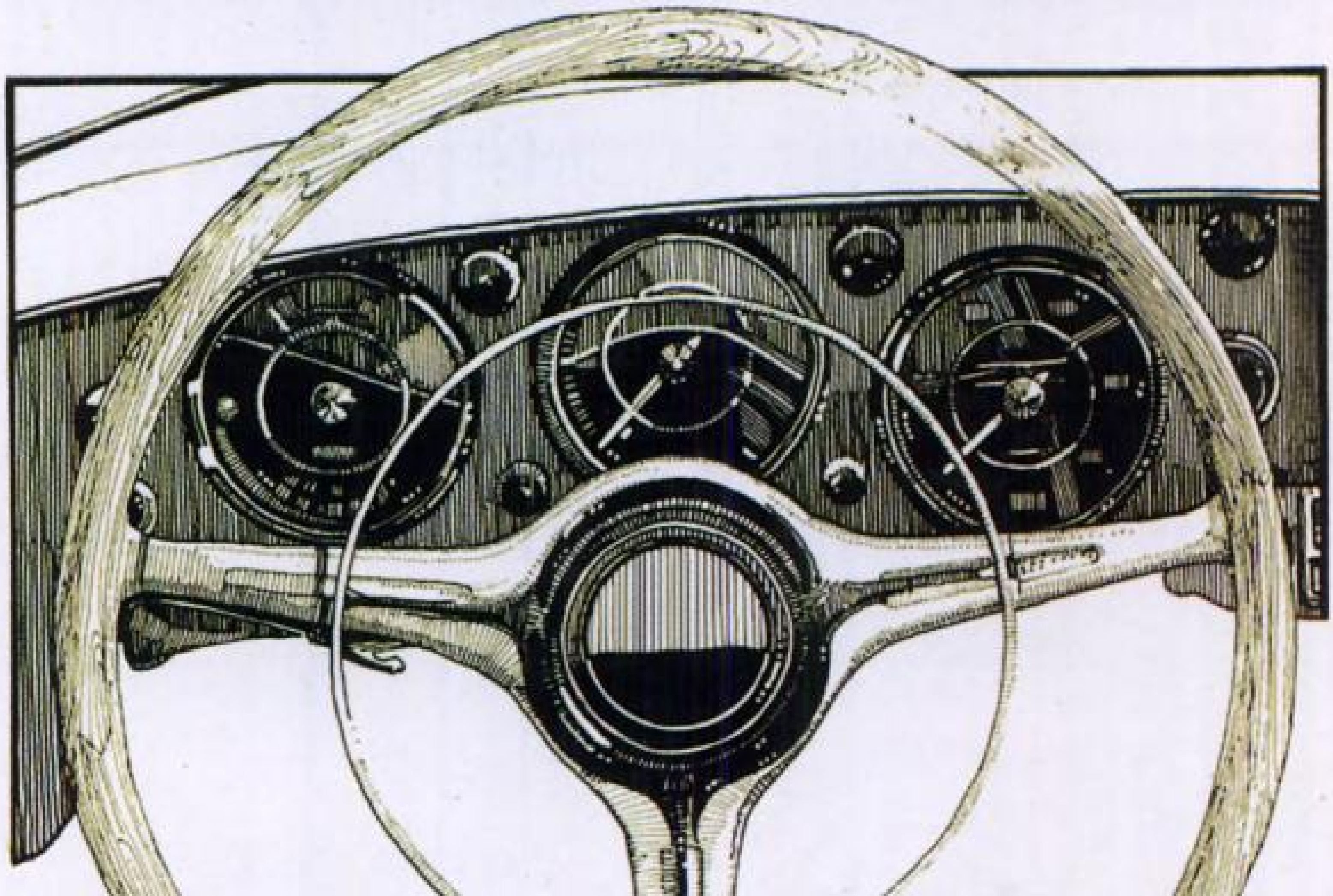
A Textbook of AUTOMOBILE ENGINEERING



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CONTENTS

1

Introduction

1.1. Introduction to an automobile. 1.2. Brief history of automobile. 1.3. Classification of automobiles. 1.4. Parts of an automobile—mechanical portion—chassis and transmission—the engine—electrical system—body or carriage portion. 1.5. Description of an automobile. 1.6. Performance of an automobile—Short Answer Questions—Highlights—Objective Type Questions—Theoretical Questions.

1.1. INTRODUCTION TO AN AUTOMOBILE

Automobile. *An "automobile" is a self-propelled vehicle driven by an internal combustion engine and is used for transportation of passengers and goods on ground.* ***Examples :*** Bus, car, jeep, truck, tractor, scooter, motor cycle.

The modern automobile, in general, is essentially a transportation equipment unit. It consists of a *"frame"* supporting the *"body"* and certain *"power developing and transmitting units" which 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.*

Automobile engineering. *Automobile (or automotive) engineering is a branch of engineering in which we study all about the automobiles and have practice to propel them.*

– Mobile or motive means one which can move. Automobile or automotive means one *which itself can move.*

The different names for the automobile are :

- Auto
- Automobile
- Autocar
- Autobuggy
- Car
- Motor
- Motor car
- Motor vehicle
- Motor coach
- Motor wagon
- Horseless coach.

1.2. BRIEF HISTORY OF AUTOMOBILE

The famous years in early automobile history are as follows :

Year	Event
• *1769*	French engineer Captain Nicholas Cugnot of France built the first road vehicle propelled by its own power (Attained a speed of about 2.5. m.p.h. in 15 minutes).
• *1801*	First steam carriage built by Richard Trevithick in England.
• *1804*	Oliver Evans built the finest American self-propelled steam vehicle.
• *1827*	Onesiphare Pacqueur of France invented first differential.
• *1832*	First 3-speed Transmission patented by W.H. James in England.
• *1880*	German and French efforts developed an internal combustion engine vehicle (which was used to carry fruits). The present day automobile is the development of this vehicle.

- *1885* Benz in Germany developed tricycle propelled by an internal combustion engine.
- *1886* One of the first gasoline engine powered automobiles by Gottlieb Daimler of Germany.
- *1894* Panhard and Levassor in France developed a car which incorporated the chief features of the modern automobile.
- *1895* First motor car race held.
- *1897* *First car arrived in India.*
- *1900* The design of the automobile was so improved that it awakened the public to the fact that this new form of transportation was really practical for use.
- *1902* First volume of production car "The Curved Dash Oldsmobile" in America.
- *1906* The production and sale of these vehicles became a business.
- *1908* Ford 'T' model car produced in America by Ford Motor Company (Ford started his model with an initial run of 20000 vehicles, an output unheard at that time).
- *1911* First electric self-starter installed in the automobile.
- *1920* There was a gradual change and refinement in automobile design ....

The design development of recent years has provided the owners with cars that are :

- Safer ;
- Easier to drive ;
- Comfortable ;
- More reliable.

"Germany is the birth place of the automobile. It was invented there, it went through its first paces there and it was developed there to a high level of technical maturity. The list of German automobile pioneers is a long one. Starting with Nicholas Cugnot, August Otto, Carl Benz, Gottlieb Daimler, Wilhelm Maybach and Rudolf Diesel and going all the way upto Ferdinand Posche and Felin Wankel."

... From SCALA INTERNATIONAL

Automobile in India :

- In India the first motor car appeared in 1897. For about 50 years from 1897, India was an importer of automobiles.
- The late Bharat Ratna Sir M. Vivesvaraya made an automobile industry in India, but the government did not approve the plan.
- In 1943 and 1944 two automobile factories namely, Hindustan Motors Limited, Calcutta and premier Automobiles Limited, Bombay were set up in India.

At present, several automobile companies are manufacturing automobiles.

Use of Diesel engines in cars :

Following are the *advantages* of using Diesel engines in cars :

1. Diesel fuel is much cheaper than petrol.

2. The diesel engine uses 50 per cent less fuel in heavy traffic than does the available spark-ignition engine.

- One reason for extra economy is that diesel's *good low-speed torque makes it possible to drive at low speeds in a higher gear.*

3. The high thermal efficiency of the diesel engine, reflected in low specific fuel consumption gives its high advantages in the matter of range.

4. The crankshaft speed of about 5000 r.p.m. enables the diesel engine to propel the cars at high speeds, with acceleration comparable to that of S.I. engine.

5. The use of diesel engine eliminates the complication of spark-ignition with its spark plugs, breaker points, condenser, ignition cables, distributor rotor and other components that may have to be replaced several times during the life of engine.

6. Operating tests are further reduced by having no carburettor to service periodically.

7. Owing to the absence of electrical ignition equipment, non-volatile fuel and lower exhaust temperature, the *diesel engine is a much smaller fire risk* than the petrol engine when working in closed places and in the neighbourhood of inflammable material.

8. The special feature of diesel engines called *"torque back up"* (an inbuilt performance feature) makes it convenient for the vehicle to *climb a steep incline* (such as ghats) *with low consumption at high load.* Under these conditions diesel engines *run comparatively cold* than an equivalent petrol engine under the similar load conditions.

Inspite of all the above mentioned advantages uptill now, diesel engines for cars were rejected from majority of customers, due to their *heavy weight and size, high noise, vibration and smoke levels.* These problems finally led to the development of *compact, light weight and fuel efficient passenger car diesel engines.* In this connection, the reference needs to be mentioned to :

— Over-square bore-stroke ratio ;
— Fast responding value gear trains ;
— Cold starting equipments ;
— Combustion chamber design ;
— Fuel injection equipment ;
— Solution of metallurgical problems to ensure satisfactory working life of aluminium alloy components, crankshaft journals, bearings, cylinder bores and other highly stressed components.

- The sacrifice of German engineer Rudolf Diesel is memorable in Automobile and I.C. engine history. He got very seriously injured when he successfully exploded coal dust as fuel. And in 1913 although he invented Diesel engine using liquid fuel 'Diesel' but he committed suicide as he could not get financial co-operation from his friend for his research and development.

1.3. CLASSIFICATION OF AUTOMOBILES

Automobiles can be *classified with different regards* which are as under :

1. **Purpose :**

(*i*) Passenger carriers	— Car, Jeep, Bus etc.
(*ii*) Goods carriers	— Truck etc.

2. **Fuel used :**

(*i*) Petrol vehicle	— Motor cycles, Scooters, Cars, Station wagons
(*ii*) Diesel vehicle	— Trucks, Buses etc.
(*iii*) Gas vehicle	— Coal gas turbine
(*iv*) Electric	— Using storage batteries
(*v*) Steam	— Using steam engine (obsolete).

3. **Capacity :**

(*i*) HTV (Heavy Transport Vehicles) or HMV (Heavy Motor Vehicles)	— Trucks, Buses, Dumpers etc.
(*ii*) LTV (Light Transport Vehicles)	— Pick up, Station wagon
(*iii*) LMV (Light Motor Vehicles)	— Jeep, Cars
(*iv*) Medium vehicle	— Station wagon, Tempo, Minibus and small trucks.

4. **Construction :**

(*i*) Single unit vehicles

(*ii*) Articulated vehicles and tractors.

5. **Drive :**

(*i*) Left hand drive	– Steering wheel fitted on left hand side.
(*ii*) Right hand drive	– Steering wheel fitted on right hand side.
(*iii*) Fluid drive	– Vehicle employing torque converter, fluid flywheel or hydramatic transmission.

6. **Wheel and axle :**

(*i*) Two wheeler	– Auto cycle, Mopped, Scooter and Motor cycle
(*ii*) Three wheeler	– Three wheeler scooter, Auto rickshaw and Tempo.
(*iii*) Four wheeler (4×2) and (4×4)	– Cars, Jeep, Station wagon, Pick up, Trucks, Buses.
(*iv*) Six wheeler (6×2) and (6×4)	– Six wheeler having two gear axles each having four wheels. Vehicles are classified by number of wheels and number of drive wheels where in it is written 4×2 or 4×4 drive etc. In this case first figure indicates *number of wheels* and the second figure indicates number of *drive wheels*. In case of 4×4 drive, the vehicle has 4 wheels and all are drive wheels, however it should be noted that wheels are considered as unit whether they have single tyre or dual tyre.

7. **Suspension system :**

(*i*) Conventional	– Leaf spring
(*ii*) Independent	– Coil spring, Torsion bar, Pneumatic.

8. **Body and number of doors :**

(*i*) Sedan	– Two doors and four doors types
(*ii*) Convertible	– Jeep, Some imported cars
(*iii*) Station wagon	
(*iv*) Delivery van/Pick ups	
(*v*) Special purpose vehicle	– Ambulances, Milk van, Mobile workshop, Mobile hospital etc.

9. **Transmission :**

(*i*) Conventional	– All Indian vehicles
(*ii*) Semi-automatic	– Most of British and Japanese vehicles
(*iii*) Automatic	– Most of the American vehicles.

A *brief classification* of the automobiles is as follows :

1. **Passenger carriers :**

(*i*) ***Light***

- Scooterets
- Scooters
- Mopeds
- Motor cycles
- Cars
- Pick-ups
- Station wagons.

(*ii*) ***Heavy***

- Buses
  - Single deck
  - Double deck
- Coaches
  - Delux
  - Air-conditioned.

2. **Goods carriers :**

(*i*) ***Light***

- Delivery van
- Light truck

(*ii*) ***Heavy***

- Truck
- Tractor trailer.

1.4. PARTS OF AN AUTOMOBILE

Every automobile consists of the following *two main parts* :

1. Machine portion
2. Carriage portion *i.e.*, Body.

1.4.1. Machine Portion

Refer to Fig. 1.1. (Automobile parts)

Every automobile irrespective of its country of manufacture or model consists of the following *three basic units* :

(*i*) The "*chassis and transmission*".

(*ii*) The "*engine*".

(*iii*) The "*electrical equipment*".

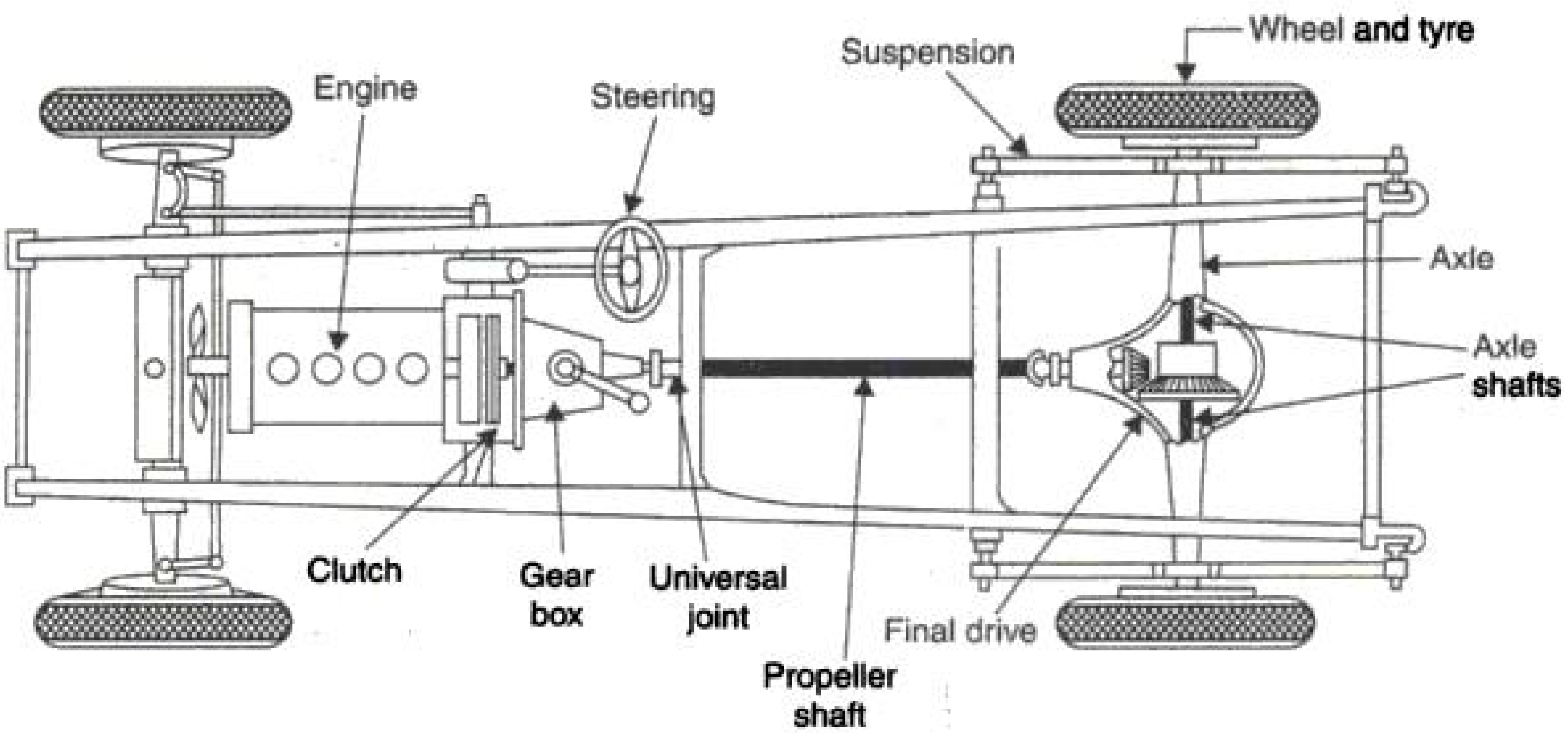


Fig. 1.1. Parts of an automobile.

1.4.1.1. Chassis and transmission

Chassis :

- This part of the automobile supports its body, engine and transmission system.
- The automotive chassis *includes* the following :
  - The frame ;
  - Springs and shock absorbers ;

— Steering system ;
— Brakes ;
— Tyres and wheels.

Transmission :

- This unit *transmits the power from the engine to the wheels.*
- It consists of the following :
  — Clutch ;
  — Gear box ;
  — Universal joint ;
  — Final drive ;
  — Axles and differential.

1.4.1.2. The engine

An engine in an automobile is the *source of power*. A *petrol engine* consists of the following four basic system, described briefly below :

(*i*) **Full system.** This system mixes petrol with air in the right proportion to give a mixture which when burnt produces pressure. This pressure is then used to move the piston(s).

(*ii*) **Ignition system.** This system of the engine provides regular sparks to set fire to the mixture coming from the fuel system.

(*iii*) **Lubricating system.** This system lubricates the moving parts of the engine so that they can work smoothly.

(*iv*) **Cooling system.** This system with the help of water cools the engine and prevents it from getting hot.

- Diesel engines incorporating similar/different systems are also used in automobiles.

1.4.1.3. Electrical system

The automotive electrical system consists of the following :

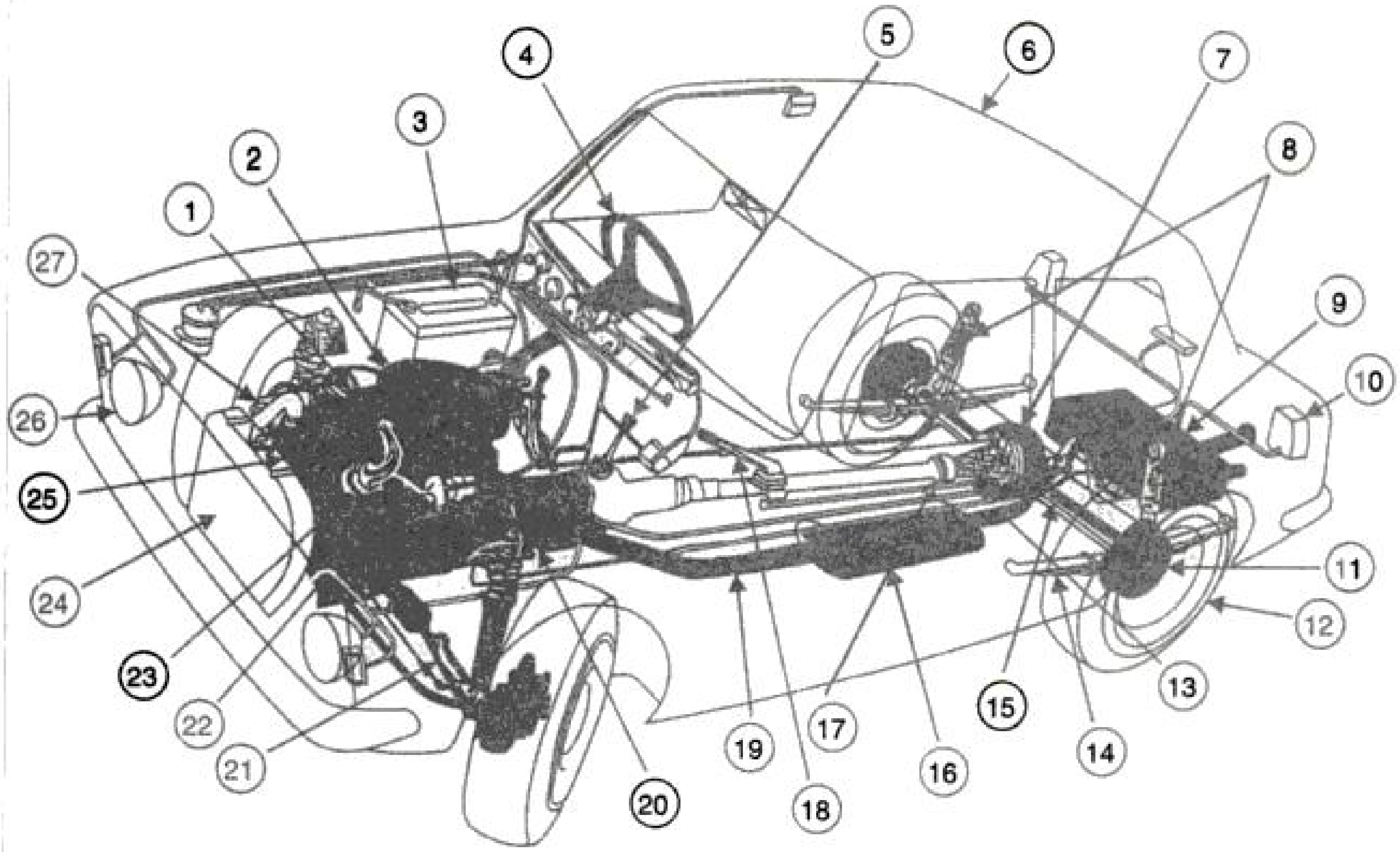
— The battery ;
— Dynamo ;
— Alternators ;
— The ignition starting and lighting systems.

- This system starts the engine when the ignition switch is turned on. It makes the spark that ignities the compressed air-fuel mixture.
- It also operates the *electric gauge head lights, indicator lights, brake lights, parking lights, wipers and also radio and cassette recorders if fitted in cars.*

1.4.2. Body or Carriage Portion

- It is that portion of an automobile where passengers have their seats or where the cargo to be carried is placed.
- The body is designed according to the nature of cargo to be carried. The body of a passenger carrier is much different from the body of a load carrier, *i.e.*, truck. Its design depends upon the utility for which the vehicle is meant for. It is made of either wood and steel or steel alone. Modern research has led to the development of plastic body.
- In trucks, tractors and certain other vehicles, a separate cabin know as *'Cab'* is provided for the driver where the instrument panel and controls are housed.

The *layout of an automobile* is shown in Fig. 1.2.



1. Engine 2. Air cleaner 3. Battery 4. Steering wheel 5. Gear lever 6. Car body 7. Differential 8. Shock obsorber 9. Fuel tank 10. Back light 11. Rear brake 12. Wheel and tyres 13. Tail pipe 14. Leaf spring 15. Rear axle 16. Silencer 17. Universal joint 18. Hand brake lever 19. Exhaust pipe 20. Clutch 21. Track rod 22. Carburettor 23. Distributor 24. Radiator 25. Fan 26. Head lamp 27. Alternator.

Fig. 1.2. Layout of an automobile.

1.5. DESCRIPTION OF AN AUTOMOBILE

The following factors should be taken into consideration while writing down the description of an automobile.

1. **Type** .... Bus, truck, car, motor cycle etc.

2. **Capacity** .....Carriage capacity— 5 ton, 3 ton etc. ; 4 seater, 6 seater, 30 seater, 45 seater etc.

3. **Make.** It is the actual name allotted by the manufacturer. In most cases, the make also indicates capacity/H.P. of the engine fitted in the vehicle, such as *Maruti 800*. This means that in Maruti make of car 800 c.c. engine, the total picton displacement is about 800 c.c.

4. **Drive.** The description of an automobile with regard to drive may be given as follows:

(*i*) *Right hand or left hand drive*. It means whether the steering is fitted on the right side or left side.

(*ii*) *Two wheel drive ; 4 wheel drive ; 6 wheel drive.* This means as to how many wheels the engine power flows or how many wheels are directly connected with the engine.

— In *majority of the cars the engine power flows to the rear wheel only and the front wheels are filled on the dead axle*. These types of cars are known as *"two wheel drive vehicles."*

— In certain vehicles, like jeep, all the vehicles are directly in contact with engine and the engine *power could be transmitted to all the four wheels.*

- Drive is usually indicated as under :

Left hand drive ; 4 × 4 (4 wheel drive)

Or

Left hand, Four wheel drive ; **4 × 4** means the vehicle contains 4 wheels and the engine power could flow towards all the 4 wheels, **6 × 4** means that there are 6 wheels but the engine power could flow towards 4 wheels only.

5. **Model.** ......Year of manufacture or special Code Number allotted by the manufacturer.

Thus for the description of an automobile following *information* will be required :

(*i*) Type (*ii*) Capacity
(*iii*) Make (*iv*) Drive
(*v*) Model.

1.6. PERFORMANCE OF AN AUTOMOBILE

When the fuel burns in the cylinder, *pressures* are developed. These pressures are transmitted to the crankshaft by the piston and connecting rod and torque is produced which sets the crankshaft in motion. *The torque produced by the engine is transmitted through the drive line to the road wheels to propel the vehicle* (The crankshaft is *coupled to the driving road wheels through clutch, gearbox, propeller shaft, differential and axle shafts*).

The torque is measured in Nm (SI units) ; the actual power delivered by the engine is known as Brake Power (B.P.) and is measured by dynamometer or prony brake.

$$\text{B.P.} = \frac{2\pi NT}{60 \times 1000} \text{ kW} \quad ...(1.1)$$

where, T = Torque, Nm, and

N = Speed in r.p.m. (revolutions per minute).

– The torque increases with the increase in engine speed upto a certain point after which it starts to fall down even though the engine speed continues to increase. The number of r.p.m. at which the torque begins to decrease, depends upon *engine design*. At higher speeds, engine vacuum falls down and less fuel enters the cylinders resulting in lesser force available at the piston and hence the fall in torque as shown in Fig. 1.3.

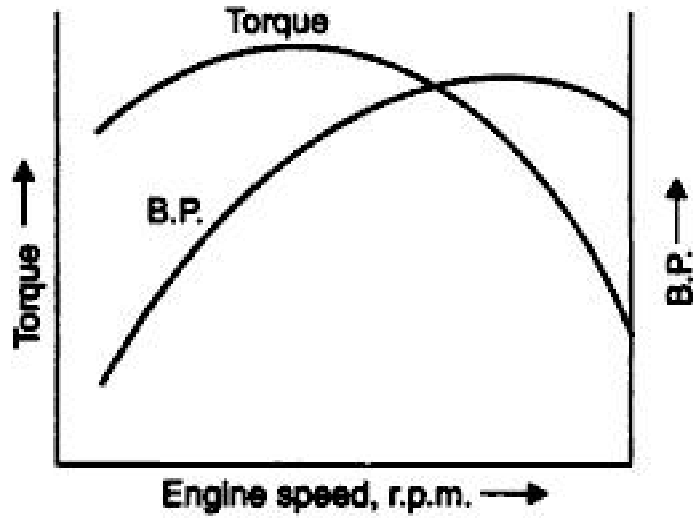


Fig. 1.3. Typical curves of torque and B.P. with speed of an engine.

The torque available at the contact between driving wheels and road is referred to as *tractive effort*. *Gear box and final drive at differential act as leverage to multiply torque which is inversely proportional to speed.* If the gear speed is lowered, the torque shall be increased in the same ratio and vice versa.

Let, T_w = Torque at driving wheels,

G = Gear box ratio,

η_t = Overall transmission efficiency,

T_E = Engine torque (Nm), and

N = r.p.m. of the crankshaft.

Then, $$T_w = G \times \eta_t \times T_E \quad ...(1.2)$$

Engine torque, $$T_E = \frac{B.P. \times 60 \times 1000}{2\pi N} \text{ Nm}, \quad ...(1.3)$$

where B.P. is in kW.

Tractive effort, $$F = \frac{T_w}{R_w} \quad ...(1.4)$$

where, R_w = Radius of the driving wheel.

The ratio between engine r.p.m. and vehicle speed depends upon overall gear ratio. A vehicle having four speed gear box shall have four different speeds and ratio between engine r.p.m. and vehicle speed shall be different.

$$\text{R.P.M. of driving wheel} = \frac{V}{2\pi R_w}$$

where, V = Vehicle speed in metres/min., and

R_w = Radius of wheel in metres.

$$\text{Vehicle speed} = \text{Wheel circumference} \times \frac{N}{G}$$

or,
$$V = \frac{2\pi R_w N}{G} \text{ m/min} \quad ...(1.5)$$

$\therefore$ Engine r.p.m.,
$$N = \frac{V \times G}{2\pi R_w} \quad ...[1.5(a)]$$

Vehicle speed,
$$\frac{V \times 1000}{60} = \frac{2\pi R_w N}{G}$$

where V is in km/h.

$\therefore$ The *ratio between engine r.p.m.* (N) and vehicle speed (V)

or,
$$\frac{N}{V} = \frac{1000 \times G}{2\pi R_w \times 60} = 2.65\left(\frac{G}{R_w}\right) \quad ...(1.6)$$

Also,
$$V = \frac{2\pi R_w N}{G} \text{ m/min} \quad \text{[Eqn. (1.5) as above]}$$

$\therefore$
$$G = \frac{2\pi R_w N}{V} \quad ...(1.7)$$

- The engine torque (T_E) can be *increased by reduction gearing*. The torque transmitted by the engine through gearbox and propeller shaft to the final drive is *increased in every gear speed except in top (direct) and overdrive.*
- The torque transmitted by propeller shaft is further increased by means of gear reduction of final drive (drive piston and ring gear at differential). The *torque of final drive, provided a differential is fitted, is always equally divided between each axle shaft irrespective of speed of road vehicles although it does not apply to limited-slip type of differential.*
- *The speed of propeller shaft is always less than the engine speed except in top gear or when overdrive is engaged.*
- *The speeds of axle shafts are always less than the speed of propeller shaft owing to final drive gear reduction.*

Power at Driving Wheels :

The power available at the driving wheels to drive the vehicle ranges from about 60 to 75%. The various power losses which take place between engine and the driving wheels are :

(*i*) Power loss due to friction of piston, bearings and gears in the engine (The power available at engine flywheel is about 85%).

(*ii*) Power loss from clutch to drive wheels due to friction in clutch, gearbox, universal joints, final drive, differential and between tyres and ground.

(*iii*) Transmission line losses.

The power lost in transmission of power from engine to road wheels reflects the transmission efficiency (η_t) which is taken into account while calculating power available at road wheels.

The *thrust* known as *tractive effort* provided by the engine at the driving road wheels varies at different engine speeds and gear positions.

A moving vehicle is opposed by various forces known as *resistances*. For keeping the vehicle moving, a driving force or tractive effort (F) equal to the sum of all the resistances has to be applied to it. When F exceeds the sum of the resistances, the excess value F will accelerate the vehicle, where as, when F is less than the sum of the resistances, the vehicle, will decelerate.

The main forces which *oppose* the motion of a vehicle are :

1. Rolling resistance.
2. Wind or air resistance
3. Gradient resistance.

1. Rolling resistance (R_r) :

- It is *mainly due to the friction between wheel tyres and road surface*. It depends upon the following *factors* :
  — Load on each road wheel ;
  — Type of tyre tread ;
  — Wheel inflation pressure ;
  — Nature of road surface.
- It is measured in kg or N and is expressed as kg/tonne or N/tonne of vehicle weight or as a *percentage of the vehicle weight*. Rolling resistance on average type of road surface is between **1 to 2% of vehicle weight.**

Rolling resistance, $R_r = k_r W$

where, k_r = Constant of rolling resistance, and
W = Total weight of vehicle.

2. Wind or air resistance (R_a) :

- This type of resistance depends upon the following **factors** :
  — The shape and size of vehicle body ;
  — Air velocity ;
  — Speed of the vehicle.
- It *increases as the square of the vehicle speed* owing to which much importance is given to streamlining and frontal area of modern automobiles. In calculating air resistance, air velocity is usually neglected.

Air resistance, $R_a = k_a A V^2$

where, k_a = Coefficient of air resistance,
A = Projected frontal area, m^2, and
V = Vehicle speed, km/h.

The values of k_a for "*best streamlined cars*," "*average cars*" and "*buses and trucks*" are 0.00235, 0.0032 and 0.0046 respectively.

3. **Gradient resistance (R_g) :**

- This resistance is due to *steepness of road gradient*. It is subject to vehicle weight and road gradient. It *does not depend upon vehicle speed*.
- Gradient resistance, $R_g = \frac{W}{G}$, or, $W \sin \theta$

(if gradient is expressed in angular dimensions)

where, W = Total weight of vehicle,

G = Gradient, and

θ = Inclination. (For small values, $\tan \theta = \sin \theta$)

When the vehicle is moving along a level road, total resistance,

$$R_{total} = R_r + R_a, \text{ and}$$

while moving up a gradient,

$$R_{total} = R_r + R_a + R_g.$$

Power-to-weight Ratio :

- An automobile's performance much depends upon its power-to-weight ratio. The *best performance can be achieved by keeping the weight of the vehicle down to a minimum and installing engines of high B.P.* The higher the effective B.P. of the engine and lower the total weight of the vehicle, the better will be its hill climbing abilities, the higher the maximum speed and better its acceleration.
- A *well designed streamlined car having a high power-to-weight ratio registers a low fuel consumption at any given speed.*
- Power-to-weight ratio (B.H.P. per ton) in small and medium cars ranges from 30 to 90 ; special high performance cars have the ratios upto 230.
- Considering maximum speed, there should be *minimum body resistance* in addition to high power-to-weight ratio because the *air resistance* of an automobile body and chassis *increases as the square of the speed whereas the power varies* as *cube of the speed.*

Although performance of an automobile is governed by the power-to-weight ratio and the resistances affecting its movement yet the *road performance is usually assessed by its rate of acceleration from rest and the top speed attainable on level roads*. The acceleration is usually measured in terms of time the car takes to reach a given speed from rest.

Note. The progressive increase in power-to-weight ratio has brought about improvement in the performance of an automobile. The *total weight* of the automobile has been *reduced* considerably by the *use of lighter materials and improved methods of chassis and body construction*. The *power output* of the engine has been *increased* by using aluminium and magnesium alloys, *improved piston, piston ring, cylinder and combustion chamber design, increased compression ratios due to use of aluminium alloy pistons and cylinder heads, better engine balancing, lubrication and cooling systems, fuels of higher octane values, balanced fuel supply and correct ignition.*

SHORT ANSWER QUESTIONS

Q. 1. What is an automobile ?

Ans. An automobile is a *self-propelled vehicle* which is used for the transportation of passengers and goods on the ground.

Q. 2. What is a self-propelled vehicle ?

Ans. A self-propelled vehicle is one is which the power required for the propulsion is produced *in the vehicle itself.*

Q. 3. Give six examples of automobiles.

Ans. The six examples of automobiles are :

(*i*) Car	(*ii*) Bus	(*iii*) Truck
(*iv*) Tractor	(*v*) Motor Cycle	(*vi*) Scooter.

Q. 4. State the basis on which automobiles are classified.

Ans. Following are the basis on which automobiles are classified :

Purpose ; Fuel used ; Capacity ; Construction ; Drive ; Wheel and axel ; Suspension system ; Body and number of doors ; Transmission.

Q. 5. Enumerate the specifications which should be considered while purchasing an automobile.

Ans. Following specifications should be considered while purchasing an automobile :

Type ; Capacity ; Make ; Drive ; Model.

Q. 6. Who built the first road vehicle propelled by its own power ?

Ans. French engineer Captain Nicholas Cugnol (Year-1769).

Q. 7. Give examples of Indian manufactures of scooters.

Ans. Andhra Pradesh scooters ; Bajaj Auto ; Lohia Machines ; Scooter India ; Girnar Scooters.

Q. 8. Give examples of Indian manufacturers of passenger cars.

Ans. Premier Automobiles Ltd. Bombay ; Hindustan Motors Ltd., Calcutta ; Maruti Udyog Ltd., Gurgaon ; Standards Motor Products of India Ltd., Madras ; Sipani Automobiles ; Mohindra and Mohindra Ltd., Bombay ; Telco, Poona ; Hyundai Motor India Ltd.

Q. 9. Give examples of Indian manufacturers of tractors and three wheelers.

Ans. Eicher Tractors Ltd. Faridabad ; Escorts Ltd., Faridabad ; Escorts Tractors Ltd., New Delhi ; Gujrat Tractor Corpn. Ltd., Baroda ; HMT Pinjore ; Mohindra and Mohindra, Bombay ; Punjab Tractors, Mohali ; Tractors and Farm Equipment Ltd. ; Bajaj Auto Ltd., Pune ; Automobile Products of India.

HIGHLIGHTS

1. An "*automobile*" is a self-propelled vehicle driven by an internal combustion engine and is used for transportation of goods and passangers on ground.
2. Every automobile irrespective of its country of manufacture or model consists of the following *three basic units* :
   (*i*) The chassis and transmission ;
   (*ii*) The engine ;
   (*iii*) The electrical equipment.
3. The following factors should be taken into consideration while writing down the description of an automobile :
   (*i*) Type (*ii*) Capacity
   (*iii*) Make (*iv*) Drive
   (*v*) Model.
4. The engine torque can be increased by reduction gearing.
5. The main forces which oppose the motion of a vehicle are :
   (*i*) Rolling resistance (*ii*) Wind or air resistance
   (*iii*) Gradient resistance.
6. A well designed streamlined car having a high power-to-weight ratio register a low fuel consumption at any given speed.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say "Yes" or "No"

1. An ...... is a self-propelled vehicle driven by an internal combustion engine and is used for transportation of passengers and goods on ground.
2. Mobile or motive means one which cannot move.
3. First motor car race was held in 1895.
4. First car arrived an India in ....
5. ...... is the birth place of the automobile.
6. Left hand drive means steering wheel fitted on left hand side.
7. Every automobile consists of machine portion and carriage portion.
8. Chassis of the automobile supports its body, engine and ...... system.
9. The ...... unit transmits the power from the engine to the wheels.
10. An ...... in an automobile is the source of power.

Answers

1. automobile	2. No	3. Yes	4. 1897	5. Germany
6. Yes	7. Yes	8. transmission	9. transmission	10. engine.

THEORETICAL QUESTIONS

1. Define the following terms :
   (i) Vehicle
   (ii) Motor vehicle
   (iii) Automobile
   (iv) Automobile engineering.
2. What do you understand by Automobile engineering ? What is the importance of automobile engineering over the other branches of engineering ?
3. Give a brief history of automobile.
4. What are the advantages of diesel engines in cars ?
5. Give the classification of automobiles.
6. What are the different types of automobile vehicles.
7. Explain briefly various parts of an automobile with the help of simple sketch.
8. Describe briefly the following three basic units of an automobile :
   (i) The chassis and transmission.
   (ii) The engine.
   (iii) The electrical equipment.
9. Explain briefly the factors which should be taken into consideration while writing down the description of an automobile.
10. Explain briefly the main forces which oppose the motion of a vehicle.
11. Explain the effect of "Power-to-weight" ratio on an automobile's performance.

2

Power Unit—Automobile Engines

I. Introduction to Internal Combustion Engines

2.1. HEAT ENGINES

Any type of engine or machine which derives heat energy from the combustion of fuel or any other source and converts this energy into mechanical work is termed as a **heat engine.**

Heat engines may be *classified* into two main classes as follows :

1. External Combustion Engines.
2. Internal Combustion Engines.

1. **External combustion engines (E.C. engines) :**

In this case, *combustion of fuel takes place outside the cylinder as in case of steam engines* where the heat of combustion is employed to generate steam which is used to move a piston in a cylinder. Other examples of external combustion engines are *hot air engines, steam turbine* and *closed cycle gas turbine.* These engines are generally used for driving locomotives, ships, generation of electric power etc.

2. **Internal combustion engines (I.C. engines) :**

In this case, *combustion of the fuel with oxygen of the air occurs within the cylinder of the engine.* The internal combustion engines group includes engines employing mixtures of combustible gases and air, known as *gas engines*, those *using lighter liquid fuel* or *spirit* known as *petrol engines* and those using heavier liquid fuels, known as *oil compression ignition* or *diesel engines*.

- Now a days, **I.C. engines** *are most-commonly used in* **automobiles.**

The detailed classification of heat engines is given in Fig. 2.1.

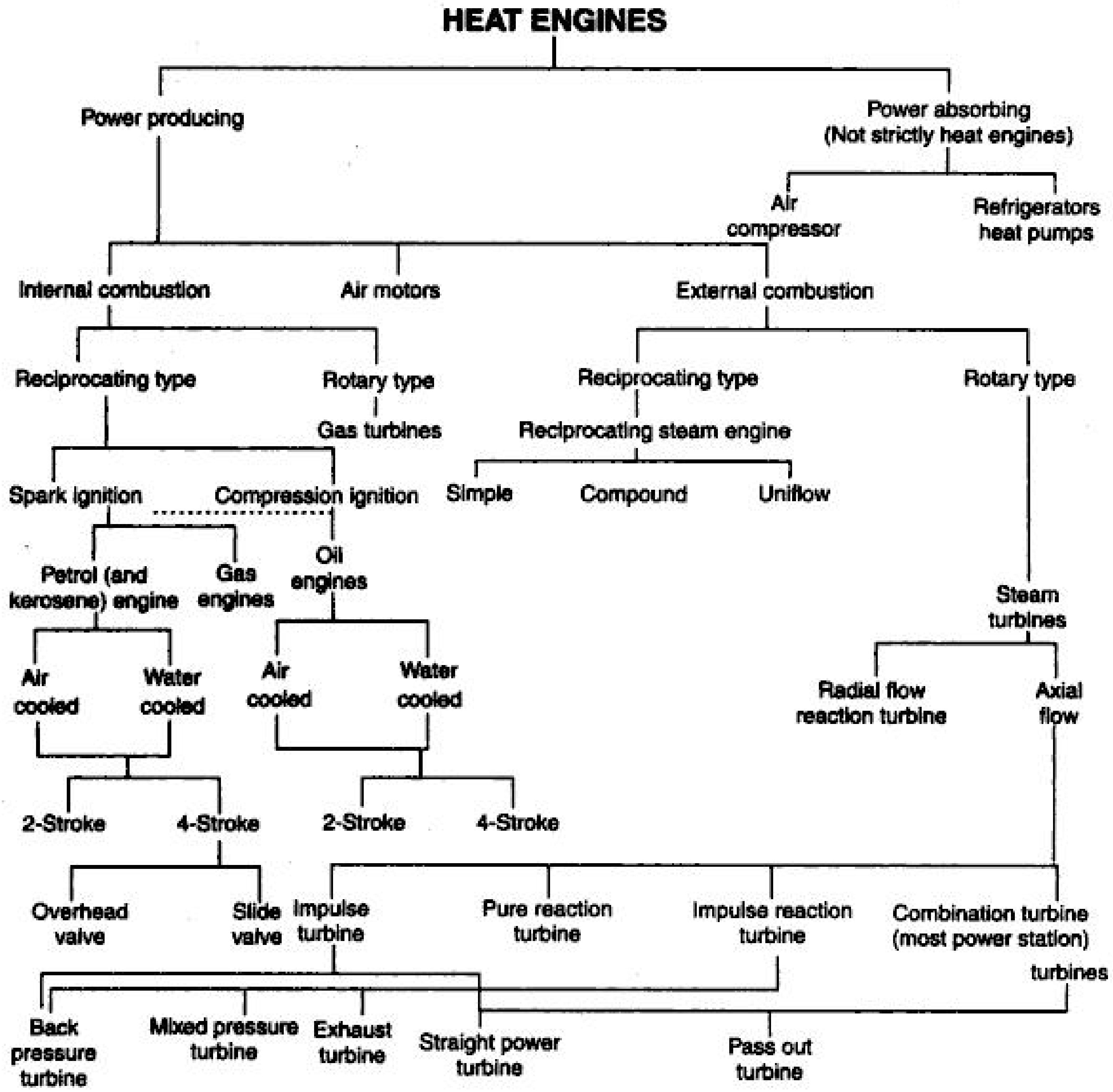


Fig. 2.1. Classification of heat engines.

Advantages of reciprocating internal combustion engines over external combustion engines :

Reciprocating internal combustion engines offer the following *advantages* over external combustion engines :

1. Overall efficiency is high.
2. Greater mechanical simplicity.
3. Weight-to-power ratio is generally low.
4. Generally lower initial cost.
5. Easy starting from cold conditions.
6. These units are compact and thus require less space.

Advantages of the external combustion engines over internal combustion engines :

The external combustion engines claim the following *advantages* over internal combustion engines :

1. Starting torque is generally high.
2. Because of external combustion of fuel, cheaper fuels can be used. Even solid fuels can be used advantageously.
3. Due to external combustion of fuel it is possible to have flexibility in arrangement.
4. These units are self-starting with the working fluid whereas in case of internal combustion engines, some additional equipment or device is used for starting the engines.

