *Camber angle* | *Caster angle* | *Kingpin inclination* | *Toe-in (mm)* |
|---|---|---|---|---|---|
| 1. | Ambassador | $1/2^0$ | $3\ ^1/_2{}^0$ | $3^0$ | 2.4 |
| 2. | Fiat/Premier | 0.30’ + 20’ | $2^0$ + 20’ | $7^0$ | 1–3 |
| 3. | Maruti-800 | 0.30’ + 10 | $3^0$30 + $1^0$ | $12^0$20’ + $0.8^0$ | 1–2 |
| 4. | Jeep Gypsy | $1^0$ | $2^0$ – 30’ | $9^0$ | 2–6 |
| 5. | Jeep CJ-3B | $1\ ^1/_2{}^0$ | $3^0$ | $7\ ^1/_2{}^0$ | 1.2–2.4 |
| 6. | Ashok Leyland Comet Passenger. | $1\ ^1/_2{}^0$ | $1^0$ | $3^0$ | – |

**Table 16.2** Types of Steering System in Some Indian Vehicles

| *Name of the vehicle* | *Steering* | |
|---|---|---|
| | *Type* | *Turning radius (m)* |
| Ambassador (Petrol) | Rack and pinion | 5.4 |
| Ambassador (Diesel) | Rack and pinion | 5.4 |
| Fiat (Padmini Premier) | Worm and roller | 5.25 |
| Maruti 800 | Rack and pinion | 4.4 |
| Maruti Gypsy | Rack and pinion | 5.7 |
| Mahindra Jeep (CJ3B) | Worm and roller | 5.3 |
| Maruti Zen | Rack and pinion | 4.5 |
| Daewoo Matiz | Rack and pinion power assisted | 4.5 |
| Hundai Santro | Rack and pinion power assisted | 4.4 |
| Telco Indica (Petrol) | Rack and pinion power assisted | 4.9 |
| Telco Indica (Diesel) | Rack and pinion power assisted | 4.9 |
| Fiat Uno | Rack and pinion | |

(c) Caster
(d) Toe-in and
(e) Toe-out.

(ii) Factors pertaining to front wheel condition:
(a) Balance of wheels
(b) Inflation of tyres
(c) Brake adjustments.

## 16.10 ADJUSTING STEERING ANGLES

Adjustment of the steering angles help in maintaining directional stability, preventing excessive wearing of tyres and wobbling of wheels, while turning.

**1.** ***Camber*** The camber is adjusted by means of shims or an eccentric cam in the control arm shaft. Excessive camber prevents the tyre from having correct contact with the road which causes it to wear only on the side directly beneath the load. Equal camber causes the vehicle to roll in the direction of the wheel having greater camber which upsets directional stability and tends to scuff the treads on the opposite tyre. Camber should not exceed 2°.

**2.** ***King-pin Inclination*** The kingpin inclination in combination with caster, is used to provide directional stability by tending to return the wheels to the straight ahead position after any turn. It also reduces steering efforts particularly when the vehicle is stationary. It reduces tyre wear also. The kingpin inclination in modern vehicle ranges from 4 to 8 degrees. It must be equal on both the sides. If it is greater on one side than the other, the vehicle will tend to pull to the side having the greater angle. Also, if the angle is too large, the steering will become exceedingly difficult. The kingpin inclination is made adjustable only by bending.

**3.** ***Caster Angle*** The caster angle in modern vehicles ranges from 3 to 8 degrees. Too much or too little caster angle may give rise to ‘kicking’ at the steering wheel, wheel wobbling and also causes hard steering. The caster angle may get disturbed owing to the flattening of wheel springs or ruptured and worn-out spring leaf. Bushes and shackles may also alter the caster angle.

The caster can be reset by reconditioning of springs leaves, bushes and U-shackles etc. The angle may also be set by the use of taper wedges fitted between the platforms and the springs.

**4.** ***Included Angle*** The combined camber and kingpin inclination is called the included angle. This angle is important because it determines the point of intersection of the wheel and the kingpin centre line. This in turn, determines whether the wheel will tend to toe-out or toe-in. If the point of intersection is above the ground, the wheel tends to toe-out. If it is at the ground, the wheel keeps its straight position without any tendency to toe-in or toe-out. In this position the steering is called *centre point steering*.

***5. Toe-in*** The amount of toe-in is usually 3 to 4 mm. Although the wheels are set to toe-in position when the car is standing still, they tend to roll parallel on the rod when the car is moving forward. Some alignment specialists set the front wheel in “straight away alignment” in preference to “toe-in adjustment”. The toe-in can be adjusted by shortening or increasing the length of the track rod. The track rod has got opposite threads at its end and is held tightened to both the steering knuckle arms. By turning the track rod the toe-in angle can be secured.

***6. Toe-out*** When the car is taking a turn, the outer wheels roll on a larger radius than the inner wheel. Therefore the inner wheel must make a larger angle with the car frame than that made by the outer wheel. The toe-out is secured by providing the proper relationship between the steering knuckle arm, tie rods and pitman arm.

## 16.11 ACKERMAN LINKAGE

In order that the wheels may roll freely without sideslip, it is necessary that they should all move about a common centre. The centre will be on a line drawn through the rear axle, where lines drawn through the centres of the front wheels intersect (Fig. 16.20). In order to achieve this common centre, the inner wheel must turn through a greater angle than the outer. This difference in movement of the inner and outer wheels is obtained by inclining the track rod arms. The effect of this will be clear from Fig. 16.21, where A represents the track rod arm on the inside of the curve and B the outer arm. If the track rod moves, say through *x* distance, measured parallel to the axle beam, arm A will move through a greater angle than B.

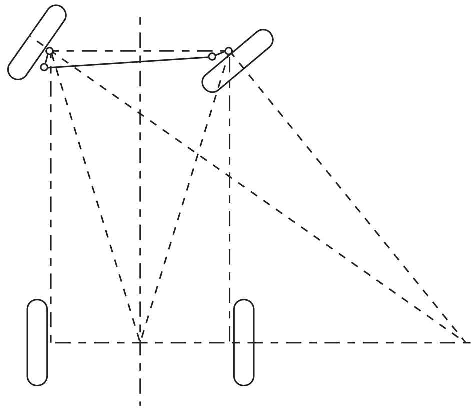


**Fig. 16.20** Principal of Ackerman Linkage

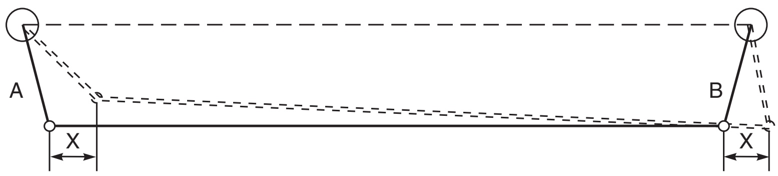



**Fig. 16.21** Angles Moved by Track Rod Arms

The inclination of the track rod arm is such that lines drawn through them will intersect theoretically at the centre of the rear axle. This arrangement, usually known as the Ackerman principle or linkage, can also be applied if the track rod is placed in front of the axle.

In practice, free rolling is not obtained in all positions of the wheels. It is an interesting geometrical problem to draw the system in a series of positions, from lock to lock, when it will be found that it is only correct in the straight ahead position and in one position on each lock.

## 16.12 POWER STEERING

Most heavy automobiles have the power steering system shown in Fig. 16.22 which requires a pump to provide a flow of hydraulic fluid. The pump, usually mounted to the front of the engine and driven with a belt, is connected by hydraulic lines to the steering gear box. Besides the regular gears, a hydraulic valve and piston assembly is located in the gearbox. When the driver turns the steering wheel, hydraulic pressure is routed by a valve to the piston, which pushes on the steering gear to help the driver turn. The hydraulic force makes handling a heavy automobile very easy. If the hydraulic system fails, the driver can still steer the automobile. The steering effort required is greater, than in an automobile without power steering.

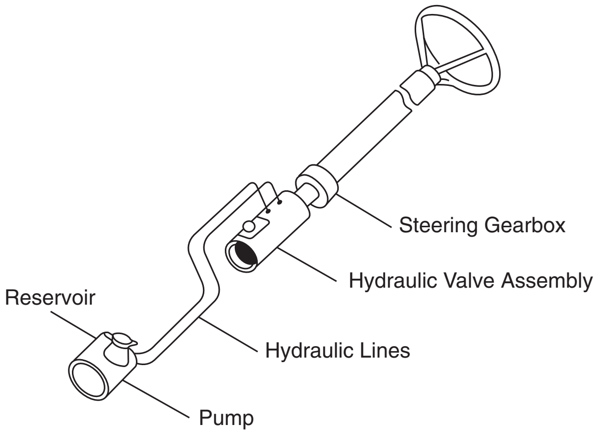



**Fig. 16.22** Power Steering System

The purpose of power steering is to reduce the driver's effort required for steering, and is particularly useful when driving at low speeds on rough grounds. Further, it is also useful when reversing the vehicle for parking purposes.

In India power steering is used in Hippo and Beaver dumpers manufactured by M/s Ashok Leyland. Figure 16.23 shows the power steering layout of these vehicles in line diagram.

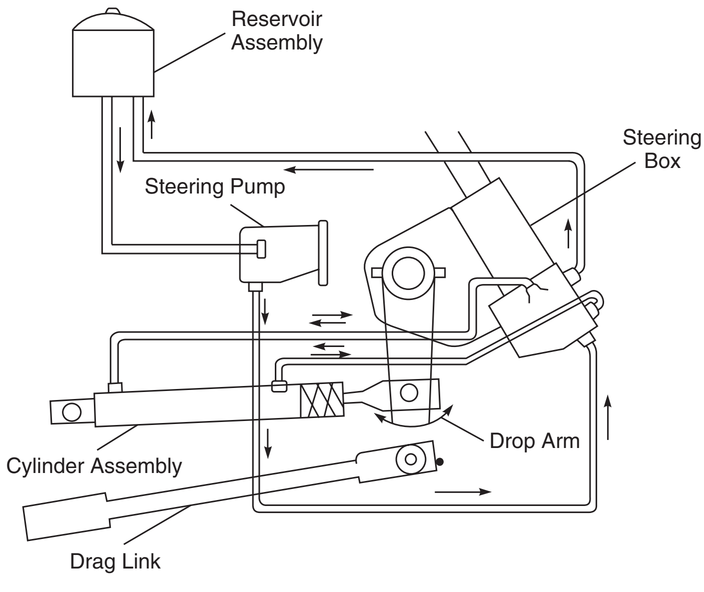



**Fig. 16.23** Power Steering Layout-hippo and Beaver Dumper

## 16.13 UNDERSTEERING AND OVERSTEERING

When a wheel and tyre assembly is steered, i.e. moved away from the direction in which it is travelling, the angular difference between the aimed direction and the direction of motion is known as the *slip of creep angle* shown in Fig. 16.24. Under these circumstances, the centre line of the tread is deflected as it contacts the ground and the reaction from the road generates a cornering force which acts behind the centre of the contact area of the tread. The size of this force per slip angle degree is known as the *cornering power*, and the cornering power depends largely upon the design of the tyre and its inflation pressure.

When the slip angle of the front wheel is greater than the rear wheel, the vehicle turns at a radius larger than that intended and the driver has to keep steering into the turn. This condition is known as understeer.

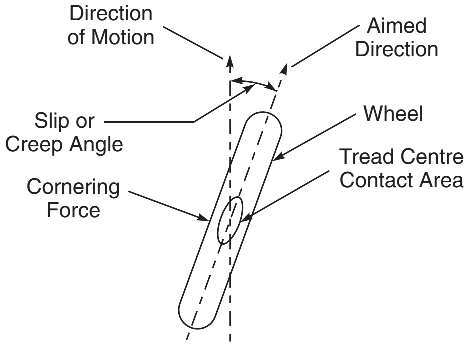



**Fig. 16.24** Slip Angle

When the slip angle is greater at the rear wheel than at the front, the vehicle tends to oversteer, then is to turn into the curve more than the driver intended.

Neutral steer occurs where the front and rear slip angles are the same.

## 16.14 STEERING LOCK

Steering lock is related to the smallest radius of turn which the vehicle can make either to the left or the right. A good or large lock resulting in a small radius of turn, is essential for easy manoeuvring, and large locks are always provided for taxis and small delivery vehicles. These can usually turn inside a circle of about 7 m in diameter. Small cars are usually able to turn in a 9 m diameter circle, while commercial vehicles may have turning circles of between 9 m and 15 m in diameter. The longer the vehicle the larger is its turning circle.

## 16.15 TURNING RADIUS

During a turn, the wheel on the inside goes through a sharper corner than the one on the outside. This is usually described as the turning radius (Fig. 16.25). The difference, usually only about three degrees, results from the way the steering linkage is designed. Turning radius is checked during wheel alignment. If it is incorrect it cannot be adjusted. A vehicle with an incorrect turning radius will drag the wheels around a corner, causing fast wearing of tyres.

The turning radius of cars varies from 5 m to 7.5 m, whereas in case of buses or trucks it is as high as 13.85 m.

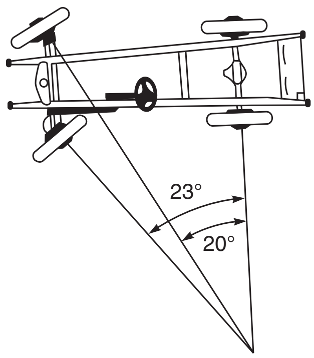



**Fig. 16.25** Turning Radius

**Table 16.3** Troubleshooting of Steering

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Hard steering | (a) Steering column bush tight. | Free-up as required or replace |
| | (b) Steering gear adjustment is too tight | Adjust as necessary. |
| | (c) Roller shaft bush seized | Replace the bush. |
| | (d) Bent control arm steering knuckle or arm | Replace as necessary. |
| | (e) Faulty wheel alignment | Carry out the wheel alignment according to specifications. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| 2. Side to side wander | (a) Excessive steering gear play | Adjust to the specifications. |
| | (b) Steering mounting bolts loose | Tighten as required. |
| | (c) Improper tyre pressure | Retain as specification. |
| | (d) Loose wheel bearing. | Tighten according to specifications. |
| 3. Excessive play | (a) Improper straining gear adjustment | Adjust according to specifications. |
| | (b) Steering mounting bolts loose | Tighten as required. |
| | (c) Tie rod ends worn-out | Replace. |
| | (d) Worn idler arm bushings | Replace bush. |
| 4. Front wheel shimmy | (a) Steering mounting bolt loose | Tighten as required. |
| | (b) Tie rod ends worn-out | Replace. |
| 5. Tyre squeals on turns | (a) Binding in first suspension joints on in steering linkages | Adjust and lubricate as required. |
| 6. Abnormal tyre wear | (a) Binding in steering linkages | Adjust or replace and lubricate. |
| | (b) Incorrect steering gear adjustment | Adjust according to the specifications. |
| 7. Poor recovery on turns | (a) Binding steering linkages and ball joints | Lubricate and free up. |
| | (b) Tight steering gear adjustment | Adjust according to specifications. |
| | (c) Improper wheel alignment | Carry out wheel alignment according to specifications. |

## Review Questions

1. State the function of the steering system.
2. Define steering ratio.
3. What are the types of steering boxes used in Indian vehicles?
4. Through what parts does the steering wheel have to transmit power to turn the front wheel?
5. How does the steering system work in a Maruti cars?
6. Describe a recirculating ball steering gear.
7. What does the steering linkage do?
8. Describe a collapsible steering column.
9. Define and explain the following:
   (a) Caster angle
   (b) Camber angle
   (c) Kingpin inclination, and
   (d) Toe-in.
10. What is wheel alignment?
11. What is Ackerman principal and explain it in detail?
12. From where is power steering hydraulic pressure obtained?
13. What is turning radius? What is its significance?
14. What are steering troubles and their causes?

# 17 Brakes

**Objectives**

After studying this chapter, you should be able to:

- Describe the function of a brake system.
- Explain the actuating mechanism of a brake system.
- Explain the meaning of leading and trailing shoe.
- Describe the parts and operation of the master cylinder and tandem master cylinder.
- Explain the operation and identify the components of a drum brake system.
- Explain the operation of self energised brakes.
- Explain the operation and identify the components of a disc brake system.
- Explain the operation and identify the components of a power brake system.
- Describe the operation of ELGI power brake.
- Explain the operation and identify the components of air hydraulic brakes.
- Describe the operation of emergency and parking brake system.

## 17.1 INTRODUCTION

Apart from the mechanisms for starting, accelerating and running a vehicle on the road, an additional system for stopping the vehicle is also required. Stopping a 2,000 kg vehicle moving at highway speed is no easy job. The heart of the brake system is a master cylinder assembly connected to the brake pedal. Pushing on the brake pedal causes the master cylinder to force hydraulic fluid through the brake lines out to each of the automobile's four wheels. The hydraulic fluid works the wheel brake assembly on each wheel, which uses friction to stop the wheel from rotating and thus stops the automobile.

## 17.2 FUNCTIONS OF A BRAKE

The brakes of a vehicle have to absorb all the energy given to the vehicle by the engine plus that due to the momentum of the vehicle. This energy must then be wasted or dissipated. In most vehicle brakes, the energy is absorbed by friction, converted into heat and the heat dissipated by the stream of air passing under and around the vehicle. As the energy is absorbed, the vehicle is slowed down; in other words, its motion is retarded. The brakes must also pull up the vehicle smoothly and in a straight line. The road wheels may be retarded, or braked, by means of a drum or disc friction brakes, or by a friction brake which is applied to some part of the transmission system.

## 17.3 REQUIREMENTS OF A BRAKE SYSTEM

In our country, the main requirement of a braking system is that "Every motor car shall be equipped with an efficient braking system or braking systems efficient under the most adverse conditions to bring the vehicle to rest within a reasonable distance."

In addition to the main requirement that a vehicle shall stop within a reasonable distance, it is further desirable that the retardation shall be smooth and free from Jark or shudder. It is also important that the rate of retardation shall be proportional to the pedal effort. This means that whilst the effort required by the driver to operate the brakes shall not be excessive, he will also feel that the harder he presses the pedal the more rapid the stop. A further requirement is that the performance should not vary, and that the rate of wear must be low. The braking system should be very reliable to promote the highest degree of safety on the road. It should not be affected by water, heat, road grit or dust etc. It is also important that the braking system should require very little maintenance and adjustments. It should have a long and economical life.

## 17.4 BRAKE ACTUATING MECHANISM

Hydraulic brakes are applied by the driver through an actuating system using hydraulic principles to multiply the brake pedal force. The science of hydraulics is based on Pascal's principle which states that *pressure applied to any area of an enclosed fluid is transmitted undiminished in all directions to every interior surface of the vessel.* In a brake actuating system, the enclosed vessel is a master cylinder and a wheel cylinder with connecting lines and hoses (Fig. 17.1). Any pressure applied to the master cylinder is transmitted undiminished to each wheel cylinder.

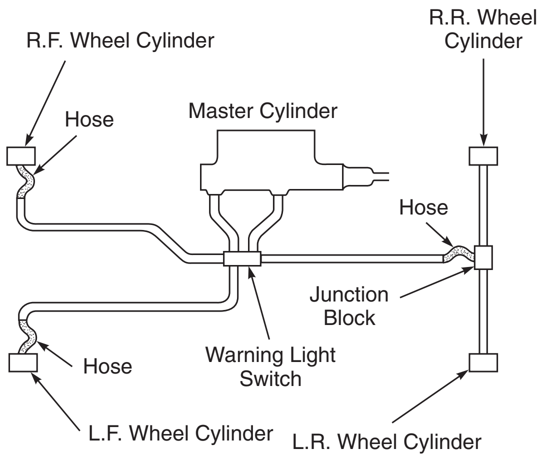



**Fig. 17.1** Brake Actuating Mechanism

## 17.5 LEADING AND TRAILING SHOES

A drum brake can be designed with two leading shoes, two trailing shoes or one leading shoe and one trailing shoe.

The leading and trailing shoe type brake is shown in Fig. 17.2. The location of the shoe anchor in relation to the forward wheel rotation is used to describe the type of shoe and its parts. The anchor end of the brake shoe is called the heel. Actuating force is applied to the toe end of the shoe. When the brake drum rotates from the shoe toe and towards the shoe heel, it is called a leading shoe. If the rotation is from the heel towards the toe end of the shoe, it is called a trailing shoe.

## 17.6 CLASSIFICATION OF BRAKES

The automobile brakes are classified according to the method of applying the brake shoes to the revolving brake drums as *internal-expanding* or *external-contracting*. Another classification is on

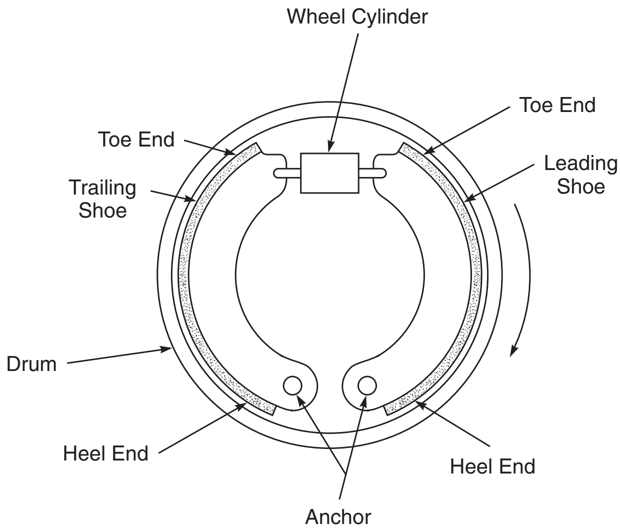



**Fig. 17.2** Leading and Trailing Brake Shoe

the basis of whether the braking force is transferred from the foot pedal or hand lever to the brake shoes by means of mechanical linkage or by hydraulic pressure. These are known as mechanical or hydraulic brakes.

## Mechanical Brakes

In a mechanical brake system the pressure from the brake pedal is transmitted to the wheel brakes by means of rods and shafts as shown in Fig. 17.3, or by means of cables and shafts. The shoes are expanded against the drum by cams or by means of levers, toggles or wedges. The entire mechanical linkage between the brake pedal and the shoes operates to transmit the pedal force to the brake shoes.

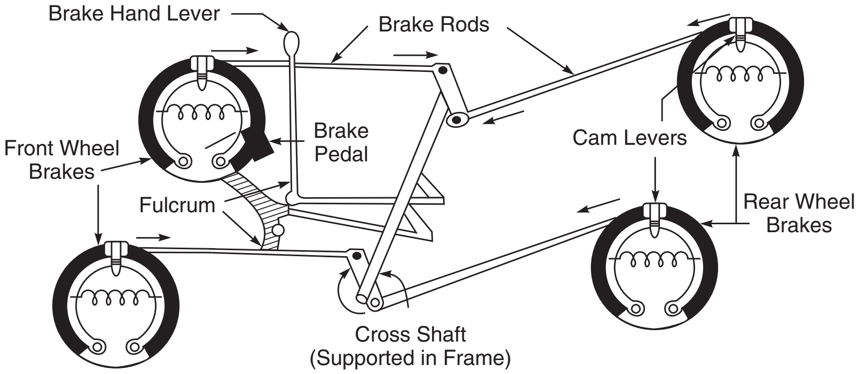



**Fig. 17.3** Mechanical Brake

***Note*** *In modern practice, the foot-operated mechanical brake is not used but in its place, the hydraulically foot-operated brakes are used. However the principle of operation of mechanical brakes is still utilised in parking and emergency brake by units.*

## Hydraulic Brakes

One of the major advantages of using a fluid to operate the brakes is that complete compensation is achieved. This is because a fluid in a closed circuit exerts an equal pressure in all directions. A further advantage is that as no mechanical linkage is necessary (except for the hand brake), frictional losses are considerably reduced. Passenger cars and medium capacity trucks have hydraulic brakes. Figure 17.4 shows the principle of the Lockhead hydraulic brake system. It is used in Ambassador car manufactured in India by M/s Hindustan motors Ltd. It comprises a combined fluid supply tank and a master cylinder in which the hydraulic pressure is generated, and a wheel cylinder which operates the brake-shoes. Steel pipe lines, unions and flexible hoses convey the hydraulic pressure from the master cylinder to each wheel cylinder.

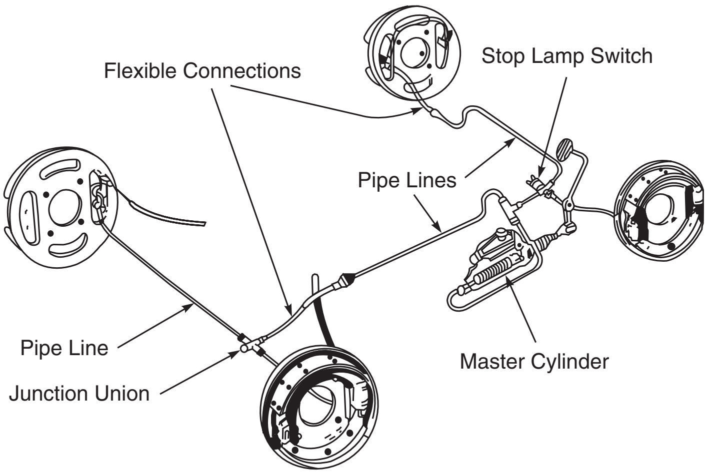



**Fig. 17.4** Lockhead Hydraulic Brake System

As the brake pedal is depressed, the rod pushes the piston of the master cylinder, thus applying pressure to the brake fluid. Moving through pipes and hoses to the wheel cylinders, the fluid forces apart the cylinder pistons, and the latter press the shoes against the brake drums. When the brake pedal is released, the piston in the master cylinder returns to the initial position, the shoes are pulled back by the return springs, the fluid flows back into the brake master cylinder, and braking ceases.

**(a)** ***Master Cylinder*** The master cylinder is a cast iron body containing a cylinder bore, a fluid reservoir and fluid passages. Ports are drilled between the reservoir and the cylinder bore to allow the make-up fluid to enter the system or to allow the expanded fluid to return to the reservoir. The master cylinder piston is a long piston with two lip-type cup seals, one close to each end. The inner seal, called a primary cup is used to build up hydraulic pressure in the system. The outer seal, called a secondary cup, keeps fluid from leaking out of the master cylinder.

Figure 17.5 shows the sectional view of the master cylinder of the jeep manufactured by M/s Mahindra and Mahindra. Referring to Fig. 17.5 it is seen that the master cylinder consists of a fluid reservoir. In some master cylinders the reservoir is fitted separately from the master cylinder and is connected through a pipe as in the Fiat and Matador vehicles, but the working is the same.

***Working of Master Cylinder*** When the brake pedal is depressed, the master cylinder piston moves forward to force the fluid under pressure into the system. The bypass port is sealed out of the

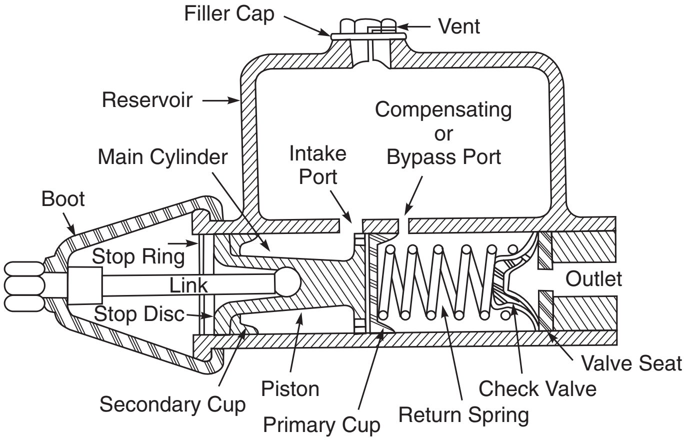



**Fig. 17.5** Sectional View of Master Cylinder

system. The liquid pressure is conducted to the wheel cylinders, where it forces the wheel cylinder pistons outwards. These pistons force the brake shoes out against the brake drums. When the brake pedal is released, the spring in the cylinder will force the piston and primary cup to act, opening the bypass port. The fluid in the lines will now be forced back by the pressure exerted on the wheel cylinders by the brake shoes return springs. When the fluid in the lines reaches a certain pressure (in some cases, 0.56 kg/cm$^2$) the two way valve will be forced into its seats by the return spring, thus holding pressure in the lines. This pressure is necessary as it gives a certain amount of initial pressure for quick brake application and also prevents air from getting into the system.

The secondary cup in the master cylinder acts as a seal to prevent fluid from leaking out of the cylinder as it comes in through the intake port. As the piston returns, the fluid comes in through the intake port and passes forward through the holes in the piston and port the edges of the primary cup.

**(b)** ***Check Valve*** The check valve opens during the pressure stroke to allow the fluid to enter the lines. The returning fluid is also to re-enter the cylinder by raising the entire valve from its seat until the pressure in the lines drops below 0.56 kg/cm$^2$ (6 to 8 lb per square inch). Then the return spring is capable of sealing the valve so as to maintain that slight pressure in the lines. This residual pressure acts as a seal to prevent gravity and the entrance of air into the system.

**(c)** ***Wheel Cylinder*** The wheel cylinder consists of two small pistons with a spring and cups. When the brake is applied the fluid pressure exerts pressure on the cups or washers. The motion is transmitted to the brake shoes to force them against the brake drum. The piston cup fits lightly in the cylinder against each piston and seals the mechanism against leakage of brake fluid. The light spring serves to hold the cups against the pistons when the pressure is released. The boots protect the cylinder from the entry of foreign material. Brake fluid enters the cylinder from a brake-line connection inlet between the opposed pistons as shown in Fig. 17.6. Bleeder valves are provided in each wheel cylinder to permit air and liquid to be pumped out of the system during the bleeding operation.

## 17.7 TANDEM MASTER CYLINDER

We have discussed earlier the working of a simple master cylinder which is mostly used in all small and medium type of vehicles. However, in some vehicles, the tandem master cylinder is used. In this system, master cylinders have been divided for safety to form two separate hydraulic systems. Loss of pressure in one system does not cause complete loss of brakes as it does in single master cylinder systems. The pistons in the two systems are in the same cylinder bore, one behind the other, so that pedal pressure is effective on both.

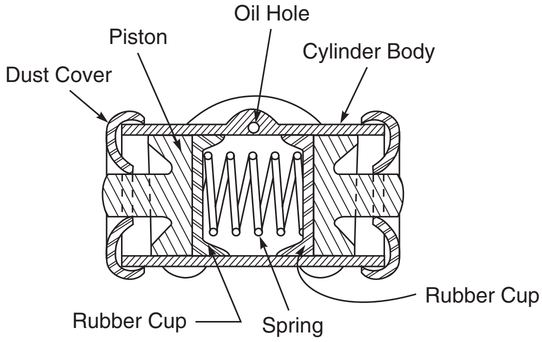



**Fig. 17.6** Sectional View of Wheel Cylinder

Figure 17.7 shows the Maruti tandem master cylinder assembly. The tandem master cylinder is similar in construction to an ordinary master cylinder, the principal differences being that it has two pistons and that hydraulic pressure is developed in two chambers, one for front left and rear right brakes and the other for front right and rear left brakes.

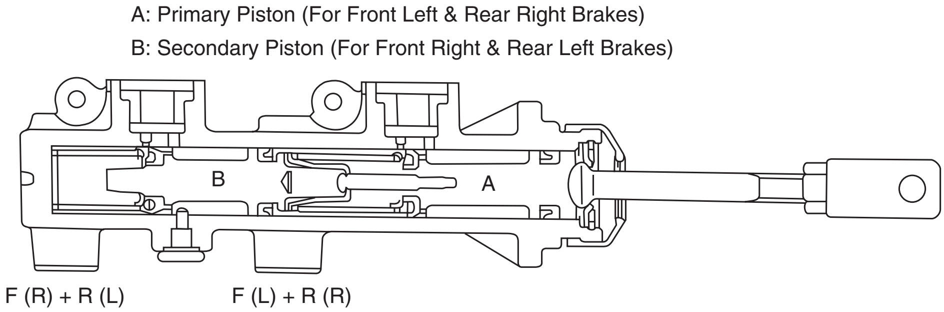



**Fig. 17.7** Sectional View of Tandem Master Cylinder

In Maruti-800 cars, the hydraulic pressure is developed in the master cylinder when the foot brake pedal is depressed. Four brake pipes are connected to the master cylinder and they make two independent circuits. One connects the front right and rear left brakes and the other connects the front left and rear right brakes. Figure 17.8 shows the Maruti car brake system; disc brake is used for the front wheel brake and a drum brake (leading/trailing shoes) for the rear wheel brake. The parking brake is mechanically operated by a cable and mechanical linkage. The same brake shoes are used for both parking and foot brakes. The working of the tandem master cylinder is now explained.

(1) *Under Normal Operation*

Depressing the brake pedal forces primary piston A (Fig. 17.9) towards the left and pressurizes the fluid immediately ahead for front left and rear right brakes. By this pressure and by the force of return spring, secondary piston B moves and pressurizes the fluid for the front right and rear left brakes.

(2) *One Circuit Operation*

Case I—(front left and rear right brakes circuit failure)

Depressing the brake pedal causes primary piston A to move as in normal operation, however as the front left and rear right brakes circuit cannot hold pressure, the fluid immediately ahead of this piston does not get pressurized. Piston A keeps moving, compressing the spring and when it

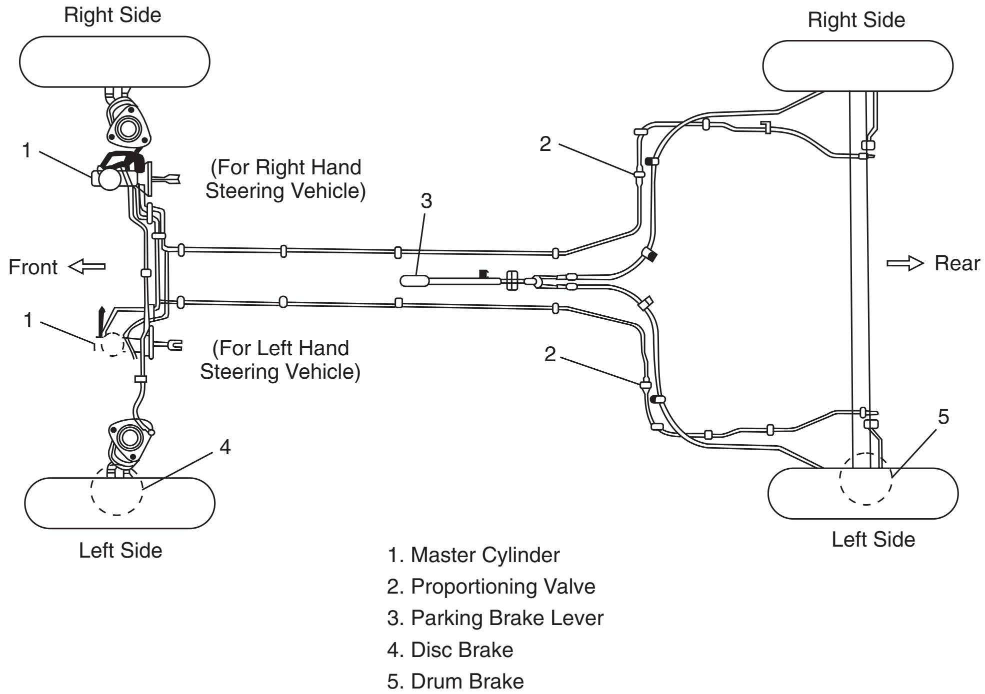



**Fig. 17.8** Brake System of Maruti Car

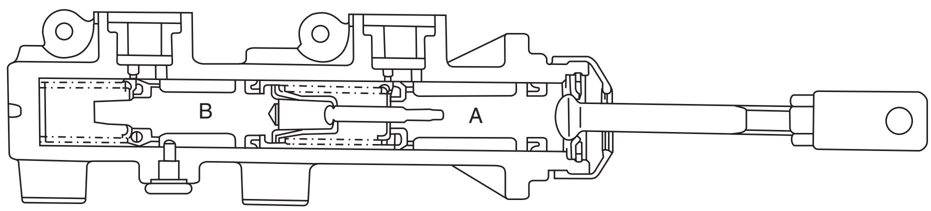



**Fig. 17.9** Operation of Master Cylinder When the Brake Pedal is Depressed

reaches the piston B retainer, it begins to push piston B. From this point on, piston B moves to pressurize the fluid ahead and thus actuate the front right and rear left brakes (Fig. 17.10).

Case II—(front right and rear left brakes circuit failure).
In this case, the leftward movement of piston A has but little effect in pressurizing its fluid (for front left and rear right brakes) at first, because the initial rise in fluid pressure causes piston B

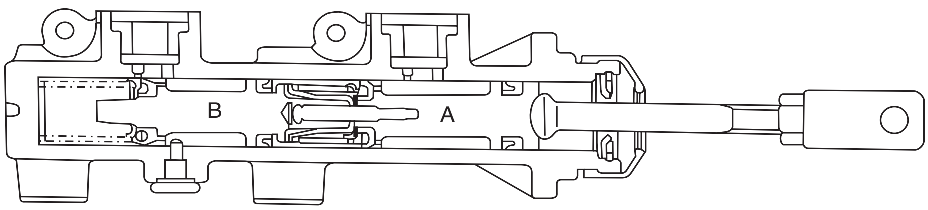



**Fig. 17.10** One Circuit Operation: From Left and Rear Right Failure

to promptly yield and move towards the left. Very soon the forward end of piston B comes to and bears against the head of the cylinder. From this point on, the leftward movement of piston A becomes effective to pressurize the fluid ahead of it for the front left and rear right brakes. Figure 17.11 shows the secondary piston B at halt.

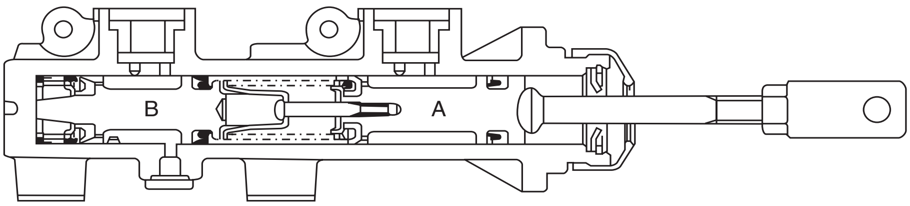



**Fig. 17.11** One Circuit Operation: Front Right and Rear Left Failure

## 17.8 DRUM BRAKES

Brakes are mounted on all four wheels. They stop the car by changing the kinetic energy of the vehicle (motion) into heat energy (heat). This is exactly the same principle as that used when dragging a foot on a skateboard or bicycle.

For many years, drum brakes were used exclusively. However, they have been almost totally replaced in the front wheels of new cars by disc brakes. Drum brakes are still used in the rear wheels of most cars.

### Drum Brake Assembly (Rear Wheel Brake)

Figure 17.12 shows the drum brake assembly of Maruti 800 cars having a self shoe clearance adjusting system. This assembly consists of the following main components:

**1. *Backing Plate and Brake Shoes*** Backing plates are bolted to the rear axle housing or spindle. Thus the backing plate and the parts mounted on it do not rotate with the wheels. Attached to the backing plates with pins and springs being two brake shoes, the shoes being free to move by limited amounts.

Brake shoes are built on a steel frame with a composition lining riveted or bonded to them. Initially, this composition material used to contain lots of asbestos. Other lining materials are—bonded resin and fillers. Such asbestos/resin linings are called *organic linings*. Some heavy-duty linings have powdered iron in them and are called *metallic linings*. Some linings use a combination of organic and metallic linings.

**2. *Wheel Cylinders*** Rigidly fixed to the backing plate between the brake shoes is the wheel cylinder. The wheel cylinder is simply a cylinder with two pistons at each end. It is similar to a small master cylinder, working in reverse and with no reservoir.

In the wheel cylinder, hydraulic pressure is converted to mechanical force. The brake lines connect to the wheel cylinders at the wheel cylinder's centre. Thus a chamber formed by the wheel cylinder and the pistons at each end are open to the brake lines. Fluid pressure from the master cylinder is felt in this chamber. It forces the wheel cylinder pistons outward. The outer end of the pistons is connected to the brake shoes. So when the pistons are pushed outward, the shoes must move outward as well.

**3. *Drums*** Covering the entire brake, including the shoes, wheel cylinder and backing plate, is the brake drum. The drum is attached to a suspension hub or axle, so that it rotates with the wheel.

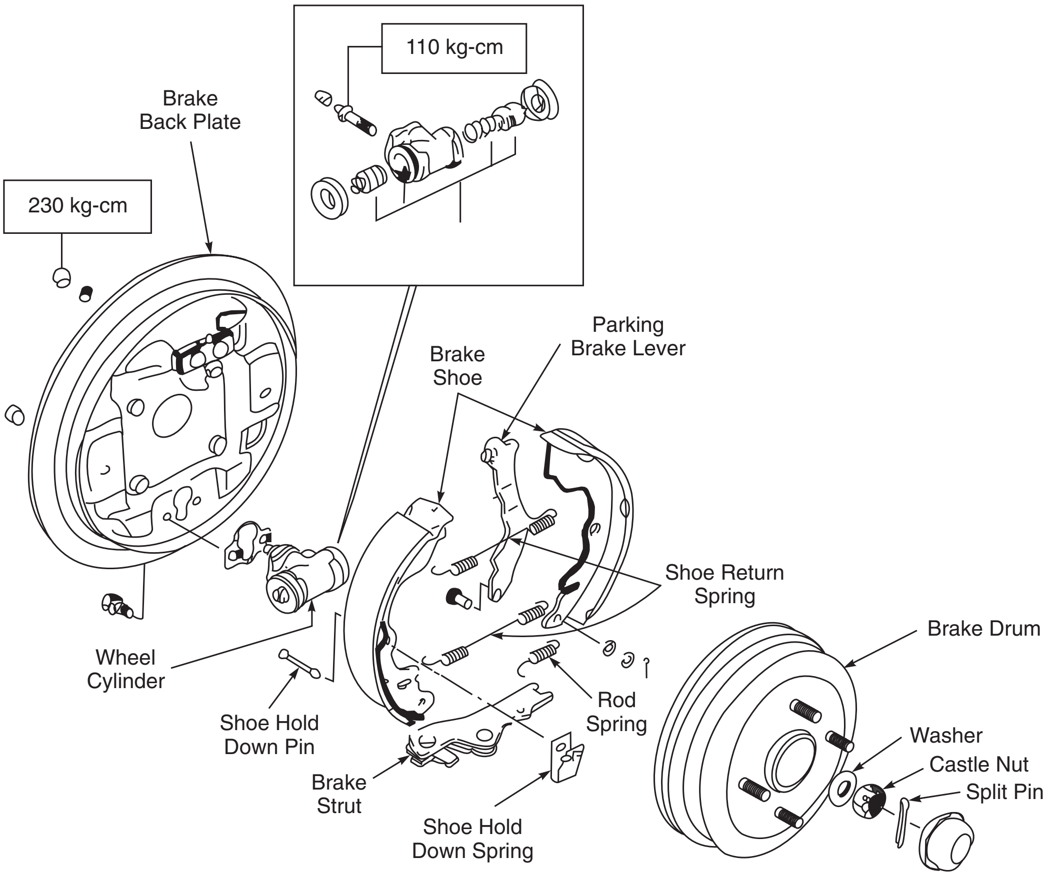



**Fig. 17.12** Drum Brake Assembly

It is the only part of the brake that rotates with the wheel and tyre. When the wheel cylinder pistons press the brake shoes outward, the shoes are forced against the rotating drum. Friction between the lining and drum turns the motion into heat causing the car to stop. When brake pressure is released, the shoes retract to their at-rest position. The springs mounted between the shoes retract the shoes.

Because the drum brake is enclosed by the drum and backing plate, cooling is difficult. Heat must pass into the drum and backing plate before it can dissipate into the atmosphere. Excessive heat warps the brake drum, causing grabby brakes.

## 17.9 SELF-ENERGIZED BRAKES

Most modern drum brake systems similar to the one shown in Fig. 17.13 are self-energizing or have servo action. When the driver presses on the brake pedal and the brake shoes move outward, they come in contact with the drum and tend to rotate with it. The primary shoe (usually the front shoe), rotating with the drum, moves away from the anchor pin and applies a rear force on the adjusting screw. At the same time the other shoe, called the secondary shoe, is rotating around until it comes in contact with the anchor pin.

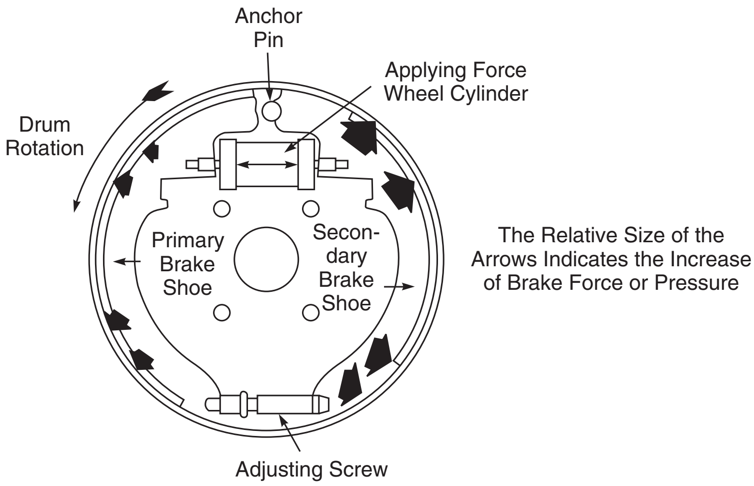



**Fig. 17.13** Self Energized Brake

As you can see, the force applied to the secondary shoe is the sum of the applied force on the primary shoe and the force caused by rotation (friction force) of the primary shoe. This combination of forces is the self-energizing action. The increased force it applies to the brake shoes means less physical effort is required at the brake pedal.

Since greater braking force is applied to the secondary shoe, the secondary shoe lining area is usually larger than the primary shoe lining area.

## 17.10 DISC BRAKES

Disc brakes are quite different from the drum brakes is that the drum is replaced by a circular plate and the brake shoes are replaced by a caliper which supports a pair of friction pads, one on each side of the disc. These pads are forced inward by the operating force and so retard the disc.

The advantages and disadvantages of disc brakes compared with drum brakes are as follows:

**1.** ***Advantages***

(i) Disc brakes are lighter than drum brakes.

(ii) Disc brakes have better cooling than the drum brakes because the braking surface is exposed directly to air.

(iii) Disc brakes offer better resistance to fade than drum brakes.

(iv) The pressure distribution is uniform since disc brakes have no self-servo effect.

(v) The brake pads can be easily replaced. It is not necessary to remove the tyre. Only two screws have to be removed and the brake pads replaced.

(vi) Disc brakes are self adjusting by design.

**2.** ***Disadvantages***

(i) There is no servo action in disc brakes.

(ii) It is difficult to install an adequate parking brake attachment.

(iii) The cost of disc brakes is higher than drum brakes because it includes the cost of a booster.

(iv) Higher pedal pressure is required for stopping vehicles.

## 17.11 FLOATING-CALIPER BRAKES

Figure 17.14 shows the sectional view of a single piston floating-caliper type of disc brake used in Maruti 800 cars. It has one cylinder and one piston. The cylinder is constructed as a mono block with the caliper. When the driver depresses the brake pedal, oil pressure generated in the cylinder causes the pad 1 on the piston side to press against the disc.

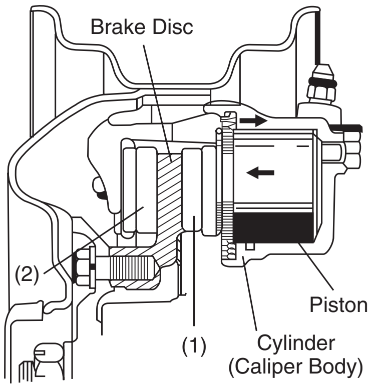



**Fig. 17.14** Sectional View of Single Position Floating Caliper Type Disc Brake

At the same time, the floating type caliper body is moved to the right by the cylinder pressure as shown in Fig. 17.14, which pulls pad 2 against the disc and so brakes the wheel.

Figure 17.15 shows the component of this type of disc brake. It has no servo assistance as in drum braking and it is necessary to increase the working pressure of the piston and pad. For this purpose, the wheel cylinders have a large bore. Only a little change in clearance between the disc and pad has a large influence on the brake pedal stroke. It is necessary to have the clearance adjusted to minimum at all times, by means of the piston (rubber) seal.

Figure 17.16 shows the two positions of rubber seal used to avoid leakage of brake fluid. When oil pressure is applied to the piston, the piston moves forward. The rubber seal, which exerts considerable pressure against the piston, moves with the cylinder. However, as a part of the rubber seal has been fixed into a groove in the cylinder, the shape of the rubber seal is distorted towards the internal end of the cylinder, as shown in Fig. 17.16. When pressure is taken off from the foot brake pedal and fluid pressure is released from the piston, restoring force is generated at the seal which pushes the piston back. As the pads wear away and the clearance between the disc and pads becomes larger, the piston moves a larger distance. The seal could then change in shape further but since the end of the seal is fixed into the groove in the cylinder, the distortion is limited to the same amount as previously described. The piston moves further to cover the distance of clearance. The piston returns by the same distance and the rubber seal recovers its shape as described and thus the clearance between the disc and pads is maintained in adjustment.

## 17.12 POWER BRAKES

Many automobiles are equipped with power brakes which operate through a power assist unit—a large canister mounted on the master cylinder shown in Fig. 17.17.

The master cylinder and wheel brake assemblies are the same as on a standard brake system. The linkage from the brake pedal goes through the power assist canister, which contains a large

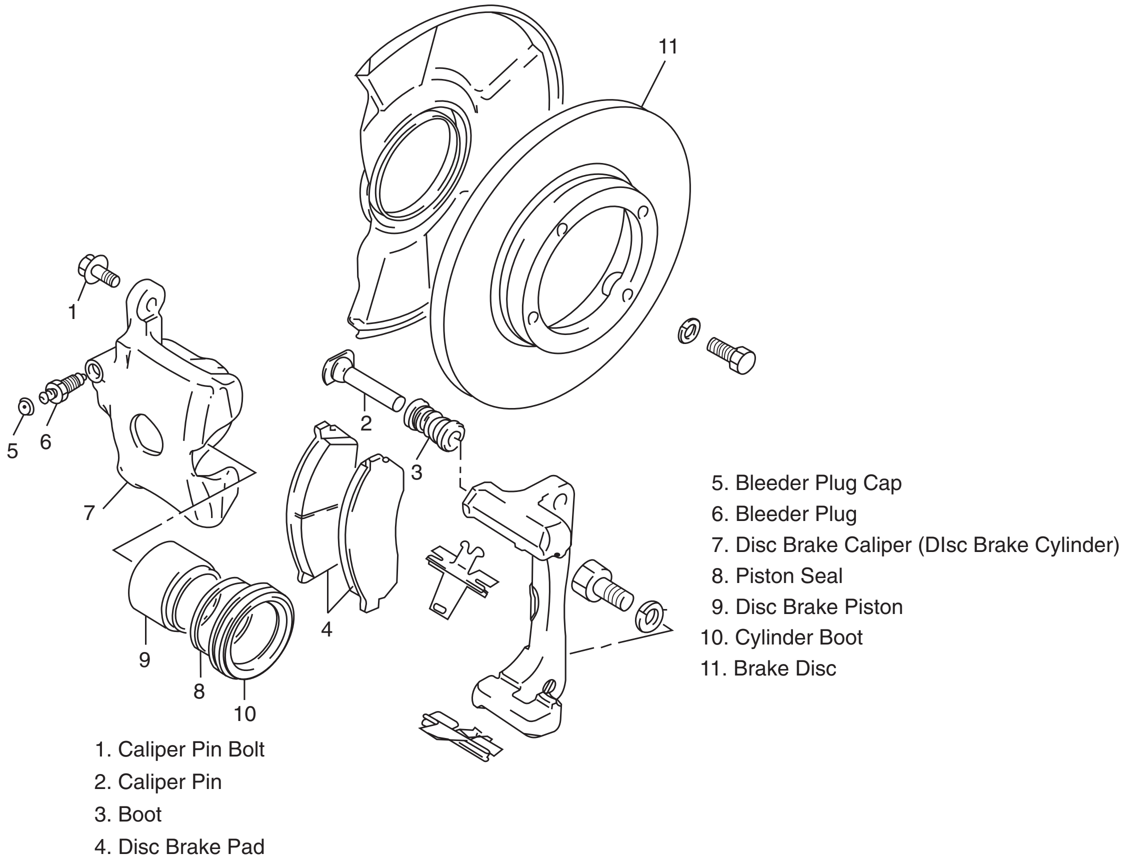



**Fig. 17.15** Components of Disc Brake System

round diaphragm. When the brake pedal is pushed, air is removed from one side of the diaphragm through a vacuum line from the canister to the engine intake manifold. With a vacuum on one side of the diaphragm and atmospheric pressure on the other, the diaphragm moves to help the driver's push on the brakes. Power brakes require much less pedal effort to apply. If the system fails, the driver can still apply the brakes, but a great deal of pedal effort is required.

M/s Hindustan Motors Ltd. offers the power brake unit ELGI type for their Ambassador cars as an optional unit. This unit has been designed to assist the normal hydraulic brake system using the available vacuum source from the engine. It is easy to fit and will not

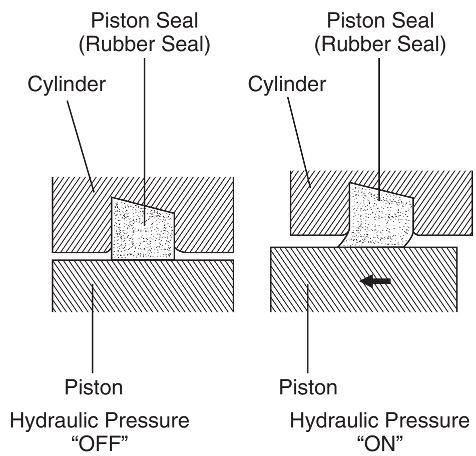



**Fig. 17.16** Working of Rubber Seal in Disc Brake

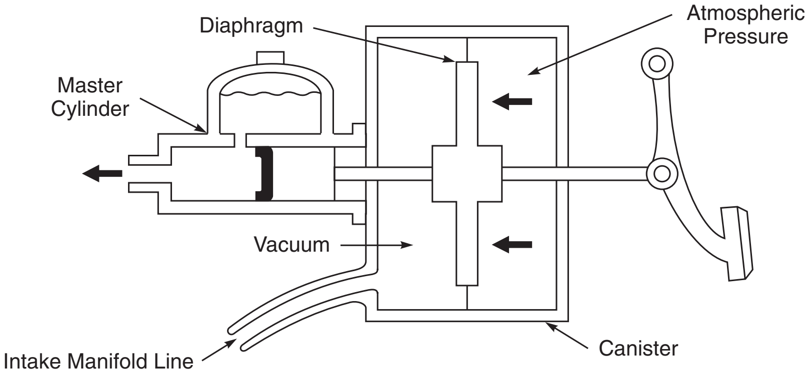



**Fig. 17.17** Power Brake

disturb the existing brake system. It is designed to operate the brake normally, even if there is a failure of vacuum, that is, with the engine stoppage. Figures 17.18 and 17.19 show the layouts of this braking system and sectional views of the power brake assembly.

## Operation of ELGI Power Brake

(i) With the brake pedal in released position (Fig. 17.20).
The air from the front dish, rear dish and pilot valve chamber is exhausted by the vacuum created in the engine suction manifold, through a non-return valve. The main diaphragm is held against the rear dish by the spring load.

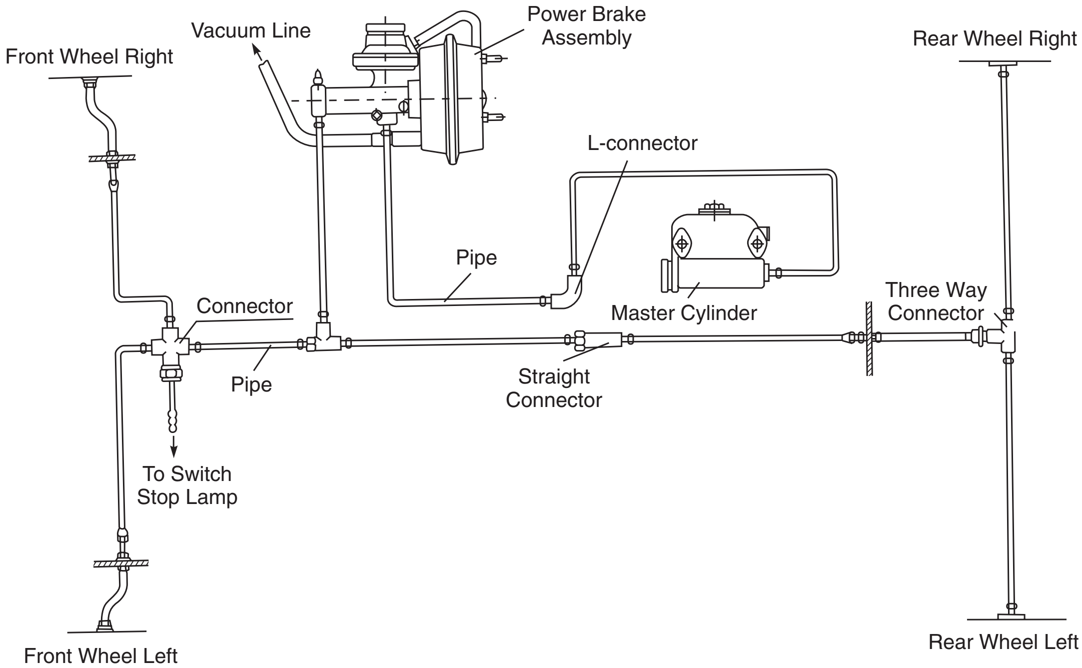



**Fig. 17.18** Layout of ELGI Power Brake Unit in Ambassador Car

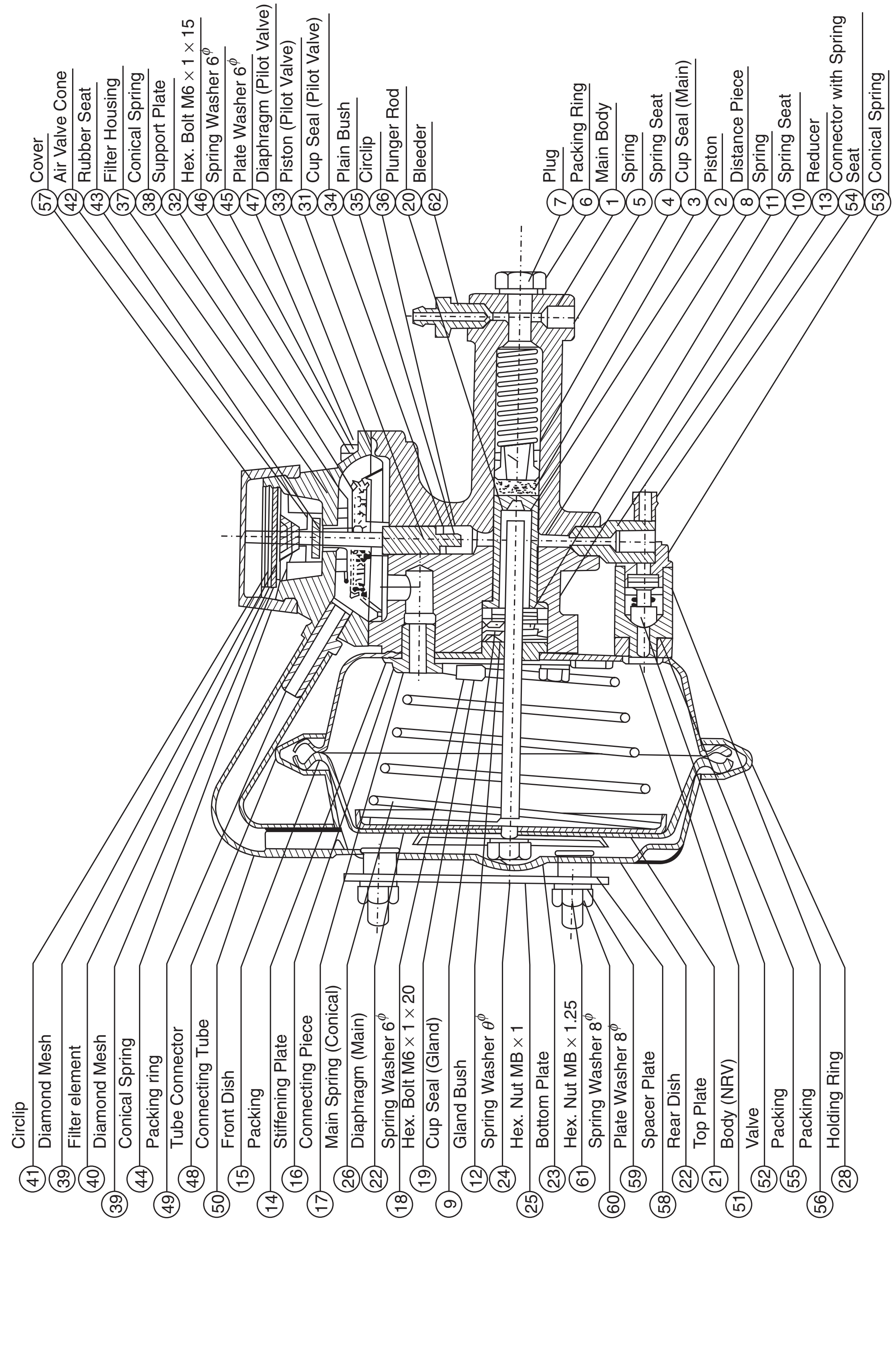



**Fig. 17.19** Sectional View of Power Brake Assembly

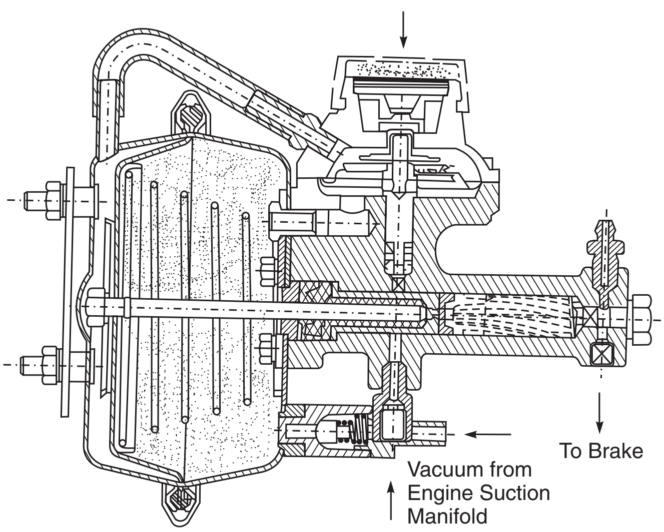



**Fig. 17.20** Brake Pedal Released Position

(ii) With the brake pedal in pressed position (Fig. 17.21).
The fluid from the master cylinder flows through the piston to the pressure line pipes and simultaneously the fluid pressure lifts the pilot valve piston. The pilot valve piston moves

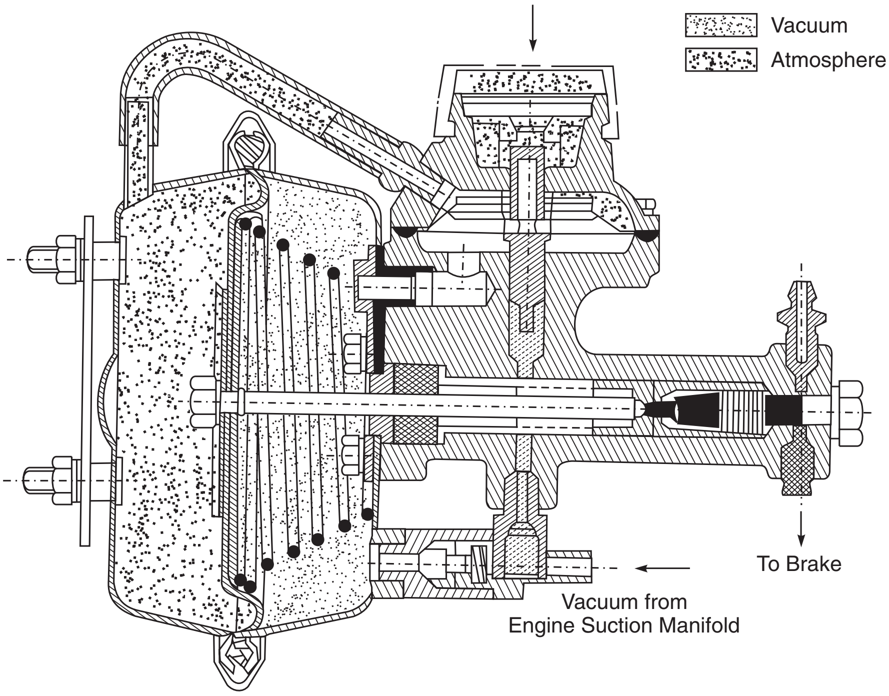


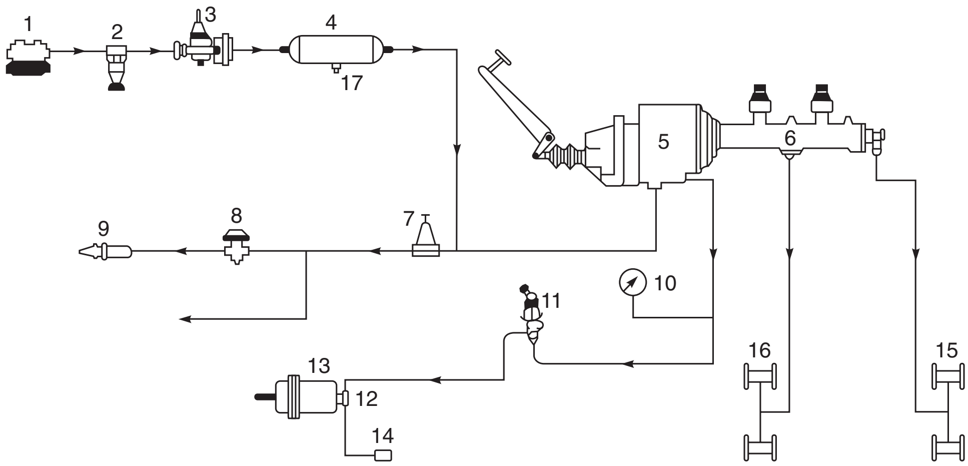

**Fig. 17.21** Brake Pedal Pressed Position

up and the air valve is seated on the pilot valve piston which isolates the vacuum on the bottom side of the pilot valve diaphragm. At the same time, since the air valve cone is lifted off the seat in the filter housing, atmospheric air enters the rear dish through the top side of the pilot valve diaphragm.

The differential pressure created in this manner on both sides of the main diaphragm forces the diaphragm to move forward and the plunger rod closes the hole in the main piston. Further movement of the piston boosts the line pressure and this fluid under boosted pressure flows to the wheel cylinders, through the connection tubes.

## 17.13 AIR-HYDRAULIC BRAKES

In air-hydraulic type of braking system, air pressure is taken for the application of brakes. As a safety aspect in this system, the brake pedal link and push rod of the master cylinder are so designed and linked that in the event of failure of air pressure, brakes can be applied but once again more foot pressure will be required. The commercial vehicles manufactured by M/s Tata Engineering and Locomotive Company have air-hydraulic brakes. Figure 17.22 shows the brake circuit diagram of Tata Truck Model 1210. The brake circuit consists of various pneumatic and hydraulic components. The function of each component is briefly explained.




1. Compressor
2. Tyre Inflator & Filter
3. Unloader Valve
4. Reservoir
5. Truck Valve
6. Tandem Master Cylinder
7. Regulator Valve
8. Exhaust Brake Valve
9. Exhaust Brake Cylinder
10. Pressure Gauge
11. Flick Valve
12. 
13. Spring Brake Chamber
14. Non-Return Valve
15. Front Wheel Cylinder
16. Rear Wheel Cylinder
17. Drain Plug

**Fig. 17.22** Air-Hydraulic Brake Circuit Diagram of Tata Truck

**(i) *Air Compressor*** The air-compressor is engine-mounted and driven directly by the camshaft eccentric. It delivers compressed air to the air tank through the tyre inflator-cum-filter and unloader valve.

**(ii)** ***Unloader Valve and Tyre Inflator*** The unloader valve and tyre inflator shown in Fig. 17.23 performs the following functions:

(a) Filters the air delivered by the compressor.
(b) Governs the air pressure in the tank.
(c) Prevents the back flow of the air towards the compressor when cut-out is reached.
(d) Provides means for inflating the tyres by using the compressor as a source of supply during emergency.
(e) Has a built-in safety valve.

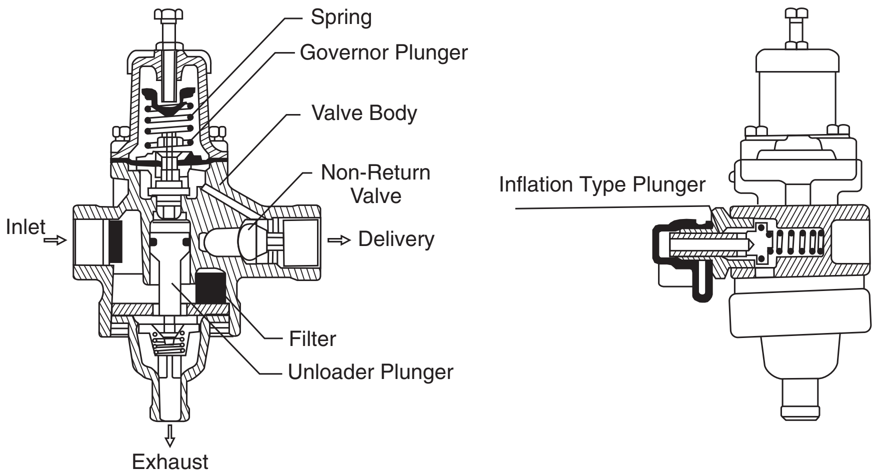



**Fig. 17.23** Unloader Valve and Tyre Inflator

**(iii)** ***Air Tank*** The air tank is a reservoir for storing and delivering uninterrupted supply of compressed air to the inlet of the truck brake valve. It also facilitates periodical draining of oil and water collected at the bottom of the tank.

**(iv)** ***Truck Brake Valve*** The truck brake valve is a lever type servo and is fitted on the chassis. The front end is linked to the brake pedal and the rear to the tandem master cylinder (Fig. 17.24). The function of the truck brake valve is to boost the force applied on the tandem master cylinder by the driver at the time of application of brake.

**(v)** ***Spring Brake Chamber*** The spring brake chamber is mounted on the chassis cross member and is connected to the parking brake operating linkage on the rear axle (Fig. 17.25). It consists of a compression spring which is kept pressed by air pressure with the help of the piston and crown with seal assembly when the brakes are in released (off position) condition. When air gets exhausted due to the operation of flick valve, the resulting spring expansion pulls the piston rod and parking brakes are applied.

**(vi)** ***Flick Valve*** The flick valve is mounted on the right side of the driver seat or near the instrument panel. The inlet is connected to air the tank and the delivery port is connected to the spring brake chamber (Fig. 17.26). With this valve in "off" position, parking brakes are in released condition while in the "on" position, the brakes are applied. Also there is a lock to keep the valve either in the on or off positions.

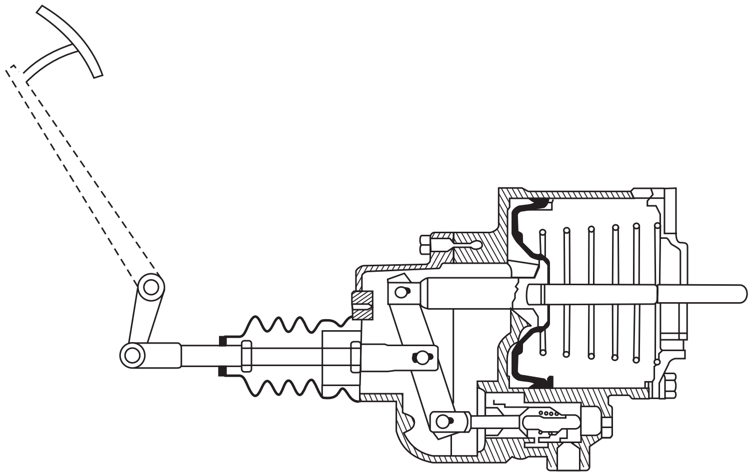
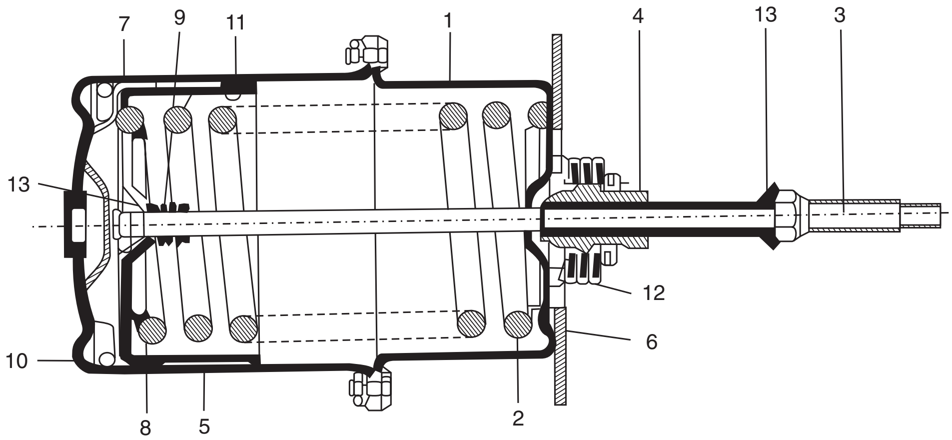


**Fig. 17.24** Truck Brake Valve

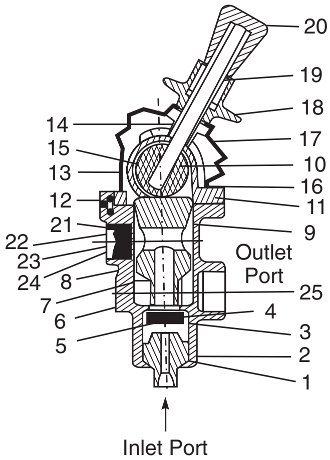



1. Spring Brake Chamber Body
2. Unloader Valve
3. Comression Spring
4. Piston Rod
5. Stopper Nut
6. Piston
7. Spring Seat (Rear End)
8. Spring Seat
9. Seat Cups
10. Springs
11. Crown with Seal Assembly
12. Wear Pad
13. Gaiter
14. Spherical Washer

**Fig. 17.25** Spring Brake Chamber

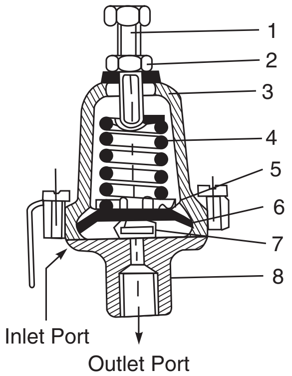
**(vii)** ***Pressure Protection Valve*** The pressure protection valve is used to protect the main service brake circuit and feed air to auxiliaries of the brake system (Fig. 17.27). This valve allows air to pass to the auxiliary system only after the tank pressure has reached 5 bar and hence ensures a minimum pressure for service brake in case of failure leakage in the auxiliary circuit.

**(viii)** ***Foot Control Valve*** The foot control valve is a foot operated engine exhaust brake valve. When it is depressed, the compressed air actuates (Fig. 17.28) the air cylinder. The air cylinder operates the butterfly valve and closes the exhaust manifold. The engine acts as a brake, the vehicle inertia runs the engine as a compressor and the speed of the vehicle is reduced/controlled.




1. Inlet Adaptor
2. Washer
3. Inlet Valve Spring
4. Valve Guide
5. Valve
6. Valve Body
7. Spring
8. 'O' Ring
9. Plunger
10. Cam
11. Top Cover
12. Counter Sunk Screw
13. Pivot
14. Lever
15. Tension Pin
16. Dial
17. Gaiter
18. Sleeve
19. Spring
20. Knob
21. Wire Mesh Filter
22. Stainer Plate
23. Split Pin
24. Exhaust Port
25. Outlet Port

**Fig. 17.26** Flick Valve




1. Adjustment Screw
2. Nut
3. Top Half
4. Adjustment Spring
5. Spring Guide
6. Diaphragm
7. Valve
8. Bottom Half

**Fig. 17.27** Regulator Valve (Auxiliary)

**(ix) *Engine Exhaust Brake Coupled with Service Brake*** The engine exhaust brake is operated by actuating a foot control valve. As a design improvement, the exhaust brake operation has now been coupled with a service brake. Hence whenever brake pedal is depressed for applying service brakes, the engine exhaust brake also gets operated automatically. This improvement has been gradually introduced in Tata truck models 1210, 1510, 1612 and 1613.

1. The major advantages derived from the improved design are:

   (a) Improved life of brake liners, brake drums and tyres.
   (b) Increased safety and better control of the vehicle.
   (c) Reduced maintenance time and cost.
   (d) Optimum fuel economy.

2. Constructional details of the improved engine exhaust brake system:

Figure 17.29 shows the arrangement of the exhaust brake coupled with the service brakes. The new brake valve is mounted on the control lever box (for mounting truck brake valve) by means of a

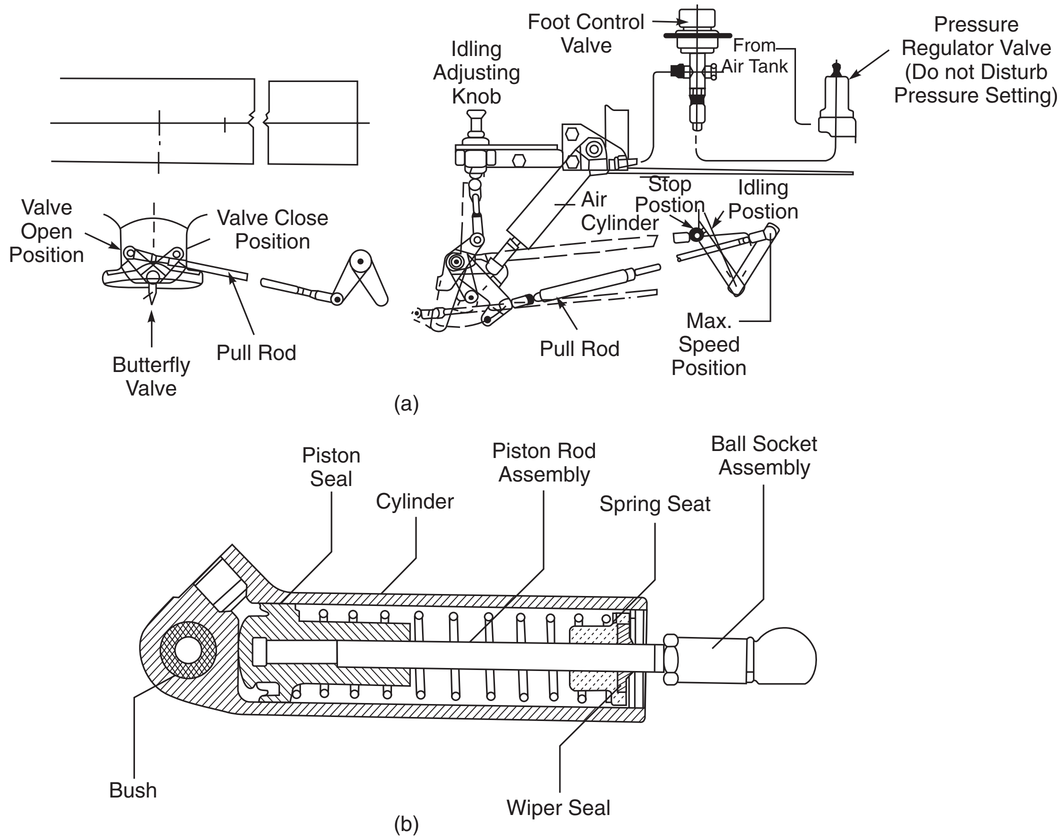



**Fig. 17.28** Exhaust Brake Air Cylinder

small bracket welded on it. The spindle of the exhaust brake valve is kept pressed, against a plate welded on the brake double lever. The exhaust brake valve is connected to the pressure regulator valve and the exhaust brake air cylinder by suitable air pipes.

The exhaust butterfly valve, exhaust manifold, air cylinder and pressure regulator valve remain the same and are interchangeable with the existing system. The foot control valve and the fuel cut-off arrangement, as in the existing system are deleted in the new system.

3. Working of the engine exhaust brake coupled with service brake:
When the brake pedal is depressed, the brake double lever rotates on its hinge, operating the truck brake valve for service brake application. With the rotation of the double lever, the spindle of the exhaust brake valve gets released, connecting the exhaust brake cylinder to compressed air, thus operating the butterfly valve in the exhaust manifold and applying the engine exhaust brake.

During this operation, since the accelerator pedal is in idling position and the exhaust manifold opening is restricted, the wheels drive the engine, assisting the service brakes in controlling vehicle speed. The engine exhaust brake remains in operation as long as the service brake pedal is depressed. When the brake pedal is released, the spindle of the exhaust valve is pushed back to its original position, thereby cutting off the compressed air supply. The exhaust brake air cylinder is then open to atmosphere through the exhaust brake valve, facilitating its spindle to return home.

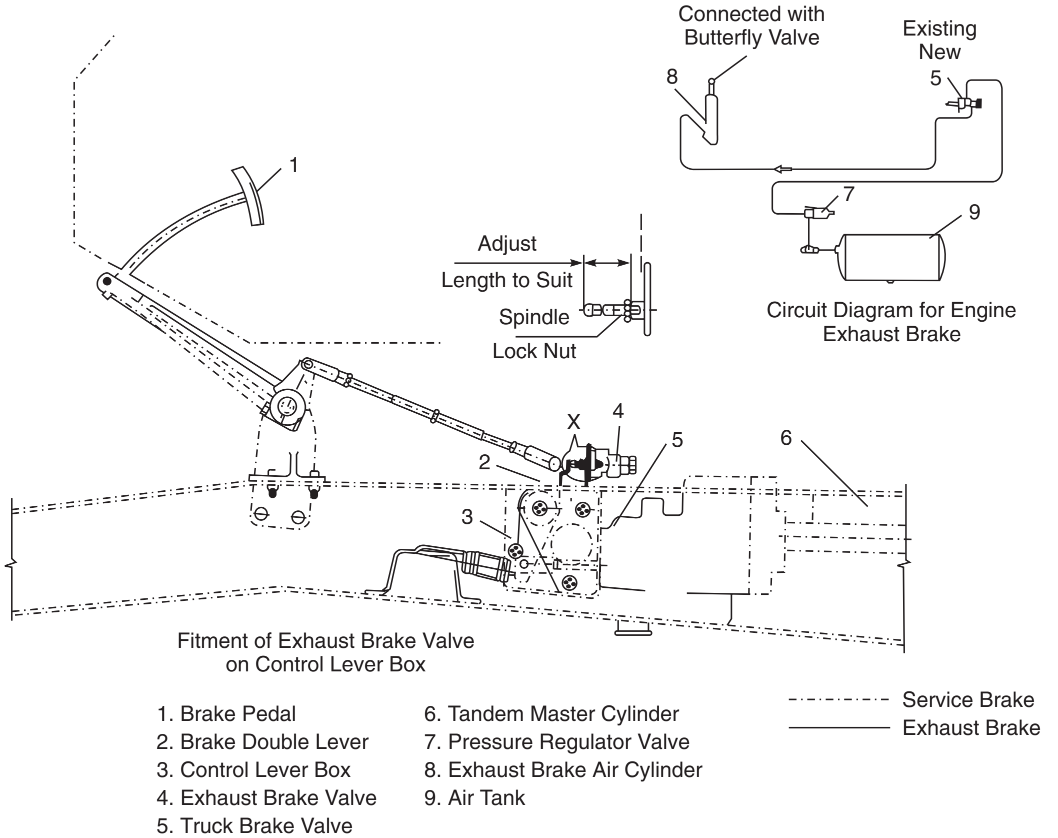



**Fig. 17.29** Engine Exhaust Brake Coupled with Service Brake

4. Exhaust brake valve adjustment and maintenance:

   (a) Check all the adjustments of the brake pedal, before fitting the exhaust brake valve.
   (b) In the released condition of the brake pedal, adjust the brake valve spindle length such that the valve is fully pressed and then tighten the lock nut.
   (c) Apply the brake pedal a few times, to make sure that the exhaust brake is operating properly.
   (d) Overhaul the exhaust brake valve every 72,000 km of operation.
   (e) Other maintenance schedules remain the same as in the existing system.

5. Precautions for efficient operation of exhaust brake:

It is important to note that the engine exhaust brake is only an auxiliary brake, supplementing the main service brake. It cannot replace the function of the service brake. In order to derive maximum benefit from the new arrangement of exhaust brake, the following practice should be adhered to:

   (a) Do not depress the clutch pedal or engage the gear lever to neutral when the brake pedal is depressed as this would render the exhaust brake ineffective.
   (b) The butterfly valve shaft is made of heat resistant material. No lubrication is required. Any lubrication would get burnt in the exhaust manifold and the carbon deposit would cause seizure of the butterfly valve.

## 17.14 AIR-BRAKE SYSTEM

In the previous paragraph, you have studied the air-hydraulic brake where through the assistance of air pressure the master cylinder push rod was pressed. Now a days, the air-brake system is more popular, as this system is considered to be more positive. Sometimes it is called a harsh brake, as it can stop the vehicle quickly. For this reason, it is necessary that the following vehicle should keep some distance.

Figure 17.30 shows the layout of an air-brake system for a bus or truck. The simplest system consists of an air compressor, a brake valve, a series of brake chambers, an unloader valve, a pressure gauge governor and a safety valve. These are all connected by lines of tubing. The air compressor, governor, pressure gauge, safety valve and the reservoir constitute the compressing and the control units whereas the rest of them are termed as application units.

The compressed air available on the vehicle is also used for the operation of additional assemblies of the vehicle such as horn, windshield wipers, etc.

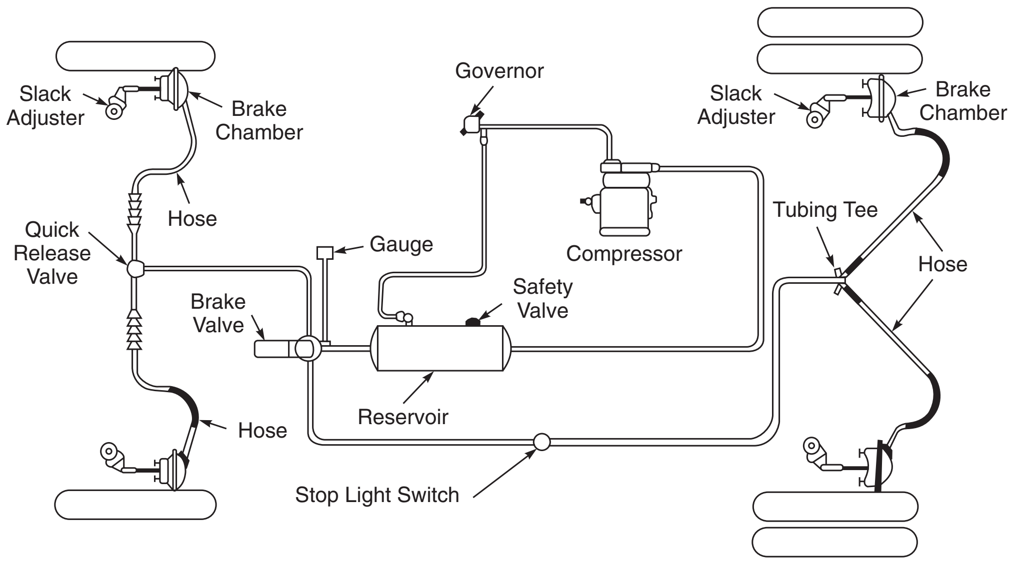



**Fig. 17.30** Layout of an Air-brake System for Bus or Truck

## 17.15 EMERGENCY AND PARKING BRAKES

All automobiles have an emergency brake system in case the regular brake system fails. It is also used to prevent the vehicle from rolling when it is parked. The system is operated mechanically so that it will continue to work even if there is a complete hydraulic system failure. Parking brakes usually operate only on the rear wheels.

Figure 17.31 shows the layout of the parking brakes of Tata (407 Model) commercial vehicle (on rear wheels). In this type of design, the parking brake is operated by a cab-mounted lever situated on the left hand side of the driver's seat. The parking brake is operated through cables and acts on the rear wheels only. On applying the parking brake, the front cable is pulled forward, placing the parking brake under tension and operating the parking brake lever within the rear brake drums. Table 17.1 lists the types of brakes used in some Indian vehicles.

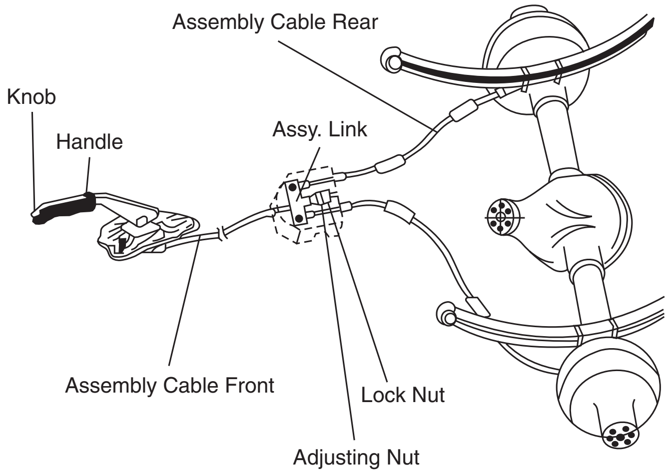



**Fig. 17.31** Layout of Parking Brake

**Table 17.1** Types of Brakes Used in Some Indian Vehicles

| | *Make of the Vehicle* | *Type of Brake* | *Drum or Disc* | *Type of Brake Lining* |
|---|---|---|---|---|
| 1. | Ambassador | Hydraulic | Drum | Ferodo |
| 2. | Premier Padmini | Hydraulic | Drum | Ferodo |
| 3. | Maruti | Hydraulic | Disc in front wheels and drum on rear wheels | Ferodo |
| 4. | Gypsy | Hydraulic | Disc in front wheels and drum on rear wheels | Ferodo |
| 5. | Jeep Mahindra 6. | (CJ–3B) Hydraulic | Drum | Ferodo |
| 7. | Ashok Leyland Comet | Compressed air Diaphragm operated. | Drum | Ferodo |
| 7. | Telco Truck | Air hydraulic. | Drum | Ferodo |
| 8. | Telco Indica Petrol | Dual circuit diagonally split vacuum assisted with P&R valves | Disc in front and drum on rear | |
| 9. | Hyundai Santro | Servo assisted with dual circuit front and self adjusting rear brakes | Disc in front and drum on rear | |

**Table 17.2** Troubleshooting of Brake System

| *Trouble* | *Causes* | *Remedy* |
|---|---|---|
| 1. Long pedal travel or pedal goes upto floor board | (a) Excessive clearance between linings and drum. | Adjust brakes |
| | (b) Weak hose | Replace with new hose. |
| | (c) Leaking wheel cylinder | Service with wheel cylinder repair kit. |

*Contd.*

*Contd.*

| | | | |
|---|---|---|---|
| | (d) | Leaking master cylinder | Service with master cylinder repair kit. |
| | (e) | Leaking stop light switch | Replace with stop light switch. |
| | (f) | Air in system | Bleed the system. |
| | (g) | Blocked master cylinder filler cap vent hole | Clean vent hole or replace cap. |
| | (h) | Low fluid level in master cylinder | Fill the reservoir with brake fluid and bleed the system. |
| | (i) | Wear of brake pedal bush | Replace the bush. |
| 2. Spring, spongy pedal | (a) | Air trapped in hydraulic system | Bleed the system. |
| | (b) | Badly lined shoes. Excessive gap between lining and shoe. | Reline the shoes. properly |
| | (c) | Shoes distorted | Replace the shoes. |
| | (d) | Bell mouthed, worn out, weak or cracked drums. | Replace drums. |
| | (e) | Master cylinder filler cap vent clogged. | Clean vent hole or replace cap, bleed system. |
| | (f) | Weak hose | Replace with new hose. |
| | (g) | Weak master cylinder mounting (yielding) | Check and strengthen master cylinder mounting. |
| | (h) | Bent master cylinder push rod and clevis. | Replace push rod and clevis. |
| | (i) | Unbedded linings. | Bed linings. |
| 3. Brakes pulling (vehicle pulls to one side) | (a) | Uneven adjustment of brakes. | Adjust all the brakes evenly. |
| | (b) | Tyres improperly inflated. | Inflate to recommended pressure. |
| | (c) | Tyre tread unevenly worn on either side, or different type of treads. | Replace with same type of treads all round. |
| | (d) | Grease or fluid soaked lining on the brake opposite to the direction of pulling. | Replace linings after remedying the cause of grease or fluid leak. |
| | (e) | Linings of different grades on either side of brake. | Replace with recommended grade of linings all round. |
| | (f) | Unbedded lining | Bed linings. |
| | (g) | Shoes wrongly fitted | Install leading and trailing shoes correctly. |
| | (h) | Rivets loose in lining | Rivet properly. |
| | (i) | Wheel cylinder piston seized | Service or replace wheel cylinder. |
| | (j) | Wheel cylinder diameter different on opposite side | Replace with correct cylinder. |
| | (k) | Clogged or restriction in hydraulic hose or pipe. | Clean and replace pipelines. |
| | (l) | Weak or broken shoe return springs | Check and replace weak open coiled or cracked springs. |
| | (m) | Drums oval or eccentric | True up or replace. |
| | (n) | Loose back plate mounting bolts, loose shoe abutment or adjuster housing | Tighten back plate mounting bolts and adjuster housing mountings. If abutment is loose, replace back plate. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | (o) Improper steering geometry | Reset according to specification. |
| | (p) Loose or worn tie rod ends. | Tighten or replace. |
| | (q) Loose king pin and bushes. | Replace pins and bushes. |
| | (r) loose wheel bearings loose steering, loose 'U' clamp nuts. | Adjust wheel bearings, adjust steering and tighten 'U' clamp nuts. |
| | (s) Weak shock absorbers | Replace. |
| 4. Fade (Fade is a temporary reduction of brake effectiveness resulting from heat) | (a) Incorrect grade of lining. | Replace with recommended grade of lining. |
| | (b) Distorted shoes | Replace shoes. |
| | (c) Over loaded vehicle | Load the vehicle to the recommended GVW. |
| | (d) Dragging brakes | Adjust or correct the cause. |
| | (e) Thin drums | Replace drums |
| | (f) Old hydraulic fluid | Replace with new fluid. |
| 5. Hard pedal, poor braking | (a) Incorrect brake adjustment. | Adjust the brakes. |
| | (b) Incorrect lining. | Replace with recommended lining. |
| | (c) Grease or fluid soaked lining. | Replace lining. |
| | (d) Unbedded linings (lining not in full contact). | Bed the linings |
| | (e) Glazed linings. | Sandpaper the lining surface. |
| | (f) Brake pedal binding on shaft. | Lubricate or recondition pedal bushes. |
| | (g) Seized master cylinder or wheel cylinder piston | Service master cylinder or wheel cylinder. |
| | (h) Shoes wrongly fitted | Install leading and trailing shoes correctly. |
| | (i) Bell mouthed barrel shaped or polished drums. | Replace or skim drums as necessary. |
| 6. Brake pedal travel decreasing. | (a) Master cylinder recuperating hole blocked. | Service master cylinder. |
| | (b) Swollen cup seal in master cylinder. | Flush the system. Replace all rubber parts. |
| | (c) Weak shoe retracting springs. | Replace springs. |
| | (d) Wheel cylinder piston sticky. | Service wheel cylinder and replace internal parts. |
| | (e) Linings swelling | Fit recommended replacement linings. |
| 7. Judder in brake pedal. | (a) Excessive ovality in drums | True up drums. |
| | (b) Loose brake drum on hub. | Tighten. |
| | (c) Worn or loose bearing. | Replace or adjust. |
| | (d) Rusty drums. | De-rust drums or replace. |
| 8. Brakes binding | (a) Pedal does not return fully. | Lubricate pedal shaft or recondition pedal-shaft and bushes. |
| | (b) No clearance between push rod and master cylinder piston. | Adjust brake pedal free play. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | (c) Maladjusted brakes or hand brake. | Check and adjust brakes and hand brake linkage. |
| | (d) Recuperating and feed port clogged in master cylinder | Remove master cylinder and service. |
| | (e) Seals swollen | Flush system and replace all rubber parts. |
| | (f) Seized wheel cylinder pistons | Service or replace wheel cylinder. |
| | (g) Improper brake fluid. | Replace with heavy duty Break fluid. |
| | (h) Shoe return springs weak or broken. | Replace springs. |
| | (i) Filler cap vent hole blocked | Clean vent hole or replace cap. |
| 9. One wheel drag | (a) Weak or broken shoe retracting springs. | Replace springs. |
| | (b) Brake shoe to drum clearance too small on one side. | Adjust brakes. |
| | (c) Loose wheel bearings. | Adjust wheel bearings. |
| | (d) Wheel cylinder piston cup seals swollen or piston seized. | Service wheel cylinder. |
| | (e) Excessive ovality in drum | True up drums. |
| | (f) Obstruction in hydraulic line. | Flush lines. |
| | (g) Distorted shoes | Replace shoes. |
| | (h) Incorrect grade of lining. | Replace with recommended lining |
| 10. Rear brake drag | (i) Maladjustment | Adjust brake shoes and parking brake mechanism. |
| | (j) Parking brake cable seized. | Lubricate and adjust cables. |
| 11. Brake squeal | (a) Back-plate bent or shoe slightly twisted. | Replace parts. |
| | (b) Metallic parts or dust embedded in lining. | Sandpaper the lining and drums and remove metal particles if any or replace lining and drum if necessary. |
| | (c) Loose rivets or lining not held evenly against shoe rim (gap between lining and shoe rim). | Reline shoes properly. |
| | (d) Drums not true, weak or distorted | True up or replace drums. |
| | (e) Incorrect grade of lining. | Replace lining with recommended linings. |
| | (f) Shoe scraping on back-plate shoe pads. | Lubricate shoe pads with high melting point graphite grease. |
| | (g) Weak or broken hold down springs | Replace defective parts. |
| | (h) Loose wheel bearing | Adjust bearings. |
| | (i) Loose back-plate, or wheel cylinder or drum. | Tighten |
| | (j) Over adjusted steady post | Adjust properly. |
| | (k) Glazed lining | Surface linings with sandpaper. |
| | (l) Highly polished drum. | Skim drum. |
| 12. Snapping noise in | (a) Deep grooves in back-plate shoe pads. | Replace back-plate. |

*Contd.*

*Contd.*

| | | | |
|---|---|---|---|
| | front end. | (b) Lack of lubrication on moving parts. | Lubricate all moving parts on back-plate with high melting point graphite grease. |
| | | (c) Loose drums or back-plate. | Tighten. |
| | | (d) Loose or worn front end parts. | Tighten or replace defective parts. |
| 13. | Thumping noise when brakes are applied. | (a) Loose back-plate, drums or axle 'U' bolts. | Tighten. |
| | | (b) Grabbing linings. | Replace with recommended grade of lining. |
| | | (c) Shoe retracting springs unequal weak. | Replace springs. |
| | | (d) Uneven brake drum inner diameter. | Skim the drums or replace. |
| 14. | Grinding noise | (a) Shoe rim fouling with the drum. | Check shoe retracting springs for correct fit. |
| | | (b) Weak shoe hold down springs or bent pin. | Replace parts. |
| | | (c) Bent shoe web. | Replace shoe. |
| | | (d) Foreign material in lining | Remove or replace lining. |
| | | (e) Worn out or broken lining. | Replace with relining kit. Skim or re place drum if scored. |
| | | (f) Rough drum surface. | Skim drums. |
| | | (g) Improper adjustment of steady post | Adjust properly. |

## Review Questions

1. Why are brakes necessary in vehicles?
2. Discuss the braking requirements of a vehicle.
3. How many types of brakes are used in automobiles?
4. What is the main advantage of hydraulic brakes?
5. Why does the master cylinder have two pistons?
6. Describe the working of the Maruti tandem master cylinder assembly.
7. What is the purpose of check valve in the master cylinder ?
8. Compare the operations of drum and disc brake systems. Which is the better system? Why?
9. What do you mean by the self-energizing action of brakes?
10. What is floating caliper?
11. What is the advantage of using a flexible rubber seal to cover the hydraulic fluid in the master cylinder reservoir ?
12. Explain the action of an ELGI power brake under the two headings: released piston and pressed position.
13. Sketch the air brake system of a heavy vehicle and describe how it works.
14. Why are parking brakes always separate from the regular braking system?
15. How can you tell if air is present in the hydraulic lines?
16. What is brake adjustment? When is it required?
17. When should the lining (pads) be replaced?
18. Give the main troubles of brakes and their causes.

# 18 Suspension System

**Objectives**

After studying this chapter, you should be able to:

- Comprehend the need for suspension system in a vehicle.
- Identify leaf springs, coil springs and torsion bars.
- Describe the different types of shock absorbers.
- Identify the parts of a MacPherson strut suspension system and describe their operations.
- Describe the operation of the rigid rear suspension system.
- List the steps in diagnosing a suspension system problem.

## 18.1 INTRODUCTION

The suspension system of an automobile separates the wheel/axle assembly from the body. All the power from the engine ultimately reaches the wheel through the power transmission system. With this power the vehicle moves on the road. The irregularities of the road are felt in the form of shocks on the wheel and at this point the suspension system acts more as a filter to screen out the shocks which would otherwise damage the body structure and cause discomfort to occupants of the vehicle. The primary function of the suspension system is to isolate the vehicle structure from shocks and vibrations due to irregularities of the road surface.

## 18.2 BRIEF HISTORY

As is well known, automobiles were initially developed as self-propelled horse carriages. The horse was replaced by an engine keeping other features of the carriage almost the same. The horse carriage did have its own suspension system with double leaf springs and dead axles. However it was designed, even at that time, for slow speeds. A car was by far a much more complex system with high speeds and height considerations. Moreover with the car becoming a status symbol the whole concept of luxury was redefined. The car should ideally move fast like a plane but be smooth like a ship on a calm sea. The designers began to pamper the needs of customers.

Improvements soon started showing in the automobile suspension system soon after the car became a reality in the beginning of the twentieth century. As the engine was moved forward from under the driver/passenger seat and as the vehicles started becoming bigger in size and less in height, suspension systems started improving. It was in 1903 when Mors from Germany fitted a car with shock absorbers. In 1920 Leyland used torsion bars in its suspension system. In 1922 unitary construction and independent front suspension were poineered on the Lancia Lambda. The independent front suspension became more common in popular cars by 1932. Peugeot and Adler led this trend. In 1934 Citroen of France launched its car 7CV. It had front wheel drive, unitary construction and an all independent suspension. In 1948 Morris (Britain) introduced the new Morris Minor with a torsion bar independent front suspension. Following this in 1949, Triumph Mayflower introduced the combined coil spring/damper unit and strut-type telescope damper. In 1950 Ford (Britain) adopted the McPherson strut independent front suspension on MK 1 consul. Citroen used hydropneumatic suspension in 1955 in its DS 19 model, while BMC used independent rubber suspension in its Mini in 1959 and improved it in its 110 model by using hydrostatic suspension in 1962.

It is clear that the suspension system was revolutionised by the independent suspension system. As cars started becoming more powerful and lighter, independent front suspension helped the car's handling to keep pace with their escalating power to weight ratios. Independent front suspension changed the shape of the car as well as improving its ride and road holding. With the disappearance of the front beam axle the engine could be moved further forward and mounted lower. On its either side, the suspension assemblies were fitted almost at the same height. Today's high speed, sleek automobiles owe a lot to the development that took place like the tiny hammer blows of an artist that chiesel out a piece of art.

## 18.3 NEED FOR A GOOD SUSPENSION SYSTEM

Although there cannot be a vehicle without a suspension system which is intermediate between the wheel axle system and the body, a good suspension system will be one which will take up all the shocks and vibrations generated due to the irregularities of the road and transmit as small a component as possible to the passenger carriage. A good suspension system must have *springiness* and *damping*. Springiness is elastic resistance to a load. On application of a sudden load the spring will compress/expand as the case may be without transmitting the same to the body. As the spring compression is complete it expands on rebound, and now damping becomes important since this will absorb the work energy as heat energy and the continuous oscillations of the spring which normally would have taken place are absorbed.

Thus the primary function of a good suspension system is to isolate the structure, as far as practicable, from shock loading and vibrations due to the irregularities of the road surface. This is achieved by flexible elements like springs and dampers. The secondary function is to achieve the first function without impairing the stability, steering or general handling qualities of the vehicle. This is achieved by controlling, by the use of mechanical linkages, the relative motions between the unsprung masses-wheel and axle assemblies and the sprung masses.

## 18.4 STAGES IN SUSPENSION SYSTEM

The function of isolation of shocks and vibrations between road and carriage is achieved by different elements at different stages. The first element which takes the impact is the tyre. With pneumatic tyres, this is achieved by flexing and compression of pneumatic tyres at the contact point.

The second stage is between the axle/wheel system and the body. The elements incorporate springs, dampers/shock absorbers, various linkages and tie bars. This part is called the suspension system and will be dealt with in greater detail in this chapter.

Finally, the last stage of the suspension system are the seats of the automobile which the passengers occupy. They are made of springs and foam/rubber cushions. They absorb all short amplitude high frequency vibrations which pass from the system to the passenger compartment.

It may further be mentioned that the wheel and the seats usually overcome these high frequency low amplitude vibrations. The central suspension system has to cope with the greater irregularities of the road which may impact all the wheels, both the wheels on one side, or one axle or only one wheel at a time. The suspension system tries to overcome these irregularities while transmitting minimum vibrations to the passenger compartment.

## 18.5 ELEMENTS OF A SUSPENSION SYSTEM

A suspension system can be represented in a schematic form as shown in Fig. 18.1 where $W_{sp}$ and $W_{us}$ are the sprung and unsprung weights respectively. $R_s$ is the spring system, $R_t$ is the tyre system and D is the damper, i.e. shock absorber. The sprung mass is the mass of the passenger carriage while the unsprung mass is the mass of the wheel axle system. While it is clear that the spring effect is provided to a small extent by the tyre and to a large extent by the spring used, the damping effect is to a large extent provided by the hydraulic dampers (or shock absorbers). However in case of leaf springs, the friction between the leaves in motion does generate some damping effect.

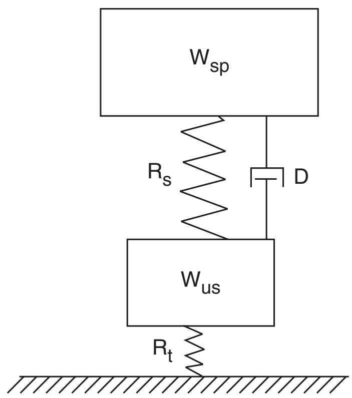



**Fig. 18.1** Suspension System

Dampers in fact have two important functions. First, they reduce the tendency of the carriage unit to continue to bounce up and down on its springs after the disturbance that caused the initial motion has ceased. Secondly, they prevent excessive build up of amplitude of bounce as a result of periodic excitation at a frequency identical to the natural frequency of vibration of the spring mass system.

Apart from a simple bounce or vibration of the carriage unit as a whole, there are two more types of vibrations known as rolling and pitching. In *rolling,* the carriage unit rolls about the longitudinal axis of the vehicle while in *pitching,* the carriage unit rolls about a transverse axis. Thus in rolling, one side of the car goes down and the rear goes up and vice versa. These actions place further constraints on the design of the suspension system.

While rolling can be checked by using anti-roll bars, pitching is a more complex phenomenon and is affected by what is known as *vibration coupling effect,* i.e. interaction between front and rear suspension. It has been found that pitching persists for longer if the rear suspension has a lower natural frequency than the front suspension. Consequently, the natural frequency of the rear suspension is normally made higher than that of the front. It must however be underlined that pitching will in general depend on the frequency of disturbances, or bumps over which the car rolls, spacing of bumps, speed of the vehicle, its mass moment of inertia about the axis of pitch and its wheel base.

Important elements of a suspension system are:

1. Springs
2. Dampers.

## Springs

Springs act as reservoirs of energy. They store the energy due to the sudden force which comes when the vehicle encounters a bump or a ditch. This energy is released subsequently and with the action of dampers, the energy is converted into heat and bounce is avoided.

The action of springs can be understood by considering what happens when a vehicle encounters a bump or a ditch. When the vehicle hits a bump, the tyre is suddenly pushed up. If there is rigid suspension (without spring), the full force will be transferred to the carriage unit and push it up with almost no loss in force in the form of a jerk or bounce. However, when a spring is present, this force will compress the spring without allowing the force from reaching the passenger unit. The force on the spring causes the vehicle body to move up at a much smaller rate of acceleration. As the wheel passes over a bump, the spring expands at a much lower acceleration, and the vibrations are quickly killed by the damping action of the dampers. Depressions present in roads produce an almost similar action.

The following types of springs are used in general:

1. Leaf springs or laminated springs
2. Coil springs
3. Torsion bars

Modern cars also use rubber, air and gas springs but they have yet to take the place of these springs in a general automobile, particularly in this country. They are used more in commercial vehicles.

The main factors governing the choice of the types of springs used are:

- overall cost of installation.
- relative capacity for storing energy.
- total weight of suspension system.
- fatigue life.
- location.
- guide linkages required.

**1. *Leaf Springs*** Leaf springs are referred to as *laminated springs* since they use steel strips or laminations one over the other with reducing length (Fig. 18.2). They are also called *semi-elliptical springs* as they are bent in that form. However nowadays they are almost straight.

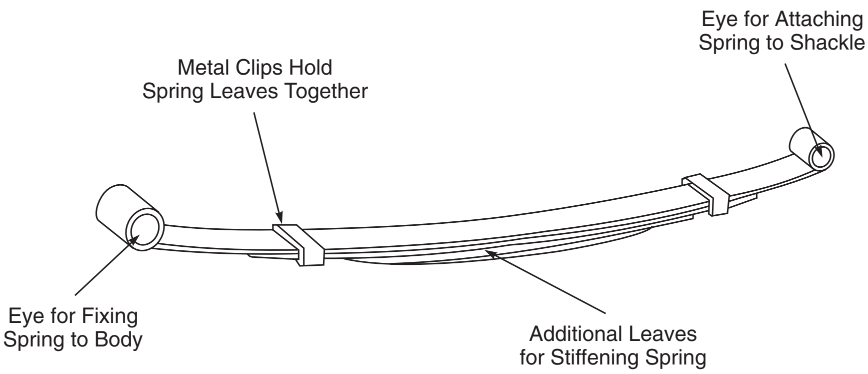



**Fig. 18.2** Leaf Spring

Leaf springs, in terms of mechanics, are beams of uniform strength, since the stress developed is maximum at the centre while it is minimum at the ends. Laminations provide damping effect due to the friction between the laminations which move relative to each other when flexing takes place.

The two ends of the topmost spring form an eye which is fitted to the body of the car through rubber bushes. One end is fitted directly to a pin while the other end is fitted through a shackle link to accommodate the increase or decrease in length of the spring due to flexing.

Leaf springs in general have approximately only a quarter of the energy storage capacity for a given stress level of either coil spring or torsion bar. Calculated on the basis of weight for a given energy storage capacity, the ratio is 3.9:1 in favour of coil or torsion bar springs.

The springiness of the leaf spring can be varied by varying the number of leaf laminations. Increase in number would stiffen it while reduction will make it more flexible. Similarly, on repeated use due to constant flexing, the leaves become flatter and their springiness is reduced. In other words, they become 'soft'. In such a case further tension is given to the leaves. After a few such operations, the springs become totally unsuitable for their purpose and have to be changed.

Another disadvantage of the leaf spring is that it is heavier than the coil or torsion bar spring. Moreover, whereas two thirds of the weight of a semi-elliptic spring is carried by the axle that has to be considered as unsprung-weight, only half that of a coil spring and virtually none of that of a torsion bar is unsprung weight.

As mentioned earlier, there is relative motion between the strips of a laminated spring where the friction opposes the motion. With rusting or dust and dirt, this motion may become excessive and no longer act as a damper but still reduce springiness to a large extent. To reduce or control friction, the spring leaves are often interleaved with plastic material having a low coefficient of friction; pads or buttons of similar materials are interposed between the ends of adjacent leaves. Also springs themselves are wrapped and sealed to prevent the entry of dust and dirt.

Leaf springs are unsuitable in independent suspension which has become almost universally used in front wheels and is gradually being used in rear axles.

It is for these reasons that laminated springs still find some use in rear axles while in front axles, it is almost completely replaced by coil springs or torsion bars.

**2. *Coil Springs*** The best energy storing shape for a given weight for a spring is circular, and a coil spring stores the energy produced by its up and down movement in the most efficient way. Coil springs have the advantage of fitting in a compact space. It is stressed during torsion like a torsion bar although there is some bending (Fig. 18.3). The life of coil springs is increased by *shot peening* their surfaces to induce compressive stresses in them and to reduce the effect of scratches in initiating fatigue cracks. Immediately after shot peening, such springs may be given an anticorrosion treatment again to increase their fatigue life.

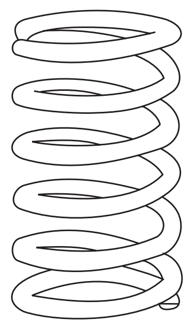


**Fig. 18.3** Coil Spring

Where coil springs are used the end coils usually sit square, for stability, upon surfaces through which the load is applied to the rest of the spring. Coil springs sometimes have a tendency to bend under the action of compressive load. However in many cases, coil springs are mounted in such a way that the cylindrical dampers or shock absorbers pass through them so that the possibility of bending is reduced to a minimum.

Coil springs were initially preferred for independent suspension only and hence were used in front axles However with improved design, coil springs have been used in live as well as dead axle and in independent as well as rigid suspension systems.

**3. *Torsion Bars*** In case of torsion bars (Fig. 18.4), a spring steel bar is fixed rigidly at one end to the body while the movement of axle or wheels is transmitted to the torsion bar through a lever in the form of torque. The resulting deformation of the torsion bar is twisting and the stress produced is shear stress. The inherent elastic properties of the material cause the bar to come back to its normal state (i.e. untwist) so that under the action of the wheel movement, the torsion bar twists and untwists.

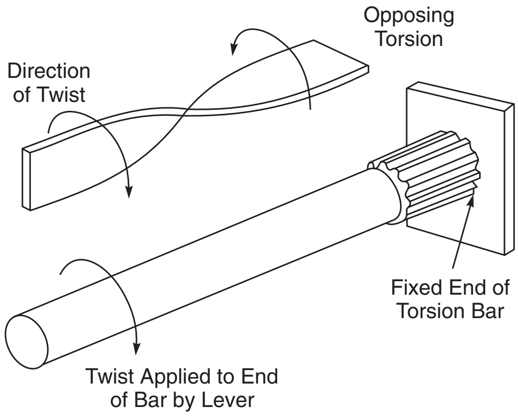



**Fig. 18.4** Torsion Bar

Torsion bars are *scragged*-that is overloaded in torsion during manufacture—to stretch outer layers beyond the elastic limit. As this leaves a residual stress in the outer layers, the maximum stress under service occurs beneath the surface where it is less likely to initiate cracks. This helps to increase the fatigue life. As in coil springs, shot peening and anticorrosion treatment is also given to the torsion bars to improve fatigue life.

Torsion bars are not very popular as suspension springs because their end fixings are more costly and provision has to be made for the adjustment of the ride height on the vehicle assembly line.

Torsion bars are however often used as antiroll devices. A steel bar is mounted in rubber bushes across the vehicle, with its ends bent round to act as levers which in turn are connected to the suspension.

When both wheels of the same axle move up and down as a pair, the antiroll bar merely rotates in bearings without any effect on suspension. However, when only one wheel rises or falls causing the vehicle to roll, for example, on a bend, the torsion bar twists reacting against the movement of the wheel.

**4. *Other Springs*** Rubber springs are used more in commercial vehicles. Rubber is however used as bushes to check the transmission of vibration, for example, in the ends of a key spring. Rubber springs have been used only in a few cases in passenger cars since the precise control of ride essential for comfort is difficult to achieve with such springs.

Rubber material is best suited for a combination of shear (side to side movement of successive layers) and compression. They have a good fatigue strength in compression. However it is worst in tension since there is a tendency for the cracks to open out. Their biggest advantage is that they are free of maintenance.

**5. *Air and Gas Springs*** In air and gas springs, compressed air or gas is filled in the cylinder or bellows against which the wheel movement is transmitted through a diaphragm. As soon as the wheel has passed over a road irregularity the compressed air pressure returns the system to its original position.

Air springs are fairly widely employed in many countries in vehicles whose loaded and unloaded weights differ greatly, for example, trucks, large draw bar trailers, tractors, etc.

Air springs give a high quality ride particularly with independent suspension. However the disadvantages overweigh this advantage. The main disadvantages of the air/gas springs are high cost, complexity of compressed air ancillary system, risk of break down, greater maintenance than other types of springs and freezing of moisture in air in cold weather. Air suspension systems are in general too bulky and too complex for cars.

## Dampers

Dampers are used in the suspension system to check any continuous vibration which may follow the initial force on the spring. Damping action is provided by the absorption of energy in one form or the other. In old days, friction was used as the damping agent. These dampers had packs of friction material interleaved between blades, or arms which were attached alternately to spring and unsprung masses. Semirotary vane type dampers were also used. However they were abandoned because the ratio of sealing length around their vanes to volume displaced was so high that these units were rapidly adversely affected by wear.

Modern cars mostly have hydraulic dampers which are of two types:

1. Telescopic dampers
2. Rocking lever dampers.

Both these dampers use hydraulic fluid as damping agent. Damping is effected by the damper piston or pistons forcing the hydraulic fluid at high velocities through small holes. Thus energy is absorbed by the fluid, converted into heat and then dissipated partly by conduction into the surrounding structure of the vehicle, but ultimately all heat passes into the air stream flowing past these components.

The amount of energy thus absorbed and dissipated for any given rate of energy input is a function of the volume, viscosity of the fluid and the number, sizes and geometry of the holes through which it is forced.

A major advantage of hydraulic damping is that the resistance to deflection of the damper is a function of the square of its velocity. Therefore, slow movements of the wheels can occur with relative freedom but the resistance increases rapidly with the velocity of motion.

**1. *Telescopic Dampers*** Telescopic dampers are quite often called incorrectly as shock absorbers. As mentioned in the previous section, they use the flow of hydraulic fluid past their pistons as the damping medium.

As shown in Fig. 18.5, telescopic dampers use a cylinder and a piston assembly which is sealed and the cylinder is completely filled with hydraulic fluid. The cylinder and the piston in turn are fitted to the

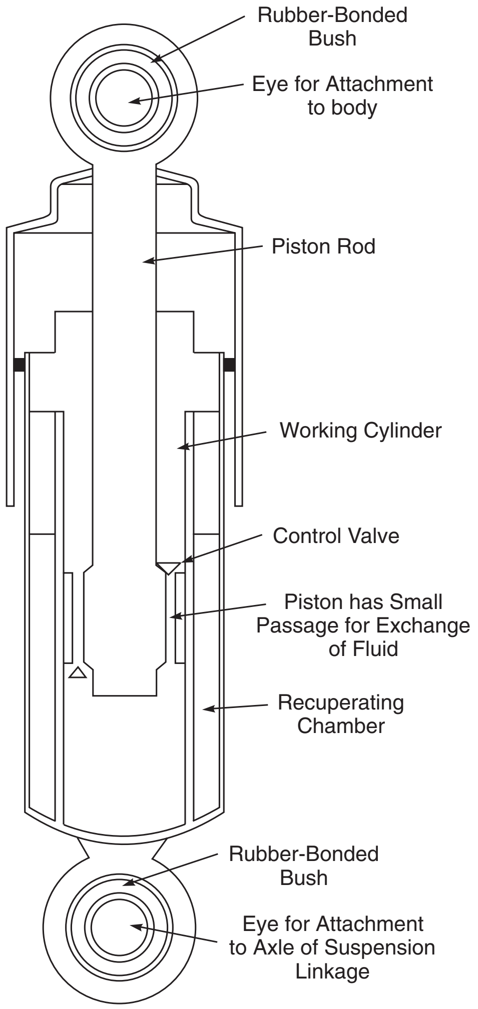



**Fig. 18.5** Telescopic Damper

wheel axle and the car body respectively through rubber bush eyes. The piston rod passes through a sealing gland on the open side of the cylinder. The piston has a small hole through which the fluid rushes to the other side as the piston is forced to move in any direction due to the motion of the wheel.

Relief valves and leak passages provide controlled flow of the oil each way through the piston. The space above the piston is smaller than that below it and this space cannot accept all the oil displaced by the piston as it travels towards the lower end of the cylinder. A valve controls the escape of the surplus oil into a reservoir or 'recuperating chamber' which surrounds the cylinder.

As the damper extends, the piston does not displace enough oil from the top section of the cylinder to fill the lower, which is topped up from the reservoir through the replenishment valve.

**2. *Rocking Lever Damper*** Rocking lever dampers (Fig. 18.6) work on the same principal as telescopic dampers but have two pistons which move in a cylinder while the oil is displaced through a valve. The motion of the dual pistons takes place due to the motion of the wheels which is passed on to the pistons through the rocker levers.

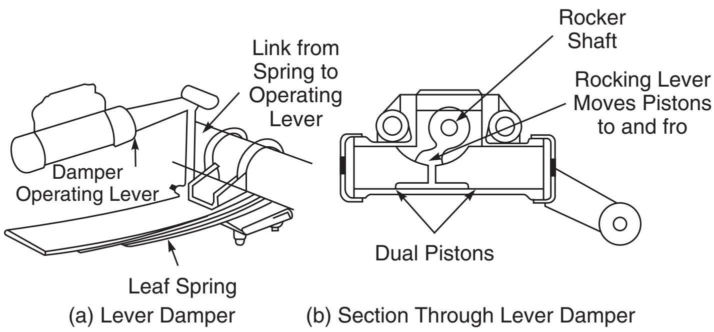



**Fig 18.6** Rocking Lever Damper

The body, incorporating the hydraulic cylinder of the lever type damper is usually mounted on the carriage unit, with its actuating lever connected to the axle. If the body were mounted on the axle, the high frequency, high velocity motions to which it would be subjected might cause aeration of the hydraulic fluid and hence adversely affect the damping capacity of the unit.

## 18.6 SUSPENSION SYSTEMS

The suspension system is assembled with the elements mentioned in the preceeding sections. The suspension of a car initially was rigid. Both the front and rear axles were connected to the carriage unit through springs. Later on, dampers were added to give better ride. Still later, suspension became independent. In what is called the one piece suspension system, the two wheels mounted on the same axle (live or dead) move together, in a way. That is, if a wheel comes over a bump it gets lifted and the whole axle is tilted and with it the car itself. This was a major drawback and hence the need gave way to the independent suspension system. In this system, a wheel moves up and down to some extent without affecting the second wheel on the same axle.

The suspension systems used in some Indian vehicles are provided in Table 18.1.

**Table 18.1** Suspension System of Some Indian Vehicles

| *S.No* | *Make of the Vehicle* | *Front Suspension* | *Rear Suspension* | *Shock Absorbers* |
|---|---|---|---|---|
| 1. | Ambassador | Independent torsion bar | Semi-elliptical leaf | Hydraulic (telescopic double acting) |
| 2. | Padmini Premier | Independent coil springs | Semi-elliptical leaf | Hydraulic (telescopic double acting) |
| 3. | Maruti 800 | MacPherson independent strut and coil springs | Leaf spring | Hydraulic (Telescopic double acting) |
| 4. | Maruti 1000 | MacPherson independent strut type | Coil spring | Hydraulic (Telescopic double acting) |
| 5. | Jeep Mahindra CJ-3B | Semi-elliptic Leaf | Semi-elliptical leaf | Hydraulic (telescopic double acting) |
| 6. | Maruti Gypsy | Semi-elliptical | Semi-elliptical multi leaf | Hydraulic double acting) |
| 7. | Ashok Leyland | Semi-elliptical Leaf | Semi-elliptical leaf | Hydraulic (telescopic double acting) |
| 8. | Tata Truck 407 & 1210 model | Semi-elliptical multileaf | Semi-elliptical multileaf | Hydraulic (telescopic double acting) |
| 9. | Daewoo Matiz | MacPherson strut | Isolated trailing links with coil springs | Hydraulic |
| 10. | Hyundai Santro | MacPherson strut with stabiliser bar | Torsion beam axle, 3-link offset coil springs | Hydraulic |
| 11. | Telco Indica (Petrol) | Independent, wish bone type with MacPherson strut | Independent semi-trailing arm with coil spray | Hydraulic |
| 12. | Maruti Esteem | Macpherson strut and coil spring | Macpherson strut and coil spring | Hydraulic (telescopic double acting) |
| 13. | Maruti Wagon R | Macpherson strut with torsion type roll control device | Coil spring, gas-filled shock absorbers with three-link rigid axle and isolated trailing arms | Gas-filled |
| 14. | Maruti Alto | Macpherson strut with torsion type anti-roll bar | Coil spring with double action telescopic shock absorbers | Hydraulic (telescopic double acting) |
| 15. | Maruti Baleno | Macpherson strut and coil spring with an L shaped lower arm and anti roll bar | Macpherson strut & coil spring with parallel link arrangement | Hydraulic (telescopic double acting) |

## Independent Suspension

Independent suspension is a term used to describe any arrangement by which the wheels are connected to the carriage unit in a manner such that the rise and fall of one wheel has no effect on the others.

There are many advantages of the independent suspension system:

(i) Since in the independent suspension system, the wheels more or less travel with their planes perpendicular to the road surface, the gyroscopic affects are reduced to a minimum.

(ii) Steering effects due to lateral movements of the tyre/road contact path, as the wheel rises and falls are avoided.

(iii) Variations in caster angle are reduced.
(iv) Unsprung mass is less, hence the ride quality is improved.
(v) Engine can be moved further. Since it has not to clear beam axle. Hence there is more passenger space.
(vi) Independent suspension uses coil springs which can be placed closer to the wheel. This is a definite advantage vis-a-vis leaf springs for a wheel to be steered.

In a car, the front axle is usually a dead axle although some cars do have front wheel drive. Independent suspension systems therefore have been almost universally adopted for the front wheels. The independent suspension system for the front wheel has to cope with the fact that they are to be steered.

Rear axle is usually a live axle with power being transmitted to the rear wheels. Hence independent suspension has not become very popular for the rear wheels. Further, the rear wheels have to carry lot of weight and while the weight on the front wheel remains more or less constant, in case of rear wheels it makes a lot of difference when the car is running empty or when it is fully occupied. The suspension system has to cater to both these conditions.

### Front Wheel Suspension System

Right from the advent of the car, designers have strived hard to enhance the comfort along with other improvements. The one piece beam axle arrangement of the earliest cars was a legacy from the horse cart era. However it had the biggest disadvantage of tilting the car even on small bumps or despressions of the road resulting in most uncomfortable rides. It was during the second world war that the beam axle arrangement gave way totally to independent suspension for the front wheels.

The independent suspension, as the name clearly suggests had independent suspension system for each of the front wheels. Each wheel has its own linkage, springs and dampers. The up and down motion of one wheel up and down with the forces of the road is totally independent of the other. However to prevent roll of the car, the antiroll bar which is hinged across the chassis, bent and joined to the lower wish bone on each side to resist body roll when cornering, does join the two independent suspensions.

The front suspension in a car has to bear a lot of forces particularly due to acceleration, braking and cornering. The assembly used for the front suspension has to provide a movement in the up and down direction along with steering. It has therefore to adhere to the following conditions:

(i) The suspension must not allow the various forces coming from the road irregularities and cornering to deflect the car from its course of movement decided by the driver.
(ii) It should not permit the wheels to wobble, move any significant distance backwards or forwards or sideways.
(iii) It should not allow the system to alter the tilt of the wheels to any serious degree.

The above conditions are necessary for the control and handling of the vehicle.

### Types of Independent Front Suspension Systems

Although over the years many arrangements have been developed and successfully fitted on the front wheels, two representative types of independent suspension systems of the front wheel are next discussed:

1. Double wish bone suspension system
2. Single wish bone, i.e. MacPherson strut assembly.

**1. *Double Wish Bone Suspension System*** As the name suggests, the assembly in the double wish bone suspension system primarily uses two wish bone shaped links (Fig. 18.7). A wish bone is a vee shaped link which is so named because of its shape. The two ends of the vee are hinged onto the body or the sub frame while the narrow ends carry between them (i.e. narrow ends of upper and lower wish bone links) the swivel member which carries the stub axle on which the wheel is mounted. Thus the two wish bones are placed one over the other while the swivel member is vertically positioned. Between the two wish bone links are placed the spring and the shock absorber (damper) system which take the shocks and reduce vibrations.

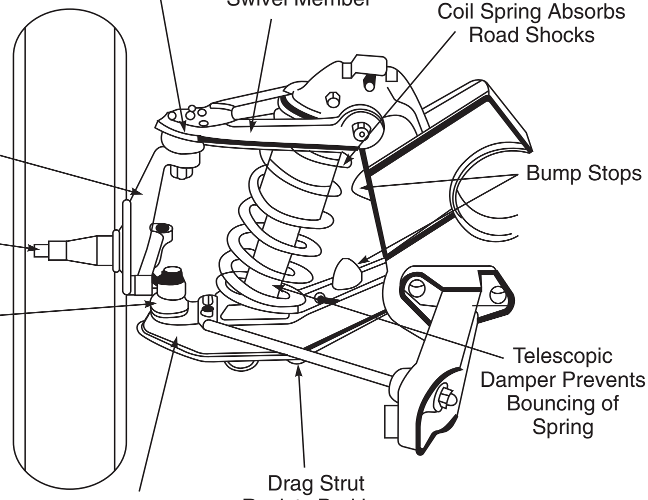



**Fig. 18.7** Double Wish Bone Suspension

The two wish bones may either be equal or unequal. Depending upon their relative lengths and also whether they are placed parallel to each other or at an angle, the response of the wheel to the up and down movement is predicted. The geometry of the wish bone layout—the lengths, positions and angles of the links-governs the path of the wheels when the car rides over bumps. This path in turn affects steering, road holding and tyre wear.

**(a) *Parallel and Equal Wish Bones*** Early double wish bone suspension systems had both the links equal and parallel to each other. This had two advantages:

(i) The wheels which are perpendicular to the road remained so while moving up and down.

(ii) There is no change in camber angle.

These advantages are to some extent disadvantages since while the wheel did not tilt and moved up and down in the same vertical plane, the track length (distance between wheels across the car) did change. This caused wheel movement perpendicular to the plane of rotation, i.e. the wheels moved towards each other or away from each other.

(i) On corners, the wheels lean outwards with the body which reduces cornering ability. In other words, it resulted in undesirable steering effects.

(ii) Variation in track length resulted in adverse tyre wear.

**(b) *Unequal Double Wish Bone System*** In modern systems, to avoid the undesirable steering effects and wearing of tyres, the two wish bones were not only made unequal but also they were made non-parallel. Usually, the upper wish bone is made shorter so that the wheels do not remain upright but have a slight lean inwards. In this case, the camber angle did change while the wheel moved up and down. However the track length remained more or less constant.

Two distinct advantages are noticeable:

(a) The track length remains constant although a slight change in camber takes place. This is better for tyre life.

(b) It gives better cornering characteristics. Thus when the body rolls outwards, the outside wheel which carries greater load and therefore exerts higher cornering power of the two, remains more or less at right angles to the road surface.

***(c) Spring Damper Arrangement*** In both the double wish bone suspension systems, when coil spring with telescopic damper is used they are usually installed coaxially. Incidentally, it is more common for the upper ends of the spring the and shock absorber to be on the vehicle structure instead of on the upper transverse arm. On some vehicles, the springs and dampers are mounted separately, so that access could be gained more easily for servicing the damper. An alternative is to arrange for the removal of the shock absorber through a hole in the spring seating pan.

With front wheel drive cars, the coil spring and shock absorbers are in most instances interposed between the upper transverse link and the vehicle structure, to leave space for the drive shaft to the wheel.

**2. *MacPherson Strut Assembly (Single Wish System)*** Earle S. MacPherson, an engineer with Ford USA, developed a single wish bone with a telescopic strut type system (Fig. 18.8) in the forties. In this system, there is a telescopic strut, a single arm and a diagonal stay. The whole system is known as the MacPherson system.

The strut is fixed to the body structure at the upper end through a flexible mounting and the lower part of the strut is connected at the bottom by a joint to the lower arm. The lower part of the strut also carries the stub axle, which in turn carries the wheel. The steering motion is supplied to the lower part of the strut and it turns the whole strut. A coil spring and a hydraulic damper surround the upper part of the strut which takes care of the road irregularity shocks and vibrations.

The MacPherson strut has some distinct advantages:

(i) It is mechanically simple.

(ii) Its light moving parts help the wheels to follow the road irregularities.

(iii) The wheel camber does not vary much.

(iv) It has distinct advantages in case of transverse engines, since in that case there is either no space or very little space for upper links to fit.

(v) Its maintenance is very easy.

However this system does have a couple of disadvantages:

(i) Radial loading comes on the piston due to the lateral forces during cornering and brake torque.

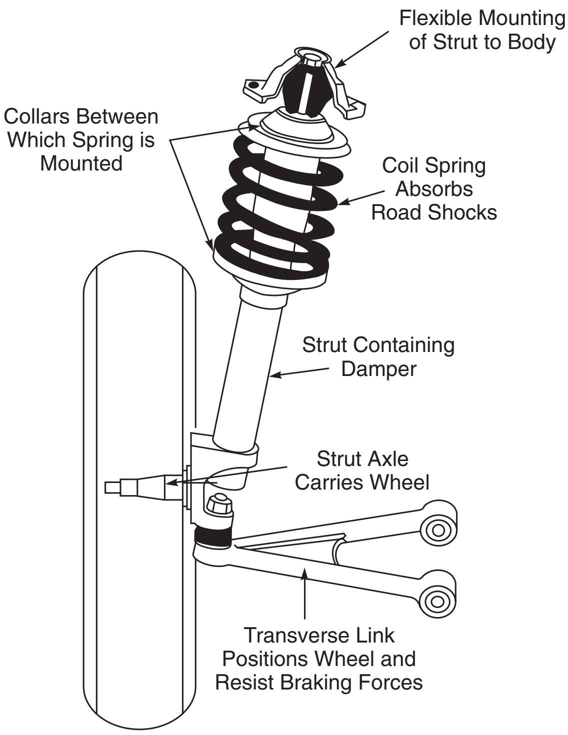



**Fig. 18.8** MacPherson Strut Assembly

(ii) The body structure has to be really strong above the wheel arches, where the struts are attached, to absorb the full suspension loads.

### Rear Wheel Suspension System

Unlike the front axle which is in most of the cars, a dead axle, except in case of front wheel drive cars, the rear axle is a live axle. Even in case of four wheel drive vehicles like jeeps, the rear axle mostly transmits the power. The front axle is designed to transmit power in situations when the four wheel drive is used. In case of heavy passenger vehicles or load carrying vehicles, the power is transmitted through the rear axle.

A live axle is one that either rotates or houses shafts that rotate, while a dead axle is one that does neither, but simply carries at its ends the stub axles on which the wheels rotate.

Live axle performs two functions:

(i) It acts as a beam that carries through the medium of springs and the other suspension system, the weight of the passenger compartment and its contents, and transmits these loads under dynamic conditions through the road wheels—rotating on its ends—to the ground. The dynamic loading is principally a result of the motions of the wheel and axle assembly over the ground and the reactions due to its mass, the flexibilities of the tyres and road springs and the mass of the carriage unit and its contents.

(ii) To house and support the final drive, differential and shafts to the road wheels and to react the torques in both the input and output shafts.

The rear axle suspension poses problems to designers since the weight on the front axle remains more or less constant, and the front axle or front suspension as it should be correctly called, is under the engine and its movements are not coming on the passengers as directly as the rear axle.

Rear suspension has to be designed not only for an empty car when the car is moving with driver, but also when the car carries occupants and also when the car boot at the rear is loaded. This variation of load on the rear axle is further complicated when it is realised that the weight of the car is shifted to a larger extent, at the time of acceleration, to the rear axle.

The springs and dampers, on the rear suspension, should therefore be soft enough to give a comfortable drive in an empty car but also hard enough to carry extra weight when running with full capacity.

The suspension system for the rear axle must be capable of dealing with:

(i) The weight of the carriage unit including contents.
(ii) Torque reaction—for both drive line and brakes.
(iii) Driving thrust.
(iv) Brake drag.
(v) Lateral forces.

The rear axle suspension system therefore has to be designed to overcome the above forces. Both rigid suspension and independent rear wheel suspension have been designed in many ways and some are specifically known by the names of the car models in which they were used. However in the present chapter, a representative of each of both rigid suspension and independent suspension is described.

### Hotchkiss Drive

The Hotchkiss drive is a rigid suspension which employs two leaf springs located as far as possible on the axle (Fig. 18.9). These springs apart from absorbing shocks, also position the axle and the axle moves up and down with it. Two telescopic hydraulic dampers, i.e. shock absorbers are attached one each to the two sides of the real axle near the leaf springs.

The axle is usually fixed exactly at the mid point of the spring. However in some cases, it is fixed a bit ahead of the mid point to give a downward tilt as the axle rises when riding over bumps. This reduces the amount by which the propeller shaft lifts on a bump and in turn minimises the height of the propeller shaft tunnel and the amount it intrudes into the car body.

The leaf springs are fitted to the body with a rubber bush in the front while the rear end of the spring is fitted to the body through a shackle with rubber brushes. This helps in accommodating the increase or decrease in length of the spring as it flexes up and down.

One of the disadvantages of leaf spring is that it tends to distort when the axle tries to turn during acceleration or braking.

Some modifications to the simple Hotchkiss drive have been made to overcome some of the shortcomings. For example, fore and aft distortion of the springs can be limited by linking the axle to the main car structure. Radius rods trailing from mountings on the structure help to position the axle. Another design uses a transverse rod known as Panhard rod which pivots on the body structure at one end and on the axle at the other. This assists in holding the axle in position (Fig. 18.10).

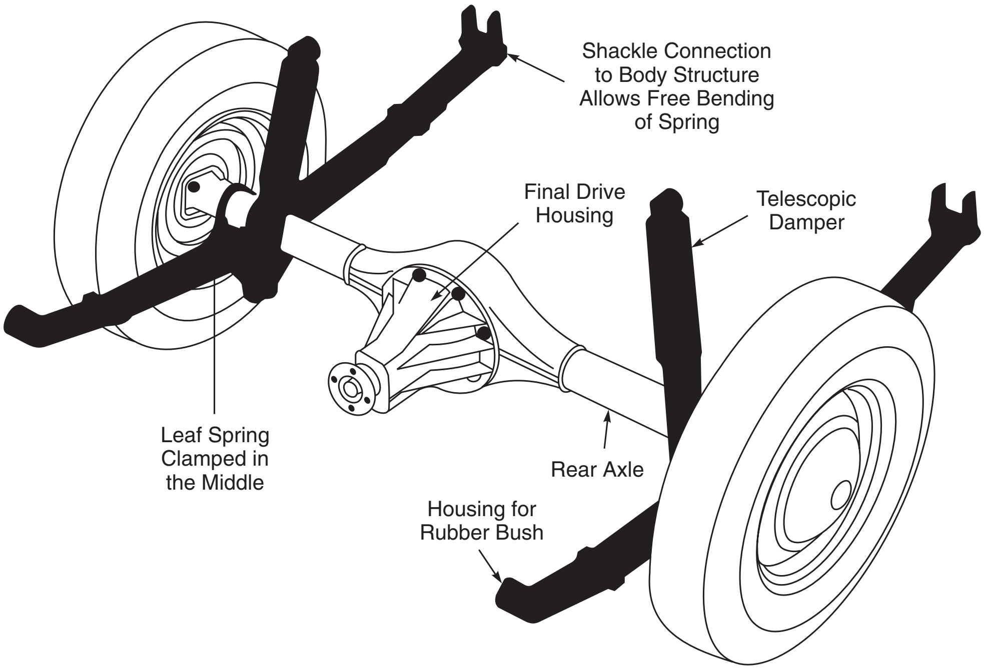



**Fig. 18.9** Hotchkiss Drive

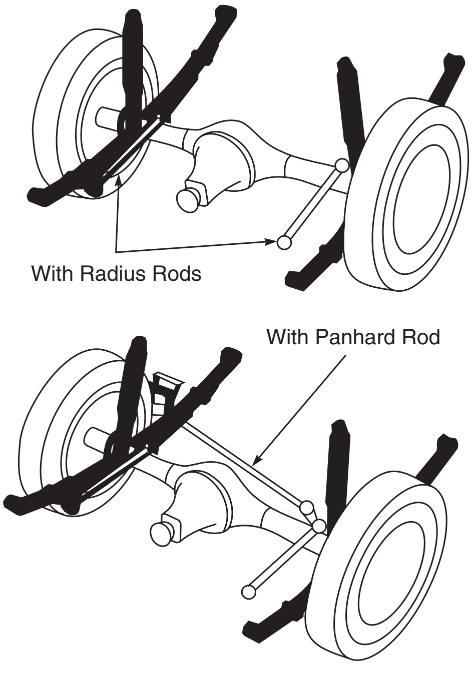



**Fig. 18.10** Leaf Springs

## Independent Rear Suspension

Many arrangements have been tried for independent rear suspension. However since the rear axle is in general a live axle, arrangements have to be made to have independent movements of the two wheels which in turn require the movements of two halves of the axle. The usual arrangement in such a case is to have a double universal coupling on each half of the rear axle, i.e. one at the point of power take off from the differential, while the other at the stub axle of the wheel. This allows the angular movement of the half rear axle while freeing the wheel from angular tilt with it.

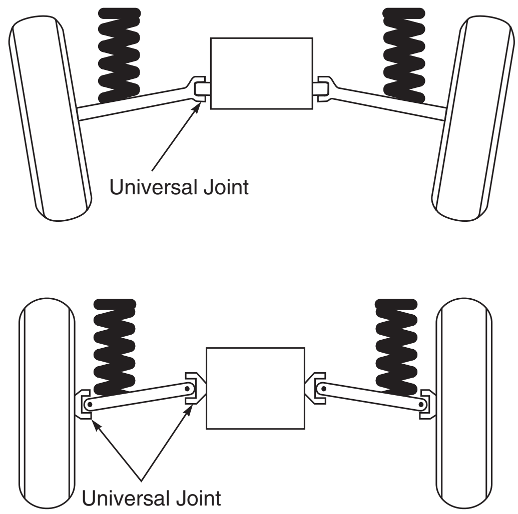


**Fig. 18.11**

**1.** ***Swinging Half Axle*** The oldest arrangement in independent rear wheel suspension was the swinging half axle type. This system has two tubes pivoted to a central drive casing carried by the car structure. A universal joint is centred on each pivot. Suspension is usually by a leaf spring lying across the car bolted to the frame or axle casing in the middle and shackled at its ends to the axle tube. A later version carried a coil spring, and a double universal joint to reduce camber changes when cornering (Fig. 18.11).

**2.** ***MacPherson Strut*** Similar to what was described in front suspension, the MacPherson strut is used in rear suspension with half axles as described in the previous section.

**3.** ***Trailing Arm Design*** In the trailing arm design, two trailing arms are used one on each side of the rear axle (Fig. 18.12). The trailing arm is a partial "Y" structure as shown and usually of forged construction. This trailing arm is hinged ahead of the rear axle to the body structure and the hinge pin is at right angles to the car axis. In such a case, the wheels move up and down without any change in camber. The coil springs are housed in between the trailing arm and the body while the hydraulic dampers are fixed to the body and the trailing arm. The trailing end of the trailing arm is hinged on the rear axle.

## 18.7 SUSPENSION SYSTEM MAINTENANCE AND TROUBLESHOOTING

Like in any other system, suspension system maintenance and troubleshooting is done in three steps:

1. Inspection and checking
2. Troubleshooting
3. Servicing

**1.** ***Inspection and Checking*** It involves visual inspection of all the joints and elements of a suspension system. Usually this is not done carefully with a notion that it is an unimportant exercise while it is patently erroneous to think so. Lots of information about the system operation and troubles arising therein are apparent in visual inspection.

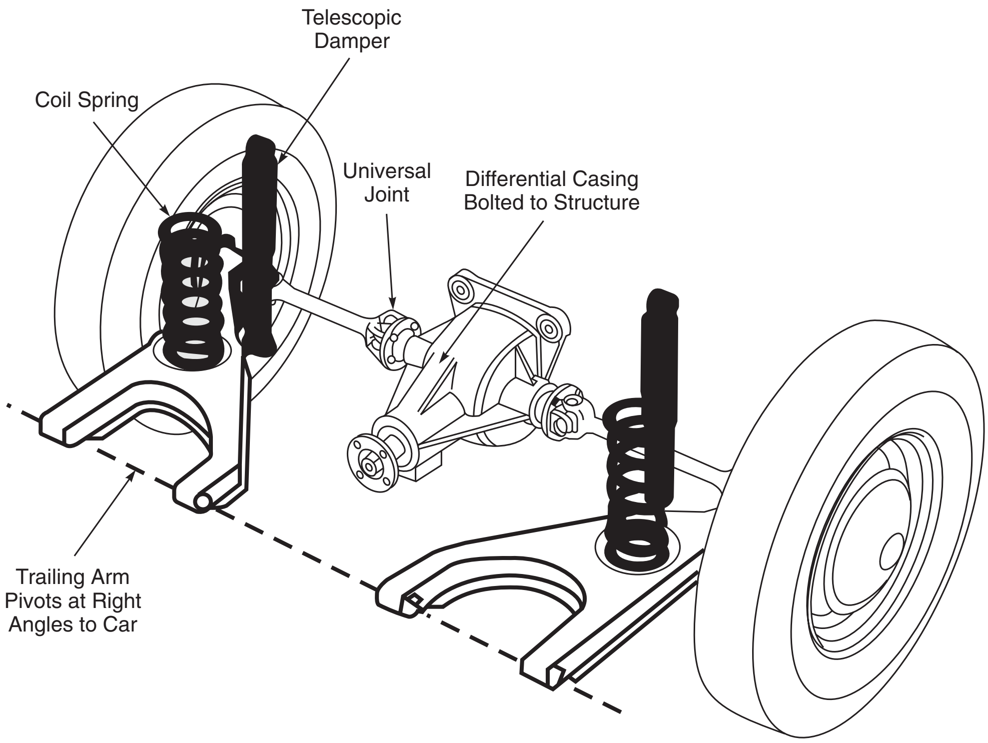



**Fig. 18.12** Trailing Arm

The second step is to check certain parameters associated with the suspension system like noisiness of shock absorber, camber and caster angles etc.

**2.** ***Troubleshooting*** Troubleshooting associates any trouble reported earlier or detected during inspection and checking with the cause of the trouble so that remedial steps can be taken.

**3.** ***Servicing*** Generally, servicing is the final step. Even when the car is not giving any trouble, regular servicing of the unit which involves the first step, i.e. inspection and checking and then lubrication, greasing etc. has to be done. This step is most important in trouble-shooting since with this step remedial steps are taken.

## 18.8 INSPECTION AND SERVICE OF SUSPENSION SYSTEM (GENERAL)

For any vehicle to give satisfactory ride and good handling characteristics the vehicle suspension must be at the correct height and all the pivot points must be secure but not loose. After a thorough visual inspection for unusual wear or rubbing, the suspension being inspected is supported against a spring with the help of a jack, or support wedge positioned between the frame and the upper control arm on suspensions having the spring above the upper control arm, so that the suspension joints are free to be moved. In this way any looseness can be detected.

Some joints like the ball joint and wheel bearings do show inherent looseness but this needs to be compared with the vehicle specifications. Any loose pivot or ball joint or bearing needs immediate replacement. However none of the joints should be too tight which may be due to the failure of bearing or the absence of lubricant etc.

Usually, both coil springs and leaf springs, sag on use and lose height. In such cases a patchy job which can put the vehicle back in service is done by putting some replacement components like rubber or metal spacers. These are manufactured specifically for this purpose by some companies. However this repair method will lead to poor handling and spring breakage. Tension adjustment of the leaf springs is also one such method. In some cases, use of booster springs around shock absorbers, inflatable air chambers built into shock absorber etc. are suggested. These are expensive alternatives but give satisfactory ride.

The torsion bar equipped front suspension has an adjustment on one end of the torsion bar that enables the vehicle height to be set without replacement or addition of height adjustment items.

The condition of the shock absorber is usually checked for leaks, physical damage and secure mounting on a visual inspection. This is followed by pushing the end of the vehicle up and down. Upon release the vehicle oscillation should stop in one or two cycles. If excessive shock absorber leakage occurs or the bouncing is not dampened, the shock absorber must be replaced. Some shock absorber manufacturers recommend replacement of the shock absorber after every 25000 miles regardless of how they appear. Front and rear shock absorbers differ in calibration and oil capacity.

Chassis suspension condition should be checked whenever the vehicle body sags at one end, at a corner or a side. It should also be checked whenever the vehicle does not handle correctly or the tyres show signs of abnormal wear. The suspension check is usually followed by alignment check to see that the front suspension geometry is correct.

The following checks in various elements of the suspension system are to be carried out during servicing:

***Front Suspension System (Independent Suspension)*** For a front suspension system, the following checks may be carried out:

(i) Check that the sub-frame has not been distorted to such an extent as to impair the proper operation of front suspension and steering, since the anchor pillars for front suspension are a part of the sub-frame.

(ii) Check that the paired coil springs installed are of the same class. Replace springs if found cracked or weakened.

(iii) Check the condition of rubber rings and replace if found damaged.

(iv) Check front wheels for any misalignment whenever noticing excessive tyre wear or irregular steering operation. For doing this:

- check the camber.
- check the caster.
- check the front wheel toe in.

These should be checked for specified values both for faulty loaded car and unloaded car conditions.

Before checking the camber, caster and toe-in, the wheels and tyres should be fully checked for:

- Tyre pressure.
- Tyre installation (for out of roundness).
- Wheel bearing play.
- Clearance between pin and bushes of steering knuckle.

- Backlash of worm to sector set.
- Steering rod ball end joints for any under play.

***Rear Suspension Systems*** For a rear suspension system, carry out the following checks:

- Leaves cracked or broken.
- No paint should be present between leaves.
- Mating faces of spring leaves should be smooth and clean.
- Check the camber of leaves. If necessary restore the required camber.
- Condition of resilient bushes force fitted on leave eyes. Defective bushes produce noise.
- Check the resilient bush pins, they should not be loose, nor incorrectly positioned in their rubber blocks.

2. Check the shock absorber for:
   - Noisiness
   - Variations in dampening effect.

## 18.9 TROUBLESHOOTING OF SUSPENSION SYSTEMS

Depending upon the troubles or faults, which manifest themselves in different ways, remedial action is to be taken after ascertaining the cause. Tables 18.2, 18.3 and 18.4 give some general troubles, their causes and remedies.

**Tables 18.2** Troubleshooting of Front Suspension

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Excessive steering stiffness or reversibility. | (a) Incorrect front geometry | Carry out wheel alignment according to specifications. |
| 2. Car pulling to one side | (a) Incorrect toe in | Correct wheel alignment |
| | (b) Broken or sagging front or rear spring. | Replace spring, carry out wheel alignment. |
| 3. Side to side wander | (a) Excessive steering play or excessive joint play. | Adjust play or replace the ball joint. |
| 4. Tyre squeals on turns | (a) Incorrect toe in | Correct it, align turn wheel. |
| | (b) Excessive steering play | Adjust according to specifications |
| | (c) Faulty wheel alignment | Carry out wheel alignment according to specifications. |
| 5. Noisiness | (a) Worn out rubber pads or bushes of stabiliser bar | Replace pads or bushes |
| | (b) Worn out shock absorber bushes or noisy shock absorber. | Replace the bushes or replace shock absorber. |
| | (c) Worn out bushes of either top or bottom or both control swinging arms. | Replace as required. |

*Contd.*

Contd.

| | | |
|---|---|---|
| | (d) Dry upper or lower control arm spider assembly. | Lubricate and replace |
| 6. Loss of cushioning effect. | (a) Cracked or weak coil springs. | Replace spring. |

**Tables 18.3** Troubleshooting of Rear Suspension

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Noise | (a) Worn out or damaged spring front or rear end bushes. | Replace bushes. |
| | (b) Worn out stabiliser bar rubber bushes. | Replace bushes. |
| | (c) Worn out spring pads | Replace pads. |
| | (d) Sagging leaf springs | Replace spring. |
| 2. Loss of cushioning effect and comfort | (a) Broken cracked or sagged leaves of leaf springs. | Replace leaf assembly. |
| 3. Noisy shock absorber. | (a) Worn out shock absorber rubber bushes. | Replace the bushes. |
| | (b) Weak or leaking shock absorber. | Replace the shock absorber. |

**Tables 18.4** Troubleshooting of Suspension System

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Car low at front. | (a) Incorrect tyre pressure | Inflate to correct pressure. |
| | (b) Broken spring(s) | Replace broken springs. |
| | (c) Weak spring(s) | Replace the front springs if the front wheel opening riding height is below specifications. |
| | (d) Weak or defective damper spring unit(s). | Check and replace. |
| 2. Car low at rear. | (a) Incorrect tyre pressure | Inflate to correct pressure. |
| | (b) Vehicle overloaded at rear | Distribute load evenly. |
| | (c) Broken spring(s) | Replace broken spring(s). |
| | (d) Weak springs | Replace the rear spring if the rear wheel opening riding height is below specifications. |
| | (e) Weak or defective damper spring unit(s). | Check and replace. |
| 3. Car low at one wheel | (a) Incorrect tyre pressure | Inflate to correct pressure. |
| | (b) Car unevenly loaded. | Distribute weight evenly. |
| | (c) Broken springs | Replace springs. |
| | (d) Weak springs | Replace springs. |
| | (e) Worn or damaged suspension components | Replace all suspension arms and bushes that are worn or damaged. |
| 4. Car tilts to one side. | (a) Incorrect hydraulic suspension pressure. | Check pressure and increase as re quired. |

Contd.

*Contd.*

| | | |
|---|---|---|
| | (b) Chassis damaged or broken. | Check alignment and repair. |
| | (c) Weak or defective damper spring unit(s). | Check and replace. |
| 5. Hard or rough ride | (a) Incorrect tyre pressure. | Check tyre pressure. |
| | (b) Vehicle overloaded or unevenly loaded | Distribute weight evenly. |
| | (c) Out of round tyre. | Replace tyre. |
| | (d) Loose or defective damper unit(s). | Tighten or replace. |
| | (e) Broken spring | Replace spring. |
| | (f) Sized suspension parts. | Lubricate or replace. |
| 6. Car sways | (a) Loose or defective damper units. | Tighten or replace. |
| | (b) Broken spring or weak spring. | Replace spring. |
| | (c) Loose or broken antiroll bar. | Replace antiroll bar if damaged. Tighten antiroll bar attachments if loose, replace damaged or worn bushes. |
| | (d) Roof rack overloaded. | Unload, use roof rack for bulky but not heavy items. |

## Review Questions

1. List some suspension system requirements.
2. What are the causes of spring oscillations?
3. State the purpose of shock absorbers used in suspension systems.
4. Describe the working of the telescopic damper with the help of a suitable diagram.
5. Describe the various types of front suspension systems.
6. Compare single unit/rigid suspension with independent suspension system.
7. State the advantages of independent suspension system.
8. Describe the functioning of a rear suspension system and its parts.
9. What causes rear suspension wind up?
10. What are the causes of weight transfer between axles?
11. Compare helical/coil springs torsion bars and leaf springs used in suspension.
12. How do shock absorbers affects spring sag?
13. How should spring sag be corrected?
14. Describe the MacPherson strut assembly of independent suspension system. Compare it with the double wish bone suspension system.
15. What are general problems that rise in a hydraulic damper? Describe their effect on riding.

# 19

# Wheels and Tyres

**Objectives**

After studying this chapter, you should be able to:

- Explain the function of wheels.
- Describe different types of automobile wheels.
- State the importance of tyres.
- Describe contact patch.
- Explain the basic requirements of good tyres.
- State different types of materials used in a tyre.
- Detail the design features of tyres.
- Describe various types of tyres.
- List tyre service parameters.
- Elaborate tyre inspection and maintenance procedures.

## 19.1 INTRODUCTION

As we know, the main function of the wheel is to support the load of the vehicle and passengers and to resist the side force, created by turning. Resistance is also necessary so that the wheel will absorb hard knocks and accidental damage.

With the development of the all metal wheel, which could be mass produced and the pneumatic tyre, the designers were able to take care of the need for lightness, combined with strength, stiffness and low cost of manufacture.

As regards our country, the first tyre factory was set up in 1936 at Calcutta. At present there are a large number of concerns engaged in the manufacture of a variety of tyres in order to meet the different requirements of vehicle manufacturers.

In case of automobiles, the essential requirements of wheels can be summarised as follows:

1. They must be of maximum strength to take the weight, road shocks, driving torque and all sorts of loads which not only change in magnitude and direction but are most unpredictable and demanding.
2. They must be strong enough to resist local deformation as and when the wheel hits against a road kerb or any other obstacle.

3. They should be of minimum weight so as to keep the unsprung weight at the lowest.
4. They must be properly balanced both, statically and dynamically.
5. They should be easy to change, easy to clean and be of good aesthetic quality.
6. They should not be too expensive.

## 19.2 TYPES OF AUTOMOBILE WHEELS

Three main types of wheels are in use today:

1. Pressed steel discs.
2. Wheels with steel wire spokes.
3. Light alloy casting wheels.

All the previously mentioned requirements are more or less met by these types. However the last two types of wheels are more expensive than the first type. It may however be mentioned that specific requirements of vehicle tyres have made all three designs much in demand in the market.

### 1. Pressed Steel Disc Wheels

Pressed steel disc wheels are the most popular type of wheels and most of the cars are fitted with this type of wheels. They are light, strong, stiff and resistant to accidental damage. Their foremost advantage is that they are easy to produce in large numbers at low cost.

The wheel has two pressings namely the rim and the disc member welded together. By making the disc member of the shape shown (Fig. 19.1), the wheel is made very strong both radially and laterally. The perforations in the disc allow fresh cool air to circulate and this assists in the cooling of brakes. A large chrome-plated or stainless steel hub cover can be sprung over the lugs in the disc. It improves the general appearance of the wheel whilst also acting as a dust and water excluder. This cover can be readily detached by a screw driver. The pressed disc wheels are secured to the axle with the help of four or five threaded studs equally spaced in a circle around the hub flanges. The holes through which the studs pass are not simply pierced through the disc. The area around each hole is pressed out to form a tapered seating which allows the hub to centre the wheel correctly. Each nut has a corresponding taper (Fig. 19.2).

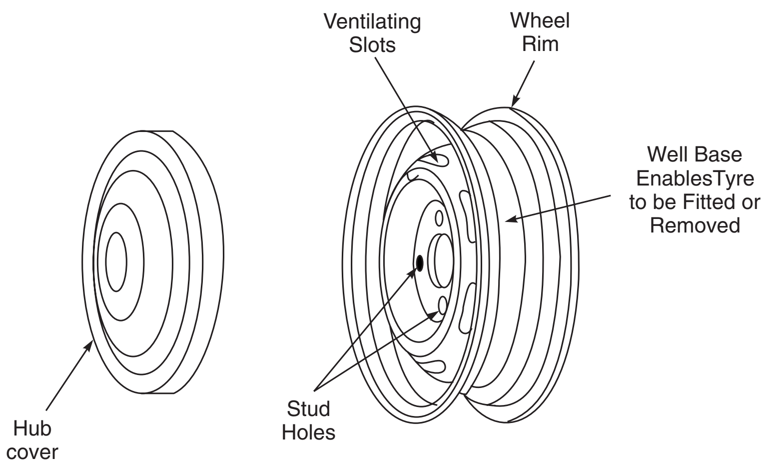



**Fig. 19.1** Pressed Steel Disc Wheel

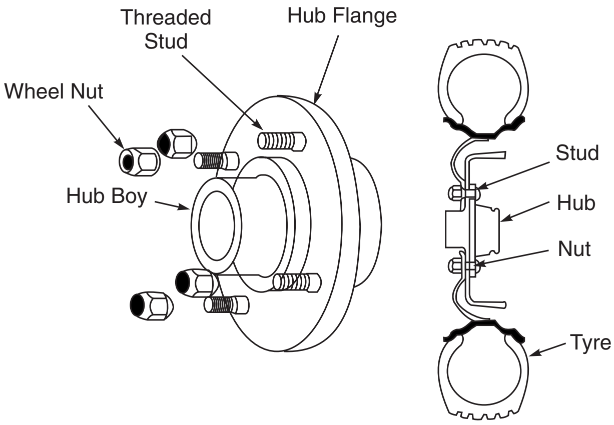



**Fig. 19.2** Fitting of the Disk Wheel to the Hub

The nuts are generally tapered on both sides although in some cases the nuts have the taper only on one end while the other end is flat. Wheel nuts should be fitted so that the tapered face engages with the tapered seating in the wheel; otherwise the nuts will not centralise the wheel on the hub and the wheel will be likely to work loose.

The wheel should not be mounted back to front since the nave area is designed to engage with the hub or brake drum over a considerable area and it is the friction between the faces that transmits the drive.

Recent wheel mounting designs have the wheel positioned by the hub itself while the studs only secure the wheel rather than locate it.

## 2. Wire Spoke Wheels

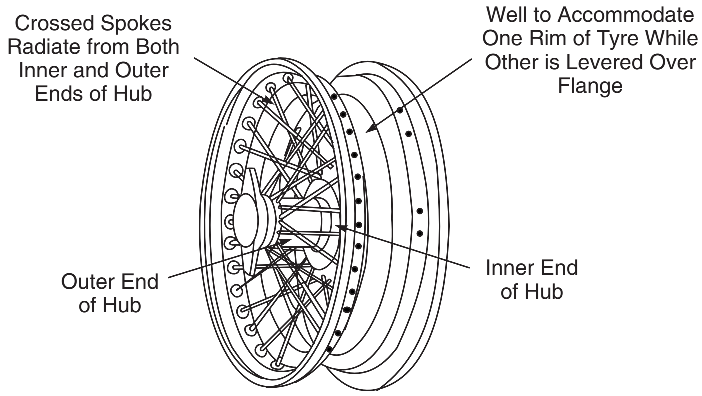
Wire spoke wheels are the oldest in design but have remained in use largely because of light weight and strong construction. However they are costly.

The wheel has a rim attached to the hub through wire spokes. These are much stronger in tension and transmit all forces to the rim. Since the spokes have very little resistance to bending, they are laced so that complex loads coming on the wheel are resolved into tensile load evenly distributed among adequate number of spokes (Fig. 19.3).

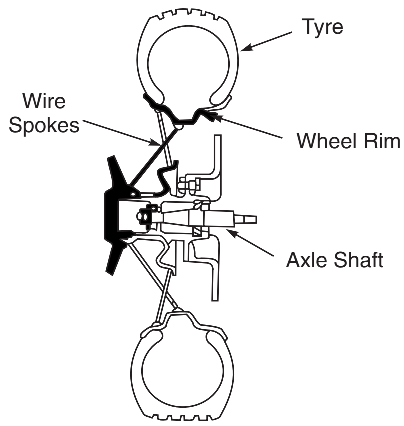
The stresses and loads faced by a car wheel are very complex. They are more critical in case of accelerating, braking and cornering and when such actions are combined. Usually the spokes have three different sets to take the acceleration, braking and weight forces. They also are able to take the side thrust during cornering by having a triangular pattern (Fig. 19.4).

The assembly of wire spokes is done skilfully by hooking each spoke at one end into the hub while the other is passed through a hole in the central plane of the pierced rim. This other end is secured with the help of a tapered nut, i.e. nipple, so as to fix the spoke in tension. The spokes are to be evenly tightened in the absence of which the flimsy rim tends to distort. The tightening is checked by monitoring the wheel rim distortion. Since the rim is pierced, this type of wheel cannot be used for tubeless tyres which require air tight rims.

The wire spoke wheel is fitted on the axle with the help of a central lock nut. The wheel hub and axle are both splined and when the wheel is slided on the axle these splines engage, and the wheel is secured by a central large wing nut which can be tightened or loosened by a soft hammer.




(a) Wire Spokes




(b) Sectional View Showing Location of Two Rows of Spokes

**Fig. 19.3** Wire Spoke Wheels

## 3. Cast Light Alloy Wheel

Cast light alloy wheels are made from castings of light alloys of aluminium and magnesium. They have wider rims, and radial ribs which also act as angled spokes to provide strength and air circulation. The construction avoids any sharp lines and angles to improve strength (Fig. 19.5).

Cast light alloy wheels have certain definite advantages over other types that make them specially useful in racing cars. Aluminium and magnesium alloys are usually used for this purpose. The advantages and disadvantages can be listed as:

***Advantages***

1. Cast light alloy wheels are light in weight.
2. Heavier sections can be used which improve the stiffness of the wheel and result in better stress distribution.