2.2. DEVELOPMENT OF I.C. ENGINES

Brief early history of development of I.C. engines is as follows :

- Many different styles of internal combustion engines were built and tested during the seond half of the 19th century.
- The first fairly practical engine was invented by J.J.E. Lenoir which appeared on the scene about 1860. During the next decade, several hundred of these engines were built with power upto about 4.5 kW and mechanical efficiency upto 5%.
- The Otto-Langen engine with efficiency improved to about 11% was first introduced in 1867 and several thousands of these were produced during the next decade. This was a type of atmospheric engine with the power stroke propelled by atmospheric pressure acting against a vacuum.
- Although many people were working on four-stroke cycle design, Otto was given credit when his prototype engine was built in 1876.
- In the 1880s, the internal combustion engines first appeared in automobiles. Also in this decade the two-stroke cycle engine became practical and was manufactured in large number.
- Rudolf Diesel, by 1892, had perfected his compression ignition engine into basically the same diesel engine known today. This was after years of development work which included the use of solid fuel in his early experimental engines.
- *Early compression engines were noisy, large, slow, single cylinder engines. They were, however, generally more efficient than spark ignition engines.*
- It wasn't until the 1920s that multicylinder compression ignition engines were made small enough to be used with automobile and trucks.
- *Wakdle's first rotary engine* was tested at NSV, Germany in 1957.
- The practical *stirling engines* in small number are being produced since 1965.
  - These engines require costly material and advanced technology for manufacture.
  - Thermal efficiencies higher than 30% have been obtained.
  - The *advantages* of stirling engine *are low exhaust emission and multi-fuel capability.*

2.3. CLASSIFICATION OF I.C. ENGINES

Internal combustion engines may be classified as given below :

1. **According to cycle of operation :**

(*i*) Two stroke cycle engines

(*ii*) Four stroke cycle engines.

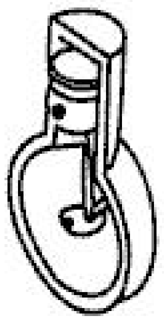
2. **According to cycle of combustion :**

(*i*) Otto cycle engine (combustion at constant volume)

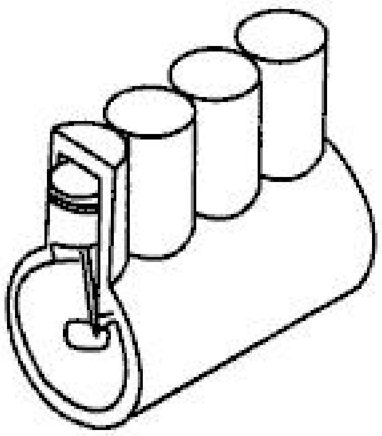
(*ii*) Diesel cycle engine (combustion at constant pressure)

(*iii*) Dual-combustion or Semi-Diesel cycle engine (combustion partly at constant volume and partly at constant pressure).

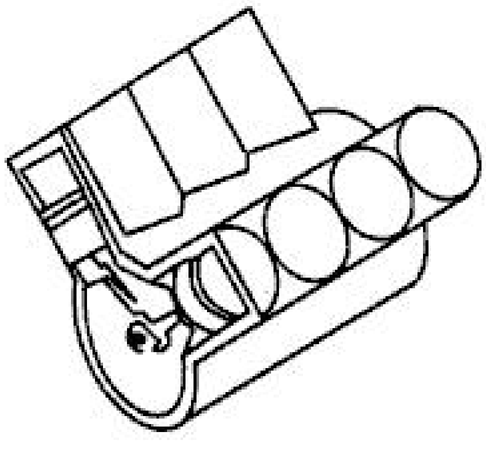
3. **According to arrangement of cylinder :** Refer Fig. 2.2.



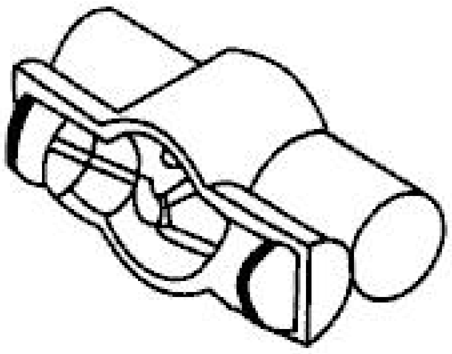
(*i*) Single cylinder



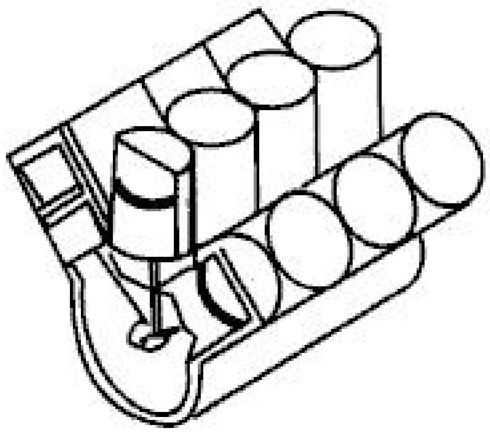
(*ii*) In line or straight



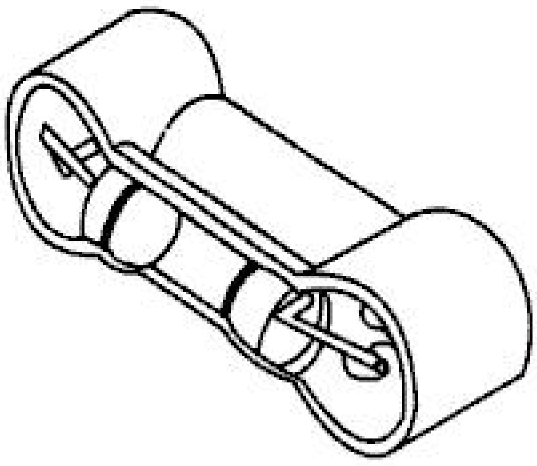
(*iii*) V-engine



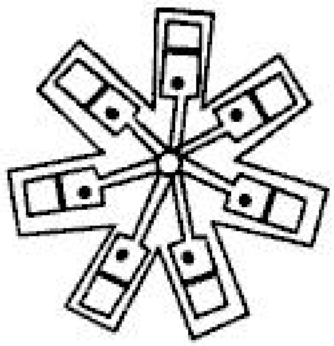
(*iv*) Opposed cylinder



(*v*) W-engine



(*vi*) Opposed piston



(*vii*) Radial engine

Fig. 2.2. Engine classification by cylinder arrangement.

(*i*) **Single cylinder engine.** Engine has one cylinder and piston connected to the crankshaft.

(*ii*) **In-line or straight engines.** Cylinders are positioned in a straight line one behind the other along the length of the crankshaft.

(*iii*) **V-engine :**

- An engine with two cylinder banks (*i.e.*, two-in-line engines) inclined at an angle to each other and with one crankshaft.

- Most of the bigger automobiles use the 8-cylinder V-engine (4-cylinder in-line on each side of V).

(*iv*) **Opposed cylinder engine :**

- Two banks of cylinders opposite to each other on a single crankshaft (a V-engine with 180° V).
- These are common on small aircraft and some automobiles with even number of cylinders from two to eight or more.

(*v*) **W-engine :**

- Same as V-engine except with three banks of cylinders on the same crankshaft.
- Not common, but some have been developed for racing automobiles.

(*vi*) **Opposed piston engine :**

- In this type of engine there are two pistons in each cylinder with the combustion chamber in the centre between the pistons.
- A single combustion process causes two power strokes, at the same time, with each piston being pushed away from the centre and delivering power to a separate crankshaft at each end of this cylinder.

(*vii*) **Radial engine :**

- It is an engine with pistons positioned in a circular plane around the central crankshaft. The connecting rods of the pistons are connected to a master rod which, in turn, is connected to the crankshaft.
- In a radial engine the bank of cylinders always has an *odd* number of cylinders ranging from 3 to 13 or more.
- Operating on a four-stroke cycle, every other cylinder fires and has a power stroke as the crankshaft rotates, giving a smooth operation.
- Many medium and large size propeller-driven aircraft use radial engines. For large aircraft two or more banks of cylinders are mounted together, one behind the other on a single crankshaft, making one powerful smooth engine.
- Very large ship engines exist with upto 54 cylinders, six banks of 9 cylinders each.

4. **According to their uses :**

(*i*) Stationary engine (*ii*) Portable engine
(*iii*) Marine engine (*iv*) Automobile engine
(*v*) Aero-engine etc.

5. **According to the speed of the engine :**

(*i*) Low speed engine (*ii*) Medium speed engine
(*iii*) High speed engine.

6. **According to method of ignition :**

(*i*) Spark-ignition engine (*ii*) Compression-ignition engine.

7. **According to method of cooling the cylinder :**

(*i*) Air-cooled engine (*ii*) Water-cooled engine.

8. **According to method of governing :**

(*i*) Hit and miss governed engine (*ii*) Quality governed engine
(*iii*) Quantity governed engine.

9. **According to valve arrangement :**

(*i*) Over head valve engine
(*ii*) *L*-head type engine
(*iii*) *T*-head type engine
(*iv*) *F*-head type engine.

10. **According to number of cylinders :**

(*i*) Single-cylinder engine
(*ii*) Multi-cylinder engine.

11. **According to air intake process :**

(*i*) *Naturally aspirated.* No intake air pressure boost system.

(*ii*) *Supercharged.* Intake air pressure increased with the compressor driven off the engine crankshaft.

(*iii*) *Turbocharged.* Intake air pressure increased with the turbine-compressor driven by the engine exhaust gases.

(*iv*) *Crankcase compressed.* Two stroke-cycle engine which uses the crankcase as the intake air compressor. Limited development work has also been done on the design and construction of four-stroke cycle engines with crankcase compression.

12. **According to fuel employed :**

(*i*) Oil engine
(*ii*) Petrol engine
(*iii*) Gas engine
(*iv*) Kerosene engine
(*v*) LPG engine
(*vi*) Alcohol-ethyl, methyl engine
(*vii*) Dual-fuel engine
(*viii*) Gasohol (90% gasoline and 10% alcohol).

13. **Method of fuel input for S.I. engines :**

(*i*) *Carburetted.*
(*ii*) *Multipoint port fuel injection.* One or more injectors at each cylinder intake.
(*iii*) *Throttle body fuel injection.* Injectors upstream in intake manifold.

2.4. APPLICATION OF I.C. ENGINES

The I.C. engines are generally used for :

(*i*) Road vehicles (*e.g.*, scooter, motorcycle, buses etc.)
(*ii*) Aircraft
(*iii*) Locomotives
(*iv*) Construction in civil engineering equipment such as bull-dozer, scraper, power shovels etc.
(*v*) Pumping sets
(*vi*) Cinemas
(*vii*) Hospital
(*viii*) Several industrial applications.

The *applications of various engines separately* are listed below :

1. **Small two-stroke petrol engines :**

- These engines are employed where *simplicity and the low cost of the prime mover are primary considerations.*
- The 50 c.c. engines develops maximum brake power (B.P.) of 1.5 kW at 5000 r.p.m. and is *used in mopeds.*
- The 100 c.c. engine developing maximum brake power of about 3 kW at 5000 r.p.m. is *used in scooters.* The 150 c.c. engine develops maximum brake power of about 5 kW at 5000 r.p.m.

- The 250 c.c. engine developing a maximum brake power of about 9 kW at 4500 r.p.m. is generally *used in motor cycles*.
- These engines also find applications in very small electric generating sets, pumping sets etc.

2. **Small four-stroke petrol engines :**

- These engines are primarily used in automobiles.
- These are also used in pumping sets and mobile electric generating sets.

These days diesel engines are taking them over, in the above mentioned applications.

3. **Four stroke diesel engines :**

- The four-stroke diesel engine (a versatile prime mover) is manufactured in diameter ranging from 50 mm to 600 mm with speeds ranging from 100 to 4400 r.p.m., the power delivered per cylinder varying from 1 to 1000 kW.
- Diesel engine is employed for the following :
  - Pumping sets
  - Construction machinery
  - Air compressors and drilling jigs
  - Tractors
  - Jeeps, cars and taxies
  - Mobile and stationary electric generating plant
  - Diesel-electric locomotive
  - Boats and ships.

4. **Two stroke diesel engines :**

- These engines having very high power are usually employed for *ship propulsion* and generally have bores above 60 cm, uniflow with exhaust valves or loop scavenged.

Example. Nordberg, *2 stroke, 12-cylinder 80 cm bore and 155 cm stroke, diesel engine engine develops 20000 kW at 120 r.p.m.*

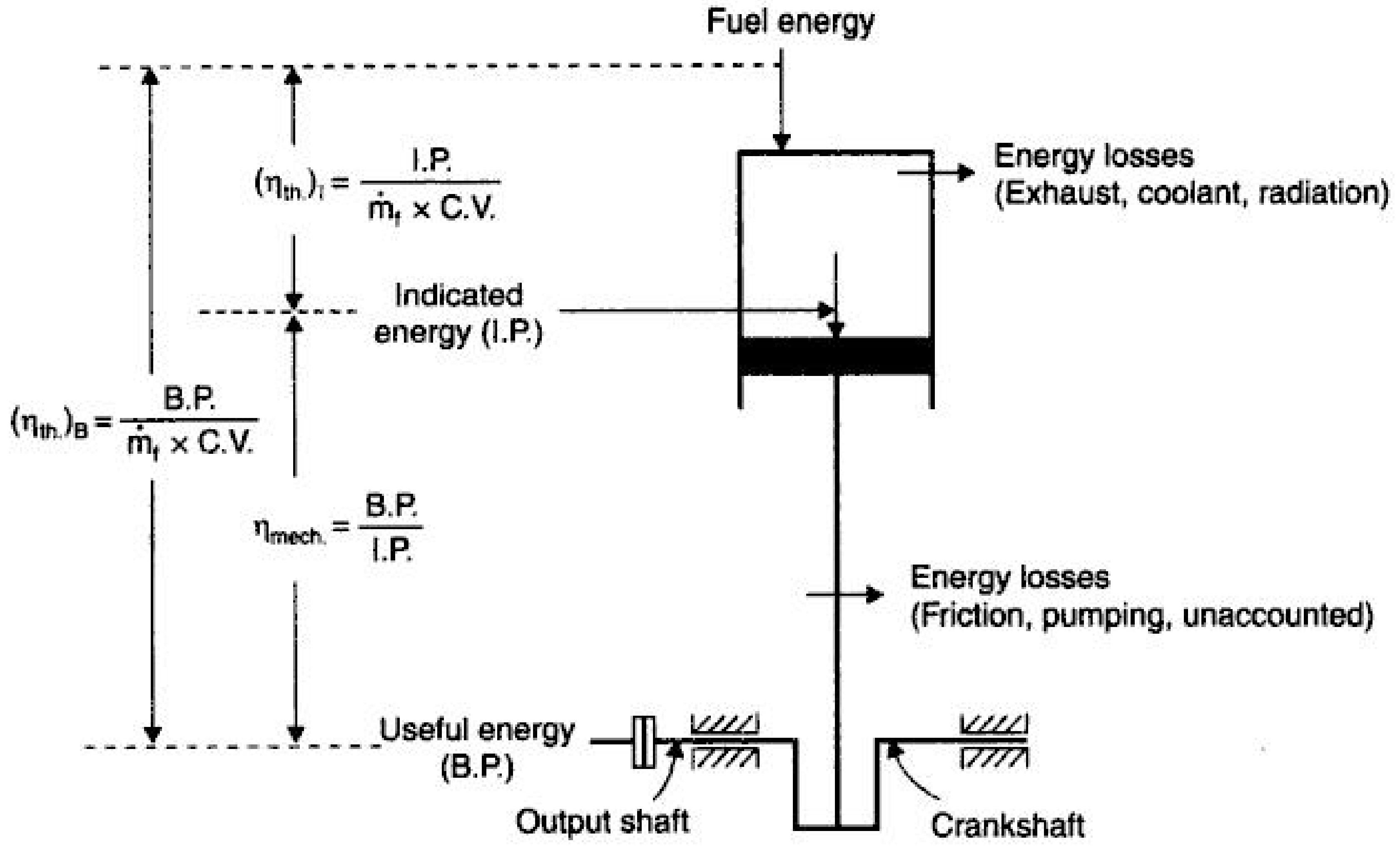
5. **Radial piston engine in small aircraft propulsion :**

- Radial four stroke petrol engines having power range from 300 kW to 4000 kW have been used in small aircrafts.
- In modern large aircrafts, instead of these engines, gas turbine plant as turboprop engine or turbojet engine and gas turbine engines are used.

2.5. ENGINE CYCLE-ENERGY BALANCE

Refer Fig. 2.3. It shows the energy flow through the reciprocating engine. The analysis is based on the first law of thermodynamics which states that energy can neither be created nor destroyed, it can be converted from one form to other.

- In an I.C. engine fuel is fed to the combustion chamber where it burns in the presence of air and its chemical energy is converted into heat. All this energy is not available for driving the piston since a portion of this energy is lost through exhaust, coolant and radiation. The remaining energy is converted to power and is called indicated energy or *indicated power* (I.P.). The ratio of this energy to the input fuel energy is called indicated thermal efficiency [$\eta_{th.(I)}$].



I.P. = Indicated power

B.P. = Brake power

$(\eta_{th.})_I$ = Indicated thermal efficiency = $\frac{I.P.}{\dot{m}_f \times C.V.}$

(where $\dot{m}_f$ = mass of fuel in kg/s and C.V. = calorific value)

$(\eta_{th.})_B$ = Brake thermal efficiency.

Fig. 2.3. The energy flow through the reciprocating engine.

- The energy available at the piston passes through the connecting rod to the crankshaft. In this transmission of energy/power there are losses due to friction, pumping, etc. The sum of all these losses, converted to power, is termed as **Friction Power (F.P.).** The remaining energy is the *useful mechanical energy and is termed as* **shaft energy** or **Brake Power (B.P.).** The *ratio of energy at shaft to fuel input energy is called* **brake thermal efficiency** $[\eta_{th.(B)}]$.
- The *ratio of shaft energy to the energy available at the piston is called* **mechanical efficiency** $(\eta_{mech.})$.

2.6. BASIC IDEA OF I.C. ENGINES

The basic idea of internal combustion engine is shown in Fig. 2.4. The cylinder which is closed at one end is filled with a mixture of fuel and air. As the crankshaft turns it pushes piston. The piston is forced up and compresses the mixture in the top of the cylinder. The mixture is set alight and, as it burns, it creates a gas pressure on the piston, forcing it down the cylinder. This motion is shown by arrow '1'. The piston pushes on the rod which pushes on the crank. The crank is given rotary (turning) motion as shown by the arrow '2'. The fly wheel fitted on the end of the crankshaft stores energy and keeps the crank turning steadily.

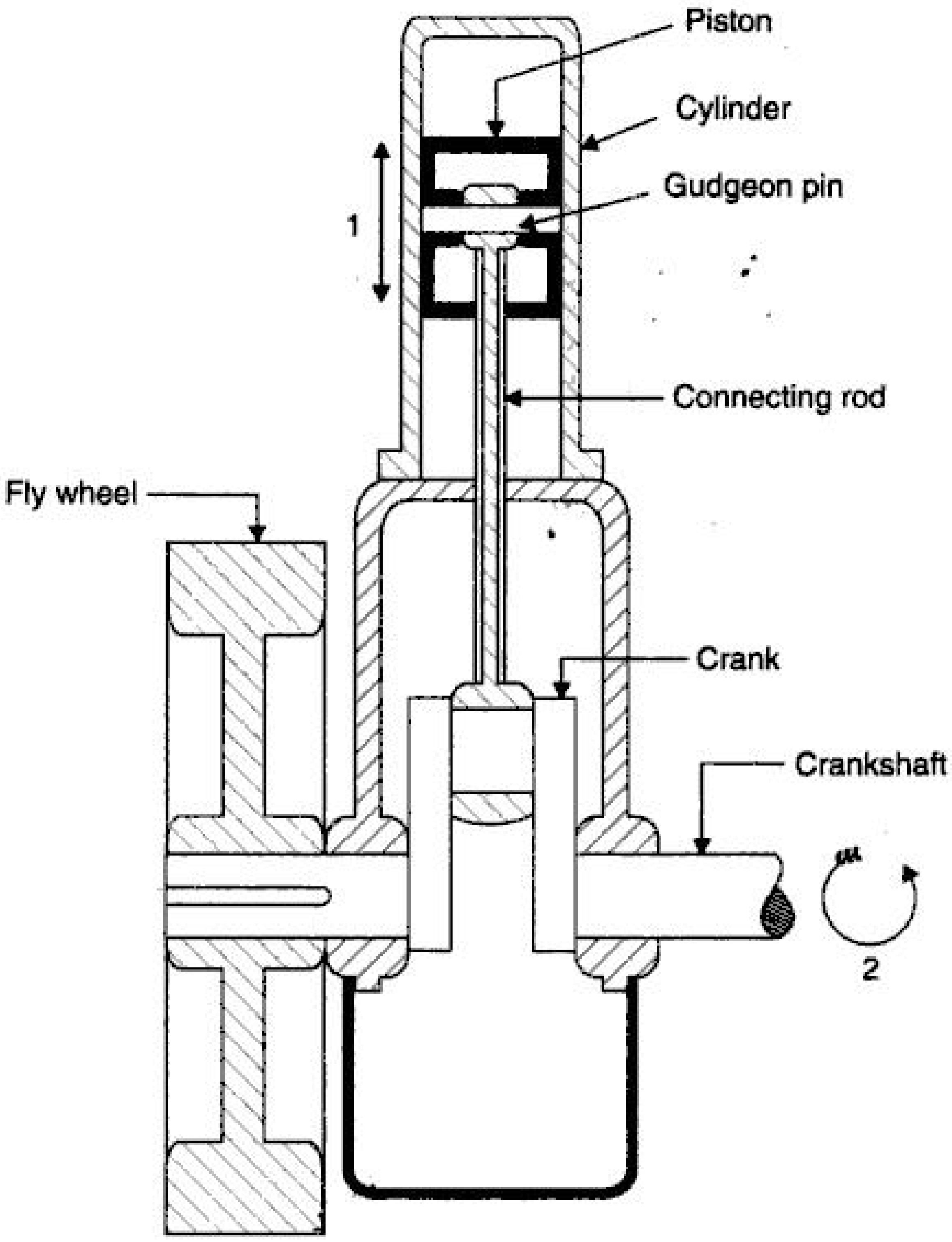


Fig. 2.4. Basic idea of I.C. engine.

2.7. DIFFERENT PARTS OF I.C. ENGINES

Here follows the detail of the various parts of an internal combustion engine.

A cross-section of an air-cooled I.C. engine with principal parts is shown in Fig. 2.5.

A. Parts common to both petrol and diesel engine :

1. Cylinder
2. Cylinder head
3. Piston
4. Piston rings
5. Gudgeon pin
6. Connecting rod
7. Crankshaft
8. Crank
9. Engine bearing
10. Crankcase
11. Flywheel
12. Governor
13. Valves and valve operating mechanisms.

B. Parts for petrol engines only :

1. Spark plugs
2. Carburettor
3. Fuel pump.

C. Parts for Diesel engine only :

1. Fuel pump.
2. Injector.

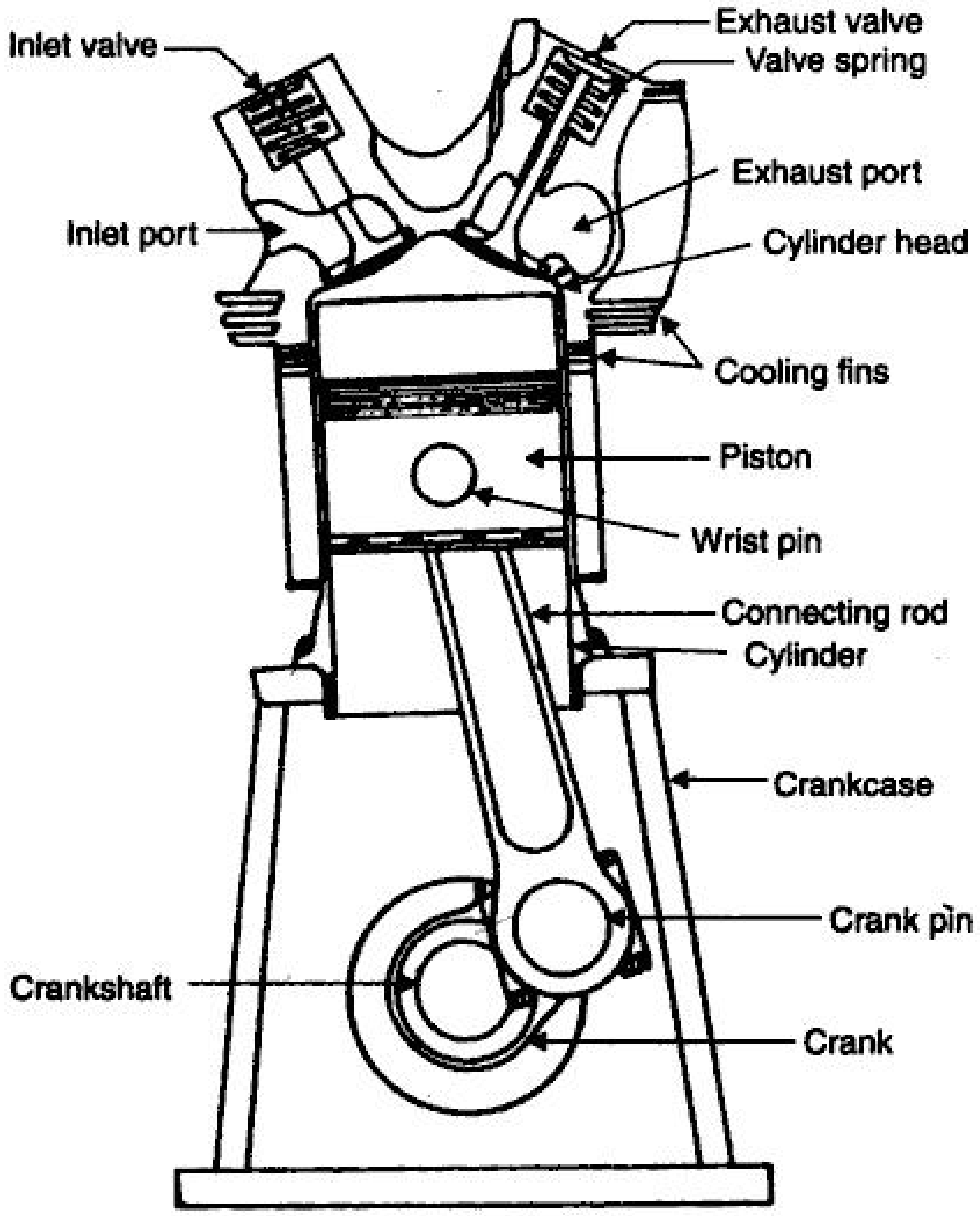


Fig. 2.5. Air-cooled I.C. engine.

A. Parts Common to Both Petrol and Diesel Engines :

1. Cylinder :

The cylinder contains gas under pressure and guides the piston. It is in direct contact with the products of combustion and it must be cooled. The ideal form consists of a plain cylindrical barrel in which the piston slides. The movement of the piston or stroke being in most cases, longer than the bore. This is known as the "*stroke-bore ratio*". The upper end consists of a combustion or clearance space in which the ignition and combustion of the charge takes place. In practice, it is necessary to depart from the ideal hemispherical slope in order to accommodate the valves, sparking plugs etc. and to control the combustion. Sections of an air-cooled cylinder and a water-cooled cylinder are shown in Figs. 2.6 and 2.7, respectively. *The cylinder is made of hard grade cast-iron and is usually, cast in one piece.*

2. **Cylinder head :**

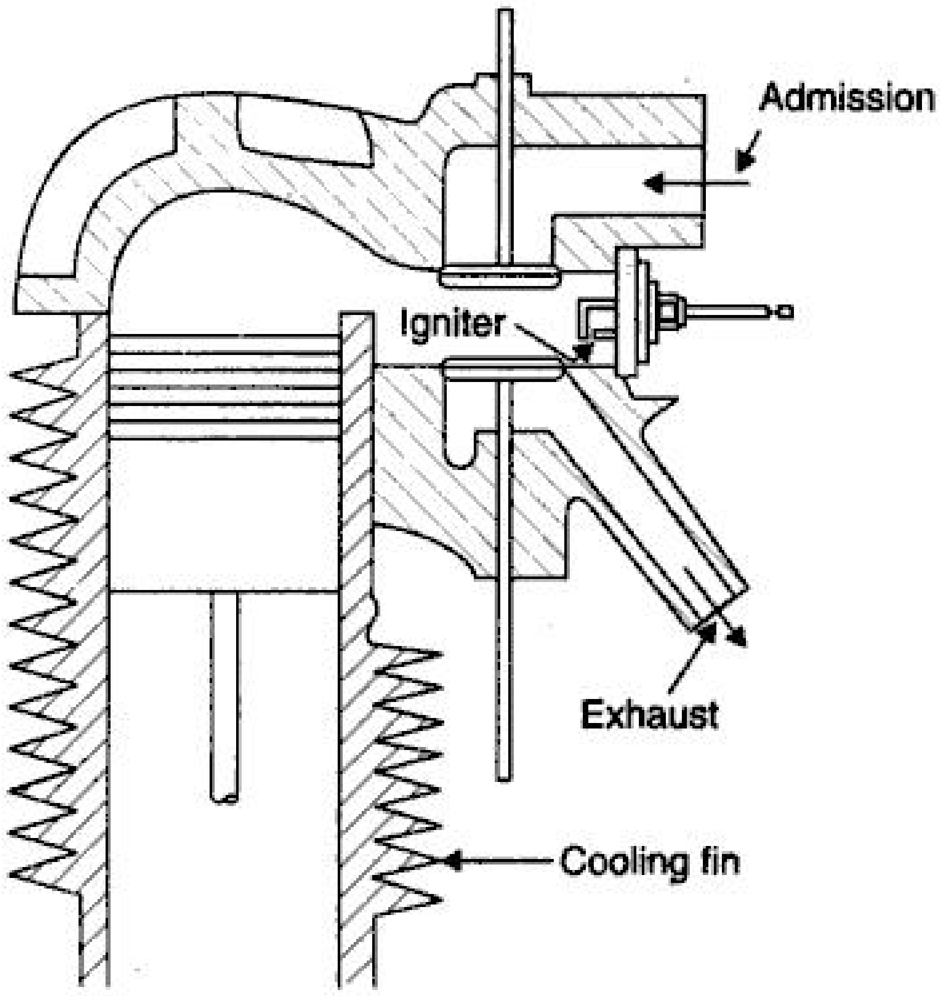


Fig. 2.6. Air-cooled cylinder.

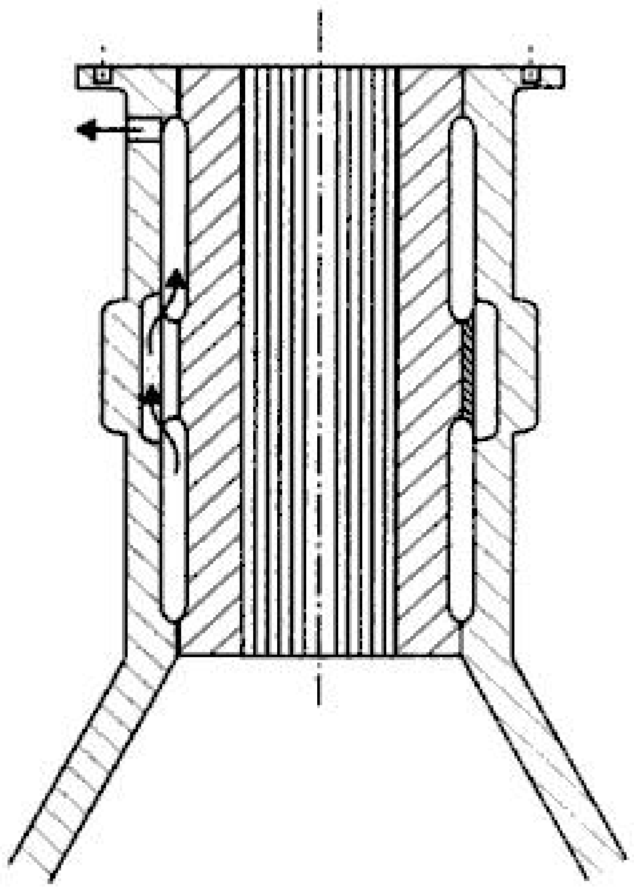


Fig. 2.7. Water-cooled cylinder.

One end of the cylinder is closed by means of a *removable cylinder head* (Fig. 2.6) which usually contains the inlet or admission valve [Fig. 2.8 (*a*)] for admitting the mixture of air and

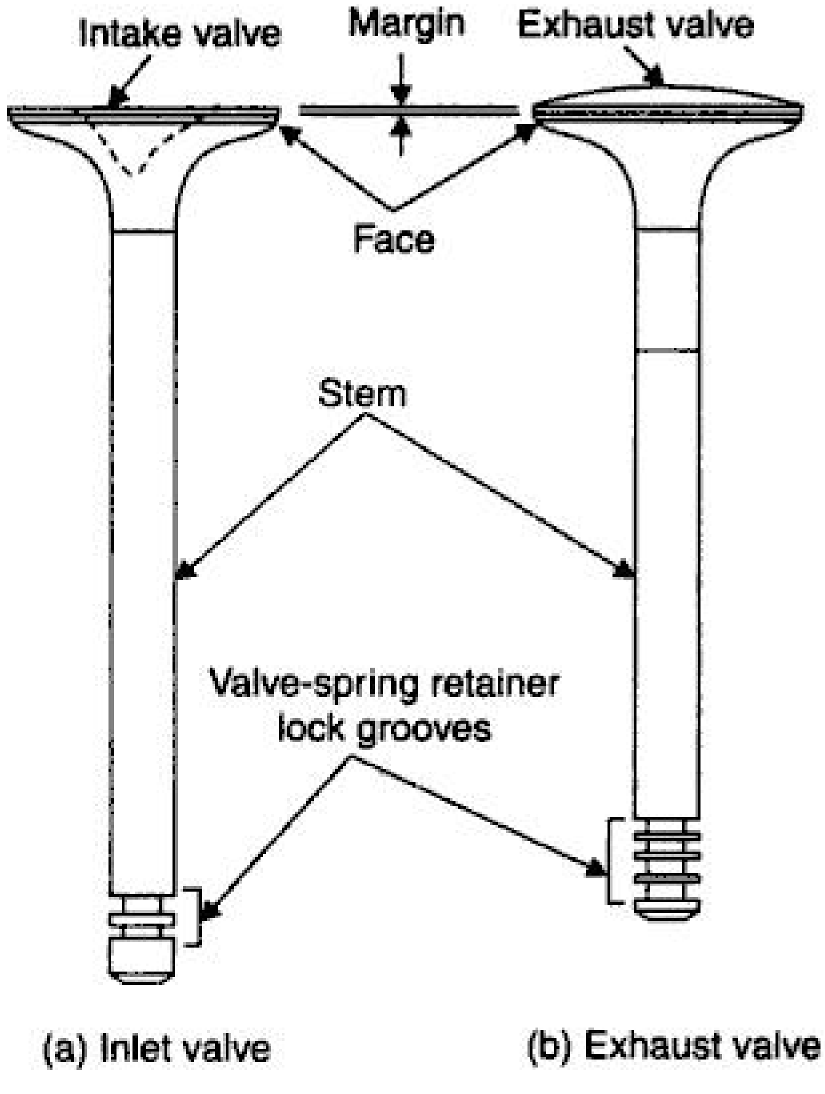


Fig. 2.8

fuel and exhaust valve [Fig. 2.8 (*b*)] for discharging the product of combustion. Two valves are kept closed, by means of cams (Fig. 2.9) geared to the engine shaft. The passages in the cylinder head leading to and from the valves are called *ports*. The pipes which connect the inlet ports of the various cylinders to a common intake pipe for the engine is called the inlet *manifold*. If the exhaust ports are similarly connected to a common exhaust system, this system of piping is called *exhaust manifold*.

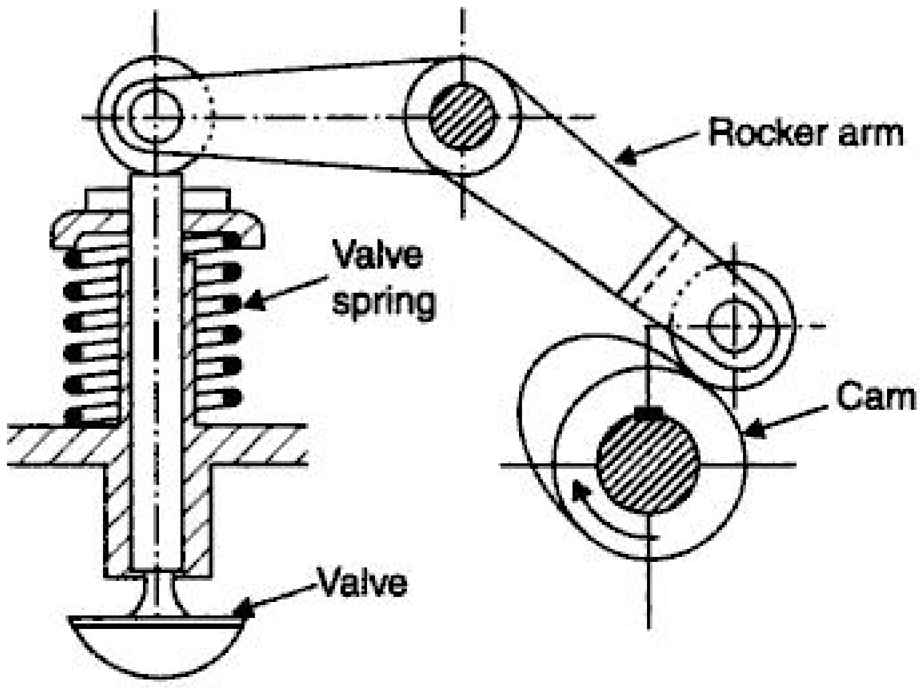


Fig. 2.9. Cam and rocker arm.

The main purpose of the cylinder head is to seal the working ends of the cylinders and not to permit entry and exit of gases on cover head valve engines. The inside cavity of head is called the *combustion chamber*, into which the mixture is compressed for firing. Its *shape controls the direction and rate of combustion*. Heads are drilled and tapped with correct thread to take the ignition spark plug. All the combustion chambers in an engine must be of same shape and size. The shape may be in part controlled by the piston shape.

The cylinder head is usually made of cast-iron or aluminium.

3. **Piston :**

A piston is fitted to each cylinder as a face to receive gas pressure and transmit the thrust to the connecting rod.

The piston must (*i*) give gas tight seal to the cylinder through bore, (*ii*) slide freely, (*iii*) be light and (*iv*) be strong. The thrust on the piston on the power stroke tries to tilt the piston as the connecting rod swings, side ways. The piston wall, called the skirt, must be strong enough to stand upto this side thrust. *Pistons are made of cast-iron or aluminium alloy for lightness*. Light alloy pistons expand more than cast-iron one therefore they need large clearances to the bore, when cold, or special provision for expansion. Pistons may be solid skirt or split skirt. A section through a split skirt piston is shown in Fig. 2.10.

4. **Piston rings :**

The piston must be a fairly loose fit in the cylinder. If it were a tight fit, it would expand as it got hot and might stick tight in the cylinder. If a piston sticks it could ruin the engine. On the other hand, if there is too much clearance between the piston and cylinder walls, much of the pressure from the burning gasoline vapour will leak past the piston. This means, that the push on the piston will be much less effective. It is the push on the piston that delivers the power from the engines.

To provide a good sealing fit between the piston and cylinder, pistons are equipped with piston rings, as shown in Fig. 2.10. The rings are usually made of cast-iron of fine grain and high elasticity which is not affected by the working heat. Some rings are of alloy spring steel. They are split at one point so that they can be expanded and slipped over the end of the piston and into ring grooves which have been cut in the piston. When the piston is installed in the cylinder the rings

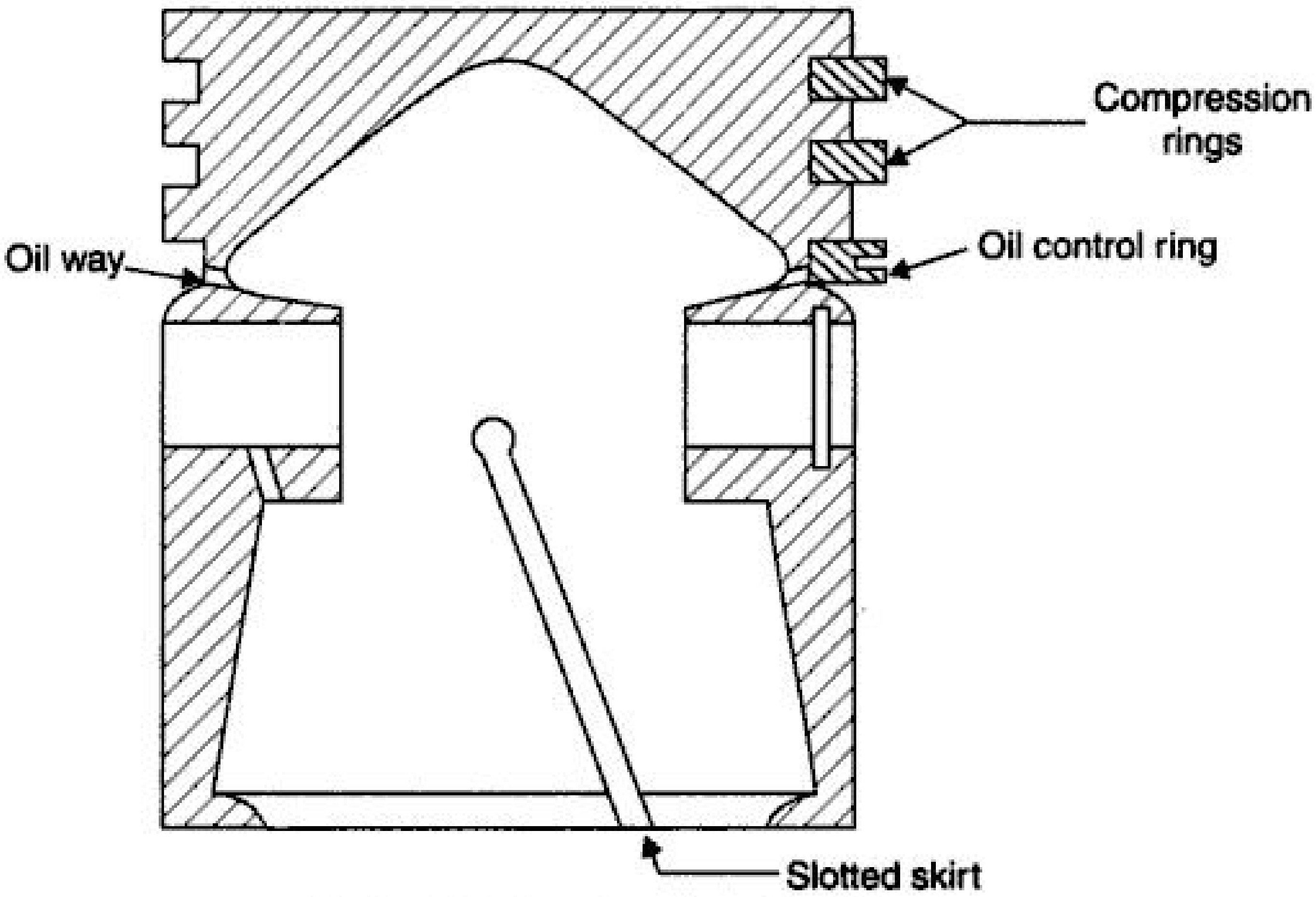


Fig. 2.10. Section through a split skirt piston.

are compressed into ring grooves which have been cut in the piston. When the piston is installed in the cylinder, the rings are compressed into the ring grooves so that the split ends come almost together. The rings fit tightly against the cylinder wall and against the sides of the ring grooves in the piston. Thus, *they form a good seal between the piston and the cylinder wall.* The rings can expand or contract as they heat and cool and still make a good deal. Thus they are free to slide up and down the cylinder wall.

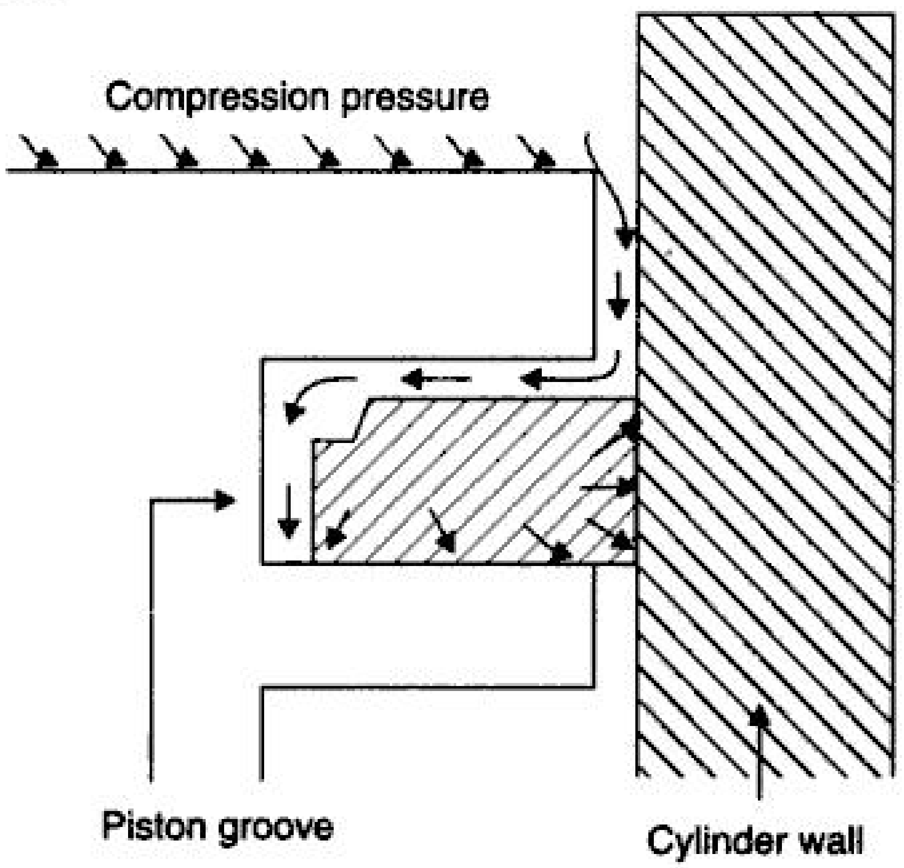


Fig. 2.11. Working of a piston ring.