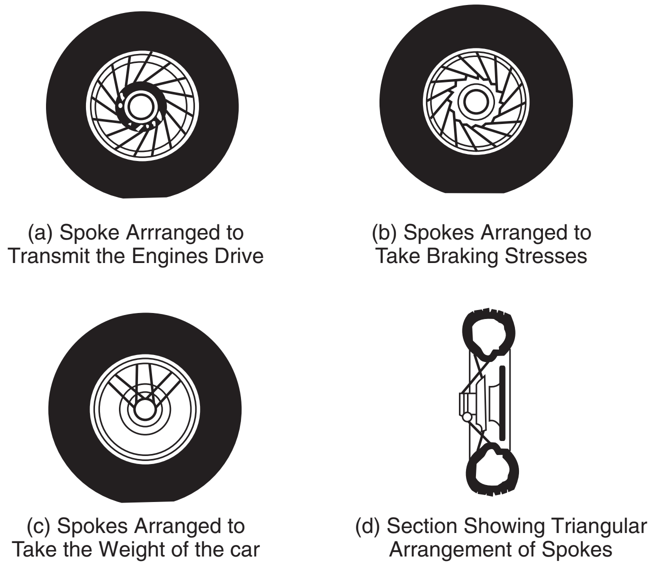



**Fig. 19.4** Wire Spoke Wheels

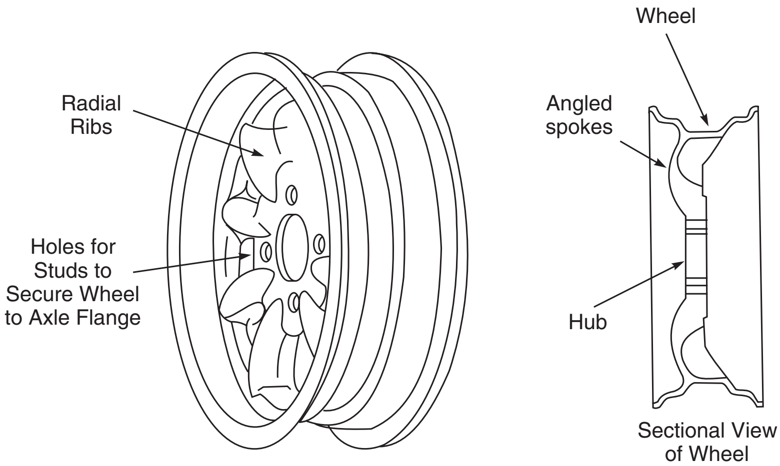



**Fig. 19.5** Light Alloy Wheels

3. Rims with larger area can be used which result in the use of wider tyres with less diameter. This is a definite advantage in racing cars since the lower centre of gravity and wider tyres result in better road grip particularly during cornering.
4. Light alloys are better conductors of heat and hence heat dissipation from tyres and brakes is improved.

***Disadvantages***

The biggest problem with alloy wheels is corrosion which places them at the biggest disadvantage. These wheels are chemically sensitive to salt spray and need regular checking and inspection for corrosion. Similarly, there is danger of electrolytic corrosion when the steel comes in contact with light alloy. This requires the location or retaining studs to be greased.

## 19.3 TYRES

Tyres are the most important members in motor car transmission and drive system. Not only do they have to cope with the worst possible forces, shocks and other parameters, they are also expected to absorb most of them along with the suspension system so that the riders do not feel any of it.

A modern car tyre is an inflatable rubber ring fitted round the wheel. It is built up on a strong carcase with metal hoops embedded in the tyre where it fits the rim. It has flexible side walls to absorb loads and a tread to grip the road under varying conditions.

Vehicle control, acceleration and braking occur through the tyres and their foot print or *contact patch* on the road surface. The demands on the tyres are low when the vehicle is operated at low speeds and light loads on smooth dry road surfaces. The requirements on them increase as speed, load and handling demands increase.

Tyres must be large enough and strong enough to support the load they are expected to carry. They must absorb or cushion sudden loads by deflecting part of the shock from road irregularities. They must develop tractive forces for accelerating, cornering and braking.

Paradoxically, tyres are expected to perform sometimes two opposite functions. For example, it has to resist damage by being strong while at the same time it has to cushion impacts by being flexible. The result is that no one tyre can be good for all conditions.

The requirements from a good tyre are quite a few in number and some of them can be enumerated as follows:

(i) It must be strong to carry loads and resist damage.
(ii) It must be flexible to cushion all shocks and impacts at least partly.
(iii) It must respond accurately to steering without deflection by the ridges on the road.
(iv) It must provide good road grip for traction, cornering, accelerating and braking.
(v) It must meet its requirement in all weathers and on all surfaces without overheating.
(vi) It must provide a comfortable ride to the motorists.
(vii) It must run quietly.
(viii) It must have a long life.
(ix) It must be economical if not downright cheap.

It is needless to say that none of the tyres can fulfill all these conditions and a good tyre is at best a compromise of some of the characteristics. For example, a tyre suitable for high speeds is unsuitable for low speeds. A tyre suitable for snow and wet conditions is unsuitable for dry conditions and high speed driving.

### Tyre Construction

A tyre is made from rubberised fabric plies over a rubber liner. The edges of the plies are wrapped around a wire bead that holds the tyre to the wheel rim. The fabric plies are covered with a rubber compound tread and a different rubber compound for the side walls. The tyre is curved in a mould to vulcanize the parts into one single unit and form the tread design. The cross-section of a tyre is shown in Fig. 19.6 which marks the different parts of a tyre.

### Tyre Materials

Basically, a tyre is an inflatable rubber tube fitted round the frame of a road wheel. Apart from the wire rope used for bead material, the tyre uses an elastomer and a fabric cord for the body and plies respectively. The materials actually used cannot be described so simply.

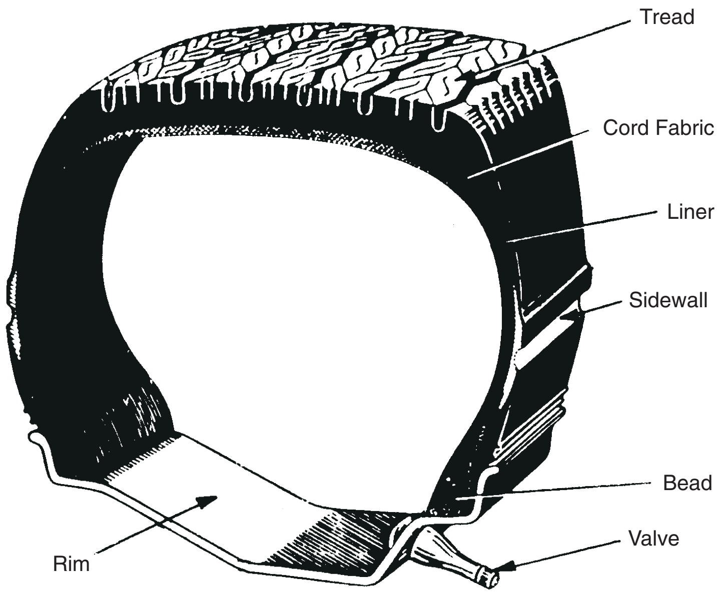



**Fig. 19.6** Section of a Tyre Showing Parts

As the motor cars evolved over the 20th century, technology developed at a faster rate with deeper insight into the compulsions and requirements of the material on one hand while material research put a wide variety of materials at the disposal of the manufacturer on the other.

For many years, natural rubber was used as tyre material but with time more and more synthetic rubber material replaced the natural rubber as the elastomer. Nowadays rubber used in tyres is an elastomer that blends natural and synthetic rubbers with the addition of chemicals and filler compounds to produce the desired characteristics.

**1. *Tyre Tread Material*** Tyre tread stock must be able to resist wear and abrasion while providing traction. A large amount of carbon black is added to the tread rubber to increase wear and abrasion resistance. Traction results from tread rubber hardness, compounding and tread design. Hard compounds provide good wear and poor traction while soft compounds provide good traction and poor wear. The tread compound is a selected compromise to provide the properties required for each tyre application.

The most widely used synthetic material in tyres is Styrene Butadine Rubber (SBR). It has much less bounce than natural rubber which means a softer ride, and when used in tyre treads SBR maintains closer contact with the road providing a good grip, especially in wet weather. It also has excellent resistance to abrasion. Another synthetic used in tyres is Poly Butadine (PB). This is hard-wearing and less sensitive to temperature than other synthetics, but too much of it in a blend makes tyres scream in dry conditions and slip in wet. PB is usually mixed in small quantities with SBR, with natural rubber or both.

The elastomer is mixed with other additives like carbon black, oil and sulphur. As mentioned earlier carbon black improves wear and abrasion resistance, sulphur acts as a vulcanising agent while oil improves road holding at the expense of tyre wear.

**2. *Side Walls Material*** The Elastomer used for side walls and ply imprigration is a more flexible rubber compound than tread rubber. It gives the tyres its required flexibility and strength properties. The side walls must be flexible enough to deflect while passing the tyre contact patch on each revolution. It must also flex to absorb any shock that is produced by irregularities in the road surface. The side walls must also have sufficient strength to transfer all acceleration and braking torque between the wheel rim and tyre tread. It also must withstand cornering forces that are applied to the vehicle.

**3. *Ply Material*** Several types of fabric cord materials are used in the tyre plies. Tyre manufacturers and fabric producers are continuously striving to improve their materials and develop new materials that will better meet tyre requirements.

Cotton was the earliest to be used as cord material which was replaced by rayon in 1938 before World War II. It was more durable, gave a soft-ride, was more resilient and less expensive than cotton. It has a good tensile strength of about 6400 kg/cm$^2$. As the synthetic material revolution started with rayon it gave way to Nylon in 1947 just after World War II. There were two forms available and they had superior tensile strength at 8300 kg/cm$^2$, 30% higher than rayons. Nylon was more resistant to heat and water than rayon and had a high impact strength. It was less flexible which resulted in better vehicle handling but a harsher ride. The major disadvantage with nylon was that it tended to take a setting while standing resulting in a flat spot. This would thump when the car started rolling. However on warming up the flat spot vanished. It was also slightly more expensive than rayon.

Polyester was introduced in 1962. With a tensile strength at 7000 kg/cm$^2$, it was between nylon and rayon. Likewise with heat resistance, i.e. better than rayon but worse than nylon. However it gave a soft ride with no tendency to flat spot.

Fibre glass was introduced almost at the same time which was much stronger at 27000 kg/cm$^2$ but had poor flexing resistance. Its strands had a tendency to chafe during flexing which was a major disadvantage. However in 1962, Owens and Corning developed a technique of mixing a plastic which prevented chafing. This improved its use as ply material. However it cannot be used in side walls since it has low flexing strength.

**4. *Breaker Cords Material*** Breaker strips are used in radial ply and bias belted tyres between tyre plys and treads. Nylon first used for breakers in aircraft tyres is stronger, more elastic and more flexible than rayon and keeps the tyre cooler. It is used in car tyres for high speeds or heavy loads but only in combination with other materials. Fibre glass was found suitable for these. Fibre glass is very strong and surprisingly elastic. However special techniques have to be used to prevent the chafing of the filaments and to achieve a satisfactory bond between them and the rubber casing.

Steel cords have of late been used for breaker belts in some tyres. They have high impact strength and are quite rigid. Steel makes a stronger cord and does not stretch under inflation pressure.

## Tyre Design Features

Since the development of the first automobile to the present state like every other component, tyres have also gone through a series of changes. Not only the material but its design also has had totally new features incorporated. Gone are the days when the tyre was considered to be a simple rubber ring inflated pneumatically. Every aspect of a tyre has a lot of effort in design, development, research and testing behind it.

### Tubed and Tubeless Tyres

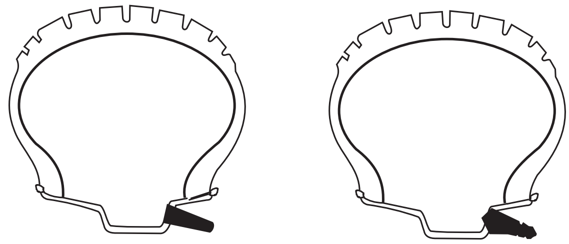



**Fig. 19.7** Tubed and Tubeless Tyres

The general tyre is a tubed tyre which has a hard tyre outside with a soft rubber inner tube. While the air is filled under pressure in the tube through a non-return valve, the tube fills the space between the tyre and the rim. Tubeless tyre on the other hand is made air-tight by a soft rubber lining to the casing. This lining also forms a seal between the tyre bead and the wheel rim. The tubeless tyre has lot of advantages over a tubed tyre (Fig. 19.7).

1. The tubeless tyre is easier to fit.
2. When punctured it deflates slowly in contrast to tubed tyres where air leaks out fast. This is because the soft lining has a self-sealing effect.
3. A temporary puncture repair can be made without removing the wheel by stopping the hole with a special rubber plug.

However tubeless tyres cannot be used in spoked wheels since in that case the rim is perforated.

### The Tyre Shape

A tyre is usually indicated by a series number, for example '78', '70', '83' and so on. This designation is derived from the *Aspect Ratio* which is numerically equal to the ratio of the section height to the section width (Fig. 19.8). The conventional tyres for quite some time had 100% aspect ratio where the height of the tyre was the same as width and hence was designated the 100 series.

With the improvement in car design, increasing speeds, and the need for better road grip led to wider car tyres with lower aspect ratios. The aspect ratio gradually dropped from 90% to 85% to 70%. In case of racing cars the aspect ratio may be as low as 35% to 45%. Wider tyres improve vehicle handling and give a performance styling to the vehicle. The wider tyres put more tread on the road and give better high speed performance, better cornering, better load carrying capacity and longer life than the old symmetrical type. Passenger cars now a days have an aspect ratio of 70% in case of radial ply tyres. However ratios below 60% are difficult to accommodate in general automobiles and are used in racing cars.

### Tyre Plies

Plies are the fabric which are usually rubber coated which form the fabric pattern giving the tyre its essential strength. Tyres may use from two to ten plies of cord fabric. A tyre's strength and load carrying capacity were at one time indicated by the number of plies a four ply tyre indicated that the casing was built up from four layers of inner lining material and could carry a specific load with safety. With modern materials it is not so. Ply ratings are still used but only to indicate the strength and load carrying capacity. A four plies rating may well be given to a tyre which has only two plies in the casing.

It has been found that in many cases the tyre manufacturers have gone from four ply to two ply construction. In fact two ply construction has certain distinct advantages over a four ply construction. The two ply tyres run cooler, are more flexible to absorb shock from road irregularities and apply greater self aligning torque to the steering system after a turn. Two ply tyres are

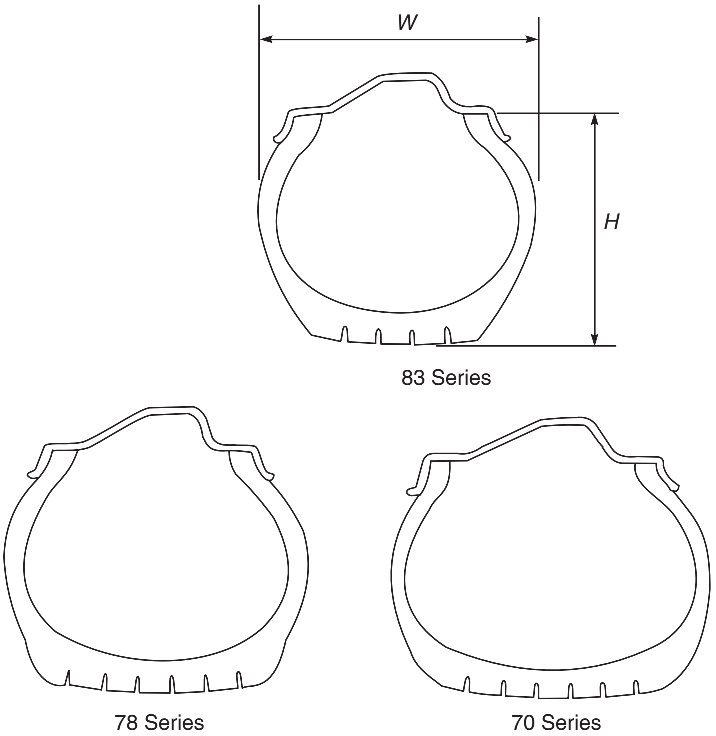



**Fig. 19.8** Cross-section of Tyre Series

as strong as four ply tyres because the tyre cord denier (small diameter nylon cord is called denier in English System) is larger that is used in four plies tyres. The strength of the ply is the result of the weight of the cord rather than the number of plies. Service experience has shown fewer failure with two ply tyres than with four ply tyres. This is primarily the result of lower temperature operation and their ability to flex over road hazards rather than resisting a hazard which could break the cord.

## 19.4 TYPES OF TYRES

Tyres are of three types based mainly on the type of the ply fabric layout.

1. Cross ply or bias angle construction.
2. Bias belted construction.
3. Radial ply construction.

### 1. Cross Ply Construction

The earliest type of tyres had the plys running across perpendicular to the direction of rotation. There were two or more layers or plies of fabric. Due to its construction, it was named the cross ply. It gave a comfortable ride but had some ill effects on steering. When plies were made parallel to the direction of rotation, the directional stability improved. This however reduced comfort. A compromise was to be found to have both comfortable ride and steering stability.

Tyres now have different layers of plies diagonally superimposed on each other to form a lattice pattern. Earlier these were placed at an angle of 45°, but now the angle has been reduced to 40° and in some cases even less (Fig. 19.9). These tyres are economical. However they have a tendency to squirm as they go through the tyre foot print or contact patch.

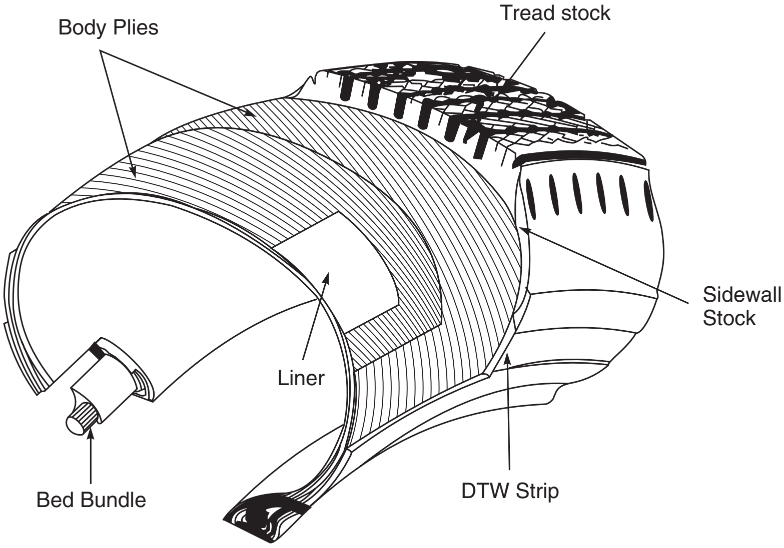



**Fig. 19.9** Cross Ply Tyre Construction

The tread is pushed together as it goes into the contact patch. This stores energy in the rubber, as the tread comes out of the contact patch the tyre rapidly expands and goes beyond the neutral point into a stretched position. The tread then contracts causing an oscillation. At high speeds the tread squirm is evidenced as a standing wave on the back side of the tyre as it comes up from the tyre contact patch or foot print. The closing and opening of the tread as it goes through the contact patch is one of the major causes of normal tyre wear.

## 2. Bias Belted Tyre Construction

An improvement to the cross ply or bias ply construction is the bias belted tyre where in addition to cross plies or body plies there are additional belt plies or breaker cords (Fig. 19.10). This results in the reduction of tyre squirm and improvement in tread stability with the result that there is almost 100% improvement in road mileage compared to cross ply construction. By keeping the tread shape they show the following advantages over cross ply:

(i) They show greater road mileage.
(ii) The bias belted tyres run cooler.
(iii) They have improved traction.

However since they do not flex as easily as the cross ply, the ride is harder since all road shocks are transmitted to the body. Hence for comfort, designed springs and suspension systems have to be employed, to reduce road shock transfer to the passenger compartment.

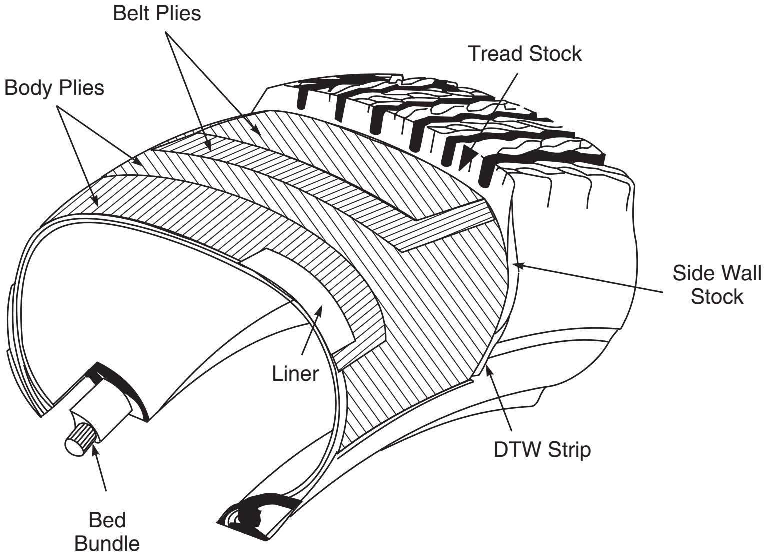



**Fig. 19.10** Bias Belted Construction

### 4. Radial Ply Construction

Radial ply construction tyres are the most modern type and are gradually replacing the other two. Essentially, they have plies running from bead to bead across the crown at right angles to rotation. On the side walls the direction of these plies is radial, and hence the name. However above the layers of these plies and below the tyre tread, there are belts of cord or breakers which run around the circumference. The angle between the cords varies from 18° to 22°. The number of layers depends upon the material used, the lateral stiffness needed and the load the tyre is required to carry (Fig. 19.11).

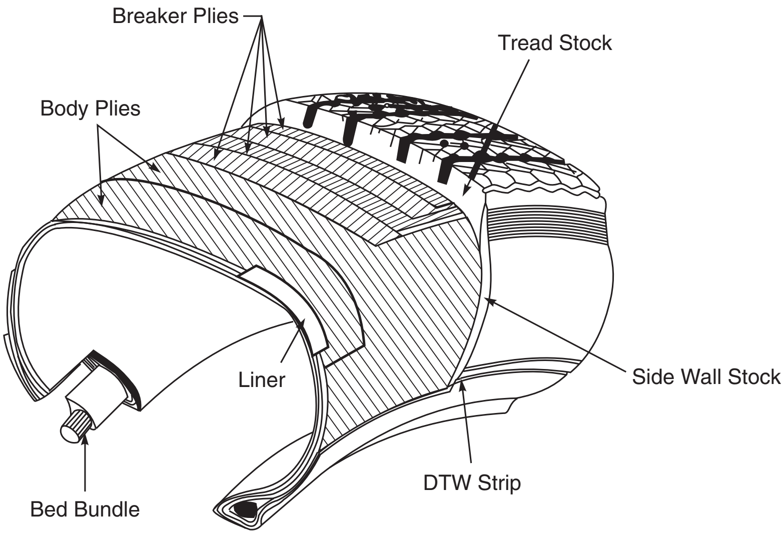



**Fig. 19.11** Radial Ply Construction

The construction of radial ply tyres reduces cornering wear and considerably increases the overall life of the tyre but this is at the expense of the slightly harder ride at low speed. The radial plies give greater pliability and comfort but little or no directional stability which comes from breakers since they firmly restrict any lateral stretching of the tread. The radial ply tyres are expensive as compared to other two types.

## 19.5 TYRE TREAD

The rough pattern of rubber either natural or synthetic on a tyre surface is known as the tyre tread. Initially it was only road grip which was considered important for tyre design but not any more. Tyre treads are important for economy, good road grip in all conditions, comfort and speed.

In case of a smooth dry surface, a smoother tyre can be said to be better since it gives the maximum area of contact known as contact patch or tyre foot print. However specific treads are necessary for different purposes. For example a trailer will need different treads as compared to a steering tyre. The driving tyre will need a still different tread. A compromise is therefore necessary by considering steering, driving, braking requirements and above all cost constructions.

The requirements of tyre tread are all the more important in wet conditions since in that case the tread first pushes water aside or pumps it through the zig-zag grooves and channels in the tread which run parallel to the wheel. In this way, water is pushed to the back of the contact patch where it spins off behind the tyre. The remaining water is mopped up like sponge by the sipes or knife-like slits in the tread and then the tread pattern grips the dry surface for traction. Water if not removed like this may form a wedge-like film between the road and the tyre called the *aquaplane* or *hydroplane*. In that case, the tyre does not touch the road surface at all and the driver is likely to lose vehicle control. At 100 km/hr on a wet road, the tread pattern on an average tyre is required to remove almost five litres of water out of the way every second. In case of heavy rain, it may be needed to remove double the amount of water. A bold and rugged tread is useful in wet conditions since the deep grooves can quickly channel away the water. A smooth tyre on the other hand is susceptible to developing aquaplane. Even otherwise water acts as lubricant between the tyre and road resulting in the car losing control.

## 19.6 TYRE SELECTION

It is normally assumed that of the four car tyres any tyre can be purchased and used on any one of them. However, it has been found that such a notion is totally erroneous. Proper combination of tyres is necessary for smooth, safe and economic driving while wrong mixing of tyres may be hazardous. Certain guidelines mentioned here have to be kept in mind.

1. Whenever possible, radial tyres should be used with cross ply or bias belted tyres on the same vehicle. If radial tyres are to be used they should be used on all four wheels.
2. If radial tyres must be used with cross ply or bias belted tyres, they should be used in pairs on common axles. The radial tyre should be used on front wheels since this is considered safer. Radial tyres should never be used on the front wheels when cross ply or bias belted tyres are used on the rear wheels.
3. When using cross ply and bias belted tyres, they should also be used in pairs on the common axle, and the cross ply tyres should be used on front wheels while bias belted tyres should be used on rear wheels.

4. Tyres in different sizes may be used on the same car only in pairs on the common axles. Also the tyres on the front axle and those on the rear axle should be no more than one series apart. The widest tyres should be used on the rear wheels. For example 78 series may be used on front wheels with 70 series tyres on rear wheels.
5. When using tyres with belted-breaker construction, steel belted tyres should be used on rear wheels while textile breakers should be used on front wheels.

It is not a universal rule, however it is considered better that the tyre types should not be mixed. As far as possible all tyres should not only be of the same type, but should also be of the same size, tread pattern and make. This ensures maximum safety. Tyre selection is based on a lot of parameters which include vehicle parameters like rim size and kind of operation expected from the vehicle. Operating parameters like type of driving, the type and condition of road surface, the weight to be carried, the miles driven per year and the length of time the vehicle is to be used are also important.

A stiffer tyre will provide better handling and a harsh ride. Belted tyres give more mileage along with a harsher ride than cross ply tyres. Wide treads have more style and are difficult to steer especially while parking.

Tyres with hard rubber in their treads wear longer, but provide less tyre to road adhesion. No one tyre is best for all types of vehicle operation. Vehicle and tyre manufacturer recommendations should be followed for most satisfactory results. Table 19.1 provides comparative data of some tyres used in Indian vehicles.

**Table 19.1** Comparative Data of Tyre in Some Indian Vehicles

| *Make of Vehicle* | *Ply rating* | *Tyre size* | *Inflationary Pressure* | |
|---|---|---|---|---|
| | | | *Front tyres (Psi)* | *Rear tyres (Psi)* |
| 1. Ambassador | 4 | $5.90 \times 15^2$ | 26 | 28 |
| 2. Premier | 4 | $5.20 \times 14^2$ | 24 | 26 |
| 3. Maruti 800 | 4 or 6 | $4.50 \times 12^2$ | 22 | 22 |
| 4. Jeep CJ-3B | 4 | $6.00 \times 16^2$ | 26 | 28 |
| 5. Ashok Leyland | 12 | $9.00 \times 20^2$ | 85 | 85 |
| 6. Tata Truck 407 | 14 | $7.50 \times 16^2$ | 55 | 100 |
| 7. Tata Truck 1210 | 14 | $9.00 \times 20^2$ | 100 | 100 |
| 8. Telco Indica (Petrol) | — | 155/70 R13 | 22 | 22 |
| 9. Hyundai Santro | — | 155/70 R13 | 22 | 22 |
| 10. Daewoo Matiz | — | 145/70 R13 | 22 | 22 |

## 19.7 TYRE SERVICE PARAMETERS

Several important features of tyre operation need special attention since they to a large extent affect the tyre function. For example wheel rim size as compared to the tyre tread width is important. If the wheel rim width is same as the tread width, the side walls are straight up and down. This results in a harsher ride. When the rim is narrower than the tread, the side walls curve inside resulting in a softer ride.

The tyre bead should fit nicely with the wheel rim since when the car accelerates, the rim tries to rotate relative to the tyre. The friction between the bead and rim prevents this motion. The same thing happens while braking. During turning the tyre is deflected sideways, the bead in this case tries to leave the rim on one side. This is undesirable.

When the wheel rotates at a high speed, the tyre expands due to the centrifugal force. The tyre bead should in such a condition also hold tightly on the rim. Cross ply tyres do not allow the tread to expand and hence have less chances of this happening.

While running, tyres flex due to the load and other forces. This is more pronounced when the vehicle is negotiating a curve. This flexing distorts the tyre which is natural and which allows the tyre to absorb the road shock and to flex through the contact patch without skidding, while turning round a corner.

The flexing of tyre results in heat being built up. This heat in normal cases increases the temperature to some extent, after which it stabilises. If the heat generated is excessive, the tyre temperature crosses the safe limit, the tyre loses its strength, the rubber leaves the cord and in some cases the tyre starts burning.

Excessive heat thus generated can be reduced by taking some precautions:

1. Reduce speed which reduces heat generation and improves cooling.
2. The tyre should not be under-inflated. Less pressure in tyre results in more flexing and more heat generation. Proper inflation should be provided.
3. Reduce load on wheels. More load causes more flexing.

The tyre inflation pressure is also an important parameter. Both over-inflation and under-inflation are detrimental to tyre operation.

***Under-inflation results in:***

(i) Excessive flexing—more heat generation and tyre body damage.
(ii) Tread edge wear.
(iii) Improper vehicle handling noticeable even at speeds as low as 60 km/hr.

***Over-inflation results in:***

(i) Reduction of flexing and heat generation.
(ii) Wear of centre of tread.
(iii) Harsher ride.
(iv) Tyre tends to puncture when hitting a pointed object. An under-inflated tyre will merely flex in such a case.

## 19.8 TYRE MAINTENANCE

The maintenance of tyres is usually a very neglected field. Car owners usually fit the tyres and forget about them till a problem arises. Visible signs of abnormal tyre wear or other such failure manifestations are usually over-looked. The result is that performance of tyres is affected adversely.

Two important steps for maintenance are suggested by tyre manufacturers. However, the most important point in tyre maintenance is to maintain a proper inflation pressure. As mentioned earlier, both under-inflation and over-inflation result in unsatisfactory tyre performance. The two important steps are:

1. Tyre rotation.
2. Tyre inspection.

**1. *Tyre Rotation*** In general, car manufacturers recommend tyre rotation in such a way that the tyres do not run in the same position for more than a specified mileage, say 5000 to 10,000 miles. Rotation equalises wear and minimises tyre noise. The tyres should be rotated in a definite pattern and the same pattern should be followed every time rotation is being carried out. Normally all five tyres should be rotated. However in case the spare tyre is in poor condition, the other four tyres should be rotated.

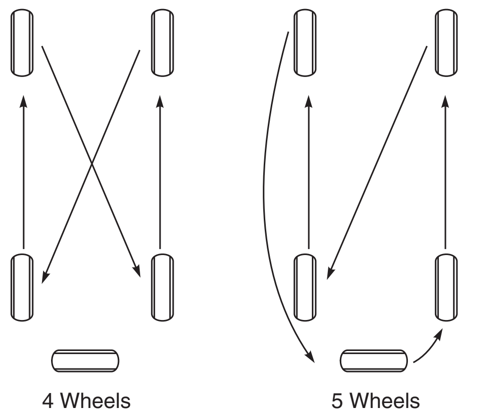



**Fig. 19.12** Typical Tyre Rotation Patterns for Bias Ply and Belted Bias Tyres

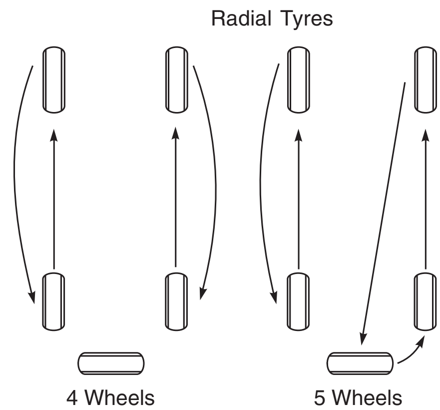



**Fig. 19.13** Typical Tyre Rotation Patterns for Radial Tyres

Cross ply tyres should be rotated as shown in Fig. 19.12. Radial ply tyres on the other hand should be rotated such that they remain on the same side of the car and longer life will be ensured if they rotate in the same direction throughout. Figure 19.13 shows the procedure to be followed for tyre rotation in case of radial ply tyres.

**2. *Tyre Inspection*** A regular inspection of the tyre for wear is very essential to extract maximum service life. Tyre tread should not wear out to a depth less than 1.6 mm. This wear should be even throughout the tread. Any abnormal tread wear should be checked and the fault should be diagnosed. Tyres have tread wear bands which appear when the tread depth reduces to less than 1.6 mm. When these bands appear on tyres in two or more adjacent grooves the tyre should be replaced.

Careful inspection of tread wear in fact almost pinpoints the causes of wear and if remedial steps are taken early, the tyre life is prolonged. The tyre should not only be inspected for tread wear but also for side wear and damage. The tyre can be damaged or excessively worn by mechanical faults, bad driving or inadequate maintenance. Whatever the reason, they can be a danger to the driver, passengers and any one else on the road. Table 19.2 provides a list of abnormal wear patterns, their causes and remedial measures. Table 19.3 lists some causes of wearing of tyres and their manifestations.

**Table 19.2** A List of the Most Commonly Found Abnormal Wear Patterns, their Causes and Corrections

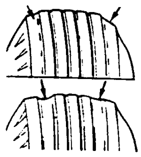
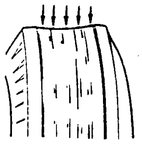
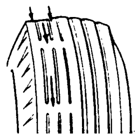
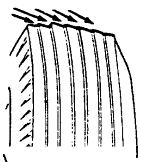
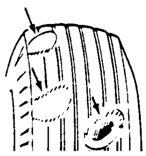
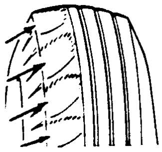
| *Wear pattern* | *Example* | *Causes* | *Correction* |
|---|---|---|---|
| 1. Excessive wear at the tread shoulders or the outer edges. |  | (a) Under inflation<br>(b) Lack of rotation<br>(c) High speed cornering | Maintain proper inflation pressure.<br>Rotate the tyres.<br>Caution the driver against high speed cornering |
| 2. Excessive wear at the centre of the tread |  | (a) Over-inflation<br>(b) Lack of rotation | Deflate tires to proper pressure if necessary.<br>Rotate the tyres. |
| 3. Excessive wear on one side of the tread. |  | (a) Excessive camber | Adjust camber to specifications. |
| 4. Saw-tooth wear |  | (a) Incorrect toe-in | Adjust toe-in to specifications. |
| 5. Random bald spots |  | (a) Unbalanced wheel and tyre assembly<br>(b) Defective tyre (soft spots) | Balance the wheel and tyre assembly, if the tyre is still usable. Replace the tyre if it is not usable and then balance the wheel and tyre assembly. |
| 6. Cupped or ocalloped wear |  | (a) Lack of rotation<br>(b) Improper alignment<br>(c) Worn steering or suspension parts. | Rotate the tyres.<br>Align the wheels.<br>Replace worn parts. |
| 7. Cracked treads |  | (a) Alternating over-inflation and under-inflation<br>(b) Over-loading,<br>(c) High-speed driving. | Inspect the tyre for internal damage, and replace the tyre if necessary.<br>Caution the driver against overloading and high speed driving |

**Table 19.3** Some Causes of Tyre Wear and Their Manifestation

| | *Cause* | *Action* | *Effect* | *Remedy* |
|---|---|---|---|---|
| 1. | Speed | High speed driving results in over-heating and softening of rubber. | "Chunking"-small pieces of tyre tread fly-off leaving a pothole. | Choose proper tyre as requirements of service. |
| 2. | Stopping and starting | Fierce acceleration and sudden braking. | Rapid tyre wear and development of flat spots. | Avoid this bad driving habit, leave it for emergency. |
| 3. | Toe-in and toe-out | Excessive toe-in (wheels of same axle closer at front than at back at axle level) or vice-versa causes scrubbing. | Results in feathering of edges of tyre. The damage is clearly visible on inspection. | Get the toe-in and toe-out checked in a garage. |
| 4. | Camber | It is the angle at which tyre meets the road. | Tyre wear excessive on one edge. May be caused by slight collision. | Get the camber checked. |
| 5. | Caster | The tendency of the steering to become straight after turning. | (a) Not enough caster—wheel will tread wear spotty.<br>(b) Excessive caster—flutter and irregular wear.<br>(c) Front wheel caster uneven—car will pull to one side, uneven wear. | Get the caster checked and any excessive or inadequate caster modified in a garage |
| 6. | Lack of balance | Badly balanced tyres, over wheel drums or high spots on the tread. | Extra spot on the tread. | Repair and corrective action needed. |
| 7. | Badly adjusted | Vehicle pulling on one side or moving to one side when braking. | Extra wear at several places. | Repair and corrective action needed. |
| 8. | Mechanical faults | Distorted wheels, worn wheel bearings, worn suspension or steering joints, ineffective dampers. | Irregular and rapid wear of tread. | Repair and corrective action needed. |
| 9. | Oil and fluid | Oil and fluid coming on tyres | Damage the rubber. | Clean the tyre, check the source of oil coming on tyre. |
| 10. | Inflation | Most important cause of uneven and excessive tyre wear if not checked properly<br>(a) Over-inflation | (a) Over-inflation causes excessive wear at the centre of the tread. Prolonged use exposes fabric. | Check tyre pressure regularly and keep it within prescribed limits. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | (b) Under inflation<br>(c) Flat tyre being used for some distance. | (b) Under-inflation Tyre wear excessive at the edges.<br>(c) Flat tyre when used causes crack at the side wall and prolonged use results in car-case failure |

## Review Questions

1. State the requirements of a tyre.
2. How many types of car wheels are there? Describe relative advantages and disadvantages of each.
3. What types of tyre cord materials are available? What advantages and disadvantages does each type have?
4. Describe tyre construction in brief.
5. What are the different tyre body designs? Describe them and discuss their relative merits and demerits?
6. Why should mixing of tyre types on one car be avoided?
7. Why it is important to have a good fit between tyre bead and the rim ?
8. What are the causes of tyre heat and how can it be reduced?
9. What are the results of under-inflation and over-inflation?
10. What are the important causes of tyre wear? What are their effects on tyre tread wear? How can they be controlled?
11. What is tyre rotation and its purpose?
12. Explain the following terms in tyres:
    (a) Tyre squirm
    (b) Tyre footprint
    (c) Aquaplane
    (d) Aspect ratio
    (e) Ply rating
13. Explain the importance of tyre maintenance.
14. What is the importance of tyre inspection? Name some prominent excessive wear patterns noticeable during tyre inspection and their possible causes.

# 20

# Chassis Layout and Frames

**Objectives**

After studying this chapter, you should be able to:

- Describe the main function of chassis.
- Explain different types of arrangements by which engine power is transmitted to the wheels.
- State how vehicles are classified:
  - (i) according to the location of power plant
  - (ii) according to drive.
- Distinguish between front engine front wheel drive and rear engine rear wheel drive.
- Describe the different types of frames used in automobiles.
- Distinguish between conventional and utilised frame construction.

## 20.1 INTRODUCTION

The term chassis is used to denote the complete vehicle except the body and incorporates all the major units such as framework, engine and power train and several other systems, viz. suspension, the steering system, the brake system, etc.

In the conventional construction, the frame serves as a platform on which the various components are attached. The frame is constructed from square or box shaped steel members and supports the engine, power train and the body. The frame is supported on wheel axles by means of springs and the whole assembly is designated as chassis.

## 20.2 LOCATION OF POWER PLANT

The engine, also called a *power plant*, provides power to drive the vehicle. These are of *reciprocating* or *rotary type internal combustion engines*. Widely used reciprocating engines may have 4,6 or 8 cylinders using petrol or diesel as fuel. Rotary engines used may be either the Vankel type engine or a turbine engine. Its use is limited to Mazda cars built in Japan and the Chrysler gas turbine car of USA. In India, these engines are yet to be used.

In most of vehicles, the engine is fitted in the front portion of the chassis. A front-mounted engine is easily accessible and easily cooled. In bus chassis, the whole engine is fitted in the driver cabins to increase floor space in the vehicle and to provide better visibility.

European vehicles like the Volkswagon of Germany and the Leyland bus of UK have used rear engine placement to make the front of the automobile more streamlined for fuel economy. Also the weight of the engine over the rear wheels can help provide traction. The gear box and differential are combined in one unit. Also the arrangement does not require a long propeller shaft.

The engine may also be fitted at the centre of the chassis to provide the full space of the chassis floor for use. Further, placing the heavy engine in the centre provides the best possible weight distribution and handling is improved. The main disadvantage is the problem of accessibility. The driver has to get out and lift up the seat to work on the engine for removing any faults. Delhi Transport buses are fitted with engines of this type.

There are different arrangements by which engine power is transmitted to the wheels:

**1.** ***Front Engine–Rear Wheel Drive*** In this system, rear wheels of the vehicle are driven by the engine, the engine power is transmitted to the rear wheels through the clutch, gear box, propeller shaft, differential and rear axle.

**2.** ***Front Engine–Front Wheel Drive*** The power is transmitted to the front wheels through the clutch, gear box, differential gear and short shafts.

**3.** ***Rear Engine–Rear Wheel Drive*** In this case, the engine power is transmitted to the rear wheels through the clutch, gear box, differential gear and short shafts.

**4.** ***Four Wheel Drive*** In this system, all four wheels of the vehicle are driven by the engine thus making the entire vehicle weight available for traction.

## 20.3 CLASSIFICATION OF CHASSIS

The classification of chassis is based on the following points:

1. On the basis of the number of wheels fitted in the vehicle and the number of driving wheels available, e.g. $4 \times 2$ drive / $4 \times 4$ drive chassis vehicles consist of 4 wheels out of which 2 wheels/4 wheels are the driving wheels respectively.

   It is to be noted that one side of the axle may consist of either one wheel or two wheels which will be considered as one unit only.
2. On the basis of wheel base size: In the long wheel base chassis vehicle (wheel base is the distance between the centres of the front and rear wheels), the distance is more thereby providing more floor area of the chassis for goods and passengers.

Two main considerations in the design of cars are

(i) obtaining good road holding at high speeds, and
(ii) providing (for passenger leg) room and comfort.

The first is assisted by mounting all the heavier assemblies lower in the chassis and bringing it closer to the ground, i.e. bringing the centre of gravity of the whole vehicle closer to the ground. Extra leg room can be obtained by providing a flat floor.

The front engine wheel drive provides one of the best arrangements in these respects. The greater proportion of the vehicle weight is always on the driving wheels and the space inside the body is not reduced by the necessity of making allowance for the fitting of a propeller shaft tunnel and the chassis and floor can be brought closer to the ground. The front wheels independently bounce and are driven by short shafts. The engine, gear box and final drive gears are assembled as a unit and mounted at the forward end of the chassis.

Examples of this arrangement are Citroen and Renault 1500.

Rear engine rear drive vehicles on the other hand have the following advantages:

(i) Excellent traction is available while climbing hills.

(ii) A larger passenger space is available for a given length of body. Further, a very compact and accessible power and transmission assembly is provided.

The disadvantages that occur are:

(i) There is a strong tendency for the vehicle to over-steer.

(ii) The space at the front has to be reduced to allow for the steering lock of the front wheels. Also space is wasted in the engine compartment.

Examples of this arrangement of the engine and transmission are the Volkswagen, Renault Darphin, Chevrolet Corvair and passenger service vehicles of Leyland and Daimler type.

As we have already noted, the main function of the chassis is to act as the frame or skeleton of the vehicle, providing a mounting for all the major assemblies and keeping them in this correct relative positions under varying loads. The chassis, usually consists of two long side members with shorter cross members. The assembled shape varies between the different types of vehicles. Actually the shape of the chassis is determined by the location of the power unit, the arrangement of the suspension system and the loads to be carried.

Figure 20.1 shows the chassis of Telco 1210 model commercial vehicle. It may be noted that the engine is located at front of the vehicle. It is connected to the clutch, which consists of two

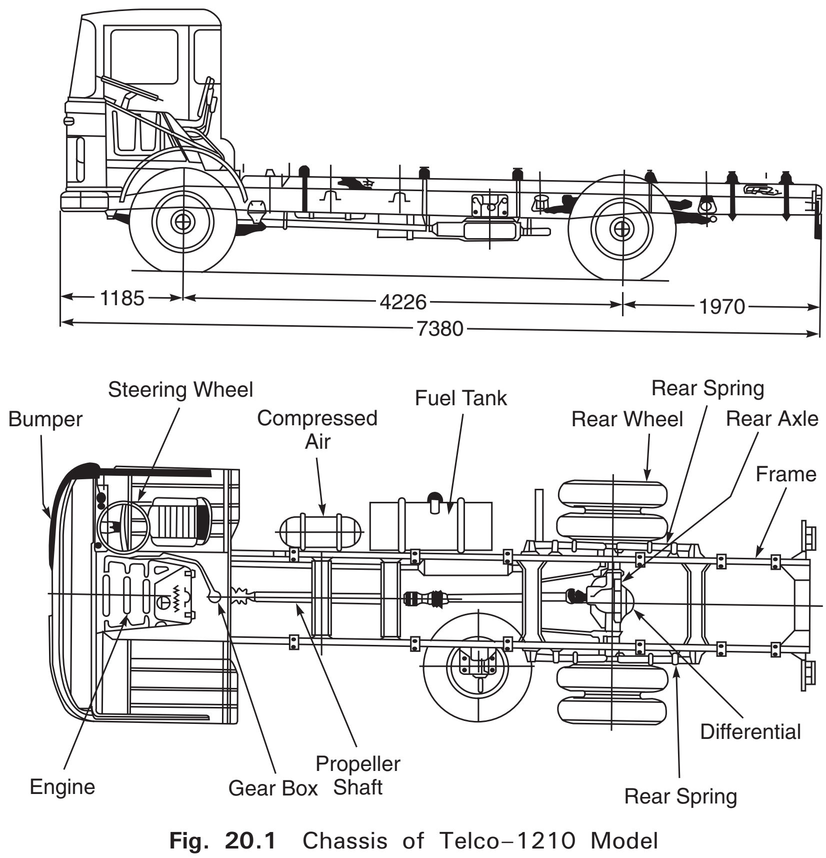



**Fig. 20.1** Chassis of Telco–1210 Model

parts, one affixed to the engine flywheel and the other to the gear box shaft. The drive of the engine can be connected or disconnected from the gear box by the driver with the help of the clutch pedal. The engine power is transmitted from the gear box to the propeller shaft, then to the differential and finally to the wheels via the rear axle.

Figure 20.2 shows the chassis of the Ambassador car, consisting of the following main parts – engine, frame, clutch, gear box, propeller shaft, rear axle, tyres, front axle, steering assembly, etc.

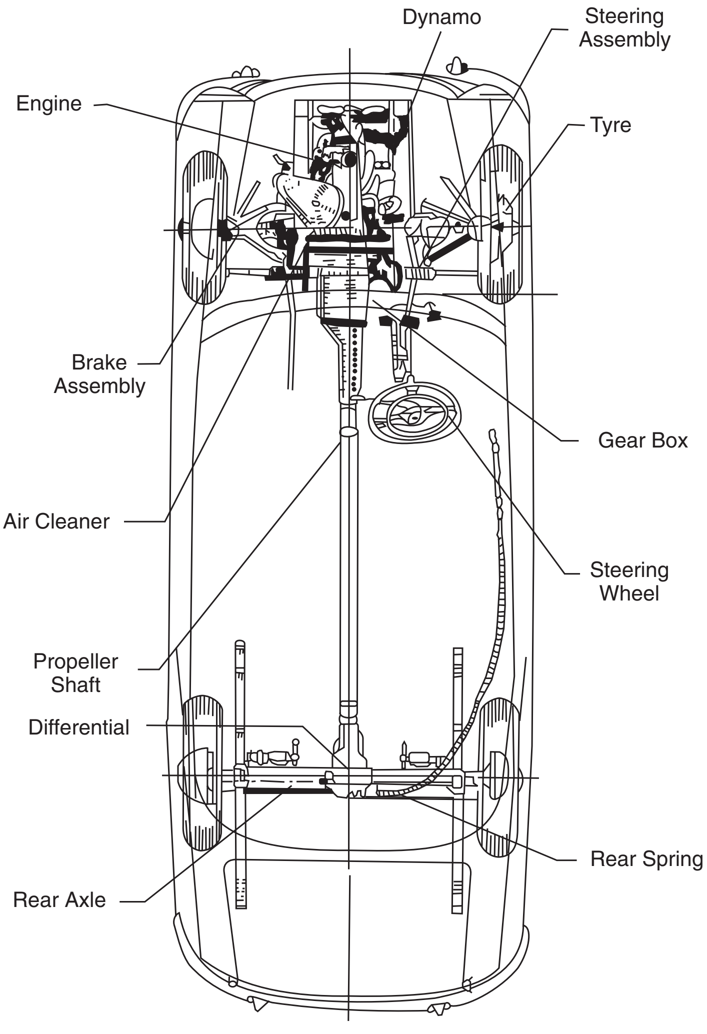



**Fig. 20.2** Chassis of Ambassador Car

## 20.4 TYPES OF FRAMES

The frame is the main part of the chassis, on which the other automobile components are attached. It is rigid and strong enough to support the weight of the vehicle and to withstand stresses, shocks and vibrations usually encountered on the roads.

The frame is usually constructed out of a box shaped tubular and/or channel steel members welded together. In a popular design, known as the ladder frame arrangement, the two large rails running beneath the sides of the vehicle are provided with a number of connecting pieces called the cross members (resembling a ladder). In an attempt to strengthen the ladder frame, the x member frame was designed, using two large members that cross under the centre of the vehicle. These members are welded to the side rails and cross members.

Figure 20.3 (a) and (b) shows a typical frame used in cars, using longitudinal members of box-section. The complete frame is fabricated by the welding process. The frame tapers from the rear to the front to permit adequate movement of the steering wheels. The longitudinal members, by sweeping upwards at the rear end, allow for the vertical movement of the rear axle. The torsional rigidity of the frame is increased by providing tubular or box-section cross members.

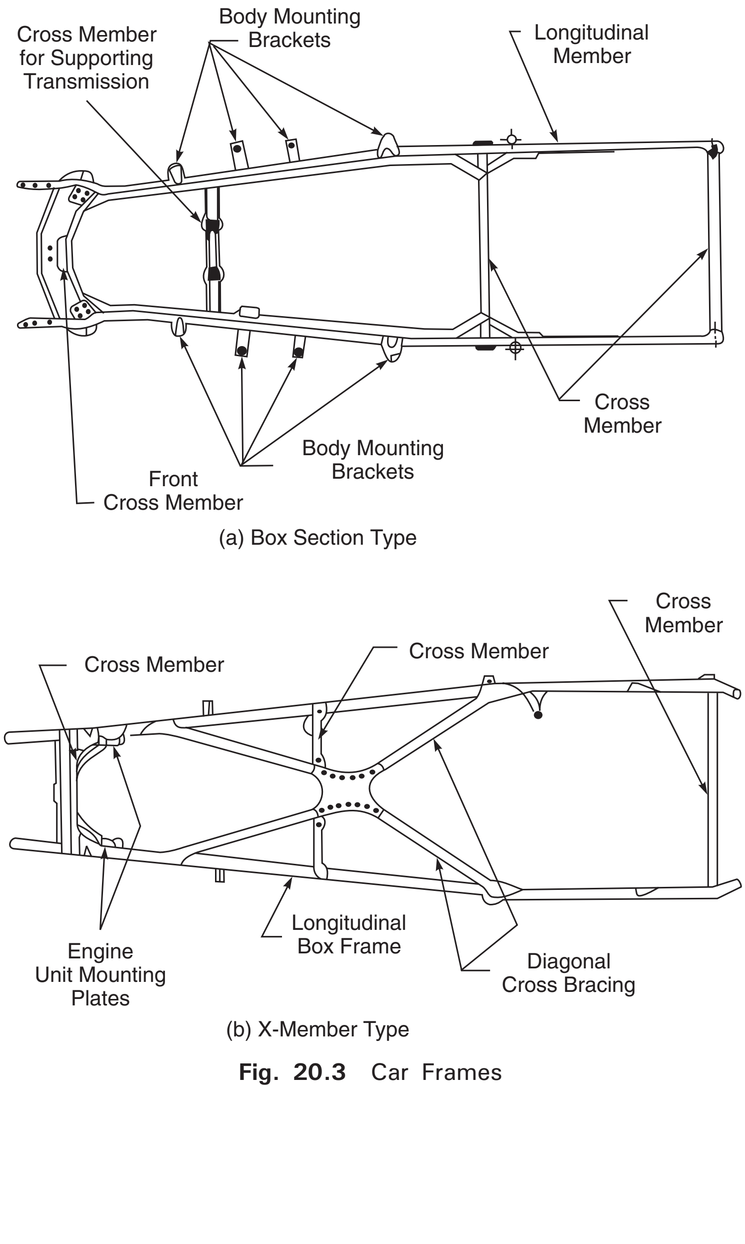



**Fig. 20.3** Car Frames

There are two types of construction commonly in use:

(i) Conventional frame also known as non-load carrying frame, and

(ii) Unitised construction also known as integral frame.

The conventional type of frame is supported on the wheel axles by means of springs. In this type of frame, the loads on the vehicle are transferred to the suspension by the frame which supports the engine, power train and the body.

The body work is made of material like wood and completely isolated from the frame deflection with the help of rubber mountings. This type of construction is widely used in trucks.

The conventional type of frame is not much suited to resist torsion. Use of a tubular or box-section backbone type of frame improves the torsional strength. In the unitized construction, there is no frame and all assembly units are attached to the body. The chassis, floor and body are assembled by welding from a large number of mild steel pressings. This design reduces vehicle weight, lowers production costs and allows a lower floor. This is the modern form of construction for almost all cars and lighter commercial vehicles. The chassis becomes a sub-frame in this form of construction and other sub-frames are often used for the front and rear suspension units.

These detachable sub-frames are attached by rubber mountings to reduce the amount of noise and vibration transmitted to the body shell (Fig. 20.4).

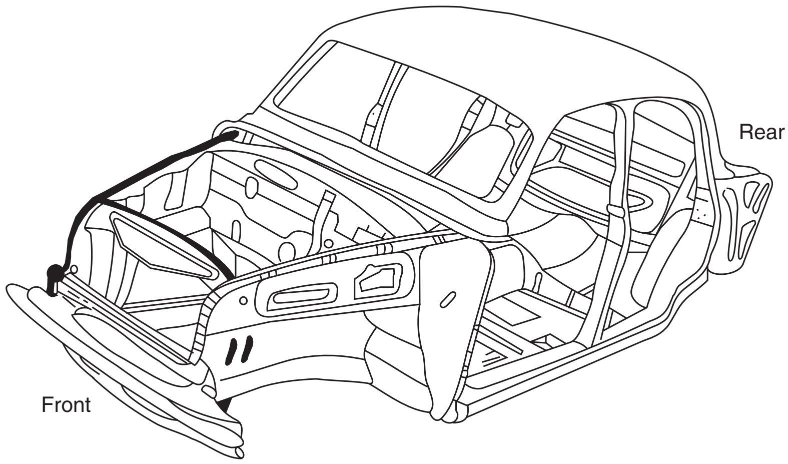



**Fig 20.4** Utilised Body Shell

**1. *Truck Frames*** A chassis frame of truck is shown in Fig. 20.5. Truck frames are made of uniform width from end to end. The longitudinal members are made of channel sections. The front two cross members on which the engine is mounted are known as engine cross members. Another cross member is provided at the middle of the frame to act as support for the central bearing of the propeller shaft. Four brackets, two in front for mounting the front spring assembly and two in the rear for mounting the rear spring assembly are rivetted or bolted to each of the long members.

**2. *Jeep Frames*** Figure 20.6 shows the other U-channel section type of Jeep frame which had been predominately used in the Mahindra Ampersand Mahindra Jeep. This frame is similar to the truck frame. In this frame, cross members are welded at the front and the rear side of the longitudinal beams. The longitudinal beams are normally arched at the rear and front positions to provide room for flexing of the rear and front axles with the springs.

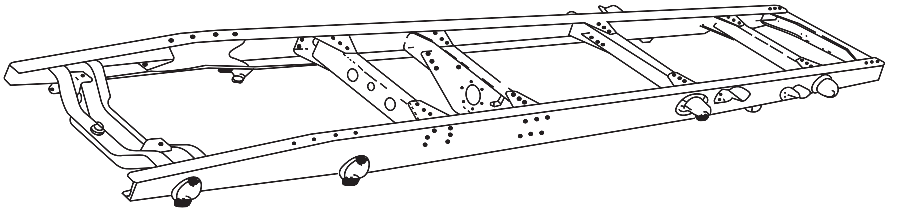


**Fig. 20.5** Truck Frame

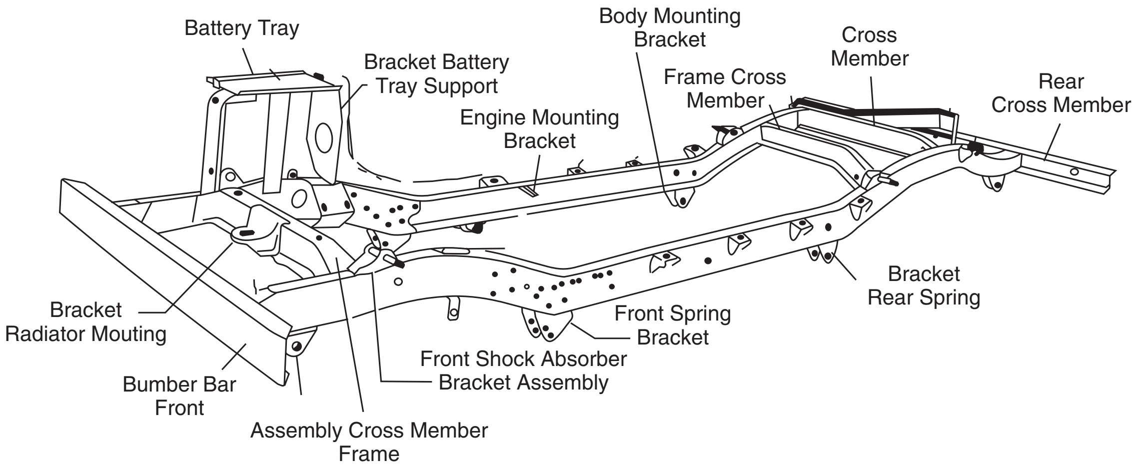



**Fig. 20.6** Jeep Frame

Figure 20.7 (a) and (b) show the side view and plan view of the Maruti Gypsy chassis frame.

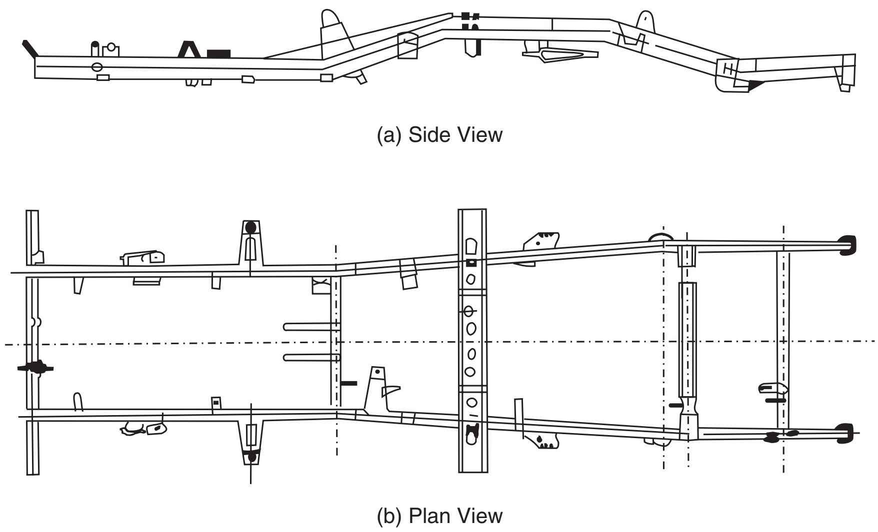



**Fig. 20.7** Maruti Gypsy Frame

## 20.5 SUB-FRAME

The various components of a vehicle are bolted directly either on the main frame members or cross members. However, sometimes the engine and gear box are carried on a sub-frame supported by the main frame usually at three points. This arrangement helps to isolate the components from the effect of twisting and flexing of the main frame. Rubber mountings are used between the engine gear box unit and the frame to reduce the vibrations. For the same reason the body is also mounted on rubber blocks on the frame.

The chassis and the body thus make the complete vehicle body being the super structure of the vehicle. In larger and heavier vehicles, the chassis and the body are each made as a separate unit and then bolted together. The body is usually made from a large number of steel pressings which are welded together. The body is bolted to the chassis at numerous points, rubber or felt strips being interposed to damp-down vibration and noise.

## Review Questions

1. What do you understand by chassis and frame?
2. Explain the construction of truck chassis.
3. Sketch a jeep frame and name its different members.
4. How will you straighten and check the alignment of bent chassis frame?
5. What do you understand by unitized chassis and what are its advantages over a conventional chassis?
6. What constructional modifications are adopted to make the conventional chassis more robust to withstand load and road thrust?

# 21
# Auto Electric System

## Objectives

After studying this chapter, you should be able to

- Explain the purpose of an automobile electrical system.
- Describe the different electrical circuits of an automobile.
- Explain the operation and construction of the starter motor.
- Follow the troubleshooting chart to find out what is wrong with a starting motor.
- Explain the function and working principle of generators.
- Explain the operation and construction of alternator.
- Explain how current and voltage is regulated in the charging system.
- Describe the operation of the different types of current-voltage regulators.
- Describe the setting procedures for LUCAS-TVS regulator.
- Find out what is wrong with the alternator with the help of troubleshooting charts.
- Explain the operation of ignition timing system.
- Describe the mechanism of centrifugal and vacuum ignition advance system.
- Explain the function and operation of spark plug.
- Describe the purpose and construction of automobile battery.

## 21.1 AUTO ELECTRIC SYSTEM

The electrical system of a car has two main functions. First, it must supply electrical energy to start and operate the engine. Secondly, it must provide the power to operate the lights, instruments and other electrical accessories. The modern car has about 60 metres of wire joining its electrical components. A colour code has been standardised in most British cars to allow quick recognition of the different circuits when any repairs are necessary. The electrical system is usually divided into five circuits. They are the ignition circuit, starter circuit, charging circuit, lighting circuit and the accessories circuits, which are sometimes controlled by the ignition switch and in most cases protected by a fuse.

The electrical components in a car are connected through switches to one side of the battery, the other side of the battery is connected to the car body or chassis. In this way, the circuit to any component is completed through the car body which becomes the earth return. This method of wiring saves the cost of about 30 m of wire and also reduces the possibility of disconnection and simplifies fault-finding.

Figure 21.1 shows a simple wiring diagram of the electrical system of an automobile showing all the five circuits. The actual wiring diagram is rather complicated as may be seen in Fig. 21.2 (a) and 21.2 (b) both for (a) Premier Padmini and (b) Jeep Universal.

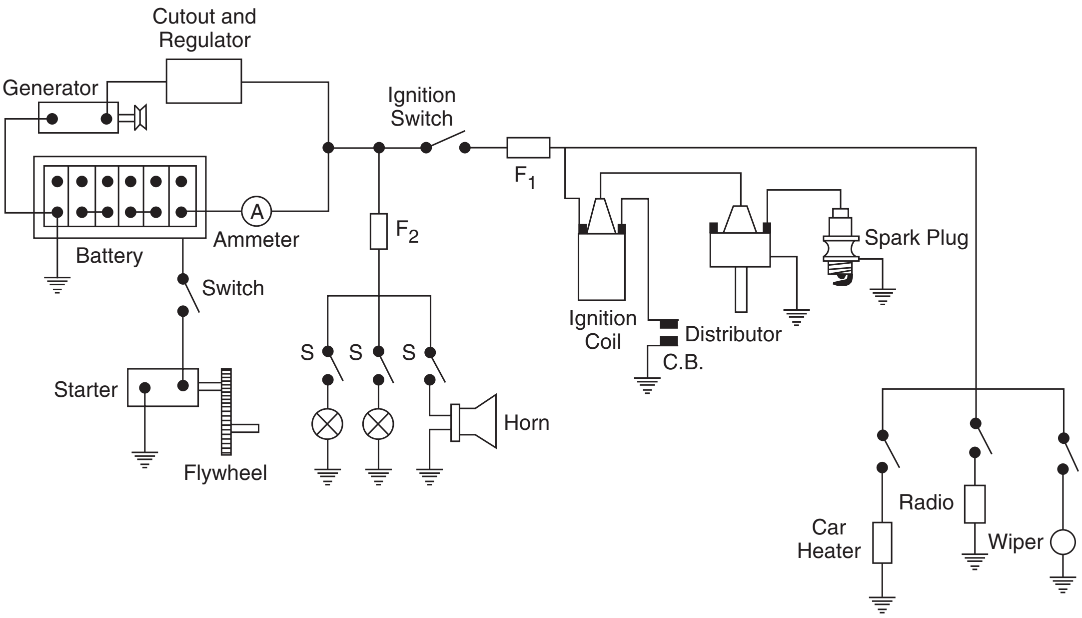



**Fig. 21.1** Simple Wiring Diagram of the Electrical System of an Automobile

## 21.2 MAIN COMPONENTS OF THE ELECTRICAL SYSTEM

Current for a car's electrical system is supplied by the battery when the engine is not running and by the generator, which is often a dynamo on older models. In most modern cars now an alternator is fitted as it more easily supplies the current needed for the various accessories. Table 21.1 lists the main components of an electrical system.

All the current is at the voltage of the battery usually 12 V or the generator (approx. 15 1/2 volts) except the current to the spark plugs which is boosted by the ignition system to as much as 30,000 volts.

*The generating or charging system* has three basic components, viz. the battery, the alternator and the regulator, (Fig. 21.3.). The battery is a source of stored electrical energy and also provides reserve power any time the alternator is not able to supply all the power needed. However, electrical energy drawn from the battery must be replaced or battery power will be used up. The alternator driven by a "v-belt" of the automobile engine changes the mechanical energy of the engine into electrical energy which is used to charge the battery and power all the electrical systems and accessories. A regulator used with the alternator protects the battery and other electrical equipment from receiving too much electrical power.

**Table 21.1** Main Components of the Electrical System

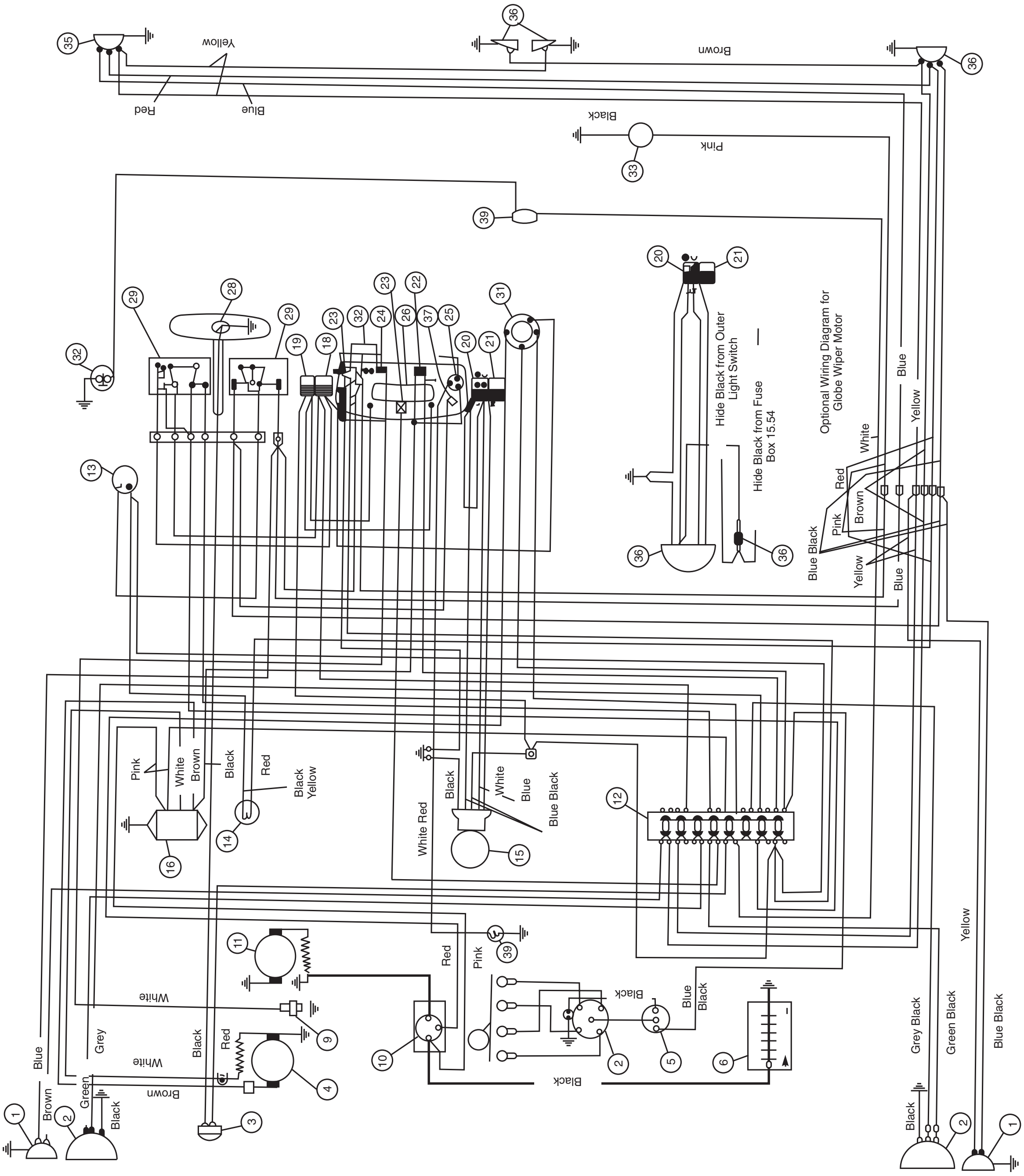
| *Generating or Charging System* | *Starting System* | *Ignition system* | *Lighting system* | *Accessories* |
|---|---|---|---|---|
| 1. Generator | 1. Battery | 1. Battery | 1. Head Light | 1. Horns |
| 2. Ammeter | 2. Starting Motor | 2. Ignition Switch | 2. Side Light | 2. Wind Screen Wiper |
| 3. The cut-out | 3. Motor control | 3. Ignition Coil | 3. Rear Light | 3. Electric Petrol Pump |
| 4. Switch | | 4. Distributor | 4. Fog Lamps | 4. Petrol Gauges |
| 5. The Battery | | 5. Spark Plugs | 5. Number Plate Illumination Lamp | 5. Radio Sets |
| 6. The Regulator | | 6. Contact breaker | 6. Interior Lights | 6. Cigar Lighter |
| | | 7. Automatic advance and retard unit. | 7. Indicator Flashers. | 7. Heater |
| | | 8. Vacuum control unit | | 8. Wind Screen Defroster |
| | | | | 9. Signalling Devices. |

*The starting system* has five main components. The starter motor converts electrical energy from the battery into mechanical energy. A starter motor drive mechanism drives a small pinion gear that meshes with the engine flywheel for starting and unmeshes when the engine runs. A remote control switch, i.e. a solenoid shifts the pinion into mesh with the flywheel and closes a switch between the battery and starter motor. The starting system is controlled with a key switch located on the steering column (Fig. 21.4).

*The ignition system* also has five main components, viz. a source of electrical power, an ignition key switch, an ignition coil, a distributor and as many spark plugs as there are cylinders. The power source for the system is the battery or alternator (Fig. 21.5). The system provides a series of precisely-timed high voltage sparks to ignite the compressed air-fuel mixture in the combustion chamber. The ignition coil steps up the 12V from the battery or alternator to the high voltage required. The distributor has three major jobs. Its switching device helps the coil develop high voltage. Then the distributor distributes the high voltage to each of the cylinders. Finally it gets the high voltage to the cylinders at the correct time to each of the engine's spark plugs.

***The Lighting and Accessory System*** (Fig. 21.6) is made up of many small circuits that operate the lights and accessories like the headlight, stoplight, indicators, instrument panel lamps, gauges and horn, etc. The system also includes a lot of wiring that connects these devices to a power source and many control switches that operate them. The four main circuits of the automobile electrical system are connected together and linked to the car battery as shown in Fig. 21.7. The generating circuit is connected to one end of the car ammeter so that the meter registers the charge direction when the current is being sent to battery. A wire connects the other end of the ammeter to the generator directly to the cable leading to the underground pole of the battery. The starting or cranking motor is connected directly to the battery through cables and a switch to provide a low resistance path for the large currents required by the motor. Ignition and lighting circuits are connected to the same side of the ammeter, as is the generator.

The branch circuits (consisting of gauge, heater, cigar lighter, wind-shield wiper, signal devices, etc.) are also connected to the same side of the ammeter as is the generator, so that when the generator is operating they receive current directly from it without going through the ammeter.




***Refer Fig. 21.2(a) Electric Wiring Diagram of a Fiat Car.***

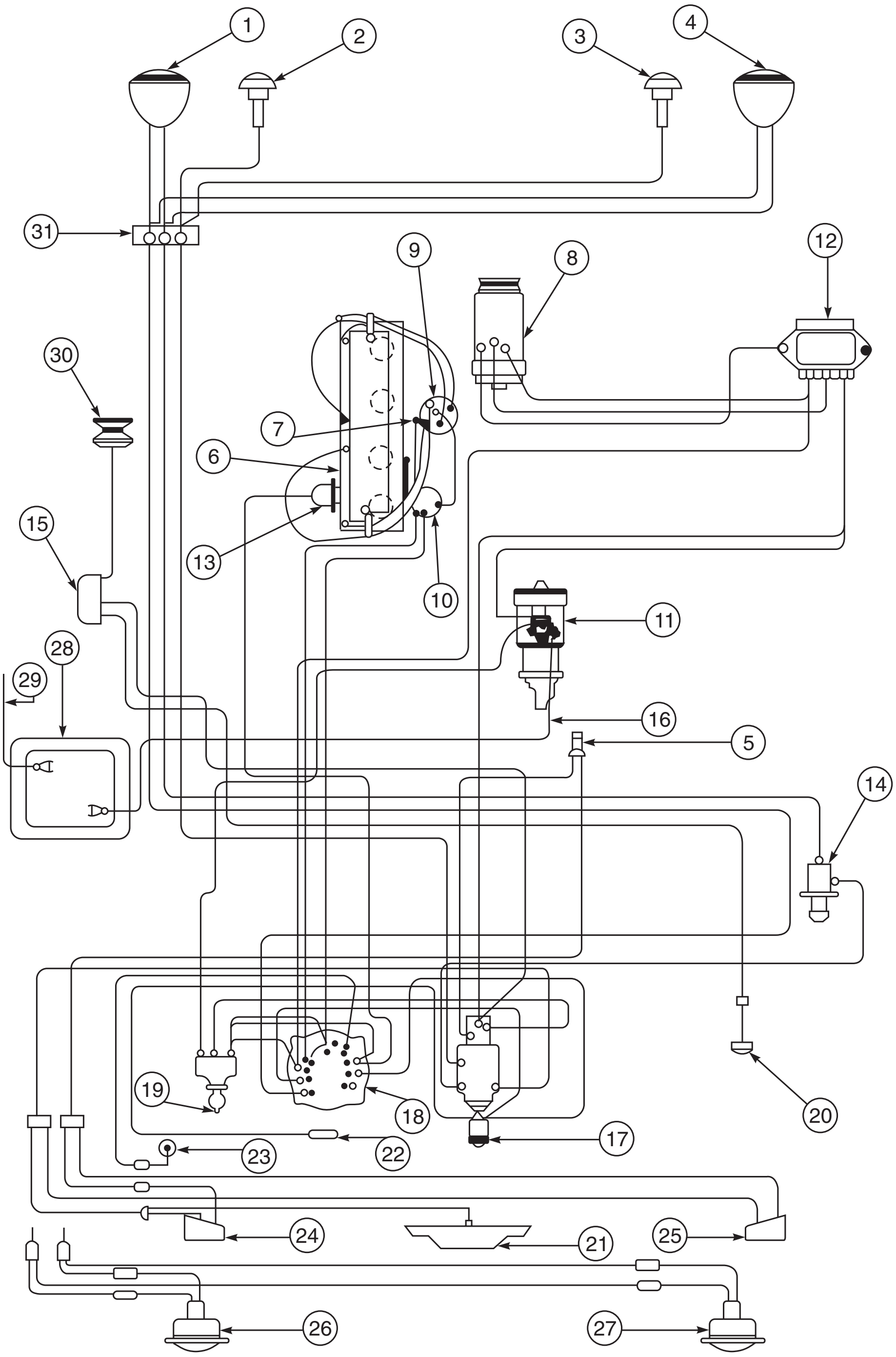
1. Front direction indicator and parking lamps.
2. Headlamps (high and low beams).
3. Horn.

4. Generator.
5. Battery.
6. Ignition coil.
7. Ignition distributor.
8. Spark plugs.
9. Insufficient oil pressure indicator-sending unit.
10. Solenoid switch.
11. Starter motor.
12. Fuses with fuse box.
13. Flasher.
14. Stop light switch.
15. Windshield wiper motor (Lucas-TVS).
15. An optional windshield wiper motor (Globe Auto).
16. Generator regulator.
17. Headlamps high beam indicating—warning lamp (blue).
18. Outer lighting switch.
19. Instrument panel light switch.
20. Windshield wiper switch.
21. Electric fan switch.
22. Generator charging—warning lamp (red).
23. Fuel gauge.
24. Insufficient oil pressure—warning lamp (red).
25. Engine water temperature gauge-electrical.
26. Speedometer.
27. Direction indicating switch.
28. Horn button.
29. Front outer lighting change over switch.
30. Roof lamp.
31. Ignition switch.
32. Jam switches between front doors and pillars for roof lamp.
33. Fuel gauge-sending unit.
34. Rear parking, stop and direction indicating lamps.
35. Number plate lamps.
36. Direction indicating—warning lamps (green).
37. Hanging fuse—windshield wiper motor.
38. Engine water temperature sending unit—electrical, thermister type.

**Fig. 21.2(a)** Electrical Wiring Diagram of Fiat Car (*Courtesy:* the Premier Automobiles Ltd.)

When the generator is not running, these circuits draw current directly from the battery or through the ammeter which reads the discharge direction. When the demands of circuits exceed generator output, the extra current is supplied by battery directly or through the ammeter.

The battery supplies current for the operation of the starting motor and ignition system when the engine is being cranked for starting. It also supplies current for light, radio, heater and several other accessory units when the generator is not operating fast enough to handle the electrical load. Thus the battery circuit is the nerve centre of the whole system. The engine cannot be started without the starting motor, since only the battery circuit can supply the required large amount of current for the purpose.




***Refer Fig. 21.2 (b) Electric Wiring Diagram of a Jeep.***

1. Headlight left
2. Parking light, left

3. Parking light, right
4. Headlight right
5. Stop light switch
6. Engine
7. Secondary cable
8. Generator
9. Distributor
10. Ignition coil
11. Starter motor
12. Voltage regulator
13. Oil pressure sending unit
14. Dimmer switch
15. Relay
16. Positive cable
17. Light switch
    - (i) Instrument cluster
    - (ii) Upper beam light
    - (iii) Auxiliary
    - (iv) Instrument light
    - (v) Oil pressure indicator
    - (vi) Charging indicator
    - (vii) Temperature gauge
    - (viii) Fuel gauge
    - (ix) Instrument voltage regulator
18. Ignition switch
19. Horn button
20. Licence plate lamp (F4-134 4×2, 4×4)
21. Dome light
22. Fuel tank gauge
23. Tail and stop light left. (F4–134 4×2)
24. Tail and stop light right. (F4–134 4×4)
25. Tail and stop light left. (F–134 4×2)
26. Tail and stop light right. (F4–134 4WD)
27. Battery
28. Negative cable
29. Horn
30. Junction block

**Fig. 21.2(b)** Wiring Diagram of Jeep (*Courtesy:* Mahindra & Mahindra Ltd)

## 21.3 STARTER

The self-starter also known as the *starting motor* or the *cranking motor* is an electric motor which can crank the engine fast enough to give a quick start under all operating conditions. The factors usually considered for selecting a suitable starter are:

(i) engine torque requirement during cranking, and
(ii) starter torque characteristics.