Fig. 2.11 shows how the piston ring works to hold in the compression and combustion pressure. The arrows show the pressure above the piston passing through clearance between the piston and the cylinder wall. It presses down against the top and against the back of the piston rings as shown by the arrows. This pushes the piston ring firmly against the bottom of the piston ring groove. As a result there are good seals at both of these points. The higher the pressure in the combustion chamber, the better the seal.

Small two stroke cycle engines have two rings on the piston. Both are compression rings (Fig. 2.12). Two rings are used to divide up the job of holding the compression and combustion pressure. This produces better sealing with less ring pressure against the cylinder wall.

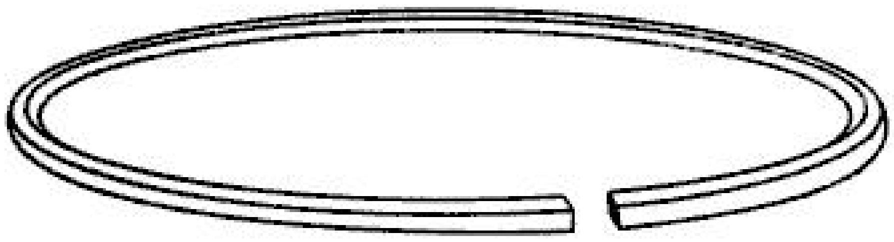


Fig. 2.12. Compression ring.

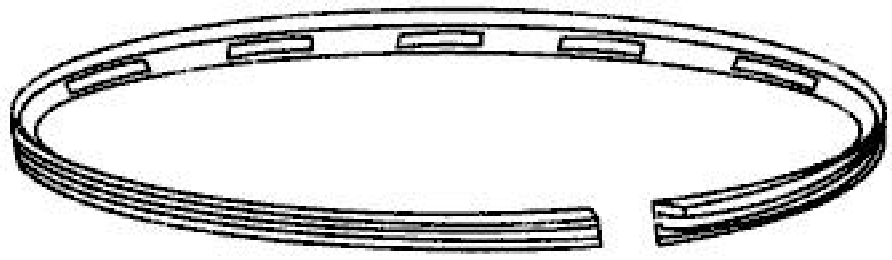


Fig. 2.13. Oil ring.

Four stroke cycle engines have an extra ring, called the oil control ring (Fig. 2.13). Four stroke cycle engines are so constructed that they get much more oil in the cylinder wall than do two stroke cycle engines. This additional oil must be scraped off to prevent it from getting up into the combustion chamber, where it would burn and cause trouble.

Refer to Figs. 2.12 and 2.13, the compression rings have a rectilinear cross-section and oil rings are provided with a groove in the middle and with through holes spaced at certain interval from each other. The oil collected from the cylinder walls flows through these holes into the piston groove whence through the holes in the body of the piston and down its inner walls into the engine crankcase.

5. **Gudgeon pin** (or wrist pin or piston pin) :

These are *hardened steel parallel spindles* fitted through the piston bosses and the small end bushes or eyes to allow the connecting rods to swivel. Gudgeon pins are a press fit in the piston bosses of light alloy pistons when cold. For removal or fitting, the piston should be dipped in hot water or hot oil, this expands the bosses and the pins can be removed or fitted freely without damage.

It is made hollow for lightness since it is a reciprocating part.

6. **Connecting rod :**

Refer to Fig. 2.14. The connecting rod transmits the piston load to the crank, causing the latter to turn, thus converting the reciprocating motion of the piston into a rotary motion of the crankshaft. The lower or "big end" of the connecting rod turns on "crank pins".

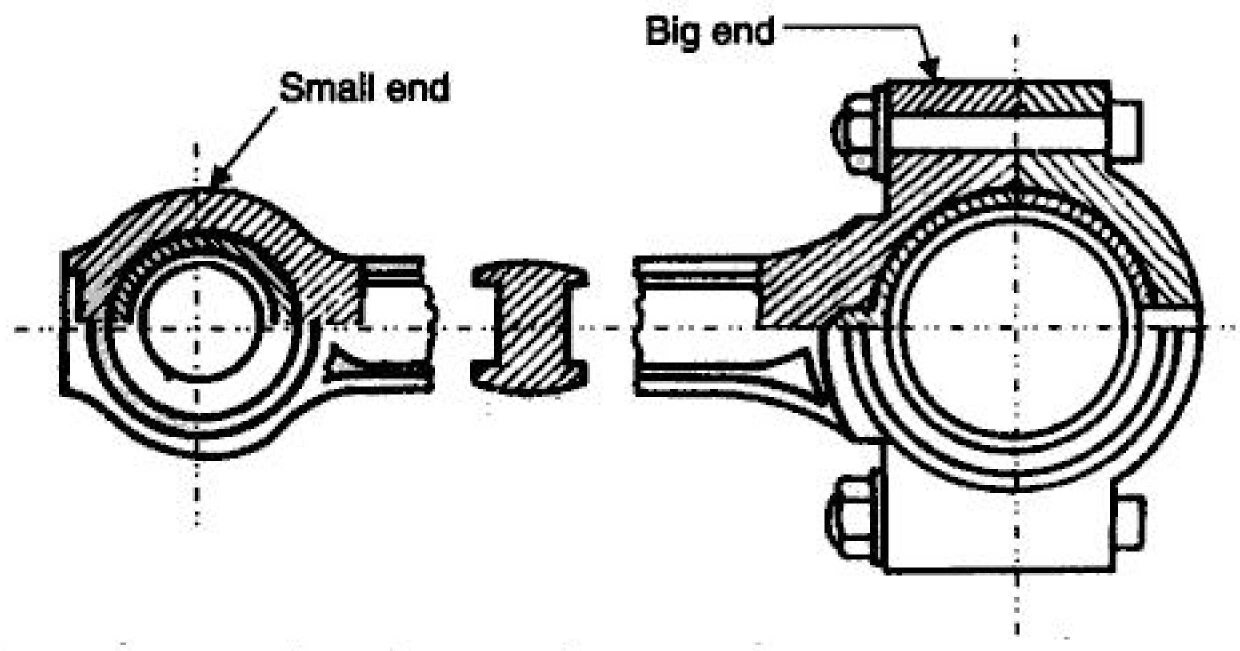


Fig. 2.14. Connecting rod.

The connecting rods are made of nickle, chrome and chrome vandium steels. For small engines the material may be aluminium.

7. Crank :

The piston moves up and down in the cylinder. This up and down motion is called *reciprocating motion*. The piston moves in a straight line. The straight line motion must be changed to rotary, or turning motion, in most machines, before it can do any good. That is rotary motion is required to make wheels turn, a cutting blade spin or a pulley rotate. To change the reciprocating motion to rotary motion a crank and connecting rod are used. (Figs. 2.15 and 2.16). The connecting rod connects the piston to the crank.

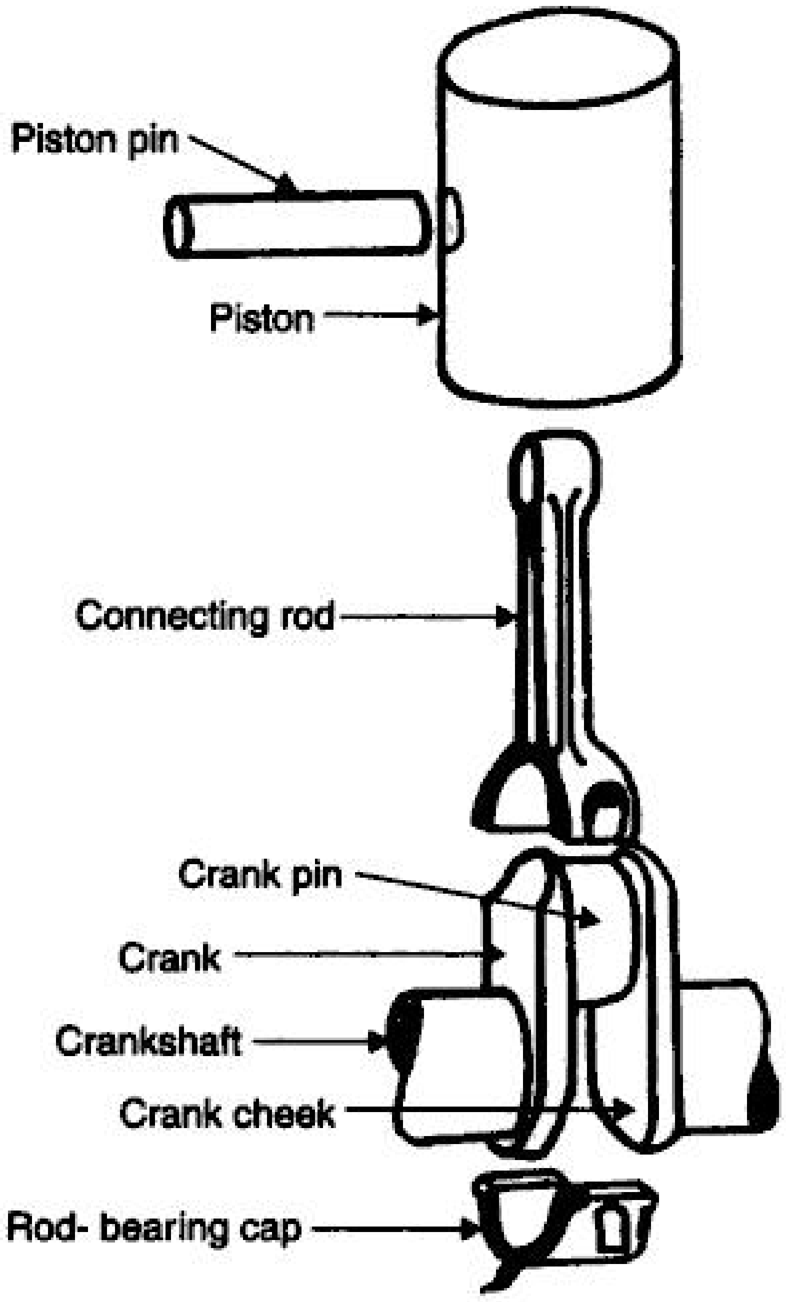


Fig. 2.15

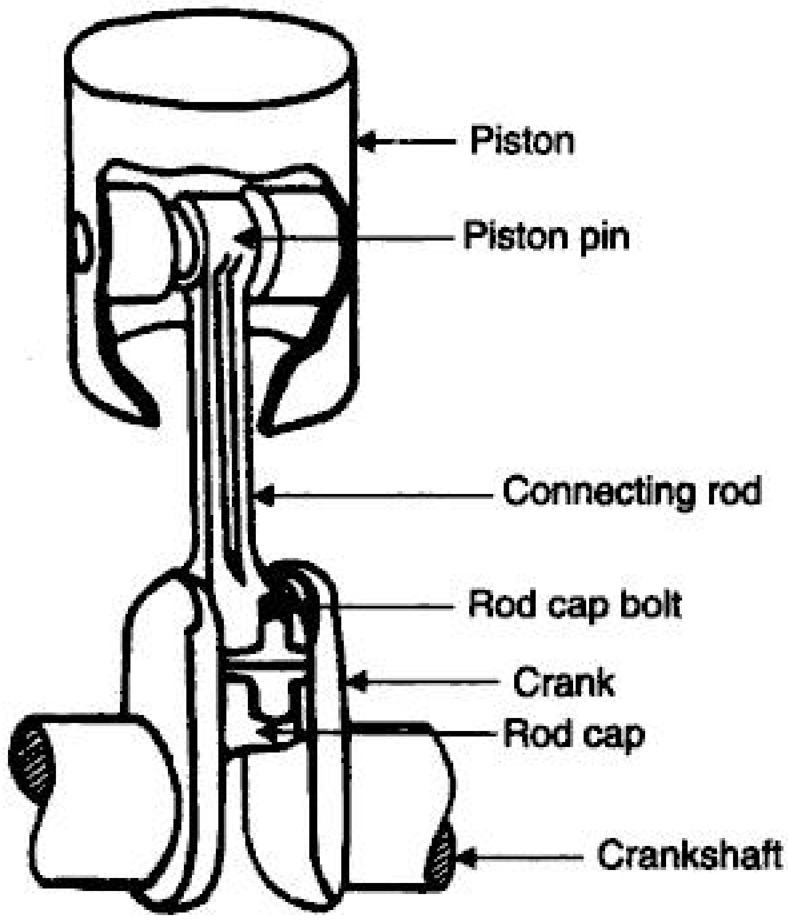


Fig. 2.16

Note. The crank end of the connecting rod is called rod *"big end"*. The piston end of the connecting rod is called the rod *"small end"*.

8. Crankshaft :

The crank is part of the crankshaft. The crankshaft of an internal combustion engine receives via its cranks the efforts supplied by the pistons to the connecting rods. All the engines auxiliary mechanisms with mechanical transmission are geared in one way or the another to the crankshaft. *It is usually a steel forging, but some makers use special types of cast-iron such as spheroidal graphitic or nickel alloy castings* which are cheaper to produce and have good service life. Refer to Fig. 2.17. The crankshaft converts the reciprocating motion to rotary motion. The crankshaft mounts in bearings which, encircle the journals so it can rotate freely.

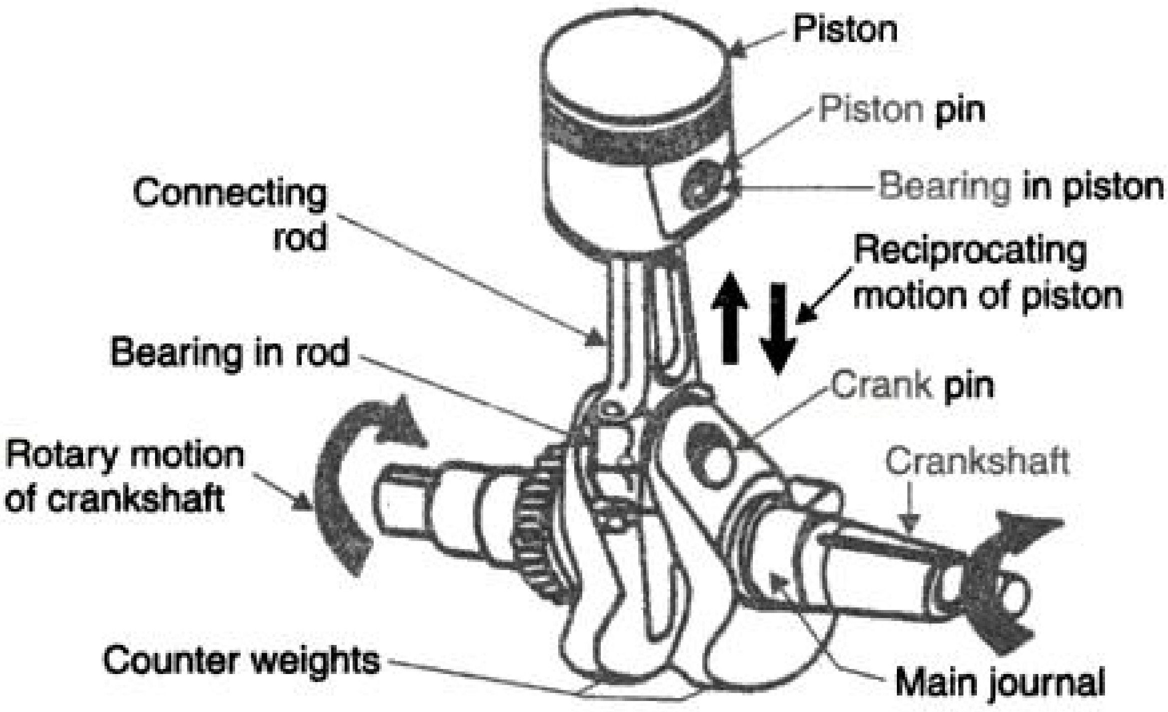


Fig. 2.17. Crank shaft and other parts.

The shape of the crankshaft *i.e.*, the mutual arrangement of the cranks depend on the number and arrangement of cylinders and the turning order of the engine. Fig. 2.18 shows a typical crankshaft layout for a four cylinder engine.

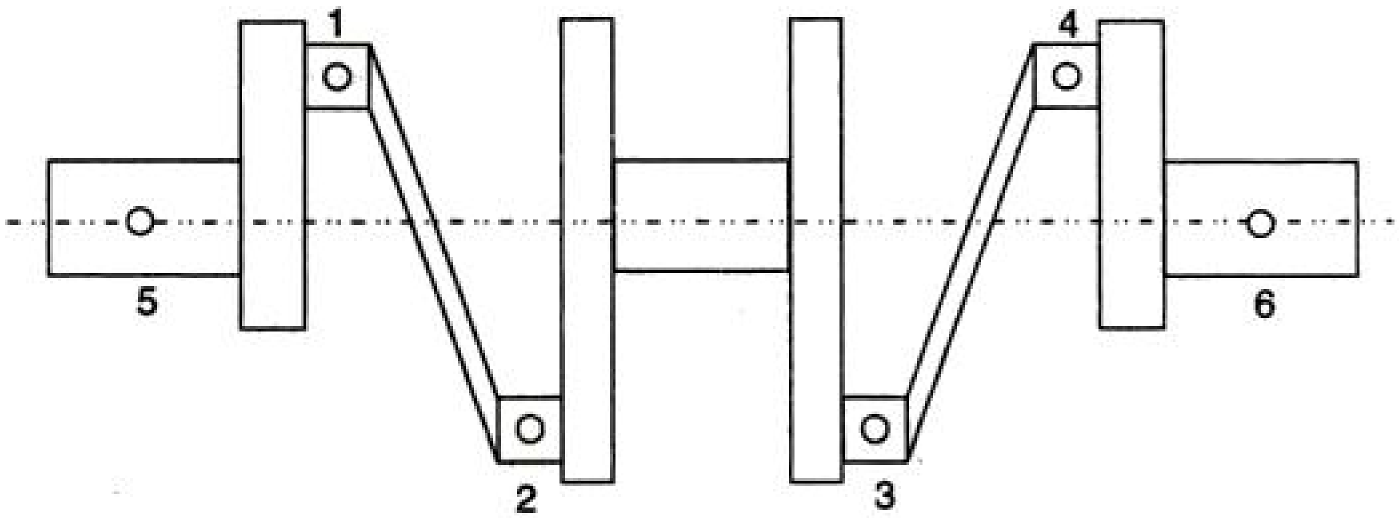


Fig. 2.18. Typical crankshaft layout.

9. **Engine bearing :**

The crankshaft is supported by bearing. The connecting rod big end is attached to the crank pin on the crank of the crankshaft by a bearing. A piston pin at the rod small end is used to attach the rod to the piston. The piston pin rides in bearings. Everywhere there is rotary action in the engine, bearings are used to support the moving parts. The purpose of bearing is to reduce the friction and allow the parts to move easily. Bearings are lubricated with oil to make the relative motion easier.

Bearings used in engines are of two types : *sliding* or *rolling* (Fig. 2.19).

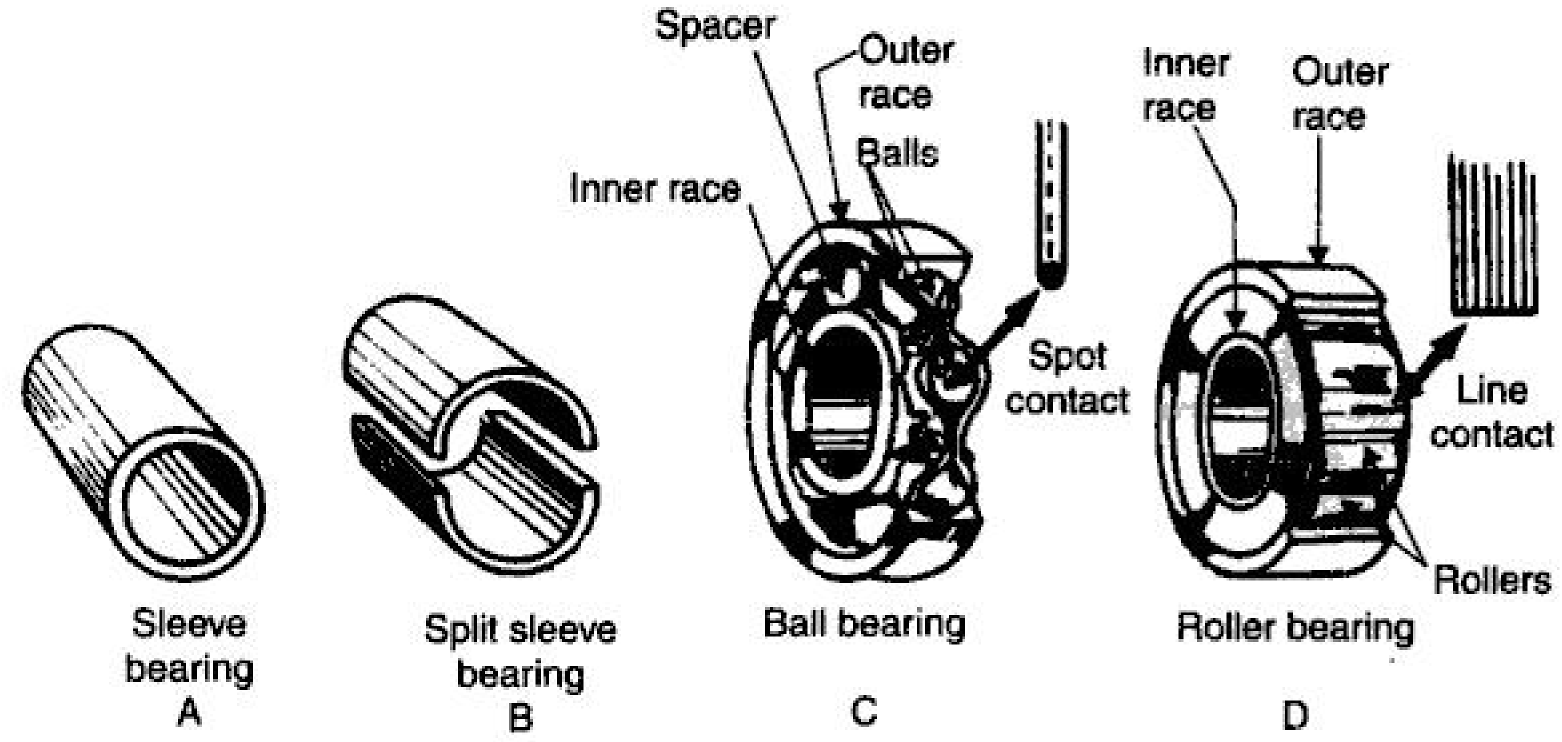


Fig. 2.19. Bearings.

The sliding type of bearings are sometimes called *bushings or sleeve bearings* because they are in the shape of a sleeve that fits around the rotating journal or shaft. The sleeve-type connecting rod big end bearings usually called simply rod bearings and the crankshaft supporting bearings called the main bearings are of the split sleeve type. They must be split in order to permit their assembly into the engine. In the rod bearing, the upper half of the bearing is installed in the rod, the lower half is installed in the rod bearing cap. When the rod cap is fastened to the rod shown in Fig. 2.16 a complete sleeve bearing is formed. Likewise, the upper halves of the main bearings are assembled in the engine and then the main bearing caps, with the lower bearing halves are attached to the engine to complete the sleeve bearings supporting the crankshaft.

The typical bearing half is made of steel or bronze back to which a lining of relatively soft bearing material is applied. Refer to Fig. 2.20. This relatively soft bearing material, which is made of several materials such as copper, lead, tin and other metals, has the ability to conform to slight irregularities of the shaft rotating against it. If wear does take place, it is the bearing that wears and the bearing can be replaced instead of much more expansive crankshaft or other engine part.

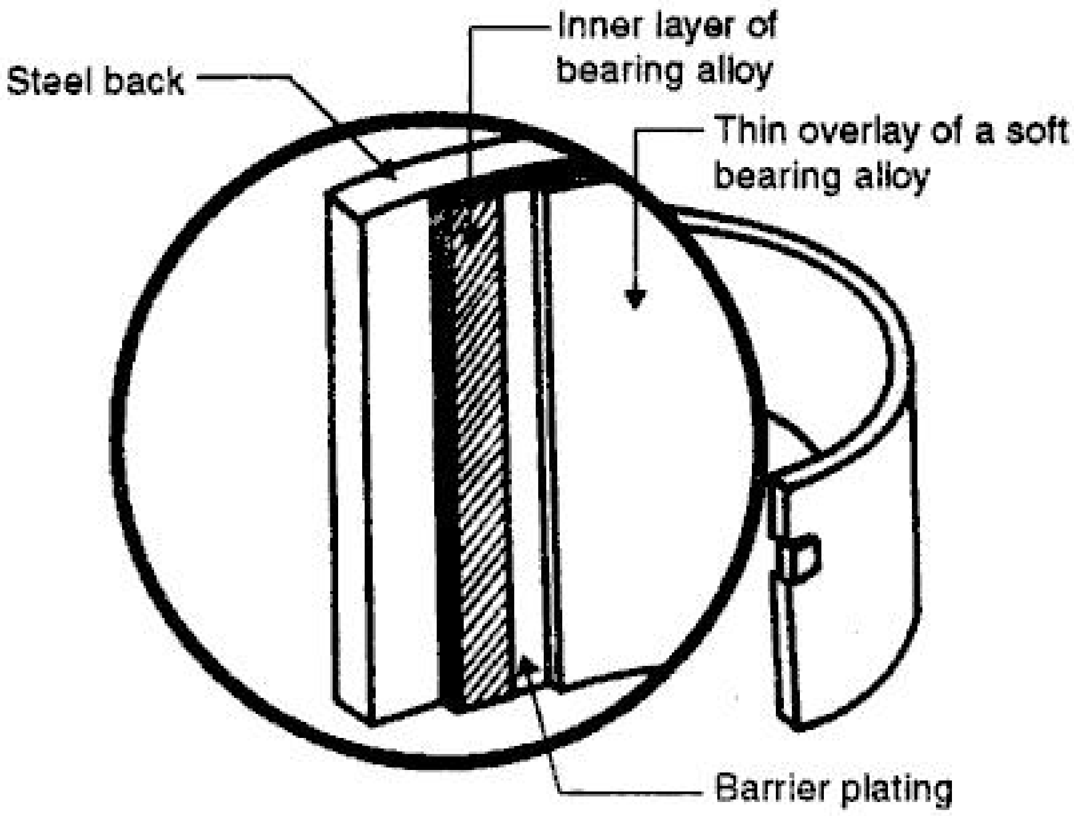


Fig. 2.20. Bearing half (details).

The rolling-type bearing uses balls or rollers between the stationary support and the rotating shaft. Refer to Fig. 2.19. Since the balls or rollers provide rolling contact, the frictional resistance to movement is much less. In some roller bearing, the rollers are so small that they are hardly bigger than needles. These bearings are called *needle bearings*. Also some rollers bearings have the rollers set at an angle to the races, the rollers roll in are tapered. These bearings are called *tapered roller bearings*. Some ball and roller bearings are sealed with their lubricant already in place. Such bearings require no other lubrication. Other do require lubrication from the oil in the gasoline (two stroke cycle engines) or from the engine lubrication system (four stroke cycle engines).

The type of bearing selected by the designers of the engine depends on the design of the engine and the use to which the engine will be put. *Generally, sleeve bearings, being less expensive and satisfactory for most engine applications, are used. In fact sleeve bearings are used almost universally in automobile engines. But you will find some engines with ball and roller bearings to support the crankshaft and for the connecting rod and piston-pin bearings.*

10. **Crankcase :**

The main body of the engine to which the cylinders are attached and which contains the crankshaft and crankshaft bearing is called *crankcase*. This member also holds other parts in alignment and resists the explosion and inertia forces. It also protects the parts from dirt etc. and serves as a part of lubricating system.

11. **Flywheel :**

Refer to Figs. 2.4 and 2.21. A flywheel (steel or cast-iron disc) secured on the crankshaft performs the following *functions* :

(*a*) Brings the mechanism out of dead centres.

(*b*) Stores energy required to rotate the shaft during preparatory strokes.

(*c*) Makes crankshaft rotation more uniform.

(*d*) Facilitates the starting of the engine and overcoming of short time over loads as, for example, when the machine is started from rest.

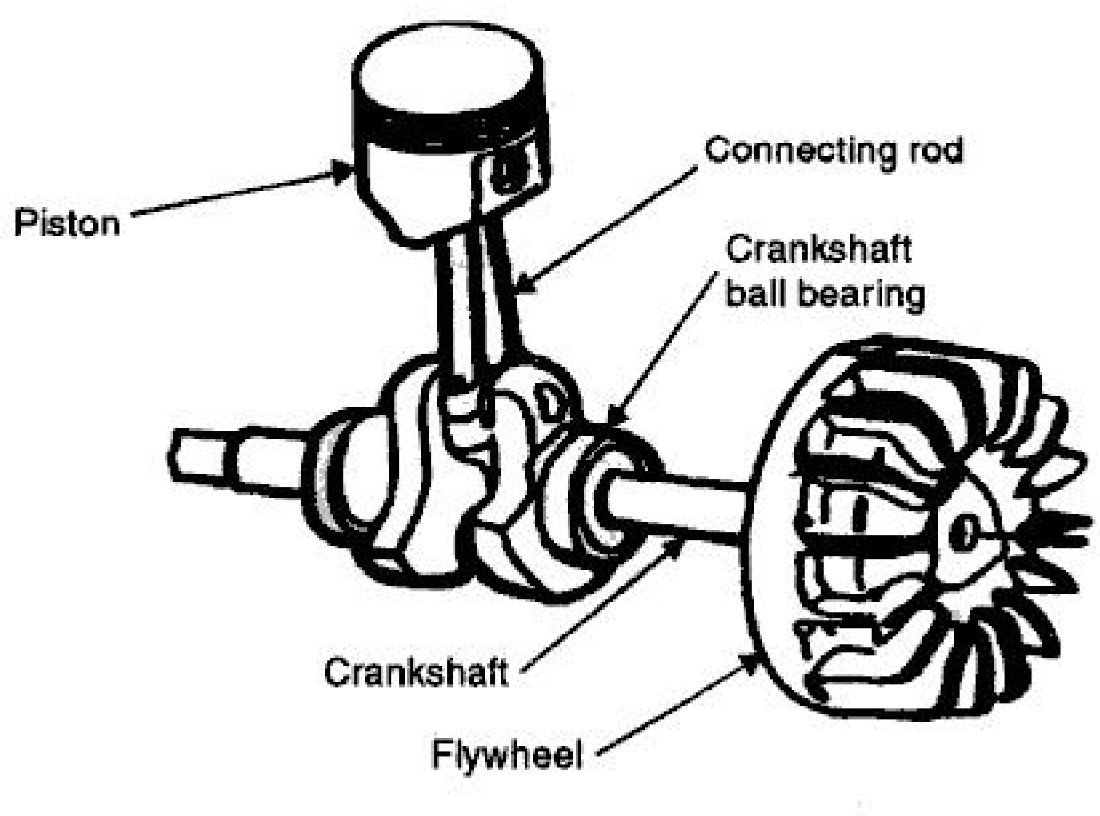


Fig. 2.21. Flywheel secured on crankshaft.

The weight of the flywheel depends upon the nature of variation of the pressure. The flywheel for a double-acting steam engine is lighter than that of a single-acting one. Similarly, the flywheel for a two-stroke cycle engine is lighter than a flywheel used for a four-stroke cycle engine. *Lighter flywheels are used for multi-cylinder engines.*

12. Governor :

A governor may be defined *as a device for regulating automatically output of a machine by regulating the supply of working fluid.* When the speed decreases due to increase in load the supply valve is opened by mechanism operated by the governor and the engine therefore speeds up again to its original speed. If the speed increases due to a decrease of load the governor mechanism closes the supply valve sufficiently to slow the engine to its original speed. *Thus the function of a governor is to control the fluctuations of engine speed due to changes of load.*

Comparison between a Flywheel and a Governor

	Flywheel	Governor
1.	It is provided on engines and fabricating machines *viz.*, rolling mills, punching machines ; shear machines, presses etc.	It is provided on prime movers such as engines and turbines.
2.	Its function is to store the available mechanical energy when it is in excess of the load requirement and to part with the same when the available energy is less than that required by the load.	Its function is to regulate the supply of driving fluid producing energy, according to the load requirement so that at different loads almost a constant speed is maintained.
3.	It works continuously from cycle to cycle.	It works intermittently *i.e.* only when there is change in load.
4.	In engines it takes care of fluctuations of speed during thermodynamic cycle.	It takes care of fluctuations of speed due to variation of load over long range of working engines and turbines.
5.	In fabrication machines it is very economical to use it in that it reduces capital investment on prime movers and their running expenses.	But for governor, there would have been unnecessarily more consumption of driving fluid. Thus it economies its consumption.

Types of governor :

Governors are classified as follows :

1. Centrifugal governor :

(*i*) *Gravity controlled*, in which the centrifugal force due to the revolving masses is largely balanced by gravity.

(*ii*) *Spring controlled*, in which the centrifugal force is largely balanced by springs.

2. Inertia and flywheel governors :

(*i*) Centrifugal type, in which centrifugal forces play the major part in the regulating action.

(*ii*) Inertia governor, in which the inertia effect predominates.

The *inertia type* governors are fitted to the crankshaft or flywheel of an engine and so differ radically in appearance from the centrifugal governors. The balls are so arranged that the inertia force caused by an angular acceleration or retardation of the shaft tends to alter their positions. The amount of displacement of governor balls is controlled by suitable springs and through the governor mechanism, alters the fuel supply to the engine. The inertia governor is more sensitive than centrifugal but it becomes very difficult to balance the revolving parts. For this reason *centrifugal governors are more frequently used.* We shall discuss centrifugal governors only.

Important *centrifugal governors* are :

1. Watt governor
2. Porter governor
3. Proell governor
4. Hartnell governor.

1. Watt governor :

It is the primitive governor as used by Watt on some of his early steam engines. It is used for a very slow speed engine and this is why it has now become obsolete.

Refer Fig. 2.22. Two arms are hinged at the top of the spindle and two revolving balls are fitted on the other ends of the arms. One end of each of the links are hinged with the arms, while the other ends are hinged with the sleeve, which may slide over the spindle. The speed of the crankshaft is transmitted to the spindle through a pair of bevel gears by means of a suitable arrangement. So the rotation of the spindle of the governor causes the weights to move away from the centre due to the centrifugal force. This makes the sleeve to move in the upward direction. This movement of the sleeve is transmitted by the lever to the throttle valve which partially closes or opens the steam pipe and reduces or increases the supply of steam to the engine. So the engine speed may be adjusted to a normal limit.

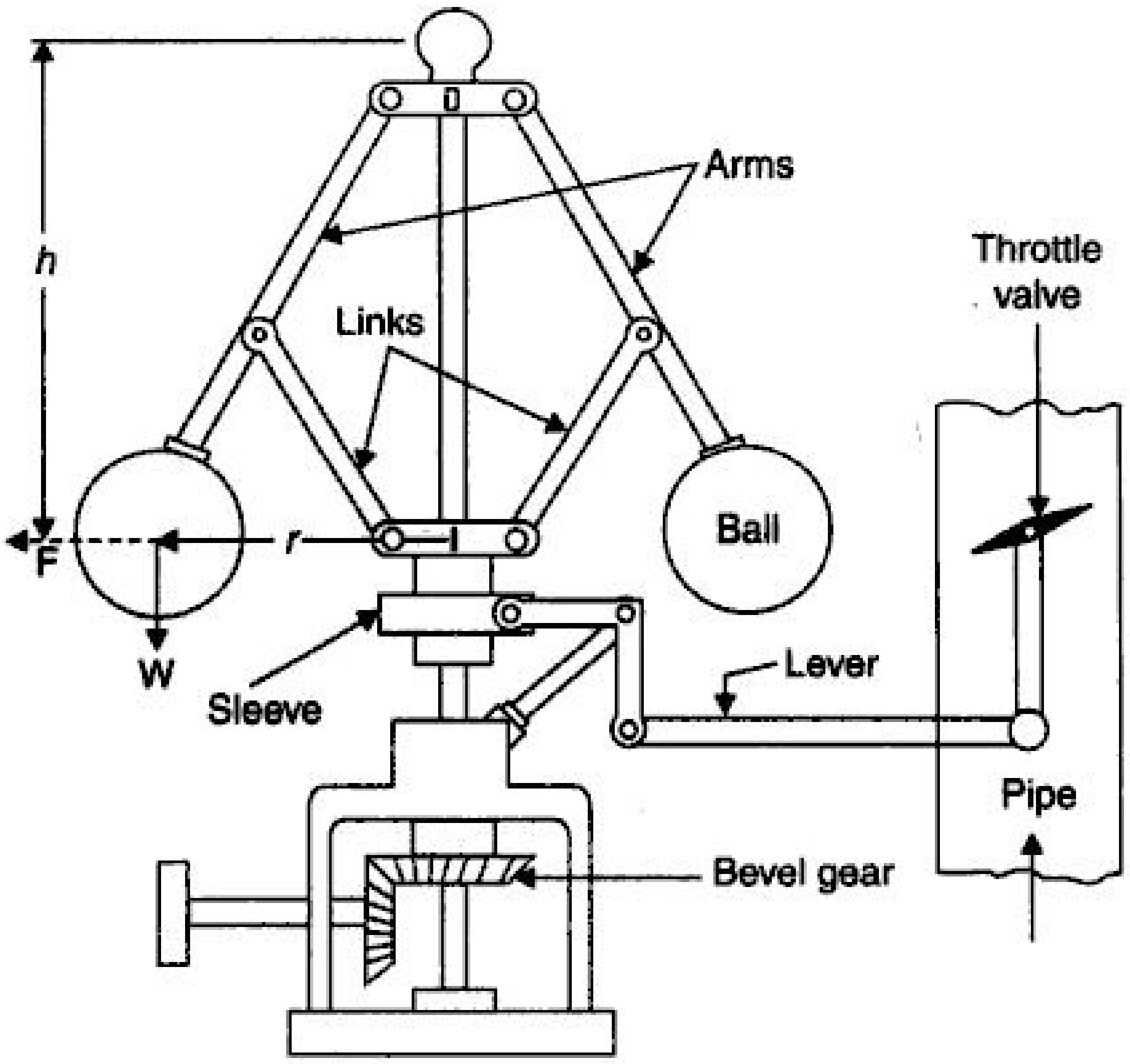


Fig. 2.22. Watt governor.

2. Porter governor :

Fig. 2.23 shows diagrammatically a Porter governor where two or more masses called the governor balls rotate about the axis of the governor shaft which is driven through suitable gearing from the engine crankshaft. The governor balls are attached to the arms. The lower arms are attached to the *sleeve which acts as a central weight.* If the speed of the rotation of the balls increases owing to a decrease of load on the engine, the governor balls fly outwards and the sleeve moves upwards thus closing the fuel passage till the engine speed comes back to its designed speed. If the engine speed decreases owing to an increase of load, the governor balls fly inwards and the sleeve moves downwards thus opening the fuel passage more for oil till the engine speed comes back to its designed speed. The engine is said to be running at its designed speed when the outward inertia or centrifugal force is just balanced by the inward controlling force.

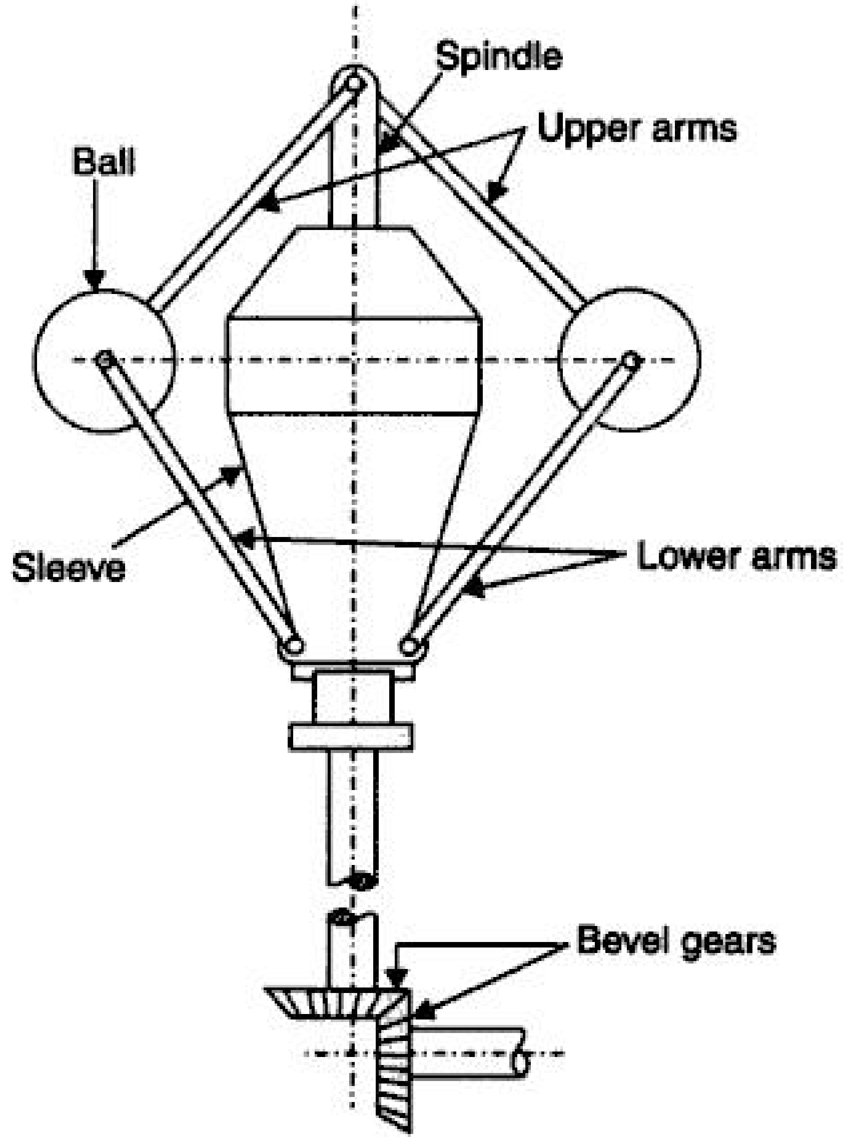


Fig. 2.23. Porter governor.

3. **Proell governor :**

Refer Fig. 2.24. It is a modification of porter governor. The governor balls are carried on an *extension of the lower arms*. For given values of weight of the ball, weight of the sleeve and height

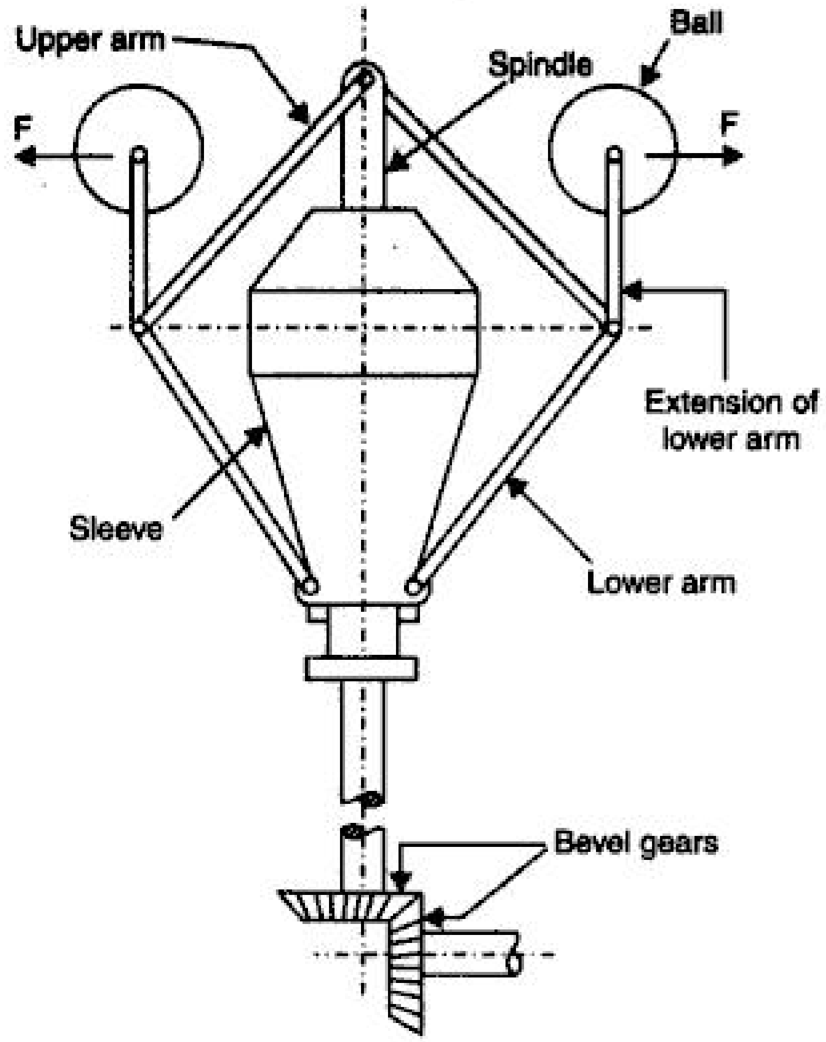


Fig. 2.24. Proell governor.

of the governor, a Proell governor runs at a *lower speed* than a Porter governor. *In order to give the same equilibrium speed a ball of smaller mass may be used in Proell governor.*

4. Hartnell governor :

The Hartnell governor is a spring loaded governor in which the controlling force, to a great extent, is provided by the spring thrust.

Fig. 2.25 shows one of the types of Hartnell governors. It consists of casing fixed to the spindle. A compressed spring is placed inside the casing which presses against the top of the casing and on adjustable collars. The sleeve can move up and down on the vertical spindle depending upon the speed of the governor. Governor balls are carried on bell crank lever which are pivoted on the lower end of the casing. The balls will fly outwards or inwards as the speed of the governor shaft increases or decreases respectively.

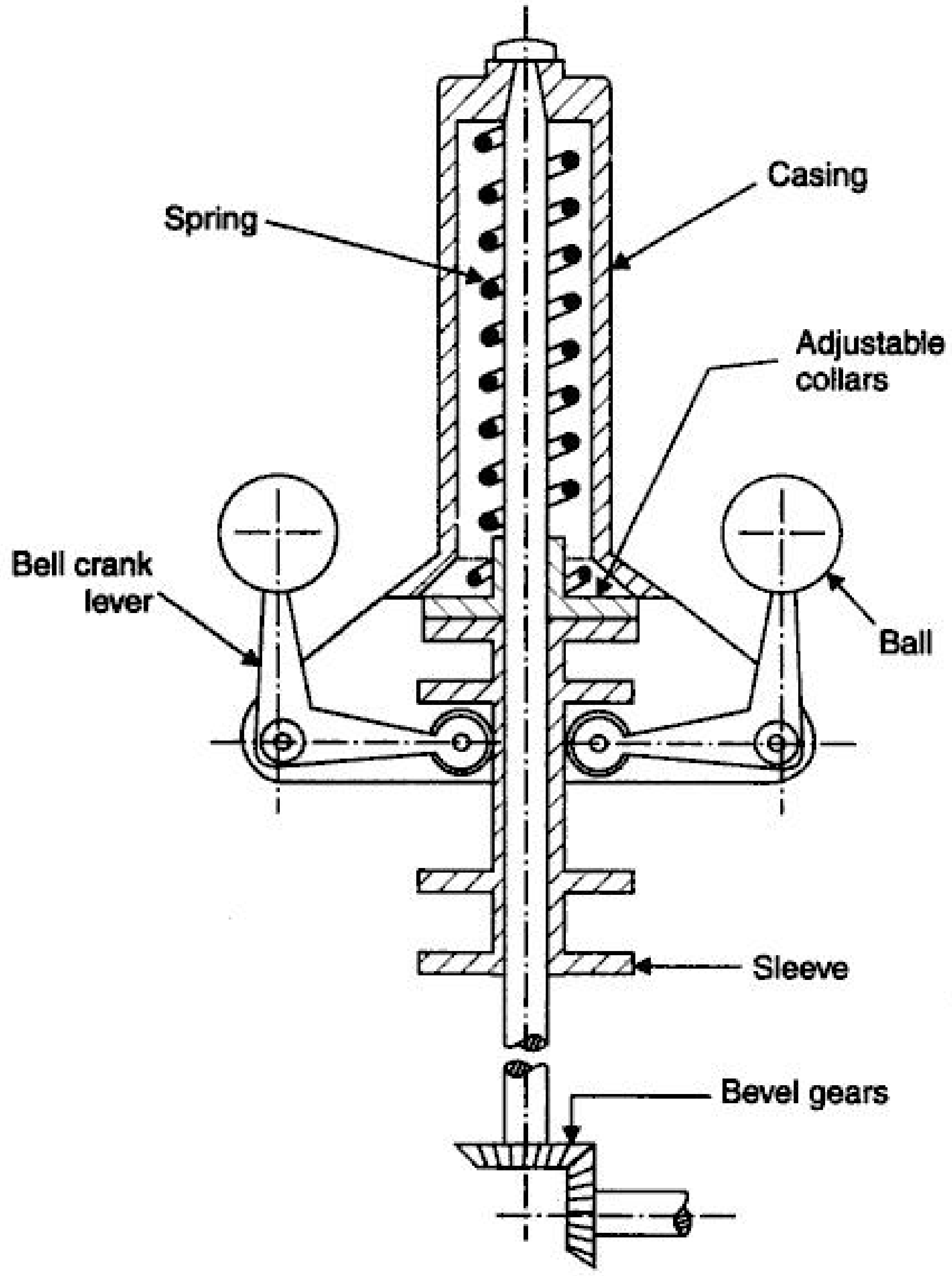


Fig. 2.25. Hartnell governor.

13. Valves and valve operating mechanisms :

With few exceptions the inlet and exhaust of internal combustion engines are controlled by poppet valves. These valves are held to their seating by strong springs, and as the valves usually open inwards, the pressure in the cylinder helps to keep them closed. The valves are lifted from their seats and the ports opened either by cams having projecting portion designed to give the period of opening required or by eccentrics operating through link-work. Of these two methods the cam gear is more commonly used, but in either case it is necessary that the valve gear shaft of an engine should rotate but once from beginning to end of a complete cycle, however many strokes may be involved in the completion of that cycle. This is necessary to secure a continuous regulation of the valve gear as required. For this purpose the cams or eccentrics of four-stroke engines are mounted on shafts driven by gearing at half the speed of the crankshaft. The curves used for the acting faces of the cams depend on the speed of the engine and rapidity of valve opening desired.

Fig. 2.26 shows a valve gear for I.C. engine. It consists of poppet valve, the steam bushing or guide, valve spring, spring retainer, lifter or push rod, camshaft and half speed gear for a four-

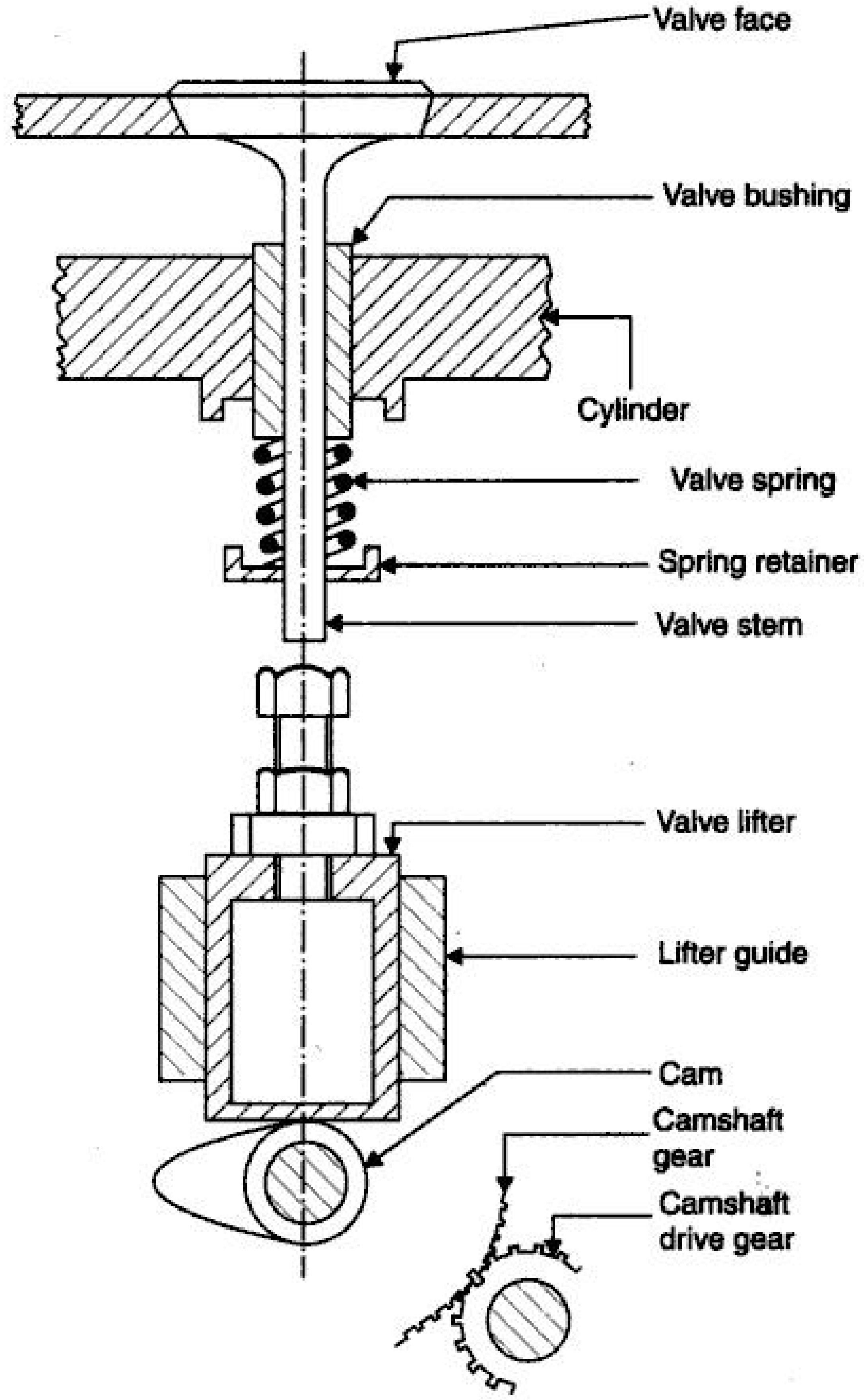


Fig. 2.26. Valve gear for I.C. engine.

stroke engine. The poppet valve, in spite of its shortcomings of noise and difficulties of cooling is commonly used due to its simplicity and capacity for effective sealing under all operating conditions. The valve is subjected to very heavy duty. It holds in combustion chamber and is exposed to high temperatures of burning gases. Exhaust valve itself may attain a high temperature while external cooling is not available. Special heat resisting alloys are therefore used in the construction of the exhaust valve and it may sometimes have a hollow construction filled with mineral salts to provide for heat dissipation. The salts become liquid when valve is working and transfer heat from the head to the stem from which it is carried through the stem guide to the cylinder block.

The timing of the valves *i.e.*, their opening and closing with respect to the travel of the piston is very important thing for efficient working of the engine. The drive of the camshaft is arranged through gears or chain and sprocket (called timing gear or timing chain). Any wearing of the gears or chain and sprocket would result in disturbing the precise timing of the valves. It is desirable, therefore, to avoid use of multiple gears of long chains in the camshaft drive.

Valve timing :

Theoretically the valves open and close at Top Dead Centre (T.D.C.) or at Bottom Dead Centre (B.D.C.) but practically they do so some time before or after the piston reaches the upper or lower limit of travel. There is a reason for this. Look at the inlet valve, for example. It normally opens several degrees of crankshaft-rotation before T.D.C. on the exhaust stroke. That is the intake valve begins to open before the exhaust stroke is finished. This gives the valve enough time to reach the fully open position before the intake stroke begins. Then, when the intake stroke starts, the intake valve is already wide open and air fuel mixture can start to enter the cylinder, immediately. Likewise the intake valve remains open for quite a few degrees of crankshaft rotation after the piston has passed B.D.C. at the end of the intake stroke. This allows additional time for air fuel mixture to continue to flow into the cylinder. The fact that the piston has already passed B.D.C. and is moving up on the compression stroke while the intake valve is still open does not effect the movement of air-fuel mixture into the cylinder. Actually air-fuel mixture is still flowing in as the intake valve starts to close.

This is due to the fact that air-fuel mixture has inertia. That is, it attempts to keep on flowing after it once starts through the carburettor and into the engine cylinder. The momentum of the mixture then keeps it flowing into the cylinder even though the piston has started up on the compression stroke. This packs more air-fuel mixture into the cylinder and results in a stronger power stroke. In other words, this improves *volumetric efficiency*.

For a somewhat similar reason, the exhaust valve opens well before the piston reaches B.D.C. on the power stroke. As the piston nears B.D.C., most of the push on the piston has ended and nothing is lost by opening the exhaust valve towards the end of the power stroke. This gives the exhaust gases additional time to start leaving the cylinder so that exhaust is well started by the time the piston passes B.D.C. and starts up on the exhaust stroke. The exhaust valve then starts opening for some degrees of crankshaft rotation after the piston has passed T.D.C. and intake stroke has started. This makes good use of momentum of exhaust gases. They are moving rapidly towards the exhaust port, and leaving the exhaust valve open for a few degrees after the intake stroke starts giving the exhaust gases some additional time to leave the cylinder. This allows more air-fuel mixture to enter on the intake stroke so that the stronger power stroke results. That is, it improves volumetric efficiency.

The actual timing of the valves varies with different four stroke cycle engines, but the typical example for an engine is shown in Fig. 2.27. Note that the inlet valve opens 15° of crankshaft rotation before T.D.C. on the exhaust stroke and stays open until 50° of crankshaft rotation after B.D.C. on the compression stroke. The exhaust valve opens 50° before B.D.C. on the power stroke and stays open 15° after T.D.C. on the inlet stroke. This gives the two valves an overlap of 30° at the end of exhaust stroke and beginning of the *compression stroke*.

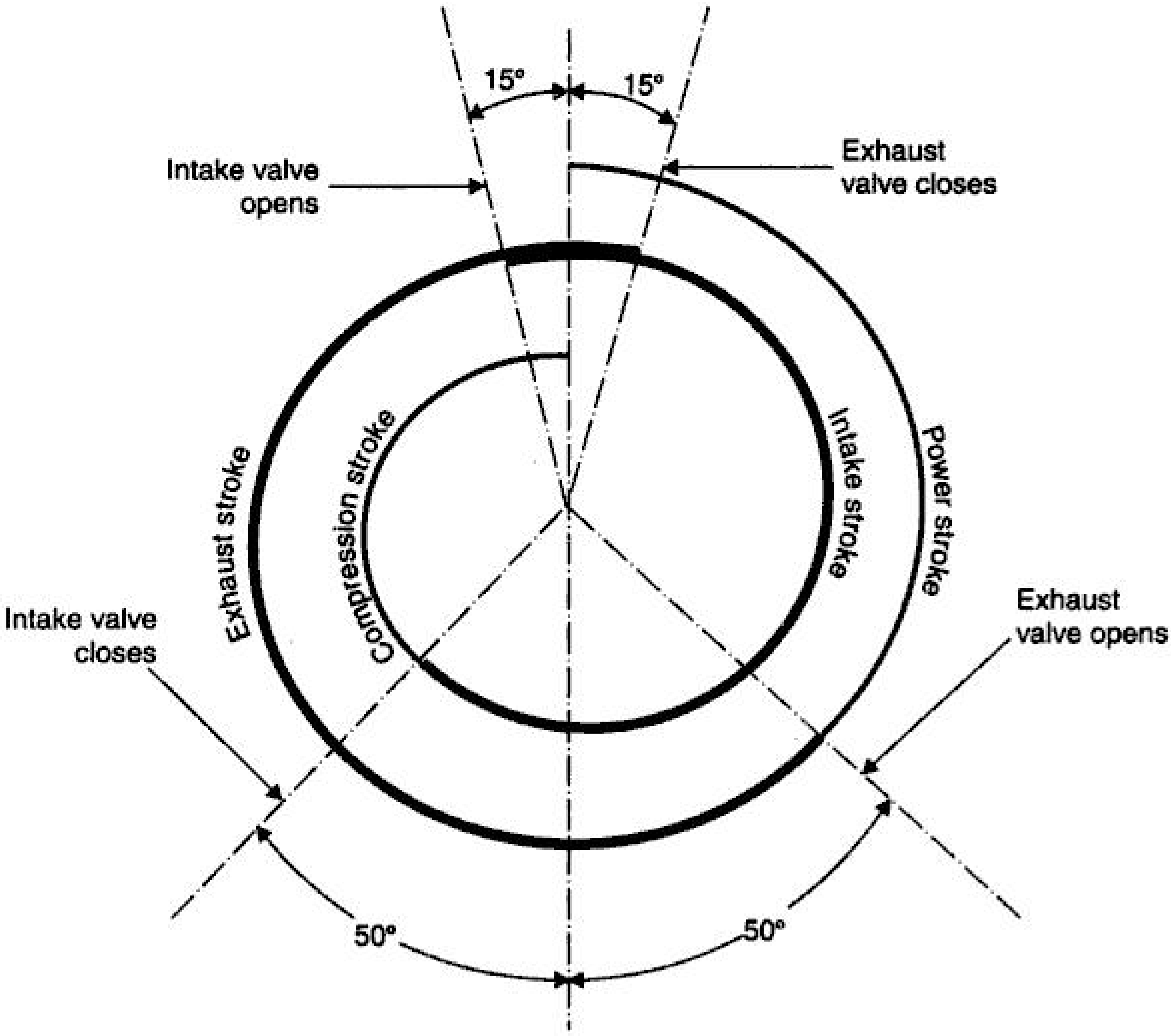


Fig. 2.27. Typical valve timing diagram.

B. Parts for Petrol Engines Only :

1. **Spark plugs :**

The main function of a spark-plug is to conduct the high potential from the ignition system into the combustion chamber. It provides the proper gap across which spark is produced by applying high voltage, to ignite the mixture in combustion chamber.

A spark-plug entails the following requirements :

(*i*) It must withstand peak pressures up to atleast 55 bar.

(*ii*) It must provide suitable insulation between two electrodes to prevent short circuiting.

(*iii*) It must be capable of withstanding high temperatures to the tune of 2000°C to 2500°C over long periods of operation.

(*iv*) It must offer maximum resistance to erosion burning away of the spark points irrespective of the nature of fuel used.

(*v*) It must possess a high heat resistance so that the electrodes do not become sufficiently hot to cause the preignition of the charge within the engine cylinder.

(*vi*) The insulating material must withstand satisfactorily the chemical reaction effects of the fuel and hot products of combustion.

(*vii*) Gas tight joints between the insulator and metal parts are essential under all operating conditions.

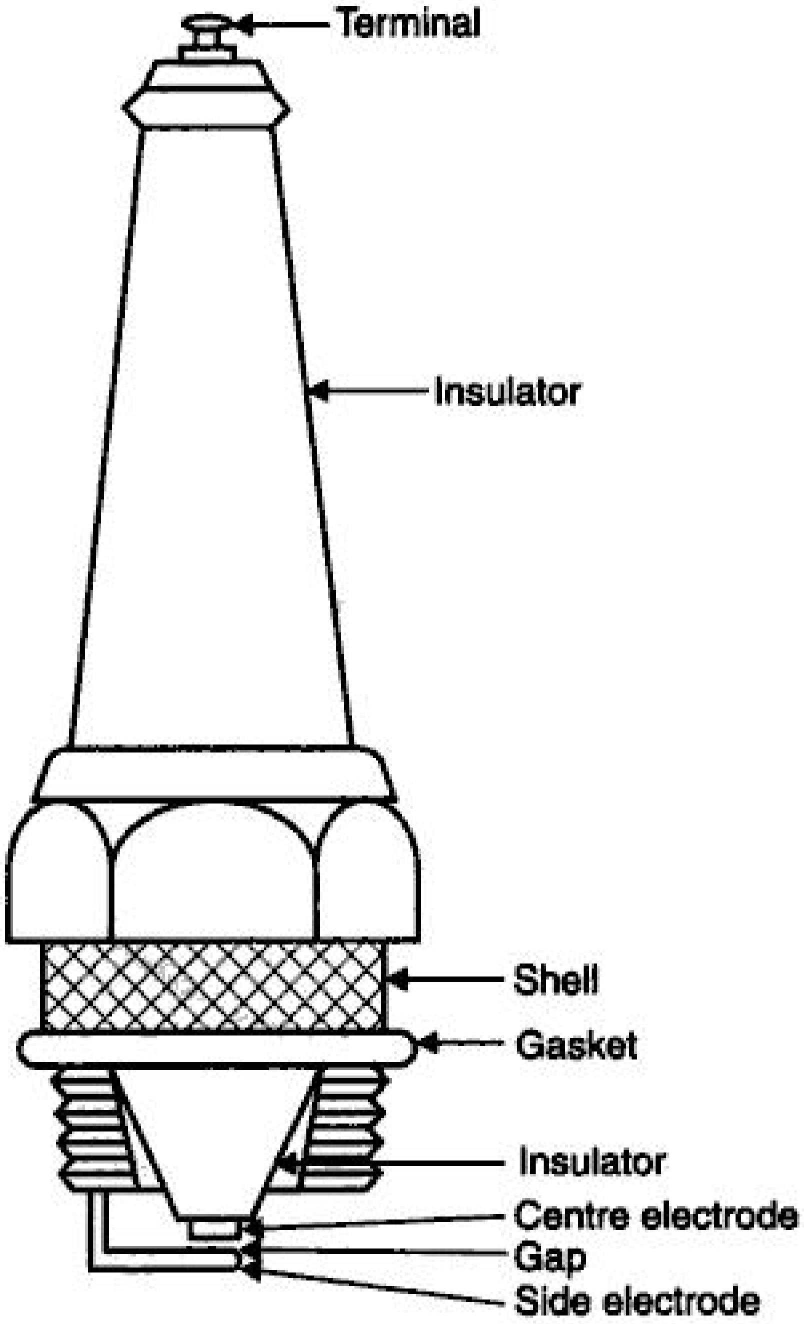


Fig. 2.28. Spark-plug.

Refer Fig. 2.28. The spark-plug consists of a metal shell having two electrodes which are insulated from each other with an air gap. High tension current jumping from the supply electrode produces the necessary spark. Plugs are sometimes identified by the heat range or the relative temperature obtained during operation. The correct type of plug with correct width of gap between the electrodes are important factors. The spark-plug gap can be easily checked by means of a feeler gauge and set as per manufacturer's specifications. It is most important that while adjusting the spark plug it is the outer earthed electrode *i.e.*, tip which is moved in or out gradually for proper setting of the gap. No bending force should be applied on the centre-electrode for adjusting the gap as this can cause crack and fracture of insulation and the plug may become absolutely useless.

Porcelain is commonly used as insulating material in spark-plugs, as it is cheap and easy to manufacture. Mica can also be used as insulating material for spark-plugs. Mica, however, cannot withstand high temperatures successfully.

- **Operating Heat Range :**
  - A spark-plug heat range is a measure of the plug's ability to transfer heat from the central electrode and insulator nose to the cylinder-head and cooling system.
  - When the heat absorbed by the plug's central electrode and insulator nose exceeds the capability of the plug to dissipate this heat in the same time, then the plug will *overheat* and the central electrode temperature will rise above its safe operating limit of about 900°C to 950°C. *Above the plug's upper working temperature-limit, the central electrode will glow and ignite the air-fuel mixture before the timed spark actually occurs.* This condition is *known as* **auto-ignition** as it *automatically starts the combustion process independently of the controlled ignition spark.* The danger of this occuring is in the fact that it may take place relatively early in the compression stroke. Consequently, the pressure generated in the particular cylinder suffering from auto-ignition will oppose the upward movement of the piston. Excessive mechanical stresses will be produced in the reciprocating and rotating components and an abnormal rise in the cylinder temperature would, if allowed to continue, damage the engine.
  - If the plug's ability to transfer heat away from the central electrode and insulator tip *exceeds* that of the input heat from combustion, over the same time span, then the plug's central electrode and insulator nose *would operate at such a low temperature as to permit the formation of carbon deposits around the central nose of the plug.* This *critical lower temperature region is usually between 350°C and 400°C* and, at temperatures below this, carbon or oil deposits will *foul the insulation,* creating conducting shunts to the inside of the metal casing of the plug. Consequently, if *deposits are permitted to form, a proportion of the ignition spark energy will bypass the plug gap so that there will be insufficient energy left to ionize the electrode with the result that misfiring will result.* Establishing a heat balance between the plug's input and output heat flow, so that the *plug's temperature remains just in excess of 400°C, provides a self cleaning action on both the surfaces of the electrodes and insulator.*
  - A good spark-plug design tries to match the heat flowing from the plug to the heat flowing into it, caused by combustion under all working conditions, *so that the plug operates below the upper temperature limit at full load, but never drops below the lower limit when idling or running under light-load conditions.*

- **Firing Voltage :**

  A certain *minimum voltage* is necessary to make the spark jump the electrode air gap, the actual magnitude of the voltage required will depend upon the following *factors* :

  (*i*) Compression pressure (*ii*) Mixture strength
  (*iii*) Electrode gap (*iv*) Electrode tip temperature.

- **Tightness of Spark-plug :**
  - The seat joint tightness is essential for good heat dissipation.
  - Spark-plugs should not be over tightened otherwise the plug metal casing may become distorted, causing the central electrode insulator to break its seal and become loose. *Combustion gas may then escape through the plug with the result that it overheats.*

– An under-tightened plug may work itself loose and cause combustion gas to escape between the plug and cylinder-head plug hole threads to the atmosphere, again this will *result in overheating and rapid deterioration of the electrode tips.*

It is best to torque the plug to a definite degree of tightness.

2. Carburettor

The function of a carburettor is to atomise and metre the liquid fuel and mix it with the air as it enters the induction system of the engine, maintaining under all conditions of operation fuel-air proportions appropriate to those conditions.

All modern carburettors are based upon Bernoulli's theorem,

$$C^2 = 2gh$$

where, C is the velocity in metres/sec, g is the acceleration due to gravity in metre/sec^2 and h is the head causing the flow expressed in metres of height of a column of the fluid.

The equation of mass rate of flow is given by,

$$m = \rho A\sqrt{2gh}$$

where, ρ is the density of the fluid and A is the cross-sectional area of fluid stream.

In Fig. 2.29 is shown simple carburettor. L is the float chamber for the storage of fuel. The fuel supplied under gravity action or by fuel pump enters the float chamber through the filter F.

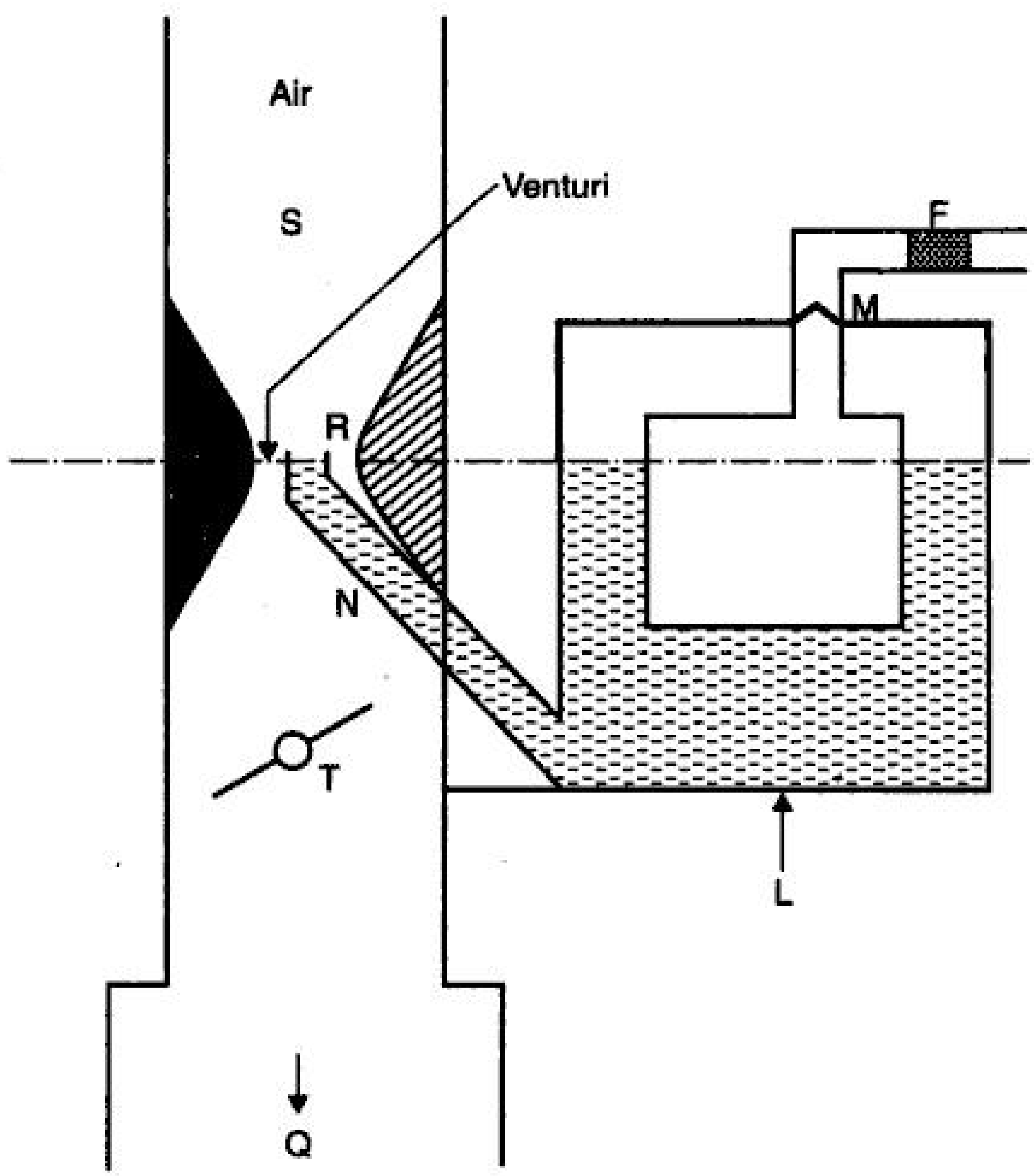


Fig. 2.29. Simple carburettor.

The arrangement is such that when the oil reaches a particular level the float valve M blocks the inlet passage and thus cuts off the fuel oil supply. On the fall of oil level, the float descends down, consequently intake passage opens and again the chamber is filled with oil. Then the float and the float valve maintains a constant fuel oil level in the float chamber. N is the jet from which the fuel is sprayed into the air stream as it enters the carburettor at the inlet S and passes through the throat or venturi R. The fuel level is slightly below the outlet of the jet when the carburettor is inoperative.

As the piston moves down in the engine cylinder, suction is produced in the cylinder as well as in the induction manifold Q as a result of which air flows through the carburettor. The velocity of air increases as it passes through the constriction at the venturi R and pressure decreases due to conversion of a portion of pressure head into kinetic energy. Due to decreased pressure at the venturi and hence by virtue of difference in pressure (between the float chamber and the venturi) the jet issues fuel oil into air stream. Since the jet has a very fine bore, the oil issuing from the jet is in the form of fine spray ; it vapourises quickly and mixes with the air. This air-fuel mixture enters the engine cylinder ; its quantity being controlled by varying the position of the throttle valve T.

Limitations :

(*i*) Although theoretically the air fuel ratio supplied by a simple (single jet) carburettor should remain constant as the throttle goes on opening, actually it provides increasingly richer mixture as the throttle is opened. This is because of the reason that the density of air tends to decrease as the rate of flow increases.

(*ii*) During idling, however, the nearly closed throttle causes a reduction in the mass of air flowing through the venturi. At such low rates of air flow, the pressure difference between the float chamber and the fuel discharge nozzle becomes very small. It is not sufficient to cause fuel to flow through the jet.

(*iii*) Carburettor does not have arrangement for providing rich mixture during starting and warm up.

In order to *correct for faults* :

(*i*) number of compensating devices are used for (*ii*) an idling jet is used which helps in running the engine during idling. For (*iii*) choke arrangement is used.

3. **Fuel pump** (for carburettor-petrol engine).

Refer Fig. 2.30. This type of pump is used in petrol engine for supply of fuel to the carburettor. Due to rotation of the crankshaft the cam pushes the lever in the upward direction. One end of the lever is hinged while the other end pulls the diaphragm rod with the *diaphragm*. So the diaphragm comes in the downward direction against the compression of the spring and thus a vacuum is produced in the pump chamber. This causes the fuel to enter into the pump chamber from the *glass bowl* through the *strainer* and the inlet valve, the impurities of the fuel ; if there is any, deposit at the bottom of the glass bowl. On the return stroke the spring pushes the diaphragm in the upward direction forcing the fuel from the pump chamber into the carburettor through the *outlet valve*.

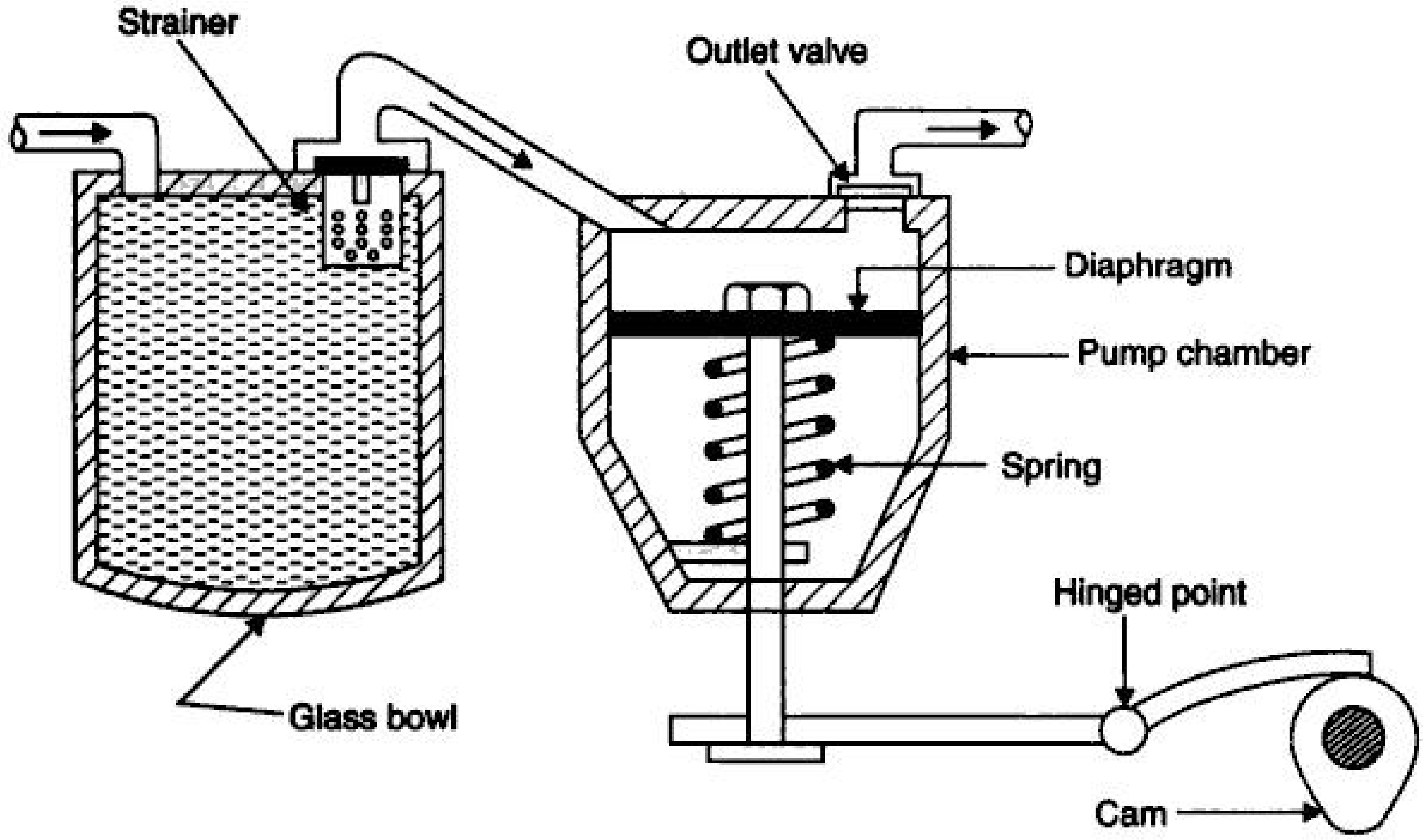


Fig. 2.30. Fuel pump for carburettor.

C. Parts for Diesel Engine Only :

1. Fuel pump :

Refer to Fig. 2.31. *L* is the plunger which is driven by a cam and tappet mechanism at the bottom (not shown in the figure), *B* is the barrel in which the plunger reciprocates. There is the rectangular vertical groove in the plunger which extends from top to another helical groove. *V* is the delivery valve which lifts off its seat under the liquid fuel pressure and against the spring force (*S*). The fuel pump is connected to fuel atomiser through the passage *P*, *SP* and *Y* are the spill and supply ports respectively. When the plunger is at its bottom stroke the ports *SP* and *Y* are uncovered (as shown in the Fig. 2.31) and oil from low pressure pump (not shown) after being filtered is forced into the barrel. When the plunger moves up due to cam and tappet mechanism, a stage reaches when both the ports *SP* and *Y* are closed and with the further upward movement of the plunger the fuel gets compressed. The high pressure thus developed lifts the delivery valve off its seat and fuel flows to atomiser through the passage *P*. With further rise of the plunger, at a certain moment, the port *SP* is connected to the fuel in the upper part of the plunger through the rectangular vertical groove by the helical groove ; as a result of which a sudden drop in pressure occurs and the delivery valve falls back and occupies its seat against the spring force. The plunger is rotated by the rack *R* which is moved in or out by the governor. *By changing the angular position of the helical groove (by rotating the plunger) of the plunger relative to the supply port, the length of stroke during which the oil is delivered can be varied and thereby quantity of fuel delivered to the engine is also varied accordingly.*

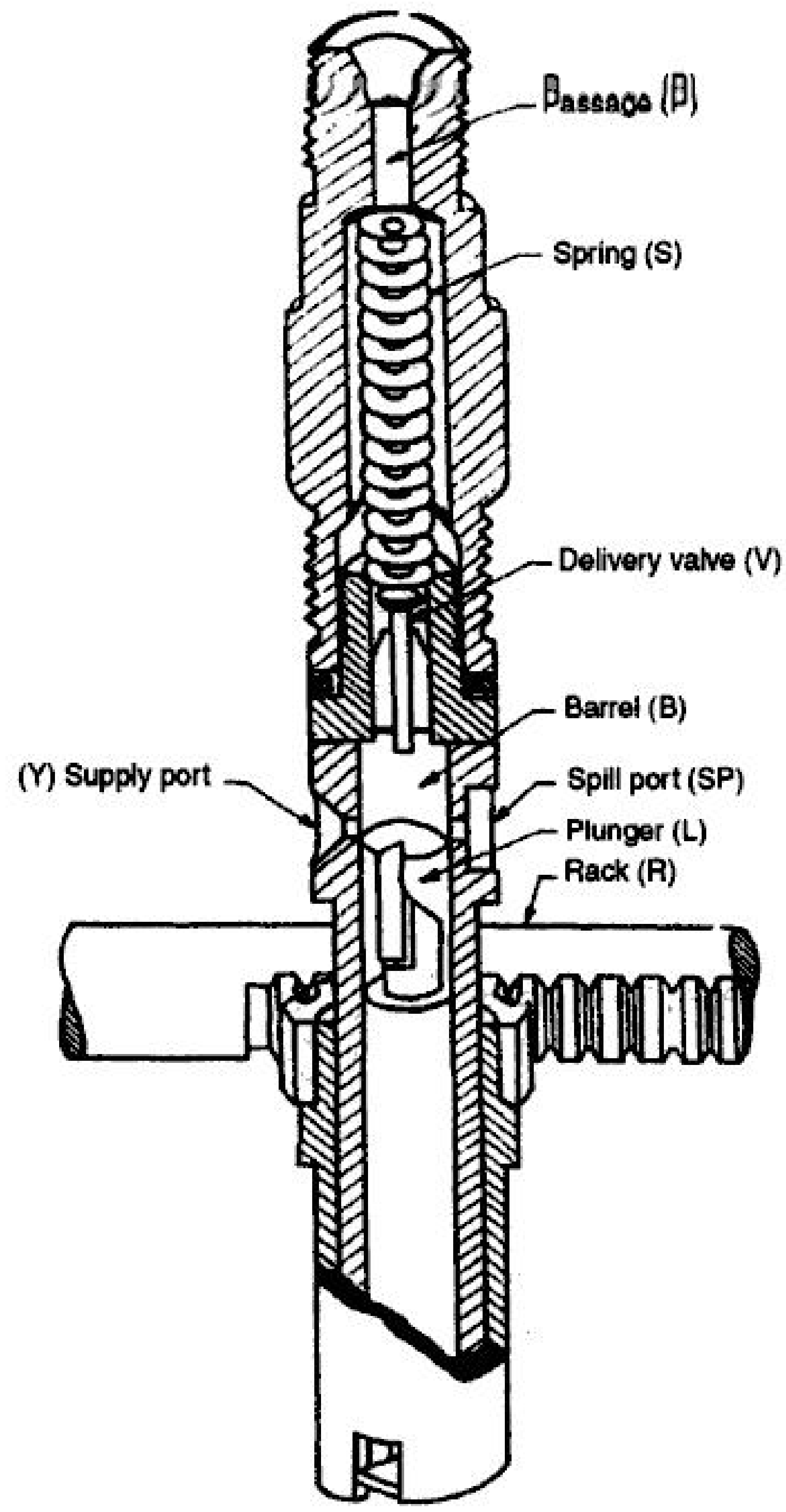


Fig. 2.31. Fuel pump.

2. Fuel atomiser or injector :

Refer Fig. 2.32. It consists of a nozzle valve (*NV*) fitted in the nozzle body (*NB*). The nozzle valve is held on its seat by a spring '*S*' which exerts pressure through the spindle *E*. '*AS*' is the adjusting screw by which the nozzle valve lift can be adjusted. Usually the nozzle valve is set to lift at 135 to 170 bar pressure. *FP* is the feeling pin which indicates whether valve is working properly or not. The oil under pressure from the fuel pump enters the injector through the passages *B* and *C* and lifts the nozzle valve. The fuel travels down the nozzle *N* and injected into the engine cylinder in the form of fine sprays. When the pressure of the oil falls, the nozzle valve occupies its seat under the spring force and fuel supply is cut-off. Any leakage of fuel accumulated above the valve is led to the fuel tank through the passage *A*. The leakage occurs when the nozzle valve is *worn out*.

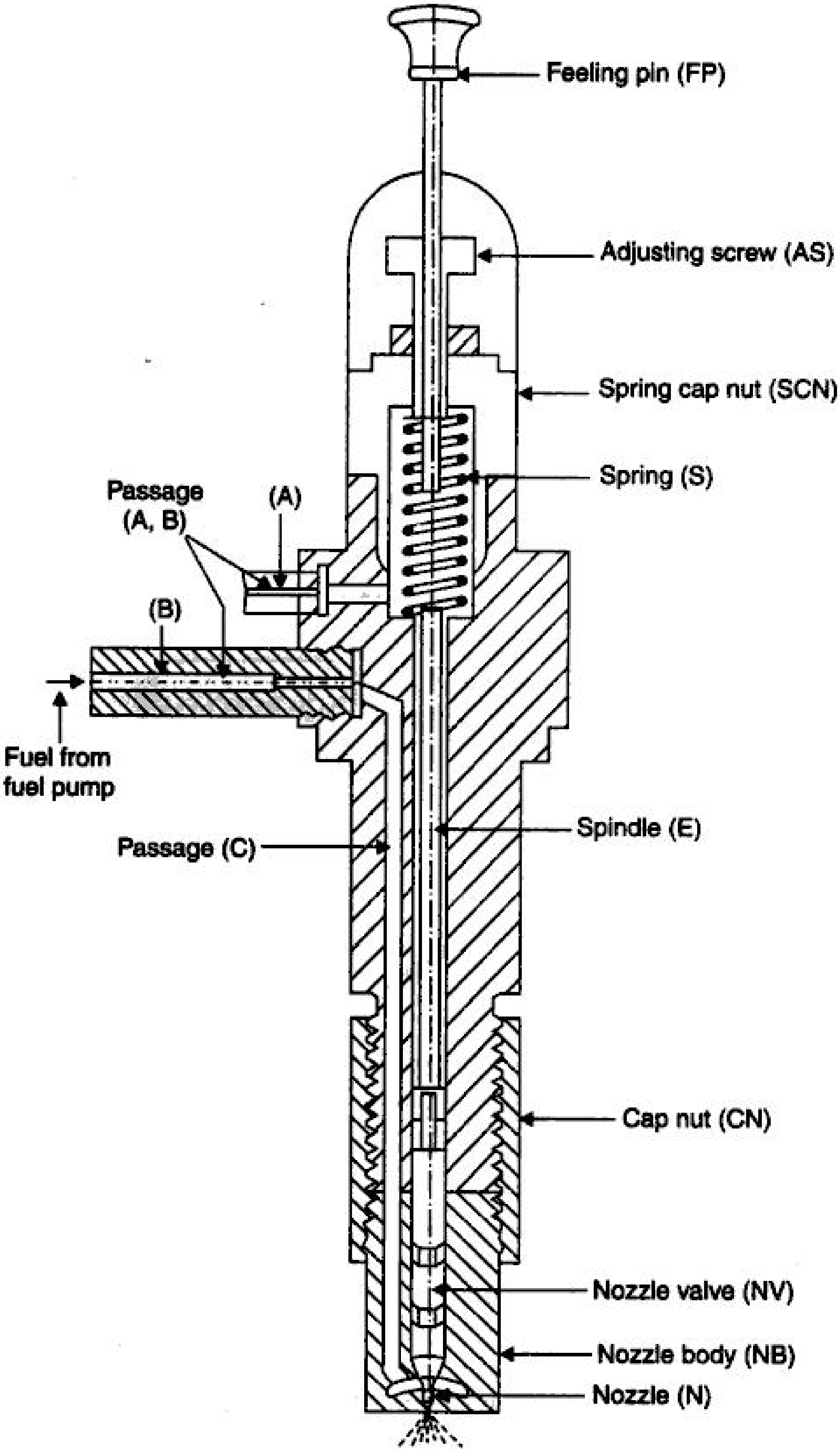


Fig. 2.32. Fuel atomiser or injector.