The initial resisting torque will decide the power required to start an engine. The torque required to initially overcome the compression, inertia, friction etc. of the engine is called *break-way torque*

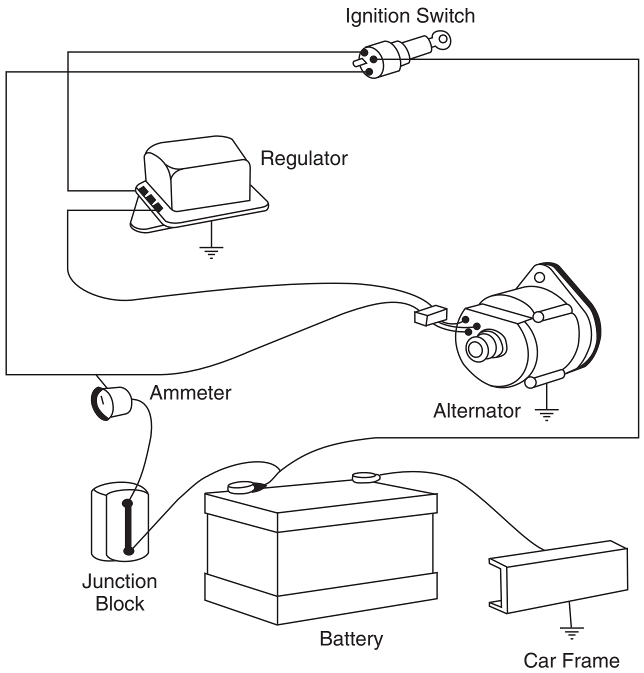



**Fig. 21.3** Charging System

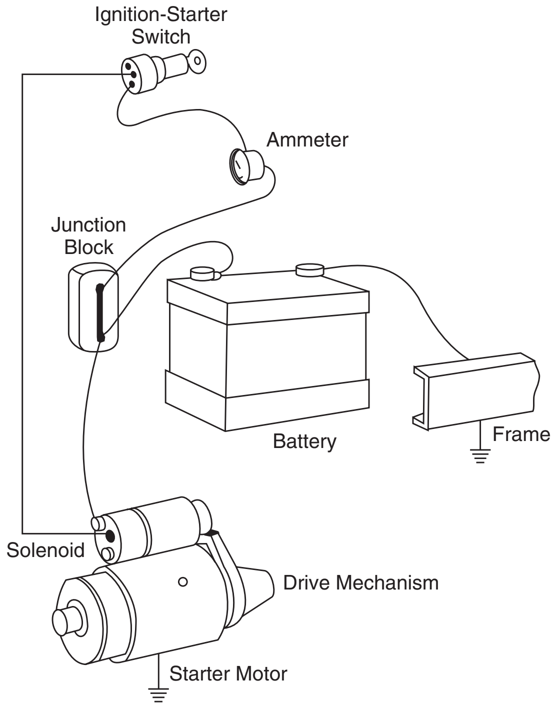



**Fig. 21.4** Starting System

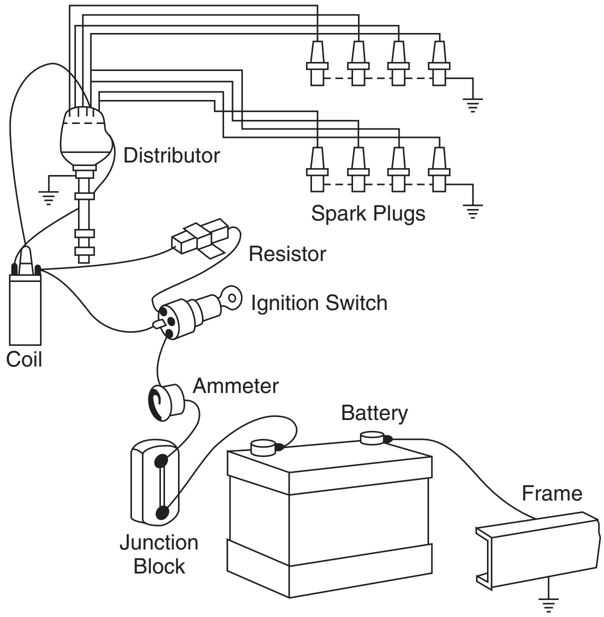



**Fig. 21.5** Ignition System

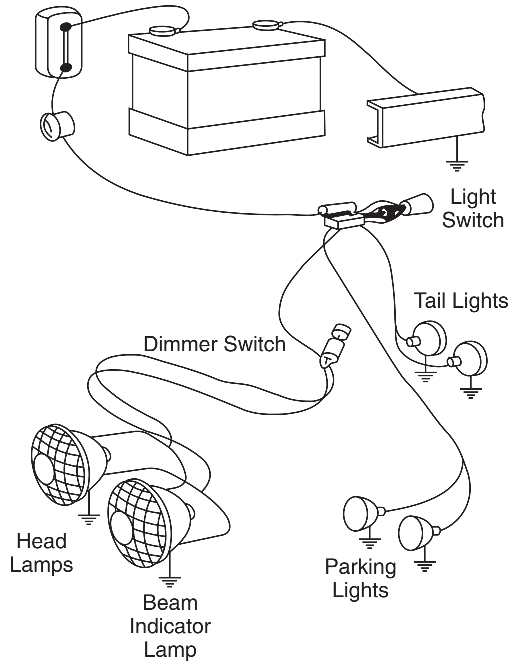



**Fig. 21.6** Lighting and Accessory System

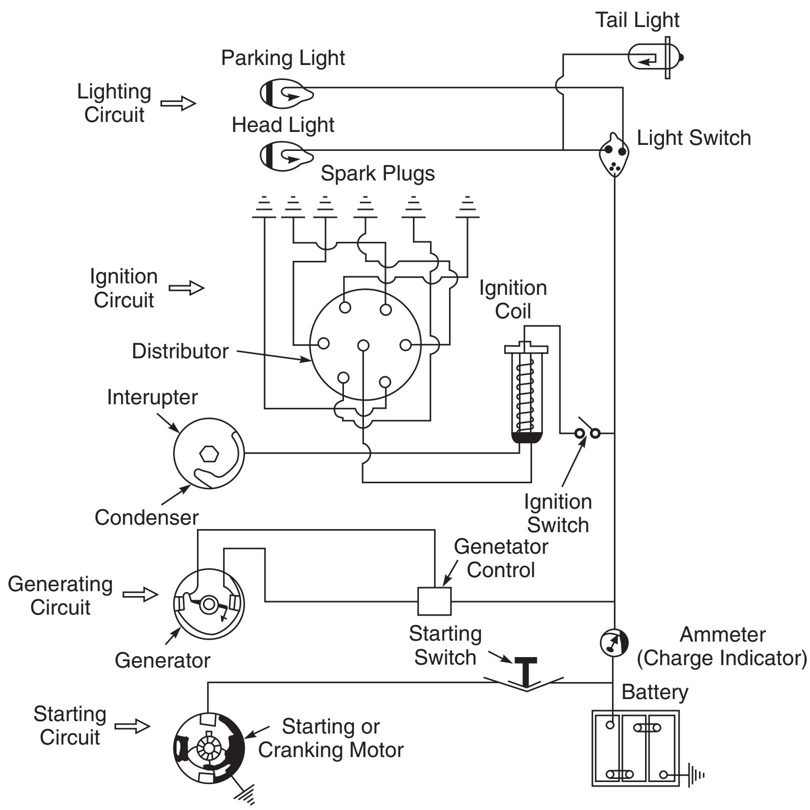



**Fig. 21.7** The Four Main Circuits of the Automobile Electrical System

and is of very high order but of very short duration. Due to this need for maximum torque at the beginning of their armature rotation, series-wound motors which are designed to operate on large currents at low voltage are used.

The armatures and fields are built with thick wire to keep the resistance low and to enable them to carry large currents without overheating. Usually a motor used in automobile car draws about 60 A when running at no load and about 600 A when cranking the engine slowly. This supply is needed for a few seconds only. The starting motor is capable of providing a very heavy torque at low speeds by including reduction gearing in the system.

## 1. Operation and Construction

The starter motor has two major parts

(i) A field winding assembly, and
(ii) An armature assembly.

The field winding assembly has a number of large magnets mounted on the starter housing or field frame. The magnets called pole pieces, create a magnetic field between them. A wire called a field winding is wrapped around the pole pieces. Current is directed through the field winding to increase the strength of the magnetic field.

If a loop of wire carrying current is placed in the magnetic field, the magnetic field around the wire and the field between the pole pieces repel each other forcing the loop to turn.

An armature contains a number of loops of wire. Metal segments attached to each end of the loops form a contact surface called a commutator, sliding contacts called brushes allow battery current to enter the rotating armature assembly. The brushes are usually made from various alloys of copper and not of carbon as they have to carry heavy current and are held in place over the commutator by brush-holders

The general construction of the armature is like the dynamo armature. It consists of an armature core armature shaft commutator and the winding fixed in the core. The armature moves in the body of the self-starter with the help of end plates fitted on either side of the starter body with bushes fixed in it. On the drive end of the armature is fixed a drive mechanism (Bendix drive, etc.).

Usually a three-piece housing holds the starter motor, (Fig. 21.8 and 21.9). The tubular centre housing contains the pole-shoes and field windings. Attached to it at one end is the drive housing. The commutator end frame is placed at the other end. Bearings or bushings in the end frame and drive housing support the armature. On most starter motors, all the current passes through the field windings and the armature in series. This arrangement, called a *series-wound motor*, provides a great deal of cranking power. Current enters the starter motor from the battery at the terminal passes through the field coils and enters the armature through the two insulated brushes. Current leaves the armature through the two grounded brushes (Fig. 21.10).

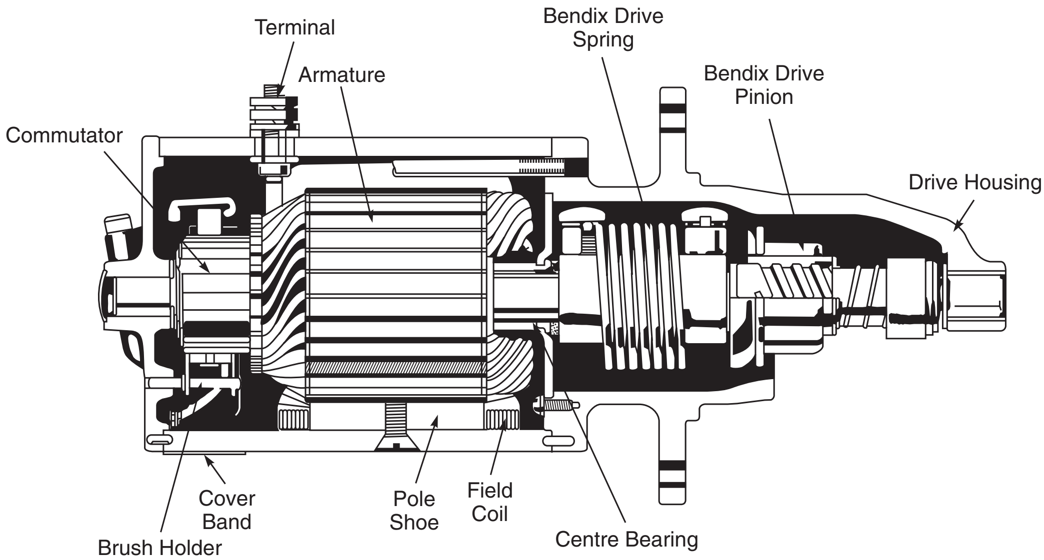



**Fig. 21.8** Sectional View of Starter Motor with Drive Mechanism

The starter circuit, as mentioned, is referred to as a *two-field four-brush circuit*. Since it uses only two-field coils, its low resistance permits high current flow. Starter motors with four field windings are called *four-field four-brush circuits*. These circuits provide stronger magnetic fields, which give greater torque or cranking ability.

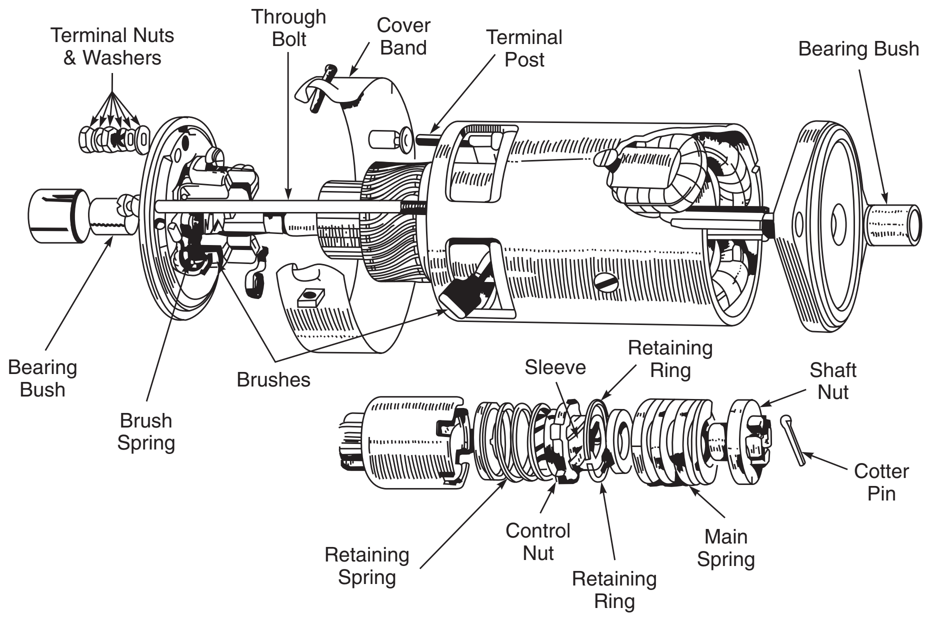



**Fig. 21.9** Exploded View of Starter Motor Parts

## 2. Drive Mechanism

The starting motor is linked to the engine flywheel through a set of gears. A pinion gear mounted on the end of the starter armature shaft meshes with the teeth on the engine's flywheel ring gear (Fig. 21.11). Usually the gear ratio is 15:1. With this ratio, the starter motor can turn very fast and develop a great deal of torque to crank the engine. When the engine starts and speeds up, the speed of the ring gear being more than the speed of pinion makes the pinion move back due to threads made on the armature shaft and thus disengages it from the armature shaft to protect the motor. Thus the cranking motor requires only $1/15^{th}$ as much power as would an electric motor directly coupled to the crank. The armature may revolve at about 3000 rpm when the cranking motor is operated and the flywheel will rotate as high as 200 rpm.

This system, where the pinion moves on the shaft of the self-starter, meshes with the ring gear and disengages or disconnects it from the shaft when the engine has started, is known as *inertia drive* or *bendix drive*.

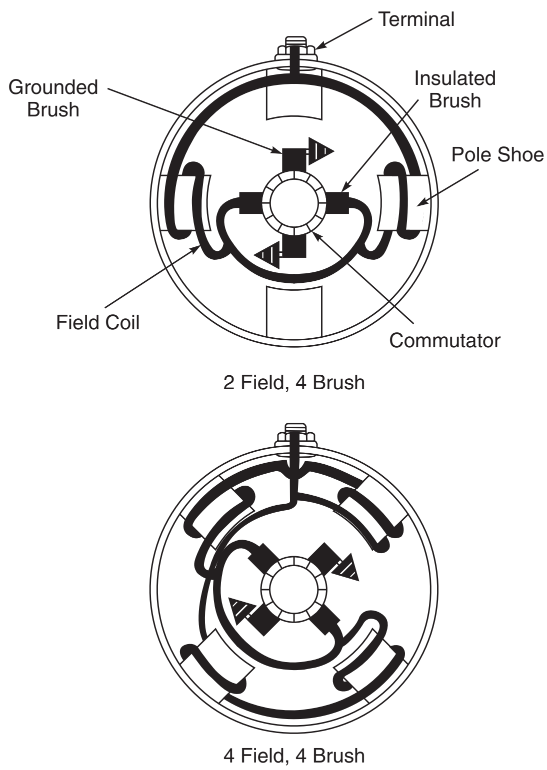



**Fig. 21.10** Starter Motor Circuits

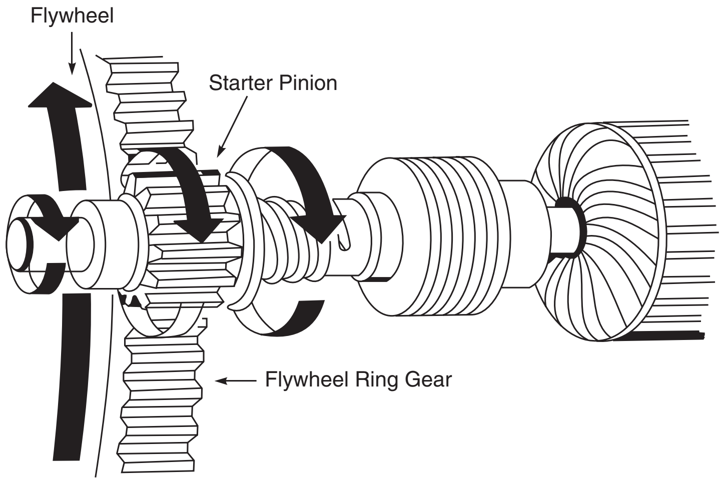



**Fig. 21.11** Pinion Meshes with Flywheel Ring Gear

## 21.4 GENERATOR

The generator is an electromagnetic device that converts mechanical energy from the engine into electrical energy. Its main function is to maintain the charge of the battery when the engine is running as well as to replace the energy consumed and taken by the starter, ignition, lighting, wiper, radio, etc. from it.

The electrical load of the automobile varies over a very wide range of conditions. The generator should be able to supply this load and develop sufficient electrical energy to keep the system voltage nearly constant. Usually the generator is designed to take the electrical load as far as possible at normal voltage and the duty of the battery being reduced to that of supplying the necessary current for starting, for standing lamp and radio loads and for short periods of driving when the speed of the generator is insufficient to generate its rated output. The generator or the dynamo is usually mounted on the side of the engine block and is driven by the engine fan belt. As the engine speed is subjected to large variations, the generator speed will also vary. Usually direct type generators are used in most of the vehicles. Certain manufacturers also use *the commutator type shunt wound generator*. Self-energised generator unit and alternator type generator employing diodes convert the generated alternating current into direct current.

### 1. Working Principle of a Generator

The basic principle of generator is *electromagnetic induction* in that whenever a conductor is moved in a magnetic field, a current is produced in it. It cuts across the field and has a direction provided by *Fleming's left hand rule*.

The conductor must move across the magnetic field, so that it cuts the lines of force. If it moves parallel to the lines of force, it will not cut the lines of force and no current will be induced in the conductor. The amount of current produced depends upon the rate at which the lines of force are cut.

Usually a conductor in the form of a loop is placed between the poles of a magnet and as the magnet (also called a rotor) is rotated, the magnetic lines of force cut across the conductor (also called a stator) and alternating current (called AC) is produced. Since automobile electrical equipment is designed to operate on direct current (called DC), some means must be provided to change AC into DC, i.e. to achieve rectification. This is done with the help of a commutator and brush in generators and with a diode in an alternator.

## 21.5 ALTERNATOR TYPE GENERATOR

An alternator is used on vehicles to charge the battery and operate the electric circuits. Alternators are much smaller, lighter in weight and produce more current than generators. The alternator has a set of rotating poles and a stationary set of winding. Solid-state diodes are used to convert AC and DC voltages. The alternator is made of a stator, rotor, slip-ring and brush assembly. Many modern alternators have regulator built into the housing as a complete unit.

### Operation and Construction

The operation of an alternator is improved by placing the stator and the rotor assembly inside an iron frame or housing which provides a conducting path for the magnetic lines of force.

The voltage can be greatly increased if the stator winding is formed into many coils or turns. A stator consisting of one winding of wire (regardless of the number of coils of wire in that winding) is called a *single phase stator*. Most alternators use three windings which is called a 3-phase stator and since the connections of the winding are like a Y, it is called a *3-phase Y - connected stator*. The advantage in this stator being that the voltage is more even between phases and that each phase reaches its highest voltage at a different time.

An alternator consists of a rotor assembly, a stator assembly and a rectifier mounted in a housing. The housing is usually made up of two pieces of die cast aluminium (Al is used because it is non-magnetic, light-weight and provides good heat dissipation). Bearings, supporting the rotor assembly are mounted in the front and rear housing.

The stator is clamped between the front and rear housing. A number of steel stampings are riveted together to form its frame. Three windings around the stator frame are arranged in layers in each of the slots on the frame. The three windings are joined together at one end. At the other end they are connected to the rectification assembly (see Fig. 21.12 and 21.13).

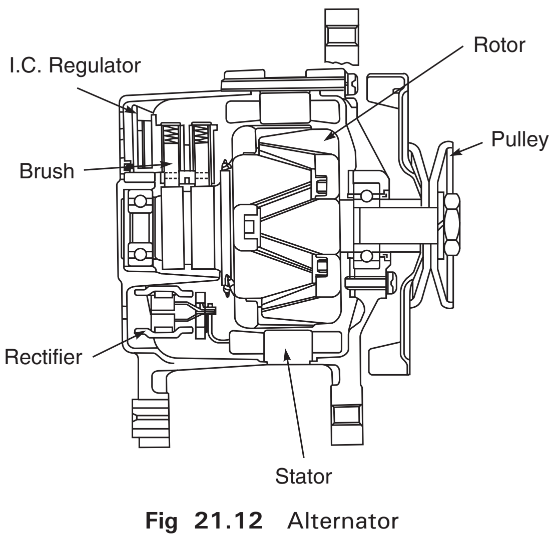



**Fig 21.12** Alternator

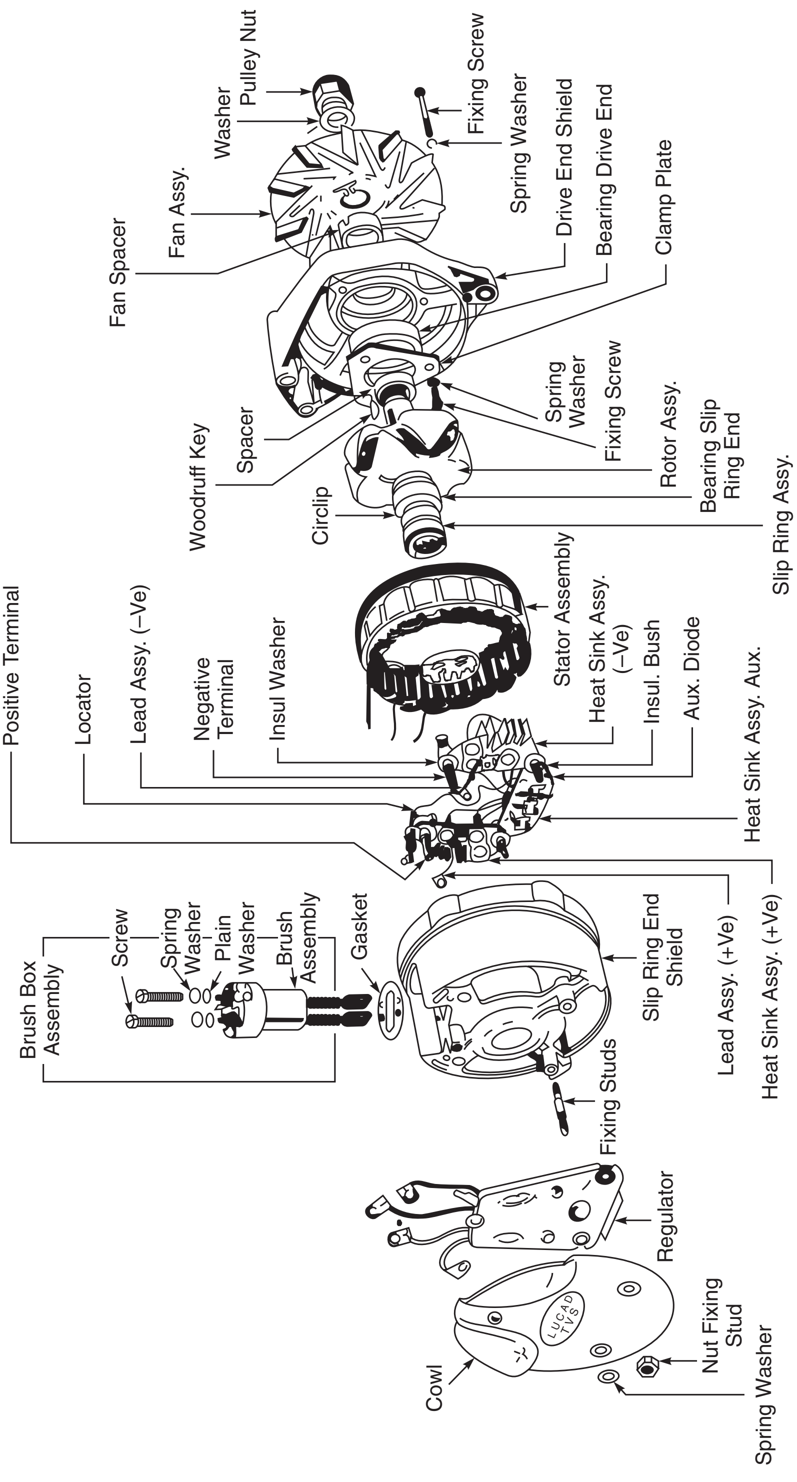



**Fig 21.13** Explode View of the Alternator (*Courtesy:* Telco)

The rotor assembly consists of a rotor shaft, a winding around an iron core, two pole pieces and slip rings. The rotor shaft is pressed into the core. Two brushes are held against the slip rings by springs and are connected through a switch to the battery.

The rectifiers are pressed in the slip ring end head or heat sinks (rectifier mounting plates) and are connected to the stator leads.

## 21.6 TYPES OF WOUND FIELD GENERATORS

The performance of an electric generator will depend upon the manner of exciting the magnetic field. Figure 21.14 shows three ways of connecting the field windings, viz. series, shunt and compound wound. A series-wound generator has field windings of a few turns of heavy gauge wire. Under no load or open circuit conditions, voltage will be zero since there is no flow of current in the field windings. The voltage increases as the load current increases. This type of generator has limited applications.

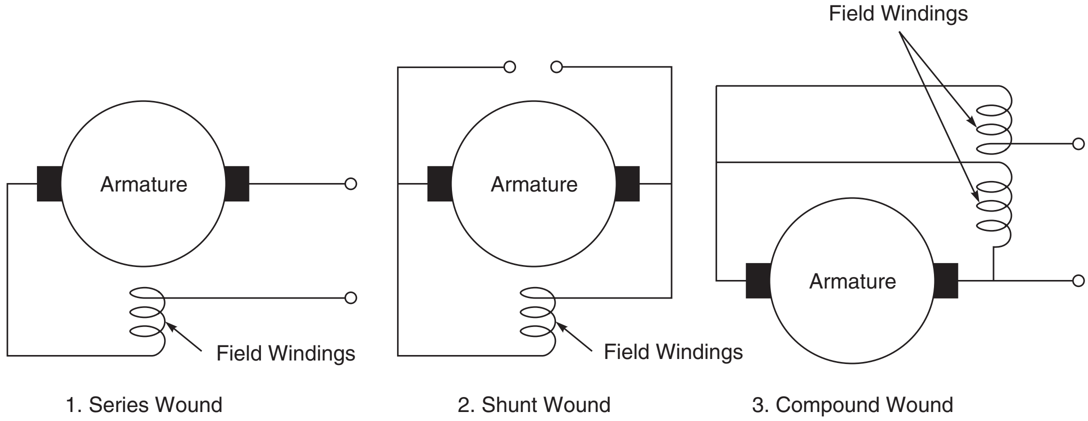



**Fig. 21.14** Generator Field Windings Connections

The shunt wound generator has field windings of many turns of fine gauge wire directly connected across the brushes. The voltage of the generator is maximum on open circuit and diminishes slightly as the load is increased. This type of generator is suitable for steady load conditions, e.g. battery charging.

The compound wound generator is most suitable for supplying power and lighting for industrial and domestic purposes. It has both series and shunt field windings. No load voltage is maintained by the shunt winding while under load conditions, the series windings increases field strength.

Figure 21.15 shows the basic elements of a shunt generator. It consists of a cylindrical frame made of soft iron which supports a pair of field coils called pole shoes, an armature and field coils. The armature has soft iron laminations on a shaft thus forming a core. The core has longitudinal slots into which the coil windings are wound. The end of the coil loops are connected to the commutator. When the armature is rotated, a current is generated in the loops which is picked up by the brushes in contact with the commutator. The current required for the field windings is supplied by the generator itself. About 8% to 12% of the current generated in the armature is shunted through the field coils.

If the voltage generated by the generator is greater than the battery voltage, it will charge the battery. If less than the battery voltage, then the battery will be discharged. This situation will also

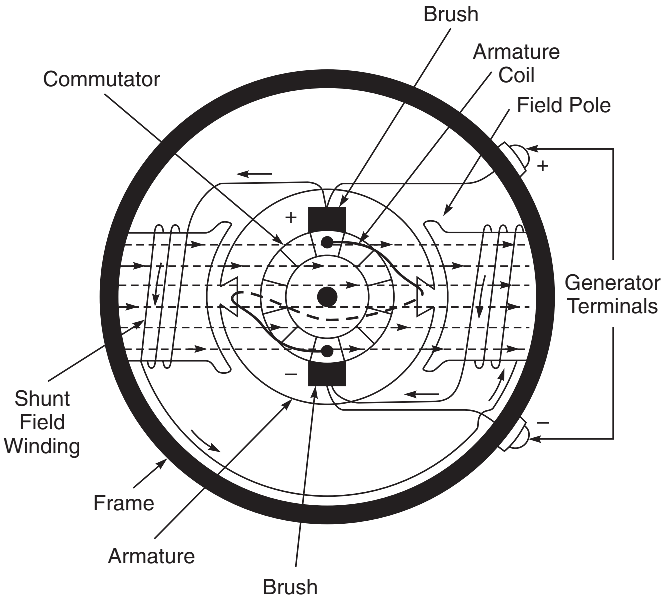



**Fig. 21.15** Basic Elements of a Shunt Generator

occur when the generator armature is stationary. To avoid this a cut-out is used to isolate the armature from the battery.

### Lucas-TVS Generators

Lucas-TVS generators are manufactured in two sizes, one with a 4″ diameter yoke and the other with a 5″ diameter yoke. All the generators are shunt wound, arranged to work in conjunction with a Lucas-TVS regulator unit. Figure 21.16 shows the Lucas-TVS generator model C40LQ used in Tata 1210, Dodge and Fargo bus/truck.

It is capable of giving an output of about 240 W and a current of about 20 A. It has a cut-in speed of 1100 rpm at 13 V and a maximum output of 20 A at 1950 rpm.

The Lucas-TVS C40 LQ generator model is used in Ambassadors as well as in the Premier Padmini Fiat.

## 21.7 REGULATION AND REGULATORS

Regulation is the process of preventing the generator from producing excessive voltage and current. A generator in the absence of regulation continues to produce and increase its output with the increase of speed and a stage comes when it produces so much current that it would get overheated and cause severe damage to the electrical equipment and circuit. This has to be avoided by reducing the strength of the magnetic field as and when required to meet the varying demands due to the varying state of the battery charge and requirements of different auxiliaries.

The control or regulation of the generator output is done by the following methods:

1. Compensated voltage control
2. Current voltage control or 3-unit regulator.

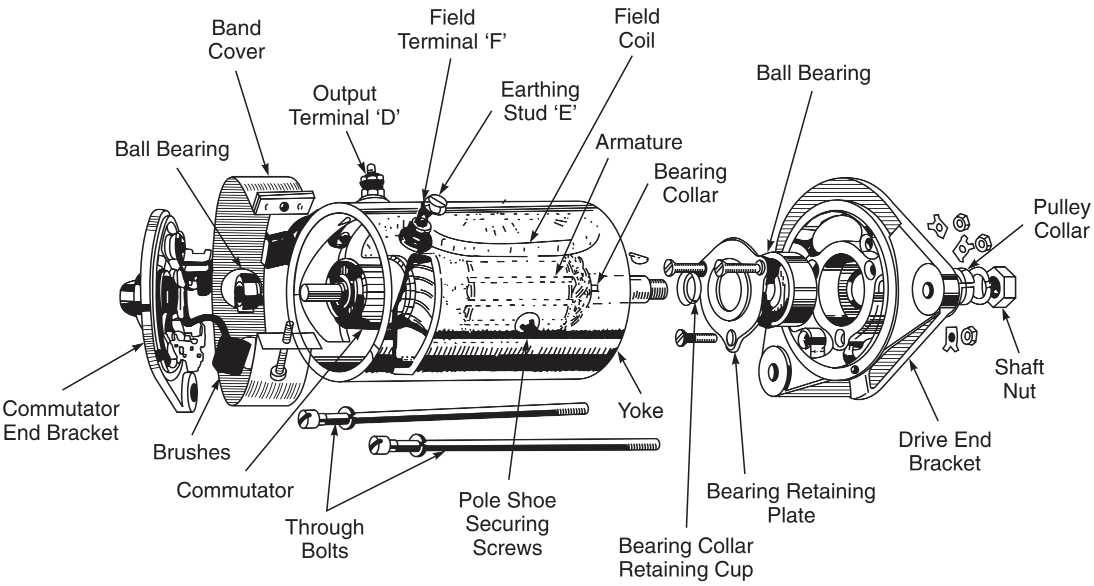



**Fig. 21.16** Exploded View of Generator Model C40 LQ (*Courtesy*: TVS)

The basic purpose of a voltage regulator is to have a resistance inserted into the generator field circuit and when the current or voltage output exceeds a preset maximum value, the inserted resistance reduces the amount of current flowing through the field windings thereby reducing the voltage generated by weakening the magnetic field.

***Compensated Voltage Regulator*** The compensated voltage regulator provides a satisfactory method of output control (Fig. 21.17). It allows a large current to flow to a discharged battery and as soon as it becomes charged, the regulator reduces the current. When lamps and other accessories are switched on, it provides an increased amount of current, but the generator is prevented from being overloaded. Thus the motorist can be sure that the battery is being well looked after under normal running conditions. To meet the requirements of the motor vehicle, it is set and fitted to the vehicle during manufacture and usually mounted on the engine side of the bulkhead. It is structurally combined with the cut-out as well as housed in the control box.

***Current Voltage Regulator or 3-Unit Regulator*** With the increased electrical loads, the necessity for increased generator output as well as more efficient utilisation of the output in comparison to the compensated voltage control arises. For this purpose, a refined means of control known as current voltage control (Fig. 21.18) is employed.

In this system two separate regulators are provided with their contacts in series with the generator field circuit instead of the voltage and current winding being wound on the same core. One of the regulators is responsive only to the voltage while the other is responsive to current. The two regulators are mounted together along with the cut-out on a common base. It is also compensated for the temperature changes.

## Delco Remy Current and Voltage Regulator

The Delco Remy current and voltage regulators are being increasingly used in many cars of American and British makes. Figure 21.19 shows the wiring diagram for a 3-unit current and

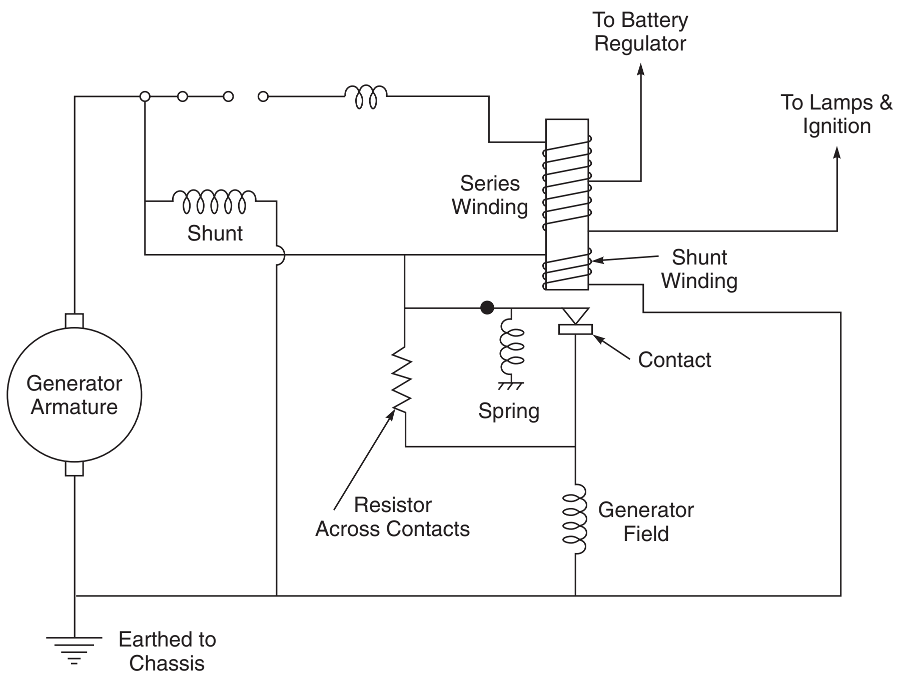



**Fig. 21.17** Compensated Voltage Control Regulator

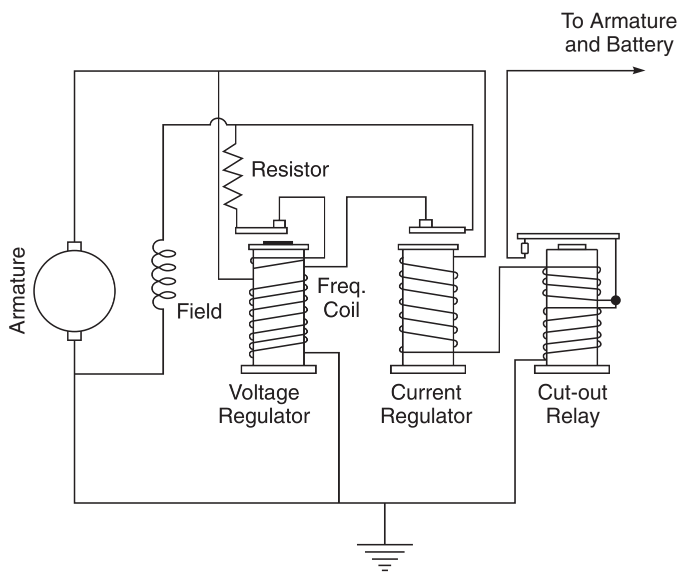



**Fig. 21.18** 3-Unit Regulator

voltage regulator of the single contact type and Fig. 21.20 shows a double contact type. The unit consists of a cut-out relay, a voltage regulator and a current regulator all of them mounted on the same base and enclosed by the same cover.

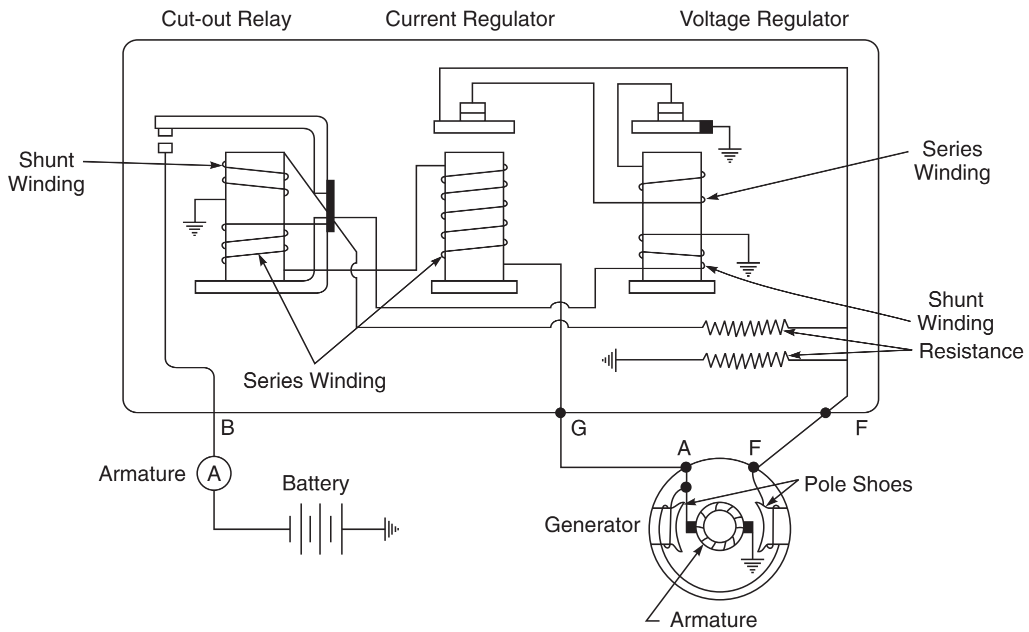



**Fig. 21.19** Wiring Diagram of the Contact Delco-remy Current and Voltage Regulator

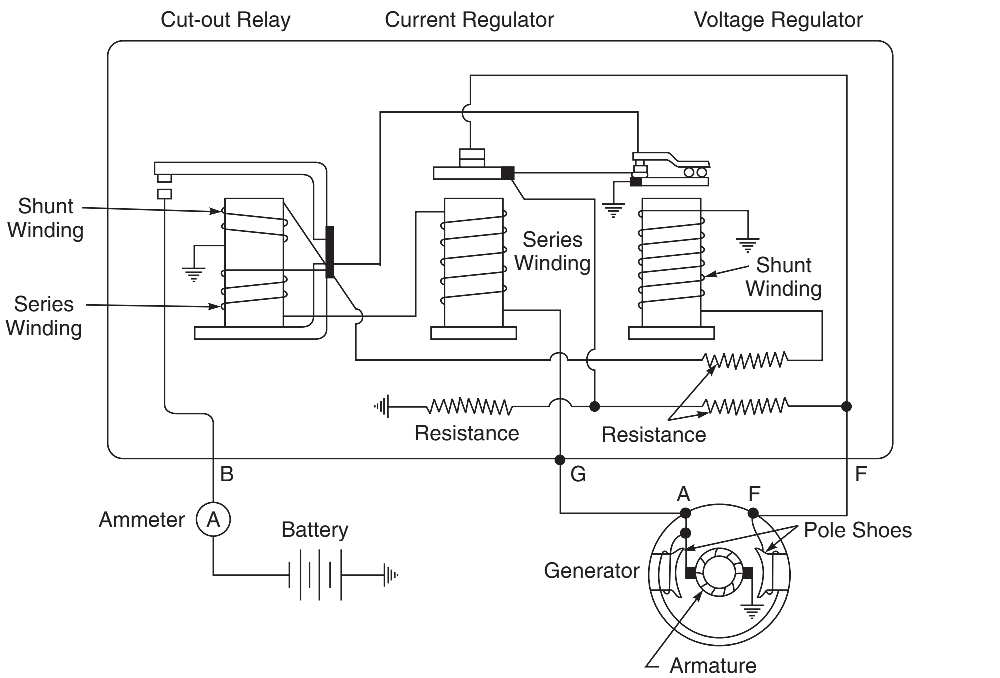



**Fig. 21.20** Wiring Diagram of the 3-unit Regulator with Double Contact Voltage Regulator

The voltage or the current regulator may be operating at any one time but never operate together at the same time. When the electric load demands are high and the battery is in a low state of charge, the generator is prevented from exceeding its safe maximum value by the current regulator, as this instant voltage is not sufficient to operate the voltage regulator.

In case of reduced load requirements or when the battery begins to charge, the voltage will increase sufficiently to cause the voltage regulator to operate. This in turn reduces the generator output and the current regulator does not operate since it is not sufficiently high.

Referring to Fig. 21.19, it is seen that the current regulator and the voltage regulator circuits insert the same resistance into the field circuit of the generator. The second resistance is connected directly across the generator field circuit and serves as a protector device for the regulator contact points. In general, single contact regulators are made for generators having a maximum output of 25 A to 35 A.

As may be seen from Fig. 21.20, the voltage has two sets of contact points. The lower set of points is in series with the field circuit of the generator, while the upper set of contact points shorts out the field circuit. When the speed of the generator is low and the electric loads are high, regulation is attained with the lower set of contact points. However, when the speed of the generator is high and the electric loads are low, the generator voltage has a tendency to go up even with the resistance in the field circuit at all times due to the lower points opened. At this stage, the armature of the regulator is pulled to such an extent that the upper set of contact points close, thus shorting out the generator field circuit. Now the upper contact points vibrate, producing the regulation.

In the case of the double contact voltage regulator, a third resistance is connected between the base plate of the cut-out relay and the voltage regulator winding. Its purpose is to reduce the magnetic pull of the voltage winding.

These resistances tend to reduce the electrical surges in the field windings when the contact points vibrate inserting and taking out the additional field resistance, in addition to controlling the generator output.

### Transistorized Regulator

As the contact breaker points of the regulator open several times a second throughout its life, it causes arcing and pitting of the contact points. This reduces its working life and requires costly materials such as silver-tungsten combination for the contact points.

To avoid these contact point problems, transistorized regulators are used in two different methods. In one, the transistors are used to reduce the amount of current through the vibrating contacts, i.e. it acts as a switch actuated by a small current. The reference spring remains the same. Such systems are very economical.

In all the transistor systems both the magnetic circuit and the spring reference is replaced by a zener diode, its breakdown voltage providing a reference. A fully transistorized regulator has no moving parts and provides very close tolerances in voltage control regardless of the vibration etc.

Recently a semiconductor type regulator has been developed by Bosch and used in automobiles. It is known as the p-n junction regulator. The essential element of this regulator is the junction of the n-type and p-type materials.

The characteristic curve of this regulator is similar to that of the current and voltage regulator but it has no current control chamber.

## Lucas-TVS Regulator

Figure 21.21 shows the wiring diagram of the LUCAS-TVS 3 GC-12V regulator. The 12V voltage regulator has one coil which is connected in parallel with the generator. The current regulator has a single low-resistance coil, which is connected in series with the generator and thus carries the generator output.

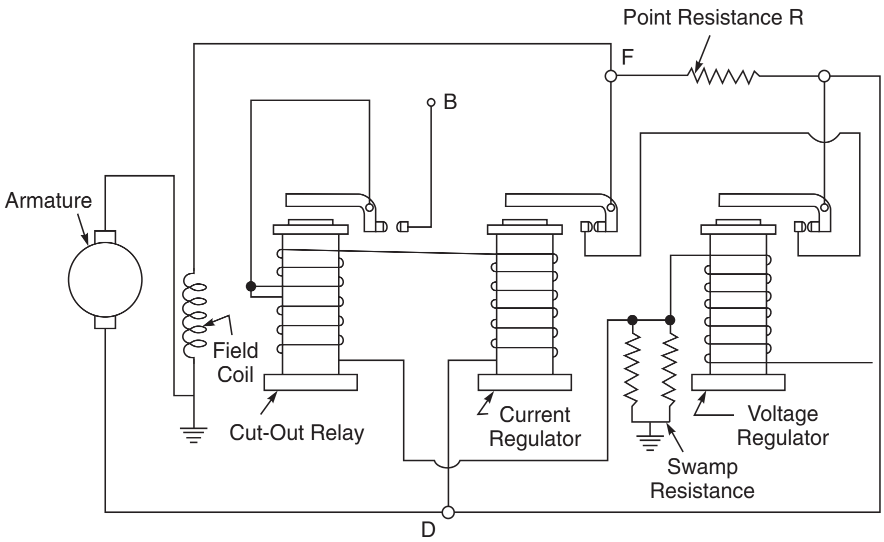



**Fig. 21.21** Circuit Diagram for 3GC-12V Regulator

The current voltage regulators are designed to regulate the charging rate and are arranged to work in conjunction with shunt wound generators. The generator has its field coils energised via the regulator contacts. These are normally closed. An alternative circuit is formed by a field current resistor (point resistance). When the generator speed rises, the field coils are energised and the open circuit voltage rises.

When a pre-determined voltage is reached the cut-out contacts close, connecting the generator to the battery. The generator terminal voltage continues to rise until under the conditions of light load and a well charged battery, the operating setting of the voltage regulator is reached. At this point, the voltage regulator contacts open, thereby inserting the point resistance R, in the field circuit. This reduces the field current, causing the generator voltage to fall. The magnetic pull on the regulator armature is also reduced and the contacts re-close causing the field strength to rise again. This cycle takes place many times per second and the generator voltage is thus limited to the preset value and only a portion of the generator output passes to the battery.

When the battery approaches a charged condition the voltage of the system is high enough to operate the voltage regulator, the current falls and the current regulator becomes inoperative. In practice, a charge-over period often occurs during which both regulators are in operation.

***Electrical Settings of Lucas-TVS Regulator*** In the Lucas-TVS regulator in the normal cases, the control box should be so mounted that the plane of its contacts is vertical, and the terminals point downwards. This is the position in which electrical settings are made during production and is the mounting position recommended by vehicle manufacturers. However, since settings are affected by change of position, bench settings should be made with the control box mounted as on the vehicle.

Checking and setting should be completed as rapidly as possible to avoid heating errors. In cases where it is necessary to adjust both the regulator and cut-out, it is advisable to first set the cut-out. This minimises the risk of errors due to heating effects arising from the operation of the regulator. The various settings are described in the following sections.

***Voltage Regulator*** Before making any adjustments, make sure that the fault in the charging system is not due to a slipping belt drive or defective battery. The settings are accurately adjusted during manufacture and they should not be disturbed unnecessarily. If however, the generator output does not fall when the battery is fully charged, or the battery is not maintained in the fully charged condition, it may be necessary to check and re-adjust the settings. The open circuit settings for the 12 V regulator at 35°C are:

3G - 12 Volt 14.3 - 15.2V.

**(i)** ***Setting on the Vehicle***

(a) Disconnect the control box terminal B. Insert a first grade moving coil full scale voltmeter between terminal D and earth, using a 0-20 V instrument for 12 V units.

(b) Start the engine and run the engine at 1700 rpm. The voltmeter reading should be between the limits given. If the reading occurs outside these limits, stop the engine and remove the control box cover.

(c) Turn the voltage adjustment cam until the correct setting is obtained. For this use a suitable Lucas-TVS tool as shown in Fig. 21.22.

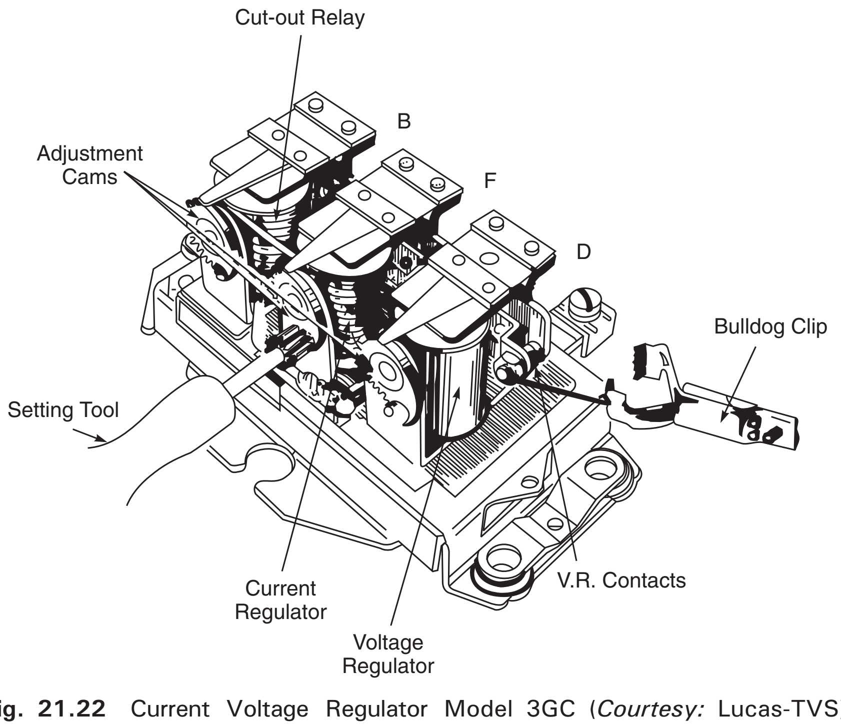



**Fig. 21.22** Current Voltage Regulator Model 3GC (*Courtesy:* Lucas-TVS)

After this adjustment, run the generator at the appropriate speed and see if the setting is correct. If not, repeat the operation till the correct setting is obtained.

To eliminate incorrect setting due to hysteresis in the regulator core, restart the generator, running it several times (stopping the generator between each successive run) to ensure that the correct adjustment has been made and that a consistent result is obtained.

Care should be taken that the generator is not run at a high speed on open circuit, as a high voltage will build up. When making adjustments to the regulator do not use more than half throttle, otherwise a false voltmeter reading will be obtained. Since continuous operation will heat the regulator windings, the necessary adjustments should be completed within 30 seconds to avoid inaccurate settings.

**(ii)** ***Setting on the Bench*** The method of adjustment is the same as that used on the vehicle, but the following should be carefully noted:

All electrical tests and settings should be carried out on a suitably equipped variable speed test drive so that maximum accuracy can be achieved.

***Current Regulator***

**(i)** ***Setting on the Vehicle*** When setting the current regulator on the vehicle, the generator must be made to develop its maximum rated output whatever may be the state of charge of the battery at the time of setting. The voltage regulator must therefore be rendered inoperative. This can be done by short-circuiting the voltage regulator contacts. Insert a clip large enough to bridge the outer armature assembly securing the screw and the insulated fixed contact bracket.

Disconnect the cable from the control box terminal B and connect a first grade moving coil ammeter (0–40A) between this cable and terminal B. Switch on all lamps and accessories to prevent the voltage of the system from rising when the engine is started.

Start the engine and run the generator at the specified speed. The ammeter needle should be steady and indicate a current equal to the maximum rated output of the generator. If these figures are not reached, the unit must be re-adjusted in a manner similar to that described for the voltage regulator.

Reconnect the lead to terminal B.

**(ii)** ***Setting on the Bench*** The load circuit should comprise a 63 Ah battery.

If the setting of the current regulator is performed away from the vehicle, a test generator and an artificial load is required. The load circuit should comprise a 63 Ah battery, a 0-40 A full-scale ammeter and a rheostat capable of carrying up to 35 amperes at 12 volts. The arrangement is shown in Fig. 21.23.

Since settings can be affected by change of position a bench setting should be made with the control box mounted as on the vehicle.

Adjust the rheostat until ammeter A1 shows a current equal to the maximum rated output of the generator normally controlled by the regulator.

Run the test generator at the appropriate speed and adjust the current regulator so that ammeter A2 shows the required setting.

**4.** ***The Cut-out*** Cut-in Voltage: 12.3 V at 20°C for contact closure.

***(i) Setting on the Vehicle***

(a) Fit a first grade moving coil 0–40 A full scale voltmeter between the control box terminal D and earth. Switch on an electrical load such as the headlamps and slowly increase the engine speed.

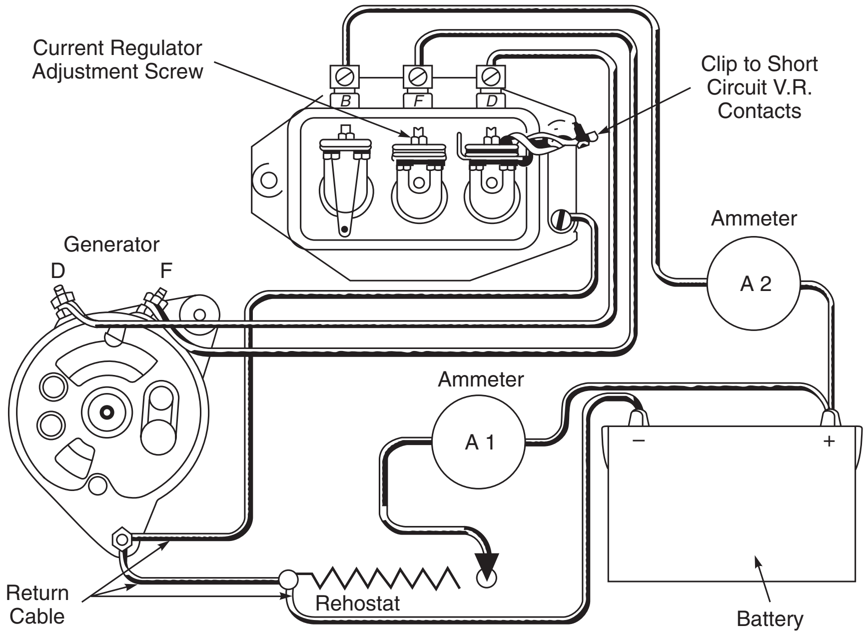



**Fig. 21.23** Current Setting Circuit-3 GC Regulator

A slight drop in the voltmeter reading, indicating closure of the contacts should occur between the limits given. If this does not happen, the unit must be adjusted as follows:

(b) Using a suitable tool, turn the cut-out relay adjustment cam by a small amount in the appropriate direction-turning the tool clockwise to raise the setting or anti-clockwise to lower it.

(c) Repeat the operation until the correct setting is obtained. Note that the generator must be stopped before each adjustment of the setting screw or the cam.

**(ii)** ***Setting on the Bench*** The method of setting is the same as that employed on the vehicle but note that a suitable load resistor capable of passing about 6 A without over-heating should be connected between the control box terminal B and earth. This will cause the voltmeter needle to flick at the instant of contact closure.

**5.** ***Method of Drop Off Adjustment*** The following procedure should be adopted for drop off adjustment

(a) Withdraw the cables from the control box terminal B.

(b) Connect a first-grade 0–20 V moving coil voltmeter between the control box terminal B and earth.

(c) Start the engine and run up to 1,700 rpm approx.

(d) Slowly decelerate and observe the voltmeter pointer. Opening of the contacts, indicated by the voltmeter pointer dropping to zero should occur between 9.5–11.0 V. If the drop off occurs outside these limits, an adjustment must be made.

(e) In this event, continue as follows: Stop the engine and remove the control box cover.

(f) Adjust the drop off voltage by carefully bending the fixed contact bracket. Reducing the contact gap will raise the drop off voltage; increasing the gap will lower the drop off voltage.

(g) Re-test and if necessary re-adjust until the correct drop off setting is obtained.

The adjustment should result in a contact follow through or blade deflection of 0.3 to 0.9 mm as shown in Fig. 21.24.

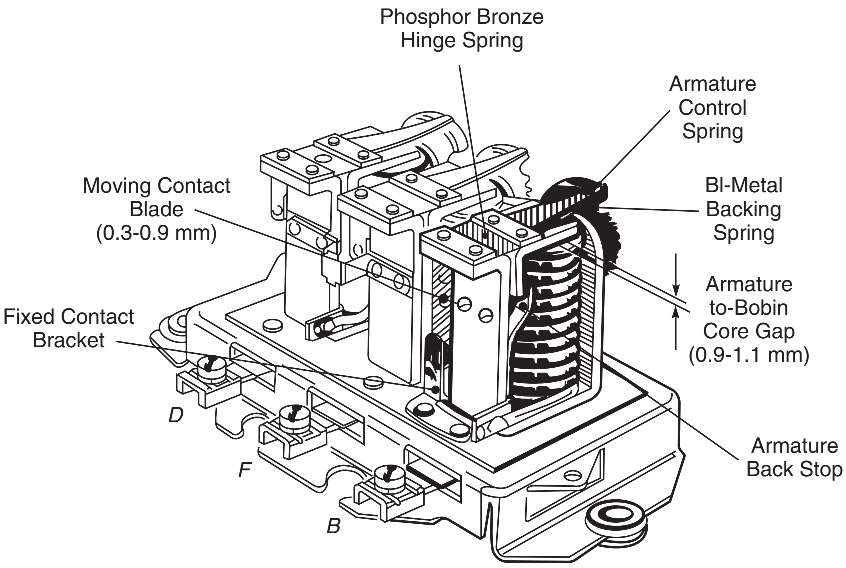



**Fig. 21.24** Cut-out Replay Settings Model-3 GC (*Courtesy:* Lucas-TVS)

## 21.8 IGNITION SYSTEMS

There are two types of ignition systems used in petrol engines.

1. Battery ignition or coil ignition system.
2. Magneto ignition system.

The battery ignition system is used in almost all petrol vehicles except small engines such as engines used in motorcycles, scooters, mopeds, motorboats etc. In this system, the current in the primary winding is supplied by the battery whereas in the other system, the magneto produces and supplies the current. Both systems are however based on the principle of mutual electromagnetic induction.

**1. *Battery Ignition System*** The principal components of the battery ignition system are as shown in the circuit diagram of Fig. 21.25.

(a) The battery which supplies the electrical energy.
(b) The ignition switch which controls the battery current when it is desired to start or stop the engine.
(c) The ignition coil which transforms the battery low tension current to high tension current which can jump the spark plug in the cylinder under compression.
(d) The distributor which delivers the spark to the proper cylinders and incorporates the mechanical breaker, which opens and closes the primary circuit at the exact times.
(e) The wiring which connects the various units.
(f) The spark plugs which provide the gap in engine cylinders.

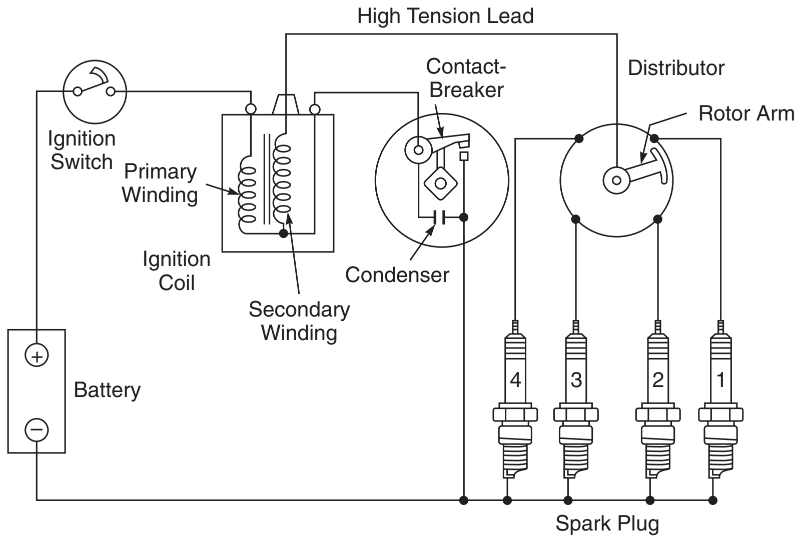



**Fig. 21.25** Battery Ignition System for Four Cylinder Engine (*Courtesy:* Maruti Udyog Ltd.)

The system is subdivided into two circuits:

(a) The low tension circuit or primary circuit, which starts at the battery and passes through the ignition switch, primary winding contact breaker points to the ground. A condenser is also connected in parallel to the contact breaker points.

(b) The high tension circuit or secondary circuit, which starts from the ground and passes through the secondary winding, distributors, spark plug to the ground.

When the ignition switch is 'ON', the current flows from the battery through the primary winding and produces a magnetic field in the coil. When the contact points open the magnetic field collapses and this movement induces current in the secondary winding. The ignition coil steps up 12 volts from the battery to high tension voltage of about 20 to 30 thousand volts required to jump the spark at the spark plug gap (15000 volts are needed to jump 1 mm gap). The distributor then directs this high voltage to the proper spark plug when it jumps the gap, producing a spark which ignites the combustible mixture in the cylinder.

**2. *Magneto Ignition System*** In the magneto ignition system, a magneto consisting of a fixed armature having primary and secondary windings and a rotating magnetic assembly, is used instead of a battery. It is mostly used in motorcycles, scooters and racing cars.

## 12.9 DISTRIBUTOR

Figure 21.26 shows the distributor unit in section to expose its internal mechanisms for easy viewing. The shaft is driven from the engine camshaft through the worm gearing, and rotates once for every two revolutions of the crankshaft. Inside the cap, are four side electrodes (for spark plugs) and one center electrode (to which the secondary side of the ignition coil is connected). The arm of the rotor, mounted on the shaft, touches the side electrodes one by one and distributes the high voltage to the spark plugs, one at a time.

Immediately below the distributing mechanism is the contact-breaker, whose cam, mounted on the shaft, actuates the breaker arm to make and break the primary current circuit for the purpose

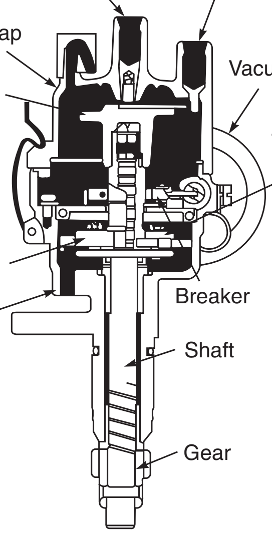



**Fig. 21.26** Internal Mechanism of Distributor (*Courtesy:* Maruti Udyog Ltd.)

already mentioned. The condenser (capacitor) secured to the distributor body is for absorbing the current surge, which would otherwise result in a sparking across the contact point gap. The surge occurs every time the contact point is opened, and is due to, so to say, the inertia of electric current. The object served by the condenser is obvious; it is to prevent the point faces from getting burnt by sparking.

The ignition timing advancer used in the distributor is operated by both the centrifugal advance mechanism (advance due to centrifugal governor action) and vacuum mechanism (advance due to vacuum control).

## 21.10 IGNITION COIL

The ignition coil is a sort of miniature transformer and, as such, has an iron core around which two coils are wound which form the primary and secondary windings. The two are so close to each other that a sudden change in the magnetic flux produced by primary current flowing in the primary winding (in a less number of coil turns) induces a very large electromotive force (voltage) in the secondary winding (in a greater number of coil turns). These live parts are housed in a tight, insulator case topped by the cap. The cap has three terminals; one high-tension terminal and two low-tension terminals. Figure 21.27 shows an assembled and internal mechanism of ignition coil.

## 21.11 IGNITION TIMING

The purpose of the ignition system is to provide a high voltage spark between the spark plug electrodes at the correct instant in each of the engine cylinders to explode the air fuel mixture. The system must take the 12 volts of electricity at the battery or alternator and step it up to 30,000 volts required for ignition. The time required for complete combustion of the air-fuel mixture is

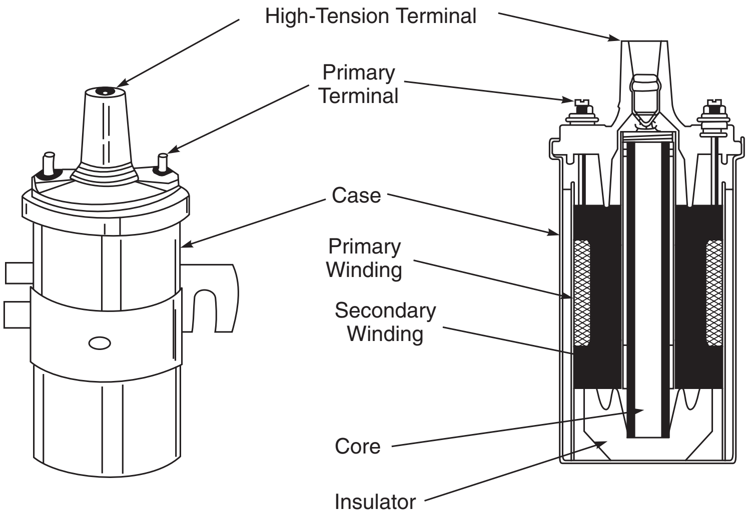



**Fig. 21.27** Assembled and Internal Mechanism of Ignition Coil (*Courtesy:* Maruti Udyog Ltd.)

affected by several engine design features, viz. combustion chamber shape, spark plug position and bore diameter and also upon the engine's operating conditions. Both rich and weak mixtures require a higher ignition voltage than the chemically correct mixture. Cold engines as well as engines having higher compression ratio require higher ignition voltage.

The ignition timing necessary for efficient engine operation changes with engine speed and load. As the engine speed increases, a shorter time is available for the mixture to ignite, burn and provide power to the engine. To get the most power, the high voltage spark must reach the cylinder earlier in the cycle or the ignition must be advanced.

The time that the spark is introduced into the cylinder is measured by the position of the crankshaft for cylinder no. 1. When piston no. 1 is at top dead centre (TDC), the crankshaft and the connecting rod are lined up vertically. When the piston is at other points, i.e. either before or after the top dead centre, the angle measured in degrees gives the position of ignition. When ignition occurs in relation to crankshaft movement, it is determined by three distributor advance system:

(i) Initial or basic advance system
(ii) Centrifugal advance system
(iii) Vacuum advance system

The purpose of these advance systmes is to adjust ignition timing to engine operating conditions.

## 21.12 IGNITION ADVANCE

When the ignition occurs early in compression stroke, before TDC, the ignition or spark is said to be advanced. A retarded spark occurs when the compression stroke is more nearly complete at the time ignition occurs.

The combustion of the fuel-air mixture is not instantaneous and occurs only after a certain time called ignition delay of spark occurrence that the pressurised combustion takes place. The point at which maximum pressure occurs is very important. Maximum useful energy from the expansion is obtained when the peak pressure occurs about 10° after TDC. Since the flame propagation speed changes with changes in engine operating conditions, the ignition timing is adjusted so that peak pressure will always occur at about 10° after TDC under all engine operating conditions. This is carried out with the help of ignition advance and retard mechanisms.

There are two general methods used in modern engines to advance and retard the ignition timing automatically in relation to engine speed and operating conditions after the initial timing is set. These methods are:

1. Centrifugal advance
2. Vacuum advance.

## 1. Centrifugal Advance Mechanism

A typical centrifugal advance mechanism as shown in Fig. 21.28. It consists of two spring loaded fly-weights, separately pivoted on a circular drive plate rigidly secured to the drive shaft of the distributor. As the engine speed increases these weights move out due to the centrifugal force which is resisted by the spring tension. This movement is transmitted through the toggle links to the contact breaker cam which causes it to advance with respect to the distributor drive shaft. Such an advance causes the cam to open and close the contact points earlier in the compression stroke.

When the engine is idling, ignition is usually timed to occur just before the piston reaches TDC. At higher engine speeds, as shorter time is available, the spark must reach earlier in the cycle. The spark advance is gradual until a final value is reached at maximum engine speed where the weights reach the outer limits of their travel. Depending upon engine design the maximum centrifugal advance can be as high as 40° which means a 20° advance of distributor cam rotation.

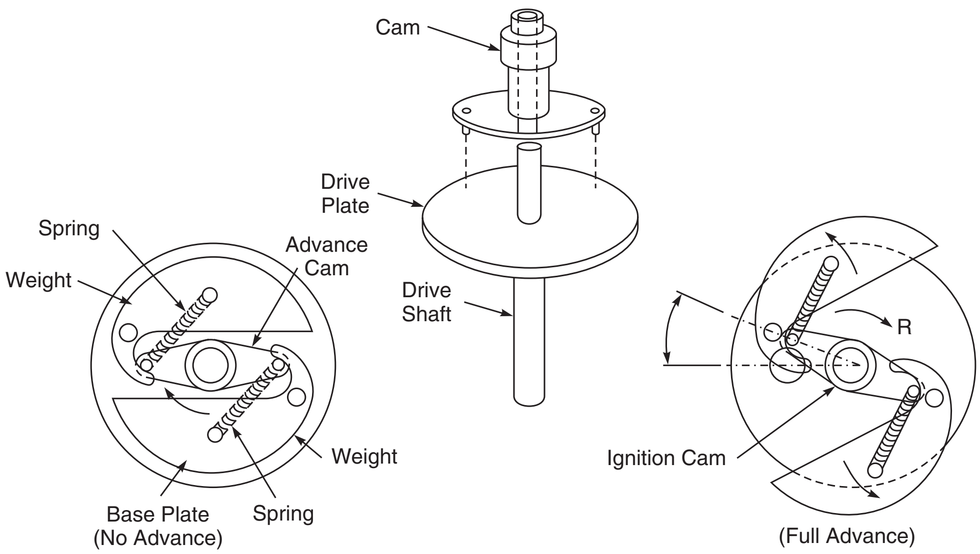



**Fig. 21.28** Centrifugal Advance Mechanism

## 2. Vacuum Advance Mechanism

Figure 21.29 shows a depression chamber which is sealed by a spring-loaded flexible diaphragm. One side of the chamber is subjected to atmospheric pressure through a vent and the other side is subjected to manifold vacuum. A linkage connects the diaphragm to the distributor.

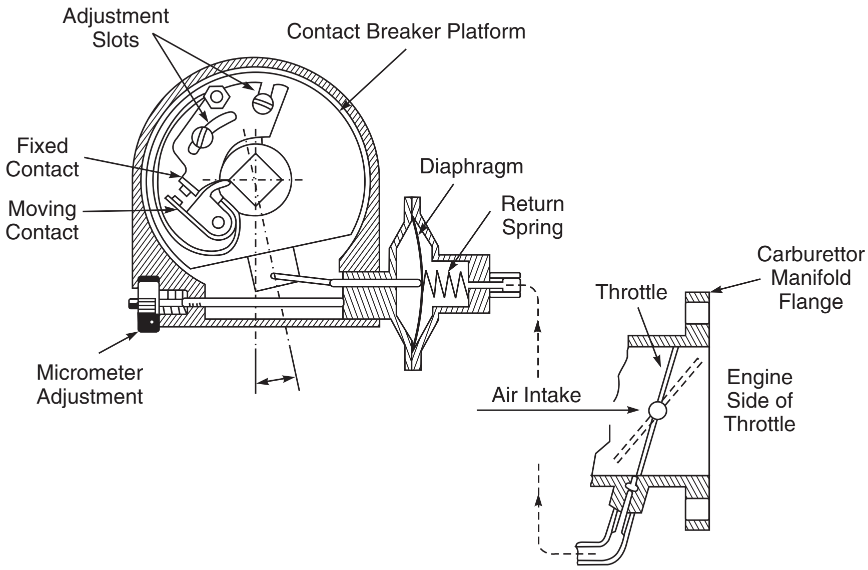



**Fig. 21.29** Typical Vaccum Advance Mechanism

When the intake manifold vacuum increases, the atmospheric pressure pushes the diaphragm whose motion is transmitted to the base plate through the link and the cam closes and opens the contact points earlier in the compression stroke thereby advancing the ignition. A decrease in vacuum allows the diaphragm to return back to its original setting retarding the ignition.

A vacuum advance mechanism is used to obtain such timing changes as may be required by the throttle position and engine load. For part throttle (high intake vacuum) light load operation when the burning rate is low, the ignition timing is advanced. For high throttle (low intake vacuum) heavy load operation when fast burning rates occur, ignition is retarded.

At full throttle the ignition retard is maximum. Thus the vacuum advance mainly provides fuel economy under part throttle operating conditions by allowing the mixture sufficient time to burn and produce peak pressure about 10° after TDC.

At full throttle, the vacuum advance is nil. As the throttle is closed, there is more vacuum in the intake manifold and the vacuum advance increases. The maximum advance which may be provided is about 30° of crankshaft rotation or 15° of distributor camshaft rotation.

It is thus seen that the centrifugal advance mechanism takes greater care of speed but not load conditions, whereas the vacuum advance mechanism takes greater care of load conditions. Therefore a combination of the two mechanisms is applied on the distributor and gives practically perfect spark timing for all driving conditions.

## 21.13 SPARK PLUG

The spark plug is a device to produce electric spark to ignite the compressed air-fuel mixture inside the cylinder. It is placed on top of the cylinder so that its electrodes project into the combustion chamber.

The spark plug provides an air gap in the engine's combustion chamber for the discharge of a high voltage electric pulse to ignite the mixture at the desired point in the cycle. The spark plug must be able to seal high pressures and resist the erosion caused by millions of spark discharges.

A spark plug consists of mainly three parts (Fig. 21.30): (i) a well-insulated centre electrode, (ii) ground electrode and (iii) insulation.

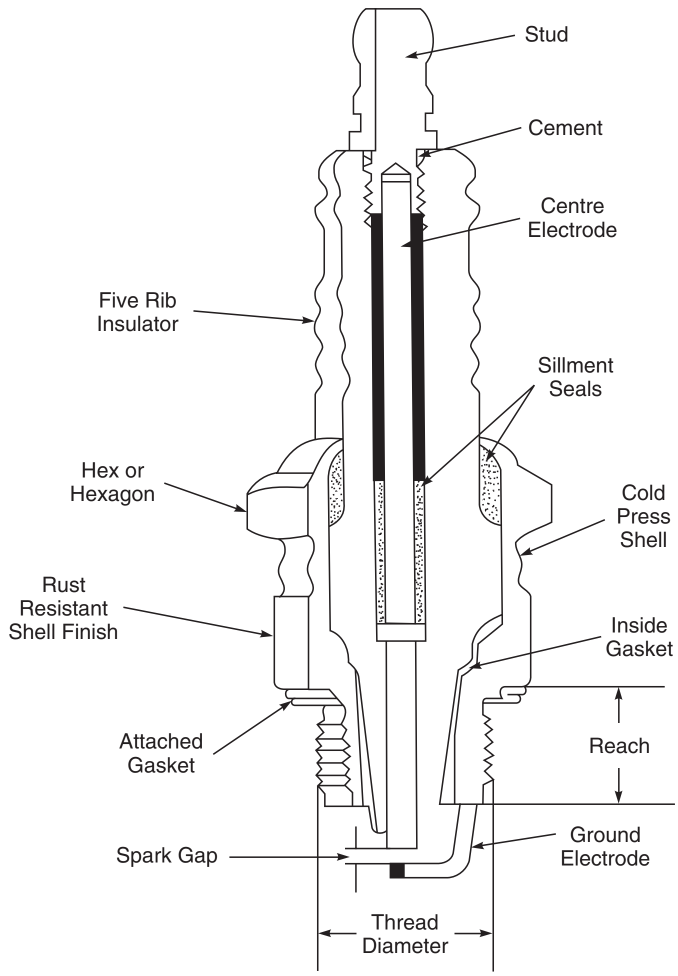



**Fig. 21.30** Sectional View of Spark Plug

Since the centre electrode must carry high voltage into the cylinder, it must be well insulated. The ceramic insulator formed around the centre electrode has ribs on its outside diameter to increase the distance between the terminal and the nearest ground. The centre electrode and ceramic insulator assembly is joined to a metal shell. The shell has threads that allow the spark plug to be screwed into the combustion chamber. A side electrode is attached to the shell and placed a small distance away from the centre electrode. This distance is the air gap or spark plug gap that the current jumps to create a spark. The gap varies from 0.4 mm to 1.00 mm.

Spark plugs are of two types according to their heat range (a) hot spark plug and (b) cold spark plug. Heat range refers to the ability of the plug to transfer combustion heat from its firing end to the cylinder head. The temperature that a plug will attain depends upon the length of the heat transfer path and the area exposed. A hot spark plug has longer path of heat travel and runs hotter than the cold spark plug which has shorter path of heat travel. A cold running plug transfers heat rapidly while a hot running plug has a lower rate of heat transfer.

The insulator tip length which controls the heat range or operating temperature is a significant design parameter. A cold plug will have a short insulator tip and a short heat rejecter path. When a plug runs too cold, the carbon deposits on the insulator around the centre electrode. A hotter running plug will burn this carbon away and prevent its formation. A plug that runs hot will wear more rapidly. Low-speed medium duty engines running at colder operating conditions require a hot spark plug. Cold spark plugs are used in heavy duty or continuous running high speed engines to avoid overheating.

The spark plug top must operate between carbon and oil fouling temperature, and the pre-ignition and electrode burning temperature. If the temperature of the tip of the spark plugs is too cold, carbon and oil will burn off the electrodes. Deposits will soon build up on the electrodes and cause misfire. If the top area is too hot, the insulator end may ignite the air-fuel mixture, causing pre-ignition. Excessive heat at the tip-end will also speed up electrode burning and erosion, reducing the useful life of the plug. Since different engines have different temperature characteristics, spark plugs with different heat ranges are manufactured to suit the specific conditions of the engine.

A spark plug will fail to function properly if

1. The plug is fouled by engine oil entering the combustion chamber or by too rich a mixture.
2. Plug is badly covered with carbon from poor ignition.
3. Plug gap is incorrect.
4. Burned electrodes or broken lower insulator caused by overheating.
5. Red/brown/yellow deposits on plug interior that short the insulator.
6. Accumulation of dirt or moisture on the outside of the insulator that short the plug.
7. Cracked or broken insulator sealing.

## 21.14 ELECTRONIC IGNITION SYSTEM

Two of the major problems with breaker-point ignition system are the wear on the points and the speed at which the primary current is stopped. From the fully mechanical breaker-point system, ignition technology progressed to basic electronic or solid state ignitions (Fig. 21.31). Breaker points were replaced with electronic triggering and switching devices. The electronic switching components are normally inside a separate housing known as a control module or control unit. The original (solid state) electronic ignitions still rely on mechanical and vacuum advance mechanisms in the distributor.

As technology advanced, many manufacturers expanded the ability of the ignition control modules. For example, by tying a manifold vacuum sensor into the ignition module circuitry, the module could now detect when the engine was under heavy load and retard the timing automatically. Similar add-on sensors and circuits were designed to control spark knock, start-up emissions, and altitude compensation.

## 21.15 ELECTRONIC SWITCHING SYSTEMS

Electronic ignition systems control the primary circuit, using an NPN transistor instead of breaker contact points. The transistor's emitter is connected to ground and takes the place of the fixed contact point.

The collector is connected to the negative (-) terminal of the coil, taking the place of the movable contact point. When the triggering device supplies a small amount of current to the base of the

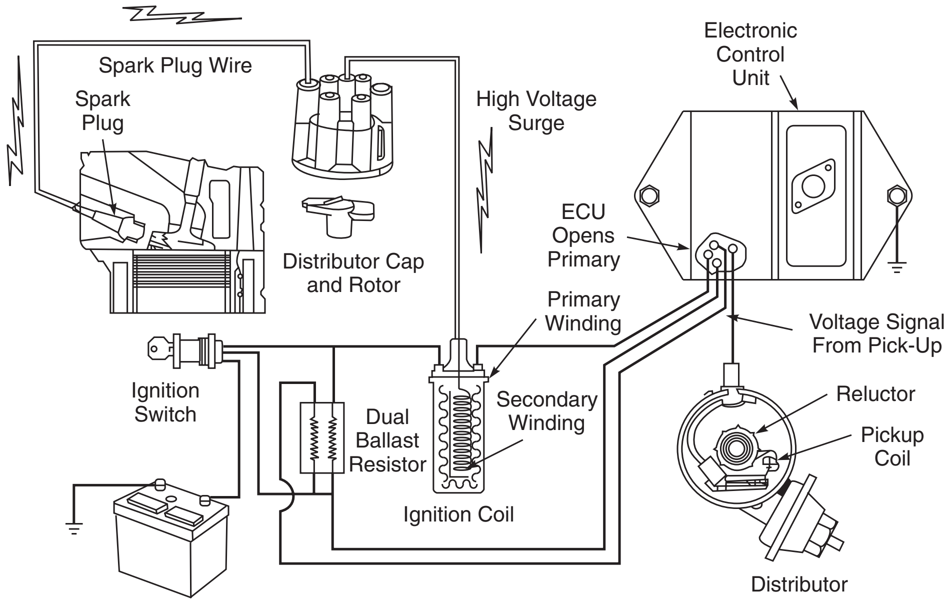



**Fig. 21.31** A Typical Electronic of Solid State Ignition System

switching transistor, the collector and emitter act as if they are closed contact points (a conductor), allowing current to build up in the coil primary circuit.

When the current in the base is interrupted by the switching device, the collector and emitter act as an open contact (an insulator), interrupting the coil primary current. An example of how this works is shown in Fig. (21.32), which is a simplified diagram of an electronic ignition system.

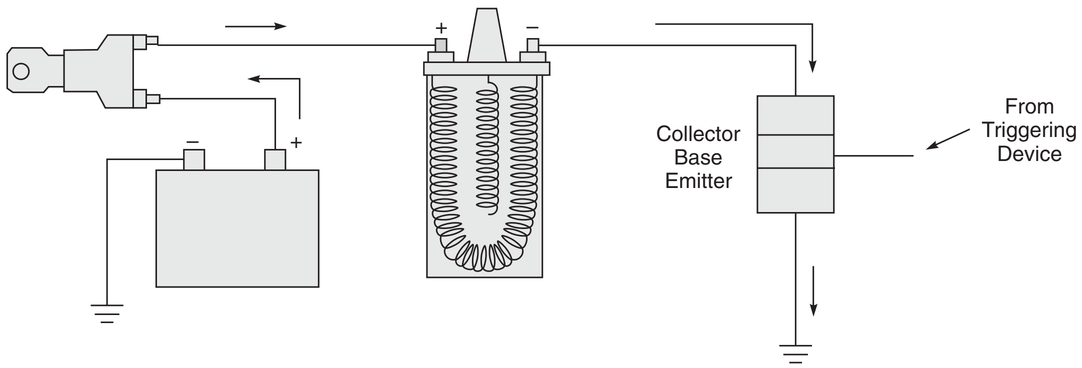



**Fig. 21.32** When the Triggering Device Supplies a Small Amount of Current to the Transistor Base, the Primary Coil Circuit is Closed and Current Flows

## Engine Position Sensors

The time when the primary circuit must be opened and closed is related to the position of the pistons and the crankshaft. Therefore the position of the crankshaft is used to control the flow of current to the base of the switching transistor.

A number of different types of sensors are used to monitor the position of the crankshaft and control the flow of current to the base of the transistor.

These engine position sensors and generators serve as triggering devices. The trigger in electronic ignitions differs among manufacturers. The trigger is either in the distributor or on the crankshaft. It can be a magnetic AC generator, a hall-effect sensor or a photoelectric sensor.

## 1. Magnetic Type AC Generator Systems

A popular type of electronic trigger is the magnetic type AC generator pickup shown in Fig. 21.33.

The system works like an alternator. A stationary sensor called a pickup coil sends signals to a transistor located in the ignition module. The pickup coil is wrapped around an iron pole piece near a permanent magnet. The magnetic field of the permanent magnet surrounds the pickup coil.