List of engine parts, materials, method of manufacture and functions :

	Name of the part	Material	Function	Method of manufacture
1.	*Cylinder*	Hard grade cast-iron	Contains gas under pressure and guides the piston.	Casting
2.	*Cylinder head*	Cast-iron or aluminium	Main function is to seal the working end of the cylinder and not to permit entry and exit of gases on overhead valve engines.	Casting, forging
3.	*Piston*	Cast-iron or aluminium alloy	It acts as a face to receive gas pressure and transmits the thrust to the connecting rod.	Casting, forging
4.	*Piston rings*	Cast-iron	Their main function is to provide a good sealing fit between the piston and cylinder.	Casting
5.	*Gudgeon pin*	Hardened steel	It supports and allows the connecting rod to swivel.	Forging
6.	*Connecting rod*	Alloy steel ; for small engines the material may be aluminium	It transmits the piston load to the crank, causing the latter to turn, thus converting the reciprocating motion of the piston into rotary motion of the crankshaft.	Forging
7.	*Crankshaft*	In general the crankshaft is made from a high tensile forging, but special cast-irons are sometimes used to produce a light weight crankshaft that does not require a lot of machining.	It converts the reciprocating motion of the piston into the rotary motion.	Forging
8.	*Main bearings*	The typical bearing half is made of steel or bronze back to which a lining of relatively soft bearing material is applied.	The function of bearing is to reduce the friction and allow the parts to move easily.	Casting
9.	*Flywheel*	Steel or cast-iron.	In engines it takes care of fluctuations of speed during thermodynamic cycle.	Casting
10.	*Inlet valve*	Silicon chrome steel with about 3% carbon.	Admits the air or mixture of air and fuel into engine cylinder.	Forging
11.	*Exhaust valve*	Austenitic steel	Discharges the product of combustion.	Forging

2.8. TERMS CONNECTED WITH I.C. ENGINES

Refer to Fig. 2.33.

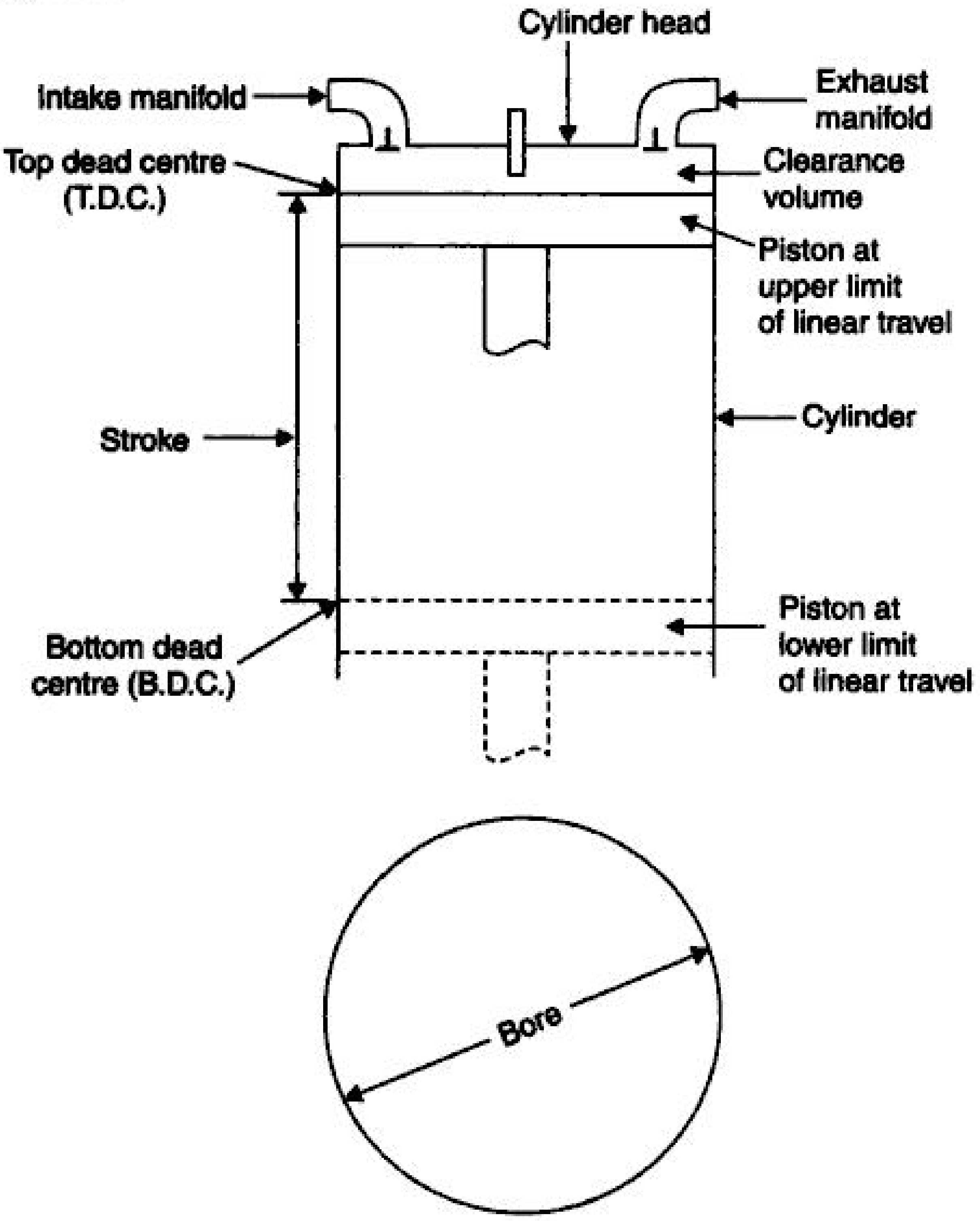


Fig. 2.33. Terms relating to I.C. engines.

Bore. *The inside diameter of the cylinder is called "bore".*

Stroke. As the piston reciprocates inside the engine cylinder, it has got limiting upper and lower positions beyond which it cannot move and reversal of motion takes place at these limiting positions.

The linear distance along the cylinder axis between two limiting positions, is called "stroke".

Top Dead Centre (T.D.C.). *The top most position of the piston towards cover end side of the cylinder is called "top dead centre".* In case of horizontal engines, this is known as *inner dead centre.*

Bottom Dead Centre (B.D.C.). *The lowest position of the piston towards the crank end side of the cylinder is called "bottom dead centre".* In case of horizontal engines it is called *outer dead centre.*

Clearance volume. *The volume contained in the cylinder above the top of the piston, when the piston is at top dead centre, is called the "clearance volume".*

- Bore sizes of engines range from 0.5 m down to 0.5 cm. The ratio of bore of stroke D/L, for small engines is usually from 0.8 to 1.2.

– An engine with $L = D$ is often called a **square** *engine* ;
– If $L > D$ the engine is **under square ;**
– If $L < D$ the engine is **over square.**

Very large engines are *always under square*, with *stroke lengths up to four times bore diameter.*

Swept volume. *The volume swept through by the piston in moving between top dead centre and bottom dead centre is called "swept volume or piston displacement".* Thus, when piston is at bottom dead centre, total volume = swept volume + clearance volume.

- Typical values for engine displacement range from 0.1 cm^3 for small model airplanes to about 8 litres for large automobiles to much large number for large ship engines. The displacement of a modern average automobile engine is about two to three litres.
- For a given displacement volume, a longer stroke allows for a smaller bore (under square), resulting in less surface area in the combustion chamber and correspondingly less heat loss. This increases thermal efficiency within the combustion chamber. However, the longer stroke results in higher piston speed and higher friction losses that reduce the output power which can be obtained off the crankshaft. If the stroke is shortened, the bore must be increased and the engine will be over square. This decreases friction losses but increases heat transfer losses. *Most modern automobile engines are near square, with some slightly over square and some slightly under square.*

Compression ratio. *It is ratio of total cylinder volume to clearance volume.*

Refer to Fig. 2.33. Compression ratio (r) is given by

$$r = \frac{V_s + V_c}{V_c}$$

where, V_s = Swept volume, and V_c = Clearance volume.

The compression ratio varies from 5 : 1 to 11 : 1 (average value 7 : 1 to 9 : 1) in *S.I. engines* and from 12 : 1 to 24 : 1 (average value 15 : 1 to 18 : 1) in *C.I. engines.*

- Modern spark ignition (S.I.) engines have compression ratios of 8 to 11, while compression ignition (C.I.) engines have compression ratios in the range 12 to 24. *Engines with superchargers or turbochargers usually have lower compression ratios than naturally aspirated engines.*
- Various attempts have been made to develop engines with a *variable compression ratio.* One such system uses a *split piston that expands due to changing hydraulic pressure caused by engine speed and load.* Some two-stroke cycle engines have been built which have a sleeve-type valve that changes the slot opening on the exhaust port. The piston where the exhaust port is fully closed can be adjusted by several degrees of engine rotation. This changes the *effective compression ratio* of the engine.

Piston speed. *The average speed of the piston is called "piston speed".*

Piston speed = 2 LN

where, L = Length of the stroke, and

N = Speed of the engine in r.p.m.

- Average engine speed for all engines will normally be in the range of 5 to 15 m/s with large diesel engines on the low end and high performance automobile engines on the high end. There are following *two reasons* why engines operate in this range :
  – *First,* this is about the *safe limit which can be tolerated by material strength of the engine components.*
  – The *second* reason why maximum average piston speed is limited is *because of the gas flow into and out of cylinders.* Piston speed determines the instantaneous flow

rate of air-fuel into the cylinder during intake and exhaust flow out of the cylinder during the exhaust stroke. *Higher piston speeds would require larger valves to allow for higher flow rates.* In most engines, valves are at a maximum size with no room for enlargement.

Some Other Terms :

Direct Injection (D.I.)—*Fuel injection into the main combustion chamber of an engine.* Engines have either one main combustion chamber (open chamber) or a divided combustion chamber made up of a main chamber and a smaller connected secondary chamber.

Indirect Injection (I.D.I.)—*Fuel injection into the secondary chamber of an engine with a divided combustion chamber.*

Smart Engine—*Engine with computer controls that regulate operating characteristics* such as *air-fuel ratio, ignition timing, valve timing, exhaust control, intake tuning* etc.

Engine Management System (E.M.S.)—Computer and electronics used to control smart engines.

Wide Open Throttle (W.O.T.)—Engine operated with *throttle valve fully open when maximum power and/or speed is desired.*

Ignition Delay (I.D.). It is the *time interval between ignition initiation and the actual start of combustion.*

Air-Fuel Ratio (A/F). It is the *ratio of the air to mass of fuel input into engine.*

Fuel-Air Ratio (F/A). It is the *ratio of fuel to mass of air input into engine.*

2.9. WORKING CYCLES

An internal combustion engine can work on any one of the following cycles :

(*a*) Constant volume or Otto cycle.

(*b*) Constant pressure or Diesel cycle.

(*c*) Dual combustion cycle.

These may be either *four stroke cycle or two stroke cycle engines.*

(*a*) **Constant volume or Otto cycle.** The cycle is so called because heat is supplied at constant volume. Petrol, gas, light oil engines work on this cycle. In the case of a petrol engine the proper mixing of petrol and air takes place in the carburettor which is situated outside the engine cylinder. The proportionate mixture is drawn into the cylinder during the suction stroke. In a gas engine also, air and gas is mixed outside the engine cylinder and this mixture enters the cylinder during the suction stroke. In light oil engines the fuel is converted to vapours by a vapouriser which receives heat from the exhaust gases of the engine and their mixture flows towards engine cylinder during suction stroke.

(*b*) **Constant pressure or diesel cycle.** In this cycle only air is drawn in the engine cylinder during the suction stroke, this air gets compressed during the compression stroke and its pressure and temperature increase by a considerable amount. Just before the end of the stroke a metered quantity of fuel under pressure adequately more than that developed in the engine cylinder is injected in the form of fine sprays by means of a fuel injector. Due to very high pressure and temperature of the air the fuel ignites and hot gases thus produced throw the piston downwards and work is obtained. *Heavy oil engines make use of this cycle.*

(*c*) **Dual combustion cycle.** This cycle is also called *semi-diesel cycle*. It is so named because heat is added *partly at constant volume and partly at constant pressure.* In this cycle only air is drawn in the engine cylinder during suction stroke. The air is then compressed in hot combustion chamber at the end of the cylinder during the compression stroke to a pressure of about 26 bar. The heat of compressed air together with heat of combustion chamber ignites the fuel. The fuel is injected into the cylinder just before the end of compression stroke where it ignites immediately. The fuel injection is continued until the point of cut-off is reached. The burning of fuel at first takes place at constant volume and continues to burn at constant pressure during the first part of expansion or working stroke. The field of application of this cycle is heavy oil engines.

2.10. INDICATOR DIAGRAM

An indicator diagram is a graph between pressure and volume ; the former being taken on vertical axis and the latter on the horizontal axis. This is obtained by an instrument known as *indicator*. The indicator diagrams are of two types : (*a*) Theoretical or hypothetical, (*b*) Actual. The theoretical or hypothetical indicator diagram is always longer in size as compared to the actual one, since in the former losses are neglected. The ratio of the area of the actual indicator diagram to the theoretical one is called *diagram factor*.

2.11. FOUR STROKE CYCLE ENGINES

Here follows the description of the four-stroke otto and diesel-cycle engines.

Otto engines. The Otto four stroke cycle refers to its use in petrol engines, gas engines, light oil engines in which the mixture of air and fuel are drawn in the engine cylinder. Since ignition in these engines is due to a spark, therefore they are also called *spark ignition engines*.

The various strokes of a four stroke (Otto) cycle engine are detailed below.

Refer Fig. 2.34.

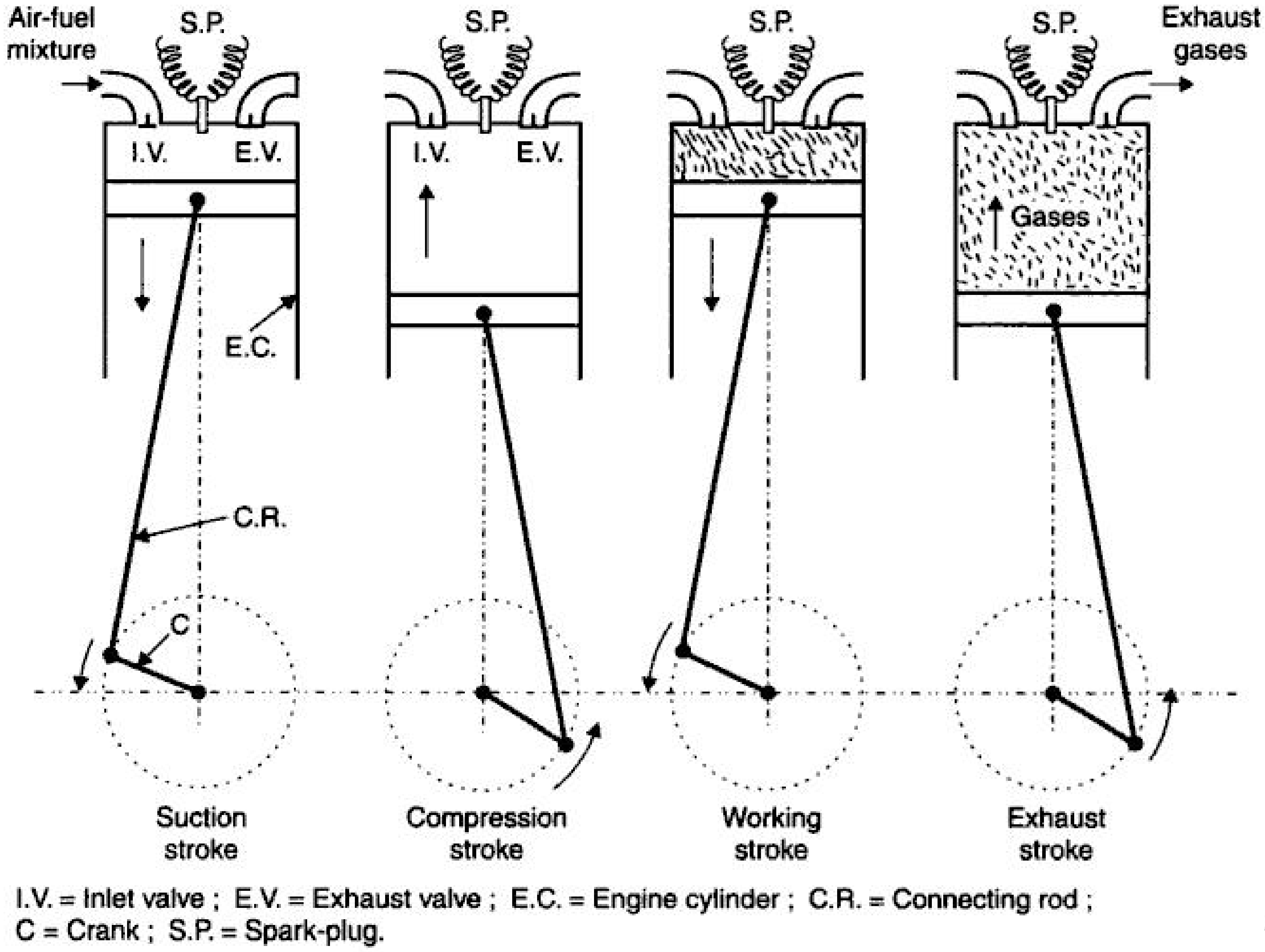


Fig. 2.34. Four stroke Otto cycle engine.

1. **Suction stroke.** During this stroke (also known as *induction stroke*) the piston moves from Top Dead Centre (T.D.C.) to Bottom Dead Centre (B.D.C.) ; the inlet valve opens and proportionate air-fuel mixture is sucked in the engine cylinder. This operation is represented by the line 5–1 (Fig. 2.32). The exhaust valve remains closed throughout the stroke.

2. **Compression stroke.** In this stroke, the piston moves (1–2) towards T.D.C. and compresses the enclosed air-fuel mixture drawn in the engine cylinder during suction stroke. The pressure of the mixture rises in the cylinder to a value of about 8 bar. Just before the end of this stroke the spark-plug initiates a spark which ignites the mixture and combustion takes place at constant volume (line 2–3) (Fig. 2.35). Both the inlet and exhaust valves remain closed during the stroke.

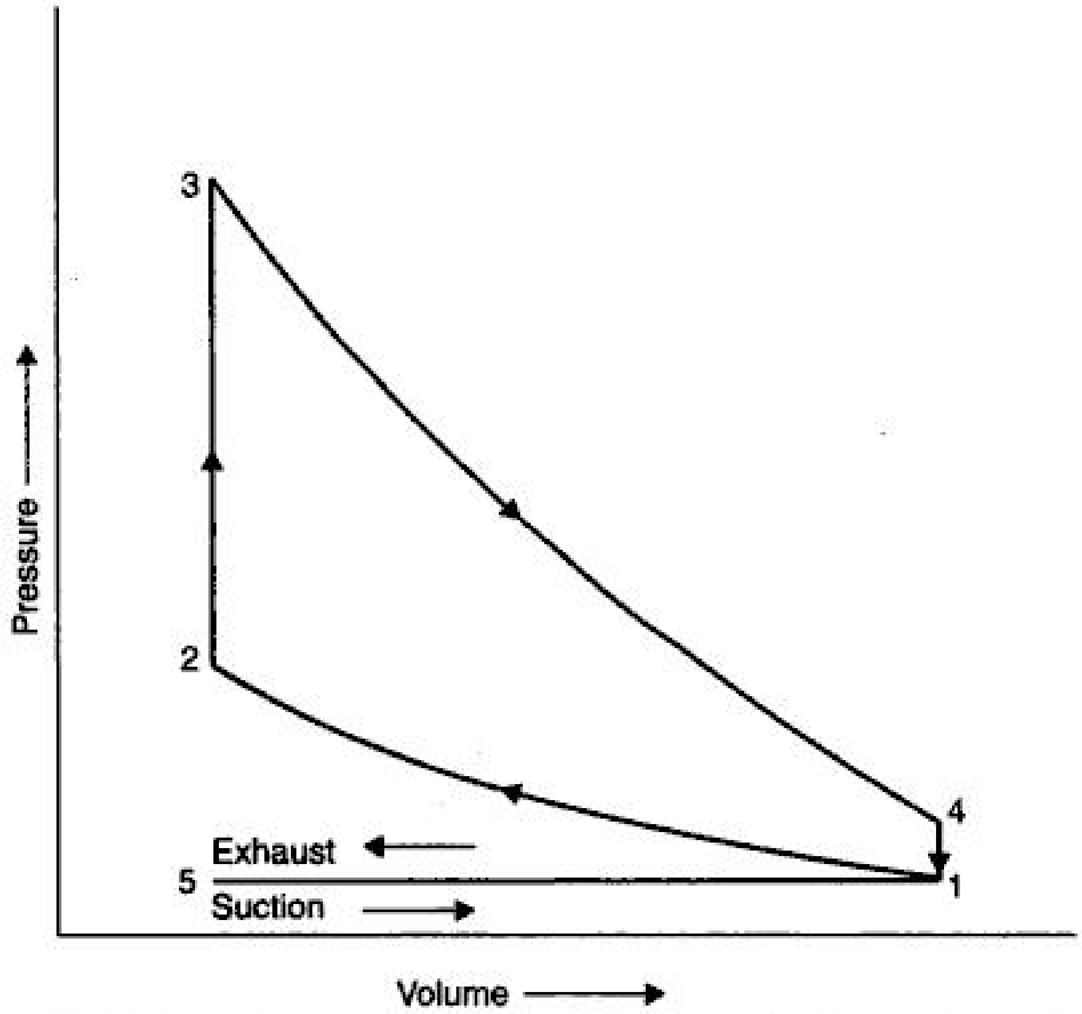


Fig. 2.35. Theoretical p-V diagram of a four stroke Otto cycle engine.

3. **Expansion or working stroke.** When the mixture is ignited by the spark-plug the hot gases are produced which drive or throw the piston from T.D.C. to B.D.C. and thus the work is obtained in this stroke. It is during this stroke when we get work from the engine ; the other three strokes namely suction, compression and exhaust being idle. *The flywheel mounted on the engine shaft stores energy during this stroke and supplies it during the idle strokes.* The expansion of the gases is shown by 3–4 (Fig. 2.35). Both the valves remain closed during the start of this stroke but when the piston just reaches the B.D.C. the exhaust valve opens.

4. **Exhaust stroke.** This is the last stroke of the cycle. Here the gases from which the work has been collected become useless after the completion of the expansion stroke and are made to escape through exhaust valve to the atmosphere. This removal of gas is accomplished during this stroke. The piston moves from B.D.C. to T.D.C. and the exhaust gases are driven out of the engine cylinder ; this is also called *scavenging*. This operation is represented by the line (1-5) (Fig. 2.35).

Fig. 2.36 shows the actual indicator diagram of four stroke Otto cycle engine. It may be noted that line 5-1 is below the atmospheric pressure line. This is due to the fact that owing to restricted area of the inlet passages the entering fuel air mixture cannot cope with the speed of the piston. The exhaust line 4-5 is slightly above the atmospheric pressure line. This is due to restricted exhaust passages which do not allow the exhaust gases to leave the engine-cylinder quickly.

The loop which has area 4-5-1 is called *negative loop* ; it gives the pumping loss due to admission of air-fuel mixture and removal of exhaust gases. The area 1-2-3-4 is the total or gross work obtained from the piston and net work can be obtained by subtracting area 451 from the area 1-2-3-4.

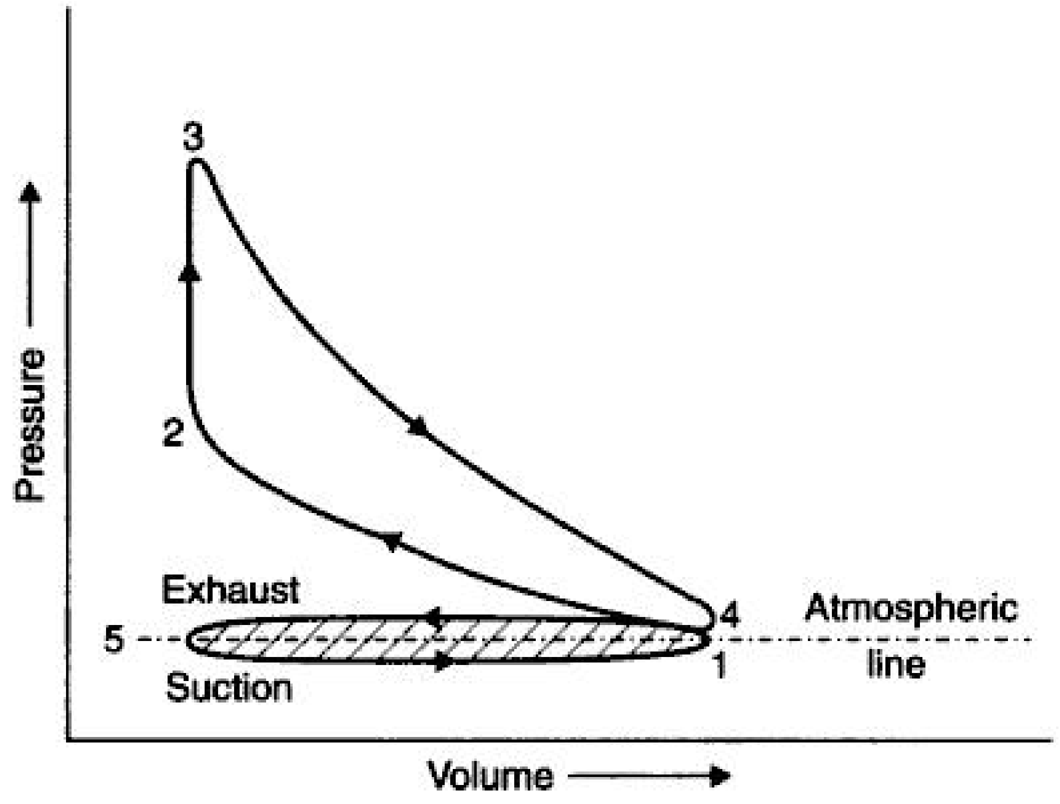


Fig. 2.36. Actual p-V diagram of a four stroke Otto cycle engine.

Diesel engines (four stroke cycle). As is the case of Otto four stroke ; this cycle too is completed in four strokes as follows. (Refer to Fig. 2.37).

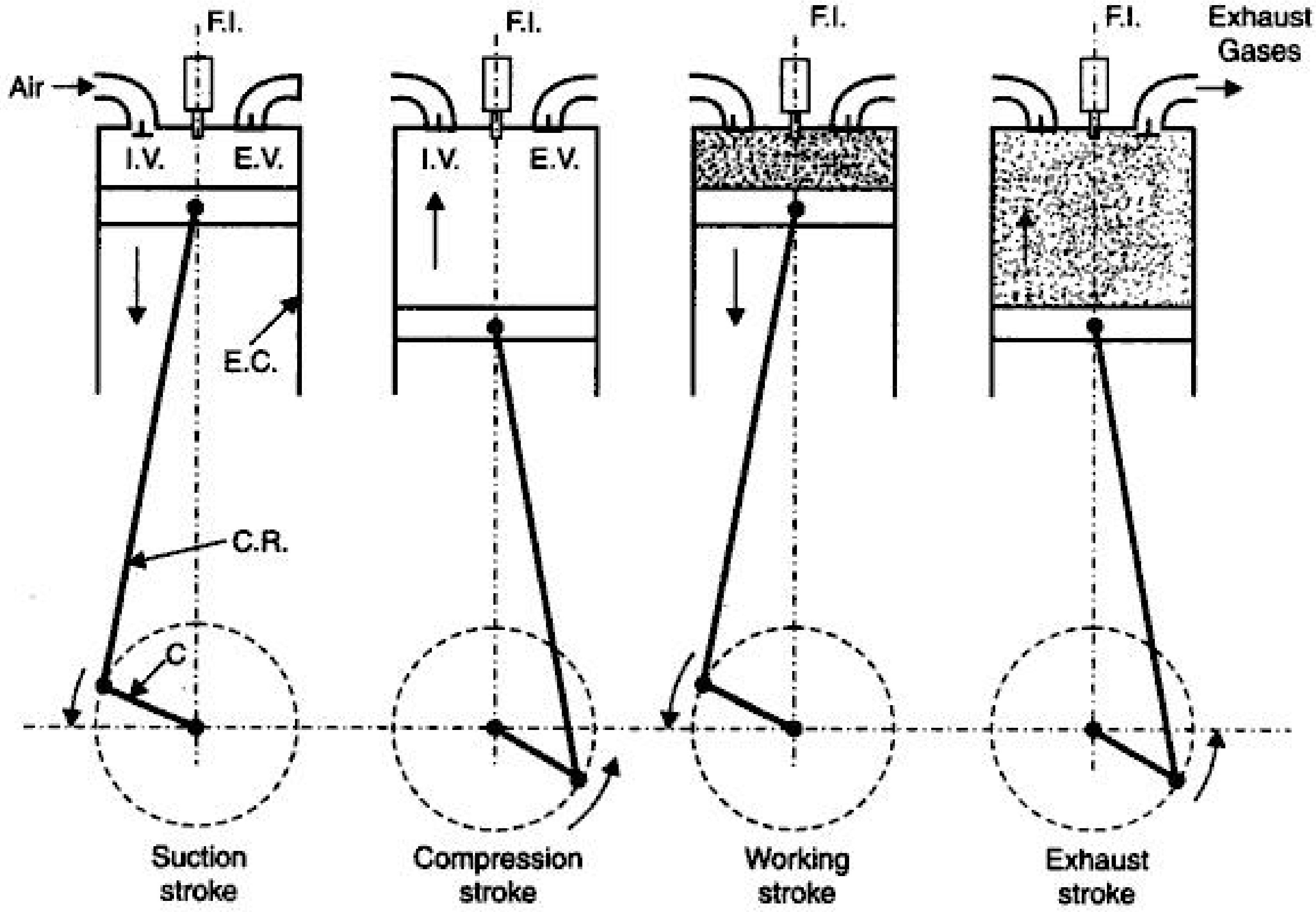


Fig. 2.37. Four stroke Diesel cycle engine.

1. **Suction stroke.** With the movement of the piston from T.D.C. to B.D.C. during this stroke, the inlet valve opens and the air at atmospheric pressure is drawn inside the engine cylinder ; the exhaust valve however remains closed. This operation is represented by the line 5-1 (Fig. 2.38).

2. **Compression stroke.** The air drawn at atmospheric pressure during the suction stroke is compressed to high pressure and temperature (to the value of 35 bar and 600°C respectively) as the piston moves from B.D.C. to T.D.C. This operation is represented by 1-2 (Fig. 2.38). Both the inlet and exhaust valves do not open during any part of this stroke.

3. **Expansion or working stroke.** As the piston starts moving from T.D.C. a metered quantity of fuel is injected into the hot compressed air in fine sprays by the fuel injector and it (fuel) starts burning at constant pressure shown by the line 2-3. At the point 3 *fuel supply is cut off*. The fuel is injected at the end of compression stroke but in actual practice the ignition of the fuel starts before the end of the compression stroke. The hot gases of the cylinder expand adiabatically to point 4, thus doing work on the piston. The expansion is shown by 3-4 (Fig. 2.38).

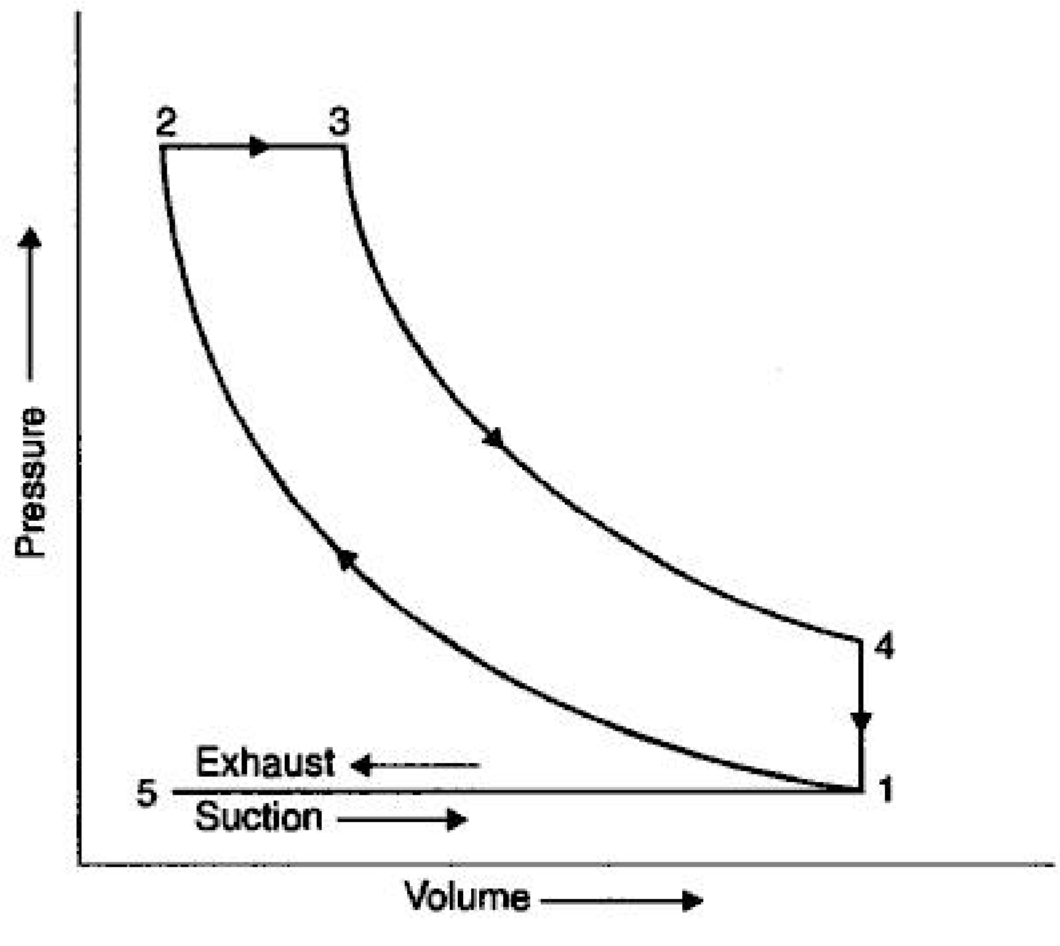


Fig. 2.38. Theoretical p-V diagram of a four stroke Diesel cycle.

4. **Exhaust stroke.** The piston moves from the B.D.C. to T.D.C. and the exhaust gases escape to the atmosphere through the exhaust valve. When the piston reaches the T.D.C. the exhaust valve closes and the cycle is completed. This stroke is represented by the line 1-5 (Fig. 2.38).

Fig. 2.39 shows the actual indicator diagram for a four-stroke Diesel cycle engine. It may be noted that line 5-1 is below the atmospheric pressure line. This is due to the fact that owing to the restricted area of the inlet passages the entering air can't cope with the speed of the piston. The exhaust line 4-5 is slightly above the atmospheric line. This is because of the restricted exhaust passages which do not allow the exhaust gases to leave the engine cylinder quickly.

The loop of area 4-5-1 is called negative loop ; it gives the pumping loss due to admission of air and removal of exhaust gases. The area 1-2-3-4 is the total or gross work obtained from the piston and net work can be obtained by subtracting area 4-5-1 from area 1-2-3-4.

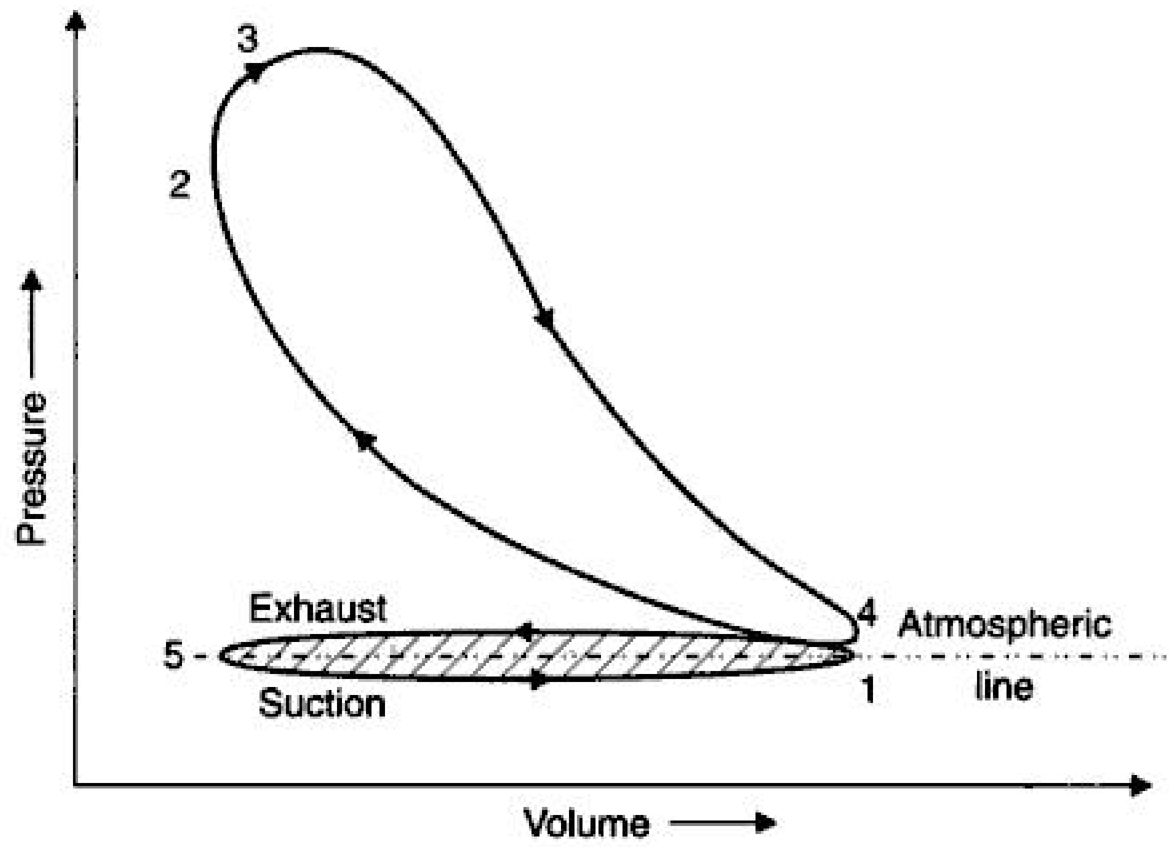


Fig. 2.39. Actual p-V diagram of four stroke Diesel cycle.

Valve Timing Diagrams (Otto and Diesel engines) :

1. **Otto engines.** Fig. 2.40 shows a theoretical valve timing diagram for *four stroke "Otto*

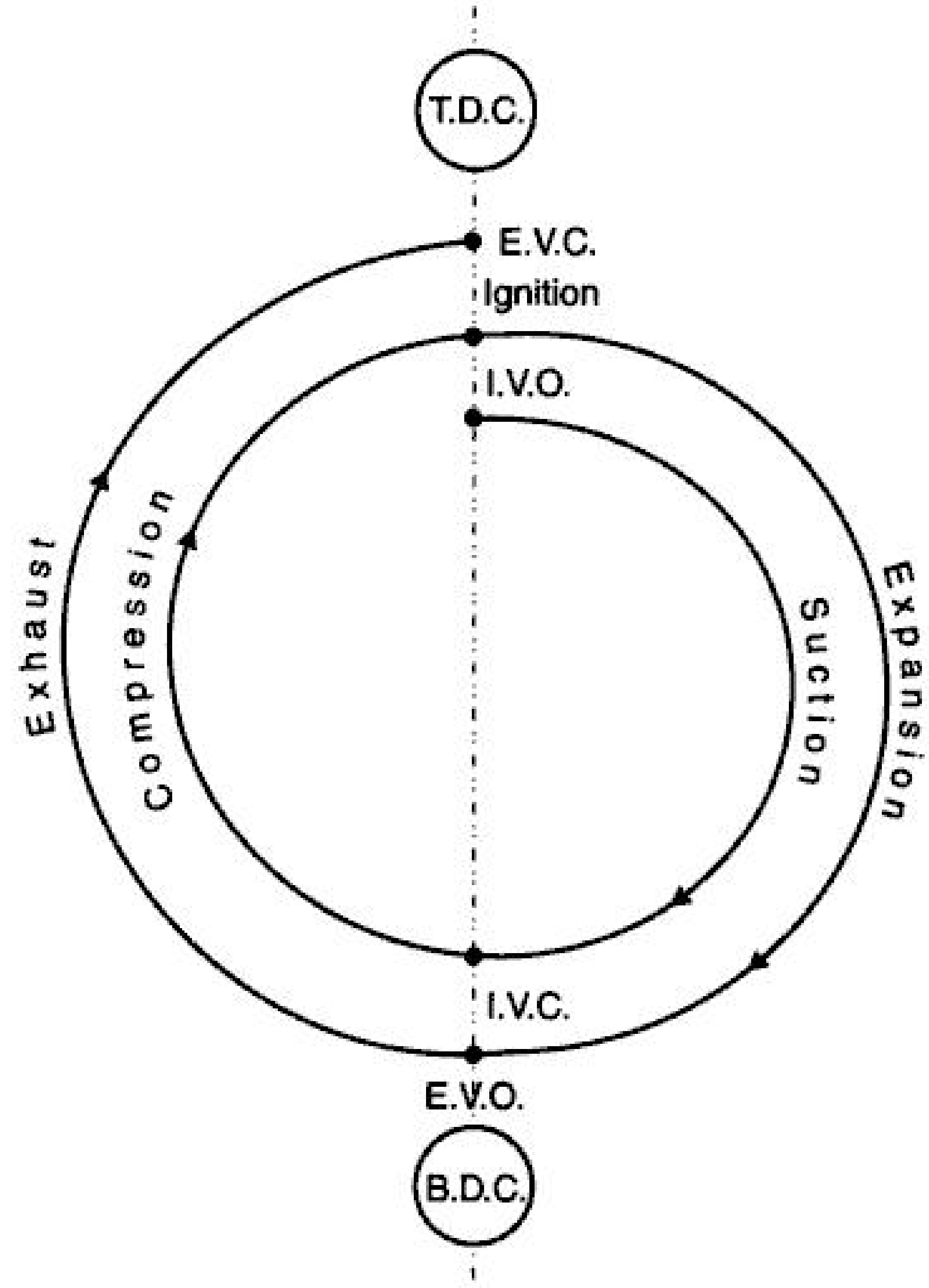


Fig. 2.40. Theoretical valve timing diagram (four stroke Otto cycle engine).

cycle" engine which is self-explanatory. In actual practice, it is difficult to open and close the valve instantaneously ; so as to get better performance of the engine the valve timings are modified. In Fig. 2.41 is shown an actual valve timing diagram. The inlet valve is opened 10° to 30° in advance of the T.D.C. position to enable the fresh charge to enter the cylinder and to help the burnt gases at the same time, to escape to the atmosphere. The suction of the mixture continues up to 30°-40° or even 60° after B.D.C. position. The inlet valve closes and the compression of the entrapped mixture starts.

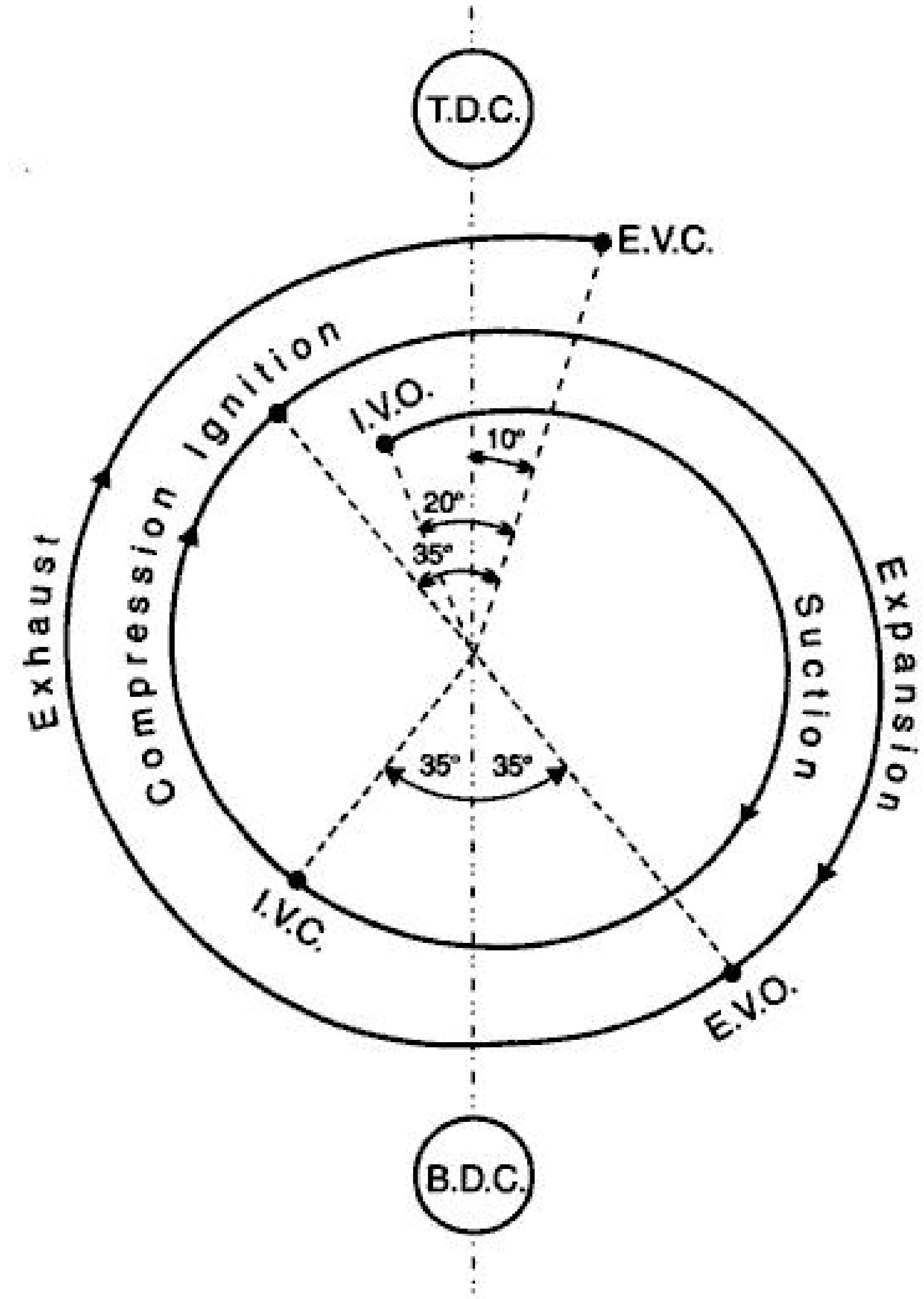


Fig. 2.41. Actual valve timing diagram (four stroke Otto cycle engines).