A non-magnetic trigger wheel, also called a reluctor, pulse ring, or armature, is attached to the distributor shaft. It replaces the distributor cam on the contact point system. The trigger wheel has as many teeth on it as the engine has cylinders. Every time a reluctor tooth passes across the windings in the pickup coil, a small voltage is generated. The ignition module senses this voltage and uses it to control the build-up of the magnetic field in the coil primary winding.

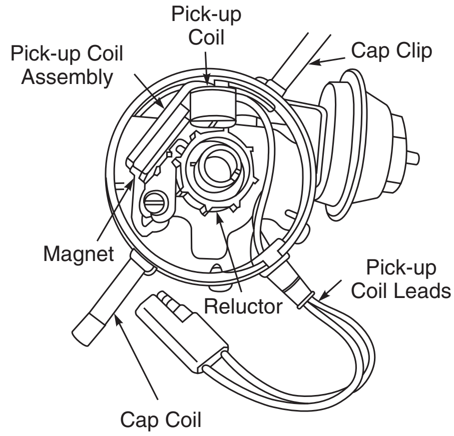



**Fig. 21.33** Magnetic Type AC Generator

The trigger wheel has low magnetic reluctance. Low reluctance can be compared to low resistance. Magnetic field is easily absorbed by a material with low reluctance. As the tooth of the trigger wheel is rotated into the magnetic field around the pole piece and pickup coil, magnetic flux becomes concentrated in the tooth (Fig. 21.34). The magnetic field around the pole piece changes and a small voltage is induced in the pickup coil. The amount of voltage changes with the rate of the magnetic flux. As the reluctor tooth moves away from the pole piece, the magnetic field becomes weaker (Fig. 21.35).

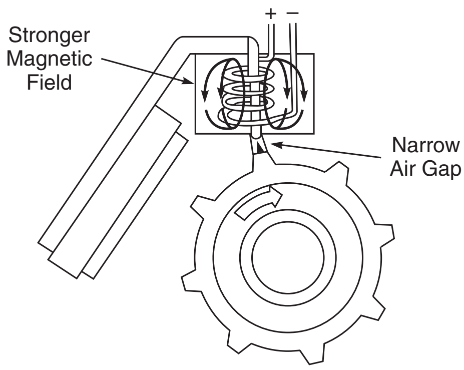



**Fig. 21.34** Narrow Gap Produces a Strong Magnetic Field

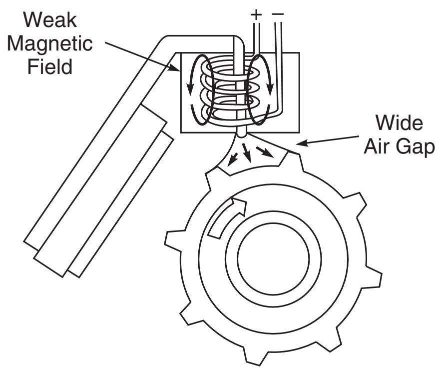



**Fig. 21.35** Wide Gap Produces a Weak Magnetic Field

The output voltage signal varies between positive and negative directions (alternating current). As the reluctor approaches the pole piece, the voltage increases towards the positive direction. When the reductor teeth align with the pole piece, voltage is at zero. The voltage increases in a negative direction when the reluctor moves further away from the pole piece.

Most electronic ignition systems open the circuit as the polarity changes from positive to negative. This is the same as when the breaker points open, resulting in a spark at the plug. As the tooth moves out of the magnetic field of the pole piece, the next tooth on the trigger wheel comes into the field and the cycle repeats itself. Once again, the current flows to create another magnetic field. The transistor in the module shuts off the current flow in the primary circuit. The AC signal voltage is made greater (amplified) by the module. The amplified voltage is applied to the base of the transistor to trigger it.

### 2. Hall-effect Sensors

In electronic ignition systems several types of electrical pickup devices are used. One such device is called the Hall-effect switch or sensor. Its purpose is to provide a signal each time a piston reaches top dead center. Hall-effect sensors are able to read various positions within the 360 degrees of rotation of the crankshaft. The signal produced by the switch is then used for ignition timing. Figure 21.36 shows an example of a typical Hall-effect sensor located inside a distributor. It consists of three parts—a permanent magnet, a shutter wheel, and a Hall-effect element. The permanent magnet is stationary. The Hall-effect element, or pickup, also called a crystal, is also stationary. The shutter wheel is rotated by the distributor shaft. As shown in Fig. 21.37, a voltage is applied to the Hall-effect element producing on output voltage. When the shutter blade is not between the magnet and the crystal, the magnetic field has the effect of reducing the signal. This produces a weak voltage in the crystal (about 0.4 volt). However, when the shutter blade (vane) is between the magnet and the Hall-effect crystal, the magnetism is reduced, producing a higher voltage (12 volts) in the Hall-effect element. Through internal circuitry, the signal is then amplified. Figure 21.38 shows the Hall-effect pickup and the shutter blade.

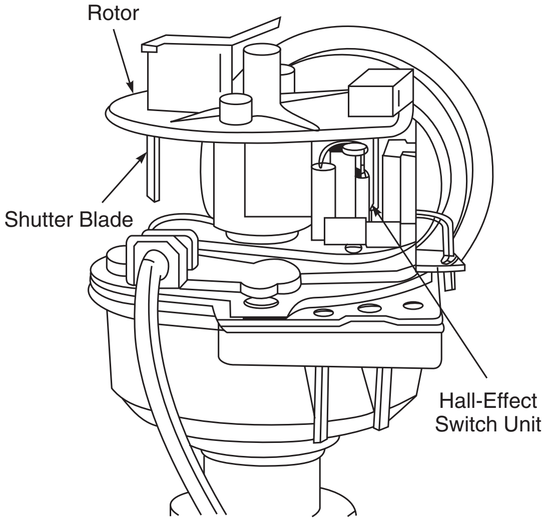



**Fig. 21.36** Hall-effect Sensor

### 3. Photoelectric Sensor

The other type of crankshaft position sensor is the photoelectric or optical sensor. The parts of this sensor include a light-emitting diode (LED), a light-sensitive photo transistor (photo cell), and a slotted disc called a light beam interrupter (Fig. 21.39).

The slotted disc is attached to the distributor shaft. The LED and the photo-cell are situated over and under the disc opposite each other. As the slotted disc rotates between the LED and photo-cell, light from the LED shines through the slots. The intermittent flashes of light are translated into voltage pulses by the photo-cell. When the voltage signal occurs, the control unit turns on the

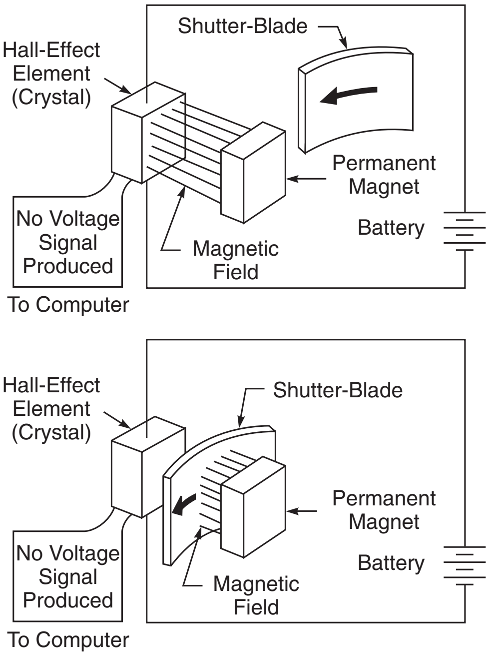



**Fig. 21.37** Hall-effect Element Producing on Output Voltage

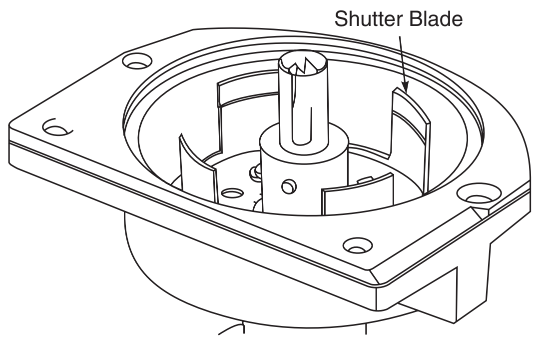



**Fig. 21.38** The Position of the Hall-effect Pickup and the Shutter Blade

primary system. When the disc interrupts the light and the voltage signal ceases, the control unit turns the primary system off, causing the magnetic field in the coil to collapse and sends a surge of voltage to a spark plug.

The photoelectric sensor sends a very reliable signal to the control unit, especially at low engine speeds. These units have been primarily used in Chrysler and Mitsubishi engines. Some Nissan and General Motors products have used them as well.

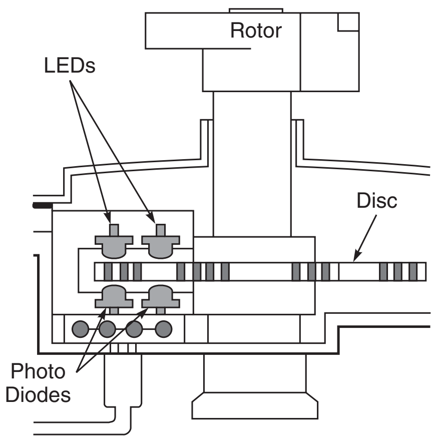



**Fig. 21.39** Photoelectric or Optical Sensor

## 21.16 OPERATION OF ELECTRONIC IGNITION SYSTEM

The primary circuit of an electronic ignition system is controlled electronically by one of the sensors just described and an electronic control unit (module) that contains some type of switching device.

Figure 21.40 shows a basic electronic ignition system. The system consists of a distributor with a magnetic pulse pickup unit and a reluctor, an electronic control module, and a ballast resistor. As described earlier, when the tooth of the reluctor passes the pickup, an electrical impulse is sent to the electronic module, which contains the switching transistor. The pulse signals the transistor to open the primary circuit, firing the plug. Once the plug stops firing, the transistor closes the primary coil circuit. The length of time for which the transistor allows current flow in the primary ignition

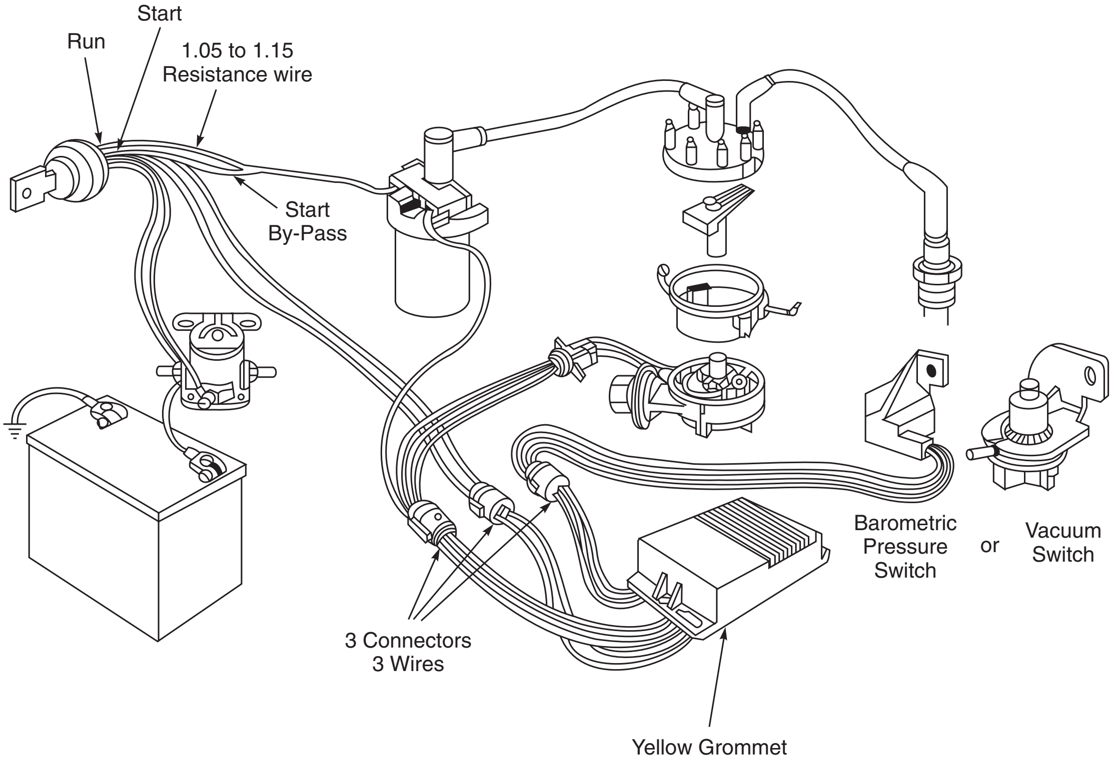



**Fig. 21.40** A Typical Electronic Ignition System

circuit is determined by the electronic circuitry in the control module. Some systems used a dual ballast resistor. The ceramic ballast resistor assembly is mounted on the fire wall and has a ballast resistor for primary current flow and an auxiliary resistor for the control module.

The ballast resistor has a 0.5 ohm resistance that maintains a constant primary current. The auxiliary ballast resistor uses a 5 ohm resistance to limit voltage to the electronic control unit.

There are some electronic ignition systems that do not require a ballast resistor. For instance, some control units directly regulate the current flow through the primary of the coil. Hall-effect systems do not require ballast resistors either. The signal voltage is not changed by the speed of the distributor as it is an inductive magnetic signal generating system.

Some systems can be enhanced with additional sensors that increase the capabilities of the control module. The module shown in Fig. 21.40 can be equipped with either a barometric pressure switch or vacuum switch. The barometric pressure switch enables the module to retard the ignition timing 3 to 6 degrees when the vehicle is operating at low elevations. The vacuum switch does the same, when the engine is under hard acceleration or heavy load. Other modules have the ability to retard ignition timing during start-up or when engine knock is detected.

Timing advance of electronic ignition systems changes the timing mechanically just like the breaker point systems.

## 21.17 AUTOMOBILE BATTERY

The automobile battery provides all of the electrical power for the automobile when the engine is not running. It is an electrico-chemical device for storing energy in chemical form and provides the energy to power the starter motor and ignition system so that the engine may be cranked and started. It also supplies current for light, radio, heater and other units when the generator is not operating fast enough.

There are mainly two types of batteries used for automotive application:

1. Lead acid battery, and
2. Nickel alkaline battery.

The lead acid battery is most widely used in automobiles. Figure 21.41 shows the cut-away view of a 12 volt lead acid battery. A lead acid battery consists of the following components:

1. Container
2. Plates
3. Separators
4. Cell covers and
5. Electrolyte

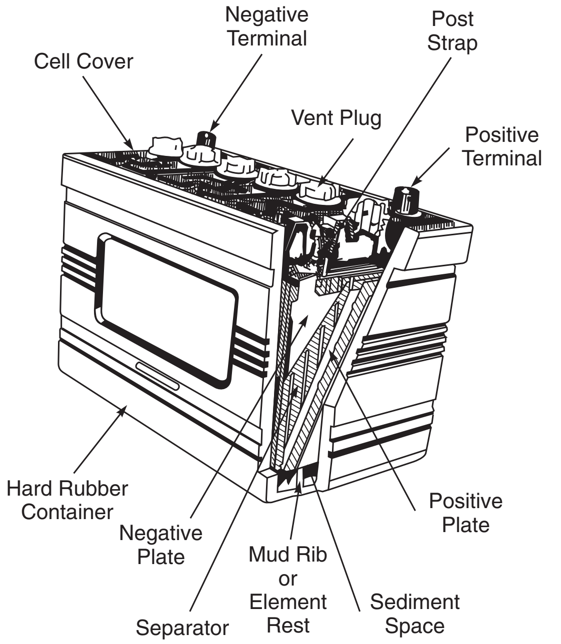



**Fig. 21.41** Cut-away View of a 12- Volt Lead-Acid Battery (*Courtesy:* chloride and exide)

Two dissimilar active materials in the form of position plates and negative plates that are kept apart by separators are assembled into units called elements. An element becomes a cell when it is installed in a container filled with an electrolyte. Each element is located in its individual cell in the acid proof battery case made of hard plastic with partitions that separate the cells.

The plates consist of perforated grids into which lead or lead peroxide is pressed. The grids are made of an alloy of lead and antimony. The plates are usually flat, rectangular lead castings. A number of plates are connected together by soldering them to a small lead casting called a plate strap. Straps connect the tops of all negative plate grids and separately connect the tops of all negative plate grids in each element. The negative (-) plate and the positive (+) plate groups are assembled so that each negative plate is next to a positive plate. Both the outside plates are negative as this practice is found to improve battery performance. Thin sheets of porous insulation material called separators are placed between the plates to avoid an electric short.

The open circuit voltage of a fully charged cell, no matter what the size of the cell or the number of plates in the element be is only a little over 2 volts. The battery voltage is the sum of the voltage of its cell. Thus a 12 volt battery consists of 6 cells. Six cells connected together in series add up to 12 volts.

Positive plates are filled with lead peroxide active material. Negative plates are filled with a porous mass of lead, in spongy form, which the electrolyte can penetrate freely. The sulphuric acid of the electrolyte supplies sulphate ions which combine with each of the plate materials and releases electrical energy. The electrolyte also helps in the conduction of current inside the battery between positive and negative plates.

**1. *Capacity Rating*** All six cell storage batteries have the same voltage but they may have a different capacity. Capacity is a measure of how long a battery can supply current. A battery usually has two capacity ratings. Several different tests are used to determine battery capacity.

One common test is called the *20 hours rating*. The test involves discharging the battery at a constant rate and a constant temperature of 27 °C (80 °F) for 290 hours to drop the average cell voltage to 1.75 volts. This capacity called the 20 hour rating, is the product of the discharge current and the 20 hour discharge time.

Another important capacity rating is the *starting* or *cranking capacity* of the battery which is related to the plate area. The car batteries are built with thin plates to give the acid quick access to as large an area of active material as possible.

The ability of a battery to supply current in cold weather is determined by the *cold cranking test*, while maintaining a minimum of 1.2 volts per cell. In this test, the battery supplies current for 30 seconds. Two separate current ratings are made, one at 18° C (0° F) and another at 7° C (– 20° F). The battery is rated according to the amount of current in amps it can supply under these conditions.

The maximum battery output in watts when cranking at – 18° C (0° F) is also used as the peak watt rating of the battery. The *reserve capacity test* measures the time in minutes that the battery can supply current at night if the alternator should fail. A fully charged battery is discharged at a constant 25 amps at a temperature of 27° C (80° F) until the cell voltage drops to 1.75 volts. The longer the battery can supply this 25 amps the higher the reserve capacity.

**2. *Overcharging*** When a battery is overcharged a violent chemical reaction in the cell rapidly breaks down the electrolyte into $H_2$ and $O_2$. The violent gasses cause a rapid water loss from the cell and wash the active material off the plates, greatly shortening the life of the battery. Overcharging also produces heat that can oxidize the positive plate grids and even buckle the plates leading to early battery failure.

***3. Improper Electrolyte Level*** If the level drops below the top of the plates, the active material is exposed which subsequently hardens and becomes chemically inactive. As water is lost from the cell, during charging, the percentage of sulphuric acid in the remaining electrolyte becomes so high that it may cause the plates to breakdown rapidly.

Overfilling removes sulphuric acid for the cell thus diluting the chemical process in the cell and causing poor performance. The spillage over the battery top and around terminal connections also causes corrosion.

***4. Effects of Temperature*** Too high a temperature shortens battery life. Low temperature due to cold climate can freeze the electrolyte which may expand and break the case, ruining the battery. The colder the weather the thicker the engine oil, and the harder it is to crank over the engine.

The electrolyte of a fully charged battery contains above 35.6% of $H_2SO_4$ (sulphuric acid) by weight or about 25% by volume. This corresponds to a specific gravity of 1.260 at 26.7° C (80° F). During discharge, the chemical reaction converts the active materials of both plates to lead sulphate, water being liberated in the process. This reduces the specific gravity of the electrolyte which is a good indication of the state of the charge of battery. At a specific gravity of 1.16, the battery barely operates and at 1.11, it is completely discharged.

During charging, the chemical process is reversed and the specific gravity of the electrolyte increased to 1.22 at 50% and 1.26 to 1.28 at 100%.

Temperature has a significant effect on specific gravity and the efficiency of the battery is affected if the temperature is lowered. A battery is only 40% efficient at 18° C (O° F) compared to 100% efficiency at 27° C (80° F). This is due to the increase in viscosity of the electrolyte with a drop in temperature which slows down the chemical process and circulation between the plates.

## 21.18 LOW-MAINTENANCE AND MAINTENANCE-FREE BATTERIES

The majority of batteries installed in today's vehicles are either low-maintenance or maintenance-free designs. Low-maintenance batteries are still equipped with vent holes and caps, which allow water to be added to the cells. A low-maintenance battery will require additional water substantially less often than a conventional battery. The low-maintenance battery grids contain about 3.4% antimony, and it is called a *dual alloy battery*. The grids intersect at a different angle for strength and better electrical conduction as shown in Fig. 21.42.

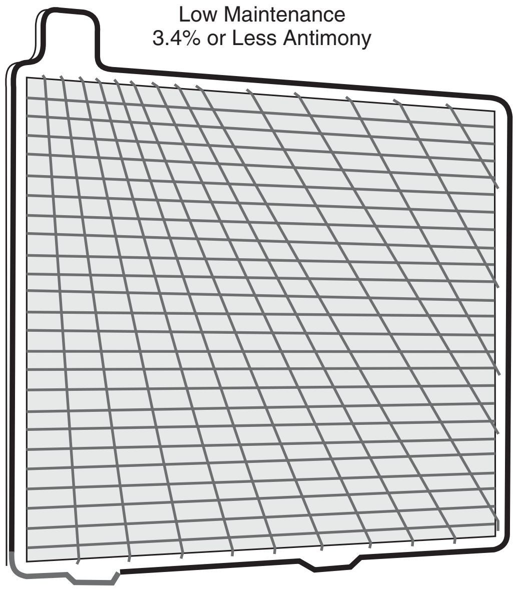



**Fig. 21.42** Low-maintenance Battery Plate Grid

Maintenance-free battery differs from the conventional battery design in two important ways-plate design and water use. Figure 21.43 shows an example of the cover of a maintenance-free battery. In maintenance-free batteries, the antimony is eliminated and replaced by calcium or strontium. Calcium or strontium is used to strengthen the plate grid. It also reduces both the battery's internal heat and the amount of gassing that occurs during charging. Gassing is the conversion of battery water into hydrogen and oxygen gas. This process is also called electrolysis. Since heat and gassing are the main reasons for battery water loss, these changes reduce or eliminate the need to periodically add water. Reduced water loss also reduces terminal corrosion.

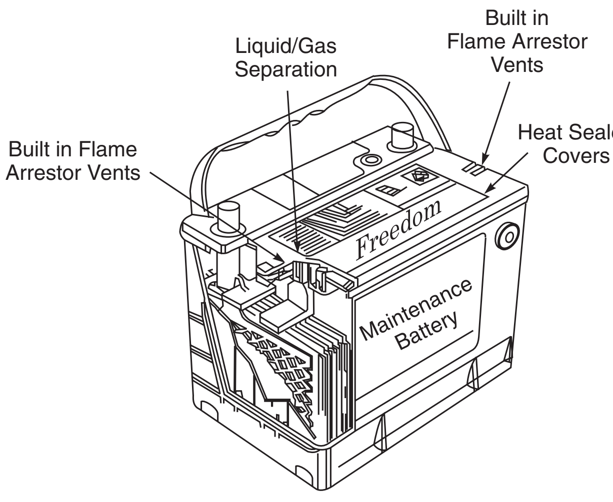



**Fig. 21.43** Maintenance-free Batteries

Maintenance-free batteries are sealed except for small breather holes (see Fig. 21.44). This is because the lead and cal-

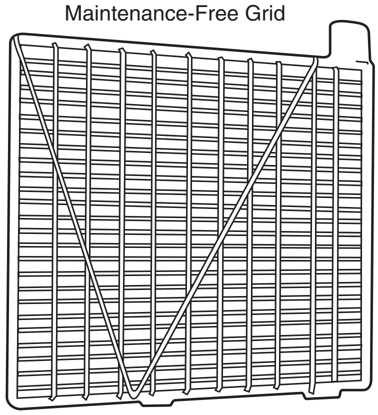



**Fig. 21.44** Maintenance Free Battery Plate Grid

cium combination is susceptible to damage from even a small amount of dirt or grease. The battery does not require water to be added if the charging system is operating properly. If the voltage regulator allows the alternator to overcharge the battery and if it drops too low, the battery must be replaced.

The advantages of a maintenance-free battery are:

1. A large reserve of electrolyte above the plate.
2. Longer shelf life.
3. It does not normally require an activation or boost charge when new.

The major disadvantages of the maintenance-free battery are:

1. It can be damaged with repeated deep discharges, reducing its plate material significantly.
2. Because these are no cell caps, hydrometer testing is not possible.
3. It has a lower reserve capacity.
4. Shorter life expectancy.

**Table 21.1** Troubleshooting of a Starter Motor

| *Trouble* | | *Cause* | *Remedy* |
|---|---|---|---|
| 1. When starter is operated it fails to rotate | (a) | Discharged/Defective battery. | Recharge Battery/Have it checked at a competent garage. |
| | (b) | Excessive voltage drop in starter circuit due to loose or oxidised battery terminals corroded or loose connection /defective earth | Check and rectify starter circuit. Clean the terminals. Tighten all connections and smear petroleum jelly. |
| | (c) | Starter terminals or carbon brushes earthed. | Spot the earth/short fault and rectify. |
| | (d) | Brushes worn out and do not have proper contact with commutator. Dirty, oily or badly burnt commutator due to sticky brushes. | Renew brushes/Clean commutator. Change brush springs if tension is weak. If commutator is badly burnt due to sticky brushes skim/replace armature. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | (e) Defective solenoid switch. | Replace solenoid switch. |
| | (f) Armature/Field coil defective. | Replace armature or field coil as the case may be. |
| 2. Pinion fails to engage though armature rotates | (a) Pinion sticky on sleeve. | Clean the sleeve and pinion. |
| | (b) Burr formation on pinion and ring gear. | De-burr it by filing. |
| | (c) Loose mounting. | Tighten mounting bolts. |
| 3. Starter continues running | (a) Sticky panel switch | Tap in panel to release the switch. If not possible, disconnect starter cable immediately at battery or starter. Replace switch. |
| | (b) Sticky solenoid switch. | Disconnect starter cable immediately at battery or starter. Replace switch. |
| | (c) Sticky drive. | Lubricate with light oil. Do not use grease. |
| | (d) Short in wiring harness. | Repair fault in wiring. |
| | (e) Jammed pinion. | Stall the engine or push the vehicle to and fro with gear engaged. Clean thoroughly and de-burr the gear and pinion by filing. |
| 4. Pinion engages but starter does not crank the engine | (a) Insufficiently charged battery corroded terminals. | Charge the battery and clean terminals smartly (Sluggish Cranking) - |
| | (b) Insufficient pressure on carbon brushes or worn-out brushes. | Change brush springs/brushes. |
| | (c) Shorted/earthing armature. | Change armature. |
| | (d) Earthing field coils. | Change field coil. |

**Table 21.2** Troubleshooting of an Alternator

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Warning light does not appear when start switch is 'ON' | (a) Fused bulb | Replace bulb. |
| | (b) Defective switch | Repair/Replace. |
| | (c) Short circuited warning lamp holder. | Replace holder. |
| 2. Warning light glows dim, | (a) High resistance in warning light circuit. | Check and correct. |
| | (b) Regulator defective | Replace regulator. |
| | (c) Rotor defective | Replace rotor. |
| 3. Warning light 'ON' ammeter shows no charge while the engine is running. | (a) Loose belt | Adjust belt tension. |
| | (b) Aux. diode lead open | Check diode connection and repair. |
| | (c) Shorted rotor | Trade short fault, rectify if possible or replace rotor assembly. |
| | (d) Stator open/shorted | Replace stator assembly. |
| 4. Warning light 'ON' or dim but ammeter shows charge (low output) | (a) Faulty rectifier bridge | Replace defective heat-sink assembly. |

*Contd.*

Contd.

| | | | |
|---|---|---|---|
| 5. Warning light goes off. Ammeter shows low output. | (a) | Faulty rectifier bridge | Replace defective heat sink assembly. |
| | (b) | Stator winding short | Rectify or replace stator assembly. |
| 6. Warning light (ammeter) flickers considerably | (a) | High resistance in the negative line | Check connections and ensure use of recommended wire. |
| | (b) | Slip ring dirty | Clean the slip ring and recheck |
| 7. Overheating (battery gases) | (a) | Faulty regulator | Replace regulator |
| | (b) | Rotor shorted to earth on negative side. | Rectify or replace rotor assembly. |

**Note** *Check lead assembly continuity before proceeding with the above checks on alternators. These alternators have lead assemblies connected between the positive and negative terminals and the corresponding heat-sinks.*

**Table 21.3** Troubleshooting of an Electric System–Ignition

| *Trouble* | | *Cause* | *Remedy* |
|---|---|---|---|
| 1. Engine will not crank | (a) | Defective ignition switch. | Connect jumper wire between battery and starter connections. If solenoid "clicks", switch is defective, replace the switch. |
| | (b) | Loose or broken battery cable connections, discharged battery. If starter relay 'clicks', but engine does not crank, check also for defective starter or connections. | Replace as needed. |
| 2. Engine cranks but will not start. | (a) | Burned of fitted breaker point contact surface | Replace as needed. |
| | (b) | Corroded distributor-cap towers and eroded terminals. | Replace as necessary |
| | (c) | Moisture in ignition cap or high-tension cables. | Clean-up or replace. |
| | (d) | Excessive distributor condenser resistance, output capacity or insulation leakage. | Check with distributor or condenser tester. Make certain connections tight and condenser lead is not frayed. Replace if required. |
| | (e) | Defective coil. | Pull centre wire from distributor cap and hold end about 6 to 9 mm. from engine block. Turn on ignition and crank the engine, or open and close breaker points by hand. If there is no spark, or spark is weak, coil is faulty or there is trouble in some other part of the primary circuit. Repair or replace. |

Contd.

*Contd.*

| | | |
|---|---|---|
| | (f) Improper primary resistance. | Using voltmeter, test voltage drop across primary resistance wire or measure resistance with ohmmeter to make sure it meets manufacturer's specifications. Replace if necessary. Quick test to determine if primary resister is faulty, is to bypass unit momentarily with jumper wire. |
| 3. Hard starting under all conditions. | (a) Weak spark. | Check condition of breaker points and inspect all wiring in primary circuit for proper connections. |
| | (b) Open or grounded ignition coil circuits. | Connect test lamp across primary terminals of coil. If lamp does not light, primary circuit is open. Now connect test lamp between high tension and primary terminals on coil. if secondary circuit is open, no sparks will appear at test lamp probes when they are rubbed across terminals. Touch one probe of test lamp to coil case and the other to primary and high tension terminals. If lamp lights or if sparks appear at points of contact, coil winding are grounded. |
| | (c) Spark plugs are fouled or out of adjustment. | Clean and adjust. |
| | (d) Spark plug cables are cracked or frayed. | Replace. Measure resistance across high-tension cables with ohmmeter to see if it is within the limit specified. |
| | (e) Low battery charge or defective batteries. | Repair or replace. |
| | (f) Defective starter or solenoid | Repair or replace. |
| 4. Hard starting when cold. | (a) One or more components in ignition system not at maximum efficiency. | Make thorough analysis of system with suitable test equipment. |
| | (b) Low battery charge or defective battery. | Recharge or replace. |
| 5. Hard starting when hot. | (a) Spark intensity between Spark plug cable and ground. | If spark cannot bridge 0.6 to 0.9 mm gap regularly, check condition of points, condenser and coil. |
| | (b) Starter motor or starter motor circuit defective. | Repair or replace. |
| 6. Engine fails to keep running | (a) Spark plugs fouled or not gapped properly. | Repair or replace. Use ohmmeter to check whether resistance of high-tension plug wiring meets specifications. |
| | (b) Voltage drop across primary resistance wire does not meet recommendations. | Correct according to specification. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | (c) Dirty breaker points. | Clean, then check dwell angle with distributor tester or dwell meter. |
| 7. Engine runs but misses steadily at all speeds. | (a) One or more defective spark plug. | Repair or replace. |
| | (b) Damaged spark-plug cables. | Test for continuity. If cables are good, inspect distributor cap for cracks, burned contacts or corrosion in sockets. |
| 8. Engine runs but misses erratically at all speeds. | (a) Dirty breaker points | Clean and then check dwell angle with dwell meter. |
| | (b) Excessive distributor condenser resistance, out-put capacity and insulation leakage. | Make sure connections are tight and condenser lead is not damaged. |
| | (c) Inefficient coil. | Check with coil tester and replace as required. |
| | (d) Worn insulation, broken stands and loose or corroded terminals in primary wiring. | With voltmeter, check voltage drop across primary resistance wire against specifications. Clean or replace if needed. |
| 9. Engine runs, but misses at idle. | (a) Incorrect breaker-point setting. | Correct according to specification. |
| | (b) Uneven or worn bushing surface of distributor shaft and cam lobes. | Replace as needed. |
| | (c) Faulty coil or condenser. | Replace. Inspect condition of ignition wiring. |
| 10. Engine runs but misses at high speed. | (a) Fouling or improper gapping of spark plugs. | Clean, adjust or replace. |
| 11. Poor high-speed performance. | (a) Ignition timing set late. | Correct it. |
| | (b) Defective distributor breaker points. | Replace. |
| | (c) Spark plugs fouled, improper gap or not of correct heat range. | Clean, adjust or replace. |
| | (d) Malfunctioning coil or condenser | Replace as needed. |
| 12. Excessive fuel consumption. | (a) Distributor breaker points are dirty or improperly set. | Clean and reset or replace. |
| | (b) Ignition timing improperly set. | Reset to specification. |
| | (c) Fouled or improperly gapped spark plugs. | Rectify as required. |
| | (d) Faulty distributor advance operation. | Check as tester and correct. |
| 13. Poor acceleration. | (a) Ignition timing set late | Check with timing light and correct. |
| | (b) Plugs fouled or improperly gapped. | Clean, adjust or replace. |
| | (c) Dirty breaker points. | Inspect and clean. |
| 14. Knock | (a) Timing improperly set. | Adjust to specification. |
| | (b) Spark plug heat range is incorrect | Replace. |

**Table 21.4** Troubleshooting of a Spark Plug

| | *Trouble* | | *Cause* | *Remedy* |
|---|---|---|---|---|
| 1. | Badly worn or burnt electrodes | (a) | Incorrect gap | Reset gap correctly. |
| | | (b) | Incorrect distributor contact breaker points gap. | Reset gap. |
| | | (c) | Timing out | Re-time. |
| | | (d) | Plug has rendered its useful life. | Replace. |
| | | (e) | Hot running conditions in engine | Replace with cooler plug. |
| 2. | External insulator broken | (a) | Careless handling | Install new plug. |
| 3. | Internal insulation cracked broken at lower end. | (a) | Engine running hot | Install cooler plug. |
| | | (b) | Carelessness in adjusting gap | Adjust gap by bending the side electrode only. |
| 4. | Glassy or blistered internal insulator | (a) | Engine running hot | Install cooler plug. |
| | | (b) | Timing out | Re-time. |
| 5. | Dry black soot on internal insulator. | (a) | Engine running cold | Install hotter plug. |
| | | (b) | Distributor contact breaker points gap incorrect. | Reset gap. |
| 6. | Oil plug | (a) | Timing out | Re-time. |
| | | (b) | Distributor contact breaker points gap incorrect. | Reset gap. |

## Review Questions

1. What is the important function of an auto electrical system?
2. List the main components of an auto electrical system.
3. Explain the four main circuits of the automobile electrical system.
4. State the function of a starter.
5. State the purpose of the field binding assembly.
6. What causes the starting motor armature to rotate?
7. What is the job of the drive mechanism?
8. Why is the starter motor called a series-wound motor?
9. Why are specially large switches required to operate the starting motor?
10. State the purpose of the following:
    - Brushes
    - Field Coil
    - Commutator
11. State the working principle of a generator.
12. What type of current does a generator produce?
13. How does an alternator change its current to DC?
14. State the main job of the rotor in an alternator.

15. What is the main job of the stator in an alternator?
16. Explain how current is regulated inside the alternator.
17. State the purpose of the voltage regulator.
18. What is transistorized voltage regulator?
19. State the function of the cut-out in the charging system.
20. What do you mean by ignition timing? Explain it briefly.
21. Justify the need for ignition advance in petrol engine.
22. Describe how the centrifugal advance system operates.
23. What is vacuum advance mechanism? How does it control part throttle condition?
24. Describe the construction of a spark plug with the help of a suitable diagram.
25. State the types of spark plugs. What do you mean by hot and cold plugs?
26. What can cause a broken lower spark plug insulator?
27. What is the result of an engine operating with a small spark plug gap and a large gap?
28. What is meant by the heat range of spark plugs?
29. Explain why it is said that a storage battery does not store electricity.
30. What are the various causes of battery failure?
31. What is battery ratings?
32. Discuss various battery ratings.
33. When does the starting motor require service?
34. What are the operating results of a defective starting motor?
35. What faults in the high tension circuit cause complete failure of ignition?
36. What effect in the ignition system contributes to general deterioration of engine performance?
37. What routine maintenance should sparking plugs receive?

# 22

# Automobile Emission and Its Control

**Objectives**

After studying this chapter, you should be able to

- Describe the meaning of complete and incomplete combustion process.
- Describe the effect of major types of air pollution produced by the automobile.
- Explain how the air-fuel ratio and the mode of driving effects engine exhaust emission.
- Describe exhaust and non-exhaust emission.
- Describe the various types of emission control approaches used in the automobile.
- Identify the purpose of the charcoal canister.
- Describe the function of catalytic converter.
- Explain the various tests of emission reduction in two-stroke engines.
- Identify safe alternative automobile fuels to reduce engine emissions.

## 22.1 INTRODUCTION

Today air pollution has been identified as a major problem and is estimated to have high increasing rates in recent years. Man has been responsible for degrading the quality of his environment by his various inventions due to the increasing demands of human comfort. We know that with the development of transport, automobiles occupy a very important role in life.

The petrol engine has provided reliable small units for personalized transport and in this way revolutionized the living standard to a great extent. The diesel engine has provided the power unit for transportation systems. However, automobiles are the major sources of air pollution.

Air pollution can be defined as *addition to atmosphere of any substance which will have hazardous effects on life, environment and health* and the term *engine emissions* refers primarily to the pollutants in the engine exhaust such as unburned hydrocarbons (HC), carbon monooxide (CO), various oxides of nitrogen (NOx) etc. which have hazardous effects.

As man is more conscious about his health and environment, research is going on to reduce automobile exhaust pollution by improving the previous techniques and finding substitutes.

## 22.2 COMPLETE AND INCOMPLETE COMBUSTION

Air and gasoline are mixed in the engine carburettor to form a combustible mixture. This mixture is burnt in the engine to produce power. Gasoline is made up largely of compounds of hydrogen and carbon called hydrocarbons. In the combustion process, carbon and hydrogen in gasoline unite with oxygen in air.

If the combustion is complete and perfect then all the carbon and hydrogen in fuel converts into carbon dioxide and water respectively.

However unfortunately, in actual practice, the combustion process is not complete. Some carbon and oxygen end up as carbon monoxide (CO) as a result of burning gasoline with insufficient oxygen. At high temperature of combustion, some nitrogen unites with oxygen to form oxides of nitrogen.

Since not all the gasoline burns, some of it exits from the tail pipe as gasoline vapour.

$$2HC + 3O = H_2O + CO_2 \text{ (Complete Combustion)}$$

$$HC + O = H_2O + CO_2 + HC + CO \text{ (Incomplete Combustion)}$$

## 22.3 CONSTITUENTS OF EXHAUST

Exhaust emissions from a petrol powered engine consist mainly of carbon monoxide, unburned hydrocarbons, oxides of nitrogen and partial oxidation products of lead and aldehyde family. In addition particulate matter in the form of lead compounds and carbonaceous matter are also emitted.

On the other hand, exhaust emissions from diesel power vehicles have comparatively low carbon monoxide and unburned hydrocarbons while nitrogen oxide is present in high concentrations. Besides, these emissions contain smoke particles, oxidised hydrocarbons including aldehydes, and odour producing compounds. Emission from diesel vehicles are as important, if not more, as from petrol vehicles. Carbon monoxide is the most important pollutant from the petrol driven vehicles. However diesel exhaust contains much higher emission of oxides of nitrogen which are primarily responsible for photo-chemical smog. Engine exhaust emissions from a typical petrol driven (SI) and diesel driven compression ignition (CI) engine are shown in Table 22.1 and Table 22.2 give the toxicity of exhaust gases.

**Table 22.1** Typical Exhaust Constituents

| *Emission* | | *IDLE ppm* | *Intermediate Load* | | *High Load* | |
|---|---|---|---|---|---|---|
| | | | *ppm* | *g/k Wh* | *ppm* | *g/k Wh* |
| Hydrocarbon | SI | 4000 | 2400 | 7.5 | 6000 | 12 |
| | CI | 200 | 50 | 0.5 | 100 | 0.3 |
| Carbon Monoxide | SI | 10000 | 10000 | 73 | 60000 | 240 |
| | CI | 150 | 700 | 3.8 | 500 | 2.2 |
| Oxides of Nitrogen | SI | 100 | 2500 | 17 | 500 | 2.2 |
| | CI | 50 | 1700 | 14 | 1400 | 14 |
| Smoke (g/$m^3$) | CI | 0.05 | 0.6 | - | 1.2 | - |

**TABLE 22.2** Toxicity of Exhaust Gases

| *Substances* | *% of Noxious Substances in Total Toxicity of Engine* | |
|---|---|---|
| | *Carburettor Engines* | *Diesel Engines* |
| Carbon Monoxide | 95 | 8 |
| Nitric Oxides | 4.32 | 26 |
| Hydrocarbons | 0.6 | 0.9 |
| Aldehydes | 0.08 | 0.1 |
| Soot | - | 65 |

## 22.4 POLLUTANT FORMATION

The process by which pollutants form within the cylinder of the conventional spark-ignition engine is illustrated qualitatively in Figure 22.1.

The schematic shows the combustion chamber during four different phases of the engine operating cycles: compression, combustion, expansion and exhaust. Nitric oxide (NO) is formed throughout the process of combustion. The high temperature burned gases behind the flame chemically combine the nitrogen and oxygen molecules, which do not attain chemical equilibrium. The higher the burned gas temperature, the higher the rate of formation of NO. As the burned gases cool during the expansion stroke, the reactions involve no freeze and leave NO concentration far in excess of levels.

Corresponding to equilibrium at exhaust condition, carbon monoxide also forms during the combustion process. With rich fuel-air mixtures, there is insufficient oxygen to fully burn all the carbon in the fuel to form $CO_2$. Also in high temperature products, even with lean mixtures, dissociation ensures significant CO levels. Later in the expansion stroke, the CO oxidation process also freezes as the burned gas temperature falls.

The unburned hydrocarbon emissions have several different sources. During compression and combustion, the increasing cylinder pressure forces some of the gas in the cylinder into crevices, or into narrow volumes, connected to the combustion chamber, the volume between the piston, rings and cylinder walls being the largest. Most of these gases consist of the unburnt fuel-air mixture. Much of it escapes the primary combustion process because the entrances to these crevices is too narrow for the flame to enter. This gas which leaves these crevices later in the expansion and exhaust processes is one source of unburned hydrocarbon emission. Another possible source is the combustion chamber walls. A quench layer containing unburned and partially burnt fuel-air mixture is left at the walls when the fume is extinguished as it approaches the wall, while it has been shown that the unburned HC in these thin layers burns up rapidly when the combustion chamber walls are clean. It has also been shown that the porous deposits on the walls of the engine, in actual operation, do increase engine HC emission. A third source of unburned hydrocarbons is believed to be any engine oil, left in a thin film on he cylinder wall piston and perhaps on the cylinder head. These oil layers can absorb and release the hydrocarbon components with fuel before and after the combustion respectively, thus permitting the fraction of the fuel to escape the primary combustion process unburned. The final source of HC in engines is incomplete combustion due to bulk quenching of the flame during that part of the engine cycles where combustion is especially slow.

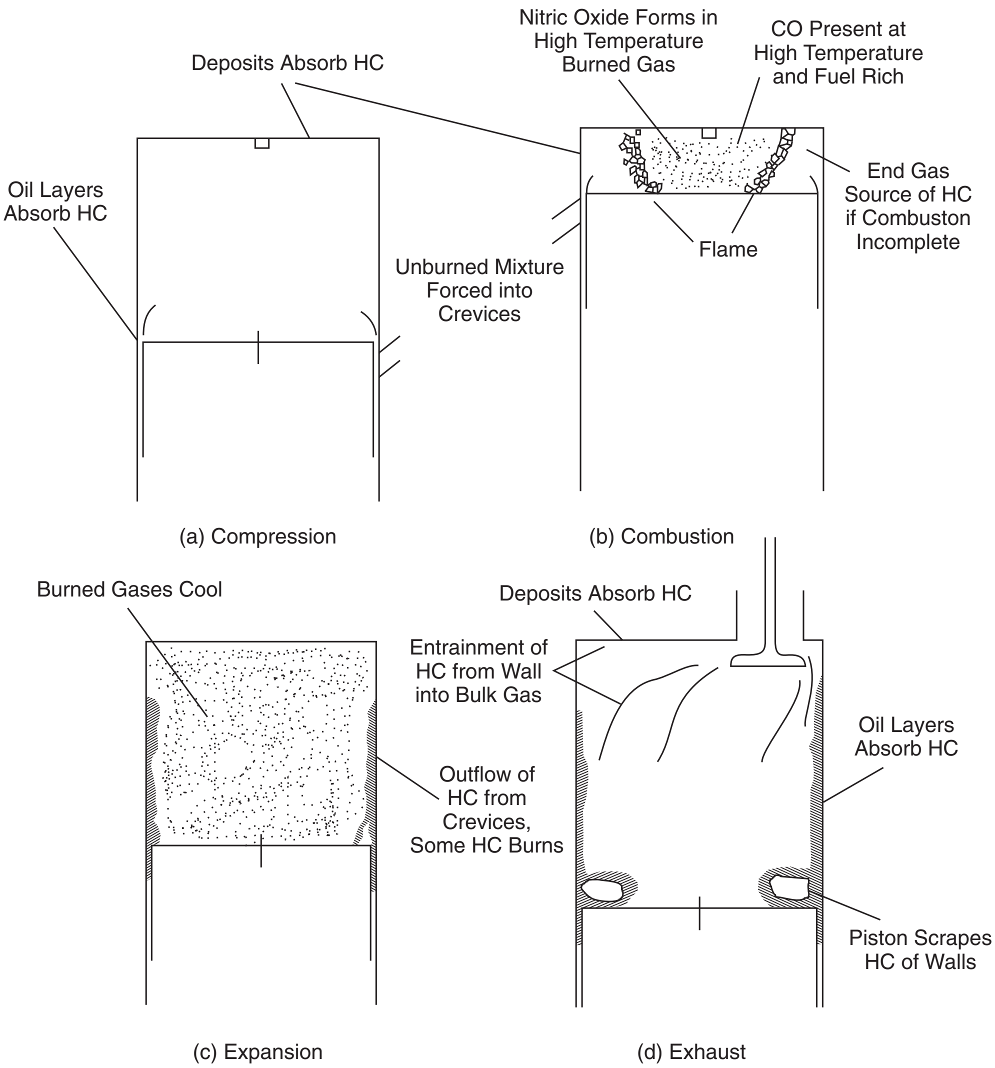



**Fig. 22.1** The Process of Pollutants form with the Cylinder of SI Engine

The diesel vehicles are compression ignition engines. When the piston descends, air is induced in the cylinder and when the piston ascends, the air, initially at atmospheric pressure, is compressed raising its temperature to 873 K. At this point, a high pressure injector injects the fuel which is heated up by the crank shaft revolutions and the fuel undergoes spontaneous ignition. The ratio of mass of air to mass of fuel is always high and so sufficient air is ensured to complete the combustion of fuel to form $CO_2$ and water. Obviously very little CO is formed.

***Carbon Monoxide (CO)*** Carbon monoxide occurs only in engine exhaust. It is a product of incomplete combustion due to insufficient amount of air in the air-fuel mixture or insufficient time in the cycle for completion of combustion. Theoretically, the gasoline engine exhaust can be made free from CO by operating it with an air-fuel mixture ratio greater than 16:1. However as is clear from Fig. 22.2 that some CO is always present in the exhaust even at lean mixtures. The percentage of CO increases at idle range and decreases with speed. The complete elimination of CO should be considered a reasonable goal. Carbon monoxide emissions are high when the engine is idling and reach a minimum value during deceleration. These are lowest during acceleration and at steady speed. Closing of the throttle valve, which reduce the oxygen supply to engine is the main cause of CO production. So deceleration from high speed will produce highest CO in exhaust gases.

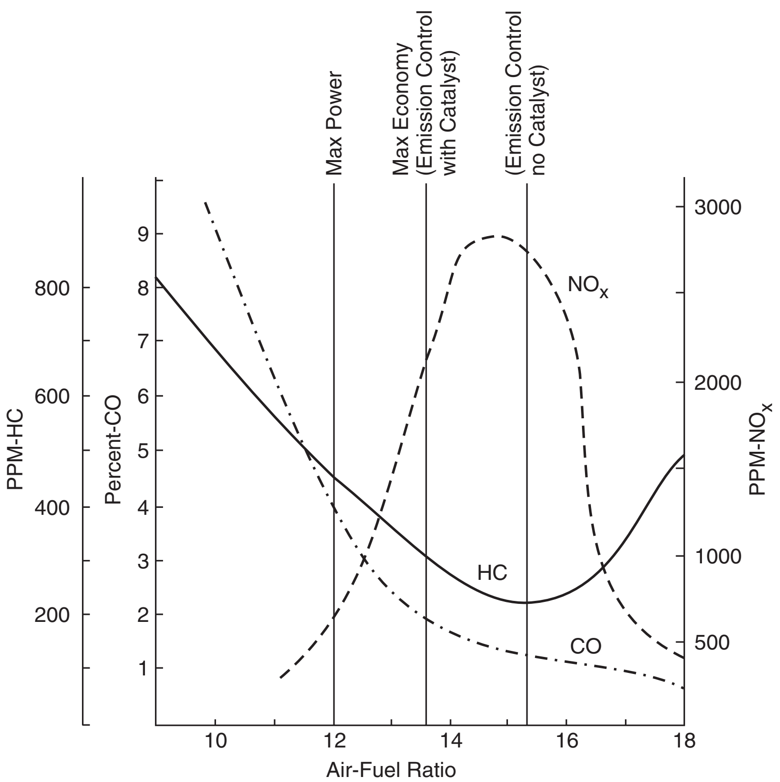



**Fig. 22.2** Exhaust Emissions Vs. Air-fuel Ratio for a Petrol Engine

**Nitrogen Oxides (NOx)** Oxides of nitrogen which are present in the engine exhaust are a combination of nitric acid (NO) and nitrogen oxide ($NO_2$). Nitrogen oxides are formed in the combustion chamber where the temperature is as high as 2500° C within the flame which is caused by an ignition at the spark plug. The high temperature makes oxygen and nitrogen combine. Formation of nitric acid is governed by two parameters, the availability of oxygen for reaction and high combustion temperature. When the proper amount of oxygen is available, at the higher peak combustion temperature, a greater amount NO is formed. NOx is formed in the atmosphere as NO oxidizes.

Availability of oxygen in the combustion zone increases with increasing air-fuel ratio. Maximum quantity of nitrogen oxide is formed for ratios between 14:1 to 16:1 (Fig. 22.2). At lean and rich air-fuel mixtures, the nitrogen oxide concentration is comparatively low. Increasing the ignition advance will result in lower peak temperature and higher exhaust temperature. This will result in a high nitrogen oxide concentration in the exhaust.

***Sulphur Dioxide ($SO_2$)*** $So_2$ is formed in spark-ignition and compression-ignition engines due to oxidation of sulphur during the combustion process. The quality of sulphur compounds present in petrol, depends on the source of crude oil and to some extent on the method used in the refining of oil. Diesel oil has a higher sulphur control which could be as high as twenty times that of petrol. The oxidation of sulphur produces sulphur dioxide.

***Hydrocarbons (HC)*** In spark-ignition engines the principle mechanism of the formation of hydrocarbons has been attributed to the destruction of flame propagation radicals due to quenching in the engine combustion chamber. The thickness of the quenched layer depends on the air-fuel ratio and pressure. High hydrocarbon emission can also result from either too lean or too rich local mixtures in the engine. The two major sources contributing to unburnt hydrocarbons in compression-ignition engines are—premixed fuel being leaner than the limit specified remains unburnt and the emptying of fuel from the nozzle sac and hole volume, resulting in local fuel rich conditions as the diesel fuel issues slowly from the nozzle.

The air-fuel ratio or engine load, injection timing, turbo charging, injection system design, rate of injection and air-swirl in the combustion chamber are some of the variables that influence the concentration of unburnt hydrocarbons in the exhaust from diesel engines. With turbo charging, higher exhaust temperatures are obtained. Mixing of burnt gases is improved and the reaction time is increased, resulting in lower hydrocarbon emission. Advanced injection timing results in higher hydrocarbon emission due to longer ignition delay, which allows more fuel vapours and small droplets to be carried away from the combustion zone.

***Lead*** Lead contamination arises from the combustion of petrol, to which alkyl lead compounds, in the form of tetra-ethyl lead and tetra-methyl lead are added during refining as anti-knock agents. In order to prevent the fuel from spontaneously exploding before its ignition by sparkplug, the Indian Standard Institute has specified the maximum permissible addition of 0.56 to 0.80 gm/litre of lead to obtain petrol of 83 and 93 octane respectively. After combustion, much of the lead(70%) is transmitted via the exhaust to the atmosphere, as particulates of lead halide. Minor amounts of lead are also evolved during the evaporative losses of petrol. Exhaust lead emission occurs in a variety of forms such as chlorides, bromides, chloro bromides, sulphates, oxides and as complexes with ammonia and phosphorus. The size of these particles varies between 0.001 to 10 microns. About two-thirds of these particles become air-borne after emission from the tail pipe. The fraction of lead escaping from petrol driven vehicles increases as vehicle mileage increases.

Lead compounds in the atmosphere near traffic zones remain air-borne for long periods of time. The transport of lead from automobile sources through the environment follows a network of paths by which the atmosphere, the lithosphere, the hydrosphere and the biosphere are connected in a complex pattern.

***Soot*** Soot emissions in the exhaust of automobiles result from the decomposition of hydrocarbons in fuel, nucleation of carbon particles in the flame, growth of soot nuclei, agglomeration of particles and finally soot oxidation. Most of the particles form and grow in the exhaust system due to condensation of vapours enhanced by coagulation. Some of the particles are emitted directly without setting. Some of them either from or deposit on the walls where agglomeration may occur. Many of these are removed when the exhaust flow rate is suddenly increased and these particles together with the rust and scale account for the increase in mass size of particles emitted during acceleration.

***Others*** Besides these principle emissions, aldehydes primarily in the form of formaldehyde (70%) and (30%) accetaladehyde, acrolene and benzaldehyde are emitted due to various factors such as partial oxidation of fuel with pre-flame reaction zone, specially when the temperature rises due to combustion being inadequate.

## 22.5 EFFECT OF AIR-FUEL RATIO ON EXHAUST EMISSIONS

At a given compression ratio, the maximum temperature is reached when the mixture is slightly rich. For formation of NOx, temperature plays an important role. Maximum NOx is emitted at the stoichiometric fuel-air ratio. The amount of CO is reduced as the mixture becomes leaner due to higher availability of oxygen and thus providing chance of complete combustion, on the same grounds. A higher percentage of hydrocarbons gets decomposed into water and $CO_2$ thus reducing pollution.

## 22.6 EFFECT OF DRIVING MODE ON EXHAUST EMISSION

The composition and quantities of emission products from automobiles depend on the mode of driving. When the engine is started from cold, due to fuel vaporization being slow, fuel flow is increased in the choke to provide an easy combustible fuel rich mixture near the spark plug. Thus until the engine warms up and the choke is released, CO and hydrocarbon concentrations in the exhaust are high, because the mixture is made fuel rich for smooth running. However, nitric oxide concentration is low because of low temperature and oxygen scarcity. When the vehicle cruises at high speed, hydrocarbon and CO emissions are very low because the mixture is set at being slightly lean for best economy. However, nitric oxide increases due to high temperature and greater oxygen availability. Deceleration results in a very high concentration of hydrocarbons and carbon monoxide in the exhaust (Table 22.3 and 22.4).

**Table 22.3** Effect of Vehicle Operating Mode (VOM) on Exhaust Emission

| *Vehicle Operating Mode* | *Air Flow* | *Exhaust emission* | | | *Blow by* | *Evaporation loss* | |
|---|---|---|---|---|---|---|---|
| | | *HC* | *CO* | *NO* | | *Tank* | *Carb* |
| Idle | Very low | High | High | Very low | Low | Mod. | Cruise |
| Low speed | Low | Very | Very | Low | Mod. | Average method | Small |
| High speed | High | Low | Low | Low | High | Do | Nil |
| Acceleration | | | | | | | |
| Moderate | High | Low | Low | High | Mod | Do | Nil |
| Heavy very | High | Mod | High | Mod | Very high | Do | Mod |
| Deceleration | Very low | Very high | High | Very | Very low | Do | Mod |

**Table 22.4** Typical Emission from Various Types of Engines

| *Type* | *CO ( %)* | *HC (ppm)* | *NO (ppm)* | *Formaldehyde (ppm)* |
|---|---|---|---|---|
| Two stroke S.I. | 3.0 | 6500 | 150 | ----- |
| Four stroke S.I. | 3.4 | 850 | 1000 | ----- |
| Full rated speed | 0.20 | 29 | 921 | 4.3 |
| Half load rated speed | 0.30 | 70 | 493 | 6.8 |
| No load rated speed | 0.30 | 90 | 109 | 1.8 |
| Idle | 0.03 | 106 | 119 | 6.8 |

## 22.7 SOURCES OF POLLUTANTS IN AN AUTOMOBILE

The main sources of pollutants from gasoline engine are fuel tank, carburettor, crankcase and tail pipe. The sources, of atmospheric pollutants from an automobile are shown in Fig. 22.3.

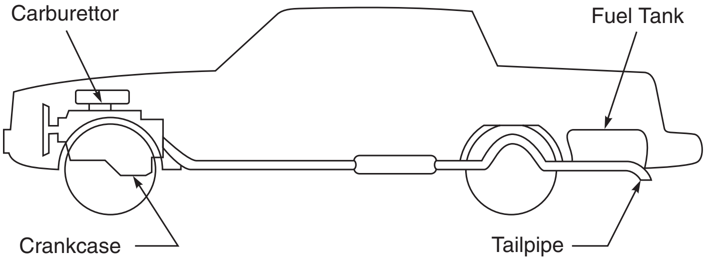



**Fig. 22.3** Sources of Pollutants in an Automobile

The emissions from an automobile can be classified into two categories:

1. Exhaust emissions
2. Non-exhaust emissions

Exhaust emissions directly pertain to combustion phenomenon and consist mainly of products of combustion, e.g. CO, $SO_2$, oxides of nitrogen etc. besides unburnt hydrocarbons, whereas non-exhaust emission has no relation to combustion and it consists mainly of unburnt hydrocarbons. Emission taking place from the crankcase and carburettor fuel tank is of non-exhaust type and from the tail pipe is of exhaust type.

### 1. Fuel Tank and Carburettor Emissions

When the automobile is idle and the engine is not running, gasoline vapour can escape uncontrolled from the fuel tank and carburettor. These are evaporative losses. At other times when the engine is running, gasoline is being pumped from the fuel tank and carburettor so that gasoline vapour does not escape.

The fuel tank breathes as temperature changes. As the tank heats up, the air inside it expands. Part of the air is forced out through the tank vent tube in the tank cap. The air is loaded with gasoline vapour. When the tank cools, the air inside contracts and more air from outside enters the tank. The breathing of the tank causes loss of gasoline. The evaporation from the tank is affected by a large number of variables of which the fuel tank temperature, the mode of vehicle operation, the amount of fuel in the tank and the volatility of fuel being important.

### 2. Crankcase Emission

Water and liquid gasoline appear in the crankcase during cold engine operation. Some blow-by always gets past the piston rings and enters the crankcase. Unless the water and liquid gasoline are removed, sludge and acid will form. Sludge can clog oil lines and starve the lubricating system which could ruin the engine. The renewal process requires that the engine must first heat up enough to vapourize the liquid water and gasoline. Then the circulating air can remove them.

In older engines, the crankcase was ventilated by an opening at the front of the engine and the vent tube at the back. The forward motion of the car and the rotation of crankcase moves air through the crankcase. The passing air removes water, fuel vapours and blow-by. However discharging these gases into the atmosphere produces air pollution.

### 3. Tail Pipe Emission

Tail pipe exhaust emissions are the major sources of automotive emissions. Petrol consists of a mixture of various hydrocarbons. In perfect combustion, the exhaust would consist of $CO_2$ and water vapour. However for several reasons, combustion is usually incomplete and hence we also get CO and unburnt hydrocarbons in the exhaust. Hydrocarbons play an active part in the formation of smog. In addition to CO and HC, the third main pollutants are the oxides of nitrogen (NO). There are large number of organic compounds, e.g. ketones, aldehydes, etc. which are chemically active and form smog in the presence of sunlight.

## 22.8 CONTROL APPROACHES FOR AUTOMOBILE EMISSION

The modification and eradication of automotive emission is one of the greatest problems in the world today. Air pollution caused by automobile emissions has harmful effects on human health. So scientists and researchers are looking for various control approaches to reduce automobile emissions. The basic emission control approaches are discussed in this section.

### 1. POSITIVE CRANKCASE VENTILATION

When the engine is running, air must circulate through the crankcase. The circulating air removes the water and liquid gasoline that appear in the crankcase when the engine is cold. Also, the air removes blow-by gases from the crankcase. Unless the water, the liquid gasoline and blow-by gases are removed from the crankcase, sludge and acid will be formed. Sludge can clog oil lines and starve the lubricating system which could ruin the engine. Acids corrode metal parts and this can cause failure of engine parts. Figure 22.4 shows the positive crankcase ventilating system. The leakage into the engine crankcase is called blow-by. Blow-by must be removed from the engine before it condenses in the crankcase and reacts with the oil, which forms sludge. Sludge if allowed to mix with engine oil, will corrode and accelerate the wear of piston rings, valves, bearings and other internal working parts of the engine. As the air-fuel mixture in an engine never completely burns, blow-by carries some unburnt fuel into the crankcase. If unremoved, the unburnt fuel dilutes the crankcase oil. When oil is diluted with gasoline, it does not lubricate the engine properly causing excessive wear.

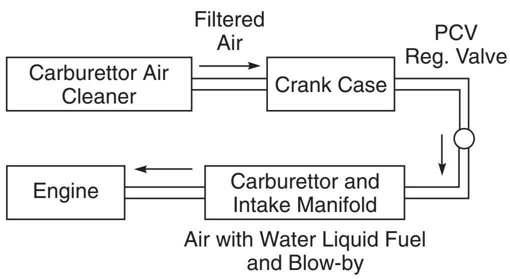



**Fig. 22.4** Positive Crankcase Ventilating System

The removal process requires the heating up of the engine to vapourise the liquid water and gasoline. Then the circulating air can remove them along with the blow-by gases. In older engines, the crank case was ventilated by an opening at the front of the engine and a vent tube at the back. The forward motion of the car and the rotation of the crankshaft, moved air through the crankcase. The air passing through, removes the water, fuel, vapours and blow-by. However discharging these gases into the atmosphere produces air-pollution. To prevent this pollution, modern engines have a closed or positive crankcase ventilating (PCV) system. Figure 22.5 shows a typical closed PCV system on a V-type engine. Filtered air from the carburettor air cleaner is drawn through the crankcase. In the crankcase, it picks up water, fuel vapours and blow-by gases. The air then flows back up to the intake manifold and enters the engine. There the unburnt fuel is burnt.

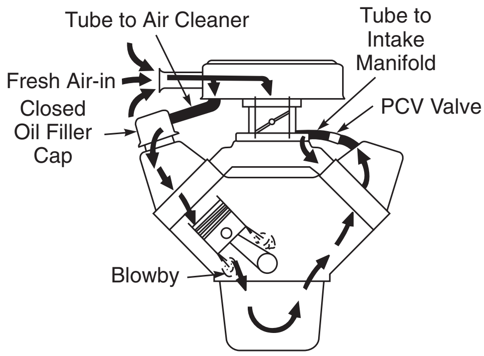



**Fig. 22.5** A Closed Ventilation System

Because the vacuum supply for the PCV system is from the engine's intake, the flow through this system must be controlled in such a way that it varies in proportion to the regular air-fuel ratio being drawn into the intake manifold through the carburettor. Otherwise, the additional air that is drawn into the system would cause the air-fuel mixture to become too lean for efficient engine operation. To prevent this, a regulator or flow control valve is used. The valve is called a positive crankcase ventilation valve (PCV). The PCV valve allows only a small amount of air to flow through during engine idling. However, as the engine speed increases, the reduced intake manifold vacuum allows the valve to open wider. This in turn, allows more air to flow through (Fig. 22.6).

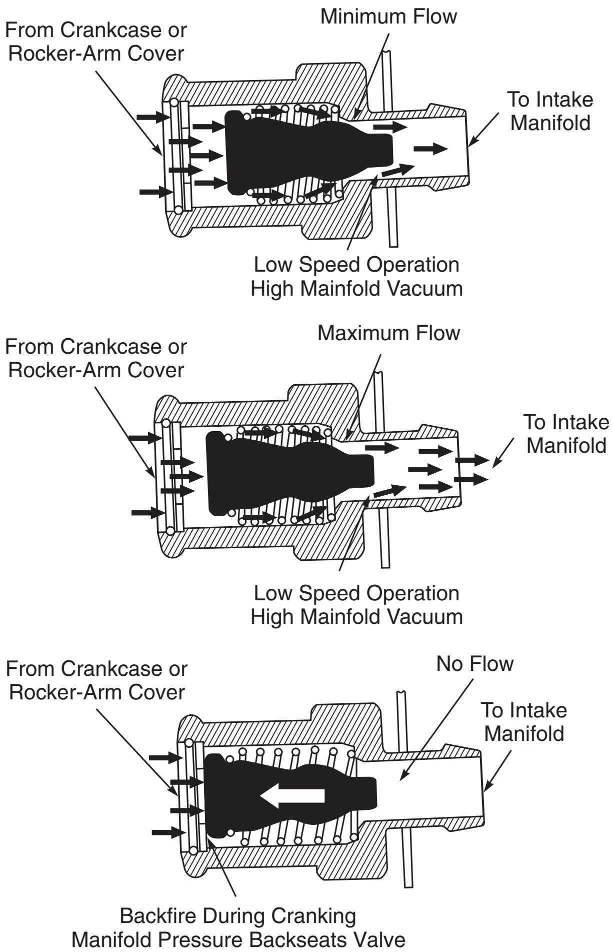



**Fig. 22.6** Air Flow Through PCV Valve

## 2. Fuel Vapour Emission Control

Both the fuel tank and Carburettor can loose gasoline vapour to the atmosphere causing pollution if the car does not have the fuel vapour emission control system. The fuel tank breathes as the temperature changes. As the tank heats up, the air inside it expands and part of the air is forced out through the tank vent tube or through the vent in the tank cap. This air is loaded with gasoline vapour. When the tank cools, the air inside it contracts and more air enters from outside. This breathing of the tank causes loss of gasoline.

The carburettor also can loose fuel vapour due to evaporation. The carburettor float bowl is full whenever the engine is running. When the engine stops, engine heat evaporates some or all of the gasoline stored in the float bowl.

Without a vapour recovery system, this gasoline vapour would pass into the atmosphere. A fuel emission control system captures this gasoline vapour and prevents them from escaping into the air, thereby reducing atmospheric pollution.

The fuel-vapour emission control system is shown in Fig. 22.7. The canister is filled with activated charcoal. Just after the engine is shut off, heat continues to enter the carburettor. The gasoline vapourises in the carburettor float bowl. The vapour passes through the control line and into the canister where it is absorbed by the charcoal. "Absorbed" actually means that the gasoline vapour is trapped by sticking to the surface of the charcoal particles.

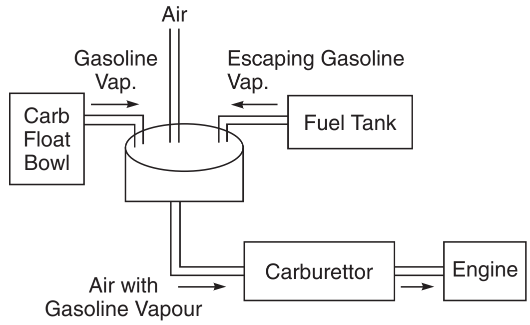



**Fig. 22.7** Fuel-Vapour Emission Control System

Some carburettor float bowls have a special vent connected by a tube to the charcoal canister. The vent and the tube carry the float bowl vapour directly. At the same time, vapour laden air from the fuel tank is carried by a special emission control pipe to the canister. As the air passes down through the canister, the gasoline vapour is trapped by the charcoal particles. The air exits from an opening in the canister, leaving the hydrocarbon (HC) vapour behind.

There is a filter at the bottom of some canisters. It comes into action during the purge phase of operation.

This occurs when the engine is started. The intake manifold vacuum draws fresh air up through the canister. This fresh air removes or purges the gasoline vapour from the canister. It takes the HC through a purge line to a connection at the carburettor.

***Fuel-Vapour Return Line*** A fuel return line runs parallels to the main fuel line. This return line connects the pressure line of the fuel tank. Any excess gasoline being pumped by the fuel pump is returned to the fuel tank. This action removes any vapour that might develop in the fuel pump. It also maintains a flow of fuel through the fuel pump. Thus it keeps the fuel pump relatively free and helps prevent vapour lock. In some systems, there is a check valve in the fuel vapour return line. Its purpose is to prevent the fuel from feeding back to the carburettor from the fuel tank through the return line.

***Charcoal Canister*** On some V-6 General Motors engine, the downward pointing arrows to the left show the flow of fuel in Fig. 22.8 for a charcoal canister. This canister is used for the vapour from the carburettor float bowl and from the fuel tank during the time the engine is not running. When the engine is running, the action is as shown on the right side. Air is pulled up through the charcoal as shown by the upward pointing arrows. This purges the gasoline vapour from the charcoal.

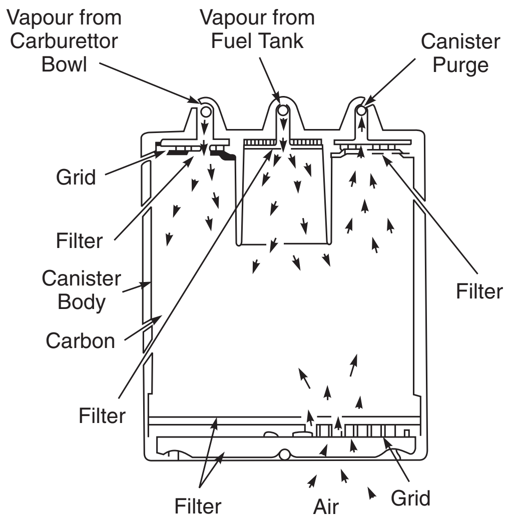



**Fig. 22.8** Charcoal Canister

### 3. Exhaust Gas Recirculation (EGR)

The exhaust gas recirculation (EGR) system allows a small amount of exhaust gas (less than 100% of the total) to be routed into the incoming air-fuel mixture (Fig. 22.9). Diluting the air-fuel mixture with this steady burned gas lowers the combustion temperatures about to 300 F because there is very little free oxygen left in the exhaust to support combustion. The purpose of EGR is to reduce NOx emission at specified times. EGR is also used to improve fuel economy. This is the reason why some of these systems are so expensive. Metering the valve provide a means of varying the engine's compression ratio. Under light load conditions, the compression ratio can be lowered so the engine can operate without having to compress the mixtures to needlessly high levels.

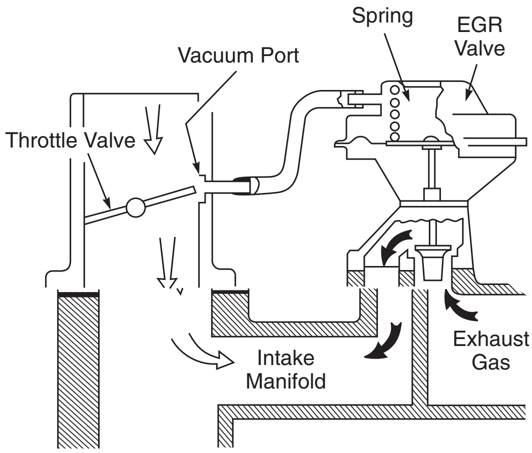



**Fig. 22.9** EGR valve Controlling the Amount of Exhaust Flowing Back into the Intake

A simple EGR system has an EGR valve. This valve is located near the back of the carburettor on the intake manifold. The exhaust is picked up on the crossover passageways in the intake manifold. On in-line engines, an external line must be connected from the exhaust side to the intake side. The EGR valve is controlled by engine vacuum. As shown in Fig. 22.9, exhaust gases are present at the base of the EGR valve. The pintle valve opens or closes to regulate the exhaust gases flowing into the intake manifold.

The EGR valve also has a diaphragm, which is controlled by spring pressure against a vacuum from the carburettor. When the throttle valve is at a specific position, it uncovers the carburettor vacuum port. The action pulls the diaphragm upward against pressure. The EGR valve is now opened, allowing exhaust gases to enter the intake manifold.

When the engine is at idle, the throttle valve has not yet uncovered the port. During this condition, no vacuum is available to operate the EGR valve. The EGR valve remains closed during idle or heavy deceleration.

A temperature-sensitive control is sometimes placed between the EGR valve and the carburettor. Exhaust gas recirculation is not needed below certain temperatures. If it is allowed to occur, it will cause poor engine performance. Figure 22.10 shows the location of the temperature control. The EGR temperature control senses the temperature of the engine coolant. When the engine temperature reaches a certain point, the EGR temperature control opens and allows the vacuum to operate the EGR valve.

Some EGR valves also have a back-pressure transducer that senses the pressure in the exhaust manifold to change the amount of opening.

### 4. Air Injection System

After the exhaust gases leave the engine cylinders, they can be treated to reduce HC, CO and NOx in the gas. One method is to blow fresh air into the exhaust manifold. This system is called a thermactor or air-injection system. It provides the additional oxygen needed to burn the HC and CO (Fig 22.11).

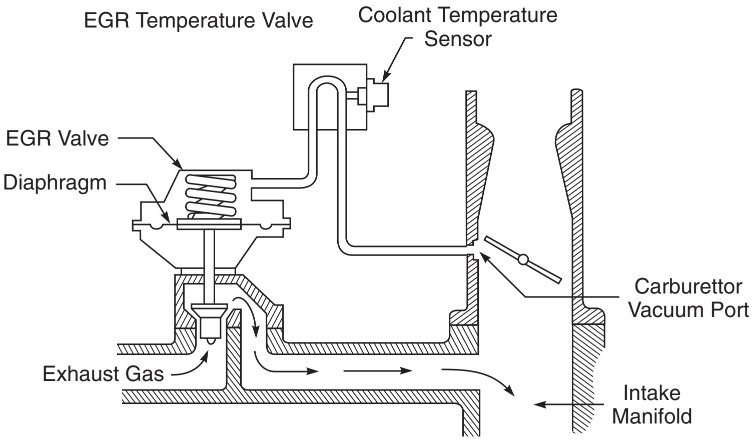



**Fig. 22.10** EGR Valve Controlled by a Temperature Valve

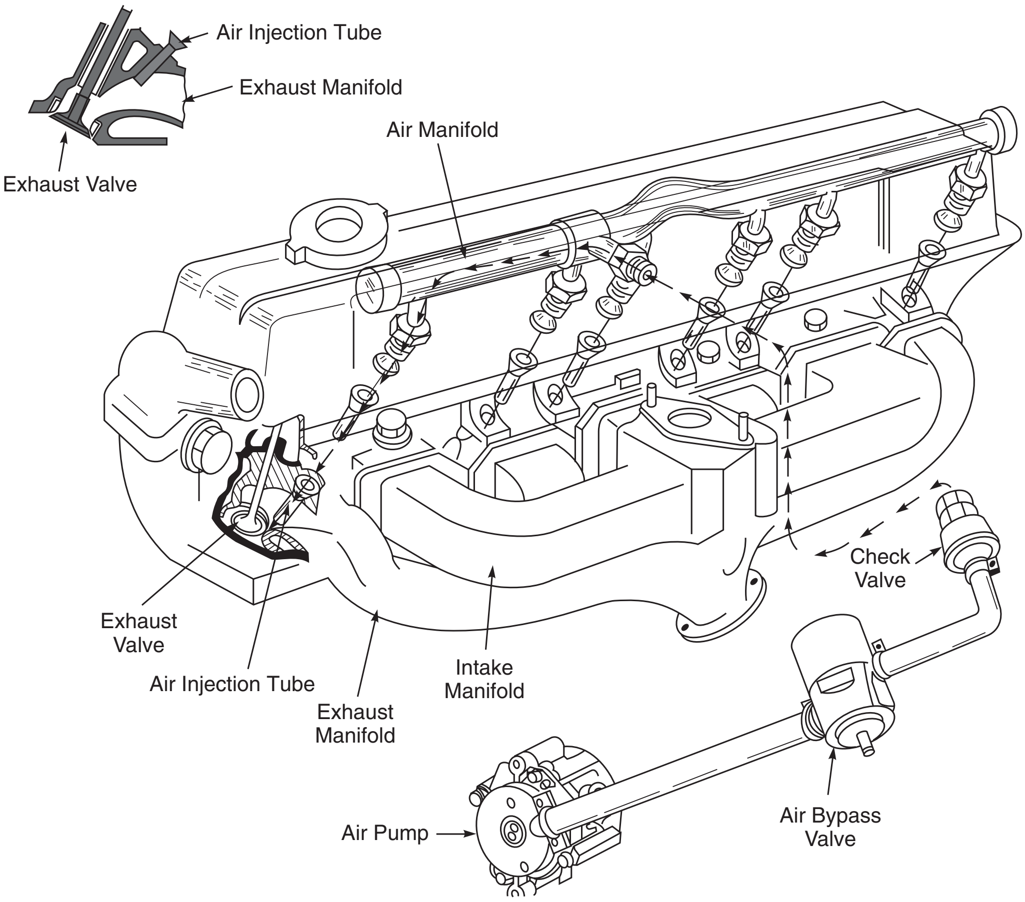



**Fig. 22.11** An Exploded View of Air Injection System

The air pump pushes air through the air lines and air manifold into a series of air-injection tubes. These tubes are located opposite the exhaust valves. The oxygen in the air, helps to burn any HC or CO in the exhaust gas. The check valve prevents any back flow of exhaust gas to the air pump, in case of a back fire. The air bypass valve operates during engine deceleration when the intake manifold vacuum is high. The bypass valve momentarily diverts air from the air pump to the air cleaner, instead of to the exhaust manifold which tends to prevent back firing in the exhaust manifold.

The thermactor system has two operating modes. When the engine is cold, the fuel system feeds a rich mixture to the engine, due to the choke action. The exhaust gas is therefore rich in unburnt and partly burnt fuel (HC and CO). With this condition, the air pump sends air into the exhaust manifold to help complete combustion of these pollutants. The additional oxygen in the air helps in the conversion of HC into $H_2O$ and $CO_2$ and CO to $CO_2$. In doing this, the air guards the catalytic converter from overload. When the engine warms up, the vacuum switch, which senses the engine coolant temperature, shuts off the vacuum to the air control valve.

As a result, the thermactor system sends the air it is pumping to the catalytic converter. Hence it aids the converter in changing the pollutants to harmless gases.

***Aspirator Air System*** The aspirator air system is used in some General Motors and Chrysler-built cars. It uses a valve connected in a line between the air cleaner and the exhaust manifold. The valve is a simple pressure vacuum valve. It uses the exhaust manifold where it mixes with the exhaust gases. The oxygen in the air helps convert the HC and CO into harmless gases. When the exhaust pressure is lower than the pressure in the air cleaner, the valve opens and fresh air flows into the exhaust manifold. When the exhaust pressure goes up, the valve closes which prevents any back flow of exhaust gas into the air cleaner.

***Thermal Reactor*** A thermal reactor is a chamber in the exhaust system, designed to provide sufficient resistance time, to allow appreciable homogeneous oxidation of CO to HC to occur. In order to improve CO conversion efficiency, the exhaust temperature is increased by spark retard. This however results in loss of fuel economy.

The schematic layout of this system is given in Fig. 22.12. It consists of two enlarged exhaust manifolds which allow greater resistance time for burning of HC and CO with oxygen in the pumped-in air. A cylindrical reactor with a tangential entry from the exhaust manifold is attached to the engine. A secondary air pump injects fresh air into the reactor to keep a flame constantly burning and thereby assuring complete combustion. This reduces HC and CO. About 10% to 15% of exhaust gas is recirculated to the air cleaner via the inter-cooler. This reduces the temperature of the combustion gases and provides for the control of $NO_x$. This packing system also includes enriched and stage carburettor temperature controls, crankcase valve to control blow-by gases and special evaporation control valves. The reactor core is made of stainless steel with a high nickel content. Now there is only one chamber, combined for all cylinders. Gas flow in the reactor is directed to give adequate mixing of exhaust gases and fresh air without creating any significant rise in back pressure. Enriched carburettor mixture and retarded spark timing are used to reduce peak combustion temperature in the cylinder. This is necessary to minimise $NO_x$

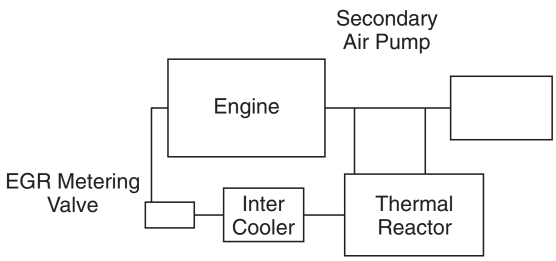



**Fig. 22.12** Thermal Reactor

concentration. However, this also lowers the oxygen concentration in the combustion chamber, resulting in an increase in the volume of unburnt HC.

The unburnt hydrocarbons are burnt in the reactor. At the same time exhaust gas recirculation is also used to control $NO_x$. The rich mixture supplied by the carburettors, preserves the drivability of the engine which is reduced by EGR. This is however affected by a loss of fuel economy. A metering valve is used to minimise the fuel waste which is fitted on the exhaust manifold and responds to the intake manifold vacuum. This keeps the exhaust gas recirculation as low as possible without exceeding the $NO_x$ limit. Maximum recirculation rate occurs when the throttle is wide open.

This attempt to decrease the $NO_x$ emission due to increased fuel supply, results in increased CO and HC emissions which must be collected and effectively burnt in the reactor. Also the restarted spark timing causes an increase in exhaust gas temperature during warm up, idle, low speed operation and deceleration. So the reactor must be designed to take adequate time to complete the burning of this increased hydrocarbon and carbon monoxide, i.e. it should be sufficiently large. The reactor core must be insulated from its cast iron casing to prevent heat loss so that a temperature of about 870 to 990° C can be maintained for proper reaction.

## 5. Catalytic Converter

The principle of the catalytic converter package is to control the emission levels of various pollutants by changing the chemical characteristics of the exhaust gases. In contrast to the thermal reactors, efficient catalytic oxidation catalysts can control HC and CO emissions almost completely at temperatures equivalent to normal exhaust gas temperatures.

Thus the loss in fuel economy necessary to increase the exhaust temperature is avoided. Catalyst materials, e.g. platinum or platinum and palladium, are applied to a ceramic support which has been treated with an aluminium oxide wash coat. This results in an extremely porous structure providing a large surface area to stimulate the combination of oxygen with HC and CO. The oxidation process converts most of these components to water vapour and carbon dioxide. The schematic diagram of a catalytic converter package is shown in Fig. 22.13. Converters for hydrocarbons, CO and $NO_x$

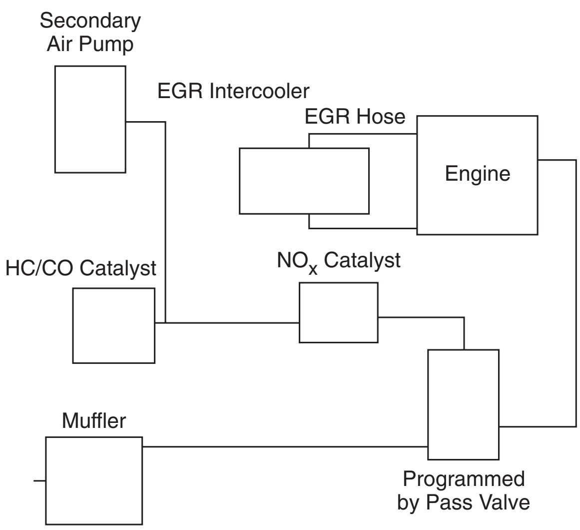



**Fig. 22.13** Catalytic Converter Package

are arranged as shown in the diagram. The catalysts used for these converters are closely guarded secrets. The catalyst for $NO_x$ is the first element in the gas flow path and does not cause any heat release. The HC/CO catalyst is the next. Its heat release is so great that there is a risk of over heating and burning of the element. This requires air injection and hence a secondary air pump. Experiments with various types of converters have led to the conclusion that the axial flow form is superior to the radial flow type.

The converter should be able to provide the largest possible surface for gas flow and provide a sufficient reaction rate without unduly increasing the back pressure which affects the drivability of the engine. In order to increase the converter life to about 80000 km, a bypass valve, ahead of the converter is used. This is operated by an electric motor controlled by sensors for speed, throttle opening, engine coolant temperature and HC/CO catalytic converter temperature. This cuts off the converters at the present value and release the untreated exhaust into the atmosphere but only under less critical conditions.

Figure 22.14 shows a three-way monolith catalytic converter. The front bed or inlet, is treated with platinum and rhodium and is termed a reducing catalyst. The rear bed is coated with palladium and is referred to as the oxidizing catalyst.

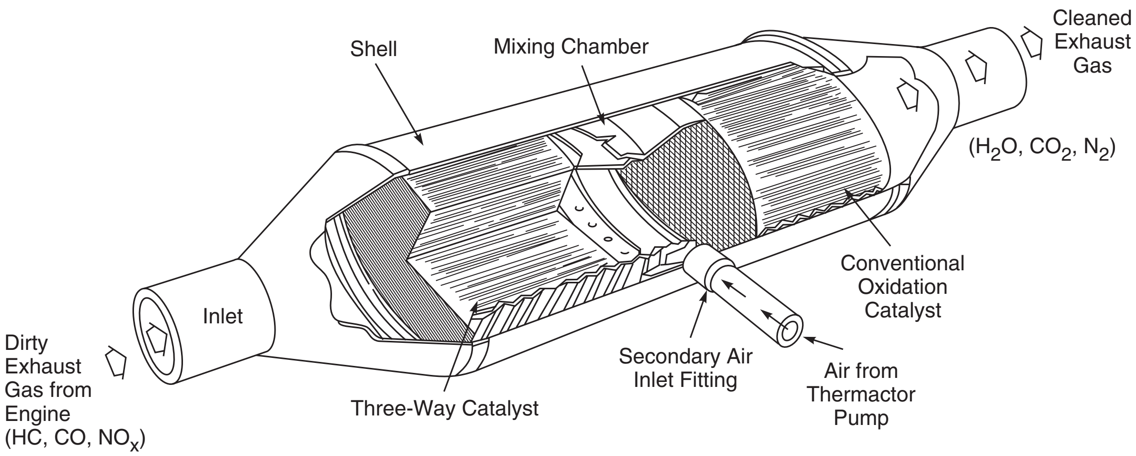



**Fig. 22.14** A Three-way Monolith Catalytic Converter

In Fig. 22.14, exhaust gases first pass through the reducing catalyst. This causes the levels of NOx to be reduced. Pressurised air from the air injection system is forced into the space between the catalyst beds. The extra air supplies additional oxygen and causes greater oxidation of the gases.

As the treated exhaust gases from the first bed continue flowing, they eventually pass through the conventional oxidation catalyst made of palladium and platinum. Here hydrocarbons and carbon monoxide emissions are reduced.

## 22.9 MUFFLER

Muffler is a device to absorb and damp out the high-pressure surges introduced into the exhaust system when exhaust valves/ports open. Figure 22.15 shows a dual exhaust system of large V-type engine having two pipes, two mufflers and two catalytic convertors and two resonators.

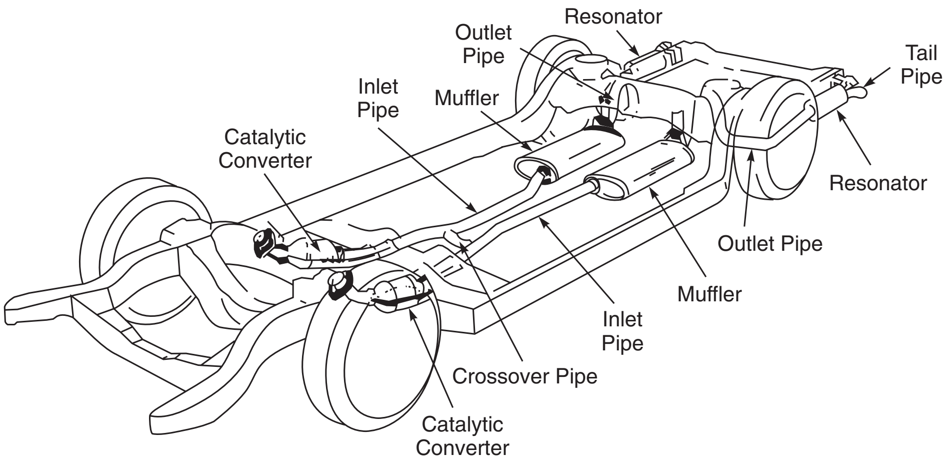



**Fig 22.15** A Dual Exhaust System of a Large V-Type Engine

Muffler are generally produced from aluminized steel. It contains a series of holes, passages and resonance chambers to absorb the resulting noise from all of the cylinders blending together results in a loud roar.

## Type of Mufflers

There are two muffler designs used by most of the automotive manufacturers

(i) Straight Through Muffler

In this design, a straight pipe is enclosed in a fiberglass and a shell. The straight pipe, which is also called a glass pack, reduces exhaust back pressure and noise. This type of muffler is shown in Fig 22.16.

(ii) Reverse Flow Muffler

It has short pipes and baffles that make the exhaust-gas move back and forward as it travels through. In this design, it uses a combination of perforations, chambers and passages enclosed in a housing to reduce noise (see Fig 22.17).

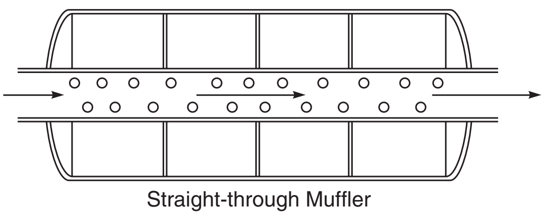



**Fig 22.16** Straight Through Muffler

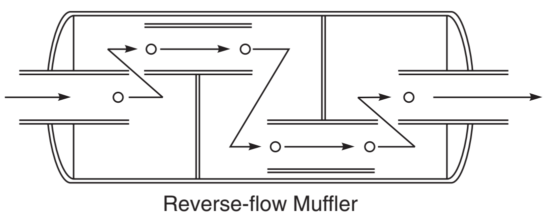



**Fig 22.17** Reverse Flow Muffler

## Resonator

A resonator is a second muffler in line with the other muffler. It further reduces the noise level.

## 22.10 VARIOUS TESTS

Environment pollution is mostly caused by industries and automobiles. Hence, it has become mandatory that emission control be installed in all automobiles. The automobile has been analysed very carefully to determine the types of pollution that it produces. Usually the fuel tank, exharest gases, crank case, and carburettor produce the majority of pollution in the automobiles. Automobile emissions can be controlled with various devices. For this a number of tests have to be carried out. In this section, we are going to learn about the various tests.

### Delayed Charging (DC)

To reduce fuel losses during the gas exchange process in a two-stroke engine, a simple delayed charging device is developed. First burnt gases are scavenged by air only and then fresh charge is fed into the cylinder.

We will discuss recent work done on 50 cc engines through geometry changes of the delayed charging circuit to reduce torque losses and further improve fuel consumption and reduce HC emission.

(i) Fuel trapping efficiency up to 87%
(ii) Mean specific fuel consumption lower than 400 gm/kWh
(iii) HC emission down to 45 g/kWh
(iv) Delivery ratio reduction due to the device presence, less than 6%
(v) Maximum torque loss of 8% for the best delayed charging circuit geometry.

#### *The L.M.P. Delayed Charging Device*

***Working Principle*** In the Delayed Charging (DC) engine there is a scavenging air circuit and a delayed charging mixture circuit. The crank-case pump sucks in air and rejects it (Fig. 22.18) to a surge tank through a non-return reed valve to the transfer ducts in order to scavenge the in-cylinder burnt gases with pure air, in a classical way. The large surge tank feeds a long thin air duct, equipped with a pressurised carburettor.

This duct issues into the cylinder through a high transfer port so that the total opening angle of the charging port is greater than or equal to the total opening angle of the exhaust port. During the cycle, at the moment this port opens, a large back flow of burnt gases deeply invades the fresh charge duct. When the pressure difference between the volumes of cylinder to surge tank converses, all burnt gases contained in the duct have first to flow out before the fresh charge reaches the cylinder. This is the first delay in fresh charge delivery.

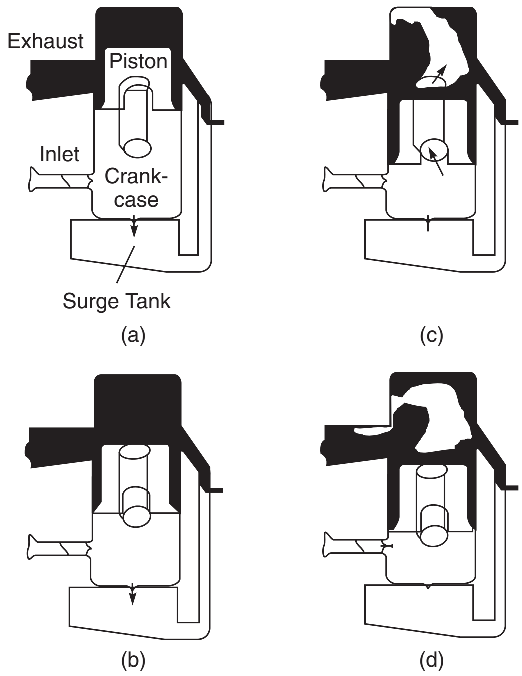



**Fig 22.18** Delayed-charging Device Principle

In the classical two-stroke engine, the fresh charge delivery ends a little after bottom dead centre (BDC) because of the quick decrease in crankcase pressure. In this engine the mixture delivery, at low speed flow is extended further due to the surge tank acting as a quasi constant moderate-pressure reserve and to the long time angle of fresh charge port opening (Fig. 22.18 (c) and (d)). This gives a second delay so that the volume of the air-fuel mixture which reaches the exhaust port is far less important, compared to a classical engine.

In addition, the fresh rich mixture flows through the previously heated delayed charging duct, i.e the element helping to homogenize the mixture through fuel vapourization and prepare it for combustion.

***Results*** The result obtained from a modified 50 cc engine showed a significant reduction in HC pollution (a mean of 35%) and consumption (20%). However it was obtained at the cost of a torque (hence power) reduction at high speed compared to a production equipped with its standard carburettor. A part of the pressure loss (responsible for delivery ratio reduction consequently for torque reduction) was attributed to the surge tank position in a branch diverted from the delayed charging transfer duct.

***An Improved Delayed Charging Circuits*** In the improved delayed charging circuit, the engine is to be modified by the incorporation of an in-line surge tank instead of the diverted one, to reduce pressure and to further improve HC emission and fuel consumption by lengthening the contact of fresh charge in the cylinder mixture with fresh air.

There are five transfer ports in the production engine cylinder. Special four transfer port cylinders (without back transfer port) were moulded with the same matrix as the production engine cylinders and modified by a delay charging transfer port addition. Among the various modified cylinders (varying in transfer port heights, width, slopes), two of them were selected for study. The characteristics of engines are given in Table 22.5.

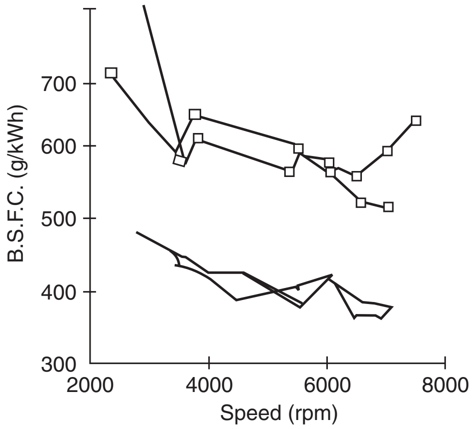
**Table 22.5** Engine Specifications

| *Engine* | *50cc PROD.* | *50cc DC engine 1* | *50cc DC engine 2* |
|---|---|---|---|
| Type | - | 2-stroke | - |
| Induction system | - | Reed valve | - |
| Cooling system | - | Air fan | - |
| Bore | - | 40 mm | - |
| Stroke | - | 39.1 mm | - |
| Transfer ports | 5 | 4+1 | 4+1 |
| Transfer port function | Scavenging and charging | Scavenging and charging | Scavenging and charging |
| Transfer port opens at | 125° at dc | 125° at dc + 100° at dc | 125° at dc + 100° at dc |
| D.C. Transfer port height | - | 8 | 4 |
| D.C. Transfer port tilt | - | 45° | 60° |

***Test Procedure*** For each delayed charging configuration, tests were carried out with the fuel supply through a stock main carburettor in the inlet duct (i.e. ahead of crankcase pump) or alternately through an adjustable pressurised carburettor in the delay charging transfer duct. To analyse the improvement, the two DC layouts were compared to the production five-transfer port engine (5 T.P.E) and to the 4 T.P.E equipped with the production engine carburettor. Figure 22.19

shows an obvious reduction of fuel consumption for these 50 cc engines, down to 380 g/kWh (giving an efficiency increase up to 40%), a part of which must be attributed to the lower richness of the delay charging engine carburation but a large part of this improvement is effective due to the delayed charged device.

***Fuel Trapping Efficiency*** Figure 22.19 indicates the quantity of fuel trapped in the cylinder taking part in the combustion process. Here the DC engine 1 is marked better than the DC engine 2 which is better than the production engine all along the speed range. The higher difference is obtained at the two speed range extremities with an improvement of up to 10 to 13 points. It must be compared to the lag (from 25 to 35 points) separating the production engine trapping efficiency line to the 100% trapping efficiency line in order to understand the relationship with the HC emission reduction or with the fuel consumption reduction. In fact, fuel trapping efficiency is dependent on the delivery ratio which is dependent on speed for a given configuration. A vigorous cylinder efficiency evaluation would be obtained by the comparison of trapping efficiency versus delivery lines but unfortunately these lines with Z shape following the increased speed order, cross each other and give a confusing diagram. Comparing the theoretical mixture-jet peripheral area to volume ratio for DC-1 and DC-2 engine, we find that the DC-1 cylinder jet has a poor ratio which may be related to its relatively high CO concentration. This, due to lower rich mixture in the trapped scavenging air, is the reason which limits the fuel delivery and hence the work done, the torque and the b-m. e.p. despite a high overall excess air ratio. Nevertheless, this limited fuel diffusion inducing less fuel losses might be partly a reason for its better trapping efficiency which gives a lower HC emission and slightly better fuel consumption.




Specific Fuel Consumption vs Speed

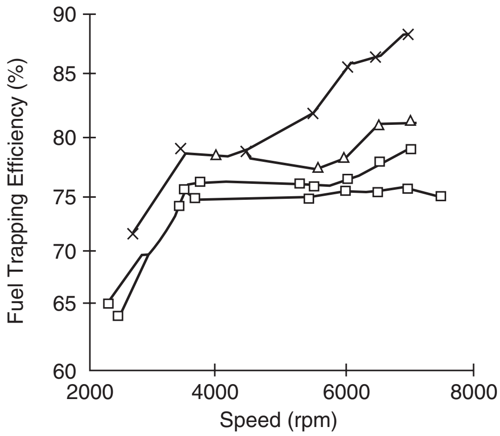



**Fig. 22.19** Figure Shows an Obvious Reduction of Fuel Consumption

***Pollutant Emission*** The hydrocarbons discharged by the engine are logically linked to fuel consumption but there is marked better fuel use with the the DC-1 engine configuration confirmed by its high trapping efficiency leading to a peak 68% reduction in the unburnt hydrocarbon. This reduction is partly attributable to the rich mixture of the production engine giving a high HC rate. The CO concentration is irregular, some times good (lower than 0.5%), and some times relatively high (upto 4%) due to the assumed heterogeneity of the cylinder contents (puff of rich mixture whose in-cylinder location at a given crankcase angle depends on engine speed and to the fixed ignition timing).

***Enleanment of Mixture and Retarding Exhaust Time*** Most small utility-stroke engines employ a carburettor and a piston valve crankcase scavenging system. Two-stroke engines, used for hand-held equipment, emit high levels of HC and CO due to rich carburettor calibration as the fuel consumption is not as much of a concern as the time for which they are used. In short, $NO_x$ levels however are low enough because the combustion temperature is much lower than needed for $NO_x$ production because of rich mixture. The enleanment of mixture implies increasing the proportion of air in the air-fuel mixture. Exhaust time in terms of crank angle is called exhaust angle. HC emission is reduced by about 30% and CO by 85% by enleaning the mixture ratio from 10:1 to 13:1. $NO_x$ emission tends to decrease as a whole by retarding the exhaust timing. In brief:

(a) To reduce mass emission of small two-stroke engines by combining enleanment of air-fuel ratio and retarding of exhaust timing, mass emissions of HC and CO can be reduced. $NO_x$ however increases slightly.

(b) By taking measures as in (a) such problems as temperature, rise of spark plug seat and exhaust gas and power output drop may occur but the problems can be solved by improving cooling ability and modifying the combustion chamber and exhaust port shape.

## 22.11 ALTERNATIVE AUTOMOBILE FUEL

The demand for petroleum products in India has been increasing at a much faster rate than the increase in domestic availability, resulting in increased imports. The automobile sector is the single largest consumer of petroleum products. Due to heavy consumption of petroleum products and continuing pressure on emission control, there is an urgent need to search for an alternative fuel as a substitute for high-speed diesel and petrol. Many things are considered when determining the viability of an alternative fuel, including emissions, cost, fuel availability, fuel consumption, safety, engine life, fueling facilities, weight, space requirements of fuel tanks and the range of a fully fueled vehicle.

Alternative fuels are those other than petrol and diesel fuel. The properties of petrol and diesel fuel were discussed earlier in Chapters 5 and 6. Among the options that are currently available as alternate fuel to petrol and diesel, LPG and natural gas have received a great deal of attention.

### Liquid Petroleum Gas (LPG)

LPG is a byproduct of crude oil refining, and it is also found in natural gas wells. Fuel grade LPG is almost pure propane with a little butane and propylene usually present. Because of its high propane content, many people simply refer to LPG as propane.

Propane burns clean in the engine and can be precisely controlled. Because it vapourizes at atmospheric temperatures and pressure, it does not puddle in the intake manifold. This means it emits less hydrocarbons and carbon monoxide. Emission controls on the engine can be simpler. Cold starting is easy, down to much below zero. At normal cold temperatures, the propane engine fires easily and produces power without surge or stumble.

One of the most noticeable differences between propane and gasoline is that propane is a dry fuel. It enters the engine as vapour. Gasoline, on the other hand, enters the engine as tiny droplets of liquid, whether it flows through a carburettor or sprayed through a fuel injector.

The propane fuel system is a completely closed system that contains a supply of pressurized LPG. Since the fuel is already under pressure, no fuel pump is needed. From the pressurized fuel tanks, the fuel flows to a vacuum filter fuel lock. This serves as a filter and a control allowing the fuel to flow to the engine. The fuel flows to a converter or heat exchanger where it changes from a liquid to gas. When propane flows through the converter, it expands as it changes into a gas. The carburettor mixes gaseous propane with air. Air flow into the engine is controlled by a butterfly valve in the venturi. The mixture is controlled by a fuel metering valve operated by a diaphragm, which is controlled by the pressure in the intake manifold. The idle system is an air bleed, similar to a gasoline engine. In fact, except for the fact that the propane carburettor does not require a fuel bowl, the two carburettor types are basically the same.

### Natural Gas

Vehicles have been designed with gasoline/CNG, diesel/CNG, and dedicated (single-fuel) CNG engine applications. Compressed natural gas (CNG) vehicles offer several advantages over gasoline.

- The fuel costs less.
- It is the cleanest alternative fuel, generating up to 99 percent less carbon monoxide than gasoline, no particulates, almost no sulphur dioxide, and 85 percent less reactive hydrocarbons than gasoline
- Natural gas vehicles are safer. The fuel tank used for CNG are aluminum or steel cylinders with walls that are 1/2 to 3/4 inch thick. They can withstand severe crash tests, direct gunfire, dynamite explosions, and burning beyond any standard sheet metal gasoline tank. Because it is lighter than air, natural gas dissipates quickly. It also has a higher ignition temperature.
- It generally reduces vehicle maintenance since it burns cleanly. Oil changes may not be needed before 12,000 miles and spark plugs could last as long as 75,000 miles.
- Natural gas is available in large quantities in India and does not need elaborate processing or refining as is the case with other petrol fuels. CNG consists mainly of methane with low percentages of other hydrocarbons like ethane, propane and butane. It has very low levels of pollution, does not materially restrict vehicle performance and is far more economical to use than petrol.

The chief disadvantage of CNG at present is it non-availability to most users. Fuel facilities are needed in greater numbers than are currently in existence due to the relatively shorter range of CNG vehicles. The space taken by CNG cylinders and their weight, about 300 pounds, would also be considered disadvantages in most applications.

***Anti Knock Property*** Due of its anti knock property, CNG can be safely used in engines with a compression ratio as high as 12:1 compared to normal gasoline (ranging from 7.5 : I to 10 : 1). At these high compression ratios, natural gas-fuelled engines have higher thermal efficiencies than those fuelled by gasoline.

CNG has a higher octane number than petrol, and it is therefore possible for CNG engines to operate at a higher compression ratio than petrol engines without knocking. The fuel efficiency of CNG engines is therefore better than that of petrol engines.

However compared to diesel engines, the compression ratio is lower for CNG engines and consequently the fuel efficiency of these engines is about 10-20 per cent lower than that of diesel engines.

CNG represents a more cost-effective emission reduction measure than quite a few options available for diesel engines. In diesel engines, the catalytic converter cannot reduce the portion of the particulate referred to as soot.

***Typical Emission Reduction in a CNG Bus Compared to a Diesel Bus*** Particulate trap is a high cost device that is still under development for diesel engines. Traps have to be regenerated to clean the deposited carbon particles, otherwise the trap will choke the exhaust. The reliability of catalytic converters for diesel engines is yet to be proved in India where diesel fuel has higher sulphur content.

CNG engines are a better way to eliminate particulates. The importance of a cost-effective, efficient, easy-to-maintain and user-friendly solution to overcome environmental problems cannot be over-emphasized. CNG meets these requirements. It also allows the use of catalytic converters more efficiently than diesel.

## Review Questions

1. Differentiate between complete and incomplete combustion process.
2. Name the main constituents of exhaust gases from a petrol driven and diesel driven engine.
3. What engine operating conditions produce the most amount of unburned hydrocarbons in the exhaust?
4. During what engine operating conditions are carbon monoxide and nitrogen oxide produced most in the exhaust?
5. Name the main sources of pollutants from gasoline engines.
6. Explain the operation of the PCV system and the function of the various PCV system parts.
7. Explain the advantages of fuel-vapour emission control system.
8. Describe the operation of the exhaust gas recirculation system.
9. How does the air-fuel mixture help to minimize emission?
10. Explain the purpose and operation of the exhaust gas recirculation valve.
11. Describe the operation of the air injection system.
12. Explain the purpose of the catalytic converter.
13. Explain what tests should be made when emission problems are suspected in two-stroke engine.

# 23

# Petrol Fuel Injection System

**Objectives**

After studying this chapter, you should be able to

- Describe the main drawbacks that might occur in the fuel system using a carburettor.
- Explain the various types of petrol fuel injection systems.
- Differentiate between timed and continuous injection systems.
- Describe the operation of mechanical fuel injection system.
- Explain the operation and control of electronic fuel injection system.

## 23.1 INTRODUCTION

A major milestone in the history of gasoline injection in 1956 was the introduction of the Bendix Eletrojector on which virtually all the modern systems are based. In 1964 the Tecalemit-Jackson Injector System was introduced. Following the introduction of electronically controlled injection systems, the most major advancement was the development by Bosch, of a device for defecting the presence of oxygen in the exhaust and this control to be exercised on the closed loop principle.

Carburation and operation provide some difficulties in an engine. The engine must have a continuous supply of combustible air-fuel mixture to run. In most engines, a carburettor (Fig. 23.1) mounted on the intake manifold supplies the mixture. This mixture then flows to the engine cylinders when the intake valves open and the amount of mixture that enters the intake manifold is controlled by the position of the throttle valves (from fully closed to wide open).

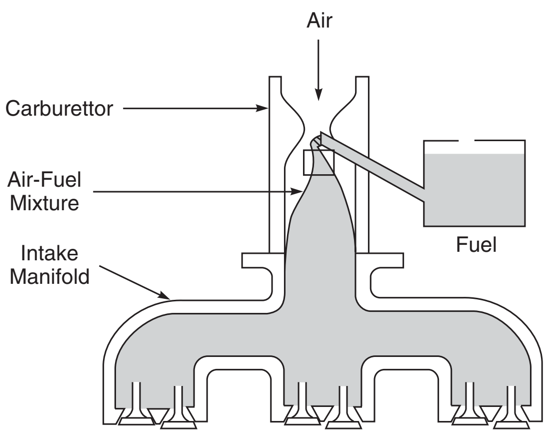



**Fig. 23.1** Carburettor Fuel System

Modern carburettors, though highly developed, cheap and reliable have certain drawbacks as explained:

1. Mal distribution of air-fuel mixture in multicylinder engine: In multicylinder engines, the carburettor supplies the air-fuel mixture to each of the several cylinders. Ideally each cylinder should receive mixture of the same air-fuel ratio. However in practice it is very difficult to achieve this condition.

   In the carburettor, complete atomization and vapourization of the fuel is not achieved. Therefore the mixture passing through the intake manifold generally contains a certain amount of petrol in the form of droplets. These droplets have greater inertia than the gaseous mixture and hence whenever the direction of flow is changed abruptly, the droplets tend to continue in their original direction of movement as shown in Fig. 23.2. As a result, there is variation in the air-fuel ratio between cylinders, the outer cylinder getting a richer mixture than the inner cylinders. The mixture proportion is also affected due to unequal resistance to mixture flow, unequal length of mixture passage and fuel condensation in the induction manifold.

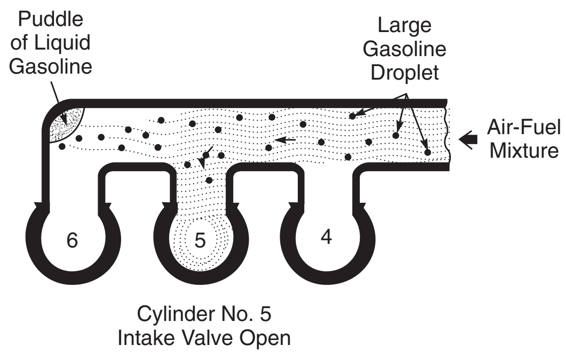



**Fig. 23.2** Distribution Pattern of Gasoline in an Intake Manifold

2. The carburettor, with its choke tubes, jets, throttle valve, inlet pipe, bends etc. does not give a free passage for the mixture. Thus there is loss of volumetric efficiency on this account.
3. Ice Formation: The vapourization of fuel injected in the current of air, requires latent heat and this heat is taken mainly from the incoming air. As a result of this, the temperature of air drops below the dew point of water vapour in the air and it condenses and freezes into ice if the temperature falls below the freezing temperature.
4. Vapour Lock: The improved volatility of modern fuels due to petrol pipes being near the hot engine, the vapourization of fuel in pipes and float chamber occurs. Formation of vapour bubbles interrupt the flow of fuel and cause carburation difficulties.
5. Spilling of fuel may take place when the carburettor is tilted or during acrobatics in aircraft, unless special means are adopted to avoid this.
6. Under certain conditions of mixture ratio there will be back firing in the intake or exhaust manifold and there is a risk of fire unless flame traps are provided.

## 23.2 PETROL FUEL INJECTION SYSTEM

To overcome the operational difficulties of the carburettor, many attempts have been made to design a satisfactory petrol injection system in which each cylinder is supplied with its correct quantity of petrol for each working cycle under all operating conditions. It is also claimed that the system devised to do this, allows the engine to produce more power and give less vapourization trouble.

The advantages of the fuel injection system over the conventional carburettor have been appreciated for many years. The quest for improved engine performance linked with fuel economy together with legislation regarding the control of exhaust emissions have enormously increased the use of the fuel injection system. The incorporation of the electronic control system has also considerably helped in the development of very efficient and commercially viable systems.

***Where to Inject?*** Indirectly injecting the fuel into pre-chambers and direct injection into the cylinder, in both cases, the hydraulic pressure needed to overcome the compression pressure in the gas, has to be high, introducing problems of noise, wasteful consumption of power by the pump and potentially, fuel leaks. Another disadvantage is that the time available for the completion of injection, evaporation and mixing after injection is very short. Injection into the manifold or some other part of the induction system, overcomes all these objections.

## 23.3 CLASSIFICATION OF PETROL-FUEL INJECTION SYSTEM

The petrol fuel injection system can be classified on the following basis.

1. Combustion chamber injection.
2. Fuel injected into inlet port or inlet manifold.
3. Timed or continuous injection.

**1. *Combustion Chamber Injection*** The combustion chamber injection system is just similar to the CI engine. However, this system is not adopted today as emission and fuel economy requirements make it impractical.

**2. *Fuel Injected into Inlet Port or Inlet Manifold*** In the gasoline fuel injection system, the fuel is injected into the intake manifold through fuel injection valves. There are two basic arrangements:

(a) Port injection or multiple point injection
(b) Throttle body injection (TBI), or single point injection.

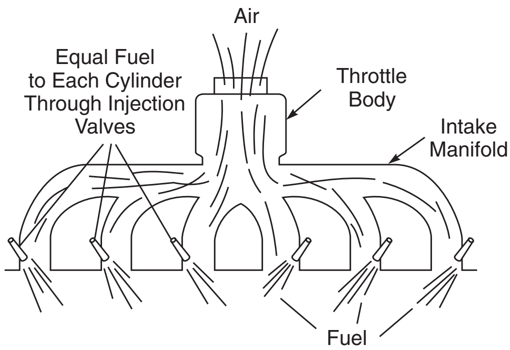



**Fig. 23.3** Port or Multiple-point Fuel Injection System

In port injection or multiple point injection (Fig. 23.3) there is an injection valve for each cylinder. Each injection valve is positioned in the intake port near the intake valve (Fig. 23.4).

In throttle body injection (TBI), an injection valve is positioned slightly above each throat of the throttle body (Fig. 23.5). The injection valve sprays fuel into the air, just before it passes the throttle valve and enters the intake manifold (Fig. 23.6).

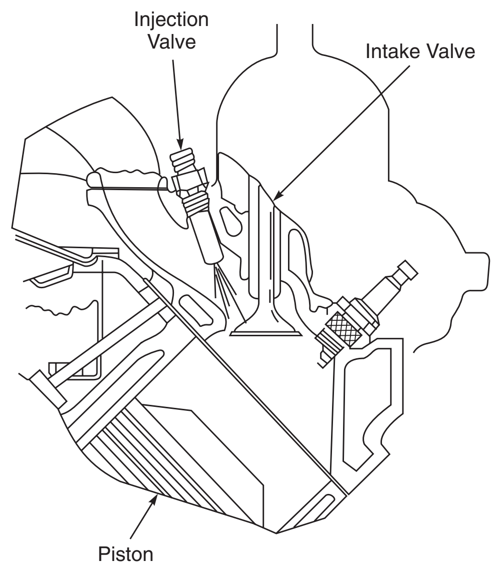



**Fig. 23.4** Method of Injecting Fuel into the Intake Manifold at the Intake Valve Port

The throttle body injection system suffers the problems associated with carburation, e.g. unequal mixture distribution, deposition of fuel, uncontrollable evaporation from the walls of the manifold, and variation in manifold pressure. Additionally, throttle body heating becomes necessary both to avoid leaning and to assist evaporation and mixing. However with the whole injection system and throttle body injection valve grouped together as a single compact sub-assembly, throttle injection is significantly less costly than a multipoint system.

**3. *Timed and Continuous Injection*** Another way to classify Fuel Injection Systems is by the injection action. Depending on the system, fuel sprays from the injection valves either in pulses (timed injection) or continuously. Port injection and throttle-body systems may be either pulsed or continuous.

In the continuous injection system, fuel sprays, continuously from the injection valves. Continuous injection has the advantage of simplicity and low cost relative to timed injection. With low pressure continuous injection, the fuel is injected increasingly into the manifold or ports, premixing it with air to form a cloud of rich mixture just upstream of the inlet valves, ready for induction into each cylinder in turn. When each valve opens, this rich mixture is swept by the incoming air into the cylinder where swirl and turbulence convert it into an ignitable mixture.

Timed injection system is similar to the system used in high speed diesel engines. In this system, control over air-fuel ratio is exercised by regulating the duration of flow through the injector or timing it.

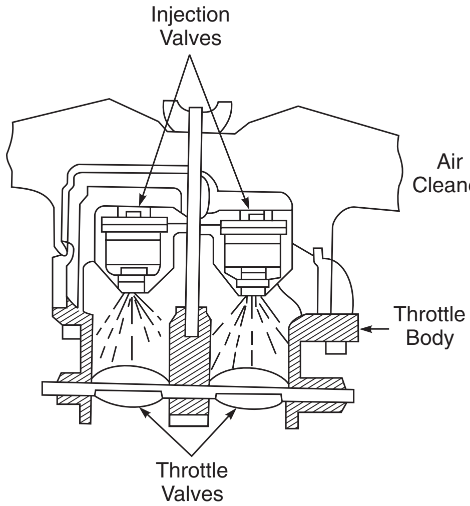



**Fig. 23.5** Position of an Injection Valve in TBI System

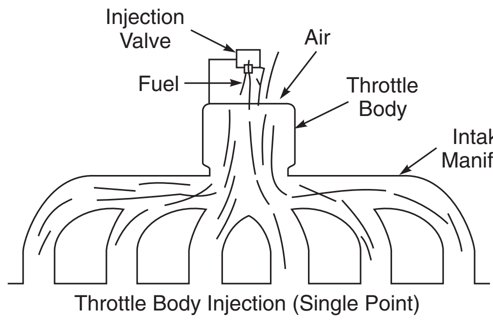



**Fig. 23.6** The Injection Valve Sprays Fuel Directly into the Air Passing Through the Throttle Body

## 23.4 ADVANTAGE OF PORT FUEL INJECTION OR MULTIPOINT FUEL INJECTION SYSTEM

Regardless of whether the port injection systems are pushed or continuous, they eliminate maldistribution in carburettor systems. One of the most difficult problems in a carburettor system is to get the same amount and richness of air-fuel mixture to each cylinder. The end cylinders receive the richest mixture and the cylinder closest to the carburettor receives the leanest mixture.

The port fuel injection system solves this problem because the same amount of fuel is injected at each intake valve port. Each cylinder gets the same amount of air-fuel mixture of the same richness.

Another advantage of the port fuel injection system is that the intake manifold can be designed for most efficient flow of air only. It does not have to handle fuel. Also because only a throttle body is used, instead of a complete carburettor, the hood height of the car can be lowered.

## 23.5 DESCRIPTION OF SOME PETROL FUEL INJECTION SYSTEMS

Many petrol fuel injection systems have been developed by automobile and aircraft companies. Most of the designs are very elaborate and complicated.

The following sections describe the operation and control of some of the petrol injection system.

1. Mechanical fuel injection system.
2. Electronic fuel injection system.

### 1. The Lucas Mechanical Fuel Injection System (Timed Port Injection System)

A simplified line diagram of the Lucas mechanical fuel injection system is shown in Fig 23.7. The petrol is sucked from the tank by a pump and pressurised petrol at 7 bar is supplied through a distributor to the fuel injector of a particular cylinder. The relief valve shown in figure, maintains the pressure and allows excess petrol to return to the tank. The pump may be driven by an engine or by a separate electric motor. The latter is preferred because it starts pumping at its normal running speed and pressurises as soon as the ignition is switched on. Here the petrol is injected into the inlet port as shown in the figure. The distribution may be made by having a separate metering pump for each cylinder. All pumps are timed by the arrangement of a series of cams on one camshaft or by having on pump operated by a single cam with a lobe for each cylinder that feeds the distribution unit which passes the petrol to each inlet port in turn. This unit may be driven by shaft, chain or V-belt.

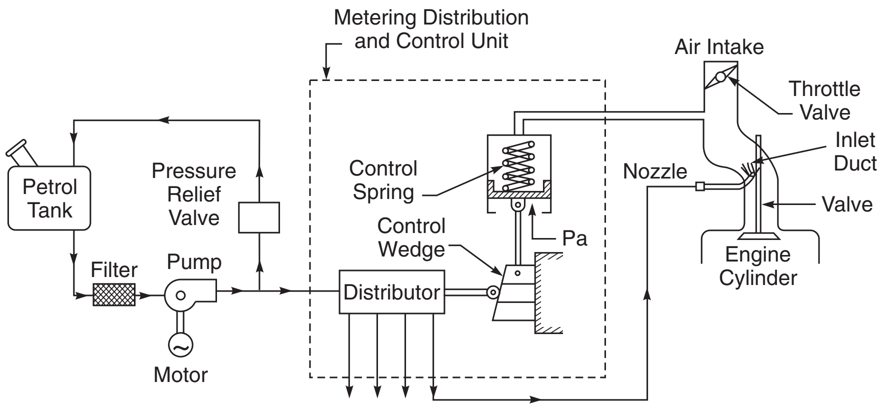



**Fig 23.7** Lucas Mechanical Fuel Injection System

This system only controls the fuel-air ratio with respect to load and has to contain a means of supplying extra fuel for cold starting, during warming and enriching the mixture during acceleration.

Ice formation is virtually impossible with this system and the danger of vapourisation is minimised because the petrol is under pressure right upto the injection port.

### 2. Electronic Fuel Injection System

The development of solid-state electronic devices such as diodes and transistors made the electronic fuel injection system possible. Now-a-days electronically controlled fuel injection systems (Fig. 23.8)

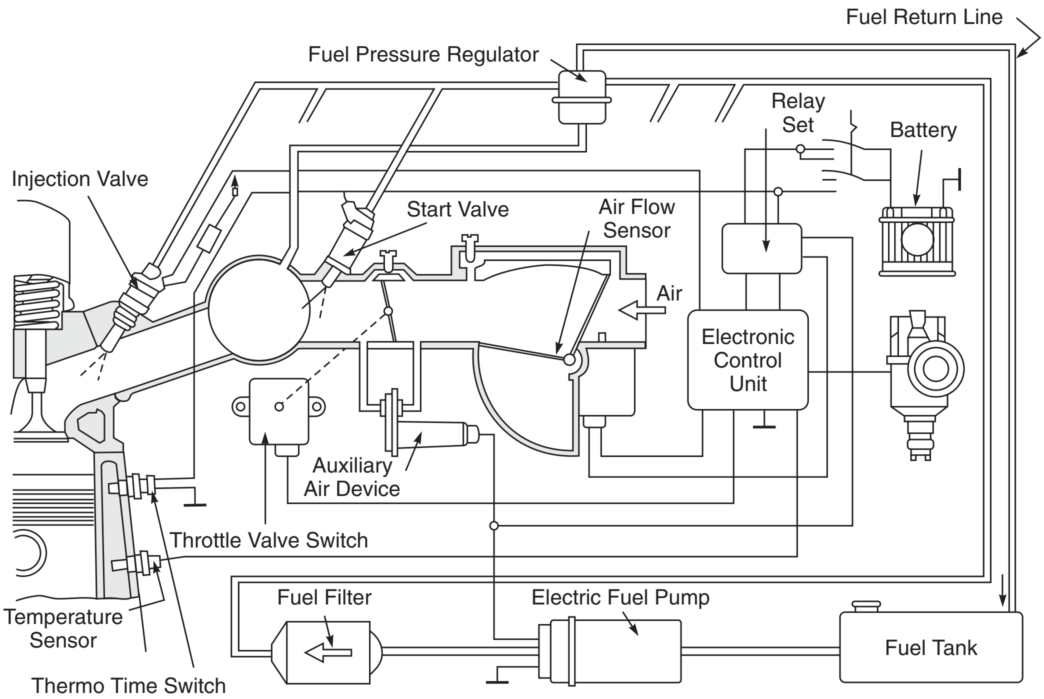



**Fig. 23.8** Bosch L-Type Electronic Fuel Injection System

are commonly used as they function rapidly and respond automatically to the change in manifold air pressure, engine speed, crankshaft angle and many other secondary factors. The electronic control unit accesses data (manifold pressure, engine speed, crank angle, oxygen in exhaust, etc.) from various sensing devices and then adjusts the air-fuel ratio for the best performance of the engine.

The main parts of the system are:

(a) Electronic control unit
(b) Fuel delivery system
  (i) Injector and Electronic Fuel Pump
  (ii) Fuel metering by measuring air flow
  (iii) Fuel metering by measuring oxygen in exhaust

**(a) *Electronic Control Unit*** The electronic control unit is the most important unit of the electronic injection system which is responsible for metering the quantity of fuel supplied to each cylinder. The unit contains a number of printed circuit boards on which a series of transistors, diodes and other electronic components are mounted. This makes the vital data analysis circuits respond to various input signals. After processing the input data, the power output circuits, in the control unit generate current pulses, which are transmitted to the solenoid injectors to operate the injector for the required period.

**(b) *Fuel Delivery System*** Fuel Delivery System means the fuel is injected either into the port before the intake manifold or into the intake valve by a throttle body injector. This system is used on petrol engine. Reason for fuel injection is to control the air-fuel ratio of the engine more precisely. The details of different gasoline fuel delivery system are given as follows.

**(i)** ***Injectors and Electronic Fuel Pump*** The solenoid operated fuel injector is shown in Fig. 23.9. It consists of a valve body and a needle valve to which the solenoid plunger is rigidly attached. The fuel is supplied to the injector under pressure from the electronic fuel pump, passing through the filter. There is a needle valve pressed against a seat in the valve body by a helical spring to keep it closed until the solenoid winding is energised. When a current pulse is received from the electronic control unit, a magnetic field builds up in the solenoid coil which attracts a plunger and lift the needle valve from its seat. This opens the path for the pressurised fuel to emerge as a finely atomised spray.

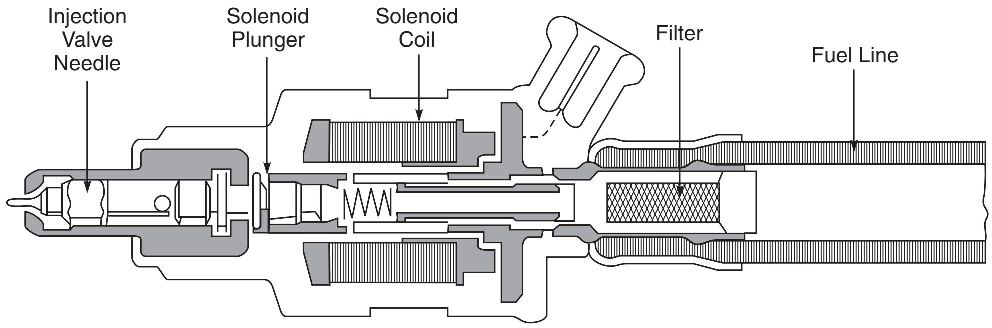



**Fig. 23.9** Construction of the Solenoid-Operated Injection Valve

**(ii)** ***Fuel Metering by Measuring Air Flow*** In the KE-Jetronic continuous flow system, an elaborate electronic control system is employed to perform the fuel metering function accurately in response to variations in operating conditions of the engine. Extra components introduced are mainly sensors. The KE-Jetronic pressure regulator maintains the pressure throughout. Below this pressure level, the injector valves lift.

In the Bosch L-type electronic fuel injection system, Fig. 23.8. fuel metering is controlled primarily by engine speed and by measuring the intake air flow.

The amount of intake air is measured by the air flow sensor as air passes through it (Fig 23.8). A pivoted flap is placed in the air passage. Attached to the flap is a small spring and a voltage sensor. As air flow increases, the spring allows the flap to move accordingly. The voltage sensor signals the ECU how much air is passing through. This information is then used by the ECU to determine the length of time that the injection valve will be held open. Then the injection valves deliver the exact amount of fuel needed to provide the proper air-fuel ratio for the operating condition.

**(iii)** ***Fuel Metering by Measuring Oxygen in Exhaust*** Modern electronic fuel injection systems include an oxygen sensor (see Fig. 23.10).

This device measures the amount of oxygen in the exhaust gas and sends this information to the electronic control unit. If there is too much oxygen, the mixture is made lean. If there is too little oxygen, the mixture is made rich. In either case, the ECU adjusts the air-fuel ratio by changing the amount of fuel injected.

The amount of oxygen in exhaust is detected by an instrument called the lambda sensor. The lambda sensor detects the deviation from a zero oxygen content in the exhaust as an indication of inefficient combustion or the presence of carbon monoxide and unburned hydrocarbons in the exhaust gases. Lambda is the ratio of the actual mixture strength to the theoretical mixture strength required for complete combustion of all the air and fuel.

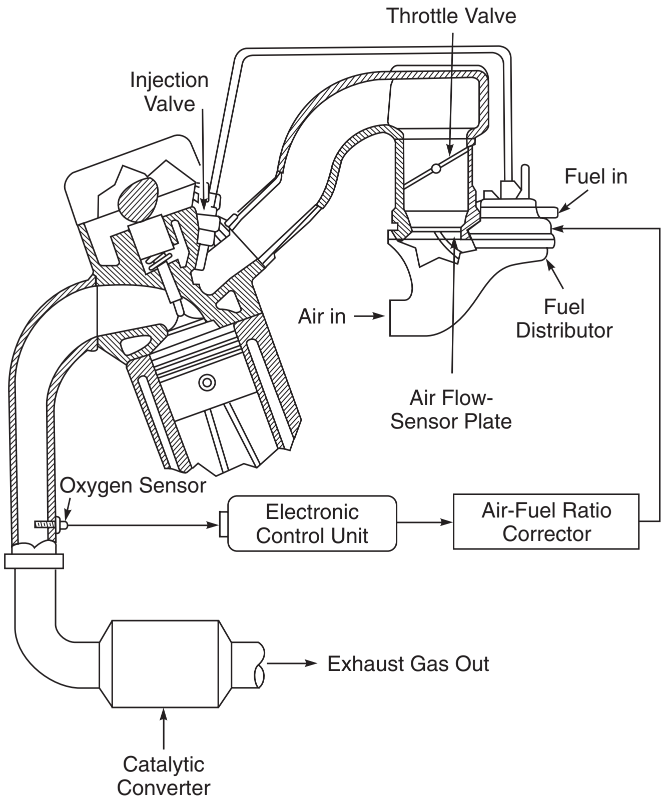



**Fig. 23.10** A Mechanical CIS Which has an Oxygen Sensor

The lambda sensor is contained in a steel housing screwed into the exhaust manifold, placing its sensitive element in the gas stream Fig. 23.11. The sensitive element is a zirconium oxide thimble, the inner and outer surfaces of which are coated with micro porous platinum to form electrodes. A lowered metal sleeve is fitted over the thimble to screen it from erosion by solid particles in the exhaust gas stream.

The outer surface is exposed to the exhaust gas stream and the inner one is exposed to atmosphere. At about 300°C, the ceramic begins to conduct oxygen ions and on detecting any difference between the oxygen content of the gases exposed to, the two platinum electrodes induce between them a voltage proportional to that difference.

This system is applicable to and desirable for all engines, particularly indispensable for those equipped with catalytic converters in their exhaust system.

## 23.6 ADVANTAGES AND DISADVANTAGES OF FUEL INJECTION SYSTEM

The advantages of a fuel injection system are:

1. The fuel injection system can precisely match the fuel to engine requirements under all load and speed conditions. This reduces fuel consumption with no loss of engine performance.

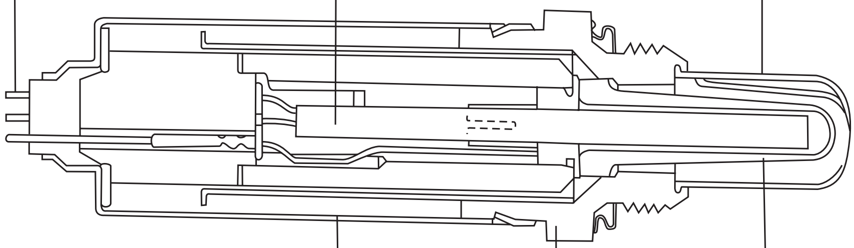



**Fig. 23.11** Bosch Lambda Sensor

2. The manifold in an injection system carries only air, so there is no problem of air and fuel separation and the design of manifold becomes simple.
3. Due to the absence of venturi which obstructs the air passage, petrol injection results in better volumetric efficiency and increased power.
4. Fuel injection system is relatively free from icing and surge when tilted, and also during cornering and braking.
5. Starting and acceleration is much better than in the carburettor system.
6. It provides identical air-fuel ratio mixtures to all the cylinders and maintains better balancing. In addition to this, the engine can work more economically, closer to its lean limit which is not the case in the carburettor multicylinder engine. It is also characterised by a lower specific fuel consumption.
7. By maintaining a precise air-fuel ratio, according to engine requirements, exhaust emissions are lowered. The improved air-fuel flow in injection system also helps to reduce emission levels.

The disadvantages of the fuel injection system are:

1. The major disadvantage is its high capital cost due to precise and complicated components of the electronic circuit.
2. The maintenance of this system is difficult and costly as this system contains four times the number of components of mechanical system.
3. A Junker 12 cylinder engine has 1576 parts against the 433 parts used with the 12 cylinder Mercedes carburettor system engine.
4. The weight of the mechanical injection system is considerably higher than that of the carburettor.
5. The mechanical injection system has many wearing parts such as a camshaft, rotor etc.
6. Injection system generates more noise.

Earlier due to the very high initial cost, the fuel injection system was used only in aircraft engines and racing cars and was offered as an optional system is some big cars.

However now due to the pressure to control air pollution and because of the advantages of better power and fuel economy, petrol injection is being offered in a large number of cars in America, Europe and Japan. In India also, almost all automobile manufacturers have launched (or are going to launch) fuel injection systems in their car in recent years.

## Review Questions

1. Describe the main drawbacks of the carburettor fuel system.
2. Enlist the advantages of the petrol injection system over the conventional carburettor system.
3. Describe the operation of multi-point injection system.
4. Explain the operation of single point injection system.
5. Compare timed and continuos injection system.
6. List the advantages of the part fuel injection system.
7. Explain the operation and functions of mechanical petrol fuel injection system.
8. Explain the purpose and operation of the electronic control unit.
9. Describe the working of fuel delivery system of the electronic fuel injection system.
10. State the disadvantages of petrol fuel injection system.

# 24

# Heating and Air Conditioning System

**Objectives**

After studying this chapter, you should be able to

- Identify the purpose of ventilation and heating systems used in the automobile.
- Identify the common parts of a heating system.
- Describe how an automobile air conditioning system operates.
- Describe the function of the various air conditioning components.
- Describe the purpose of refrigerant used in the air conditioning system and its effect on environment.
- Explain the various methods used to check refrigerant leaks.
- Explain how to visually check an air conditioning system.
- Use a trouble-shooting chart for servicing heating and air conditioning systems.

## 24.1 INTRODUCTION

The comfort systems of a car's interior include ventilation, heating, and air conditioning. Many motor vehicle air conditioners combine a heater, cooler and ventilation system in an enclosed body. It serves as a heater in cold climate and as a cooler in a hot climate. When the air is high in humidity and low in temperature, the air conditioner can be used in such a way enabling the cooler to remove moisture and heat as per the requirement.

Today, ventilation, heating and air conditioning systems are very important elements for providing passenger comfort. Ventilation and heating systems are standard equipment in all passenger vehicles and air conditioning is standard in some and available for nearly all.

The large number of vehicles with air conditioning plus recent changes in the methods used to cool and heat a vehicle and to service the systems makes a basic knowledge of air conditioning systems a must for automobile technicians. In this chapter, the basic operation and service of these systems will be covered.

## 24.2 VENTILATION SYSTEM

The ventilation system in most vehicles is designed to allow fresh air into the passenger compartment, replacing stale air and to prevent the entry of smoke-filled air from the vehicle exhaust. There are several systems used to vent air into the passenger compartment. The most common is the flow-through system. In this system, a supply of outside air, which is called ram air, flows into the vehicle when it is moving. When the car is not moving, a steady flow of outside air can be produced by the heater fan. In operation, ram air is forced into the inlet grill and sent throughout the passenger compartment. The air then flows out of the vehicle through the exhaust area.

In some vehicles, air is admitted by opening or closing two vent knobs under the dashboard. The left knob controls air through the left inlet. The right knob controls air through the right inlet. The air is still considered ram air and is circulated through the passenger compartment. Ventilation using outside air does not work when the vehicle is moving at slow speeds or is stopped in traffic. The ventilation system's electrically driven blower takes care of these needs. The blower motor has a squirrel cage fan as shown in Fig. 24.1. The motor has multiple speed settings. In many vehicles, instead of an 'off' setting, the blower runs at low speed when the ignition key is turned on. This maintains a fresh flow of air inside the vehicle.

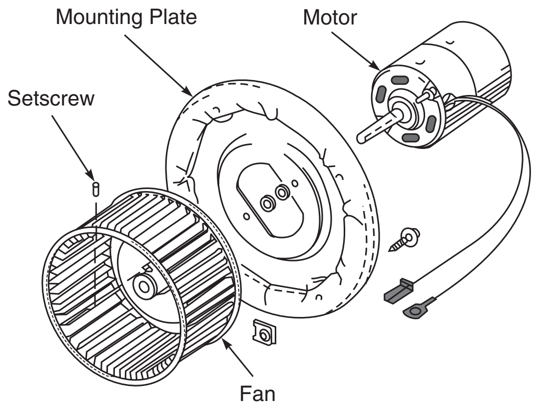



**Fig. 24.1** A Blower Motor and Squirrel Cage Fan

## 24.3 HEATING SYSTEM

The heating system in most vehicles is designed to work with the cooling system to maintain proper temperatures inside the vehicle. The heating system's main function is to provide a comfortable passenger compartment temperature and to keep vehicle windows clear of fog or frost. The major components of the heating system are the heater core, the heater control valve, the blower motor the fan, the heater and defroster duct hoses as shown in Fig. 24.2.

In the liquid-cooling system, heat from the coolant circulating inside the engine is converted into hot air, which is blown into the passenger compartment. Hot coolant from the engine is transferred by a heater hose to the heater control valve and then to the heater core inlet. As the coolant circulates through the core, heat is transferred from the coolant to the tubes and fins of the core. Air blown through the core by the blower motor and fan then picks up the heat from the surfaces of the core and transfers it into the passenger compartment of the vehicle. After giving up its heat, the coolant is then pumped out through the heater core outlet, where it is returned to the engine to be recirculated by the water pump.

The heater core is generally designed like a small radiator that functions exactly like the engine's radiator. Like the radiator, heater core tank, tubes and fins can become clogged over time with rust, scale and mineral deposits circulated by the coolant. Heater core failures are generally caused by leakage or clogging. Feel the heater inlet and outlet hoses while the engine is idling and warm with the heater temperature control on hot. If the hose downstream of the heater valve does not feel hot, the valve is not opening.

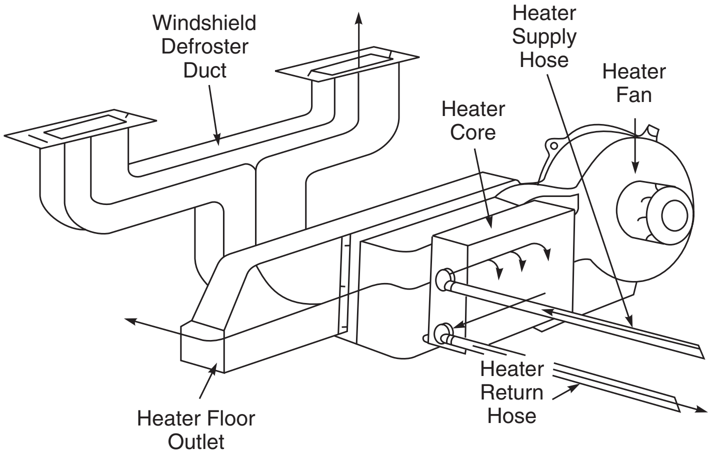



**Fig. 24.2** Major Components of a Typical Heating System

The ventilation and heating system of Maruti 1000 has been shown in Fig. 24.3. It consists of components such as control levers, blower motor, heater core and air ducts. The blower motor runs on electricity to send air inside. In the heater core, cooling water warmed by the engine keeps circulating. Each control lever controls the blower motor speed, temperature and operation of the dampers in the air ducts so that the air is delivered where necessary.

## 24.4 HEATER CONTROLS

There are numerous types and styles of heater controls. Figure 24.4 shows a heater control panel for a system using cables. When a driver moves the heater/defroster slide switch of a cable-actuated control system, a stiff steel wire moves inside an outer housing. Movement of the wire controls the position of the heater valve or baffle plates in the air duct system. Cable actuation is used in majority of vehicles because it is reliable and inexpensive to manufacturers. Cables sometimes become stiff and difficult to move.

To overcome this difficulty, many cars are fitted with air servos to actuate heater controls. When a control switch is moved, engine vacuum actuates the heater valve or the baffle plates. Although less common, some heater systems are actuated by electrical solenoids or motors. When the heater switch on the dash is moved, a solenoid or motor switches on. The solenoid or motor opens the hot water valve or the air door.

Figure 24.5 shows an operation of a heater control panel which is fitted in Maruti cars having 1000 cc engine. This control panel provides temperature control, ventilation and defrosting functions. Their operation is controlled by selecting the position of the control levers on the instrument panel. Each lever position and the function of heater and ventilation are as given in Fig. 24.5.

## 24.5 PURPOSE OF AIR CONDITIONING

During summer, a great amount of heat enters the passenger compartment as shown in Fig. 24.6. This heat comes from the engine and from the sun or the air temperature outside. Air conditioning systems are designed to remove this excess heat so that passengers are comfortable. Another reason for using air conditioning is that an air conditioning system dehumidifies the air. Often in warm and damp driving conditions, there is so much moisture inside the vehicle that the windows

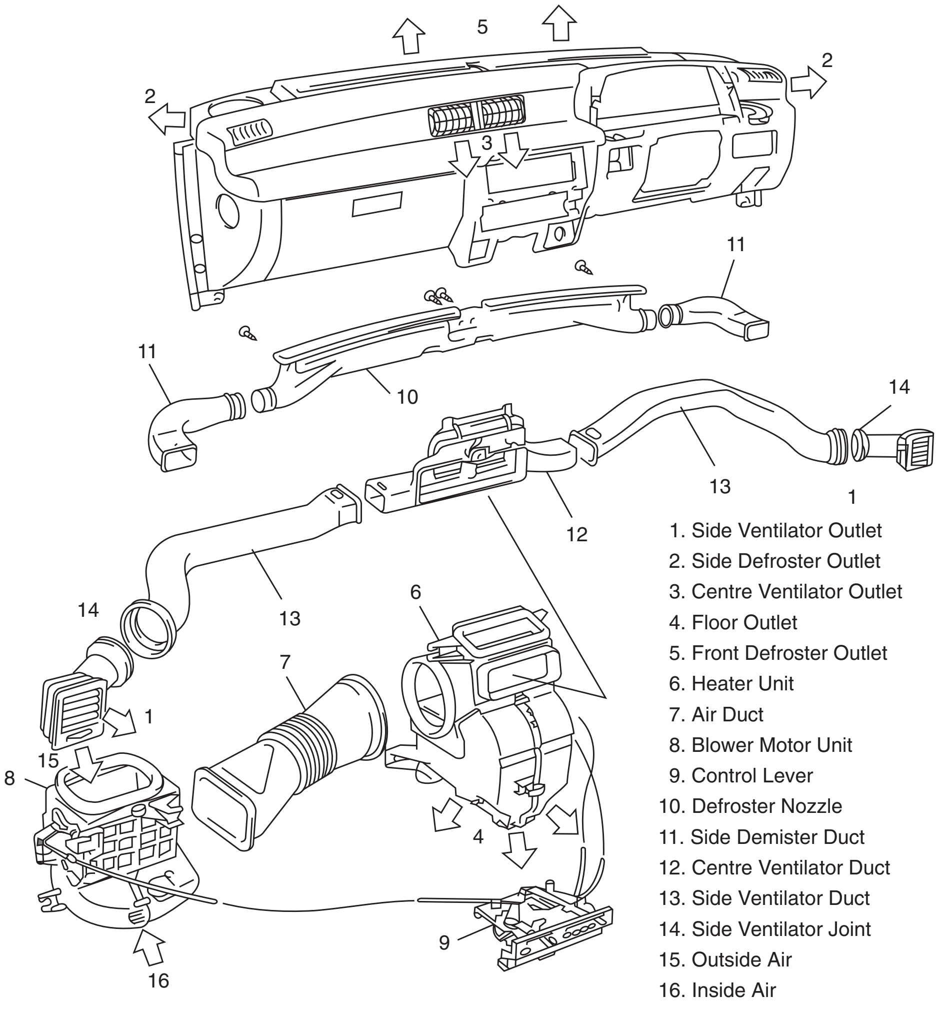



**Fig. 24.3** Ventilation and Heating System of Maruti 1000 (*Courtesy:* Maruti Udyog Ltd.)

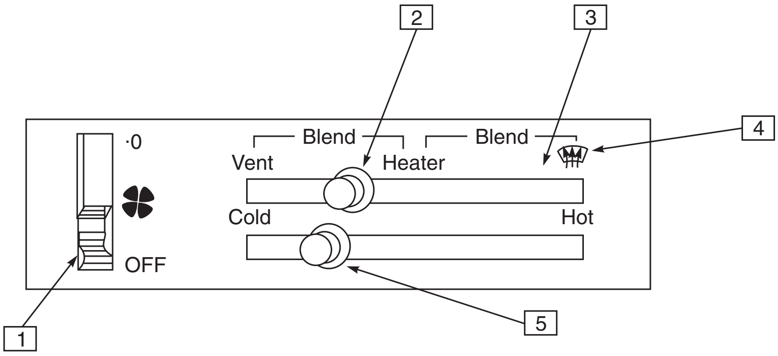
fog up. Although all vehicles have a defrost mode on their dash board, when the air conditioning system is turned on the air inside the passenger compartment is dehumidified rapidly.

## 24.6 PRINCIPLES OF AIR CONDITIONING

Air conditioning is the process in which the air inside the passenger compartment is cooled, dried and circulated.

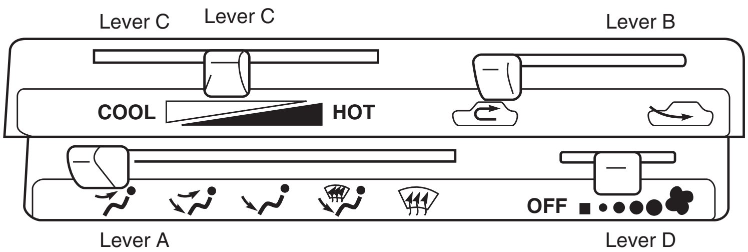
Automotive air conditioning works on the same principles on which household refrigerators and air conditioning work. A liquid refrigerant is changed to a gas and then back to a liquid again. If a change of state of the refrigerant is to take place, there must be a transfer of heat. Two principles apply here:

1. For a liquid to change to a gas, it must absorb heat.
2. For a vapour to change to liquid, it must release heat.




1. The Fan Control Lever (OFF-HI) Provides Speed Control of the Fan.
2. Position of this System Selector Lever Determines Air Flow from Floor, Instrument Panel or Windshield Outlet in Heater Flow is about 80% to floor and 20% to Windshield Outlets (and side Window Defoggers).
3. This Position Allows Outside Air Flow to Floor Outlet. (Additional Vented Air can be Distributed Inside Car by Operating Vent Knobs.
4. This Position Allows About 80% Air Flow to Windshield and 20% to Floor.
5. Temperature Lever Position will Regulate Outlet Air Temperature by Blending the Incoming Outside Air Through/Around the Heater Core.

**Fig. 24.4** A Typical Type of Heater Control Panel




**Lever A**
Heater Control Lever

| | | |
|---|---|---|
| | Ventilation | (Air Flow from Centre and Side Outlets) |
| | Bi-Level | (Air Flows from Centre and Floor Outlets) |
| | Heat | (Air Flows from Floor Outlet) |
| | Heat/ Defroster | (Air Flows from Floor Outlet, Front Defroster and Side Demister Outlets) |
| | Defroster | (Air Flows from Front Defroster and Side Demister Outlets) |

**Lever B**
Fresh Air Control Lever

| | |
|---|---|
| | Circulation |
| | Fresh Air |

**Lever C**
Temperature Control Lever

| |
|---|
| Cool |
| Hot |

**Lever D**
Blower Motor Speed Selection Lever

**Fig. 24.5** Heater Control Panel of Maruti–1000
(*Courtesy:* Maruti Udyog Ltd.)

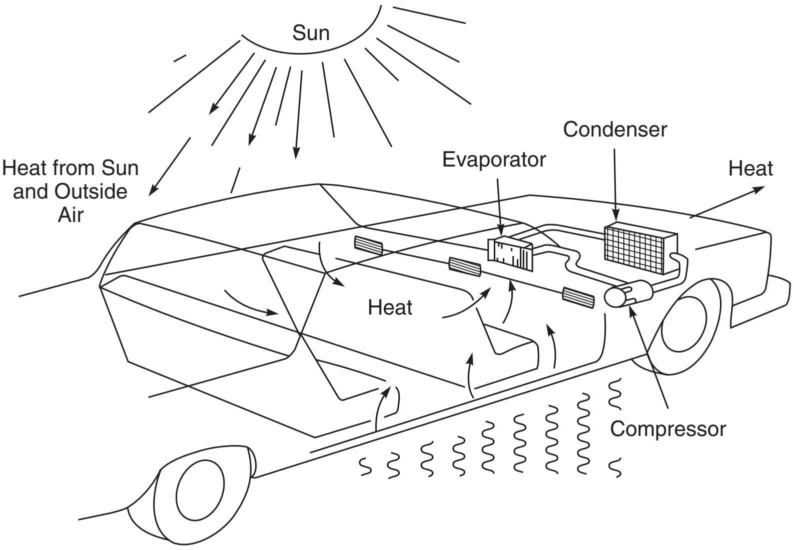



Fig. 24.6 Heat Inside the Passenger Compartment

## 24.7 OPERATION OF THE AIR CONDITIONING SYSTEM

The basic refrigeration system used in air conditioners is shown in Fig. 24.7. In this system, the heat is absorbed and transferred in the following steps.

1. Refrigerant leaves the compressor as a high-pressure, high-temperature vapour.
2. By removing heat via the condenser, the vapour becomes a high-pressure, high-temperature liquid.
3. Moisture and contaminants are removed by the receiver dryer, where the clean refrigerant is stored until it is needed.
4. The expansion valve controls the flow of refrigerant into the evaporator.
5. Heat is absorbed from the air inside the passenger compartment by the low-pressure, warm refrigerant, causing the liquid to vapourize, and greatly decrease its temperature.
6. The refrigerant returns to the compressor as a low-pressure, low-temperature vapour.

This system is divided into two sides: the high side and low side. High side refers to the side of the system that is under high pressure and high temperature. Low side refers to the low-pressure, low temperature side of the system.

Figure 24.8 shows the expansion valve type air conditioning system installed in a car. The gaseous Freon 12 fluid sucked by the car engine drives the compressor at an average pressure ranging from 14 to 20 psi (1.0 to 1.4 kg/cm$^2$), and is compressed to an average pressure ranging from 140 to 210 psi (10 to 15 kg/cm$^2$). This fluid, heated by compression to approximately 186° to 212° F (80° to 100° C) and retaining its gaseous state, is conveyed to the finned pipe coils of a heat exchanger, known as a condenser. The condenser is located in the front of the car radiator, where it is cooled by heat dissipation from the air stream provided by the combined action of the radiator fan and the motion of the car. As a result of cooling, the compressed gaseous fluid reaches its condensation point about 122° F (50° C) and changes from a gas to a liquid; this is why the heat exchanger is designated as a condenser.

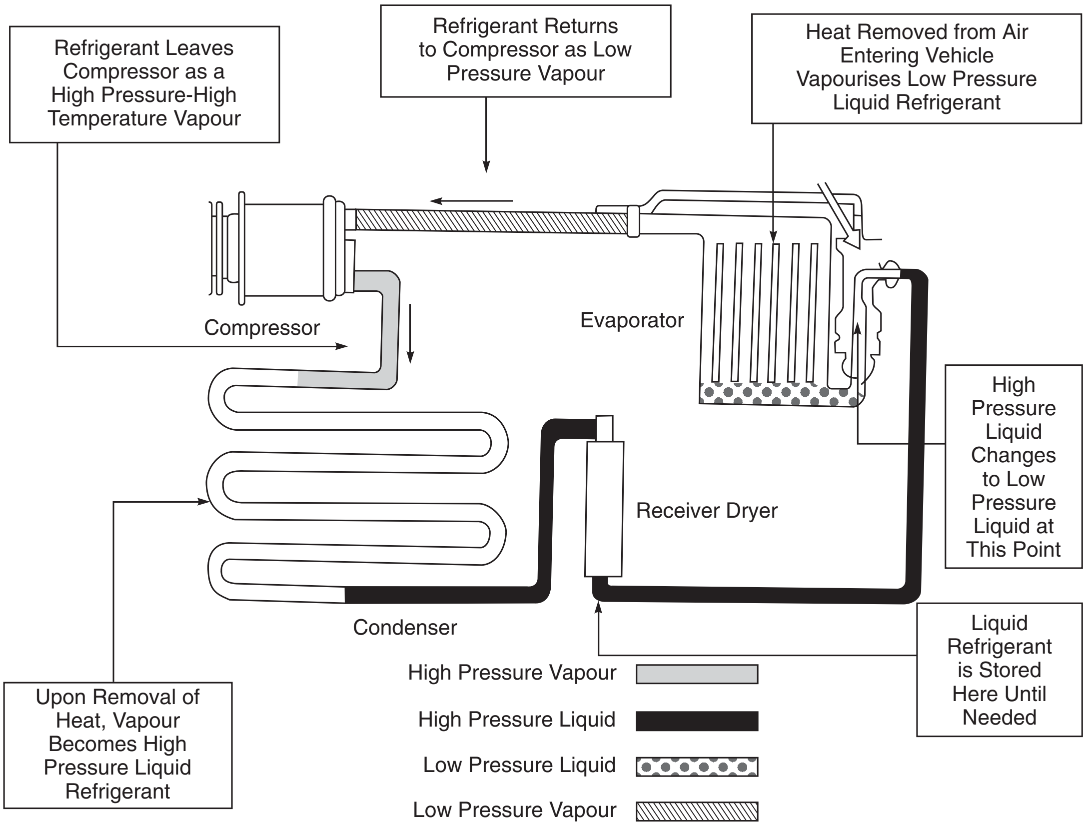



**Fig. 24.7** Basic Refrigeration System

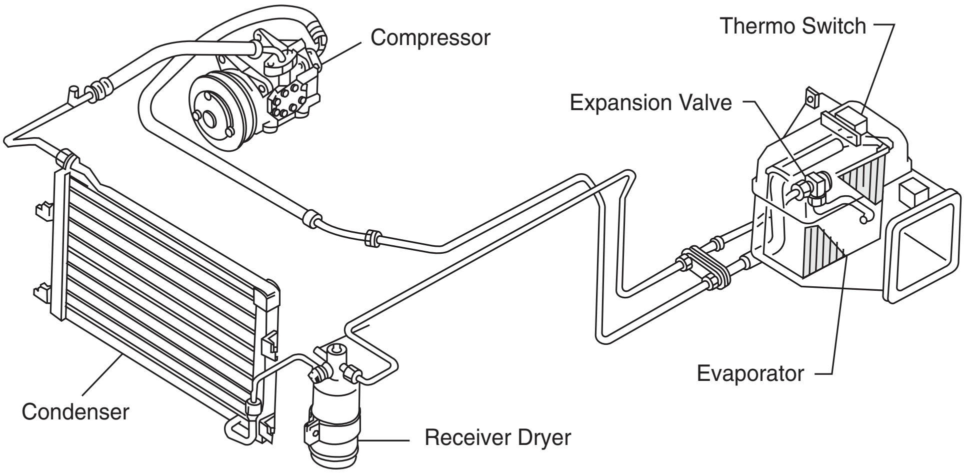



**Fig. 24.8** Expansion Valve Type Air Conditioning System

The liquid Freon 12 passes through the receiver dryer, which serves the purpose of trapping any traces of moisture and acts as a reservoir or receiver. From the reservoir the liquid Freon goes to the expansion valve, which automatically controls the expansion of the fluid from the high pressure circuit to the evaporator coils. The expansion causes the liquid Freon12 to change back to a gas; the heat required by the vapourization process is removed from the air in the passenger compartment, which is forced around the evaporator coils by the blower. Upon leaving the evaporator, the gaseous and cold (about 10° to 21° F, –12° to –6°C) Freon 12 is sucked by the compressor and the cycle starts all over again.

## 24.8 AIR CONDITIONING SYSTEM COMPONENTS

All automotive air conditioning systems have several major components. These include the compressor, condenser, receiver dryer, expansion valve and an evaporator. The major components of an air conditioning system are shown in Fig. 24.8.

### Compressor

The compressor is the heart of the air conditioning system. The primary purpose of the unit is to draw the low pressure and low temperature vapour from the evaporator and compress this vapour into high temperature, high pressure vapour. This action results in the refrigerant having a higher temperature than the surrounding air, and enables the condenser to condense the vapour back to a liquid. The second purpose of the compressor is to pump the refrigerant through the air conditioning system under the different pressures required for proper operation. The compressor is located on the engine and is driven by the engine's crankshaft via a drive belt.

A variety of compressors have been used. They are usually of three types.

**1. *Piston Compressor*** A piston compressor (Fig. 24.9) is driven by a belt from the engine crankshaft. This type of compressor uses two pistons to compress the refrigerant. On piston down-stroke, Freon is drawn through a valve into the compressor cylinder port. As the piston rises, Freon is compressed and valved to the high pressure side of the system. While one position is compressing the refrigerant on an upstroke, the other piston is drawing in Freon on a down-stroke. Compressors may not have an in-line, side-by-side piston. Some compressors may have a piston that is arranged axially or in a vee design. However the basic principle of operation remains the same.

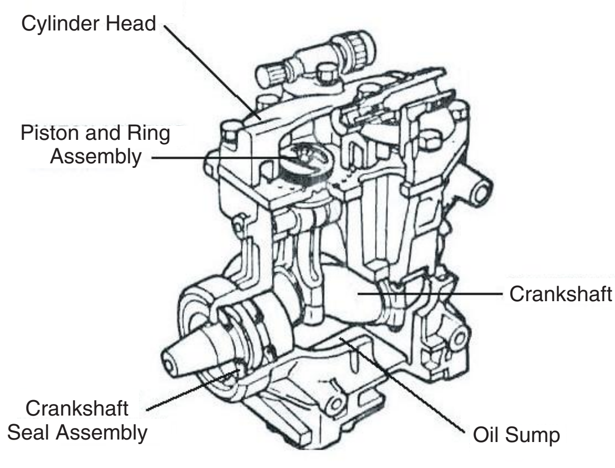



**Fig. 24.9** Pistion Compressor

**2. *Swash Plate Compressor*** The Swash Plate compressor using a swash plate (or axial plate) is used for smooth rotation and a less vibrating operation of the compressor. In Fig. 24.10, the swash plate is attached to the centre shaft at an angle. As the centre shaft turns, the swash plate also turns.

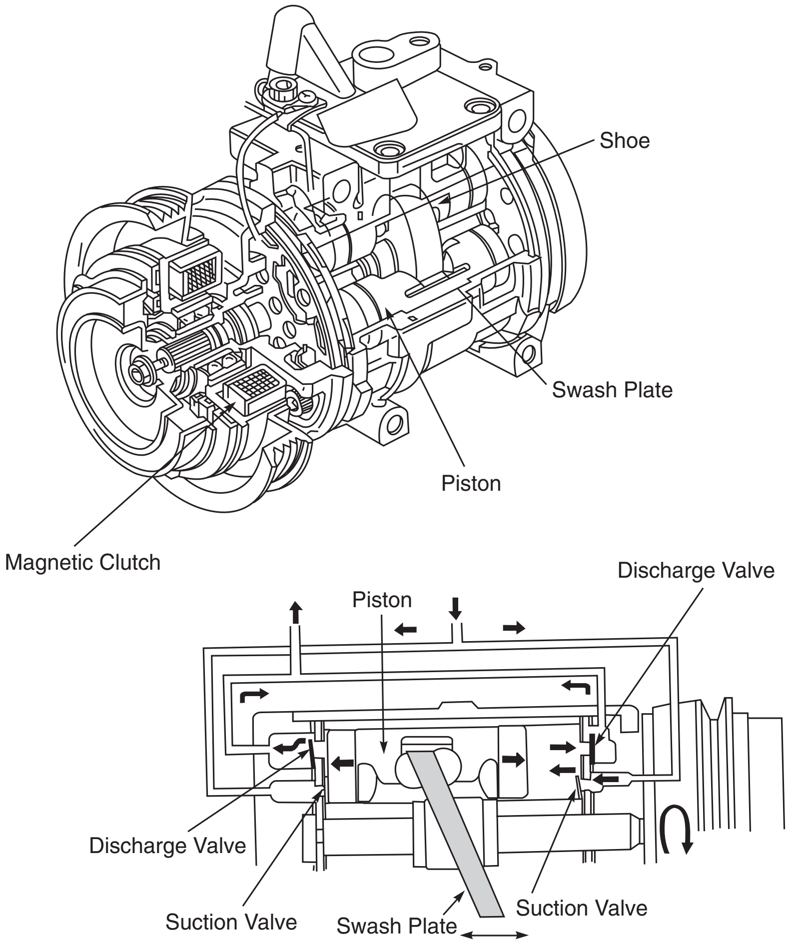



**Fig. 24.10** Swash Plate Type Compressor

This action causes the small piston attached to the swash plate to move back and forth. This reciprocating motion of the piston permits the vapourized refrigerant to be sucked in and compressed. The piston and cylinder form a chamber on each side of the piston. When the piston moves to one side, the refrigerant is admitted into one chamber (intake stroke), and the refrigerant in the other chamber is compressed (compression stroke). Thus the compressor performs two strokes at the same time.

**3. *Rotary Type of Compressor*** The rotary type of compressor (Fig. 24.11) offers the following features as compared to the Swash Plate type.

(a) Quite and less vibrating operations.
(b) Small size and light in weight, which provides better cooling efficiency compared to the swash plate type having the same discharge rate.
(c) This type of compressor is characterized by a round rotor that rotates in an oval chamber and the vanes (generally 4 pieces) which are built in to the rotor.

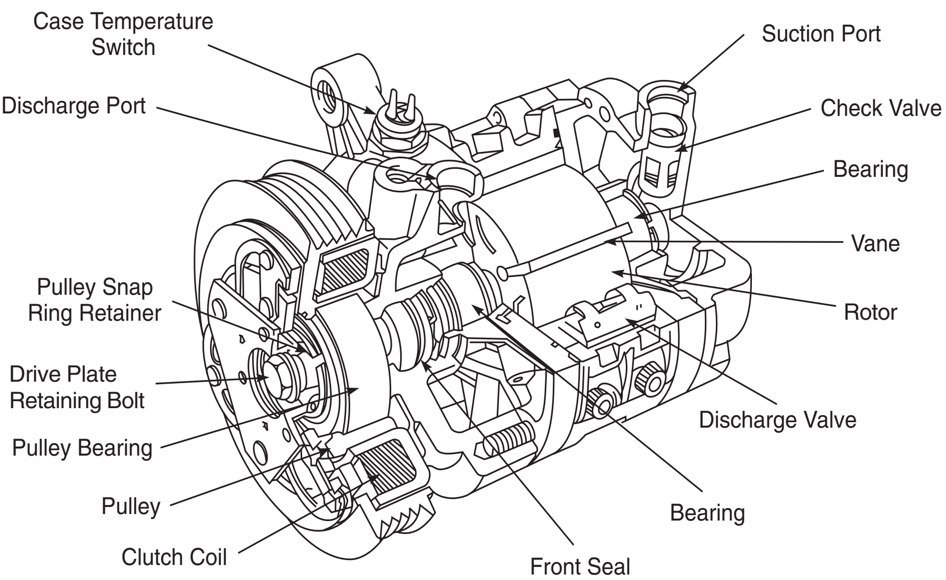



**Fig. 24.11** Rotary Vane Compressor

The working principle of the rotary vane type compressor is shown in Fig. 24.12. When the round rotor makes a quarter turn, a cycle of intake compression and discharge strokes occur. There are eight cycles of operations in all, four cycles in each upper and lower chamber.