The sparking plug produces a spark 30° to 40° before the T.D.C. position ; thus fuel gets more time to burn. The pressure becomes maximum nearly 10° past the T.D C. position. The exhaust valve opens 30° to 60° before the B.D.C. position and the gases are driven out of the cylinder by piston during its upward movement. The exhaust valve closes when piston is nearly 10° past T.D.C. position.

2. **Diesel engines.** Fig. 2.42 shows the actual valve timing diagram of a *four stroke "Diesel cycle" engine* (theoretical valve timing diagram, is however the same as Fig. 2.40). Inlet valve opens 10° to 25° in advance of T.D.C. position and closes 25° to 50° after the B.D.C. position. Exhaust valve opens 30° to 50° in advance of B.D.C. position and closes 10° to 15° after the T.D.C. position. The fuel injection takes place 5° to 10° before T.D.C. position and continues up to 15° to 25° near T.D.C. position.

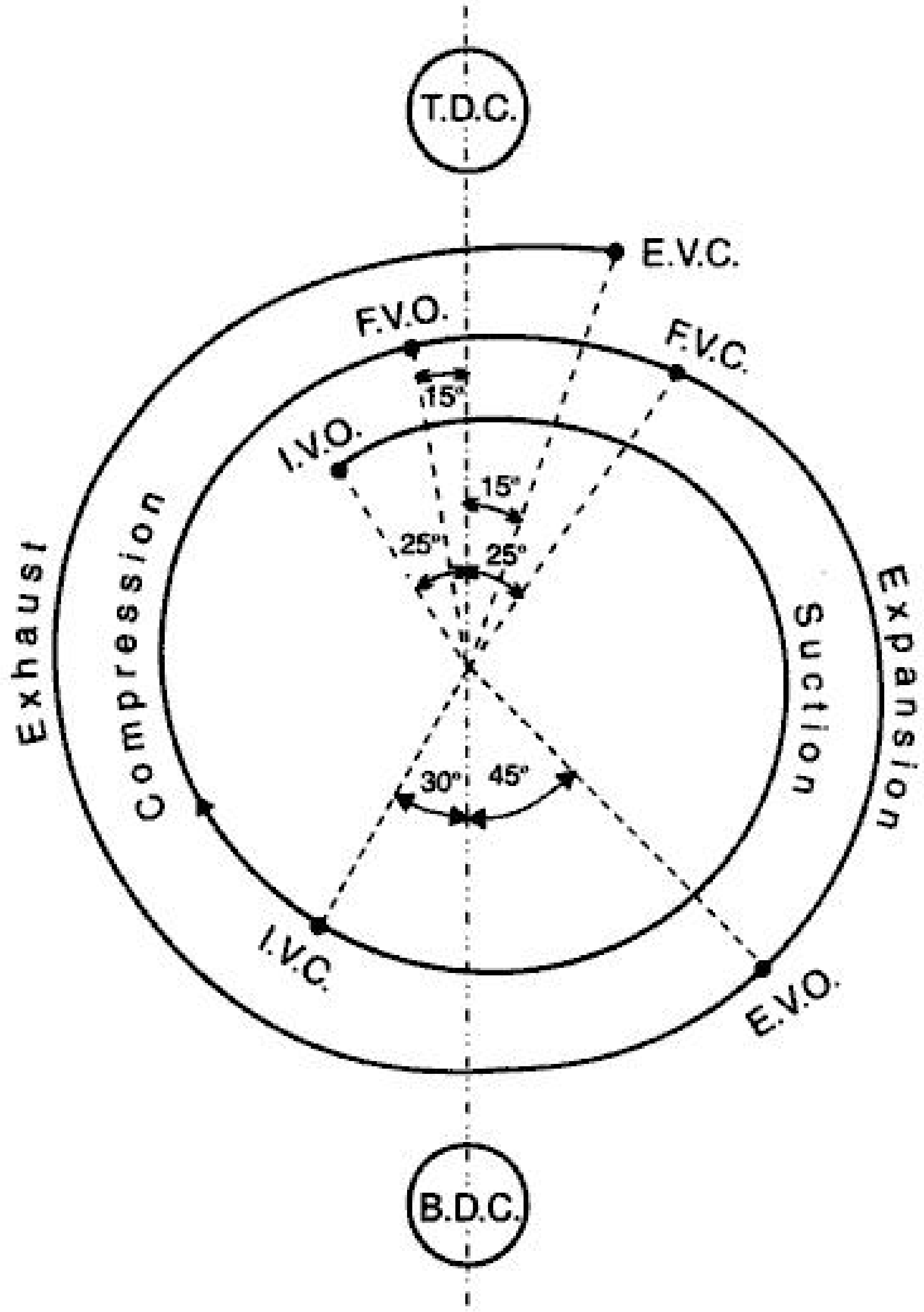


Fig. 2.42. Actual valve timing diagram (four stroke Diesel cycle engines).

2.12. TWO STROKE CYCLE ENGINES

In 1878, Dugald-clerk, a British engineer introduced a cycle which could be completed in two *strokes of piston rather than four strokes* as is the case with the four stroke cycle engines. The engines using this cycle were called two stroke cycle engines. In this engine suction and exhaust strokes are eliminated. Here *instead of valves, ports are used. The exhaust gases are driven out from engine cylinder by the fresh charge of fuel entering the cylinder nearly at the end of the working stroke.*

Fig. 2.43 shows a two stroke petrol engine (used in scooters, motor cycles etc.). The cylinder L is connected to a closed crank chamber C.C. During the upward stroke of the piston M, the gases in L are compressed and at the same time fresh air and fuel (petrol) mixture enters the crank chamber through the valve V. When the piston moves downwards, V closes and the mixture in the crank chamber is compressed. Refer to Fig. 2.43 (*i*), the piston is moving upwards and is compressing an explosive charge which has previously been supplied to L. Ignition takes place at the end of the stroke. The piston then travels downwards due to expansion of the gases (Fig. 2.43 (*ii*)) and near the end of this stroke the piston uncovers the exhaust port (E.P.) and the burnt exhaust gases escape through this port (Fig. 2.43 (*iii*)). The transfer port (T.P.) then is uncovered immediately, and the compressed charge from the crank chamber flows into the cylinder and is deflected upwards by the hump provided on the head of the piston. It may be noted that the incoming air-petrol mixture helps the removal of gases from the engine-cylinder ; if, in case these exhaust gases do not leave the cylinder, the fresh charge gets diluted and efficiency of the engine will decrease. The piston then again starts moving from B.D.C. to T.D.C. and the charge gets compressed when E.P. (exhaust port) and T.P. are covered by the piston ; thus the cycle is repeated.

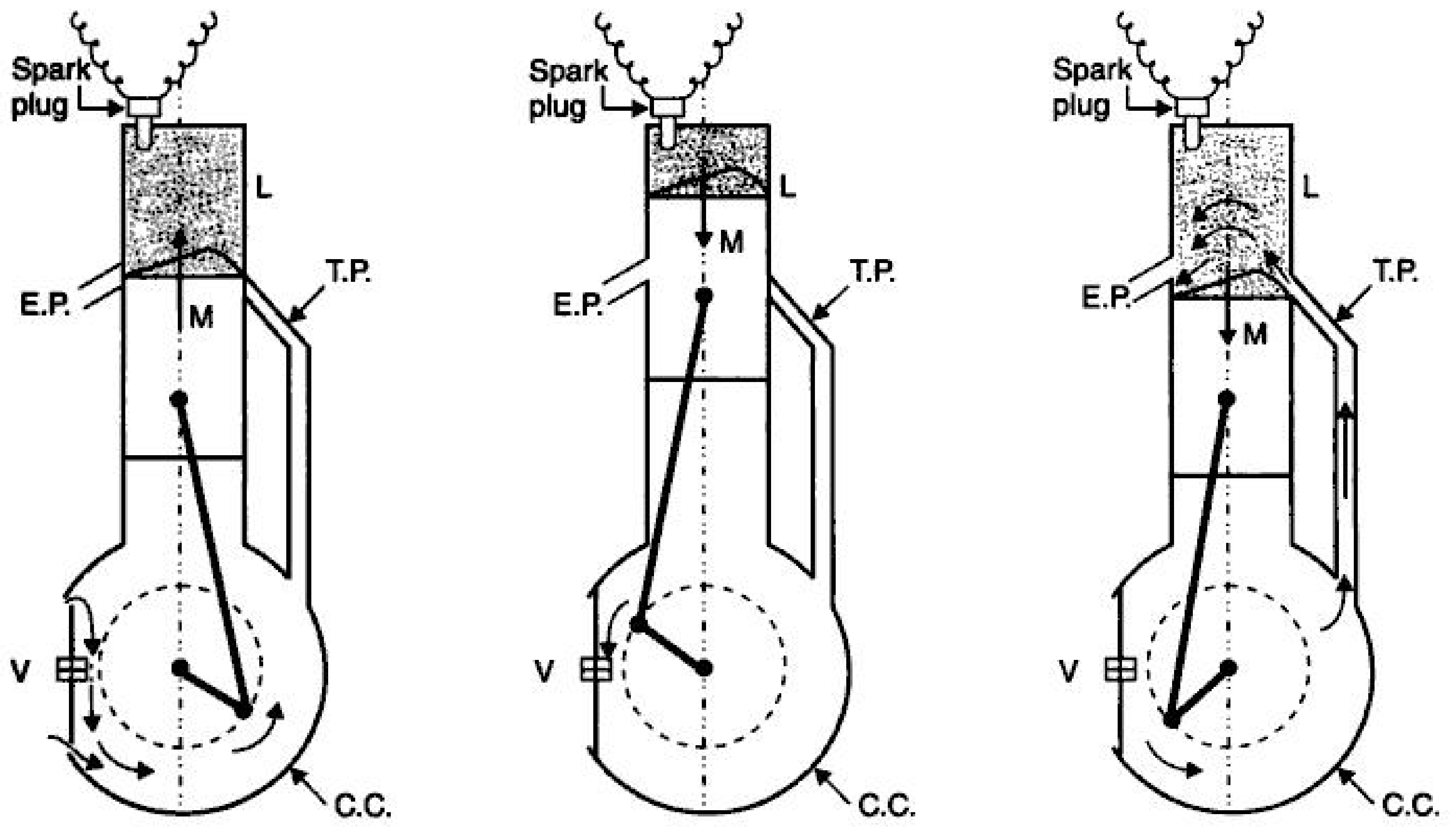


Fig. 2.43. Two stroke cycle engine.

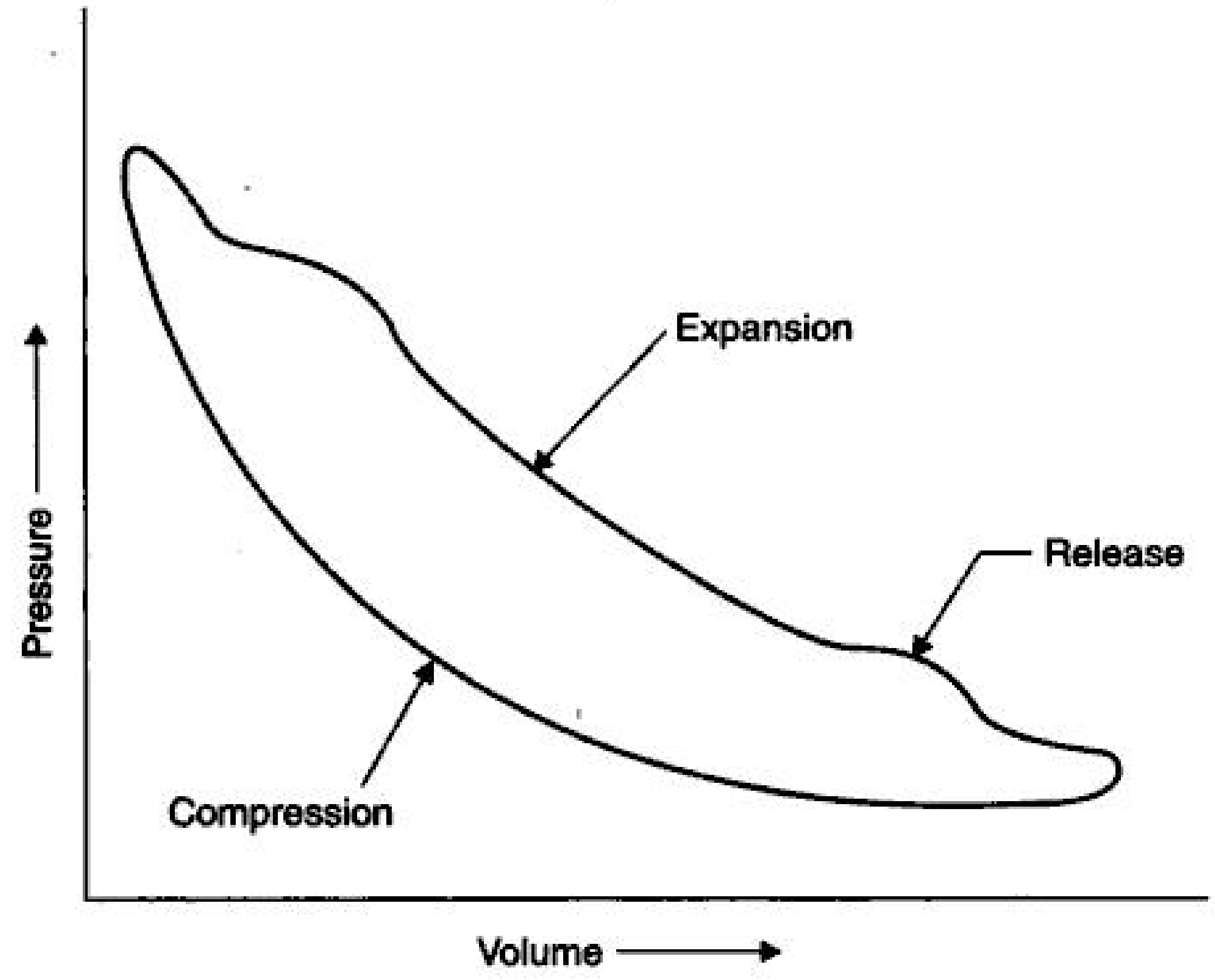


Fig. 2.44. ***p-V*** **diagram for a two stroke cycle engine.**

Fig. 2.44 shows the *p-V* diagram for a two stroke cycle engine. It is only for the main cylinder or the top side of the piston. Fig. 2.45 shows self-explanatory port timing diagram for a two stroke cycle engine.

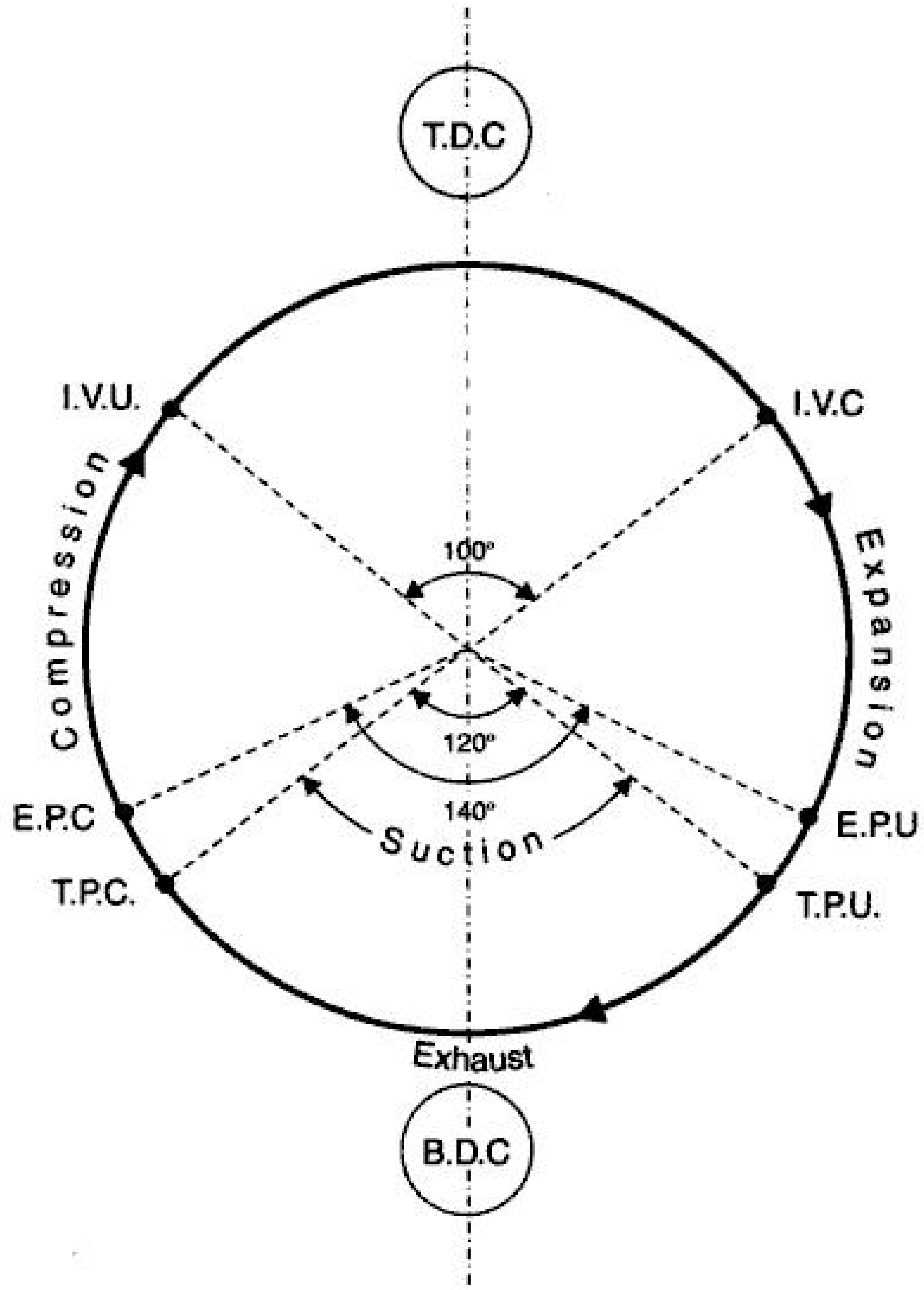


Fig. 2.45. Port timing diagram.

In a two stroke Diesel cycle engine all the operations are the same as in the spark ignition (Otto cycle) engine with the differences ; firstly in this case, only air is admitted into cylinder instead of air-fuel mixture and secondly fuel injector is fitted to supply the fuel instead of a sparking plug.

2.13. INTAKE FOR COMPRESSION IGNITION ENGINES

- *The Compression Ignition (C.I.) engines are operated unthrottled with engine speed and power controlled by the amount of fuel injected during each cycle.* This allows for high volumetric efficiency at all speeds, *with the intake system designed for very little flow restriction of the incoming air.* Further raising the volumetric efficiency is the fact that no fuel is added until late in compression stroke, after air intake is fully completed. In addition many C.I. engines are *turbocharged, which enhances air intake even more.*

- The addition of fuel is made late in the compression stroke, starting somewhere around 20° before T.D.C. Injectors mounted in the cylinder head inject directly into the combustion chamber, where self ignition occurs due to the high temperature of the air caused by compression heating.
- It is important that fuel with the correct cetane number be used in an engine so that self-ignition initiates the start of combustion at the proper cycle position.
- For C.I. engines, the injection pressure must be much higher than that required for S.I. engines. The cylinder pressure into which the fuel is first injected is very high near the end of the compression stroke, due to high compression ratio of C.I. engines. By the time the final fuel is injected, peak pressure during combustion is being experienced. *Pressure must be high enough so that fuel spray will penetrate across the entire combustion chamber.* Injection pressures of 200 bar to 2000 bar are common *with average fuel droplet size generally decreasing with increasing pressure.* Orifice hole size of injectors is typically in the range of 0.2 to 1.0 mm diameter.
- The mass flow rate of fuel ($\dot{m}_f$) through an injector, during injection, is given by the relation :

$$\dot{m}_f = C_D A_n \sqrt{2\rho_f \Delta p} \qquad \text{...(2.1)}$$

The total mass of fuel (m_f) injected into one cylinder during one cycle is given as :

$$m_f = C_D A_n \sqrt{2\rho_f \Delta p}\ (\Delta\theta/360\ N) \qquad \text{...(2.2)}$$

where, C_D = Discharge co-efficient of injector,
A_n = Flow area of nozzle orifice(s),
ρ_f = Density of fuel,
Δp = Pressure differential across injector,
$\Delta\theta$ = Crank angle through which injection takes place (in degrees), and
N = Engine speed.

Again, $$p_{\text{inj.}} \simeq \Delta p \qquad \text{...(2.3)}$$

and, $$p_{\text{inj.}} \simeq N^2 \qquad \text{...(2.4)}$$

(To ensure that the crank angle of rotation through which injection takes place is almost constant for all speeds)

— *Large engines must have very high injection pressure and high spray velocity.*

— *For optimum fuel viscosity and spary penetration, it is important to have fuel at the correct temperature.*

Often engines are equipped with temperature sensors and means of heating or cooling the incoming fuel. *Many large truck engines are equipped with heated fuel filters. This allows the use of cheaper fuel that has less viscosity control.*

— *In small engines more costly, lower viscosity fuel is required.*

2.14. COMPARISON OF FOUR STROKE AND TWO STROKE CYCLE ENGINES

S.No.	Aspects	Four stroke cycle engines	Two stroke cycle engines
1.	*Completion of cycle*	The cycle is completed in *four strokes of the piston* or in *two revolutions of the crankshaft.* Thus one power stroke is obtained in every two revolutions of the crankshaft.	The cycle is completed in *two strokes of the piston* or in *one revolution of the crankshaft.* Thus one power stroke is obtained in each revolution of the crankshaft.

2.	*Flywheel required heavier or lighter*	Because the turning-movement is not so uniform and hence *heavier* flywheel is needed.	More uniform turning movement and hence *lighter* flywheel is needed.
3.	*Power produced for same size of engine*	Again because of one power stroke for two revolutions, power produced for same size of engine is *small* or for the same power the engine is heavy and bulky.	Because of one power stroke for one revolution, power produced for same size of engine is *more* (theoretically twice, actually about 1.8 times) or for the same power the engine is light and compact.
4.	*Cooling and lubrication requirements*	Because of one power stroke in two revolutions *lesser* cooling and lubrication requirements. Lesser rate of wear and tear.	Because of one power stroke in one revolution *greater* cooling and lubrication requirement. Great rate of wear and tear.
5.	*Value and valve mechanism*	The four stroke engine *contains* valve and valve mechanism.	Two stroke engines have *no* valves but only ports (some two stroke engines are fitted with conventional exhaust valves).
6.	*Initial cost*	Because of the heavy weight and complication of valve mechanism, *higher* is the initial cost.	Because of light weight and simplicity due to absence of valve mechanism, *cheaper* in initial cost.
7.	*Volumetric efficiency*	Volumetric efficiency *more* due to more time of induction.	Volumetric efficiency *less* due to lesser time for induction.
8.	*Thermal and part-load efficiencies*	Thermal efficiency higher, part load efficiency better than two stroke cycle engine.	Thermal efficiency lower, part load efficiency lesser than four stroke cycle engine.
9.	*Applications*	Used where efficiency is important ; in *cars, buses, trucks, tractors, industrial engines, aeroplane, power generators etc.*	In two stroke petrol engine some fuel is exhausted during scavenging. Used where (*a*) *low cost*, and (*b*) *compactness and light weight important.* Two stroke (air cooled) petrol engines used in very small sizes only, *lawn movers, scooters motor cycles* (lubricating oil mixed with petrol). Two stroke diesel engines used in *very large sizes* more than 60 cm bore, for *ship propulsion* because of *low weight and compactness.*

2.15. COMPARISON OF SPARK IGNITION (S.I.) AND COMPRESSION IGNITION (C.I.) ENGINES

S.No.	Aspects	S.I. engines	C.I. engines
1.	*Thermodynamic cycle*	Otto cycle	Diesel cycle ...... For slow speed engines. Dual cycle ...... For high speed engines.
2.	*Fuel used*	Petrol	Diesel.

3.	*Air-fuel ratio*	10 : 1 to 20 : 1	18 : 1 to 100 : 1.
4.	*Compression ratio*	upto 11 ; Average value 7 to 9 ; Upper limit of compression ratio fixed by *anti-knock quality of fuel.*	12 to 24 ; Average value 15 to 18 ; Upper limit of compression ratio is limited by *thermal and mechanical stresses.*
5.	*Combustion*	Spark ignition	Compression ignition.
6.	*Fuel supply*	By carburettor ...... cheap method	By injection ...... expensive method.
7.	*Operating pressure*		
	(*i*) Compression pressure	7 bar to 15 bar	30 bar to 50 bar
	(*ii*) Maximum pressure	45 bar to 60 bar	60 bar to 120 bar.
8.	*Operating speed*	High speed : 2000 to 6000 r.p.m.	Low speed : 400 r.p.m. Medium speed : 400 to 1200 r.p.m. High speed : 1200 to 3500 r.p.m.
9.	*Control of power*	Quantity governing ...... by throttle	Quality governing ...... by rack.
10.	*Calorific value*	44 MJ/kg	42 MJ/kg.
11.	*Cost of running*	High	Low.
12.	*Maintenance cost*	Minor maintenance required.	Major overall required but less frequently.
13.	*Supercharging*	Limited by *detonation*. Used only in *aircraft engines.*	Limited by *blower power and mechanical and thermal stresses. Widely used.*
14.	*Two stroke operation*	*Less suitable*, fuel loss in scavenging. But small two stroke engines are used in mopeds, scooters and motorcycles due to their *simplicity and low cost.*	No fuel loss in scavenging. *More suitable.*
15.	*High powers*	No	Yes.
16.	*Distribution of fuel*	A/F ratio is not optimum in multi-cylinder engines.	Excellent distribution of fuel in multi-cylinder engines.
17.	*Starting*	Easy, low cranking effort.	Difficult, high cranking effort.
18.	*Exhaust gas temperature*	High, due to low thermal efficiency.	Low, due to high thermal efficiency.
19.	*Weight per unit power*	Low (0.5 to 4.5 kg/kW).	High (3.3 to 13.5 kg/kW).
20.	*Initial capital cost*	Low	High due to heavy weight and sturdy construction, costly construction, 1.25-1.5 times.
21.	*Noise and vibration*	Less	More idle noise problem.
22.	*Uses*	Mopeds, scooters, motorcycles, simple engine passenger cars, aircrafts etc.	Buses, trucks locomotives, tractors, earth moving machinery and stationary generating plants.

2.16. COMPARISON BETWEEN A PETROL ENGINE AND A DIESEL ENGINE

S.No.	Petrol engine	Diesel engine
1.	Air petrol mixture is sucked in the engine cylinder during suction stroke.	Only air is sucked during suction stroke.
2.	Spark-plug is used.	Employs an injector.
3.	Power is produced by spark ignition.	Power is produced by compression ignition.
4.	Thermal efficiency up to 25%.	Thermal efficiency up to 40%.
5.	Occupies less space.	Occupies more space.
6.	More running cost.	Less running cost.
7.	Light in weight.	Heavy in weight.
8.	Fuel (Petrol) costlier.	Fuel (Diesel) cheaper.
9.	Petrol being volatile is dangerous.	Diesel is non-dangerous as it is non-volatile.
10.	Pre-ignition possible.	Pre-ignition not possible.
11.	Works on Otto cycle.	Works on Diesel cycle.
12.	Less dependable.	More dependable.
13.	Used in *cars* and *motor cycles*.	Used in heavy duty vehicles like *trucks, buses* and *heavy machinery*.

2.17. HOW TO TELL A TWO STROKE CYCLE ENGINE FROM A FOUR STROKE CYCLE ENGINE ?

S.No.	Distinguishing features	Four stroke cycle engine	Two stroke cycle engine
1.	*Oil sump and oil-filter plug*	It has an oil sump and oil-filter plug.	It does not have oil sump and oil-filter plug.
2.	*Oil drains etc.*	It requires oil drains and refills periodically, just an automobile do.	In this type of engine, the oil is added to the gasoline so that a mixture of gasoline and oil passes through the carburettor and enters the crankcase with the air.
3.	*Location of muffler (exhaust silencer)*	It is installed at the head end of the cylinder at the exhaust valve location.	It is installed towards the middle of the cylinder, at the exhaust port location.
4.	*Name plate*	If the name plate mentions the type of oil and the crankcase capacity, or similar data, it is a four stroke cycle engine.	If the name plate tells to mix oil with the gasoline, it is a two stroke cycle engine.

II. Combustion in S.I. Engines

2.18. INTRODUCTION TO COMBUSTION IN S.I. ENGINES

2.18.1. Definition of Combustion

Combustion *may be defined as a relatively rapid chemical combination of hydrogen and carbon in the fuel with the oxygen in the air, resulting in liberation of energy in the form of heat.*

Following conditions are necessary for combustion to take place :

1. A combustible mixture.
2. Some means to initiate combustion.
3. Stabilization and propagation of flame in the combustion chamber.

In spark ignition (S.I.) engines, a carburettor generally supplies a combustible mixture and the electric spark from a spark-plug initiates the combustion.

2.18.2. Ignition Limits

- It has been observed through experiments that ignition of charge is only possible within certain limits of fuel-air ratio.

  The 'ignition limits' correspond approximately to those mixture ratios, at lean and rich ends of the scale, where the heat released by the spark is no longer sufficient to initiate combustion in the neighbouring unburnt mixture.
- Fig. 2.46 shows the ignition limits for hydrocarbons.

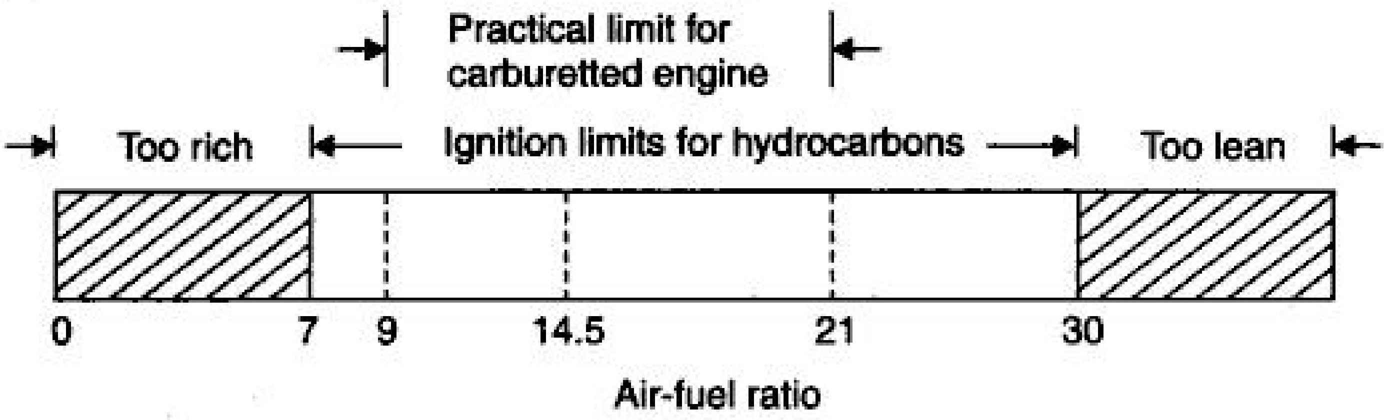


Fig. 2.46. Ignition limits for hydrocarbons.

– The ignition limits are wider at increased temperatures because of *higher rates of reaction and higher thermal diffusivity coefficients of the mixture.*

– The lower and upper limits of ignition of the mixture depend upon the *temperature and mixture ratio.*

– In case of hydrocarbon fuel the stoichiometric air-fuel ratio is about 15 : 1 and the air-fuel ratio lies between about 30 : 1 and 7 : 1.

2.19. COMBUSTION PHENOMENON

2.19.1. Normal Combustion

In a S.I. engine a single intensely high temperature spark passes across the electrodes, leaving behind a thin thread of flame. From this thin thread, combustion spreads to the envelope of mixture immediately surrounding it at a rate which *depends primarily upon the temperature of the flame front itself and to a secondary degree, upon both the temperature and the density of the surrounding envelope.* In the actual engine cylinder, the mixture is not at rest but is in highly turbulent condition. The *turbulence breaks the filament of a flame into a ragged front, thus presenting a far greater area of surface from which heat is being radiated ; hence its advance is speeded up enormously.*

According to Ricardo, the combustion process can be imagined as if developing in the following *two stages* :

(*i*) The growth and development of a self-propagating nucleus of flame (*ignition lag*). This is a *chemical process* and depends upon the following :
- The nature of fuel ;
- The temperature and pressure ;
- The proportion of the exhaust gas ;
- The temperature co-efficient of the fuel *i.e.*, the relationship between temperature and rate of acceleration of oxidation or burning.

(*ii*) The spread of the flame throughout the combustion chamber.

Fig. 2.47 shows the p-θ diagram of a petrol engine :

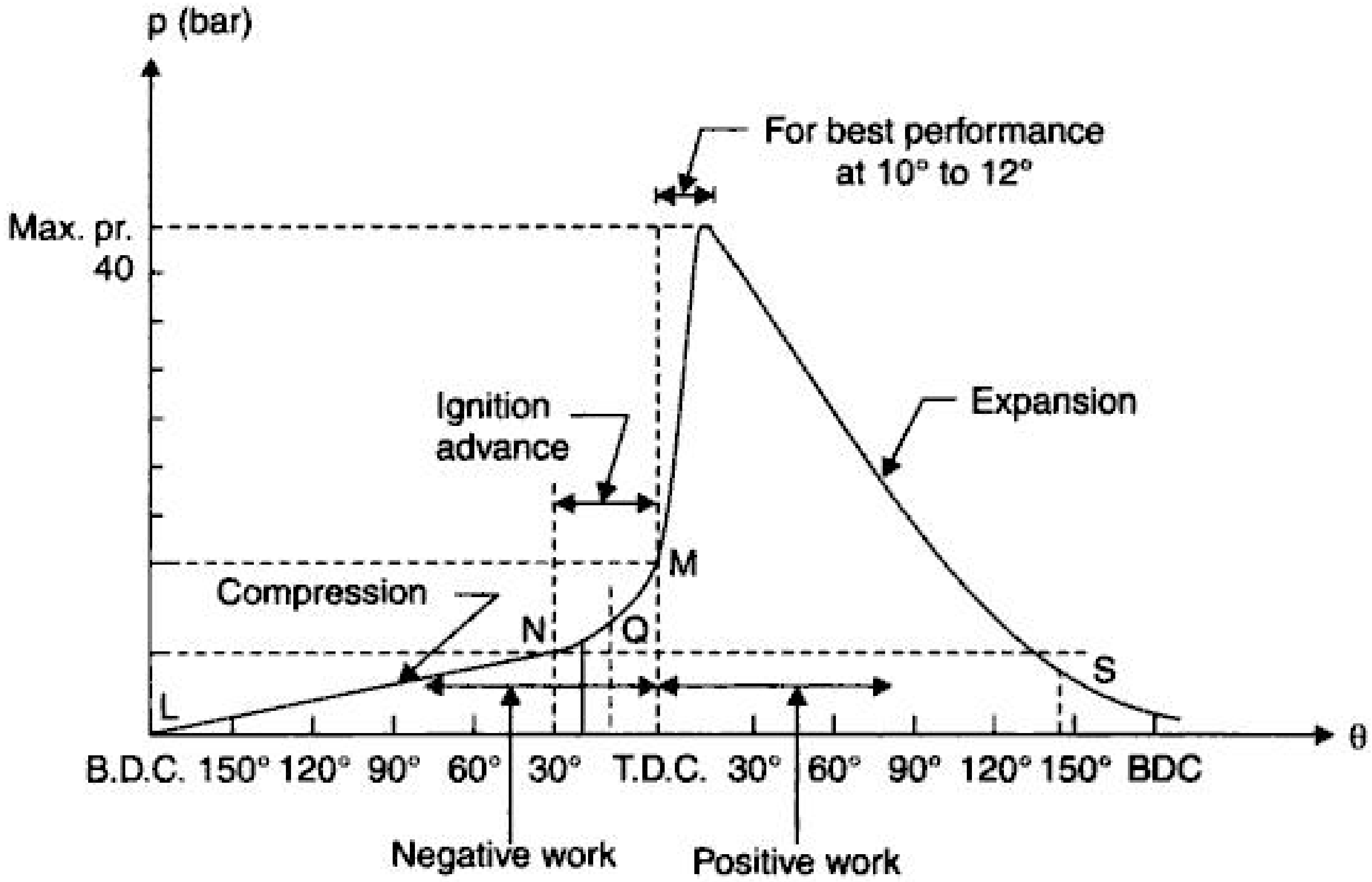


Fig. 2.47. Pressure-crank angle diagram of a petrol engine.

LNQM assumes *compression curve* having *no ignition*.

- First stage of combustion, the *ignition lag*, starts from this point and *no pressure rise is noticeable*.
- *Q* is the point where the *pressure rise can be detected*. From this point it deviates from the simple compression (motoring) curve.
- The time lag between first igniting of fuel and the commencement of the main phase of combustion is called the *period of incubation* or is also known as **ignition lag**. The time is normally about 0.0015 seconds. The maximum pressure is reached at about 12° after top dead centre point. Although the point of maximum pressure marks the completion of flame travel, it does not mean that at this point the whole of the heat of fuel has been liberated, for even after the passage of the flame, some further chemical adjustments due to reassociation, etc., will continue to a greater or less degree throughout the expansion stroke. This is known as ***after burning***.

Effect of engine variables on flame propagation :

1. ***Fuel-air ratio.*** When the *mixture is made leaner or is enriched and still more, the velocity of flame diminishes*.

2. ***Compression ratio.*** The *speed of combustion increases with increase of compression ratio*. The increase in compression ratio results in increase in temperature which increases the tendency of the engine to detonate.

3. ***Intake temperature and pressure.*** *Increase in intake temperature and pressure increases the flame speed.*

4. ***Engine load.*** As the *load on the engine increases,* the cycle pressures increase and hence the flame *speed increases*.

5. ***Turbulence.*** The flame speed is very low in non-turbulent mixture. A turbulent motion of the mixture intensifies the processes of heat transfer and mixing of the burned and unburned portions in the flame front. These two factors cause the *velocity of turbulent flame to increase practically in proportion to the turbulent velocity*.

6. ***Engine speed.*** The *flame speed increases almost linearly with engine speed*. The *crank angle required for flame propagation, which is the main phase of combustion, will remain almost constant at all speeds*.

7. ***Engine size.*** The number of crank degrees required for flame travel will be about the same irrespective of engine size, provided the engines are similar.

2.19.1.1. Factors affecting normal combustions in S.I. engines.

The factors which affect normal combustion in S.I. engines are briefly discussed below :

1. ***Induction pressure.*** As the pressure falls delay period increases and the ignition must be earlier at low pressures. A *vacuum control* may be incorporated.
2. ***Engine speed.*** As speed increases the constant time delay period needs more crank angle and ignition must be earlier. A *centrifugal control* may be employed.
3. ***Ignition timing.*** If ignition is too early the peak pressure will occur too early and work transfer falls. If ignition is too late the peak pressure will be low and work transfer falls. Combustion may not be complete by the time the exhaust valve opens and the valve may burn.
4. ***Mixture strength.*** Although the stoichiometric ratio should give the best results, the effect of dissociation shown in Fig. 2.48 is to make a slightly rich mixture necessary for maximum work transfer.
5. ***Compression ratio.*** An increase in compression ratio increases the maximum pressure and the work transfer.

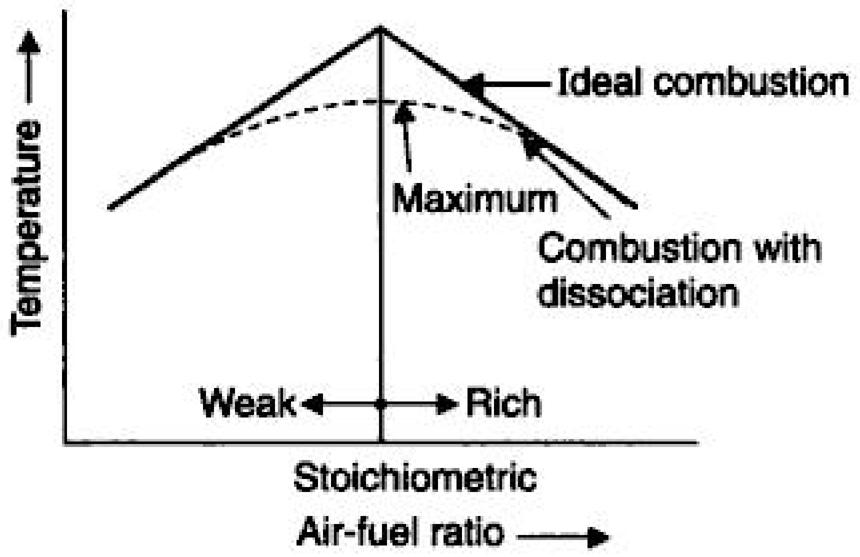


Fig. 2.48

6. **Combustion chamber.** The combustion chamber should be designed to *give a short flame path to avoid knock and it should promote optimum turbulence*.

7. **Fuel choice.**
   - The induction period of the fuel will affect the delay period.
   - The calorific value and the enthalpy of vaporisation will affect the temperatures achieved.

2.19.2. Abnormal Combustion

Due to excessively weak mixtures combustion may be slow or may be mis-timed. This is however obvious.

There are *two combustion abnormalities,* which are less obvious :

- The *first* of these is **pre** or **post ignition** of the mixture by *incandescent carbon particles in the chamber.* This will have the *effect of reducing the work transfer.*
- The *second* abnormality is generally known as *knock* and is a complex condition with many facets. A simple explanation shows that knock occurs when the unburnt portion of the gas in the combustion chamber is heated by combustion and radiation so that *its temperature becomes greater than the self ignition temperature. If normal progressive combustion is not completed before the end of the induction period then a simultaneous explosion of the unburnt gas will occur.* This explosion is accompanied by a detonation (pressure) wave which will be repeatedly reflected from the cylinder walls setting up a high frequency resonance which gives an audible noise. The detonation wave causes excessive stress and also destroys the thermal boundary layer at the cylinder walls causing overheating.

[**Note.** Refer to articles 2.22 and 2.23 for details of pre-ignition and detonation respectively.]

2.20. EFFECT OF ENGINE VARIABLES ON IGNITION LAG

Ignition lag (the time lag between first igniting of fuel and the commencement of the main phase of combustion) is not a period of inactivity but is a chemical process. The ignition lag in terms of crank angles is 10° to 20° and in terms of time, 0.0015 second or so.

The duration of ignition lag depends on the following factors :

1. **Fuel.** Ignition lag depends on chemical nature of fuel. The *higher the Self Ignition Temperature (S.I.T.) of fuel, longer the ignition lag.*
2. **Mixture ratio.** Ignition lag is the *smallest for the mixture ratio which gives the maximum temperature.* This mixture ratio is *somewhat richer than stoichiometric ratio.*
3. **Initial temperature and pressure.** Ignition lag is *reduced if the initial temperature and pressure are increased* (and these can be increased by increasing the compression ratio).
4. **Turbulence.** *Ignition lag is not much affected by the turbulence.*

2.21. SPARK ADVANCE AND FACTORS AFFECTING IGNITION TIMING

Spark advance. In order to obtain maximum power from an engine, the compressed mixture must deliver its maximum pressure at a time when the piston is about to commence its outward stroke and is nearest to T.D.C. Since there is a time lag between the occurrence of spark and the burning of the mixture, the *spark must take place before the piston reaches T.D.C. on its compression stroke, i.e.,* the *spark timing is advanced.* Usually the spark should occur at about 15° before T.D.C.

The correct instant for the introduction of spark is mainly determined by the **"ignition lag"**. The *factors affecting the ignition timings* are discussed as follows :

1. **Engine speed.** Suppose an engine has an ignition advance of θ degrees and operating speed in n r.p.s. Then time available for initiation of combustion is $\frac{\theta}{360n}$ seconds. Now if the engine speed is increased to $2n$ r.p.s. then in order to have the same time available for combustion, an ignition advance for 2θ degrees is required. Thus as the engine speed is *increased,* it will be necessary to advance the ignition progressively.