Note: Presently most of the compressors in Indian market are of swash plate compressors.

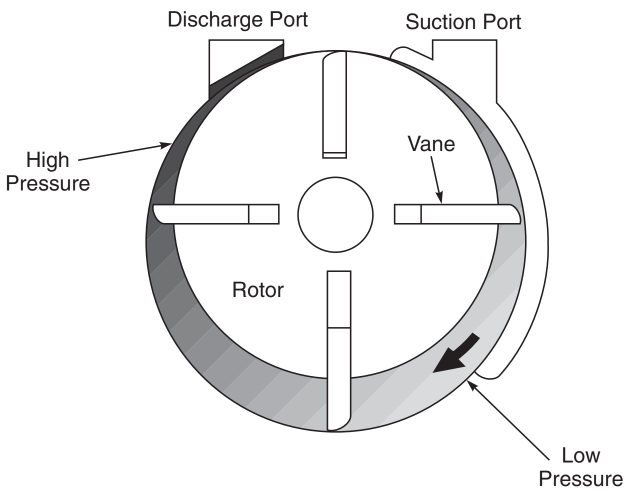



**Fig. 24.12** Sectional View of a Rotary Vane Compressor

## Compressor Clutch

In all air conditioning systems, the compressor is equipped with an electromagnetic clutch as part of the compressor pulley assembly. A compressor clutch disconnects the compressor when it is not is use, allowing the compressor to be driven only when needed. These clutches conserve fuel and reduce needless compressor wear. Figure 24.13 shows the parts of a compressor clutch assembly. The compressor clutch is engaged and disengaged by a magnetic field. When the control calls for compressor operation, the electrical circuit to the clutch is energized. The pulley is connected to the compressor shaft. When the electric circuit is opened, the clutch disengages the compressor. Hence no power is taken from the engine to drive the compressor.

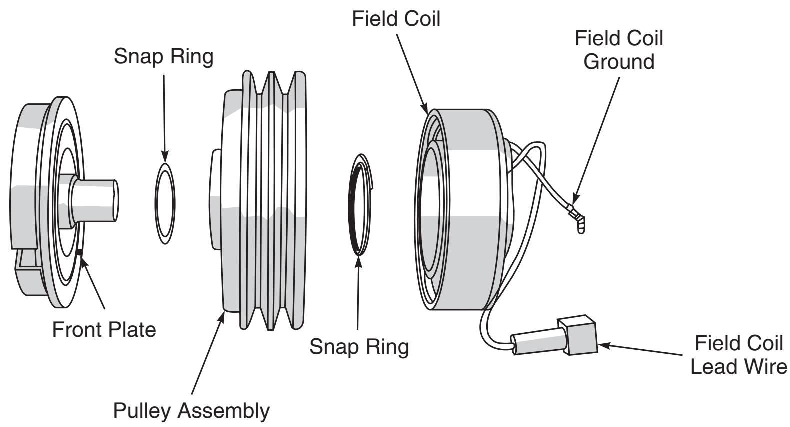



**Fig. 24.13** Parts of a Compressor Clutch Assembly

## Condenser

The condenser is basically a heat exchanger. It consists of a series of tubes and fins as shown in Fig. 24.14. It is mounted in front of the engine radiator. The hot high pressure gaseous refrigerant from the compressor flows into the condenser, where it is cooled by a fast moving air stream. The gaseous refrigerant entering the condenser is thus chilled and changes into liquid. During this gas to liquid change, huge amounts of heat are given up to the air stream and dissipated.

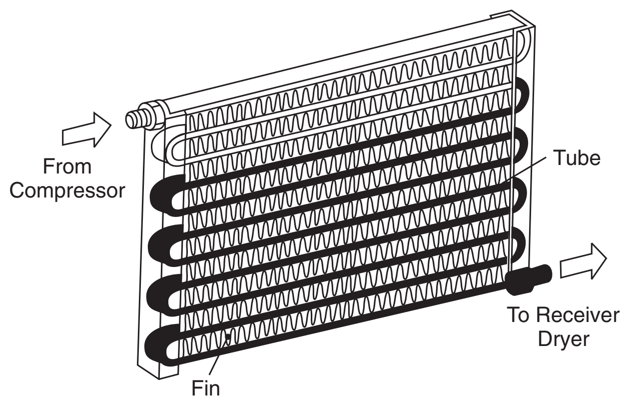



**Fig. 24.14** Condenser

## Receiver Dryer

The receiver dryer unit is placed between the condenser and the evaporator in the air conditioning system as shown in Fig. 24.15. Its purpose is to trap moisture that enters the system during the original assembly or charging. Moisture is an enemy of air conditioning systems because it can react with the refrigerant and corrode the inside of the system. Further, it assures the supply of pure liquid refrigerant to the thermostatic expansion valve. The receiver dryer is used as a storage place for the excess liquid refrigerant until it is needed again by the evaporator. Note that the refrigerant is a high pressure liquid after passing through the condenser.

## Expansion Valve

The car air conditioning refrigerant is a high-pressure liquid when it reaches the expansion valve with its heat-sensitive bulb as shown in Fig. 24.16. The valve performs three functions.

1. It has a metered orifice that changes refrigerant pressure from high to low by allowing the refrigerant to expand.
2. The valve controls the amount of refrigerant allowed into the evaporator. This ensures that all the refrigerant vapourizes before it leaves the evaporator.
3. The expansion valve is sensitive to the changing level of heat exchanged by the evaporator. When air passing over the evaporator becomes warmer or cooler, the expansion valve regulates the amount of refrigerant released into the evaporator.

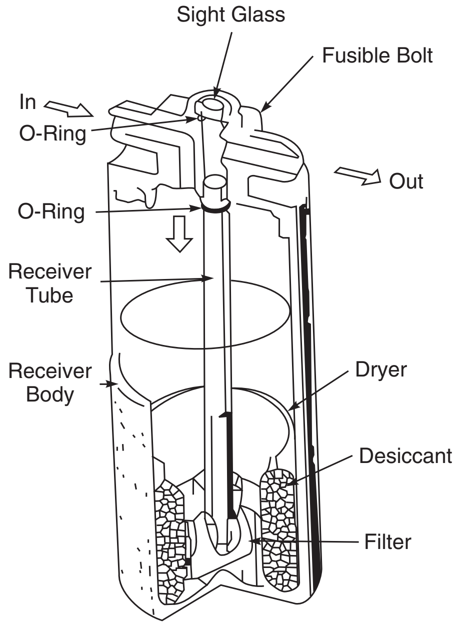



**Fig. 24.15** Receiver Dryer

## Evaporator

The evaporator is a heat exchanger similar to the condenser, but performing a reverse function (Fig. 24.17). In the evaporator, heat is transferred from the air in the passenger compartment to the liquid refrigerant. The refrigerant entering the evaporator fins cools the fins in the process. Thus warm car air circulating around the cold fins releases heat into the evaporator. As heat is applied to the refrigerant, the refrigerant boils and changes to vapour again. As it boils, it is able to absorb huge quantities of heat. The result is a rapid heat loss in the air inside the passenger compartment. When the refrigerant exits the evaporator, it is once again a gas, at low temperature and low pressure. The system then continues to recycle back to the compressor, repeating the cycle.

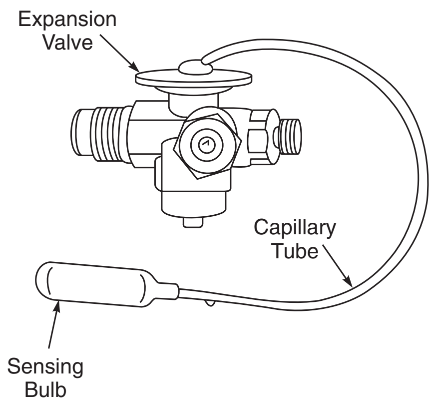



**Fig. 24.16** Expansion Valve

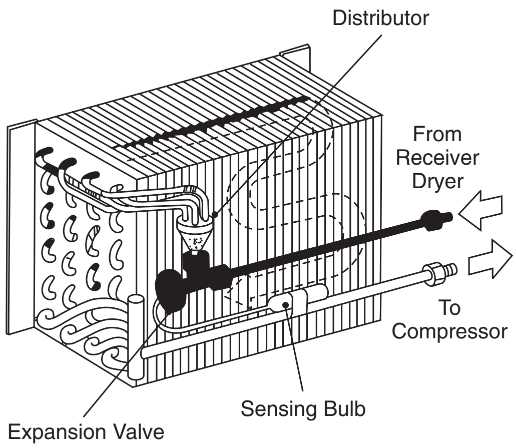



**Fig. 24.17** Evaporator

A thermal sensor is located in the evaporator, to control the temperature of the air circulating in the passenger compartment. This is accomplished by cutting out the compressor by means of the magnetic clutch pulley. When the thermostat contacts are open the pulley idles, and when the contacts are closed the pulley drives the compressor. It is possible, within limits, to manually control the temperature by adjusting the thermostat knob.

### Sight Glass

The sight glass unit is located at the top of the receiver dryer and is meant for diagnosis of troubles. Fig. 24.18 shows the three different states of troubles likely to occur in the air conditioning system. Figure 24.18(a) indicates some bubbles flowing in the system. In this case, the system needs a slight charge. Figure 24.18(b) indicates heavy foaming. In this case, there is very low charge and the system needs more charge. Finally, Fig. 24.18(c) shows oil streaks indicating the absence of refrigerant. In this case, recharging is essential in the system. Such conditions shown by the sight glass indicate that the air has entered into the system or there is insufficient refrigerant thereby resulting in improper condensing in the condenser.

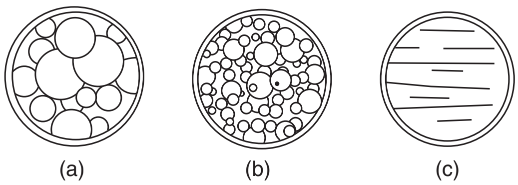



**Fig. 24.18** Sight Glass Showing Different Conditions of Refrigerant

## 24.9 REFRIGERANT AND THE ENVIRONMENT

The substance used to remove heat from the inside of an air conditioned vehicle is called the refrigerant (abbreviated as 'R'). Today there are two major types of refrigerants used in automobiles. One is called R-12 or Freon and the other is called HFC-134a. R-12 is dichlorodifluoromethane ($CCl_2$ $F_2$) and HFC-134a is hydrofluorocarbon-134a. These refrigerants have a very low boiling point (between – 16 and – 22 degrees Fahrenheit). This means that the refrigerant changes from liquid to vapour at these temperatures.

The main requirements in a refrigerant are that it should be noncorrosive, nontoxic, have no effect on moisture, have a high latent heat value, should be oil soluble and not damage rubber seals, gaskets or hoses. Oil solubility is important because the refrigerant circulates through the system with oil. A special oil is added to the air conditioning refrigerant to lubricate the compressor. Keeping in view the above qualities, R-12 is already used as a refrigerant in automobile air conditioning systems.

Over the past few years research has shown that Freon R-12 is one of the major contributors in reducing the ozone layer above earth. The ozone layer is a transparent shield of gases located in the earth's stratosphere (about 10-30 miles above the earth surface). This delicate layer protects against the harmful effects of the sun's ultraviolet rays as shown in Fig. 24.19.

The thinning of the ozone layer has become a world-wide concern. Ozone depletion is caused in part by the release of chlorofluorocarbons (CFCs) into the atmosphere. Freon R-12, a refrigerant, is in the chemical family of CFCs. Since air conditioning systems with R-12 are susceptible to leaks, further damage to the ozone layer can be avoided by not using R-12 in air conditioning units. About 30% of released CFCs are from automobile air conditioning sources.

In 1987, many government agreed (under the Montreal protocol agreement) to phase out over a 10 year period, the use of product CFCs. Thus new types of refrigerants are being tested and are replacing R-12. In 1994, almost all cars in developed countries were equipped with R-134 refrigerant with the redesign of the air conditioning system.

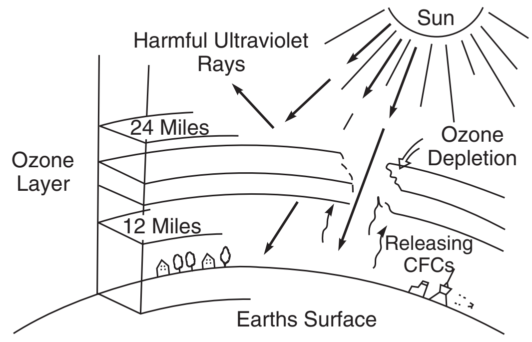



**Fig. 24.19** The Ozone Layer Filters Out the Sun's Harmful Rays

## Refrigerant Leak Detecting Methods

Testing the refrigerant system for leaks is one of the most important phases of troubleshooting. Over a period of time, all air conditioners lose some refrigerant. Refrigerant leaks are most often found at the compressor hose connections and at the various fittings and joints in the system. Any suspected leak should be detected by using any one of the three methods of detection.

**1.** ***Flame (Halide) Leak Detector*** Figure 24.20 shows a flame leak detector and how the flame looks if there is no leak, a small leak, or a large leak. This type of leak detector consists of a combustible gas supply with a small burner on top. A tube from the bottom of this burner forms the probe. When this probe is moved near a large leak, the refrigerant going into the tube combines with the flame to cause a perceptible change in the flame colour.

The following is a guide for colour changes.

- Pale blue flame – No refrigerant is escaping
- Pale yellow flame – very small amount of refrigerant is escaping
- Bright yellow flame – Small amount of refrigerant is escaping
- Purple-tinted blue flame – Large amount of refrigerant is escaping
- Violet flame – Very large amount of refrigerant is escaping

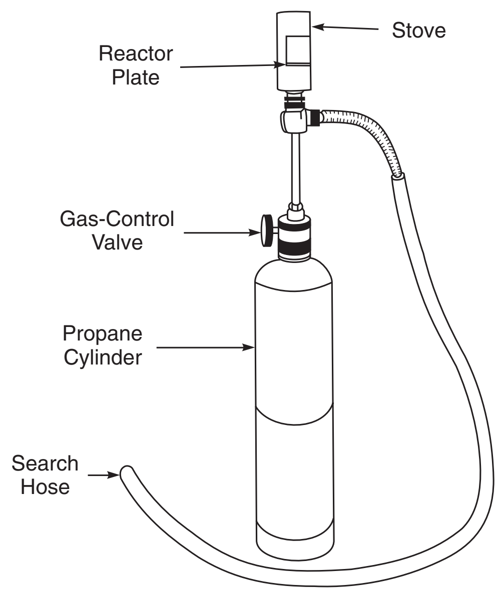



**Fig. 24.20** Flame (Halide) Leak Detector

**2.** ***Electronic Leak Detector*** The electronic leak detector is more sensitive than the flame type detector. Figure 24.21 shows an electronic leak detector. To use the electronic leak detector, place the sensitivity switch in the search position. Turn the control knob clockwise until a steady ticking sound is heard. Then move the probe tip slowly around the various joints in the system. The probe is held at a distance within ¼″ of the joint being checked. When a leak is found, the ticking sound will increase. A large leak will increase the signal to a high pitched squeal. To detect small leaks, move the sensitivity switch to the pinpoint position. The pinpoint setting changes the leak detector sensitivity.

**3. *Fluid Leak Detector*** Leaks can also be located by applying leak detector fluid around the areas to be tested. If a leak is present, it will form clusters of bubbles around the source. A very small leak will cause a white foam to form around the leak source within several seconds to a minute. Adequate lighting over the entire surface being tested is necessary for an accurate diagnosis.

***Note*** *Use this method only when it is certain that the system has positive pressure.*

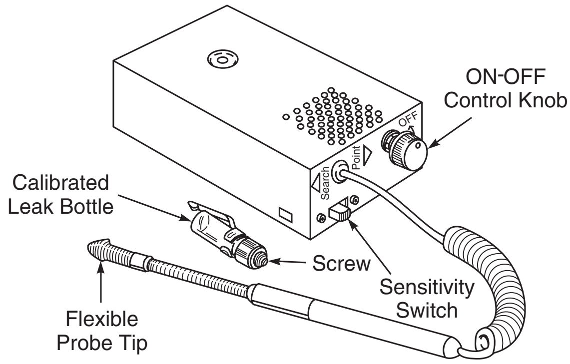



**Fig. 24.21** Electronic Leak Detector

## 24.10 INSPECTION OF AIR CONDITIONER

Always perform a quick visual inspection first, looking for obvious causes of problems. The following visual check are associated with air conditioning.

1. Is the V-belt too loose?
   If the V-beft is too loose, it will be torn off because of slippage. To prevent such trouble, keep the belt tight. Replace a torn belt with a new one.
2. Noise around the compressor.
   Check the compressor mounting bolt and the bracket mounting bolts for looseness and tighten if necessary.
3. Noise from inside the compressor.
   This may indicate that either a delivery or suction valve has been damaged or that the connecting rod has become loose.
4. Mud and dirt on the condenser and fins.
   If the condenser and fins are fouled with mud or dust, the cooling effect of the condenser will decline to a marked degree and the room cooling capacity of the air conditioner will also be reduced. Be sure to wash the mud and dust off the condenser. If the condenser fins are washed with a hard hair brush, they will be scratched or bent. Therefore, clean them very carefully.
5. Dirty connection and portions with oil.
   The presence of oil indicates that the refrigerant is leaking. The compressor oil contained in the refrigerating gas escapes from the cycle together with the leaking refrigerant. Consequently, the gas leaking portions get fouled with oil. If any place has become dirty with oil, retighten the fastener or replace the related parts to prevent gas leakage. Oil stains are frequently found in compressor gaskets and piping connections, so check these portions carefully.
6. Noise around the blower.
   Run the blower at low, medium, and high speeds. If you notice any abnormal operating noise or unsatisfactory rotation, replace the blower motor. However, before replacing the

blower motor, see if the noise is caused by foreign matter stuck in the motor or if the motor is running unsatisfactorily because of loose parts.

7. Checking the quantity of refrigerant through the sight glass.
   When many air bubbles are seen through the sight glass, it indicates a lack of refrigerant. In this case, see if there are any oil stains and confirm that the refrigerant is not leaking from any point. If no air bubbles are seen through the sight glass even when the condenser is cooled with water, it indicates that too much refrigerant has been charged into the condenser.

## 24.11 TROUBLESHOOTING

The troubleshooting methods provided in Table 24.1 and Table 24.2, list the most common operating faults along with the possible causes and suggested checks and correction for each. The tables are intended to provide a quick reference to the cause and correction of a specific fault.

***Note*** *Air conditioners are expensive and complex, so it is advisable to start servicing and repairing with a look at a manufacturer service manual.*

**Table 24.1** Troubleshooting of a Heating System

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Heater blower does not work even when its switch is ON | (a) Blower fuse blown | Replace fuse to check for short. |
| | (b) Blower resistor faulty | Check continuity. |
| | (c) Blower motor faulty | Replace motor. |
| | | Repair as necessary. |
| 2. Incorrect temperature output | (a) Control cables broken or binding | Check cables. |
| | (b) Air damper broken | Repair damper. |
| | (c) Air ducts clogged | Repair air ducts. |
| | (d) Heater radiator leaking or clogged | Replace radiator. |
| | (e) Heater hoses leaking or clogged | Replace hoses. |
| 3. Coolant leaks | (a) Hose or hose connection broken/cracked. | Check hoses, hose connections, heater core, water valve |
| | (b) Water valve defective | |
| 4. Too much heat | (a) Temperature-door cable out of adjustment | Readjust |
| | (b) Engine-cooling system thermostat stuck closed | Replace thermostat |
| 5. Insufficient defrosting | (a) Defrost-door control cable out of adjustment | Readjust cable |
| | (b) Defrost outlets blocked | Remove obstructions |
| 6. Vent door does not operate | (a) Defective vacuum motor, leaky vacuum connections, or a defective control assembly | Check vaccum motor. Either repair or replace |
| | | Check vacuum connections and tighten. |

*Contd.*

*Contd.*

| | | |
|---|---|---|
| | | Have a thorough inspection of the control assembly. |
| 7. Controls hard to operate | (a) Loose or binding control cable or a sticky door | Repair |

**Table 24.2** Troubleshooting of an Automobile Air Conditioning System

| *Trouble* | *Cause* | *Remedy* |
|---|---|---|
| 1. Insufficient cooling | (a) Low air flow | Check blower option. Check for obstruction in air distribution system. Check for clogged evaporator. If iced, de-ice core and check adjustment and operation of suction throttle valve. |
| | (b) Defective heater temperature control valve | Check operation of valve. Adjust or replace as necessary. |
| | (c) Heater controls or ventilator control not in the "off" position. | Advise operator to correct operation of controls. |
| 2. Compressor discharge | (a) Engine overheated | Check for possible cause. |
| pressure too high | (b) Overcharge of refrigerant or air in system | Systems with excess discharge pressures should be slowly depressurized. |
| | | 1. If discharge pressure drops rapidly, it indicates air (with possibility of moisture) in the system. When pressure drop levels but still indicates in excess of specifications, slowly bleed system until bubbles appear in the sight glass and stop. Add refrigerant until bubbles clear, then add one-half pound of refrigerant. Recheck operational pressures. If system pressures still remain above specifications, and the evaporator pressure is slightly above normal, then a restriction exists in the high pressure side of the system. |
| | | 2. If discharge pressure drops slowly, it indicate, excessive refrigerant. If pressures drop to specifications and sight glass remains clear, stop depressurizing and recheck operational pressures. If pressures are satisfactory, depressurize until |

*Contd.*

Contd.

| | | |
|---|---|---|
| | | bubbles appear. Then add one-half pound refrigerant. Recheck operational pressures.<br>3. If discharge pressure remains high after depressurizing the system, continue depressurizing until bubbles appear in the sight glass. If evaporator pressures also remain high, there is a possibility of a restriction in the high pressure side of the refrigeration system, or the suction throttle valve may require adjustment. |
| | (d) Restriction in condenser or receiver liquid indicator. | Remove parts, inspect, and clean or replace. |
| | (e) Condenser air flow blocked | Clean condenser and radiator core surfaces as well as the space between the condenser and radiator. |
| | (f) Evaporator pressure too high | See 4. Evaporator pressure too high. |
| 3. Compressor discharge pressure too low | (a) Insufficient refrigerant | Check for presence of bubbles or foam in liquid indicator. If bubbles or foam are noted (after five minutes of operation), check system for Leaks. If no Leaks are found, refrigerant should be added until the sight glass clears, then add an additional ½ lb. |
| | (b) Low suction pressure | See 5. Evaporator pressure too low. |
| | (c) Defective compressor and/or broken compressor reed valves. | Repair compressor. |
| 4. Evaporator pressure too high | (a) Thermostatic expansion-volve capillary-tube bulb not tight to evaporator outlet tube | Check for tightness. |
| | (b) Thermostatic expansion valve improperly adjusted or inoperative. | Replace valve. |
| | (c) Suction throttle valve adjusted improperly or defective. | Check operation of suction throttle valve. Repair valve, if necessary. |
| | (d) Vacuum modulator defective. | There should be no vacuum in the suction throttle valve when “cool” level on the instrument panel is on maximum “on” position. Replace vacuum modulator if defective. Note: If compressor suction line from suction throttle valve is ex- |

Contd.

*Contd.*

| | | |
|---|---|---|
| | | tremely cold than the suction throttle valve inlet line from evaporator, this indicates that suction throttle valve outlet pressure is much lower than inlet pressure, and suction throttle valve may be defective. |
| 5. Evaporator pressure too low | (a) Valve capillary tube broken, inlet screen plugged, or valve otherwise failed. | Replace valve or clean inlet screen of valve. |
| | (b) Restriction in system tubes or hoses. | Replace kinked tube or restricted hose. |
| | (c) Suction throttle valve adjusted improperly or defective. | Check operation of suction throttle valve. Repair if necessary. |

## Review Questions

1. State the purpose of the ventilation system.
2. Describe the purpose of the heating system.
3. What are the troubles occurring in the heating system?
4. Describe the various parts of the heating system.
5. Explain the function and operation of the heater control panel.
6. Explain the purpose and operation of an automobile air conditioning system.
7. Enlist the major components used in an air conditioning system and explain their functions.
8. Explain how a compressor clutch works.
9. Why is a receiver dryer used in the air conditioning system?
10. What are two types of refrigerants commonly used in automobiles?
11. Discuss refrigerant importance and its effects on the environment.
12. What is the purpose of sight glass? How does it help in diagnosing troubles?
13. List the visual checks carried out to locate air conditioning troubles.

# 25

# Maintenance of Automobile Body and Painting

**Objectives**

After studying this chapter, you should be able to

- Describe the causes of corrosion and their prevention.
- Explain how to a prepare the vehicle body for painting.
- Elaborate various steps involved in carrying out painting work for a automobile vehicle.
- Explain the spray painting processes.
- Define and illustrate sophisticated precision spray and bake booth system.
- Develop proper attitudes concerning body care and maintenance of automobile vehicles.

## 25.1 AUTOMOBILE BODY

Earlier Automobiles had wooden bodies with wooden framework and laminated material of wood like plywood, mica etc. Due to increase in the demand of automobiles, new stamping techniques for sheet metal were developed with the help of different dies and heavy presses, so as to get the right shape using jigs and fixture. Different body panels and stampings are assembled together by spot welding in an all-steel-body shell. In this chapter we shall discuss various processes involved in automobile maintenance.

***Prevention of Corrosion*** It is important to take good care of vehicles to protect them from corrosion. Keep the vehicle, particularly under frame of the body, as clean and as dry as possible. Repair damage to the paint or protective coating as soon as possible.

***Common Causes of Corrosion*** Some common causes of corrosion are:

1. Accumulation of road salt, dust, moisture or chemicals in hard to reach areas of the vehicle underframe or frame.
2. Chipping, scratches and any damage to treated or painted metal surfaces resulting from minor accidents or abrasion by stones and gravel.

***Some Environmental Conditions Accelerating Corrosion are:***

1. Road salt, dust, chemicals, sea air or industrial pollution.
2. High humidity particularly when the temperature range is just above the freezing point.
3. Moisture in certain areas of a vehicle for an extended period of time.
4. High temperatures cause an accelerated rate of corrosion to parts of the vehicle which are not well ventilated to permit quick drying.

***Some Methods Adopted to Prevent Corrosion are Listed below***

1. Wash your vehicle frequently to preserve the finish on the vehicle and to help avoid corrosion. In case of a drive on salted roads, wash once a month in winter.
2. Remove foreign material deposits such as salts, chemicals, road oil or tar, tree sap, bird droppings and industrial fall out which may damage the finish of the vehicle if left on painted surfaces. Remove these types of deposits as quickly as possible. Use a cleaner which is not harmful to the painted surface.
3. Repair any damage to finish carefully and in time to the painted surfaces. Any chip or scratch in the paint should be touched up immediately to prevent corrosion right from starting. A body shop should make a repair if the scratches have gone through to the bare metal.
4. Keep the passenger and luggage compartments clean. Moisture, dirt or mud can accumulate under the floor mats and cause corrosion. Frequent checks are necessary. Certain cargos should be transported in sealed containers.

## Vehicle Care

Vehicle care should be carried out regularly with the following points in mind.

1. Store the vehicle in a dry, well ventilated area. Do not apply additional under coating or rust preventive coating on or around the exhaust system components. A fire could result if the under coating substance gets overheated.
2. Protect the vehicle with a cover if a garage is not available. Years of exposure to midday sun can cause the colours in paint, plastic parts and fabrics to fade. A high quality, breathable vehicle cover can protect the finish from harmful UV rays in sunlight, from dust and air pollution.
3. Ensure safety. Do not wash and wax the vehicle with the engine running. While cleaning the underside of the body and tender, avoid injury to your hand from sharp edged parts. Use hand gloves. After washing, check up brakes before driving for safety.
4. Cleaning the vehicle—When cleaning the outside or the inside of vehicle, do not use volatile cleaning solvents such as acetone, lacquer thinners, enamel reducers, nail polish removers, laundry soaps, bleaching or reducing agents etc. Never use carbon tetrachloride, gasoline, benzene or naphtha for any cleaning. Use proper cleaning techniques and cleaners while cleaning the interior for which vacuum cleaners may be used for dirt. Safety belts can be cleaned with only mild soap and luke warm water. Glass surfaces should be cleaned on a regular basis. Use of a glass cleaner will remove tobacco smoke and dust films. Never use abrasive cleaners on any vehicle glass to avoid scratches. The exterior paint finish providing beauty should be taken care of. Frequent washings with luke warm or cold water will help. Do not use a strong soap or a chemical detergent. Periodic polishing and waxing will help to maintain the shine. Special care with aluminum parts is to be taken. Never use auto or

chrome polish, steam or caustic soap to clean aluminum. A coating of wax, rubbed to a high polish is recommended for all bright metal parts. Wheels and wheel covers, should be regularly cleaned to preserve original appearances.

When cleaning the interior or vinyl upholstery, apply solution of soap or mild detergent with warm water with a sponge or soft cloth, let it soak for few minutes to loosen dirt and rub the surfaces with a clean cloth. Damp cloth to remove dirt and soap solution.

When cleaning the fibre upholstery, a vacuum cleaner can be used to remove the dirt. Use a mild soap solution, rub with a clean damp cloth and remove the stains.

5. Washing the vehicle—Flush the underside of body and wheel housings with pressurised water to remove mud and debris. Avoid steam or hot water more than 80°C on plastic parts. Use soft sponge or brush which does not give scratches to the paint. Wash the entire exterior with a mild detergent or car wash soap, using a sponge or soft cloth. Soak the sponge frequently in soap solution. After removing the dirt completely, rinse off the detergent with running water. Wipe off the vehicle body with a wet cloth and allow it to dry in shade. Touch up where necessary. After washing and waxing the vehicle, polishing may be done to protect and beautify the paint. Use quality wax and polishes.
6. Foreign material deposits—Calcium chloride and other salts, ICC melting agents, road oil and tar, tree and bird droppings, chemicals from industrial chimneys and other foreign matter may damage the vehicle finish if left on the unpainted surface. Prompt washing may not completely remove all of these deposits. Other cleaners may be needed which may be safe for use on painted surfaces.
7. Damage to finishing - Any stone chips, fracture or deep scratches in the finish should be repaired promptly. Bare metal will corrode quickly and may develop into a major repair expense. Minor chips and scratches can be repaired with touch-up materials. Large areas of finish damage can be corrected by a body service dealer and paint shop.
8. Underbody parts such as fuel lines frame, floor pans and the exhaust system should be saved from corrosion, including every spring. Flush materials from the underbody with plain water. Clean any areas where mud and other debris can collect.

## 25.2 AUTOMOTIVE PAINTS AND PRIMERS

It is a general practice to thoroughly clean the steel structure and apply protection treatment with the help of paints and primers. Before applying the primes, the loose scale and rust have to be removed. For specified undercoat and finishing coat, standard primers and paints have to be applied which are discussed in this section.

The various steps of operations for doing painting work.

**1. *Preparation of Surface of Steel Body (Scrapping)*** Clean the surface with kerosene oil and emery papers. In case of rusty surface, the crude method of cleaning with brick and water may also sometimes be used. Wash with water thoroughly and wipe off with petrol. The surface should be thoroughly cleaned and should be free from rust, wax, grease etc.

**2. *Red-Oxide Primer Application*** After the surface is ready in a dry condition, the primer may be brushed or sprayed after appropriate thinning. The surface dries in half an hour and hardens with excellent adhesion in about 6-8 hours. The primer surface is recommended to be dry cut with a zero number sand paper before the application of the subsequent coat. The primer, ideally suiting for conventional uses, can be applied for over spraying of nitro cellulose lacquers containing powerful solvents without any danger of lifting. Being formulated with a selected anticorrosion pigment and specially prepared with a synthetic binder, it renders superb electrolytic protection. Two coats of primers are to be given. Rub with 320 number emery paper. Now it is ready for the next operation.

Some primers (automatic finish) which are commonly used are:

- Tractor – Red-oxide oil primer
- ESDEE – Syncoat synthetic enamel
- ADDISONS – Duroflex synthetic finish
- DUCO – Primer – NC Primer thinner – Petrol thinner
- NC touch-up primer brown
- Zinc chromate primer

**3. *Surfacer Application*** After the application of primer over a prepared surface and drying, it is now ready for putting the surfacer. Quick touch-ups and repair work can be done on the bare metal in the initial stages and finished with a lacquer prime surfacer. Put putty, if necessary and rub with 150 number emery paper. Finally, when dry and a good base is available, apply the surfacer. Lacquer primer surfacer should be applied in two coats. (One part of lacquer primer to 1 1/2 parts of thinner). Rub with 400 number emery paper. Dry immediately.

(Thinner - F 2486. Best result, F-2440 - less expensive, F-2424 - Avoids blushing.)

**4. *Colour Application*** Clean the surface thoroughly with water, wet sand paper, water proof emery paper (no. 400) for an uniform and smooth finish before application of the finish coat. Ensure that the metal is not exposed during wet sanding. In case of exposed metal surfacer touch up the area with red-oxide primer, putty and NC primer surfacer. After the surface is dry, apply two coats of auto paint (1 part of finishing paint with 1 part of thinner by volume). Allow an interval of 10 minutes between the coats. These automatic paints are specially developed to give better gun gloss, higher film build, superior performance in terms of weathering and durable characteristics, colour retention and brightness with quick drying.

Some commonly used automatic paints are:

- DUCO super acrylic automatic paint
- ESDEE sparkle metallic finish
- ICI auto colour - permobel Metallic paint
- Nerolac auto paint
- ASPA Asian paint

No two different grade/company colours should be mixed.

**5. *Finish and Polish*** After drying for one or two hours and using water rubbing component, use the silicon polish. A varnish hardener may then be sprayed.

A typical example of the preparation of automobile body while using DUCO brand paint is given in Table 25.1.

## 25.3 SPRAY PAINTING GUN AND DRIVE

Manual painting with the help of brushes doesn't give uniform thickness of paint and a smooth finish. As a result the paint comes off and the body becomes spotted. Therefore, the guns for spray painting using compressed air have been devised for this process.

**Table 25.1** Preparation of Automobile Body While Using DUCO Paint

| *Metal Surface Preparation - P80/120* | *2 coats* |
|---|---|
| DUCO Oil Primer : DUCO thinner (4 : 1) | 4 hrs dry rub with 320 emery |
| Primer Surfacer - PS Grey : DFT (30-35 microns) 1 : 1.5 | 2 coats dry immediately. Rub wet with 400 emery |
| Putty Application—DUCO Putty | 1 coat very thin film, 4 to 6 hrs dry in air. Rub with 400 emery |
| Sealer Coat- P.S. Grey : DUCO Thinner (1 : 1.5) | 1 coat, 4 hrs. dry. Rub with 600 emery |
| Top Paint Coat 1 and 2—Paint : DUCO Super Arcylic Thinner (1 : 1.5) | 2 Coats 15–20 min. dry. |
| Top Paint Coat 3 and 4—(1 : 1.75) | 2 coats 15–20 min. dry. |
| Application of polish—Silicon Polish | 1 coat, very thin film |

## 1. Spray Gun

The spray gun shown in Fig. 25.1 is to be connected to the uniform supply of compressed air at pressure (40 to 60 psi) from 2.80 to 4.20 kgs/sq.cm. It consumes about (5–7 cfm) 140 to 200 litres per minute at this pressure, depending on the quality of the material to be applied. The material to be used should be stirred and thinned according to the manufacturer's instructions. Strain the material into the cup through the gauge and fill the cup about three quarters full. Hold the gun by the cup when removing or replacing the cover and ensure that the vent hole in the cover is always clear.

The fluid flow is controlled by the trigger but the maximum volume may be controlled by means of the needle adjusting screw. The volume is decreased when the needle adjusting screw is screwed in and increased when it is unscrewed.

The spray produced can be varied from a round spray to a wide fan pattern by means of the spreader control valve. The round spray can be obtained when the spreader control valve is fully closed and as it is unscrewed, the width of the pattern is gradually increases. For horizontal work, the air cap jaws are set in a vertical plain and in a horizontal plain for vertical work. The air cap locking nut must be screwed to grip the air cap firmly to prevent air leakage at this point and allow the operator to turn the air cap by hand.

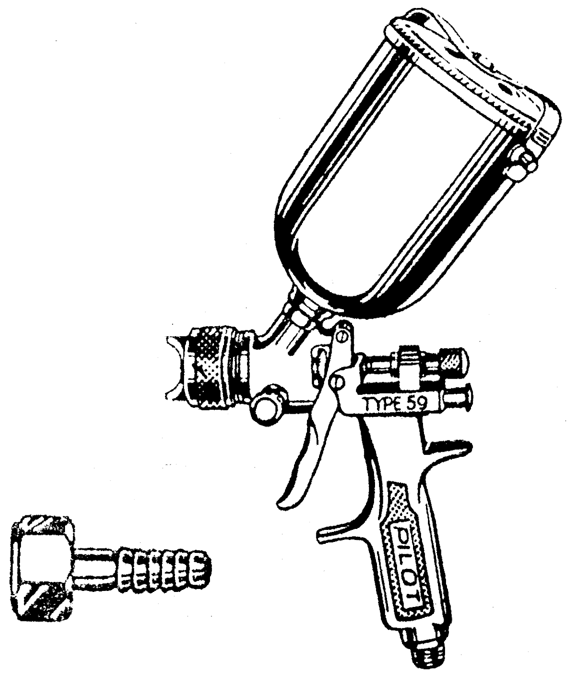



**Fig. 25.1** Spray Gun

## 25.4 SOPHISTICATED PRECISION SPRAY AND BAKE BOOTH

The sophisticated precision spray and bake booth are of high-end type with regards to both aesthetic and technical features specially designed for automobile repair shops and garages for heavy duty work. These may be used for vehicle production like bus, car, truck painting etc. ensuring ultimate fit and high finish quality (Fig 25.3 and Fig 25.4).

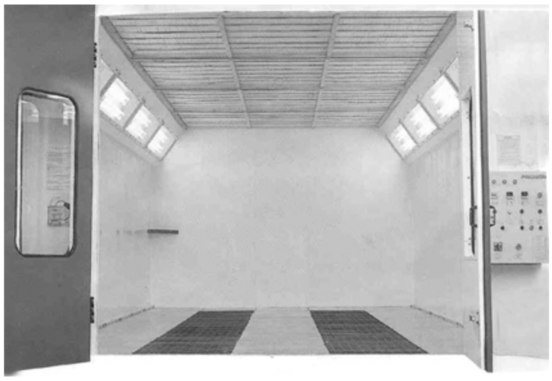


**Fig. 25.3** Sophisticated Precision Spray Bake Booth

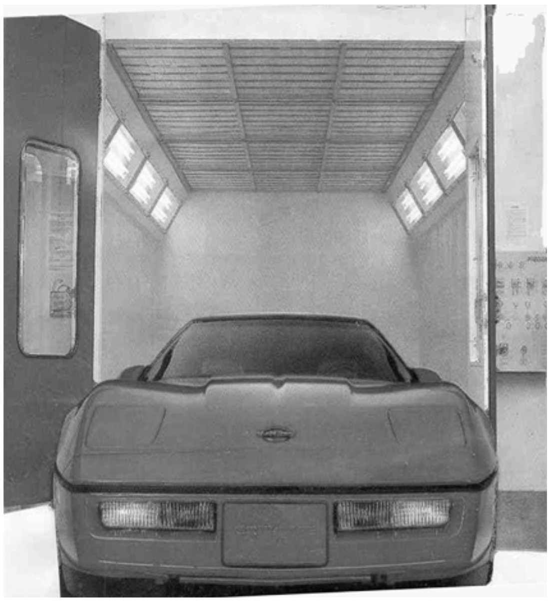


**Fig. 25.4** Sophisticated Precision Spray Bake Booth with Car

**1. *Quality*** The spraymate is built using pre-coated galvanized sheet metal for protection and durability. All the panels are bolted together rather than riveted or welded, making it a long lasting and rust-free installation. Safety glass is used in doors and lights and the electrical components supplied are pre-wired, making it very fast, simple and fool proof to connect.

The side walls consist of double walled monoblock elements with insulation, sandwiched in between and featuring the tounge and groove type of joints between the lengths of the two panels for an air tight fit.

The front door has three folds, two of which are connected together and have a locking system consisting of an internal rod activated system to ensure straightness of door panel and air tightness. One fold which opens independently is used as a service door and is fitted with-pressure activated door catch. Some parts are imported, e.g. diesel burner, some switch gear and filters etc. Spraymate series of booths feature double wall insulated panels with tounge and groove joints in between for a better air tight fit by design itself, in order to keep the heat within the unit, save energy and reduce noise level.

Spraymate (6 m or 7 m) booths are fitted with a 5.5/7.0 HP motor directly coupled to a reverse blade turbine fan which has an air capacity output of around 20% more than the cheaper and less efficient solution of a belt driven system generating less air pressure and therefore resulting in frequent filter changes.

The more reliable and efficient turbine system allows for approximately four or more air changes per minute in the empty booth, a value that is excellent considering that in many competition booths it is just around two to three air changes per minute. The advantage being that over spray is completely eliminated and filter life is extended.

The spraymate indirect fire heating unit in stainless steel is fitted with a high capacity diesel burner which allows for a suitable baking temperature all year round. The specific design allows us to introduce 100% fresh air into the booth while painting and then by means of a fully automatic damper, to recycle about 80% of the booth air during the baking cycle. About 20% of fresh air is replaced at all times in order to evacuate the gas that evaporates from the paint when drying. Here there are large surface area pocket type replaceable intake pre-filters, and full width branded ceiling filters which guarantee an even air flow within the booth chamber. Spraymate features full width ceiling filters.

**2. *Booths with Motorised Extraction System*** Both the spraymate models 6 and 7 are available with a single motor or with a double motor system. The single motor booths have a heating/ventilating unit which blows air into the booth. The air is then forced out by the fresh incoming air. This type of down draft booth is always pressurized and the booths' internal pressure is determined mainly by the degree of clogging of the under-grating filters.

Double motor booths are the same as the single motor type but with the addition of a motorized air extraction unit, which has the double function of sucking the air out of the booth and filtering it at the same time. Because of the extraction unit, which is fitted with a damper, it is possible to adjust the booth internal pressure according to one's preference, allowing for better painting conditions even in the case of partially clogged under-grating filters. The extraction unit is fitted with pocket type filters for additional filteration of the exhaust air. Overall, a two motor system is more efficient than a single motor type.

**3. *Advanced Control Panel*** The spraymate is controlled by an advanced control panel featuring double digital displays, separate for spray and bake modes and an automatic electronic timer for controlling the bake time. It also features automatic control for change-over from spray to bake mode and a host of safety features.

**4. *Booth Floors*** Depending on whether the booth is required above ground or not, it is available in two versions:

(a) *Above ground* or *metal basement type*: It is on a 40 cm high metal base and one can enter the booth using ramps. It does not need foundation work. Alternatively, it can also be fitted into the ground digging a 40 cm deep pit, so one can enter the booth without the need for a ramp.

(b) *Pit version*: In this, one has to make an air exhaust pit and foundation work underneath the booth floor in order to allow the exhaust air to flow out of the booth through the floor grates.

**5. *Safety Features*** We have to ensure:

- Maximum temperature thermostat switch is set at 99°C to cut off the diesel burners in the event of failure of the programmable thermostat to control the set temperature.
- Pressure manometers should display the differential pressure in mm Hg across the inlet filters and extraction (optional).
- Pressure manometer should display the pressure inside the booth chamber.
- Negative pressure switch should locally cut off the supply to the booth in the event of a drop in pressure inside the chamber (below – 4 mm Hg (optional)).

- Automatic door opening is necessary in the event of a rise in pressure beyond 12 mm Hg inside the booth.
- The emergency OFF master switch should be on the control panel.
- All glasses should be safety glasses.

**6.** ***Paint Mixing Room*** The paint mixing room has to be designed to provide a clean, well-illuminated, well ventilated area for paint mixing operations.

(Approx. - Dimensions - Mixmate : 2.5 m length × 2.5 m width × 2.6 m height.)

**7.** ***Preparation Stations*** Preparation stations are created to handle the complete surface preparation before applications of paint. There are several options available.

**8.** ***Apollo Series of Booths*** Apollo series of booths have been introduced because of general demands of a low cost but a professional spray bake booth for small and medium sized businesses. Apollo is an excellent combination of size, quality, efficiency and price.

(Internal dimensions—6.4 m length × 3.75 m width × 2.6 m height.)

## 25.5 BODY CARE AND MAINTENANCE

Body care and maintenance involve the following main parts:

- Protecting the car
- Paint body
- Undercarriage
- Interior
- Windows
- Engine compartment
- Cleaning plastic parts
- Vehicle storeup recommendations

**1.** ***Protecting the Car*** The car body must be protected from corrosion due to air pollution, air born salt and humidity, and seasonal conditions, road salt, etc.

- Dust, dirt, sand, mud, gravel kicked up by other cars are all abrasive and may damage the paint and underbody.
- Use of corrosion and abrasion—resistant paints and painting methods, use of highly resistant galvanised sheet steel; spraying the underbody, wheel arches and other hollow spaces in chassis member with protectine wax scalants: application of protective resins to door sills, rocker panels, mudguards etc; use of pollution-resistant channels; use of open box type cross and side member construction to prevent the build up of water and the formation of rust, can take care of all the aspects.

**2.** ***Paint Body*** The body paint not only makes your car beautiful, it also protects the sheet steel used in construction.

Chips or scratches should always be touched up immediately to prevent rust. Make sure to use original touch-up paint.

Wash your car regularly. Remember to wash more frequently in areas with high levels of air pollution or when parking under trees (sap may drip onto the car). In addition, bird droppings should be immediately removed as uric acid is particularly damaging the paint.

Wash the car using a low-pressure jet of water. Sponge gently with a 2-4% solution of car wash. Rinse the sponge often. Rinse the car thoroughly and then dry it with a jet of air or a chamois-leather.

Dry the car carefully including less visible areas such as the door frames, bonnet and headlight housings—those areas where water can easily stagnate. Do not park in a closed garage immediately after washing to allow air to circulate and dry the remaining water.

Do not wash the car after it has been parked in the sun or if the bonnet is still hot to prevent damage to the high gloss finish.

The occasional use of wax or silicone polish will protect the car's paint and retain its original lustre. If the paint becomes dull due to smog or other factors, use a slightly abrasive wax polish.

**3. *Undercarriage*** The less visible body parts and box-type members have to be treated by using state-of-the-art techniques.

However, get the car checked regularly, especially if frequently driven it in adverse climatic conditions. Underbody inspections should be performed to ensure that the metal and mechanical assemblies are in good condition.

In very severe climates, the chassis box sections and door frames should be periodically sprayed with protective compounds.

These protective materials should be applied by specialised body shops. Spray at least once every two years (annually under very severe conditions) at the beginning of winter.

**5. *Interior*** It is also extremely important to take care of the car's interior. Check to make sure there is no standing water under the mats from shoes or umbrellas that could cause corrosion.

Remove dust from seats and cloth upholstery with a soft brush.

Grease stains can be removed using an appropriate upholstery dry cleaning product. Always make sure to follow the manufacturer's instructions very carefully.

If the seats are very dirty, try using a sponge dampened in soapy water (2-4 grams of detergent per liter). Rub gently using a chamois-leather or damp cloth to remove dry dirt from leather seats.

Liquid or grease stains can often be removed with a dry, absorbent rag (do not rub). If one is unable to remove the stain, try rubbing very gently with a chamois-leather or soft cloth moistened with soapy water.

**6. *Windows*** Use an appropriate window cleaner and a clean rag to prevent streaking and scratches.

Clean the inside of the rear window surface very carefully to prevent damage to the defroster elements. Always rub gently in a horizontal fashion.

**7. *Engine Compartment*** Thoroughly wash the engine compartment at the end of winter to remove road salt.

Before washing the engine compartment, ensure that the ignition key has been removed and the engine is cold.

After washing, check all protective rubber parts (e.g. low/high voltage cable boots) ensuring that they are positioned properly and have not been damaged.

**8. *Cleaning Plastic Parts*** The exterior plastic parts can be cleaned using the same procedure given for washing the car. If still dirty, use specific plastic cleaning products, not paint cleaning compounds.

Do not use alcohol for cleaning the instrument panel. Avoid using products that shine the plastic (especially products containing silicon) because they will alter the appearance of the parts with a matte finish. Use soapy water, a very dilute solution of alcohol (but not for the instrument panel) or detergents intended for use with plastics.

**9. *Vehicle Storeup Recommendations*** If one is not planning on using the car for several months, follow these recommendations:

- Clean and protect the paint with silicone wax clean the chrome using standard cleaning products.
- Store the car in a dry covered, ventilated place.
- Fully release the handbrake.
- Disconnect the cable from the battery terminals.
- Remove all wiper blades and coat the rubber with talc.
- Open the windows about an inch.
- Cover the car with tarpaulin that is NOT waterproof (made of cloth or perforated plastic). Never use plastic car covers as they will trap moisture.
- Increase the tyre pressures by about 0.5 bar and check the pressure periodically.
- Do a battery state-of-charge check every 1 1/2 months. Whenever necessary use a 24-hour trickle charger.
- Do not drain the engine coolant.

## Review Questions

1. Define corrosion of an automobile vehicle body.
2. How can you prevent corrosion?
3. State the main causes of vehicle corrosion.
4. What are the major operations of vehicle body painting? Explain the same briefly.
5. Enlist different types of primers, surfacers & paints used for body painting and explain their salient features.
6. Explain the working of the spray gun and drive.
7. State the vehicle storeup recommendations.

# 26

# Passenger Safety

**Objectives**

After studying this chapter, you should be able to:

- Describe various passenger safety features used in modern automobile vehicles.
- Describe working of seat belt system.
- Illustrate the precautions while using safety belt system.
- Explain the function of child safety locking system.
- Define and illustrate common safety gadgets fitted in automobile vehicles for safe operations.
- Develop proper attitudes concerning safe driving of vehicles.

## 26.1 INTRODUCTION

Occupant protection in a vehicle is of prime importance. We should know how to protect infants and children in vehicles. Our utmost attention should be towards all safety precautions during our journey in automobiles in addition to knowing fully well the use of gadgets, accessories provided and the facilities made available in the cars.

Seat belts and other features work together to protect the occupants of the car during a crash. Seat belts are the most important part of the occupant protection system. When working properly, this can reduce the chances of serious injury or death in an accident. The seats and head restraint play a major role in passenger safety. Reclining the seat-back can decrease the effectiveness of the seat belts. Head restraint can help protect neck and head especially during rear-end impacts. Use of hazard light and controls provided, and the driver's air bag facility are few other items which should be known to the person driving the car.

Generally, the following measures should be adopted.

(i) Injuries can be reduced by being careful in many crash situations. Beware of severe crashes which can be fatal.

(ii) Seat backs should be upright and head restraints should be properly adjusted.

(iii) No loose item should be allowed that could be thrown around and may hurt someone during crash or sudden stops.

(iv) A pregnant women needs to wear a seat belt to protect herself and the unborn child.

(v) All doors should be closed as far as possible.

## 26.2 SEAT BELTS

When you are inside a moving car, both you and the vehicle are moving at the same speed. However, if the car suddenly stops, you are hurled forward because you continue to move at about the same speed as the car at the time of the impact. So your head and chest smash into whatever is in front of you, the wind screen, the dash board or steering wheel. Some times you can be thrown out of the car through the wind shield or an open door causing death. The seat belts restrain you in such a situation and hold you back to your seat thus preventing you from hitting any hard structure in the car. This could mean the difference between life and death.

Most of today's car seat belts comprise a lap band and a shoulder band, held in place by a single buckle and bolts fastened on the car's body. There are two types of seat belts in Indian passenger cars *Non-retracting* and *automatic – retracting*. The first, an older design, does not adjust to the wearer's movements and is less convenient. The second, which is common today, allows you to move around freely but has a mechanism that restrains you when the car hits something or stops suddenly. It is not only the front seat passengers who risk life and limb but also the back seat passengers, if not buckled in. They can be hurt by other seat occupants, if they are hurled against them.

Buckling up children is also a must. Regular seat belt are too big for infants and small kids and so a separate child restraint system should be properly installed in your car's backseat for them. Holding a child in the lap of a front seat passenger is extremely unsafe.

There is a pressing need to educate people to wear seat-belts for safety from serious accidents anywhere, anytime and with anybody.

### 1. Seat Belt System

Wearing seat belts and wearing them properly is most important in case of an accident which helps in keeping occupants from being thrown against the insides of the car, against other occupant or out of the car. In most cases, seat belts reduce the chances of serious injury or even save lives. Two persons can never wear the same belt which may cause very serious injury in an accident. Putting the shoulder portion of a lap/shoulder belt under the arm or behind the neck should be avoided. Take care that the effectiveness of the belts is not spoiled by putting unwanted accessories on the seat belt.

***Precautions*** The following precautions should always be observed.

- Seat belts are designed to bear upon the bony structure of the body, and should be worn low across the front of the pelvis or the pelvis, chest and shoulders, as applicable. Wearing the lap section of the belt across the abdominal must be avoided.
- Seat belts should be adjusted as firmly as possible, consistent with comfort, to provide protection for which they have been designed. A slack belt will greatly reduce the protection afforded to the wearer.
- Belts should not be worn with straps twisted.
- Each belt assembly must only be used by one occupant; it is dangerous to put a belt around a child being carried on the occupant's lap.

### 2. Working of the Seat Belt System

**(i)** ***Lap/Shoulder Belt*** This style of seat belt has a single belt that goes over your shoulder, across your chest, and across your hips (Fig. 26.1). Each lap/shoulder belt has an emergency locking retractor. In normal driving, the retractor lets you move freely in your seat while it keeps some tension on the belt. During a collision or sudden stop, the retractor automatically locks the belt to help restrain your body.

**(ii) *Lap Belt*** The lap belt has one manually adjusted belt that fits across the hips (Fig. 26.2). It is similar to safety belts used in aeroplanes.

**(iii) *Wearing a Lap/Shoulder Belt*** Before putting on the seat belt, move the driver's seat as far back as is practicable while still allowing you to maintain full control of the vehicle.

Make sure the seat-back is upright. The front seat passenger should move the seat as far back as possible.

(a) Pull the latch plate across your body and insert it into the buckle. Tug on the belt to make sure that the latch is securely locked. (Fig. 26.3(a))
(b) Check that the belt is not twisted. Position the lap portion of the belt as low as possible across your hips, not across your stomach. This lets your strong pelvic bones take the force of a crash (Fig. 26.3(b)).
(c) Pull up on the shoulder part of the belt to remove any slack. Make sure the belt goes over your collar-bone and across your chest (Fig. 27.3(c)).

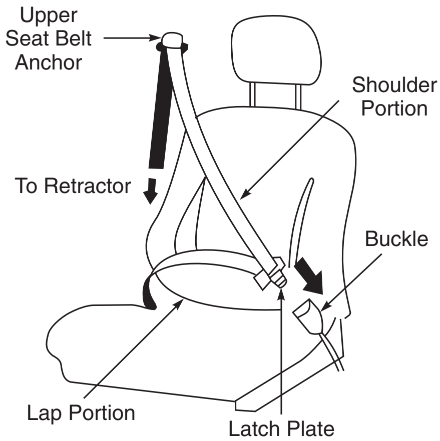



**Fig. 26.1** Lap/Shoulder Belt

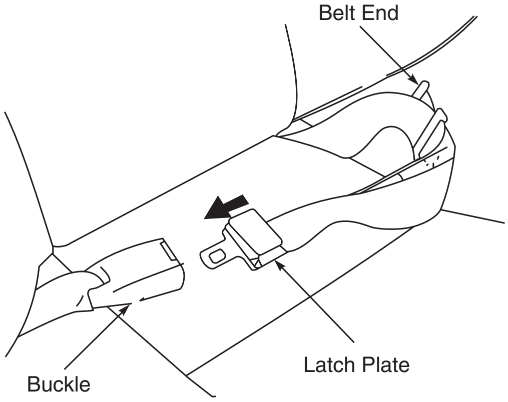



**Fig. 26.2** Lap Belt

**Fig. 26.3(a)** A Lap/Shoulder Belt

**Fig. 26.3(b)** Wearing a Lap/Shoulder Belt

(d) To unlatch the seat belt, push the red 'PRESS' button on the buckle.

Guide the belt across your body to the door pillar. After you exit the vehicle, make sure that the seat belt is out of the way and will not get closed in the door (Fig. 26.3(d)).

**Fig. 26.3(c)** Wearing Lap Belt

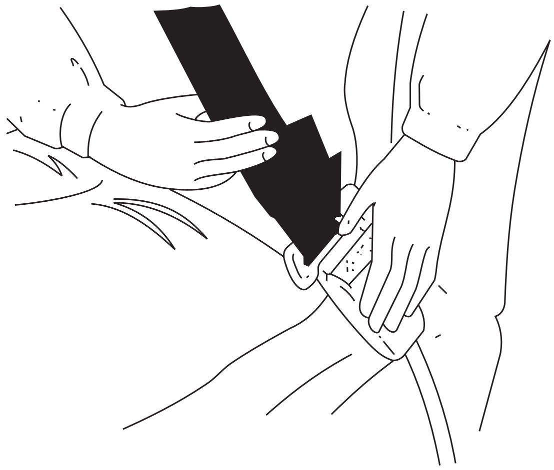


**Fig. 26.3(d)** Unlatching

**(iv) *Wearing the Lap Belt***

(a) Pull the latch plate across your hips and insert it into the buckle. If the belt is too short, hold the latch plate at a right angle, and pull to extend the belt.
Insert the latch plate into the buckle (Fig. 26.4(a)).

(b) Position the belt as low as possible across your hips and pelvic bones, not across your stomach. Pull the loose end of the belt to adjust for a snug but comfortable fit (Fig. 26.4(b)).

(c) To unlatch the belt, push the red PRESS button on the buckle (Fig. 26.4(c)).

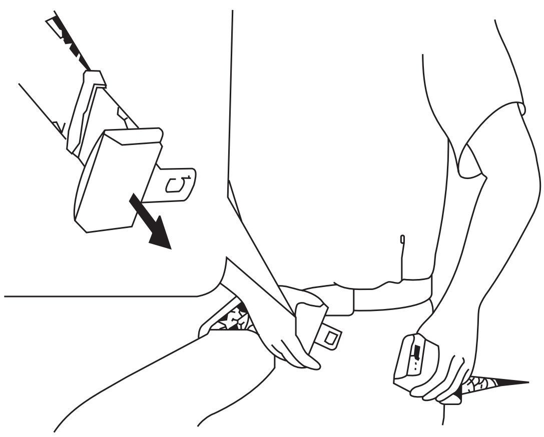


**Fig. 26.4(a)** Wearing the Lap Belt

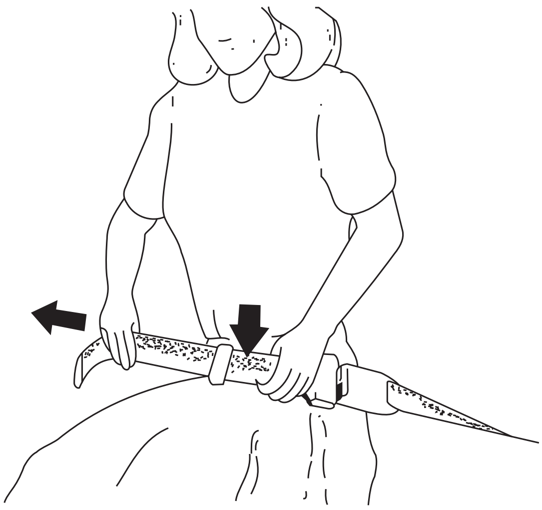


**Fig. 26.4(b)** Positioning the Belt

**(v)** ***Advice for Pregnant Women (Fig. 26.5)*** Protecting the mother is the best way to protect her unborn child. Therefore, a pregnant woman should wear a properly-positioned seat belt whenever she drives or rides in a car. If possible, use a lap/shoulder seat belt, remembering to keep the lap portion as low as possible.

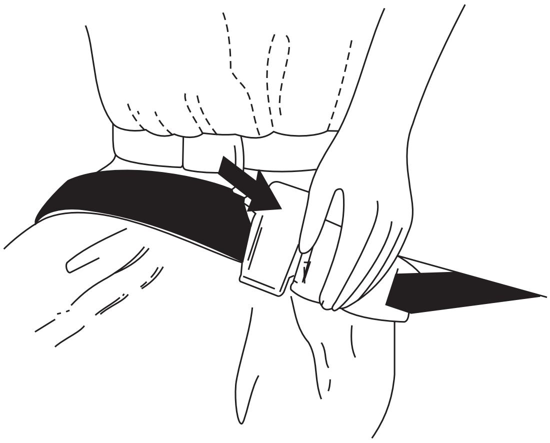


**Fig. 26.4(c)** Unlatching

**Fig. 26.5** Advice for Pregnant Women

Each time you have a check-up, ask your doctor if it is advisable for you to drive and how you should position a lap/shoulder seat belt.

**(vi)** ***Seat Belt/Maintenance*** For safety, you should check the condition of your seat belts regularly.

Pull out each belt fully and look for frays, cuts, burns, and wear. Check that the latches work smoothly and the lap/shoulder belts retract easily. Any belt not in good condition or not working properly should be replaced.

**(vii)** ***Anchorage Points*** When replacing the seat belts, make certain to use the anchorage points shown in the illustrations (Fig. 26.6(a) and 26.6(b)).

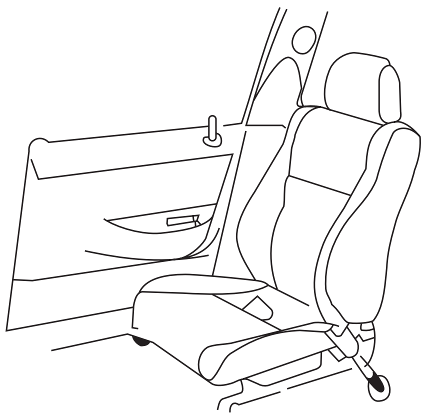


**Fig. 26.6(a)** Front Seat

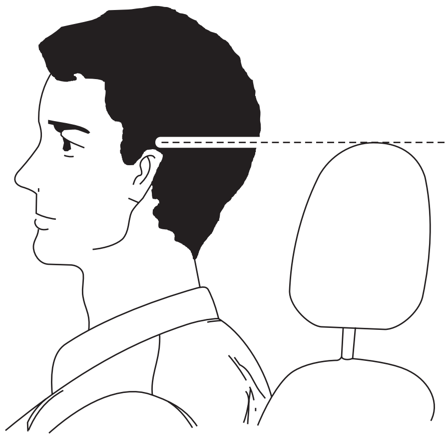


**Fig. 26.6(b)** Rear Seat

**(viii)** ***Head Restraints (Fig. 26.7(a) and 26.7(b))*** The front head restraints help protect you and passengers from whiplash and other injuries. They are most effective when you adjust them so that the top of the restraint is even with the top of your ears.

Adjust the front head restraints for height. You need both hands to adjust the restraint. Do not attempt to adjust it while driving. To raise it, pull upward. To lower the restraint, push the release button sideways and push the restraint down.

To remove a front head restraint for cleaning or repair pull it up as far as it will go. Push the release button and pull the restraint out of the seat back.

Driving a car without head restraints can lead to serious injuries to the passengers in a crash. Make sure that the head restraints are in place and adjusted properly before driving.

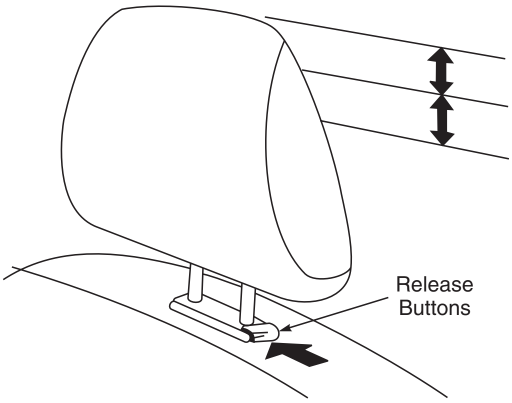



**Fig. 26.7(a)** Head Restraints

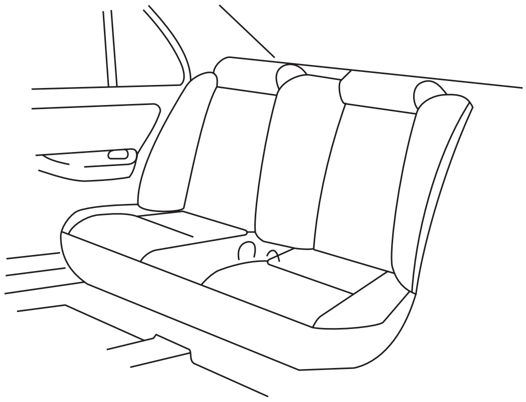


**Fig. 26.7(b)** Head Restraints

**(ix)** ***Rear Seat Armrest (Fig. 26.8)*** The rear seat armrest is located at the centre of the rear seat. Pivot it down to use it.

**(x)** ***Seat-Back Position*** The seat-backs should be in an upright position for you and your passengers to get the most protection from the seat belts.

If you recline a seat-back, you reduce the protective capability of your seat belt. The farther a seat-back is reclined, the greater the risk that you will slide under the belt in a severe crash and be very seriously injured.

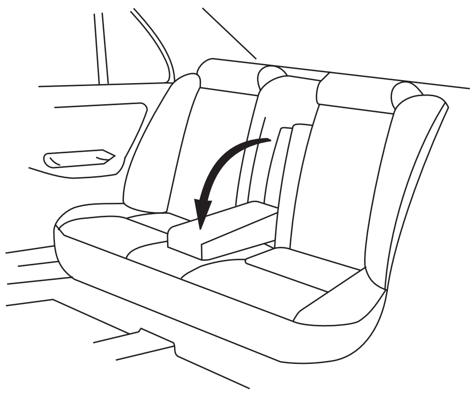


**Fig 26.8** Rear Seat Armrest

**(xi)** ***Storing Luggage Safety*** Before you drive, make sure you first securely store or tie down any items that could be thrown around the car and hurt someone, or interfere with your ability to operate the controls.

Do not put any items on top of the rear shelf. They can block your view and they could be thrown about in the car in a crash.

Be sure to keep compartment doors closed when the car is moving. If a front passenger hits the door of an open glove box, he could injure his knees.

You can store small items in the pockets under the instrument panel on the driver's side. Make sure the items do not roll out and interfere with the pedals.

Do not place any items on the tray on the top of the dashboard when the car is moving. They could be propelled inside the car and hurt someone or interfere with the driving.

**(xii)** ***Child Safety (Fig. 26.9)*** Children depend on adults to protect them. Infants and young children should always be properly restrained whenever they ride in a car.

We also recommend that any child, who is too large to use an infant or toddler seat, ride in the rear seat. The child should then wear the seat belt properly for protection. If the child is not large enough to wear the lap/shoulder belt properly, you should use a booster seat.

Never hold a baby or child in your lap when riding in a car. If you are wearing your seat belt, the violent forces created during a crash will tear the child from your arms. The child could be seriously hurt or killed.

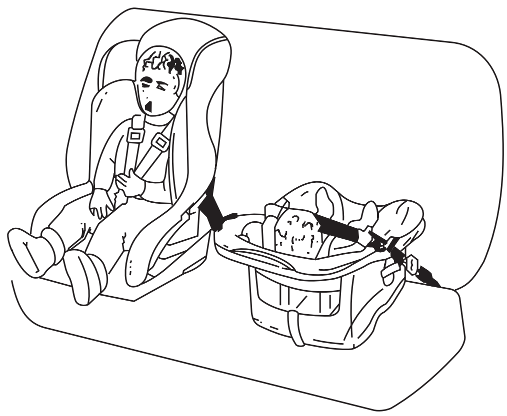


**Fig. 26.9** Child Safety

If you are holding a child and not wearing a seat belt in a crash, you could crush the child against the car's interior.

Never put your seat belt over yourself and a child.

During a crash, the belt could press deep into the child, causing serious internal injuries.

Never let children kneel on seats or stand while the vehicle is in motion. The violent forces created during emergency braking will cause the children to be thrown forward. Children could be seriously injured or killed.

Two children should never use the same seat belt. If they do, they could be very seriously injured in a crash.

If you are driving with small children in the car, you should use the childproof door locks to prevent them from opening the rear doors.

For their safety, do not leave children alone in your car without adult supervision.

**(xiii)** ***Restraining Children Under 18 kg/40lbs*** Use the seat of the right size which fits the child. Secure the child seat to the car by the lap belt. The safeguard recommendations for child safety are provided in Table 26.1.

**(xiv)** ***Using a Seat Belt Locking Clip*** Always use a seat belt locking clip while securing a child seat to the car with a lap/shoulder belt to prevent the seat from shifting and overturning Fig. 26.11.

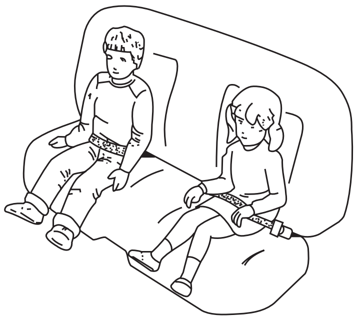
(a) Place the child restraint in the seat with a lap/shoulder belt. Route the lap/shoulder belt through the restraint properly.

(b) Insert the latch plate into the buckle. Pull on the shoulder part of the belt to make sure that there is no slack in the lap portion.

(c) Tightly grasp the belt near the latch plate. Pinch both parts of the belt together so that they do not slip through the latch plate. Unbuckle the seat belt.

(d) Install the locking clip as shown. Position the clip as close as possible to latch plate.

**Table 26.1** Recommendations for Child Safety

| *Weight* | *Recommendations* | *Figure* |
|---|---|---|
| Less than 9 kg/20 lbs | Must be restrained in an infant seat or a convertible seat designed for a baby. |  **Fig. 26.10(a)** |
| Between 9 and 18 kg/20 and 40 lbs | Toddler seats which should be placed in the rear seat. Use lap belt with a locking clip. |  **Fig. 26.10(b)** |
| Over 18 kg/40 lbs | Use lap/shoulder belt in the front passenger's seat. Put the belt on child and check its fit. The shoulder belt should fit over the collar bone and across the chest. The lap belt should sit on child's hips and not across the stomach. If the shoulder belt crosses the neck, use a booster seat. |  **Fig. 26.10(c)** |

(e) Insert the latch plate into the buckle. Push and pull the child seat to verify that it is held firmly in place. If it is not, repeat these steps untill restraint is secured.

(f) When the infant seat or child restraint are not in use, remove it or properly secure it so that it may not be thrown around during a crash.

## 26.3 GADGETS FITTED IN CARS FOR SAFE OPERATION

### 1. Drivers' Air Bag

The air bag is a safety device that cuts in immediately during a head collision. It is fitted for driver's i.e. front seat only for both the driver and front passenger seats. The air bag is stored in the centre pad of the steering wheel (Fig. 26.12) and in the dash board on the passenger side. It consists of an instantly inflatable cushion housed in a special compartment in the centre of the steering wheel on the driver's side and in the dash board on the passenger side.

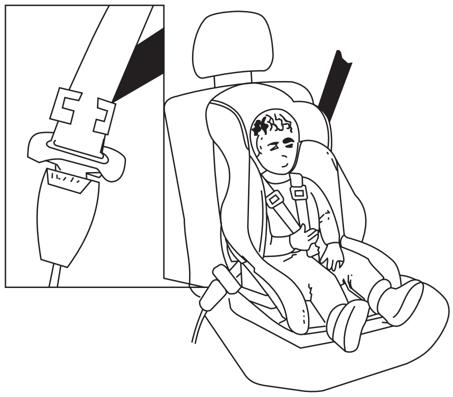


**Fig. 26.11** Installing a Locking Clip

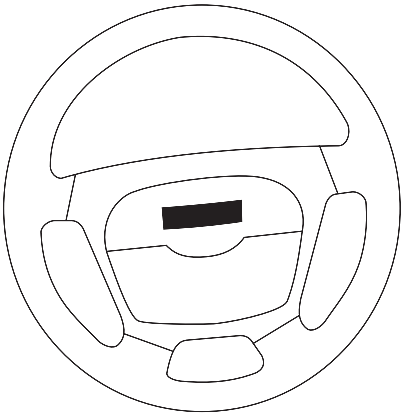


**Fig. 26.12(a)**

**Fig. 26.12(b)**

If there is a collision of such magnitude that it exceeds the setting of the special sensor, the mechanism is activated, the cushion inflates instantly and acts as a soft protecting barrier between the front passenger side seat, the passengers, and the structures in front of them that could cause injury.

The air bag *Supplementary restraint system* helps protect the drivers' head and chest against injuries in the event of a collision. The air bag activates during severe collisions which are either frontal or when the impact angle is up to 30° from straight ahead. The life of the air bag system is ten years.

The air bag inflates within milliseconds during a crash and forms a safety cushion for the driver. After the air bag completely inflates, it immediately deflates so that it does not interfere with the driver's visibility or ability to steer and operate other controls. The air bag inflates with considerable force

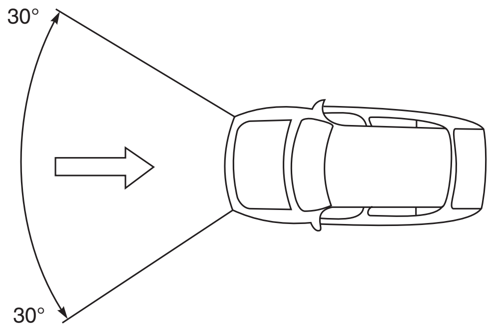



**Fig. 26.12(c)**

and speed. It is therefore important that the driver's seat and seat back should be correctly adjusted for the air bag to be fully effective. The driver's seat should be adjusted so that the steering wheel can be reached with the arms slightly angled.

When the air bag inflates, an operating noise may be heard and a small amount of smoke—like gas or dust will be released. The gas is harmless and does not indicate that there is a fire.

The air bag system will not be triggered in the event of rear impact, side impact, rollovers or minor frontal collisions. The seat belts must therefore always be worn. The air bag system serves to supplement the seat belt. Never affix anything to or over the centre of the steering wheel as it could cause injury when the air bag is triggered. Air bag system should not be disturbed or else it may trigger abruptly and unwantedly. The air bag can be triggered only once and is to be replaced thereafter. The air bag can be triggered when the engine is running even when the car is still if another vehicle crashes in the front of it.

### 2. ABS Braking System

The ABS braking system prevents the wheels from locking when braking, makes the best road grip and gives the best and safest control while emergency braking under difficult road conditions. The driver can feel that the ABS system comes into play when the brake pedal pulsates slightly and the system gets noisier. This indicates that the ABS system is working and the car is travelling at the limit of the road grip and that he should change the speed to fit the type of road surface. The ABS system is in addition to the basic braking system. If a failure occurs and consequently the anti-lock function is not effective, the braking system will continue to work as usual. Practice is required for using the system on slippery terrain. The advantage in using the ABS system is that it continuously gives maximum manoeuverability even when braking hard in conditions of poor grip by preventing the wheels from locking. If there is a fault, the warning light will light up on the dash board warning the driver to reduce speed.

### 3. Pollution Control and Environment Protection

Pollution control devices make it essential to use unleaded petrol only. Petrol with a rated octane number (RON) equal to 87 has to be used. An efficient catalytic converter will allow harmful exhaust fumes to be emitted and thus contribute to air pollution. The materials and creation of devices should be such so that the reduction or considerable curtailing of the harmful influence on environment is as per control standards. None of the car components should contain asbestos padding. Manual climate control systems do not contain CFC's (chlorofluora carbides), gases considered responsible for the destruction of ozone layers. The colouring and anticorrosion coatings of nuts and bolts now use environmentally friendly substances instead of the air or water-table polluting cadmium or chromates used previously.

All mechanical parts with friction components that are subjected to wear have been manufactured without use of asbestos. All the seals and gaskets are also made without the asbestos. The emission control system comprises a centrifugal separator which permits oil droplets from being aspirated with exhaust gases. The blow-by gases are mixed with the aspirated air and then recycled into the combustion process. A three-way catalytic converter is installed to takes care of the pollutants. As per the directions of the Govt. of India, all new cars are to be fitted with catalytic converter as a measure to control harmful exhaust emissions. The catalytic converter converts harmful CO into inert $CO_2$ and water vapour. The converter can function only if unleaded petrol is used.

## 4. Ventilation

Proper air vents should be provided directed towards the wind screen, side windows, passenger compartment and front and rear passenger foot wells to give adequate ventilation.

## 5. Turn Signals and Hazard Warning Indicators

The left or right turn signal light must be in proper order and should blink when you signal a lane change or turn. When you turn on the hazard warning switch, both signals turn into blinking lights (Fig. 26.13).

All the turn signals on the outside of the car should flash. Hazard lights should be switched when the car is stationery. Press the switch 'A' as shown in Figure 26.13 for switching on the hazard light regardless of the position of the ignition key. Symbol 'A' flashes. Press again to switch them off. Similarly the control buttons on the panel should be properly used.

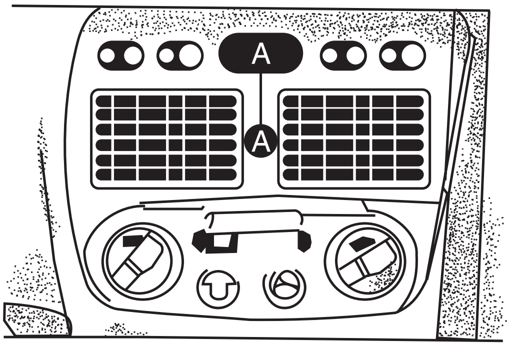



**Fig. 26.13** Warning Indicator

## 6. Other Devices

**(i)** ***Power Window Switch*** The windows can be operated by switches located in the driver's door arm-rest when the ignition switch is in the 'ON' position.

Care must be taken when operating the power windows. There is a risk of injury particularly for children and danger that articles could become trapped. Vehicle occupants should know the operation correctly (Fig. 26.14 and 26.15).

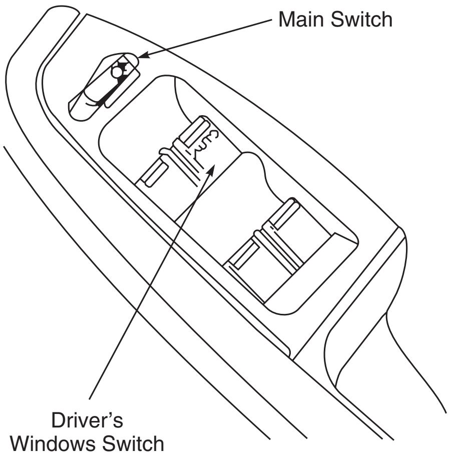



**Fig 26.14**

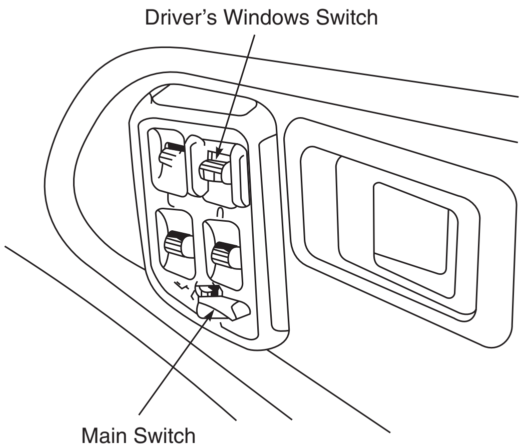



**Fig 26.15**

**(ii)** ***Inside Rear View Mirror*** The inside mirror can be adjusted up, down or sideways to obtain the best view. Always adjust the mirror with the selector, set to the day position. Only use night position to reduce glare from the head lights of the vehicles travelling behind for safe driving (Fig. 26.16).

**(iii)** ***Outside Rear View Mirror*** The outside rear view mirror can be folded flat against the side of the vehicle by pushing it backward when driving on narrow roads. Take care in judging the size or distance of a vehicle or object seen in the side convex mirror because the objects will look smaller and appear farther away than when seen in a flat mirror (Fig. 26.17).

**(iv)** ***Tiltable Steering Wheel (Fig. 26.18)*** Do not adjust the tiltable steering wheel while the vehicle is moving for safe driving. It may loosen vehicle control (Fig. 26.18).

**(v)** ***Lambda Sensor*** All petrol versions are fitted with the lambda sensor. It ensures that the air and fuel are constantly mixed in the correct proportion.

**(vi)** ***Three-Way Catalytic Converter*** Carbon monoxide, nitrogen oxides and unburned hydrocarbons are the main harmful components in the exhaust gases. The catalytic exhaust pipe and the devices connected to it are a "miniature laboratory" where a very high percentage of these components is converted into harmless substances.

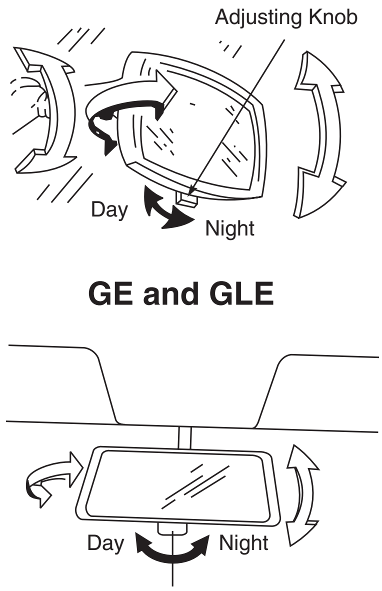



**Fig 26.16** Inside Rear View Mirror

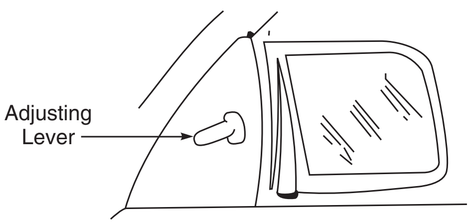



**Fig 26.17** Outside Rear View Mirror

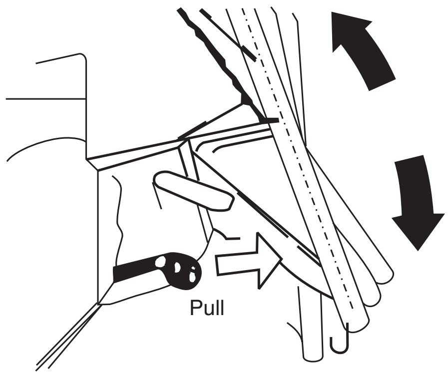



**Fig. 26.18** Tiltable steering wheel

**(vii)** ***First-Aid Kit*** It must contain all the items required for first-aid in case of an injury or accident. A fire extinguisher and a blanket may also be kept in the car.

**(viii)** ***Central Locking and Child Safety Locks (Fig. 26.19)*** The use of central and child safety locks should be done properly to avoid untoward happenings.

**(ix)** ***Alcohol and Drugs*** Driving a car requires your full attention and alertness. Traffic conditions change rapidly and the driver must react just as rapidly. Alcohol and drugs directly effect the alertness and ability to react and as such these should be avoided for safe driving.

**(x)** ***Carbon Monoxide Hazard*** Car exhaust contains carbon monoxide gas which is toxic. Breathing in can cause unconsciousness and even kill you. You must drive with the boot lid open and the ventilation in order.

## 26.4 SAFE DRIVING

One should be conscious of not only one's safety while driving but also the safety of others on the road.

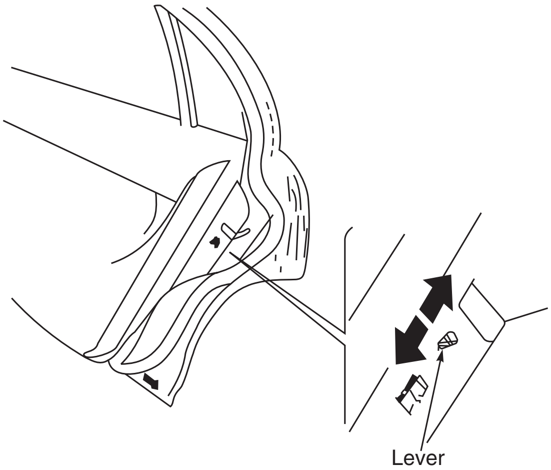
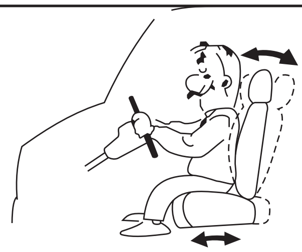
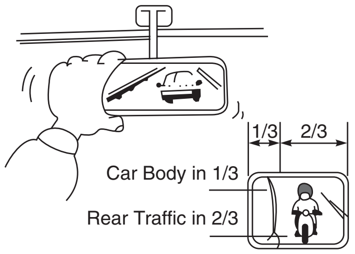
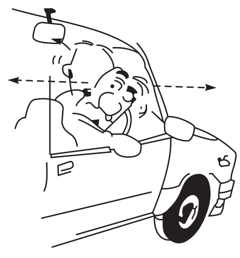
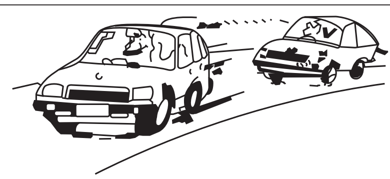
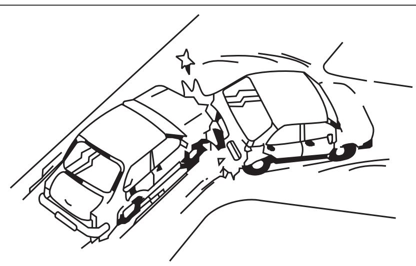
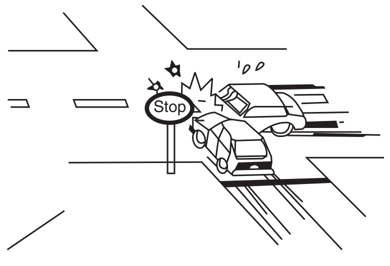
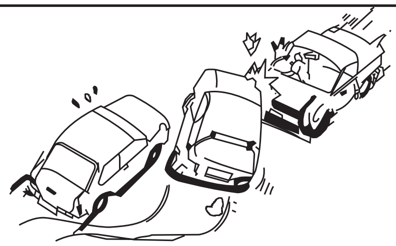
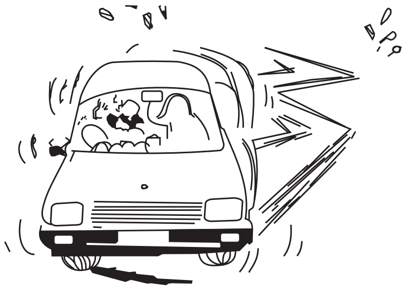
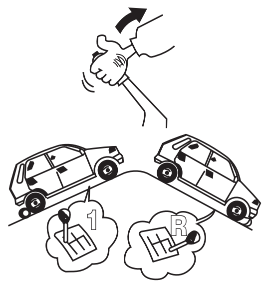


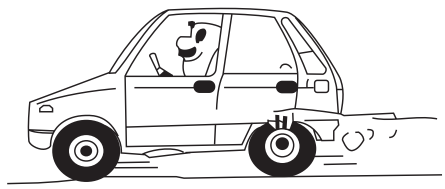
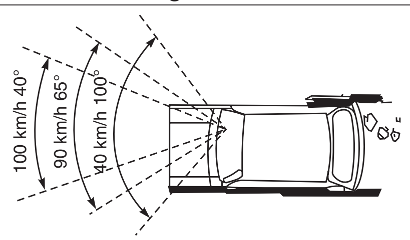
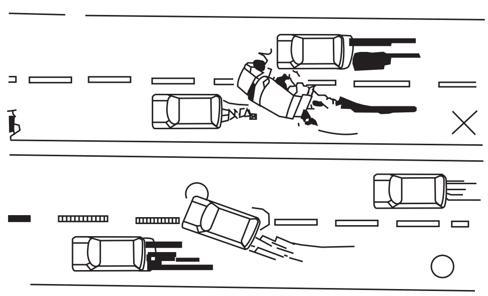

**Fig. 26.19** Central Locking

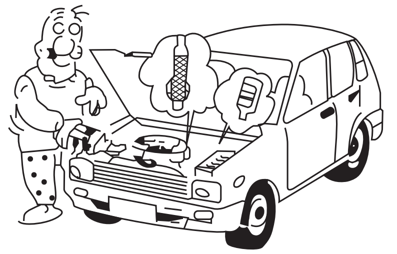
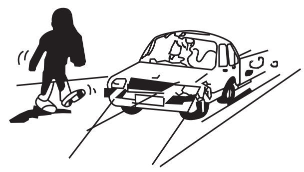
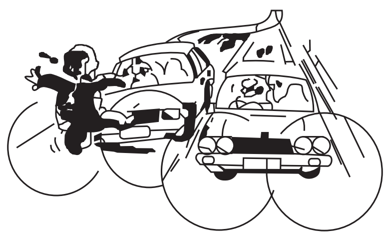
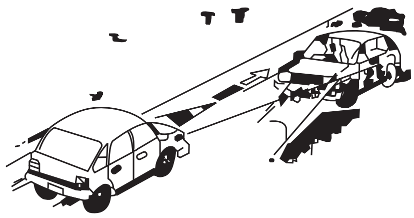
### Do's and Don'ts

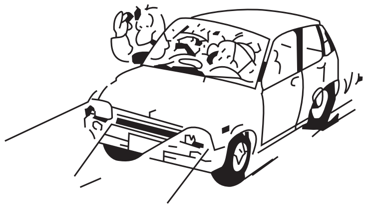
| | |
|---|---|
| (i) Starting<br>(a) Adjust the driver's seat for proper driving posture (Fig. 26.20). | <br>**Fig. 26.20** |
| (b) Adjust the rear view mirror so as to obtain the best possible rear view (Fig. 26.21). | <br><br>**Fig. 26.21** |
| (c) Before moving off, look forward and back to confirm safety (Fig. 26.22). | <br>**Fig. 26.22** |

| | |
|---|---|
| (d) Do not start quickly for it is dangerous and wastes fuel (Fig. 26.23). |  **Fig. 26.23** |
| (ii) General Driving<br><br>(a) Be sure to stop before the stop light and stop signal. When moving into the inter-section without any traffic lights or signs, drive slowly to confirm safety (Fig. 26.24). |  **Fig. 26.24** |
| (b) Always follow other vehicles at a safe distance in order to prevent a rear end collision in case of sudden stopping by the car ahead (Fig. 26.25). |  **Fig. 26.25** |
| (c) Turn 'ON' the turn signal at least 30 metres before making a turn or changing lane so as not to be hit from behind (Fig. 26.26). |  **Fig. 26.26** |
| (d) Before entering a corner, decelerate to a safe speed. Do not apply brakes during cornering avoiding a cornering skid. |   **Fig. 26.27** |

| | |
|---|---|
| (e) When over-taking other cars, watch out for the coming car and carefully confirm safety (Fig. 26.28). |  **Fig. 26.28** |
| (f) Do not attempt zigzag driving which will hinder your control over the car and cause an accident (Fig. 26.29). |  **Fig. 26.29** |
| (iii) Braking<br>(a) Use the parking brake when parking your car and shift the gearshift lever into the first gear or reverse gear position for the sake of safety (Fig. 26.30). |   **Fig. 26.30** |
| (b) Do not use hand braking unless unavoidable to avoid skiding. It is specially dangerous with worn tyres for they allow a larger skid. | |
| (c) Use foot brakes. Warn the car behind you. Gradually apply the brakes or bring the car to a halt (Fig. 26.31). |  **Fig. 26.31** |

| | |
|---|---|
| (d) When driving downhill, do not try to apply brakes but use the engine brake effectively. Overuse of foot brake may result in total brake failure (Fig. 26.32). |  **Fig. 26.32** |
| (e) Avoid reckless high speed driving and try to drive at a safe speed suitable for the road conditions while maintaining a constant speed (Fig. 27.33). |  **Fig. 26.33** |
| (f) The higher the speed, the narrower the driver's visual range becomes. It is difficult to anticipate any hazard and the driver feels much fatigued (Fig. 26.34). |   **Fig. 26.34** |
| (g) Never indulge in sharp handling during high speed driving to avoid loosing control (Fig. 26.35). |  **Fig. 26.35** |
| (h) When overtaking or changing the lane at high speed, keep an ample car-to-car distance (Fig. 26.36). |  **Fig. 26.36** |

| | |
|---|---|
| (iv) Long Distance Driving<br>(a) Be sure to perform safety checks before starting on a trip (Fig. 26.37). | <br>**Fig. 26.37** |
| (b) Take rest at certain intervals to prevent an accident which may occur if you are tired or sleeping (Fig. 26.38). | <br>**Fig. 26.38** |
| (v) Night Time Driving<br>(a) Drive more slowly at night than in daytime for the visual range is restricted at night (Fig. 26.39). | <br>**Fig. 26.39** |
| (b) Do not overtake other cars at night. Darkness effects your sense of speed and judgement (Fig. 26.40). | <br>**Fig. 26.40** |
| (c) Do not use the high headlight beam unless the use is inevitable to avoid dazzle to others (Fig. 26.41). | <br>**Fig. 26.41** |

| | |
|---|---|
| (d) Always keep the window glasses clean. Do not operate the wind shield wiper when the glass is dry (Fig. 27.42). | <br>**Fig. 26.42** |
| (vi) Margin for Safety<br>(a) It is important to allow yourself a margin for safety during driving so that you can cope with the erroneous or unexpected driving of other drivers. Be safety conscious and ensure your safety and also other's safety. | |

## 26.5 MORE POINTS FOR SAFE DRIVING

- Always disconnect the negative(-ve) cable first and reconnect it last. The negative cable is connected to the body/cab.
- During normal operation the battery generates gas which is explosive in nature. A spark or open flame can cause the battery to explode, causing very serious injuries.
- Getting electrolyte in your eyes or on skin can cause severe burns. Swallowing the electrolyte can cause fatal poisoning.
- Under-inflated tyres are prone to failures due to high temperature.
- The reverse gear should be engaged only when the car is stationary.
- Use parking brake, on a gradient, if necessary.
- Never remove the cap from the coolant reservoir when the engine is hot else hot water with steam may come on you.
- Take care that the driver's vision is not blocked due to sunvisors.
- While raising the glass or closing the doors, take care that fingers/hands are not trapped between the glass and frame or door and the body.
- Do not touch the cigarrette lighters' top to avoid burns.
- Do not forget to extinguish the cigarette butts before putting them in the ashtray. Do not put paper or other flammable materials in the ash trays.
- Do not wear your seat belt over hard or breakable objects in pockets or on your clothing. If an accident occurs, objects, e.g. glasses, pen etc. under the seat belt can cause injuries. Avoid contact of brake fluid with skin or eyes. Do not work under the jacked up car without proper support. To avoid possible injury do not operate controls by reaching through the steering wheel.
- Never drive with the glove box lid open to avoid injury in case of an accident.
- Petrol is extremely flammable. Do not smoke when refuelling and make sure there are no open flames or sparks in the area.

- Do not hold items on the assist grips. They could obstruct the driver's view resulting in an accident or could be thrown about in an accident or abrupt manoeuvre causing injury.
- Make sure that the bonnet is fully closed and latched before driving to avoid its fly-up unexpectedly during driving, obstructing your view and resulting in an accident.
- Avoid breathing exhaust gases containing carbon-monoxide which is colourless and odourless. Do not leave the engine running in garages or confined areas.
- Personal injury may result from spinning the wheels too fast.
- To prevent personal injury, keep hand tools and clothing away from the engine cooling fan.
- Avoid jacking up the vehicle on sloping surface. Use the jack properly. Passengers should not remain in a jacked vehicle particularly if the engine is running.
- For personal safety and avoiding accidents take care of air pressure in your tyres including wheel alignment. Under inflated tyres are prone to failures due to high temperature.
- Tyres should not be of different sizes. Excessively worn out tyres can cause trouble.
- For road safety, you should regulate the volume of sound systems in your car so that you can hear noises of horns, amublance, sirens, etc. from outside the car. Do not travel with objects on floor in front of driver's seat which will block the pedals making acceleration or make braking impossible.
- To prevent accidental movement of the vehicle, the hand brakes are provided and should be pedal pressed.
- Do not take the cap off the reservoir when the engine in very hot as you run the risk of scalding yourself.
- Make sure that the highly corrosive brake fluid does not drop on to the paint work. If it does, wash it off immediately with water. Brake fluid is poisonous. In the event of accidental contact, wash the effected part with water and mild soap rinse. Swallowing the fluid is highly dangerous.
- Improper wiring connections should never be allowed particularly if they effect safety devices.
- Visibility in bad weather is reduced with worn out viper blades.
- Never use flammable products like petroleum ether or petrol to clean the inside of the car. Electrostatic charge generated by rubbing, while cleaning, could cause fire.
- The radiator fan can operate even after the ignition key has been removed. Immediately after stopping the engine the fan may remain on if the engine is still hot. Keep your hands away from the fan for several minutes.
- For safe driving and enough road light, both headlights must always be set to the same position.
- Heavy loads which are not secured/anchored could seriously injure passengers in the event of an accident.
- Do not let the engine run in an unventilated area. It consumes oxygen and emits $CO_2$ and other gases which are harmful for the organism.
- Never stop your car near inflammable materials, e.g. dried grass, leaves or pine needles to avoid starting a fire.
- Never attempt to close a circuit using anything other than a fuse.
- Use proper wiper blades and spray nozzles correctly for the purpose they are given.
- Remove the key from the ignition switch only when parked.

- Stop the engine and keep heat sparks and flame away. Handle fuel only outdoors and wipe up spills immediately.
- Use extra care when driving on slippery surface.
- Prolonged exposure to used motor oil may cause skin cancer. Wash your hands with strong soap as soon as possible after handling used oil.
- Loose item can fly all around the interior in a crash and could seriously injure the occupants. Store the wheel, jack and tools securely.

## 26.6 PRECAUTIONS IN CASE OF AN ACCIDENT

In the event of an accident, the following precautions can be taken to minimize injury and loss of life.

(a) It is important to keep calm.
(b) If you are not directly involved in the accident, stop at least ten metres away.
(c) If you are on a motorway, do not obstruct the emergency lane with your car.
(d) Turn off the engine and turn on the hazard lights.
(e) At night, illuminate the scene of the accident with your headlights.
(f) Act carefully, you must not risk being run over.
(g) If you cannot open the car doors do not attempt to break the wind screen to get out. The windscreen is stratified. Side and rear windows can be broken more easily.
(h) Mark the accident by putting the red triangle at the regulatory distance from the car where it can be clearly seen.
(i) Call the emergency services making the information you give as accurate as you can.
(j) In pile-ups on the motorway, particularly when the visibility is bad, there is a high risk of other vehicles running into those already immobile. Get out of the vehicle immediately and take refuge behind the guard rail.
(k) Remove the ignition keys from the vehicles involved.
(l) If you can smell petrol or other chemicals, do not smoke and make sure all cigarettes are extinguished.

Use a fire extinguisher, blanket, sand or earth to put out fires no matter how small they are. Never use water.

## 26.7 SOME FEATURES IN CARS OF TODAY

Almost all Safety precautions and features are available in cars, in general, but the cars being manufactured now are giving some special features as regards to safety to make the car models more popular. Some of them are described below.

### 1. Tata Indica

Tata Indica is a safe car designed for quality performance. In order to maintain the level of performance and reliability, it is important that the fitment of any accessory or modification should be carried out with extreme caution. Any improper fitting installation can hamper the safety of the car.

**Table 26.2** Recommended Maximum Speed During Normal Operation

| *Gear* | *Speed (kmph)* |
|---|---|
| 1 | 35 |
| 2 | 65 |
| 3 | 95 |
| 4 | 130 |

**(i)** ***Hazard Warning*** This can be operated without turning ignition 'ON'. Press the hazard warning switch on the cluster will flash simultaneously to warn the other road users about, the hazardous condition of the car. Depress the knob again to switch 'OFF' the hazard function.

## 2. Fiat Siena

The ABS braking systems prevent the wheels from locking and take care of grips between the tyres and road surface.

The vehicle is equipped with an aerial fixed to the roof of the vehicle which can tune you to radio and wireless sets to get any wrong and danger signals from outside.

## 3. Wagon R—Multiactivity Vehicle from Maruti

Wagon R is ideally suited for today's active families and their lifestyles with its unique combination of power, spaciousness, safety the driving pleasure. Wagon R has the following features:

(a) 8 inch booster—assisted brakes for solid, controlled stopping power.
(b) Variable power steering which uses sensors to impart greater control and takes care of road grips at higher speeds.
(c) Side impact beams in front and rear doors.
(d) Self-diagonising 16-bit on-board computer.
(e) Sturdy monocoque body designed to absorb front and rear impact through crumple zones.
(f) Collapsible steering column.
(g) Large, vertical head lamps for enhanced visibility.
(h) Central locking.
(i) Roll control device for greater stability while cornering at high speeds.

## 4. Alto

Crazy, spunky, cool and a sizzler on the road, small but powerful, smooth and muscular, stylish yet understood, secure inside but on the road a little mean—A Compact Car with four valves per cylinder and 16-bit computer having smooth performance. It has optimum fuel efficiency and is equipped with high tensile steel side door, beam guard against front, rear and side collision impact, meeting the highest international safety standards. Unique halogen head lamps make the car a stunner.

## 5. Cielo

A very comfortable car where all safety requirements are met with.

## 6. Santro

Balanced Body with spaciousness, well proportioned giving more cabin space, higher ground clearance and greater visibility. Its aerodynamic, wind tunnel shape induces lower drag and faster motion, taking all safety measures.

## 7. UNO

It is highly economical with regard to fuel usage and is considered a balanced vehicle.

## Review Questions

1. Explain the working of seat belt system.
2. Explain the following
   (a) Lap belt
   (b) Seat-back position
   (c) Child safety
   (d) Installation of locking
   (e) ABS braking systems
3. Enlist the DO's and DON'TS for safe driving.
4. Discuss important features of modern cars like, TATA Indica, FIAT Siena, Maruti Wagon R and Santro.

27

# Engine Performance and Testing

**Objectives**

After studying this chapter, you should be able to:

- Define cylinder bore, piston stroke, piston displacement and compression ratio.
- Identify various factors which affect engine power.
- Describe engine ratings and related factors.
- Determine engine torque, engine brake horsepower, engine-indicated horsepower, etc.
- Explain the method of determining the indicated and break horsepower of an engine.
- Calculate mechanical, thermal and volumetric efficiency of an engine.

## 27.1 INTRODUCTION

Over the past years automobile manufacturers have produced various sizes and types of engines. These engines differ in the amount of power they can produce. Horsepower, torque and efficiency have changed and improved. The purpose of this chapter is to describe different terms used to measure engine performance. This also includes physical measurements such as cylinder bore, piston stroke, displacement as well as engine horsepower and efficiency, etc. to study the engine performance and operation.

## 27.2 ENGINE MEASUREMENTS

**1. *Cylinder Bore*** The diameter of the cylinder is referred to as cylinder bore, which is measured in inches or millimetres. When the cylinder bore is increased, the engine displacement is also increased.

**2. *Piston Stroke*** A piston stroke takes place when the piston moves from bottom dead centre (BDC) to top dead centre (TDC) in the cylinder. Engine displacement may be increased by designing the crankshaft to provide a longer stroke. The *crankthrow* is the distance from the centre line of the crankshaft to the centre of the connecting rod journals. A piston stroke is twice as long as the crankthrow.

**3. *Piston Displacement*** The total amount of air displaced by all the pistons when they move from TDC to BDC is referred to as the engine displacement. Displacement may be calculated by finding the piston displacement volume in one cylinder and then multiplying this displacement volume by the number of cylinders.

*Example 1*
To find the piston displacement of a four-cylinder engine which has a 4 inch bore and a 3 inch stroke.
Use the formula for piston displacement

$$\text{volume} = \pi R^2 \times \text{stroke}$$
$$\text{Radius } (R) = 1/2 \text{ cylinder bore}$$

The displacement in one cylinder of the engine is $\frac{22}{7} \times 2^2 \times 3$

$$= \frac{22}{7} \times 4 \times 3$$
$$= 37.7 \text{ cubic inches}$$

Hence, the total displacement of the four cylinder engine is $37.7 \times 4 = 150.8$ cubic inches.

*Example 2*
In the second example, a four-cylinder motor vehicle engine has a 66 mm bore and a 73 mm stroke. Find the piston displacement of this engine.

Piston displacement volume = $\pi R^2 \times$ stroke

The displacement in one cylinder of the engine is.

$$= \frac{22}{7} \times 33 \times 33 \times 73$$
$$\text{since } 10 \text{ mm} = 1 \text{ cm therefore,}$$
$$33 \text{ mm} = 3.3 \text{ cm}$$
$$73 \text{ mm} = 7.3 \text{ mm}$$
$$= \frac{22}{7} \times 3.3 \times 3.3 \times 7.3$$
$$= 249.8 \text{ cm}^3$$

Therefore, the total displacement of the engine is

$$249.8 \times 4 = 999.2 \text{ cm}^3$$

Engine displacement may be increased by increasing the cylinder bore, lengthening the piston stroke, or increasing the number of cylinders. When engine displacement is increased, engine power is also increased because a greater quantity of the total volume of air-fuel mixture can be taken into the cylinder.

**4. *Compression Ratio*** The compression ratio of an engine is the ratio of the total volume of the cylinder with the piston at bottom dead centre (piston displacement plus clearance volume) to the volume of the combustion chamber when the piston is at top dead centre (clearance volume).

This can be shown by the following equation

$$\text{Compression ratio} = \frac{\text{Total volume}}{\text{Clearance volume}}$$

*Example 3*

To find the compression ratio of a four-stroke engine with each piston displacing 37.7 cubic inches and with a clearance volume of 4.94 cubic inches. We proceed as follows:
37.7 + 4.94 = 42.64 cubic inches (total cylinder volume).

Then 42.64 ÷ 4.94 = 8.6 : 1

In the metric system 1 cubic inch equals 16.387 cubic centimetres.

$$\therefore \qquad 42.64 \text{ cu in.} = 698.741 \text{ cm}^3$$
$$4.94 \text{ cu in} = 80.951 \text{ cm}^3$$

Therefore the compression ratio is

$$698.741 \div 80.951 = 86 : 1$$

An increase in the compression ratio results in a higher degree of compression. Combustion occurs at a faster rate because the molecules of the fuel mixture are more closely packed together and the space through which the flame must travel is small. However, compression ratios are limited by the design of the engine, the ignition qualities of the fuel available, detonating or knocking factors, and the availability of high-octane fuels. In gasoline engines, compression ratios seldom exceed a ratio of 11.5 to 1. In diesel engines, compression ratios are as high as 20 to 1.

## 27.3 FACTORS AFFECTING ENGINE POWER

**1. *Atmospheric Pressure*** The decrease in atmospheric pressure indicates that the density of atmosphere decreases as the altitude increases above sea level. The atmospheric density and pressure increases as the humidity of air increases.

Since atmospheric pressure and engine vacuum cause the air-fuel mixture to flow into the engine cylinders, engine power is affected by atmospheric pressure. Higher atmospheric pressure will increase air flow into the engine, which causes an increase in power. Therefore, engine power increases slightly when the engine is operated at lower altitudes, and reduces when the engine is operated at high altitudes.

**2. *Friction*** Friction is resistance to motion between two objects in contact with each other. For example, if you put a metal block on a table and then push the block, you would find that it took a certain force to move it. If you put another metal block on top of the first block, you would find that you had to push harder to move the two blocks on the table top. Therefore friction or resistance to motion, increases with the load. The higher the load, the greater the friction.

Engine friction reduces engine power. For example, a certain amount of engine power is required to overcome the friction of the piston rings on the cylinder walls. If engine friction can be reduced, increased engine power will result. Some engines are now equipped with roller-type valve lifters which reduce friction between the lifters and the camshaft. Synthetic lubricating oil reduces engine friction and provides a slight increase in power.

**3. *Wind or Air Resistance*** The motion of a vehicle moving on a road is resisted by aerodynamic forces, known as the wind or air resistance, and road resistance generally termed as the rolling resistance. In addition to these two types of resistance, the vehicle has to overcome grade resistance when it moves on a gradient, because the weight of the vehicle is to be lifted through a vertical distance. Hence the power required to propel a vehicle is proportional to the total resistance to its motion and the speed.

When wind resistance is increased or vehicle speed is also increased, more engine power is required to overcome the wind or aerodynamic forces. On the other hand, if the vehicle weight and wind or air resistance are reduced, more engine power is available to drive the motor vehicle and less engine power is wasted in overcoming there forces.

## 27.4 ENGINE RATING AND RELATED FACTORS

**1. *Work*** Work is measured in terms of distance and force. It is measured by the following formula

$$\text{Work} = \text{distance} \times \text{force}$$

In the metric system work can be measured in metre-kilograms (mkg). For example lifting a 6 kg weight a distance of 1/2 metres requires 3 mkg of work.

**2. *Energy*** Energy is the ability or capacity to do work. When work is done on an object, energy is stored in that object.

For example, lifting a 15 kilogram weight for a distance of 3 metres, the weight will store 45 mkg of work. Similarly if a spring is compressed, energy is stored in it, and it can do work.

**3. *Power*** Power is the rate or speed of doing work. The work can be done slowly or rapidly. A machine that can do a great deal of work in a short time is called a *high-powered machine.*

**4. *Torque*** Torque is twisting or turning force which may be calculated by multiplying force $F$ and radius $R$. Therefore,

$$\text{Torque} = F \times R$$

Whey you steer a car around a turn then you apply torque to the steering wheel. The engine applies torque to the wheels to make them rotate. In the metric system, torque is measured in Newton-metres.

When engine torque is measured, a friction clutch is connected to the engine flywheel. An arm is connected from the friction clutch to a scale which has a metre that reads the force applied by the friction clutch through the arm. A basic friction clutch and scale are illustrated in Fig. 27.1.

If a 1/2 metre arm is connected between the brake and the scale, and the highest reading on the scale is 70 N with the engine running and the clutch engaged, than the engine torque is:

$$F \times R = 70 \times 2 = 140 \text{ Nm}$$

Torque indicates the amount of force an engine can exert, but does not measure how much work the engine can do in a specific length of time.

Maximum engine torque is produced when the highest pressure is available in the cylinders. The highest cylinder pressure occurs when there is maximum air-fuel mixture flow into the cylinders. Torque decreases at high speeds, because the air-fuel mixture has less time to flow into the cylinders on the intake strokes and hence the air-fuel mixture is reduced. If the air-fuel mixture flow into the cylinders can be increased by improving the intake manifold design or with the use of a turbocharger, engine torque will be higher.

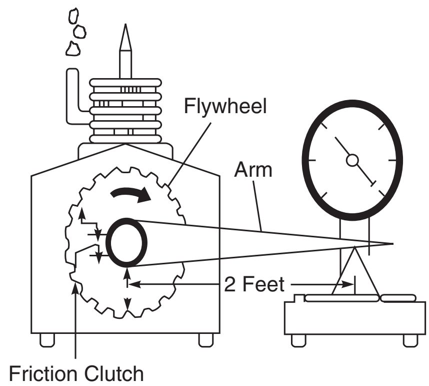



**Fig. 27.1** Friction Clutch Measuring Engine Torque

**5. *Horsepower*** The horsepower of an engine is measured by the rate at which it can do work. The horsepower developed by an engine depends upon the pressure exerted on the piston by the expanding gases and the rate at which the power impulses are applied to the crankshaft.

## 27.5 METHODS OF DETERMINING THE ENGINE HORSEPOWER

The horsepower that an engine develops can be measured by several methods.

**1. *SAE Horsepower*** A simple formula approved by the Society of Automotive Engineers for determining horsepower is sometimes used for licensing purposes. Although the formula does not give an accurate indication of the actual horsepower developed, it does provide a simple method of comparing engines according to their displacement.

$$\text{Horsepower} = \frac{(\text{bore of cylinder})^2 \times \text{No. of cylinders}}{2.5}$$

*Example 4*
To find the horsepower of a four-cylinder engine for licensing purposes, you would proceed as follows:

$$\text{Bore} - 4.0 \text{ inch Stroke} = 3.0 \text{ inch}$$
$$\text{Horsepower} - (4.0)^2 \times 4 \div 2.5 = 25.6$$

**2. *Brake Horsepower*** The brake horsepower of an engine is the actual horsepower delivered by the crankshaft and can be measured by means of an electric dynamometer.

**3. *Indicated Horsepower*** The rate at which work is done by the expanding gases in pushing the piston downward is known as the indicated horsepower. The indicated horsepower of an engine is the actual power developed within the cylinder during the combustion process.

When the indicated horsepower (IHP) is calculated, the following facts must be known:

$P$ = mean effective cylinder pressure in pounds per square inch
$L$ = piston stroke length in feet.
$A$ = area of the cylinder cross-section in square inches.
$N$ = number of power strokes per minute in one cylinder.
$K$ = number of engine cylinders.

The mean effective pressure (MEP) is the average pressure during the power stroke minus the average pressure during the other three strokes. The MEP is the pressure that actually forces the piston to move down during the power stroke. To calculate the IHP, use this formula:

$$\text{IHP} = \frac{\text{PLANK}}{33{,}000}$$

The IHP is the actual power that is developed in the engine cylinders, and this rating is always higher than the BHP because of loss of power due to friction in the engine.

**4. *Friction Horsepower*** Friction horsepower (FHP) is the horsepower that is required to overcome the loss of power due to friction in an engine. Friction horsepower increases in relation to engine speed, and this horsepower is calculated by subtracting the BHP from the IHP. Therefore,

$$\text{FHP} = \text{IHP} - \text{BHP}$$

## Dynamometer

A dynamometer enables the torque output of the engine to be balanced mechanically, hydraulically, or electrically.

### Types of Dynamometers

***Mechanical or Friction Dynamometers*** The mechanical dynamometer imposes a load on the engine by means of an asbestos band which is in contact with a flywheel attached to the engine output shaft. The band can be adjusted until a known load carried by the band is in a state of balance. When this is achieved, the output torque of the engine is equal to the applied torque which is a measurable quantity, since the load and its distance from the centre line of the output shaft are known. A drawback to the mechanical brake is its unsuitability for engines running at speeds above 750 rev/min. However, since it illustrates simply the basic requirements of dynamometers a mechanical brake is shown in Fig. 27.2.

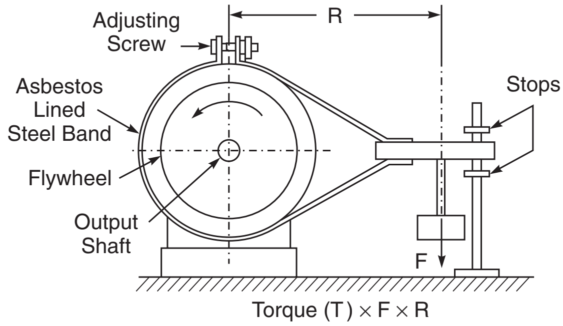



**Fig. 27.2** Mechanical Brake Dynamometer

***Hydraulic Dynamometers*** With hydraulic dynamometers, the engine drives the dynamometer shaft which carries a rotor running in water inside a casing. Rotation of the rotor shaft creates a hydraulic resistance which reacts equally upon the casing. The casing is mounted on trunnion bearings, being connected by a balance arm to a weighing device. In the same fashion as the mechanical dynamometers the balancing torque applied by the balance arm is equal to the output torque of the engine.

***Electric Dynamometers*** The electric dynamometer is actually an electric generator which generates an electric current when driven by the engine undergoing the test. The current developed may be absorbed through suitable resistances or may be used for lighting and other uses. The output produced by the generator is known as the electric horsepower and is always less than the horsepower of the engine that drives it, due to friction in the generator and other losses. Knowing the efficiency of the generator, the electric horsepower of the generator can readily be converted into actual brake horsepower developed by the engines.

## 27.6 ENGINE EFFICIENCY

The efficiency of any engine is determined by the relationship between the *results* obtained and the energy expended to produce such results. While we think of the modern internal-combustion engine as being an efficient mechanism, actually its efficiency in some respects is quite low. Efficiency is commonly measured as (1) mechanical efficiency, (2) thermal or heat efficiency, and (3) volumetric efficiency.

**1. *Mechanical Efficiency*** Mechanical efficiency is a relationship between the power delivered (BHP) and the power that wou1d be available if the engine operated without any power loss. Mechanical efficiency is the relationship between BHP and IHP, expressed as a percentage:

$$\text{Mechanical Efficiency} = \frac{\text{BHP} \times 100}{\text{IHP}}$$

The mechanical efficiency of an internal combustion engine is approximately 90%.

**2. *Thermal Efficiency*** The thermal or heat efficiency of an engine is the ratio of work done to the energy contained in the fuel. Thermal efficiency is expressed as a percentage and can be computed as follows:

$$\text{Thermal Efficiency} = \frac{\text{Brake Horsepower} \times 33{,}000}{\text{Wt. of fuel used per min.} \times \text{heat value} \times .778}$$

If an engine could convert all the heat developed by the combustion of fuel in the cylinders into useful work, its thermal efficiency would be 100 per cent. Actually, it is not possible. Much of the heat energy in the fuel is carried away by the cooling and lubrication system as these systems cool the engine parts. The exhaust gases carry away part of the heat produced by combustion. Some of the heat energy in the fuel is used to overcome friction in the engine and power train. From the total thermal energy in the fuel, the following losses may occur:

(a) 35 percent loss due to cooling and lubrication system.
(b) 35 percent loss due to exhaust gas.
(c) 5 percent loss due to engine friction.
(d) 10 percent loss due to drive train friction.

Therefore, only 15 percent of the thermal energy in the fuel is actually left to drive the vehicle. Improvements have been made in engine design and in engine and drive train lubricants, but thermal efficiency is usually below 30 percent.

**3. *Volumetric Efficiency*** The volumetric efficiency of an engine is the ratio of the air-fuel mixture that enters the cylinders compared to the total piston displacement of the engine. The volumetric efficiency of engines is expressed in terms of percentages and can be calculated as follows:

$$\text{Volumetric Efficiency} = \frac{\text{Vol. of charge at atm. temp. and pressure}}{\text{Piston displacement}}$$

It must be realized that a given mass (weight) of air-fuel mixture occupies different volumes under different conditions of atmospheric pressure and temperature. In determining volumetric efficiency, a comparison must be made with the volume the mass of air-fuel charge would occupy under particular conditions, such as standard atmospheric pressure and temperature.

The volumetric efficiency of modern internal-combustion engines is usually less than 100 per cent.

Other conditions that affect volumetric efficiency include the following:

- Exhaust restriction
- Air cleaner restriction
- Carbon deposits on cylinder and valves
- Shape and design of valves
- Shape of the intake and exhaust manifold.

## Review Questions

1. Define the following terms:
   - Cylinder bore
   - Piston stroke

- Piston displacement
- Compression ratio

2. Calculate the displacement of a V8 engine that has a 4.25 inch bore and 3.50 inch stroke.
3. Describe the meaning of energy and torque.
4. Define and explain the following:
   - Brake horsepower
   - Indicated horsepower
   - Frictional horsepower
5. Identify several ways in which frictional horsepower can be reduced.
6. Explain the basic principle of a dynamometer for determining the brake horsepower of an engine.
7. Describe the method of determining the approximate indicated power of an engine.
8. What is the difference between mechanical and volumetric efficiency?
9. List three engine modifications that could increase volumetric efficiency.
10. A four-cylinder engine is running at 2000 rpm. The arm from the clutch brake to the scale is 3/4 metre in length and the reading on the clutch brake scale is 80 N. Calculate the brake horsepower (BHP) of the engine.

# 28

# Garages and Service Stations

## Objectives

After studying this chapter, you should be able to:

- Describe types of garages.
- List features of good location and layout of garages and service stations.
- Explain factors to be taken into consideration while selecting site for a garage.
- List the different types of equipment needed in a garage or service station.
- State the purpose of each equipment
- Briefly describe the procedure for servicing an automotive vehicle.

## 28.1 INTRODUCTION

Since the end of the 1939-45 war, car population has steadily increased almost doubling every 10 years. This has necessitated the availability of garages and service stations, carrying out repair work and providing maintenance services for different types of vehicles. Depending upon the extent of repair work carried out, the garages are designated as big or small. Authorised garages approved by vehicle manufactures are also located in every big city or town to provide the required servicing and repairing facilities.

Availability of repair work and number of vehicles running on road greatly influence the scope of garages. Usually, there are two different kinds. The first kind is a general repair type which is typically owned by a mechanic turned business person. The general repair shop works on different makes and models of automobiles to fix any of the hundreds of different parts from the engine to rearaxles. The second kind is the sort of specialised shop working on one kind of vehicle, e.g. Ambassador or Fiat or specialising in limited repairs like engine rebuilding, tune-up, brakes, transmission etc. Such a shop is run by a businessmen who employ several mechanics.

Many service stations also repair and service automobiles. They may have one or several service boys and employ a number of mechanics. Some stations do only light maintenance; oil changes, lubrication or installation of tyres, batteries and other accessories. Other stations do heavier types of repair such as tune-ups, brake service, front-end alignment, etc.

## 28.2 TYPES OF GARAGES

Automobile Association's (AA) garage plan has provided spanner grading for the size, facilities and equipment of garages. According to the range of services available and provided to the public, garages are allowed to display one, two or three spanner signs indicating small, medium or large garages. The Automobile Association also provides a breakdown truck sign to certain garages where breakdown service facilities and electrical services are available upto midnight and even after that. Before permitting garages to display a particular sign they are inspected by the Automobile Association to see that they are well-equipped and staffed by trained and experienced mechanics.

**1.** ***Small Garages*** Small garages deal with replacement and adjustment of most of the major components for a particular range of vehicles and stock a large range of tools, parts and accessories.

**2.** ***Medium Garages*** Medium garages provide all types of routine services and repair work including tune-up and brake-testing. They also have parking facilities and suitable reception areas for customers.

**3.** ***Large Garages*** Large garages have well-trained and qualified staff to carry out inspection, diagnosing, servicing and urgent repairs without advance booking, Body work repairs are of high standard.

Adequate and comfortable waiting and parking facilities are available in these garages.

In advanced countries, new automotive service centres called *diagnostic centres* or *diagnostic lanes* have been established with the latest automotive testing equipment. A thorough analysis is made of each system of automobiles and the test report, indicating the condition of the various components and how soon they will need repair, is given to the customer.

**4.** ***Service Station*** In general, the service station includes facilities in addition to the care of motor vehicles like mechanical service and minor service, e.g. providing petrol and lubricating oils. Some stations provide comprehensive repair services also for vehicles.

## 28.3 LOCATION AND LAYOUT OF GARAGES AND SERVICE STATIONS

The layout of a garage/service station is a crucial factor in its successful running. Narrow entrances and badly placed petrol pumps mean a lot of wastage of time in shunting a car in and out and the possibility of scratching it. Further, the facility of simple services like cleaning, washing, checking of air pressure, accessories, sales etc. all form part of the layout. The site of the garage/station also plays an important part in its success. Its location should be such that it is easily approachable and near to the market and highway.

The internal layout of a garage should be such as to provide ample space for bench work, tool storage and repair work. It should have clean floors, sufficient lighting for the work benches and proper ventilation.

The layout of any workshop will depend mostly upon the work anticipated or the work already being done in an existing station. Small workshops usually have a bench at the closed end of a workshop with one pit or lift to enable work to be carried out underneath a car. The need to keep cars moving for rapid completion of repairs and servicing is obvious and the layout should be such as to facilitate quick servicing.

Usually the following factors are taken into consideration while selecting the site for a garage.

1. Approachability
2. Nearness to market and highway
3. Traffic flow
4. Adequate car population
5. Availability of qualified and experienced technical people near the surroundings.
6. Availability of facilities for drainage and sanitation.

Certain sites should be avoided, for example, sites where it is dangerous and difficult to turn into the area, one-way street areas where access is obtainable from one side only and where other repair and maintenance facilities are not available over a long distance. Sites near blind corners and busy cross-roads are also not suitable.

## 28.4 LAYOUT OF A WORKSHOP

The layout of a workshop is shown in Fig. 28.1. A workshop should be of sufficient size say 50 m by 30 m. Workshop areas with painted lines at 60° slope make it easy to run in and backout.

Benches with steel tops and 15 cm jaw vice for every bay provide the basic equipment for repair work of a general nature.

Jobs requiring use of a lift move into the work area where lifts are part of standard equipment in the repair bays. With each repair bay there must be certain services. If possible an inter-communications connection at the bench may be provided for speaking directly to the stores for keeping spare parts ready.

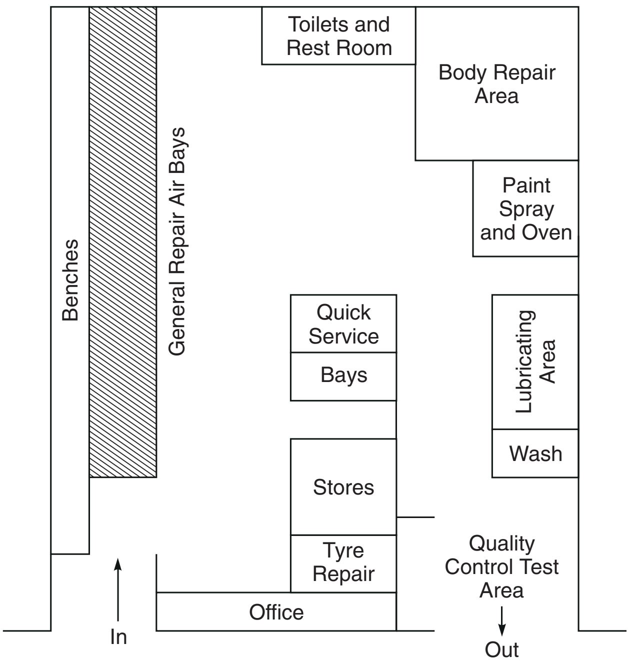



**Fig. 28.1** Workshop Layout

A good size drawer capable of holding tools belonging to a mechanic should form part of the bench. Jacks, stands, wheel braces, wheel-pullers, stocks and dies should be kept in a central position in the stores.

## 28.5 EQUIPMENT FOR GARAGES AND SERVICE STATIONS

For carrying out various types of repair works, different types of equipments are needed in a garage or service station. These equipment are classified usually as:

(i) Work benches
(ii) Compressor air plant
(iii) Battery charging and testing equipment
(iv) Lubrication bay
(v) Salvage equipment
(vi) Lifting tackles like jacks, lifts, hoists, etc.
(vii) Radiator cleaning service
(viii) Cleaning equipment like washing, hose, polishing and vacuuming
(ix) Plug cleaning and testing equipment, decarbonizing, valve grinding and engine tuning service
(x) Overhaul and repairs of electrical equipment
(xi) Tyre repair equipment
(xii) Wheel alignment and balancing
(xiii) Body repairs-renovation and finishing
(xiv) Fire extinguishers
- Sand buckets for petrol fire
- Sawdust and soda mixture for oil fire
- Chemical fire extinguishers.

Additional equipments like brake-testing and adjusting, steering geometry alignment, cylinder boring and housing equipment, carburettor and fuel pump test rigs, armature testing growler, tyre test tank and vulcanizers, drilling machines, grinding machines, centre lathe, etc. are also provided.

In every approved testing station the following three essential equipments are also provided:

(i) Brake testing metres and machines
(ii) Instruments for checking lamp beam alignment and dipper light.
(iii) Hoist or inspection pit for four wheel vehicles for raising at least 406 kg with fixed ramps to provide a ground clearance of 229 mm.

For breakdown/emergency servicing and repairing vehicles broken down at far off places away from the garage the following equipments are provided:

(i) Towing trucks with recovery devices like slings, shackles, towing bar, poles and rope, wooden planks, large steel levers, etc.
(ii) Wrecking crane adjustable at almost every angle so as to carry a wrecked or damaged car.
(iii) Service car to provide quick and efficient service just like a mobile service station for damaged cars.

Breakdown vehicles fully equipped are now supplied by manufacturers also. The size of the breakdown vehicle will depend upon its use. A car-recovery vehicle will have a capacity upto

3000 kg whereas a commercial recovery vehicle will have at least twice this capacity with high capacity engines to give a very high tractive effort at their road wheels. As a precautionary measure, many garages, mark breakdown equipment kept in the vehicle with a special bright paint so that it is easily located. They are kept on the vehicle only and not transferred to the workshop.

As already stated, different types of garages perform servicing and repair operations according to their size and capacity. Equipment/tools must be of a certain standard if the Automobile Association authorisation is being sought. Normally a garage will choose for itself from the tools and equipment listed in the next section to suit its needs and requirements.

## 28.6 MOTOR VEHICLE WORKSHOP TOOLS

Motor vehicle workshop tools are tools normally held in stores or on steel racks, for use by mechanics and may comprise:

1. Sets of box spanners ranging from 4.5 to 25 mm sets of ring spanners-short and long reach as also open-ended spanners. Socket spanners-assorted sockets to suit bolt and nut sizes normally used.

Pipe wrench-wheel wrench-torque wrenches, sets of feeler gauges, screw-thread gauges, sets of screw cutting dies and taps. Drills 1 mm to 25 mm, reamers, taper and parallel, also expanding reamers in most commonly used ranges of 10 mm to 30 mm.

Scrapers of various shapes and sizes for bearing and decarbonizing bolt cutters upto 20 mm, extractors for bearing and bolt, screw drivers of various sizes, connector screw driver, hammers-various shapes and weights, hacksaws, cold chisels, oil cans large and small, grease guns.

Tyre pressure gauges, Multi-wheel braces for assorted wheels, portable electric safety inspection lamp.

2. Work benches usually 50 cm thick in sizes 2.4 m to 3 m long, 90 cm high and 75 cm wide. Shop benching with tool racks and tool-cupboards and steel vices 7.5 cm and 15 cm jaws. Power drills-bench pillar type with capacity upto 30 mm dia drill. Portable drills upto 15 cm dia, lathe 15 cm to 24 cm centres with various tools and attachments.

Tyre repair and service—special tools, floor jacks, tyre changer and spreaders. Tyre levers and vulcanizing unit for repairs to tubeless tyres and inner tubes.

Axle stands for cars and vehicles.

## 28.7 IMPORTANT SERVICES AND EQUIPMENT

Some important services and the tools required for servicing are:

**1.** ***Brake Service*** Brake-drum turning and lining equipment, brake relining and riveting machines, special tools, honing sets, plug gauges, etc.

**2.** ***Wheel Alignment Service*** Special equipment for wheel alignment and wheel balancing.

**3.** ***Battery Serivce*** Battery testers and analysers, battery charging unit including hydrometer, voltameter, high rate discharge tester, etc.

**4.** ***Engine Tune up Including Carburettor, Fuel Pump Service***

(i) Special tools for adjusting carburettor fuel pump setting, tube cutting and flaring tools, etc.

(ii) Ignition and electrical testing instruments for analysing the conditions of the engines. Neon timing light for checking ignition timing, spark plug testing tools (cleaners, wrenches, etc.), tools for adjusting valves.

**5.** ***Engine Conditioning*** Engine conditioning needs engine overhaul equipment comprising engine stands, cylinder boring, grinding and re-sleeving plant, connecting rod alignment jig, piston and piston ring service tools, various cylinder gauges, micrometers, etc. valve reconditioning, i.e. valve seat grinding and reseating equipment, main bearing and big-end bearing boring equipment.

**6.** ***Welding and Cutting Service*** Oxyacetylene and metallic arc welding equipment.

**7.** ***Radiator Cleaning Service*** Flushing equipment, cleaning outfit, test tank, soldering iron, etc.

**8.** ***Body Repair Equipment*** Special tools and jigs for checking car dimensions, straightening jacks, frame straightening, *sanders* (pneumatic or electric), paint spraying equipment, sheet metal cutting, folding and rolling equipment

(a) Portable crane or hoists for lifting vehicles or engines.
(b) Fire-fighting and first-aid equipment
(c) Shot-blasting cabinet for cleaning parts which have cavities in difficult positions.

## 28.8 STANDARD SERVICE FOR CARS AND LIGHT VANS

Standard servicing for cars and light vans comprises the following steps:

1. Check steering and wheel alignments.
2. Check brakes and adjust as necessary.
3. Check engine for loose, worn components such as fan belt.
4. Check plugs and clean points and reset the electronic engine analyser.
5. Check full lubrication service.
6. Check chassis and body for deterioration.
7. Check suspension.
8. Check the battery for its specific gravity.

A regular servicing of the vehicle is necessary to safeguard it against major and serious defects. As per recommendations of the manufacturer, servicing at intervals of 4800 or 8000 km should be done. By proper servicing the vehicles become safer and easier to drive. Servicing in general is the process of either maintaining or restoring the vehicle to its original state of perfection and performance.

Further, most of the components of a vehicle are subject to wear and deterioration because of high speed running and road conditions and also due to neglect. As such it is necessary to know which parts are subject to deterioration and the factors controlling the rate of deterioration and the schedule for adjusting or replacing these parts before complete failure of the vehicle occurs.

A normal repair due to wear will include tuning the engine, fitting new suspension elements relining the brakes, overhauling the clutch and fitting new tyres. Dents and body damages are also inspected and repaired at suitable intervals.

## 28.9 SERVICE PROCEDURE

For servicing a vehicle, it should be mounted on a lift or hoist or on the ramp. A four post lift which enables a car to be lifted and also allows a car to be lifted with its wheels free, is the best for all working conditions as it enables the inspection and repair of wheel hubs and the brakes and drives to be worked on quite easily. In the case of hoist, all four wheels are stripped off to enable servicing to be done at the time of fitting them back. The position of the wheels is interchanged diagonally.

The service procedure may be carried out in the following steps:

***Step 1*** The under-frame of the vehicle is cleaned with water and dried with air. A mixture of mobile oil and kerosene is then sprayed on the under-frame under pressure. The under-frame is then rubbed with cloth soaked in the above mixture of oils and later washed with water again and dried with compressed air.

***Step 2*** To clean engine of dirt, grease, etc. spray method with compressed air is used. A kerosene spray under pressure is sprayed on the engine, wheels, spindles, springs, steering knuckles etc. After some time, it is sponged off with soap suds (linseed oil soap) followed by rinsing with cold water and then sponged off dry.

***Step 3*** For cleaning engine the exhaust system, the exhaust manifold, pipe and muffler are taken apart and soaked in kerosene oil overnight. Alternately, a long wire packed with kerosene-soaked waste, may be drawn through it for cleaning the pipe and manifold.

***Step 4*** Grease all points with a grease gun. Open the front wheel axle cups and grease.

***Step 5*** Check the mobile oil of the engine, differential gear box oil, steering column oil and hydraulic brake oil.

***Step 6*** For proper maintenance of 12 V battery, carry out the following:

(a) Wash and dry the top of the battery.
(b) Wash the corrosion product from the hold-down frame.
(c) Dry it thoroughly and apply black acid resistant paint, if necessary.

Use cell testers for checking individual cells and also check for gravity.

## Review Questions

1. What factors are taken into consideration while selecting the site for a garage?
2. List the different types of equipment needed in a modern garage or service station.
3. Describe the standard procedure for servicing an automobile vehicle.

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# Glossary

**Accelerator:** A pedal or lever that controls the power output of the engine.

**Accelerator pump:** Mechanical fuel pump that squirts an extra amount of fuel into the venturi during sudden acceleration.

**Accumulator:** Another term for a rechargeable battery.

**Ackerman principle:** The principle adopted in steering system wherein a line intersecting each kingpin and tie rod end intersects or near the differential.

**Additive:** A material added to oil or fuel to improve its quality.

**Air bleed:** Controls the amount of air that will be supplied to the engine during idle circuit operation.

**Air bleed screw:** This is a small screw to release unwanted air from a sealed fluid system.

**Air cleaner:** Device that filters air entering the engine.

**Air-cooled engine:** An engine containing fins around the cylinder head, cylinder block, exhaust ports, etc. and cooled by surrounding air contacting the fins.

**Air-fuel ratio:** The proportion of air and fuel (by weight) supplied by the carburettor to the engine.

**Air injection system:** Air is injected near the exhaust valve or port in order to supply extra oxygen to convert HC and CO into harmless products.

**Air lock:** A bubble of air trapped in a fluid line, which obstructs the normal flow of fluid.

**Air resistance:** The amount of air resistance to a vehicle depends upon its frontal area and its shape. It increases with the square of the speed of the vehicle.

**Alignment:** Adjustment of the front wheels of the car. Correct setting of the headlamps.

**Alternating current (AC):** Current that reverses direction regularly.

**Alternator:** Alternating current generator used in automobile in which alternating current is changed into direct current by a rectifier.

**Ampere-hour:** It represents the capacity of a battery. The product of current in amperes and the hours it can flow till the battery is completely discharged gives ampere-hours.

**Antifreeze:** Chemical added to cooling water to form coolant. A mixture of alcohol glycerine or ethylene glycol and water used in the cooling system for avoiding freezing of water.

**Anti-knock:** Certain quality chemicals are added to petrol to get anti-knock quality. These prevent detonation when the fuel is used in high compression ratio engines.

**Anti-lock braking system:** Brake system controlled by the computer to prevent the driver from over applying the brakes, which would cause the wheels to lock.

**Anti-roll bar:** A bar fitted between the wheels to resist cornering roll when the vehicle corners. It winds up to resist cornering forces.

**Armature:** The core as in generator, which rotates within the pole shoes surrounded by the field coils.

**Asbestos:** A natural fibrous mineral having great heat resisting ability.

**Aspect ratio:** Ratio of tyre treads width to tyre height. The lower the ratio, the wider the tyre for its height.

**Atmospheric pressure:** Pressure exerted by the weight of air in all directions upon all objects on the earth. Average atmospheric pressure at sea level is 14.7 lbs.per.sq.inch.

**Atomize** To split up to fine particles.

**Axle:** Steel shaft used to support the weight of the vehicle and to transmit torque from the differential to the drive wheels.

**Axle casing:** A cover enclosing the two half shafts and the differential.

**Axle ratio:** The ratio between the rpm of the propeller shaft and that of the road wheels, generally 4:1 in the case of cars.

**Back fire:** Ignition of a mixture in the induction manifold by a flame from the cylinder due to leaking intake valve.

**Backlash:** The clearance or play between two parts such as gears meshing with each other.

**Backing plate:** Fixed part to which all drum brake parts are attached except the drum. Called a plate because it is round and flat.

**Baffle:** Steel sheet mounted inside the fuel tank that moderates or resists the slush and flow of fuel in the tank due to the motion of the car.

**Balance shaft:** Weighted shaft rotated to cancel vibrations in large displacement four-cylinder engines.

**Ball bearing:** An anti-friction bearing consisting of a hardened inner and outer race with hardened steel balls interposed between the two races.

**Ball joint:** Spherical bearing used on front suspension. It allows limited motion in two planes.

**Barrel:** In a carburettor, the tube through which most of the air flows.

**Battery:** Electrical cells assembled in one case.

**BDC:** Bottom dead centre.

**Bearing:** A part in which a journal, pivot, or a similar thing turns or moves.

**Beam axle:** Simple axle connecting the rear wheels on some front-wheel drive vehicles.

**Belt:** One layer of material used to construct a tyre. A belt can be made of many different materials, such as rayon, steel, kevlar, fiberglass, and so on.

**Bendix:** Type of starter drive that depends on intertia to engage the pinion gear into and out of mesh with the ring gear.

**Bias-belt ply:** Tyre construction where the belt cross over each other at right angles and at least one additional belt runs around the tyre under the tread.

**Bias ply:** Tyre construction where the belts cross over each other at right angles.

**Bimetal:** Literally, “two metal” A construction for small arms and coils. Two metals with different heat characteristics are formed into the part. When heated, the part bends because of the difference in the metals’ heat characteristics. Used in relays, gauges, and circuit breakers.

**Bleeder valve:** Valve used on wheel cylinder, calipers, and master cylinders for forcing air out of the braking system.

**Blow-by:** Combustion gases which pass by the rings and into the crankcase. They dilute engine oil and promote acid formation.

**Blower:** Another name for a supercharger. It is not used for turbochargers.

**Bonding material:** Material to act as a cement for uniting particles or parts.

**Booster:** A device to boost the power applied by the operator in operating clutch, brake, steering, etc.

**Bore:** Inner diameter of engine cylinder or any hole in which a bushing fits.

**Boss:** Projections within the piston which support the gudgeon pin.

**Brake bleeding:** Procedure where brake fluid is forced out of the brake system, air, water, and other hazards are removed with the fluid.

**Brake line:** Steel line that connects the master cylinder to the brakes at each wheel. Flexible rubber brake lines are used between the steel lines and the brakes.

**Brake pedal:** Driver-operated pedal that controls the brake master cylinder.

**Brake shoe:** Friction-material part in a drum brake.

**Brake-warning-light switch:** Actuates brake warning dash light when front or rear brake system fails.

**Breaker points:** Cam driven mechanical switch used to interrupt coil current to create a spark.

**By-pass:** An alternate passage for the flow of liquid or gas.

**Cab:** Separate driver's cabin provided on trucks and tractors.

**Calibrate:** To determine or adjust the graduation of any instrument giving quantitative measurements.

**Cam:** An eccentric projection on a revolving shaft designed to give some requisite linear motion to a follower.

**Camber:** Curvature of road or spring or angle or inclination of road wheel.

**Camshaft:** The shaft containing lobes or cams to operate engine valves.

**Carburettor:** A device for automatically mixing fuel with air in correct proportions to produce a combustible mixture.

**Casing:** Another name for housing.

**Caster:** Backward tilt of front axle.

**Cell:** Unit of battery containing a group of positive and negative plates, separators and electrolyte.

**Centrifugal force:** A force which tends to move a body away from its centre of rotation.

**Chassis:** Body to house all mechanical systems and assemblies that make up a car.

**Check valve:** Non-return valve which gives passage to a liquid or gas in one direction only.

**Choke plate:** Flat plate located at the top of the carburettor that restricts air flow into the engine to increase the fuel content of the mixture.

**Choke valve:** A butterfly valve placed in the carburettor air intake passage to control the entrance of air.

**Circuit breaker:** Multiple use fusing device that "kicks out" or opens up when an over-current circumstance is encountered. Circuit breakers can be reset once the over-current condition is removed.

**Clearance:** The space allowed between two parts.

**Clutch:** A mechanism for connecting and disconnecting driving member from driven member.

**Clutch linkage:** Mechanical or hydraulic mechanism that transfers motion from the driver's leg to the clutch.

**Coil spring:** Spring made from a length of round bar which is wound into a spiral. Valve springs and suspension springs often are coil springs.

**Collapsible steering column:** Steering column designed to shorten during a crash. This helps prevent the column from protruding into the passenger compartment.

**Combustion chamber:** Enclosed area where combustion takes place. It is formed by cylinder head, valves, spark plug, head gasket, cylinder walls, piston, and rings.

**Commutator:** A ring of adjacent copper bars insulated from one another to which the windings are attached.

**Compression ratio:** Ratio between the volume of a cylinder with the piston at BDC and with the piston at TDC.

**Compression ring:** Piston ring designed to hold combustion pressure. These rings are the top rings on a piston.

**Compression stroke:** Upward stroke of the piston as it compresses the air/fuel mixture.

**Compressor:** Mechanical device used to convert vaporous Freon into a liquid by pressurizing it.

**Condenser:** An electrical condenser is a device for temporarily collecting and storing a surge of electrical current for later discharge.

**Conductor:** A material through which electricity can flow with slight resistance.

**Connecting rod:** Rod which connects piston with the crankshaft.

**Constant mesh transmission:** An arrangement of gearing wherein the gears remain constantly meshed instead of being slid into and out of engagement with one another.

**Contact breaker:** Circuit breaker for interrupting an electrical circuit.

**Contact points:** Two separable points usually faced with platinum, silver or tungsten, which interrupt the primary circuit in ignition system.

**Coolant:** Usually a 50-50 mixture of anti freeze (ethylene glycol) and water used in the cooling system of the automobile. "Coolant" can actually refer to any material, such as water, that is used to cool the engine.

**Cooling system:** System that removes excess heat from the engine and radiates it to the atmosphere. Water, air and oil are used to carry the heat to the atmosphere.

**Core:** The centre portion of an electromagnet or armature around which the wire is coiled.

**Core hole:** Hole left in large castings (cylinder block, heads) to let core sand out.

**Coupling:** A connecting means for transferring movement from one part to another.

**Crankcase:** The housing within which crankshaft and allied parts of the engine operate.

**Crankshaft:** The main shaft to the engine which in conjunction with the connecting rods, converts reciprocating motion of the pistons into rotary motion.

**Crown:** Top of a piston. It is also called the dome.

**Cut-out:** Automatic switch for operations taking place according to established sequence.

**Cylinder:** The part in the engine block in which piston operates.

**Cylinder block:** The main engine block which contains cylinders.

**Cylinder head:** Usually a detachable portion of an engine which covers the cylinders and provides combustion chambers in the engine.

**Dashboard:** Instrument panel fitted before the driver's seat.

**Dead axle:** Axle that does not rotate with the wheels attached to it.

**Dead centre:** The extreme upper or lower position of the crankshaft throw at which the piston is not moving in either direction.

**Decarbonising:** During overhaul, carbon is removed mechanically from piston crown, grooves, combustion chamber and valves.

**Detonation:** When petrol of very low octane rating rapidly burns inside the combustion chamber, it gives rise to a metallic sound. Referred as knocking, it may also be caused due to over-advanced ignition timing.

**Diaphragm:** Tightly stretched circle of a rubber like material. The diaphragm is used to convert mechanical motion into vacuum or pressure.

**Diaphragm spring clutch:** Clutch in which the clamping load is applied by a diaphragm spring.

**Differential gear:** A device incorporated generally on rear axles. It allows the wheels to be driven at different speeds when the vehicle takes a bend or falls into a ditch.

**Disc brakes:** A braking system which comprises friction pads, calipers and a metal disc rotating with the wheel. Braking action is caused where the pads held in the calipers press against the metal disc.

**Distributor:** A rotary switch which distributes high voltage surges to engine cylinders in proper sequence. It is generally run by the camshaft.

**Distributor cap:** Plastic housing that holds the coil tower insert that is a portion of the high-voltage secondary switch.

**Double cardan joint:** Type of constant-velocity joint resembling two normal U-joints.

**Down draft:** Carburettor in which the airflow pattern is vertical. The air and fuel flow down into the engine.

**Drum brake:** Brake design using a rotating drum stopped by expanding or contracting brake shoes.

**Dual exhaust:** Exhaust system using two separate exhaust pipes, mufflers, and catalytic converts.

**Dual piston:** Master cylinder using two pistons. Each piston operates a separate brake circuit.

**Dwell:** That period of time during which the current level is building up in the coil. It is the period of time during which energy is being stored in the magnetic field of the coil.

**Dynamic balance:** Balance that takes into consideration forces at work when the wheel and tyre rotate.

**Dynamometer:** Measuring instrument that shows engine power.

**Electrode:** Electrical terminal from which or to which a current flows.

**Electrolysis:** Using an electrical current to split up water molecules into hydrogen and oxygen gases.

**Emission control:** A device to limit or reduce automobile pollution.

**Emitter:** Connection into which the current flows in a transistor.

**Engine block:** Central frame or skeleton of an engine. It typically contains the cylinders and several shaft bores. All other engine parts bolt directly or indirectly to the engine block.

**Engine code:** Number of group of letters signifying a specific engine in parts, repair, interchange, and electronics literature.

**Engine timing:** Number of degrees before top dead centre at which the spark is made to occur.

**Epicyclic gearing:** It comprises a central sun wheel in mesh with pinion gears which are in turn in mesh with a big toothed ring known as annulus.

**Ethylene glycol:** Main ingredient in antifreeze.

**Evaporation:** Change in state between liquid and gas.

**Evaporator:** Heat exchange device that removes heat from the passenger compartment to the expanding refrigerant.

**Exhaust gas:** The remains of combustion of fuel-air mixture which are emitted out of an engine. It consists of carbon dioxide, carbon monoxide, unburnt hydrocarbons, oxides of nitrogen and water vapour.

**External power steering:** Power steering design that applies hydraulic pressure to the steering linkage, not the steering box.

**Fan:** Cooling system's air movement device. The engine fan is either engine or motor driven.

**Fan belt:** A vee-section fan belt takes its drive from the crankshaft pulley and runs the dynamo and water pump. It should have a reasonable tension.

**Feeler gauge:** Thin steel metal strips (from 0.02 mm. to 0.5 mm) used to measure clearances between valve and rocker, contact breaker points etc.

**Final drive:** The section of transmission system between the engine and the wheels.

**Floating axle:** Axle which transmits torque to the road wheels but does not support the weight of the vehicle. Used in heavy vehicles. Also known as fully floating axle.

**Fluid coupling:** An automatic clutch having a driving and a driven member. Power is transmitted through oil.

**Fluid flywheel:** It is similar to fluid coupling except that it has an additional stator in between the driving and the driven member. It can provide a variable gear-ratio.

**Four wheel drive:** A transmission system in which the engine power can be transmitted to all the four wheels. Such vehicles are used in rough terrain.

**Free play:** The distance through which a pedal has to be moved in order to start engagement or disengagement of clutch or any other effect.

**Front wheel drive:** Vehicles in which the engine gives power to the front wheels. Results in good directional stability and a compact engine and other assemblies.

**Full throttle:** When the accelerator pedal of the vehicle is depressed fully, the throttle valve of the carburettor is in wide-open throttle position.

**Full flow filter:** The filter through which all the lubricant oil passes. This is not the case in by-pass filter.

**Gap:** The air space between the two electrodes of the spark or between the C.B. points.

**Gasket:** A packing placed between two metal surfaces to act as a seal.

**Gear ratio:** The relative speeds at which two gear revolves. The speeds are proportional to the gear diameters.

**Generator:** A device consisting of an armature, field coils and other parts which when rotated produces electricity.

**Governor:** A mechanical device which puts a limit to the speed of the engine. If load increases, the engine speed goes down. A governor operates to increase fuel supply and hence the speed.

**Grease:** A thick non-flowing lubricant used in places where oil is unsuitable.

**Grease nipple:** The heat of such a nipple has a spring loaded non-return ball valve so that grease from the grease gun travels in one direction only.

**Gudgeon pin:** Also known as wrist pin or piston pin. It is the pin which connects piston with the connecting rod.

**Helical gear:** A gear design wherein the gear teeth are cut at an angle to the shaft.

**Hemispherical combustion chamber:** Semi-circular shaped combustion chamber. The valves are inclined to each other and the spark plug lies between them. It has maximum efficiency.

**High tension:** The secondary or induced high voltage electrical current.

**Horsepower:** A unit for measuring power. It is the rate for doing work at 45,000 mkg per minute.

**Hotchkiss drive:** A design wherein torque reaction and driving thrust are taken through road springs.

**Hot spot:** A spot in the engine manifold which is surrounded by exhaust gases to heat the incoming mixture.

**Hub bearings:** Ball or taper-roller bearings which the wheels revolve.

**Hydrocarbon:** Petrol and diesel are compounds of hydrogen and carbon.

**Hypoid bevel gear:** Spiral-cut gears on the crown wheel and pinion of the differential. Such a shape allows the pinion to be set below the crown-wheel centre line. This helps to bring down the centre of gravity of the vehicle.

**Idle port:** Outlet of the idle passage in the carburettor.

**Idler gear:** A gear placed between a driving and driven gears to make them rotate in the same direction.

**Idling speed:** The lowest speed for the engine without load.

**Ignition coil:** An electrical coil which transforms low tension current into high voltage surge to produce a spark at the spark plug gap.

**Ignition system:** The system of providing ignition in the engine.

**Independent suspension:** Type of suspension in which the wheel on one side of the vehicle rises or falls independently of the wheel on the other side.

**Induction manifold:** Engine part which provides a series of passages for the flow of fuel mixture from carburettor to the engine.

**Injector:** A device by means of which fuel is injected into the engine combustion chamber.

**Inlet valve:** Also known as intake valve. It permits the entrance of fuel air mixture or air into the engine cylinder.

**Insulator:** An electrical conductor covered with a non-conducting material.

**Internal combustion engine:** An engine in which combustion of fuel takes place inside the engine.

**Jackets:** Pockets around the cylinder and combustion chamber through which water circulates.

**Journal:** The finished part of a shaft which rotates in a bearing.

**King pin:** The pin around which the steering spindle or arm moves.

**King-pin inclination:** The angle at which the kingpin is inclined.

**Knock:** When the flame fronts of a spark-ignited explosion and a compression-ignited explosion meet, an explosion or knocking, audible to the driver, occurs. This knocking may damage the engine.

**L-Head engine:** Type of engine in which both intake and exhaust valves are located on one side of the cylinder.

**Lay gear:** The gear on the countershaft (lay shaft) which meshes with the input gear.

**Leaf spring:** Suspension spring made from flat of arced bars. Each bar is called a leaf.

**Lean:** An air/fuel mixture with more than 14.7 parts of air per part of fuel.

**Live axle:** Any axle that rotates with the wheel. In common automotive usage, an axle differential assembly contained in one housing.

**Load:** Any electrical requirement drawn on the system that uses electrical power generated by the alternator or stored by the battery.

**Lockup torque converter:** A torque converter that includes a special extra solenoid-driven clutch that under certain conditions locks the input and the output of the torque converter.

**Lubrication:** Act of applying any compound that reduces friction between two parts.

**Magnetic field:** The flow of magnetic force or magnetism between the opposite poles of a magnet.

**MacPherson strut:** Suspension design that mounts a coil spring over the shock absorber and uses the assembly to locate the upper part of the suspension. This does away with the upper control arm.

**Manifold:** A combination of multichannels used to connect various cylinders to one inlet or outlet.

**Master cylinder:** The main cylinder in the hydraulic brake system which is used to force hydraulic fluid to the wheel cylinders in applying the brakes.

**Mechanical efficiency:** Ratio of an engine's actual horsepower to its theoretical power.

**Mechanical fuel injection:** In this system the airflow sensor is mechanically linked to a fuel management device which mechanically controls the fuel allotted to each injector.

**Mechanical lifter:** Valve lifter with no internal moving parts. Any lifter besides a hydraulic lifter.

**Metering rod:** A stepped rod in the carburettor which measures quantity of fuel going out of the float chamber into the main nozzle.

**Mixing chamber:** The part of the carburettor between the venturi and the throttle valve in which fuel and air are mixed up.

**Mono-Block:** Enblock in which all the cylinders of an engine are contained in one casting.

**Muffler:** A chamber in the exhaust system which allows exhaust gases to expand and cool in order to silence them.

**Needle valve and seat:** Type of valve used to control the flow of a fluid. When the needle projects into the tapered seat orifice, no fuel can flow. When the needle is drawn back away from the seat, fuel can flow into the float bowl.

**Normalizing:** Releasing of stress in a part. Refers to the loosening of bolts after torquing.

**Nozzle:** Tiny hole or orifice.

**Octane rating:** A measure of the anti-knock quality of petrol. A high octane number petrol is used in high compression ratio engines.

**Oil-bath cleaner:** It traps dirt from intake air which enters into the carburettor.

**Oil-control ring:** Slotted ring placed below the compression ring of the piston. It scrapes excess oil from the cylinder to return it to the oil sump.

**Oil filter:** Filter element that strains the oil, removing small particles of metal and dirt.

**Oil pan:** Encloses the lower portion of the crankcase and holds the oil when it is not circulating in the engine.

**Oil pump:** Pump that sucks oil from the pan and pushes it throughout the engine. It is driven by engine rotation.

**Overhead-camshaft engine (OHC):** The camshaft is placed over the cylinder head.

**Oversteer:** When the rear-tyre slip angles are greater than the front-tyre slip angles, the vehicle will turn more sharply than intended.

**Parking brake:** Mechanically actuated brake used to hold the car when parked.

**Part number:** Identification number for parts in the parts department. The number is used for ordering, identification, inventory and other tasks.

**Pedal bleeding:** Using the brake pedal to force contaminated fluid out from the hydraulic system.

**Pilot jet:** The jet in the carburettor through which petrol passes when the throttle is slightly open or fully closed.

**Pinion gear:** Gear fitted between the two side gears in the differential, allows the transfer of motion and energy between the two axles.

**Piston crown:** The piston head which receives the pressure of the expanding gases.

**Piston skirt:** The portion of the piston below the piston pin.

**Pitman arm:** Arm connecting the steering box to the steering linkage running across the car.

**Planetary gear set:** Set of gears consisting of a sun gear, a ring gear, and a planet gear carrier. If one of the three gears is held motionless while a second gear is driven, a third gear will produce output motion.

**Plate:** A grid pasted with the active materials of the battery.

**Poppet valve:** Elongated mushroom-shaped valve that seals against a valve seat. All autmotive valves are poppet valves. Other valve types are called sleeve and reed, and are used in two-stroke engines.

**Port:** Passage leading from the intake manifold runner to the combustion chamber. It is closed at one end by the intake valve. The opposite path is found in the exhaust port.

**Port injection:** Type of fuel injection that uses individual injectors located near or pointed directly at the intake valve.

**Positive crankcase ventilation:** System that uses engine vacuum to draw blow-by out of the crankcase and send it down the intake to be burned.

**Pour point:** Temperature at which an oil begins to flow.

**Power booster:** Vacuum or hydraulic device used to increase pressure to the master cylinder.

**Power cable:** Heavy electrical wire used to carry large amounts of current. The cables leading to and from the battery are good examples.

**Power steering:** Steering that is assisted by hydraulic pressure.

**Prechamber:** A small prechamber is often the site for direct injection on passenger car diesel engines. The small chamber is attached to main combustion chamber where the burning continues once it has started.

**Pre-ignition:** Due to overheated combustion chamber, the mixture burns before the production of actual spark in the spark plug.

**Pressure plate:** Heavy steel ring pressed against the friction disc by spring pressure. Commonly used to mean the entire pressure plate, spring, cover, and lever assembly.

**Pressure relief valve:** Valve located in the oil pump or just before the oil filter which vents excess oil pressure back into the oil pan.

**Preventive maintenance:** Program of replacing and servicing parts before they fail.

**Primary cell:** Type of battery cell that cannot be recharged.

**Primary coil:** Input windings of a transformer.

**Propeller shaft:** Shaft that carries torque from the engine/transmission to the drive axle on most cars.

**Push rod:** Straight rod used to carry camshaft motion from the valve lifter to the rocker arm. It is used on OHV engines only, here the cam is below the cylinder head.

**Quadrant:** Part of a ratcheting device with teeth on it. It helps hold the adjustment in one position.

**Quench:** Area in combustion chamber tightly sqeezed between piston and cylinder head. It promotes mixture turbulence.

**Rack and Pinion:** Steering design using pinion gear at the end of the steering staff, engaging the rack, which moves directly right or left. The rack is a flat bar with teeth cut into it.

**Reciprocating:** Back-and-forth motion, such as the up-and-down strokes of a piston.

**Recirculating ball:** Steering design featuring large amounts of gear reduction, protection against backlash and low steering effort.

**Ring gear:** Large-diameter circular gear to accomplish the change in power flow direction.

**Road draft tube:** Obsolete method of clearing blow-by pollutants from the engine crankcase.

**Rocker arm:** Arm that reverses or transfers push rod or camshaft motion. Some rocker arms used on OHC systems pivot at one end so they do not reverse camshaft motion. A rocker arm may also multiply camshaft motion.

**Roller bearing:** Bearing consisting of an inner and outer race upon which hardened steel rollers operate.

**Rotary engine:** An engine of Wankel design in which there is a rotor which moves inside an oval chamber and which contains no pistons.

**Rotary valve:** A type of valve in which ported holes coincide to provide entrance and exit of fluids or gases.

**Rotor:** Rotating valve or conductor for carrying fluid or electrical current from a central source to the individual outlets as required.

**SAE:** Society of Automatic Engineers.

**Secondary brake shoe:** The brake shoe in a set which is energized by the primary shoe and which increases this self energization of the brake.

**Secondary winding:** In an ignition coil or magneto, a wire in which a secondary or high tension current is induced by the interruption in the primary circuit.

**Self energization:** In automobile brakes, placing of brake shoes in such position that the brake drum tends to drag the shoe along with it, resulting in wedging action between the anchor and the drum and hence the self-energization.

**Semi-Floating axle:** A type of drive axle in which the axle shafts support the weight of the vehicle.

**Servo action:** In brake construction wherein a primary shoe pushes a secondary shoe to generate self-energization.

**Shackle:** A swinging connection for a road-spring which permits it to vary in length as it deflects.

**Shock absorber:** A device which controls excessive deflection or jerks while on road by providing mechanical or hydraulic friction.

**Shunt winding:** An electric winding which forms a bypass or alternate path for electric current.

**Sleeve valve:** A reciprocating sleeve with ported openings to act as a valve.

**Solenoid:** An iron core surrounded by a coil of wire which moves due to magnetic attraction when current flows into the coil.

**Solid injection:** The fuel injection system in which fuel in the fluid state is injected into the cylinder.

**Spark plug:** A device containing an insulated central electrode for carrying high tension current from distributor and to provide spark in the engine cumbustion chamber.

**Speedometer:** A device for measuring and indicating the speed of a vehicle.

**Spur gear:** A gear in which the teeth are cut parallel to the shaft.

**Steering:** A device for controlling directional change of a vehicle.

**Steering geometry:** The related angles assumed by the front wheels of a vehicle when turning.

**Steering knuckle:** Front suspension part connecting the upper and lower control arms. It has mountings for wheel bearings, steering linkage, brakes, and a stabilizer bar.

**Steering linkage:** All rods, arms and rod ends that connect the front wheels to the steering box or rack.

**Storage battery:** Device that stores electrical energy in a Chemical reaction.

**Stroke:** One complete passage of the piston through its cylinder.

**Stub axle:** Nonflexible type of half-shaft.

**Sun gear:** The central gear around which the other gears revolve in a planetary gear system.

**Supercharger:** A blower which forces air into the cylinders at higher than atmospheric pressure.

**Swept volume:** Volume occupied by a piston as it travels through a cylinder on one stroke.

**Synchromesh gear box:** Transmission in which gear speeds are obtained through synchronizing unit.

**Tappet:** A sort of valve lifter which rides against the cam and lifts the valve or push rod.

**TDC:** Top dead centre.

**T-Head engine:** Type of engine in which intake valves are located on one side of the cylinders and the exhaust valves on the other side.

**Thermal efficiency:** It is the ratio of work accomplished compared to the total quantity of heat combined in the fuel.

**Thermostat:** A heat controlled valve used in the engine cooling system.

**Thermo-Syphon system:** A method of engine cooling which utilizes the difference in specific gravity of hot and cold water.

**Throttle valve:** A valve in the carburettor, operated by the accelerator, which regulates the flow of fuel air mixture from the carburettor.

**Tie rod:** Track rod which connects the steering spindle arms on opposite sides of the vehicle.

**Timing chain:** Chain used to drive camshaft.

**Timing gears:** Group of gears through which movement is affected to the camshaft for operating valves, ignition distributor or magneto and other parts of the engine at the scheduled time during the engine cycle.

**Toe-In:** The difference in measurement between the front of the wheels and the rear of the wheels.

**Torque:** A twisting or turning effort.

**Torque converter:** A device by means of which torque is multiplied while it is transmitted from the driving to driven member by hydraulic action.

**Transmission:** A drive for changing the ratio between the engine revolutions and the driving wheel revolutions.

**Turning radius:** The diameter of a circle within which a vehicle can be turned around.

**'U'-bolt:** An U-shaped bolt which secures the leaf spring to the axle of the vehicle.

**Understeer:** When the vehicle takes a bend, it runs away from the steered path.

**Universal joint:** Mechanical linkage in a drive shaft or axle which allows angular changes while transmitting torque.

**Unsprung weight:** Any weight not supported by the springs. This typically includes the tyre, wheels, brakes, and part of the suspension.

**Vacuum advance:** A mechanism attached to the distributor which advances the spark timing according to intake manifold vacuum.

**Valve clearance:** Distance adjusted into the valve train to account for engine growth from heat.

**Valve guide:** Machined portion of the cylinder head, which touches the valve stem. Most commonly a replaceable insert hammered into the head.

**Valve overlap:** The period in degree during which both the inlet and exhaust valves remain open.

**Valve seat:** Hardened portion of the cylinder head, or a replaceable insert that the valve seals against.

**Valve seat insert:** An alloy steel ring inserted in the cylinder head. It acts as a seating to the valve. It is corrosion and heat resistant.

**Valve train:** All parts of the engine required to operate the valves in their entirety.

**Variable-choke carburettor:** A carburettor which has a piston to move up or down depending upon suction pressure. The area of choke is thus varied.

**Variable jet:** In the variable choke carburettor, a tapered needle attached to the piston bottom varies the area of the jet. In this process, the quantity of fuel sprayed is controlled.

**Venturi:** The reduced area of the carburettor. Here the velocity energy of air-stream increases and therefore pressure energy decreases. This creates a vacuum to suck in petrol.

**Viscosity:** The property of oil to flow. It decreases with increase in oil temperature.

**Viscosity index:** A measurement by which the viscosity of oil changes with temperature.

**Water jacket:** Coolant passages cast into a cylinder block or head.

**Water pump:** Engine accessory that pumps coolant through an engine. Normally, belt driven.

**Wedge:** Type of combustion chamber where part of the roof is angled to form a wedge shape. Provides lots of quench area.

**Wet sump lubrication:** The lubrication system which has oil in the sump positioned underneath the crankcase.

**Wheel alignment:** Aligning the front wheels relative to each other. Setting of castor, camber, toe-in or toe-out and king-pin inclination.

**Wheel-base steering** Being in the straight ahead position, the distance between the front and rear wheel axles of a car.

**Wheel cylinder:** Hydraulic break cylinders used in drum brakes which operate under the command of the master cylinder. They force the brake shoes outward against the drum.

**Windings:** Coil of wire in a transformer, relay, or coil.

**Wire harness:** Group of wires that are taped together for installation as a unit into the automobile.

**Wiring diagram:** Road map of lines and symbols that describes the interconnections of a vehicle's wiring system.

**Wishbones:** Triangular steel frames which connect the vehicle's body to each road wheel in the independent suspension system.

**Worm and nut steering gear:** Steering design similar to recirculating ball, but not as popular.

**Yoke:** Y-shaped section of the drive shaft which helps form the U-joints.

**Zerk fitting:** Very small check valve which allows grease injection into suspension parts.

# Index