2. **Mixture strength.** In general *rich mixtures burn faster.* Hence, if the engine is operating with rich mixtures the optimum spark timings must be *retarded, i.e.,* the number of crank angle before T.D.C. at the time of ignition is *decreased* and the spark occurs *closer to T.D.C.*

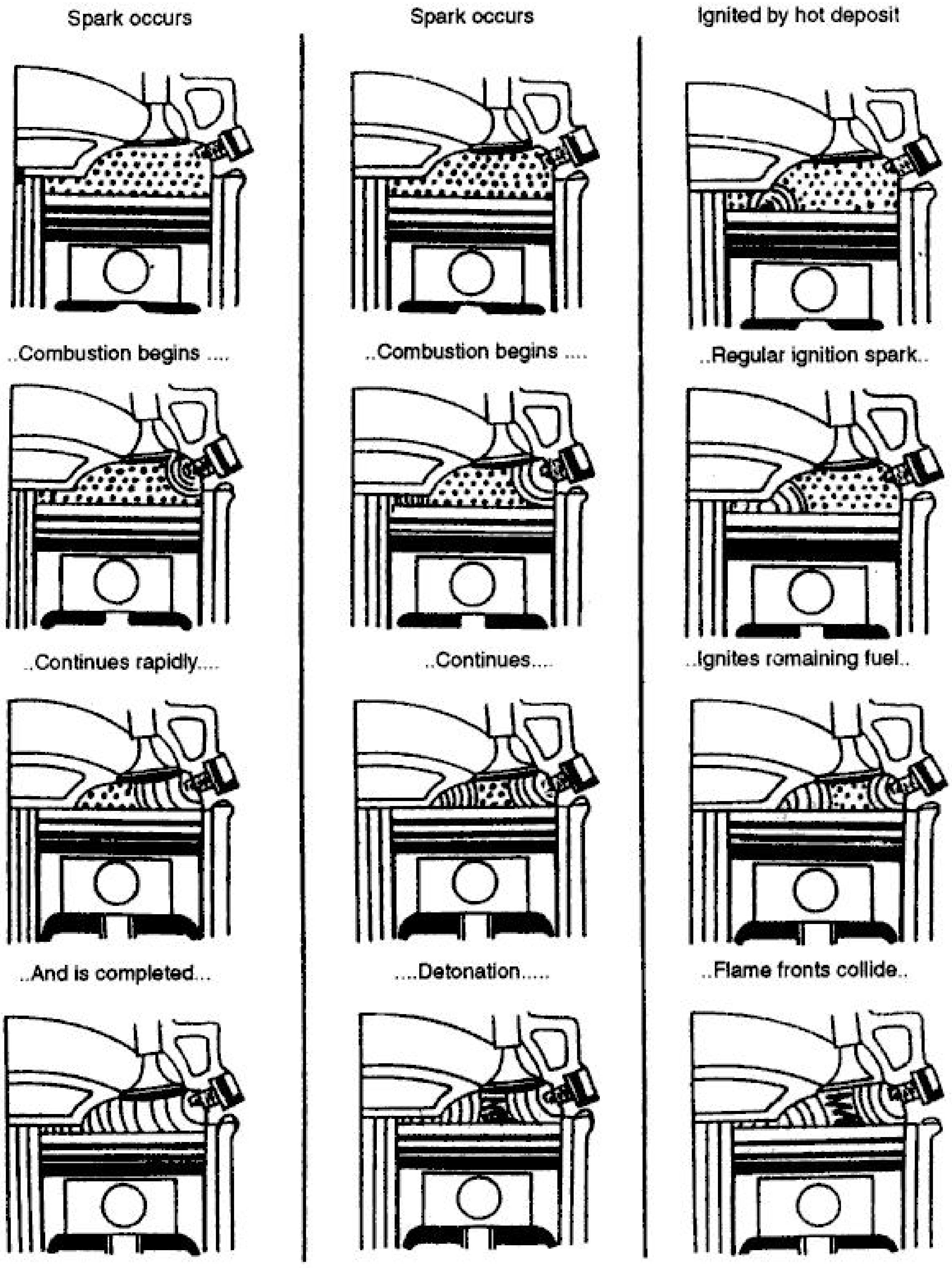
3. **Part-load operation.** Part-load operation of a spark-ignition engine is affected by throttling the incoming charge. Due to throttling a small amount of charge enters the cylinder, and the dilution due to residual gases is also greater. In order to overcome the problem of exhaust gas dilution and the low charge density, at part-load operation the *spark advance must be increased.*

4. **Type of fuel.** Ignition delay will depend upon the type of fuel used in the engine. For *maximum power and economy a slow burning fuel needs a higher spark advance than a fast burning fuel.*

2.22. PRE-IGNITION

Refer to Fig. 2.49.

- **Pre-ignition** is *the ignition of the homogeneous mixture in the cylinder, before the timed ignition spark occurs, caused by the local overheating of the combustible mixture.* For premature ignition of any local hot-spot to occur in advance of the timed spark on the combustion stroke it must attain a minimum temperature of something like 700–800°C.
- Pre-ignition is *initiated by some overheated projecting part such as the sparking plug electrodes, exhaust valve head, metal corners in the combustion chamber, carbon deposits or protruding cylinder head gasket rim etc.*
  - However, *pre-ignition is also caused by persistent detonating pressure shockwaves* scoring away the stagnant gases which normally protect the combustion chamber walls. The resulting increased heat flow through the walls, raises the surface temperature of any protruding poorly cooled part of the chamber, and this therefore provides a focal point for pre-ignition.
- The initiation of ignition and the propagation of the flame front from the heated hot-spot is similar to that produced by the spark-plug when it fires, the only difference between the hot-spot and spark-plug is their respective *instant of ignition.* Thus, the sparking-plugs provides a timed and controlled moment of ignition whereas the heated surface forming the hot-spot builds upto the ignition temperature during each compression stroke and therefore the *actual instant of ignition is unpredicable.*
- The early ignition created by pre-ignition extends the total time and the burnt gases remain in the cylinder and therefore *increases the heat transfer on the chamber walls, as a result, the self-ignition temperature will occur earlier and earlier on each successive compression stroke.* Consequently, the peak cylinder pressure (which normally occurs at its optimum position of 10°–15° after T.D.C.) will progressively *advance* its position to T.D.C. where the cylinder pressure and temperature will be maximised.



A B C

(A) Normal combustion, (B) Detonation, (C) Pre-ignition

Fig. 2.49

— The accumulated effects of an extended combustion time and rising peak cylinder pressure and temperature cause the self-ignition temperature to creep further and further ahead of T.D.C., and with it, peak cylinder pressure, which will now take place before T.D.C. so that **negative work** *will be done in compressing the combustion products* (Fig. 2.50).

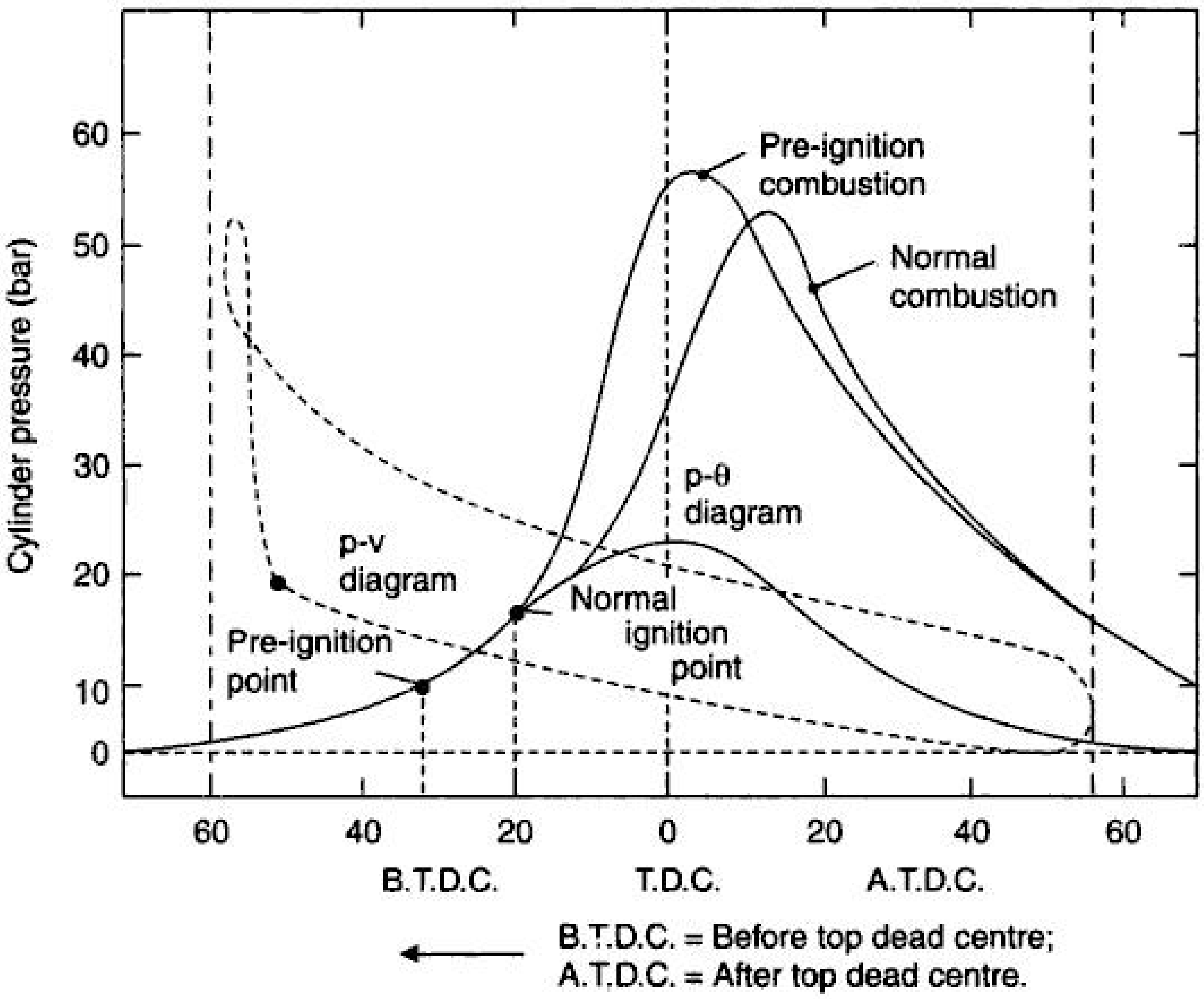


Fig. 2.50. Cylinder pressure variation when pre-ignition occurs.

Effects of pre-ignition :

1. It increases the tendency of detonation in the engines.

2. Pre-ignition is a serious type of abnormal combustion. It increases the heat transfer to the cylinder walls because high temperature gases remain in contact with the cylinder for a longer period. The load on the crankshaft during compression is abnormally high. This may *cause crank failure*.

3. Pre-ignition in a single-cylinder engine will result in a *steady reduction in speed and power output*.

4. The *real undesirable effects of pre-ignition are when it occurs only in one or more cylinders in a multi-cylinder engine*. Under these conditions, when the engine is driven hard, the unaffected cylinders will continue to develop their full power and speed, and so will drag the other piston or pistons, which are experiencing pre-ignition and are producing negative work, to and fro until *eventually the increased heat generated makes the pre-igniting cylinders' pistons and rings sieze*.

— Thus, the danger of the majority of cylinders operating efficiently while one or more cylinders are subjected to excessive pre-ignition is that the driver will only be aware of a loss in speed and power and therefore may try to work the engine harder to compensate for this, which only *intensifies the pre-ignition situation until siezure occurs*.

The following points are *worth noting* :

1. Pre-ignition is not responsible for abnormally high cylinder pressure, but there can be a slight pressure rise above the normal due to the ignition point and, therefore, the peak pressure creeping forward to the T.D.C. position where maximum pressure occurs.

2. If pre-ignition occurs at the same time as the timed sparking plug fires, combustion will appear as normal. Therefore, if ignition is switched-off, the engine would continue to operate at the same speed as if it were controlled by the conventional timed spark, provided the self-ignition temperature continues to occur at the same point.

3. *Over-heated spark-plugs and exhaust valves which are the main causes of pre-ignition should be carefully avoided in the engines.*

Tests for pre-ignition

- *The standard test for pre-ignition is to shut-off the ignition. If the engine still fires, it is assumed that pre-ignition was taking place when the ignition was on.* Experience shows that this assumption is not always valid. *Sudden loss of power with no evidence of mechanical malfunctioning is fairly good evidence of pre-ignition.*
- The *best proof of pre-ignition is the appearance of an indicator card taken with a high speed indicator of the balanced-pressure type.*

2.23. DETONATION

2.23.1. Introduction

At present the amount of power that can be developed in the cylinder of a petrol engine is *fixed by the liability of a fuel to detonate, i.e.*, just before the flame has completed its course across the combustion chamber and remaining unburnt charge fires throughout its mass spontaneously without external assistance.

The result is a tremendously rapid and local increase in pressure which sets up pressure waves that hit the cylinder walls with such violence that the walls emit a sound like a '*ping*'. It is the ping that manifests detonation. *Thus a very sudden rise of pressure during combustion accompanied by metallic hammer like sound is called* **detonation.**

The region in which detonation occurs is farthest removed from the sparking plug, and is named the "detonation zone" and even with severe detonation this zone is rarely more than one quarter the clearance volume.

2.23.2. Process of Detonation or Knocking

- The process/phenomenon of detonation or knocking may be explained by referring to the Fig. 2.51, which shows the cross-section of the combustion chamber with flame advancing from the spark plug location *A*. The advancing flame front compresses the end charge *BB'D* farthest from the spark plug, thus raising its temperature. The temperature of the end charge also increases due to heat transfer from the hot advancing flame front. Also some preflame oxidation may take place in end charge leading to further increase in its temperature.

  If the end charge *BB'D* reaches its auto-ignition temperature and remains for some time to complete the preflame reactions, the charge will autoignite leading to *knocking combustion*. During the preflame reaction period the flame front could move from *BB'* to *CC'*, and the knock occurs due to auto-ignition of the charge ahead of *CC'*. Here we have combustion unaccompanied by flame, producing a very high rate of pressure rise.

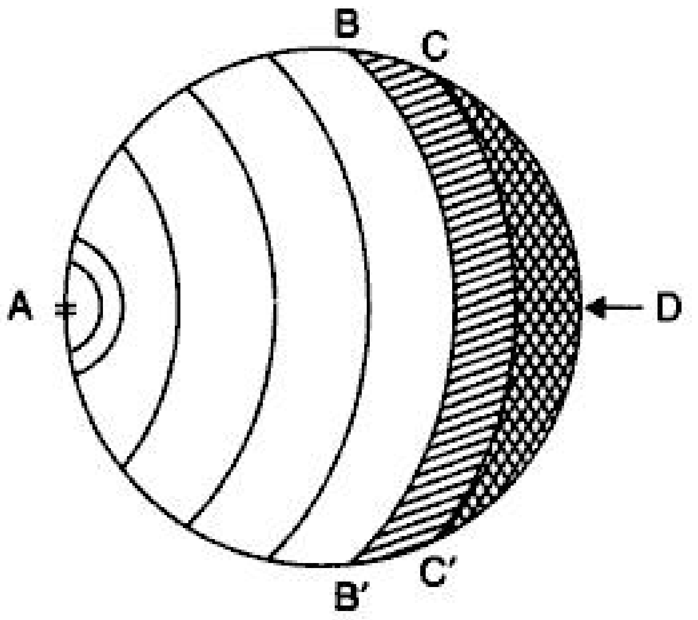


Fig. 2.51. Combustion with knocking.

- The pressure-time diagram of detonating combustion in S.I. engines is drawn and labelled below :

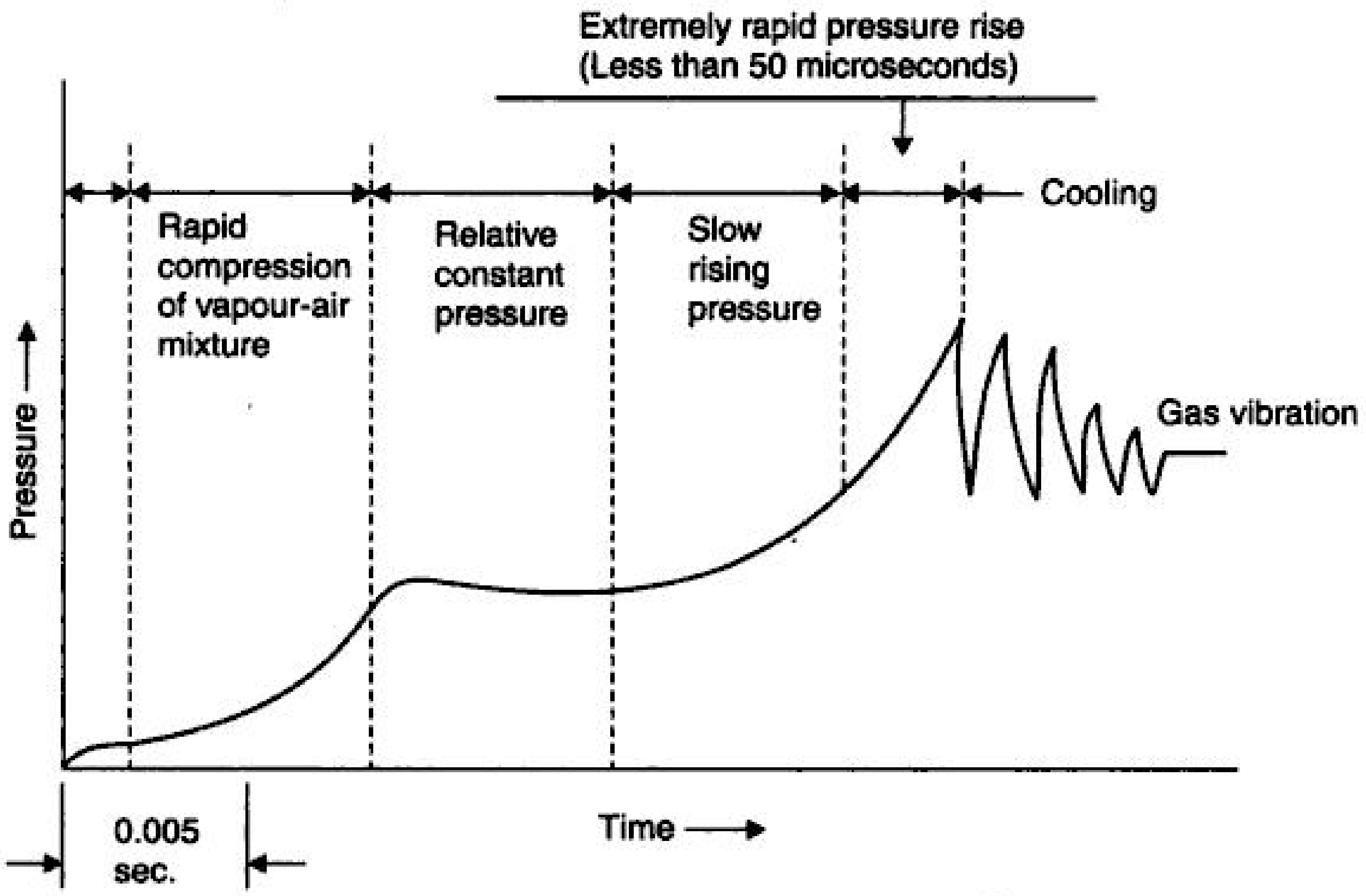


Fig. 2.52

- The *'intensity of detonation'* will depend mainly upon the *amount of energy contained in the 'end-mixture' and the rate of chemical reaction which releases it in the form of heat and a high intensity pressure-wave.* Thus, the earlier in the combustion process the detonation commences, the more unburnt end-mixture will be available to intensify the detonation. As little as 5 per cent of the total mixture charge when spontaneously ignited will be sufficient to produce a very violent knock.

2.23.3. Theories of Detonation :

There are two general theories of knocking/detonation :

(*i*) *The auto-ignition theory.*

(*ii*) *The detonation theory.*

(*i*) **Auto-ignition theory.** Auto-ignition refers to initiation of combustion without the necessity of a flame. The auto-ignition theory of knock assumes that the flame velocity is *normal* before the onset-of auto-ignition and that gas vibrations are created by a number of end-gas elements auto-igniting almost simultaneously.

(*ii*) **Detonation theory.** In the auto-ignition theory, it is assumed that the flame velocity is normal before the onset of auto-ignition whereas in detonation theory a true *detonating wave* formed by preflame reactions has been proposed as the mechanism for explosive auto-ignition. Such a shock wave would travel through the chamber at about twice the sonic velocity and would compress the gases to pressures and temperatures where the reaction should be practically instantaneous.

In fact knocking or detonation is a complex phenomenon and no single explanation may be sufficient to explain it fully.

2.23.4. Effects of Detonation

1. Noise and roughness.
2. Mechanical damage.
3. Carbon deposits.
4. Increase in heat transfer.
5. Decrease in power output and efficiency.
6. Pre-ignition.

Control of detonation :

The detonation can be controlled or even stopped by the following *methods* :

1. Increasing engine r.p.m.
2. Retarding spark.
3. Reducing pressure in the inlet manifold by throttling.
4. Making the ratio too lean or too rich, preferably latter.
5. ***Water injection.*** Water injection increases the delay period as well as reduces the flame temperature.
6. Use of high octane fuel can eliminate detonation. High octane fuels are obtained by adding additives known as dopes (such as tetra-ethyl lead, benzol, xylene etc.), to petrol.

Fig. 2.49 shows normal combustion, detonation and pre-ignition.

2.23.5. Factors Affecting Detonation/Knocks :

The likelihood of knock is increased by any reduction in the induction period of combustion and any reduction in the progressive explosion flame velocity. Particular factors are listed below :

1. **Fuel choice.** A low self-ignition temperature promotes knock.

2. **Induction pressure.** Increase of pressure decreases the self-ignition temperature and the induction period. Knock will tend to occur *at full throttle*.

3. **Engine speed.** Low engine speeds will give low turbulence and low flame velocities (combustion period is constant in angle) and knock may occur at low speed.

4. **Ignition timing.** *Advanced ignition timing* increases peak pressures and *promotes* knock.

5. **Mixture strength.** *Optimum mixture strength* gives high pressures and *promotes* knock.

6. **Compression ratio.** *High compression ratios* increase the cylinder pressures and *promotes* knock.

7. **Combustion chamber design.** Poor design gives long flame paths, poor turbulence and insufficient cooling all of which *promote* knock.

8. **Cylinder cooling.** *Poor cooling* raises the mixture temperature and *promotes* knock.

2.24. PERFORMANCE NUMBER (PN)

Performance number is a *useful measure of detonation tendency*. It has been developed from the conception of knock limited indicated mean effective pressure (*klimep*), when inlet pressure is used as the dependent variable.

$$\text{Performance number (PN)} = \frac{\textit{klimep} \text{ of test fuel}}{\textit{klimep} \text{ of iso-octane}}$$

The performance number is *obtained on specified engine, under specified set of conditions by varying the inlet pressure.*

2.25. HIGHEST USEFUL COMPRESSION RATIO (HUCR)

The **highest useful compression ratio** *is the highest compression ratio employed at which a fuel can be used in a specified engine under specified set of operating conditions, at which detonation first becomes audible with both the ignition and mixture strength adjusted to give the highest efficiency.*

2.26. COMBUSTION CHAMBER DESIGN—S.I. ENGINES

Engine torque, power output and fuel consumption are profoundly influenced by the following :

(*i*) Engine compression ratio.

(*ii*) Combustion chamber and piston crown shape.

(*iii*) The number and size of the inlet and exhaust valves.

(*iv*) The position of the sparking-plug.

The following are the objects of good combustion chamber design :

1. *To optimize the filling and emptying of the cylinder with fresh unburnt charge respectively over the engine's operating speed range.*

2. *To create the condition in the cylinder for the air and fuel to be thoroughly mixed and then excited into a highly turbulent state so that the burning of the charge will be completed in the shortest possible time.*

3. *To prevent the possibility of detonation at all times, as far as possible.*

In order to achieve these fundamental requirements it is imperative to be aware of the *factors that contribute towards inducing the charge to enter the cylinder, to mix intimately, to burn both rapidly and smoothly and to expel the burnt gases.*

2.26.1. Induction Swirl

Refer to Fig. 2.53.

- ***Swirl*** *is the rotational flow of charge within the cylinder about* its axis.

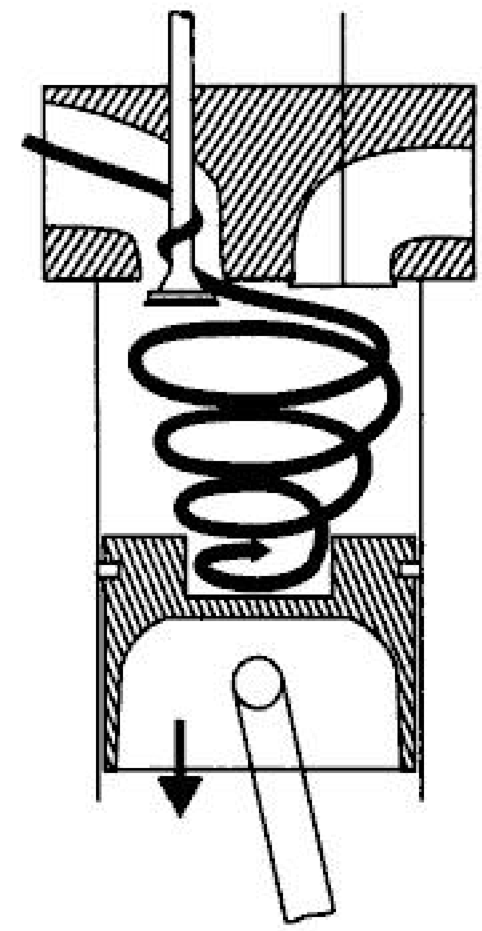
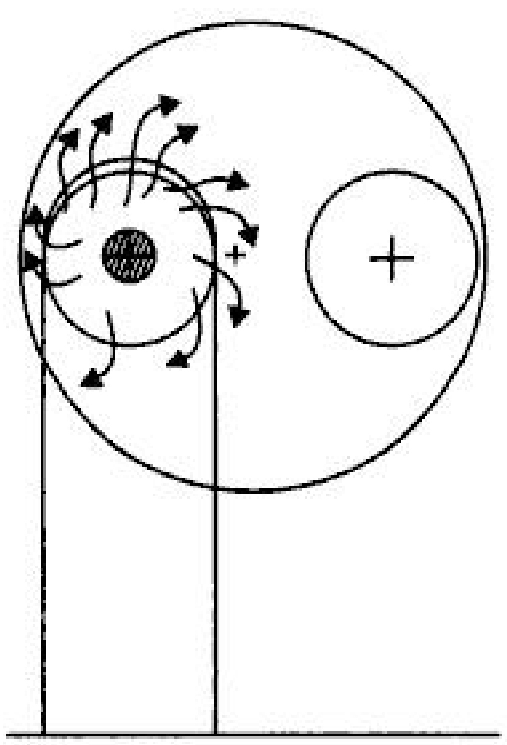


Fig. 2.53. Induction swirl.

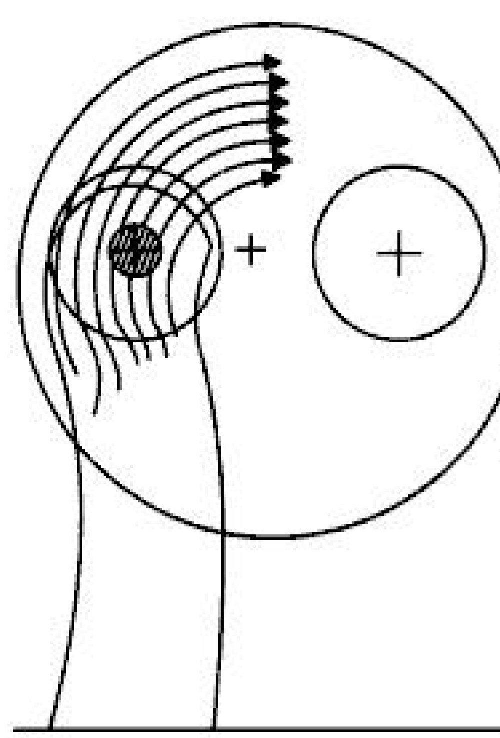
- *Swirl* is generated by constructing the intake system to give a tangential component to the intake flow as it enters the cylinder. This is done by *shaping and contouring the intake manifold, valve ports and even the piston face.*
- *Swirl greatly enhances the mixing of air and fuel* to give a homogeneous mixture in the very short time available for this in modern high speed engines. It is also a main mechanism for spreading of the flame front during the combustion process.

The induction ports are classified as follows : Refer to Fig. 2.54.

1. *Direct straight port.*
2. *Deflector wall port.*
3. *Masked valve port.*
4. *Helical port.* The intensity of swirl is influenced by the steepness of the port helix and the mean diameter of the spiral flow path about the valve axis.
   - Helical ports usually provide *higher flow discharges for equivalent levels of swirl compared with directed ports because* the whole periphery of the valve opening area can be fully utilized, and, as a result, higher volumetric efficiencies can be obtained in the low-to-mid speed range of the engine.
   - These ports are *less sensitive to their position relative to the cylinder axis* since the swirl generated depends mainly on the port geometry above the valve and not how it enters the cylinder. Generally, the magnitude of swirl rises with increased valve lift.
   - These ports, however, *suffer from a loss of volumetric efficiency in the upper speed range of the order 5 to 10%.*



(*i*) Directed straight port



(*ii*) Deflector wall port

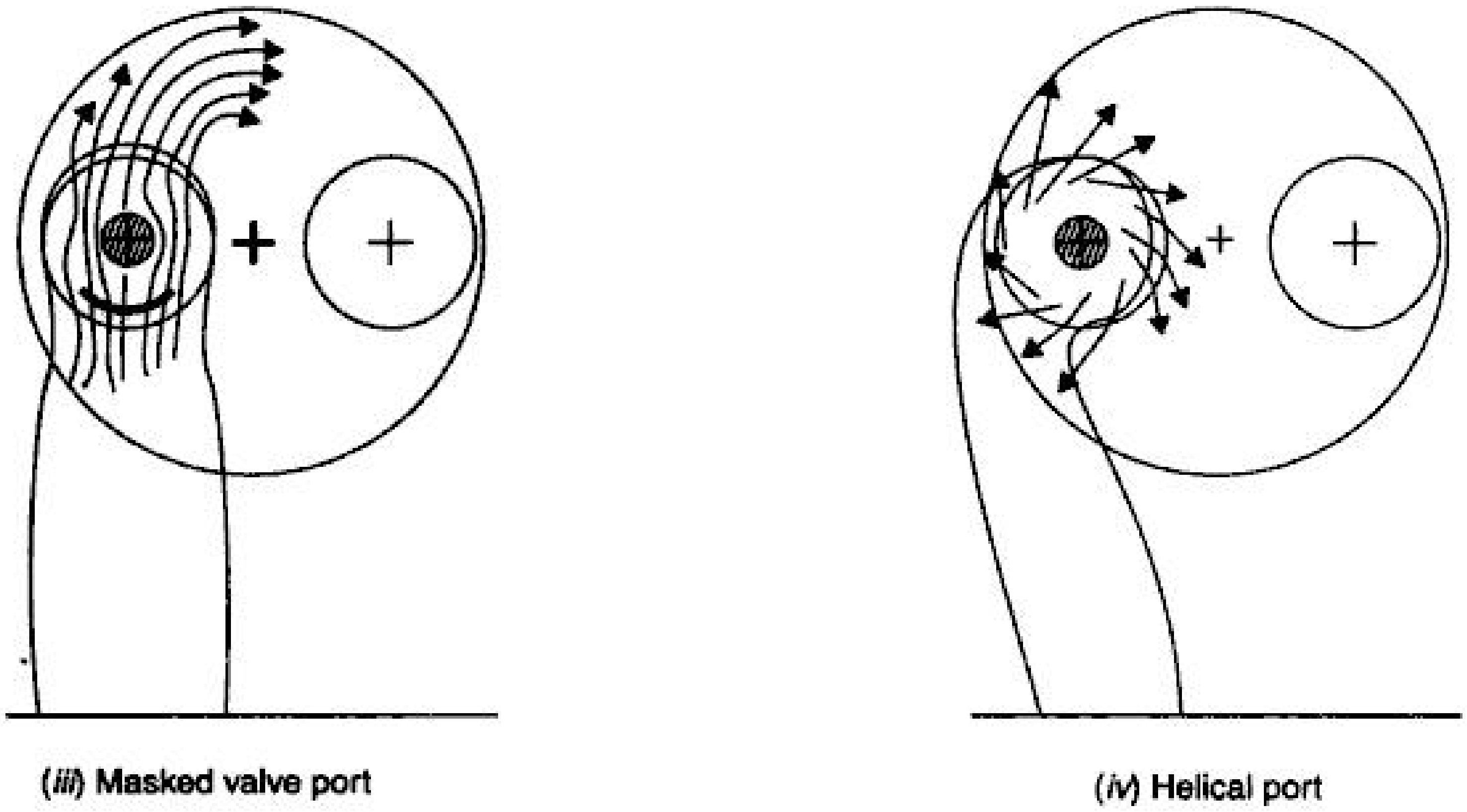


Fig. 2.54. Induction ports.

- In **chamber wall deflected induction swirl,** the downward and circular movement of the mixture *generates an expanding, and then a contracting special swirl about the cylinder axis during both the induction and compression strokes, respectively.*

Methods of Intensifying the Rate of Burning :

2.26.2. Squish and Tumble

- As the piston approaches T.D.C. at the end of compression stroke, the volume around the outlet edges of the combustion chamber is suddenly reduced to a very small value. Many modern combustion chamber designs have most of the clearance volume near the centreline of the cylinder. As the piston approaches T.D.C. the gas mixture occupying the volume *at the outer radius of the cylinder is forced radially inward as this outer volume is reduced to near zero. This radial inward motion of the gas mixture is called* **'squish'.** It adds to other mass motions within the cylinder to mix the air and fuel and to quickly spread the flame front. Fig. 2.55 shows a typical compression squish.
- As the piston nears T.D.C. squish motion generates a *secondary rotational flow called* **"tumble"**. *This rotation occurs about a circumferential axis near the outer edge of the piston bowl.*

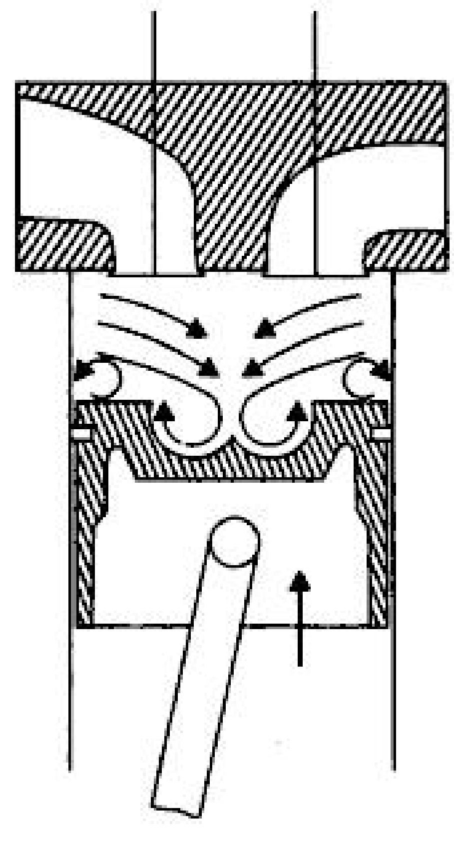


Fig. 2.55. Compression squish.

2.26.3. Quench Area

- The quench area is defined by the *parallel portion of the piston and cylinder head which almost touch each other as the piston approaches T.D.C.* These opposing flat surfaces sandwiching a thin lamina of charge between them, *have a large surface relative to the small volume trapped between them.* Consequently there will be a large amount of heat transferred from this thin lamina of hot charge through the metal walls. The result is a rapid cooling or quenching effect, by these parallel surfaces.

- The quench area is defined as *percentage of opposing flat area relative to the piston crown area.*

2.26.4. Turbulence

- *"Turbulence" consists of randomly dispersed vortices of different sizes which become superimposed into the air, or air and petrol mixture flow stream* (Fig. 2.56). These vortices, which are carried along with the flow stream, represent small irregular breakways that take on a concentric spiral motion (Fig. 2.57).

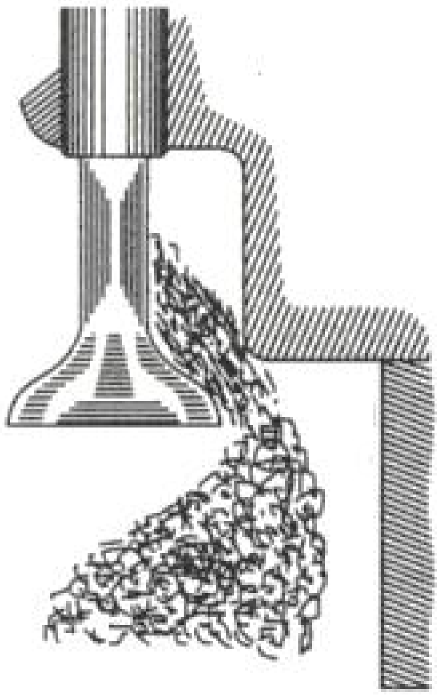


Fig. 2.56. Intake turbulent mixture flow.

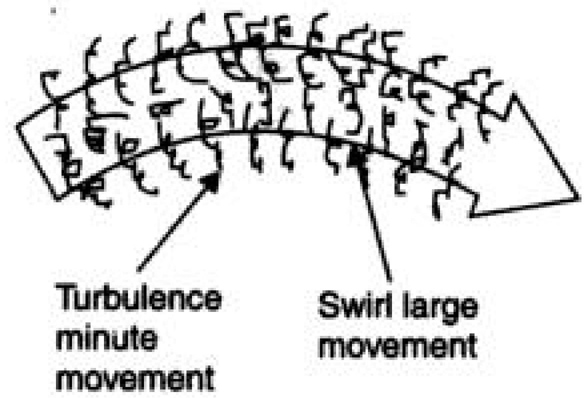


Fig. 2.57. Illustration of turbulence superimposed on mixture swirl.

- As the vortices whirl they will contact adjacent vortices causing viscous shear interaction. This rapidly speeds up the rate of heat transfer and fuel mixing.
- The amount of vortex activity, that is the formation of new vortices and the disintegration of others, *increases the turbulent flow with rising engine speed.*
  - Turbulence plays a very important role in combustion phenomenon in S.I. (as well C.I.) engines. The flame speed is very low in non-turbulent mixtures. *A turbulent motion of the mixture intensifies the processes of heat transfer and mixing of the burned and unburned portions in the flame front* (diffusion). These two factors cause the velocity of turbulent flame to increase practically in proportion to the turbulent velocity. The turbulence of the mixture is due to admission of fuel-air mixture through comparatively narrow sections of the intake pipe, valves etc., in the suction stroke. The turbulence can be increased at the end of the compression stroke by suitable design of combustion chamber which involves the geometry of cylinder head and piston crown.
  - The degree of turbulence increases *directly* with the piston speed.

The *effects of turbulence* can be summed up as follows :

1. Turbulence accelerates chemical action by intimate mixing of fuel and oxygen. Thus *weak mixtures can be burnt.*
2. The increase of flame speed due to turbulence reduces the combustion time and hence *minimises the tendency to detonate.*

3. Turbulence increase the heat flow to the cylinder wall and in the limit excessive turbulence may *extinguish the flame.*
4. Excessive turbulence results in the more rapid pressure rise (though maximum pressure may be lowered) and the high pressure rise causes the crankshaft to spring and rest of the engine to vibrate with high periodicity, resulting in *rough and noisy running of the engine.*

2.26.5. Flame Propagation

- Typical flame propagation velocities range from something like 15 to 70 m/s. This would relate to the combuston flame velocity increasing from about 15 m/s at an idle speed of about 1000 r.p.m. to roughly 70 m/s at a maximum speed of 6000 r.p.m.
- *When ignition occurs the nucleus of the flame spreads with the whirling or rotating vortices in the form of ragged burning crust from the initial spark-plug ignition site.*
- *The speed of the flame propagation is roughly proportional to the velocity at the periphery of the vortices.*

2.26.6. Swirl Ratio

- Induction swirl can be generated by tangentially directing the air movement into the cylinder either by creating a preswirl in the induction port or by combining the tangential-directed flows with a preswirl helical port. *"Cylinder air swirl"* is defined *as the angular rotational speed about the cylinder axis.*
- ***Swirl ratio*** is defined as the *ratio of air rotational speed to crankshaft rotational speed.*
  - Helical ports can achieve swirl ratio of 3 to 5 at T.D.C. with a flat piston crown. However, if a bowl in the piston chamber is used, the swirl ratio can be increased to about 15 at T.D.C.

2.26.7. Surface-to-Volume Ratio

- In order to *minimise* the heat losses and formation of hydrocarbons within the combustion

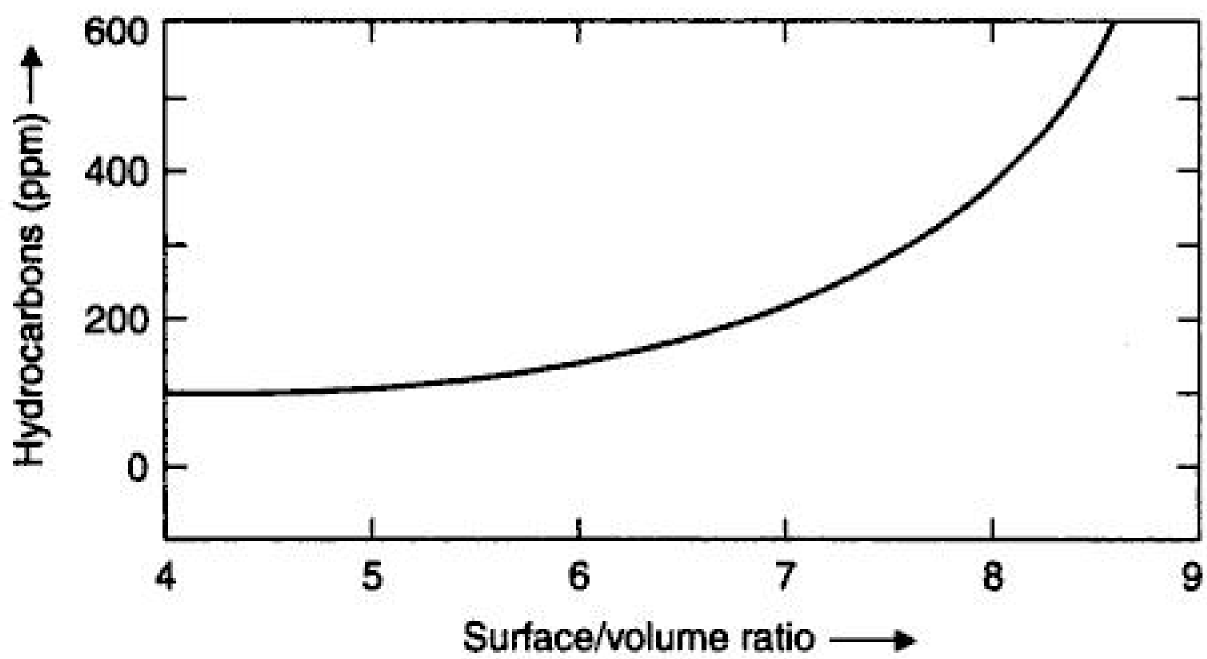


Fig. 2.58

chamber, the chamber volume should be maximised relative to its surface area, that is, the *chamber's surface area should be as small as possible relative to the volume occupied by the combustion chamber* (Fig. 2.58). The surface-to-volume ratio is the *ratio of the combustion surface area to that of its volume.*

- The surface-to-volume ratio *increases linearly with rising compression ratio.*

2.26.8. Stroke-to-Bore Ratio

- For various engines the stroke-to-bore ($L : D$) ratio can range from 0.6 : 1 to 1.4 : 1.
  - When $L = D$, the $L : D$ ratio is said to be *square* ;
  - When $L < D$, the $L : D$ ratio is said to be *oversquare* ;
  - When $L > D$, the engine is said to be *undersquare*.
- *"Oversquare" engines are more suitable for saloon car petrol engines,* whereas *"undersquare" engines are better utilised for large diesel engines.*

2.26.9. Compression Ratio (C.R.)

- When compression ratio increases from 5 : 1 to 10 : 1 the cylinder's compression pressure increases from 8.0 bar to 19.0 bar respectively (Fig. 2.59). Correspondingly, the maximum cylinder pressure increases from 32 bar to 82 bar and b.m.e.p. generated also increases from 9.4 bar to 11.8 bar over the same compression range respectively.
- The effect of higher cylinder pressure is to cause a corresponding rise in cylinder temperature from 360°C to 520°C over the same compression ratio rise. Raising the cylinder temperature reduces the ignition delay period for one set engine speed (Fig. 2.60). Thus, for an engine running in its mid-speed range, the ignition timing would be reduced from 37.5° to 12.5° before T.D.C. if its compression ratio is increased from 5 : 1 to 10 : 1.

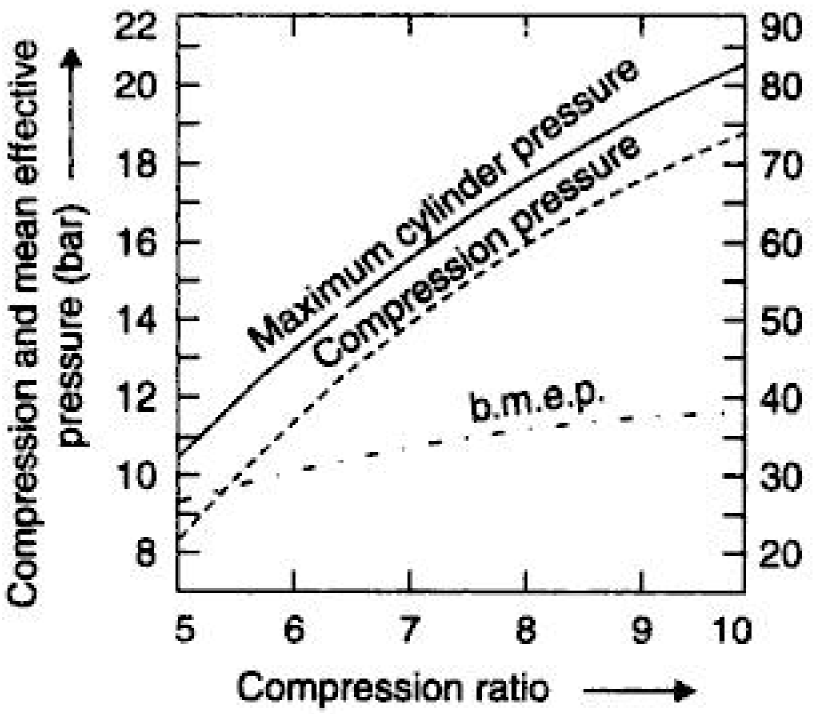


Fig. 2.59. Effect of compression ratio on the b.m.e.p. compression and maximum cylinder pressures.

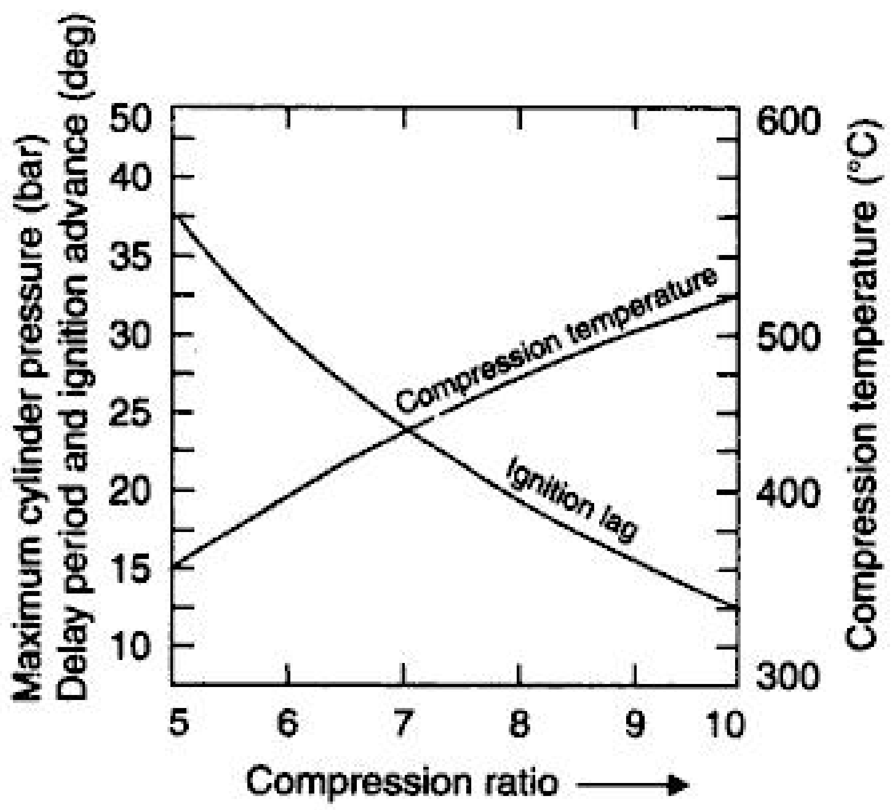


Fig. 2.60. Effect of compression ratio on the air temperature and ignition lag.

- The effects of compression ratio on the characteristic pressure-volume diagram and the characteristic pressure-crank angle diagram for a petrol engine are shown in Fig. 2.61 and 2.62, respectively.
- *The main reason for raising the engine compression ratio is due to the increased density of the air-fuel mixture at the point of ignition, so that when the energy is released it is better utilized. It therefore, raises both the engine thermal efficiency and the developed power.*
- Out of the *major unwanted side effects* of raising the compression ratio is that there will be a corresponding *increase in cylinder pressure which,* in turn, *increases the piston-ring to cylinder-wall friction and compression and expansion heat losses.* Consequently, the *higher compression ratio produces a reduction in the mechanical efficiency.* Subsequently, increasing the compression ratio produces an *increase in thermal efficiency but at the expense of a falling mechanical efficiency.*

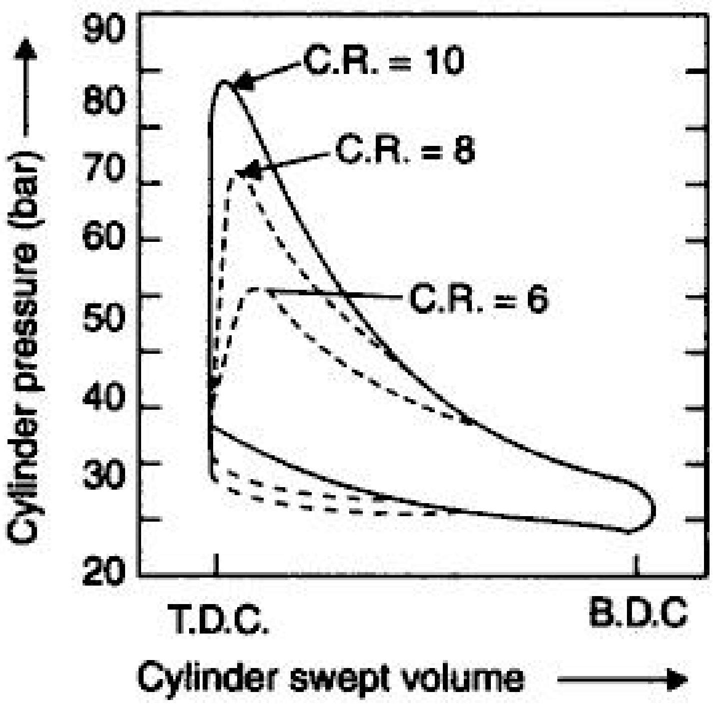


Fig. 2.61. Effect of compression ratio on the characteristic pressure-volume diagram for a petrol engine.

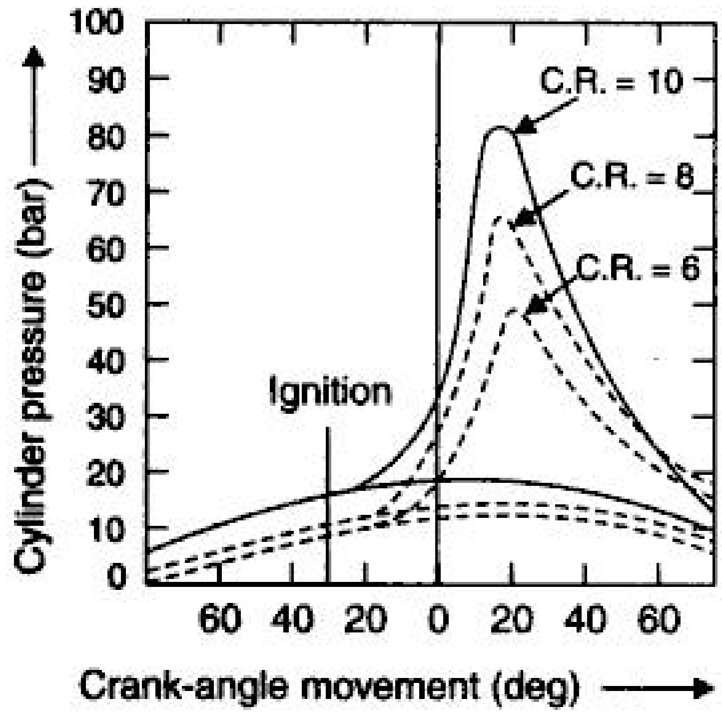


Fig. 2.62. Effect of compression ratio on the characteristic pressure-crank-angle diagram for a petrol engine.

- The *merits* and *limitations* of raising the compression ratio with regards to thermal efficiency and mechanical efficiency are shown in Fig. 2.63, whereas Fig. 2.64 shows the *benefits* of increased power and reduced specific fuel consumption with rising compression ratio.

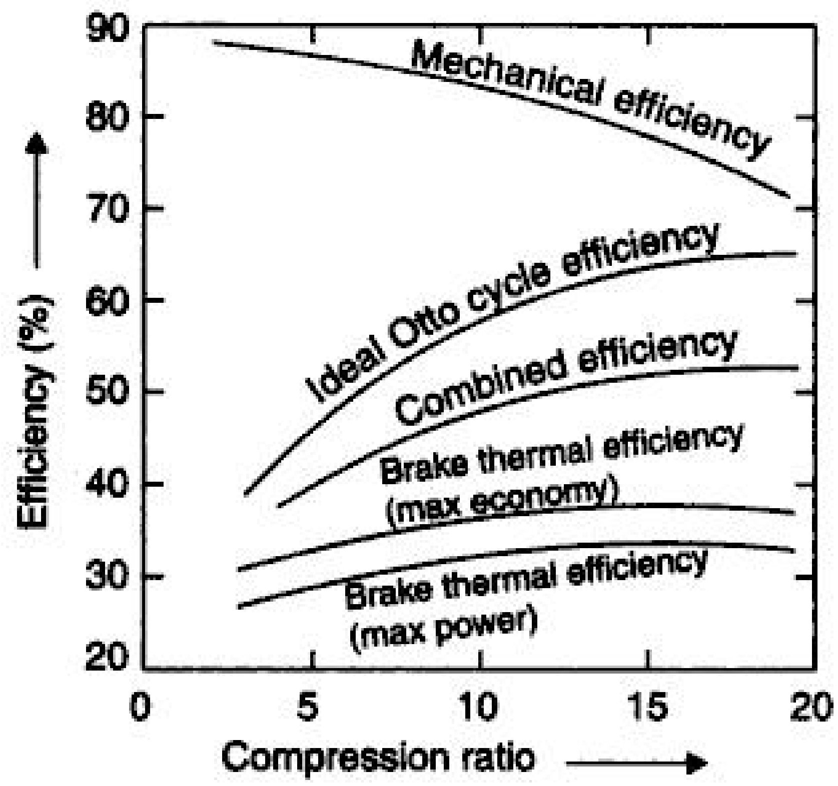


Fig. 2.63. Effect of compression ratio on an engine's thermal and mechanical efficiencies.

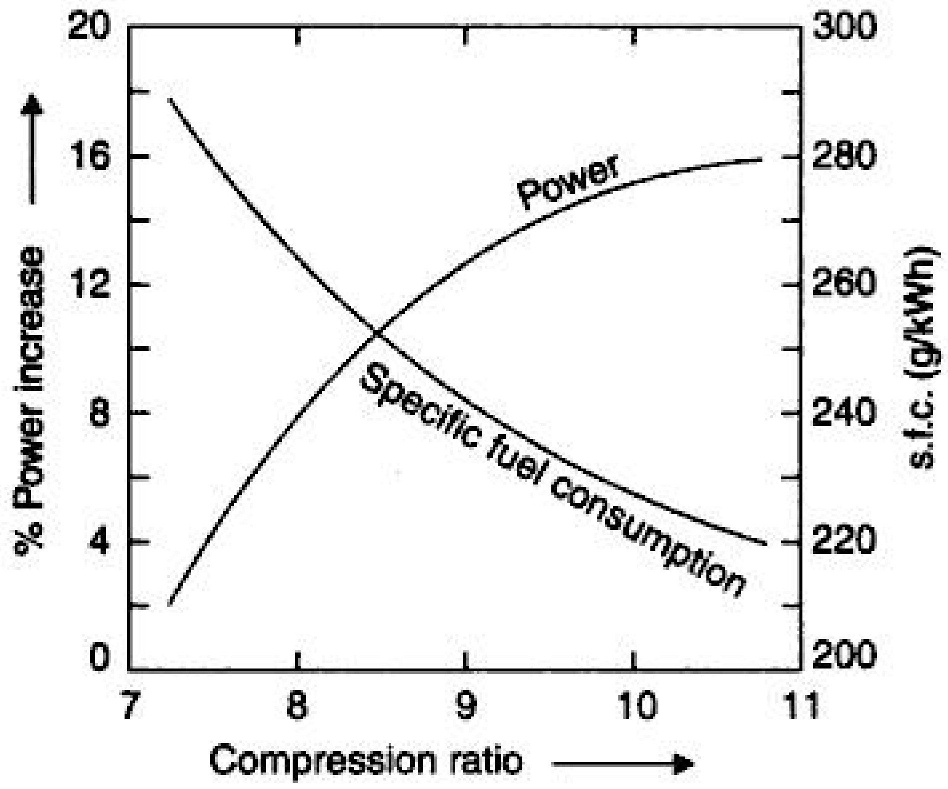


Fig. 2.64. Effect of compression on engine power and specific fuel consumption.

For S.I. engines' combustion design practice, summarily, the following are required :

1. The smallest ratio of chamber surface-area to chamber volume as possible ... *to minimise heat losses to the cooling system.*
2. The shortest flame-front travel distance as possible ... *to minimise the combustion period.*
3. The provision for quenching the mixture farthest from the sparking plug ... *to prevent the end-gas overheating*. However, it must not be excessive as this would prevent the end-gases burning and, therefore, it would cause a high level of hydrocarbons to be expelled to the exhaust.

4. The most central sparking plug position possible ... *to minimise the flame spread path* (or, alternately, *twin plugs* can be used to achieve the same objective).
5. The location of the sparking plug should be as close as to the exhaust valve as possible ... *to maximise the temperature of the mixture surrounding the sparking plug electrodes.*
6. The incoming mixture must have adequate swirl (but not too much as this could lead to excessive heat losses) ... *to mix the air and fuel rapidly and intimately.*
7. The provision for squish zones ... *to excite the mixture into a state of turbulence just before the combustion occurs.*
8. The provision for cooling of the exhaust valve ... *to prevent overheating, distorting, and burning occurring.*
9. The provision for incoming fresh charge to sweep past and cool the sparking plug electrodes ... *to avoid pre-ignition under wide throttle opening.*
10. The utilisation of the highest possible compression ratio ... *to maximise the engine's thermal efficiency without promoting detonation.*
11. The inlet and exhaust valve sizes and numbers should be adequate ... *to expel the exhaust-gases and to fill the cylinder with the maximum mass of fresh charge in the upper speed range.*
12. The degree of turbulence created should be controlled ... *to prevent excessively high rates of burning and, correspondingly, limit very high rates of pressure rise which would cause rough and noisy running.*

2.27. SOME TYPES OF COMBUSTION CHAMBERS

A few representative types of combustion chambers of which there are many more variations are enumerated and discussed below :

1. *T*-head combustion chamber.
2. *L*-head combustion chamber.
3. *I*-head (or overhead valve) combustion chamber.
4. *F*-head combustion chamber.

It may be noted that these chambers are *designed to obtain the objectives namely* :

- A *high combustion rate at the start.*
- A *high surface-to-volume ratio near the end of burning.*
- A *rather centrally located spark plug.*

1. **T-head combustion chamber.** Refer to Fig. 2.65.

This type of combustion chamber (earliest type) was used by Ford-motor corporation in 1908 in its famous model '*T*'.

The *T*-head design has the following *disadvantages* :

(*i*) Requires two cam shafts (for actuating the inlet valve and exhaust valve separately) by two cams mounted on the two cam shafts.

(*ii*) Very prone to detonation. There was violent detonation even at a compression ratio of 4 (with a fuel of octane number of 50).

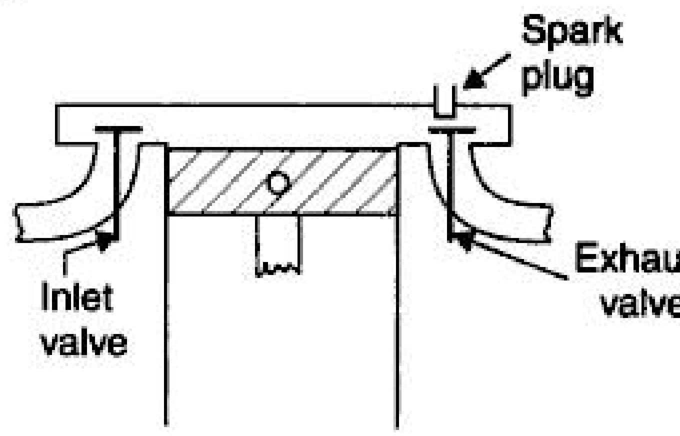
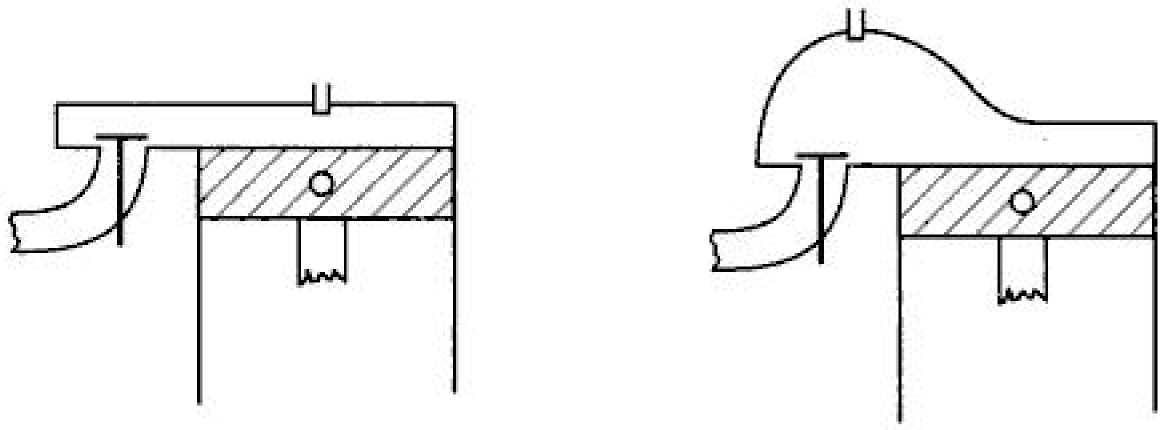


Fig. 2.65. *T*-head combustion chamber.

2. **L-head combustion chamber.** Refer to Fig. 2.66.



(*a*) (*b*) Ricardo's turbulent head

Fig. 2.66. *L*-head combustion chamber.

- It is a modification of the *T*-head type of combustion chamber. It provides the *two valves on the same side of the cylinder,* and the valves are operated through tappet by a *single camshaft*.
- Fig. 2.66 (*a*) and (*b*) shows two types of this side-valve engine. In these types *it is easy to lubricate the valve mechanism* with the detachable head, it may be noticed that *the cylinder head can be removed for cleaning or decarburising without disturbing valve gear etc*.
  - In Fig. 2.66 (*a*), the air flow has to take two right-angled turns to enter the cylinder. This causes a loss of velocity head, and a loss in turbulence level, *resulting in slow combustion process*.
  - Fig. 2.66 (*b*) is the ***Ricardo's turbulent head design.*** The main body of the combustion chamber is concentrated over the valves leaving a slightly restricted passage communicating with the cylinder, thereby *creating additional turbulence during the compression stroke*. This design *reduces the knocking tendency by shortening the effective flame travel length* by bringing that portion of the head which lay over the further side of the piston into as close a contact as possible with the piston crown, forming a *quench space*. The thin layer of mixture (entrapped between the relatively cool piston and also cooled head) loses its heat rapidly, thereby avoiding knock. By placing the spark plug in the centre of the effective combustion space but with slight bias towards the exhaust valve, the flame travel length is reduced.

Advantages :

(*i*) Valve mechanism simple and easy to lubricate.

(*ii*) Detachable head easy to remove for cleaning and decarburising.

(*iii*) Valves of larger sizes can be provided.

Disadvantages :

(*i*) More surface-to-volume ratio and therefore *more heat loss*.

(*ii*) Longer length of flame travel.

(*iii*) Valve size restricted.

(*iv*) Thermal failure in cylinder block also. In *L*-head engine the thermal failure is confined to cylinder head only.

3. **I-head (or overhead valve) combustion chamber.** Refer to Fig. 2.67.

This type of combustion chamber has both the inlet valve and the exhaust valve located in the cylinder head. An overhead engine is superior to side valve engine at high compression ratios.

Advantages :

(*i*) Reduced pumping losses.

(*ii*) Higher volumetric efficiency (since the larger valves and larger lifts can be accommodated).

(*iii*) Less prone to detonation (since the path of flame travel is reduced).

(*iv*) Less force on the head bolts and therefore less possibility of leakage of compression gases or jacket water.

(*v*) Lower surface-volume ratio and, therefore, less heat loss and less air pollution.

(*vi*) Easier to cast.

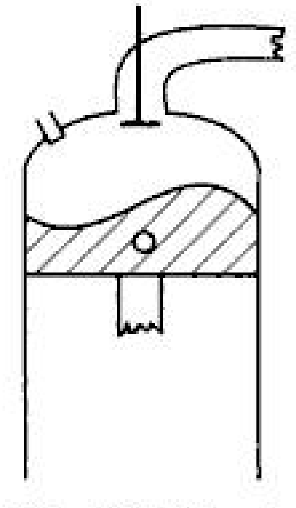


Fig. 2.67. *I*-head combustion chamber.

4. **F-head combustion chamber :**

- In such a combustion chamber one valve is in head and other in the block. This design is a compromise between *L*-head and *I*-head combustion chambers.
- One of the most perfect *F*-head engines (wedge type) is the one used by the Rover company for several years. Its *advantages* are :

(*i*) High volumetric efficiency.

(*ii*) Maximum compression ratio for fuel of given octane rating.

(*iii*) High thermal efficiency.

(*iv*) It can operate on leaner air-fuel ratios without misfiring.

The *drawback* of this design is the *complex mechanism for operation of valves and expensive special shaped piston.*

— Another successful design of this type of chamber is that used in Willys jeep.

Note 1. Some modern engines have divided chamber. These offer *high volumetric efficiency, good fuel economy,* and *cycle operation flexibility.* Their main *disadvantages* are *greater heat loss,* due to high surface area, and *high cost* and *difficulty in manufacturing.*

2. Very large engines are almost always C.I. engines. Because of their large combustion chambers and corresponding long flame travel distance, combined with slow engine speed, they would require very high octane fuel and very low compression ratio if operated as an S.I. engine. With the very long real time of combustion in the cylinder, it would be impossible to avoid serious knock problems.

2.27.1. Divided Combustion Chambers

- Some engines have divided combustion chambers, usually with about *80 percent* of the clearance volume in the **main chamber** above the piston and about *20 percent* of the volume as a **secondary chamber** *connected through a small orifice* (Fig. 2.68). *Combustion is started in the small secondary chamber, and the flame then passes through the orifice, where it ignites the main chamber.* Intake swirl is not as important in the main chamber of this type of engine, so the intake system can be designed for greater volumetric efficiency. It is desirable to have very high swirl in the secondary chamber, and the orifice between the chambers is shaped to supply this often, the *secondary chamber is called a "swirl chamber".* As the gases in the secondary chamber are consumed by combustion, the pressure rises and flaming gas expands back through the orifice and acts as a *torch ignition* for the main chamber. The expanding gas rushing back through the orifice creates a large secondary swirl in the main chamber,

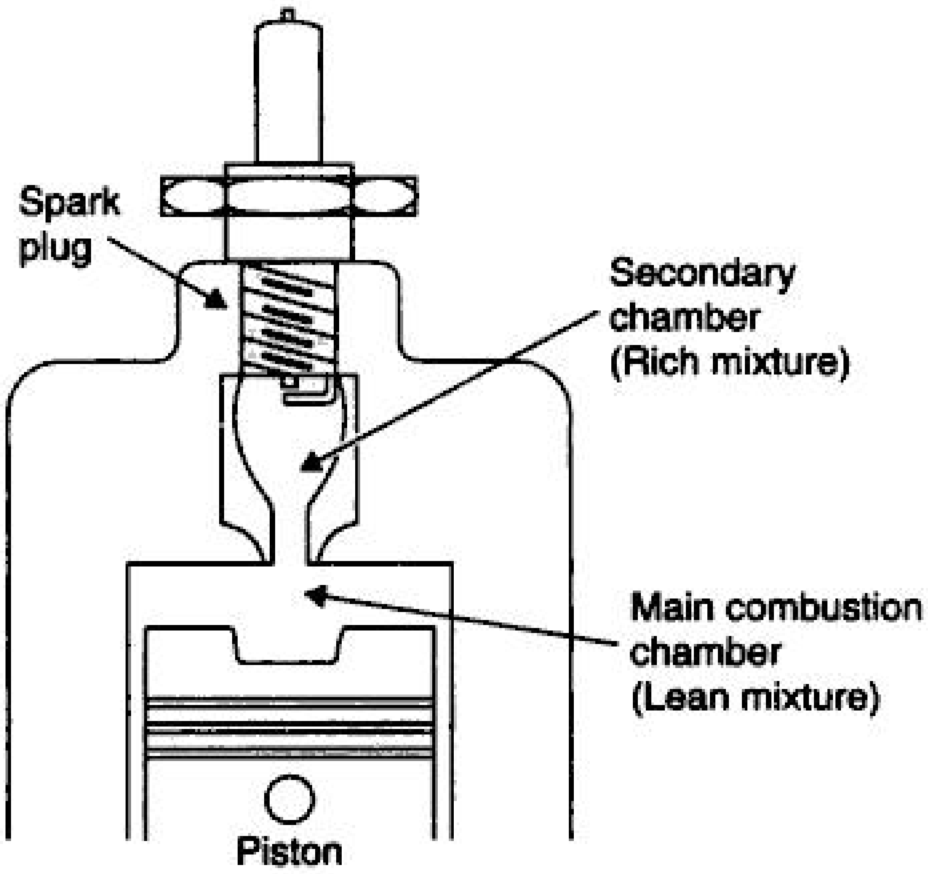


Fig. 2.68. Divided combustion chamber.

which enhances the combustion there. Creating an orifice that can do all this is a major design challenge.

- A divided chamber engine, oftenly, will also be a stratified charge engine. *The intake system is designed to supply a rich mixture in the secondary chamber and a lean mixture in the main chamber*. The rich mixture with very high swirl in the secondary chamber will ignite readily and combust very quickly. The flaming gases expanding back through the orifice will then ignite the lean mixture in the main chamber, a mixture often so lean that it would be difficult to ignite with a spark-plug alone. The net result is *an engine that has good ignition and combustion, yet operates mostly lean to give good fuel economy*. Placement and timing of intake valves injectors to supply the proper air and fuel to all parts of this engine are extremely important.

Note. A variation of this type of combustion chamber on some C.I. engines is one with a totally passive secondary chamber, with all valves and injectors located in the main chamber. When combustion occurs in the main chamber, high pressure forces gas through the very small orifice and raises the pressure in the secondary chamber also. *When the pressure in the main chamber is reduced during the power stroke, the high pressure gases in the secondary chamber flow back into the main chamber. This holds the pressure in the main chamber to a higher level for a short time and gives a smooth, slightly greater force off the piston during the power stroke.* This kind of secondary chamber usually consists of about 5-10 percent of the clearance volume.

WORKED EXAMPLES

Example 2.1. *A S.I. engine operating at 1200 r.p.m. has a 10.2 cm bore with spark-plug offset by 6 mm from the centre. The spark plug is fired at 20°C before T.D.C. It takes 6.5° of engine rotation for combustion to develop and get into flame propagation mode, where the average flame speed is 15.8 m/s. Calculate :*

(i) Time of one combustion process (i.e., time for flame front to reach the farthest cylinder wall) in sec. ;

(ii) Crank angle position at the end of combustion. **(Madras University)**

Solution. Maximum distance of flame travel

$$= \frac{1}{2} \text{ bore + spark-plug offset}$$

$$= \frac{1}{2} \times 10.2 + \frac{6}{10} = 5.7 \text{ cm}$$

Time of flame travel $= \dfrac{5.7 \times 10^{-2}}{15.8} = 3.6076 \times 10^{-3}$ s

$$1200 \text{ r.p.m.} = \frac{1200}{60} \times 360 = 7200 \text{ deg./s}$$

∴ Crank angle for flame travel

$$= 3.6076 \times 10^{-3} \times 7200 = 25.975 \text{ deg.}$$

Time for combustion to develop = 6.5 crank degrees

$$= \frac{6.5}{7200} \quad \text{or} \quad 0.9028 \times 10^{-3} \text{ s}$$

(*i*) **Time for one combustion process**

= Time to develop + Time for propagation

$= 0.9028 \times 10^{-3}$ s $+ 3.6076 \times 10^{-3}$

$= \mathbf{4.5104 \times 10^{-3}}$. **(Ans.)**

(*ii*) **Total crank rotation**

= 6.5 + 26.975 = 33.48 degrees of crank rotation.

Since spark is fired at 20° before T.D.C, the crank position will be (33.48 – 20)

or, **13.48 degrees after T.D.C. (Ans.)**

Example 2.2. *In a trial on S.I. engine at full speed full power (i.e., fully open throttle) the spark occurred 26° bT.D.C (before Top Dead Centre) and delay ended 4° bT.D.C. Assuming that the combustion period should finish 13° aT.D.C. (after top dead centre) for maximum power and that the effect of half closing the throttle at constant speed is to increase the delay period by 14% of the valve at full throttle, estimate the optimum spark timing for maximum power under following conditions :*

(i) Under full throttle conditions when the engine is operated at half the maximum speed ;

(ii) When the engine is operated at conditions of half the maximum speed and the throttle half open.

State how these alterations in optimum spark timing may be achieved in practice.

(Bombay University)

Solution.

• *The delay period, at constant throttle, is constant in time and thus increases in angle with the speed.*

• The *combustion period is constant in crank angle.*

The delay period = From 26° T.D.C. to 4° *b*T.D.C. *i.e.*, 22°

The combustion period = From 4° T.D.C. to 13° *a*T.D.C. *i.e.*, 17°.

(*i*) Full throttle half speed will result in delay angle being reduced to $\dfrac{22}{2} = 11°$ for the same time thus ignition timing should be arranged so that the total of 11 + 17 = 28°, ends 13° *a*T.D.C.

∴ **Time of spark** = 28 – 13 = **15° *b*T.D.C. (Ans.)**

A *centrifugal device* is used to accomplish this task.

(*ii*) Half throttle half speed will result in an increase of 14% in delay time over that at full throttle half speed *i.e.*, by

$$\frac{14}{100} \times 11 = 1.54°$$

∴ Delay angle = 11 + 1.54 = 12.54°

Combustion period remains same as 17°

∴ Total period = 12.54 + 17 = 29.54° ; end is 13° *a*T.D.C.

∴ **Time of spark** = 29.54 − 13 = **16.54° *b*T.D.C. (Ans.)**

This is accomplished by *a vacuum device connected to the inlet manifold.*

III. Combustion in C.I. Engines

2.28. INTRODUCTION TO COMBUSTION IN C.I. ENGINES

The compression ignition (C.I.) engine was developed by Dr. Rudolf Diesel, he got a patent of his engine in 1892.

It is a very important prime mover these days and is finding wide applications in :

- Buses trucks, tractors ;
- Locomotives ;
- Pumping sets ;
- Stationary industrial applications ;
- Small and medium electric power generation ;
- Marine propulsion.

The following points are worthnoting about C.I. engines :

- *Its thermal efficiency is higher than S.I. engines.*
- C.I. engine fuels (diesel oils) are less expensive than S.I. engine fuels (petrol or gasoline). Furthermore, since C.I. engines fuels have a higher specific gravity than petrol, and since fuel is sold on the volume basis (litres) and not on mass basis (kg), more kg of fuel per litre are obtained in purchasing C.I. engine fuel.

Due to the above mentioned factors the *running cost of C.I. engines is much less than S.I. engines* and as a consequence these engines find wide application in industrial, transport and other applications.

- A *C.I. engine is not much favoured in passenger cars due to the following reasons :*
  (*i*) Heavier weight ;
  (*ii*) Noise and vibration ;
  (*iii*) Smoke ;
  (*iv*) Odour.
  - In view of the utilisation of heavier compression ratios (12 : 1 to 22 : 1 compared to 6 : 1 to 11 : 1 of S.I. engines) the heavy forces act on the parts of the engine and therefore heavier parts are required.
  - Also, because of heterogeneous mixture, lean mixture is used.

These factors make the engine heavier.

- The *incomplete combustion of heterogeneous mixture, and droplet combustion result in the smoke and odour.*

- C.I. engines are manufactured in the following range of speeds, speeds and power outputs :

Particulars	*Range*
1. Piston diameters	50 mm to 900 mm
2. Speeds	100 r.p.m. to 4400 r.p.m
3. Power output	2 B.P. to 40000 B.P.

2.29. COMBUSTION PHENOMENON IN C.I. ENGINES

- The process of combustion in the Compression Ignition (C.I.) engine is fundamentally different from that in a spark-ignition engine. In C.I. engine combustion occurs by the high temperature produced by the compression of the air, *i.e.*, it is an *auto-ignition*. For this a minimum compression ratio of 12 is required. The efficiency of the cycle increases with higher values of compression ratio but the maximum pressure reached in the cylinder also increases. This requires heavier construction. The upper limit of compression ratio in a C.I. engine is due to mechanical factor and is a compromise between high efficiency and low weight and cost. The normal compression ratios are in the range of 14 to 17, but may be upto 23. The air-fuel ratios used in the C.I. engine lie between 18 and 25 as against about 14 in the S.I. engine, and *hence C.I. engines are bigger and heavier for the same power than S.I. engines.*
- In the C.I. engine, the intake is air alone and the fuel is injected at high pressure in the form of fine droplets near the end of compression. This leads to delay period in the C.I. engine, is greater than that in the S.I. engine. The *exact phenomenon of combustion in the C.I. engine* is explained below.
  - Each minute droplet of fuel as it enters the highly heated air of engine cylinder is quickly surrounded by an envelope of its own vapour and this, in turn and at an appreciable interval is inflamed at the surface of the envelope. To evaporate the liquid, latent heat is abstracted from the surrounding air which reduces the temperature of the thin layer of air surrounding the droplet, and some time must elapse before this temperature can be raised again by abstracting heat from the main bulk of air in this vicinity. As soon as this vapour and the air in actual contact with it reach a certain temperature, ignition will take place. Once ignition has been started and a flame established the heat required for further evaporation will be supplied from that released by combustion. The vapour would be burning as fast as it can find fresh oxygen, *i.e.*, *it will depend upon the rate at which it is moving through the air or the air is moving past it.*
  - In the C.I. engine, the fuel is not fed in at once but is spread over a definite period. The first arrivals meet air whose temperature is only a little above their self-ignition temperature and the delay is more or less prolonged. The later arrivals find air already heated to a far higher temperature by the burning of their predecessors and therefore light up much more quickly, almost as they issue from the injector nozzle, but their subsequent progress is handicapped for there is less oxygen to find.
  - If the air within the cylinder were motionless, only a small proportion of the fuel would find sufficient oxygen, for it is impossible to distribute the droplets uniformly throughout the combustion space. Therefore some air movement is absolutely essential, as in the S.I. engine. But there is a fundamental difference between the

air movements in the two types of engines. In the S.I. engine we call it *turbulence* and mean a confusion of whirls and eddies with no general direction of flow, (to break up the surface of the flame front, and to distribute the shreds of flame throughout an externally prepared combustible mixture). In the C.I. engine we call it *air swirl* and mean an orderly movement of the whole body of the air, with or without some eddying or turbulence, so as to bring a continuous supply of fresh air to each burning droplet and sweep away the products of combustion which otherwise tend to suffocate it.

Three phases of C.I. engine combustion :

In the C.I. engine, combustion may be considered in *three distinct stages* as shown in Fig. 2.69.

1. Ignition delay period.
2. Period of rapid or uncontrolled combustion.
3. Period of controlled combustion.

The *third phase is followed by* ***after burning*** (or burning on the expansion stroke), which may be called the *fourth phase of combustion.*

1. **Ignition delay period**

- The delay period is counted from the start of injection to the point where the p-θ combustion curve departs from air compression (or no ignition or motoring) curve.
- The delay period can be roughly sub-divided into ***physical delay*** and ***chemical delay.*** The period of *"physical delay" is the time between the beginning of injection and the attainment of chemical reaction conditions.* In the physical delay period, the fuel is atomized, vaporized, mixed with air, and raised in temperature. In the *"chemical delay" period reaction starts slowly and then accelerates until inflammation or ignition takes place* (it may be noted that the ignition delay in the S.I. engine is essentially equivalent to the chemical delay in the C.I. engine).

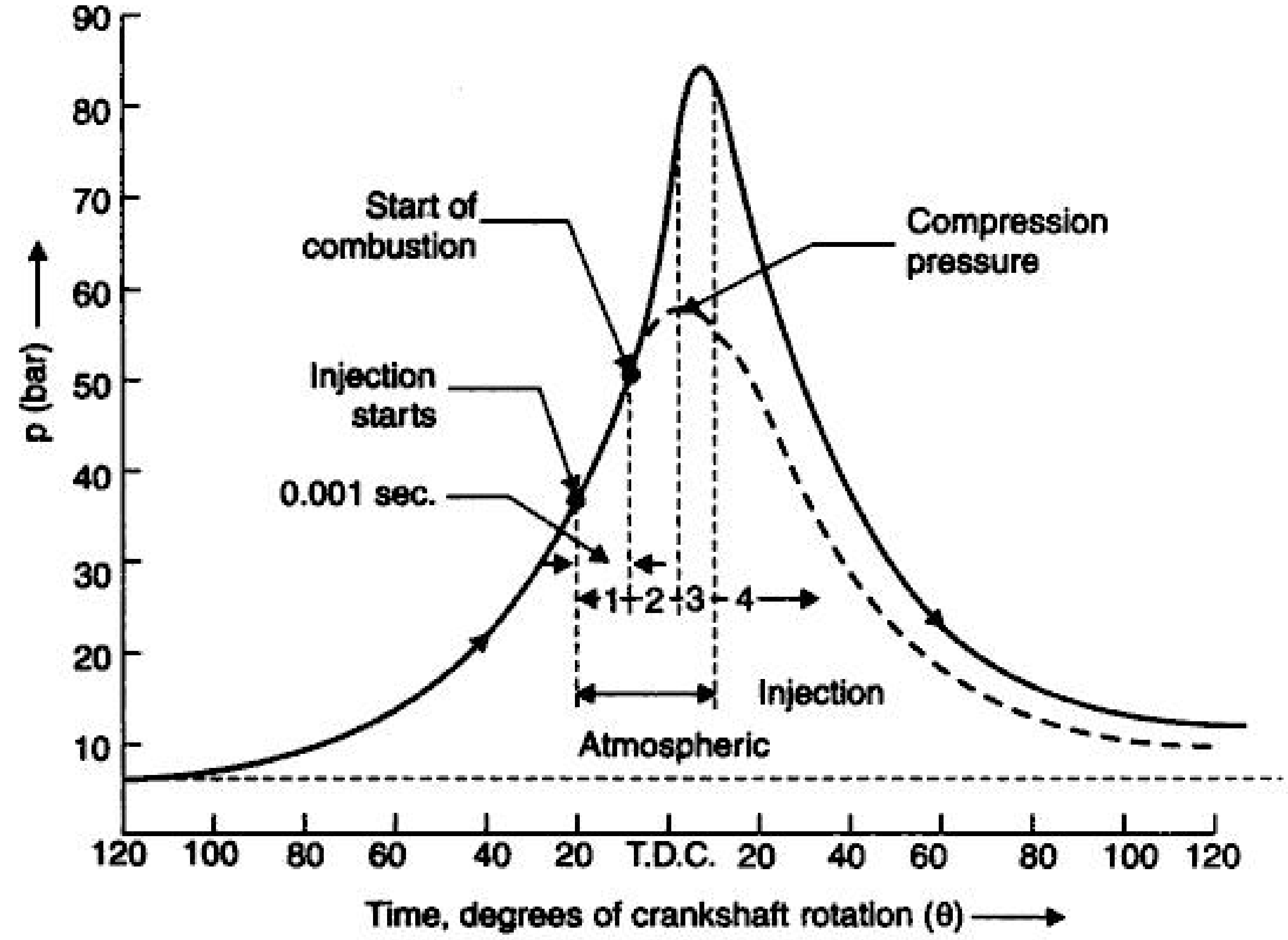


Fig. 2.69. Combustion phenomenon of C.I. engine.

- The delay period exerts a great influence in the C.I. engine combustion phenomenon. It is clear that the pressure reached during the second stage will depend upon the duration of the delay period ; *the longer the delay, the more rapid and higher the pressure rise*, since more fuel will be present in the cylinder before the rate of burning comes under control. This causes rough running and may cause *diesel knock*. Therefore we must *aim to keep the delay period as short as possible, both for the sake of smooth running and in order to maintain control over the pressure changes. But some delay period is necessary otherwise the droplet would not be dispersed in the air for complete combustion.* However, the delay period imposed upon is greater than what is needed and the designer's efforts are to shorten it as much as possible.

2. **Period of rapid or uncontrolled combustion.** The second stage of combustion in C.I. engines, after the delay period, is the *period of rapid or uncontrolled combustion*. This period is *counted from the end of the delay period to the point of maximum pressure on the indicator diagram*. In this second stage of combustion, the rise of pressure is rapid because during the delay period the droplets of fuel have had time to spread themselves out over a wide area and they have fresh air all around them. About one-third of heat is evolved during this process.

The rate of pressure rise depends on the amount of fuel present at the end of delay period, degree of turbulence, fineness of atomization and spray pattern.

3. **Period of controlled combustion.** At the end of second stage of combustion, the temperature and pressure, are so high that the fuel droplets injected in the third stage burn almost as they enter and any further pressure rise can be controlled by purely mechanical means, *i.e.*, by the injection rate. The period of controlled combustion is assumed to end at maximum cycle temperature.The heat evolved by the end of controlled combustion is about 70 to 80 per cent.

4. **After burning :**

- The combustion continues even after the fuel injection is over, because of poor distribution of fuel particles. This burning may continue in the expansion stroke upto 70° to 80° of crank travel from T.D.C. This continued burning, called the *after burning,* may be considered as the *fourth stage of the combustion*. The total heat evolved by the end of entire combustion process is 95 to 97% ; 3 to 5% of heat goes as unburned fuel in exhaust.
- In the p-V diagram, the stages of combustion are not seen because of little movement of piston with crank angle at the end and reversal of stroke. So for studying the combustion stages, therefore, a pressure-crank angle or time, p-θ or p-t diagram is invariably used. In the actual diagram, the various stages of combustion look merged, yet the individual stage is distinguishable.

Factors affecting combustion in C.I. engine :

The factors affecting combustion in C.I. engine are as follows :

(1) Ignition quality of fuel (cetane number).

(2) Injection pressure of droplet size.

(3) Injection advance angle.

(4) Compression ratio.

(5) Intake temperature.

(6) Jacket water temperature.

(7) Intake pressure, supercharging.

(8) Engine speed.

(9) Load and Air to fuel ratio.

(10) Engine size.

(11) Type of combustion chamber.

2.30. FUNDAMENTALS OF THE COMBUSTION PROCESS IN DIESEL ENGINES

Effect of Compression Ratio and Engine Speed on Cylinder Pressure and Temperature :

- The power output of a *diesel engine* is controlled by *varying the amount of fuel spray injected into a cylinder filled with compressed and heated air* whereas the *petrol engine* is controlled by *throttling the pre-mixed charge entering the cylinder.*
- The *pressure and temperature reached at the end of the compression stroke will depend primarily upon the compression ratio, intake temperature and speed of the engine.*
  - It has been observed that injection usually commences 15° to 20° before T.D.C. when both cylinder pressures and temperatures are much lower. As an *example*, a 15 : 1 compression ratio engine would have something like 600°C maximum temperature at T.D.C. but at 15° before T.D.C. this would only amount to 530°C.
  - Further it can be seen that the pressure and temperature rise in the cylinder with increased speed is largely *due to the reduced time available for compressed air to escape past the piston rings and heat to be lost through the cylinder walls and head.*

Diesel Engine Heterogeneous Charge Mixing :

The air-fuel mixture formation, in the diesel engine, is of a *heterogeneous* natures, that is, it is locally concentrated at various sites and is therefore *unevenly distributed throughout the cylinder and combustion chamber.*

- Injected fuel spray penetrates the highly compressed and heated air mass where it is pulverised into many very small droplets in a localised formation. The mixing of the localised spray of fuel droplets in the hot air charge causes stoichiometeric (14.7 : 1 by weight) air-fuel ratio combustion zones to be established which are completely surrounded by pure air only. Thus the overall (averaged out) air-fuel mixture ratio range may vary from a rich, full load, 20 : 1, to a weak no-load, 100 : 1, air-fuel ratio.
- Most engines *operate with at least* **20% excess air** *due to difficulty of introducing sufficient exposed oxygen to the fuel vapour in the given time available so that the combustion process can be completed before the exhaust valve opens.* If the oxygen supply is *partially prevented from getting to the fuel vapour early enough during the power stroke then incomplete combustion, polluted exhaust gas and dark smoke will result.*

Diesel Engine Injected Spray Combustion Process :

- Towards the end of the compression stroke when injection of the fuel into the combustion chamber commences, the quantity of fuel discharged is spread out over a predetermined period.
- The fuel spray enters the hot combustion chamber but does not immediately ignite, instead it breaks up into very small droplets (Fig. 2.70) and once these liquid droplets are formed, *their outer surfaces will immediately start to evaporate so there will be a liquid core surrounded with a layer of vapour.* At this point it should be explained that the burning of a hydrocarbon fuel in air is purely an *oxidation process.* Thus, initially, heat liberated from the oxidation of the fuel vapour is *less than the rate at which heat is extracted by convection and conduction,* but eventually a *critical temperature* is reached when the *rate of heat generated by oxidation exceeds the heat being dissipated by convection and radiation.* As a result, the temperature rises which, in turn, speeds up the oxidation process thus further increasing the heat released until a *flame site or sites*

are established, this being known as the **ignition** and the temperature at which it occurs is called the **self-ignition temperature** of the fuel under these condition. *The heat required for further evaporation of the fuel droplets will thus be provided from heat released by the oxidation process, which is referred to as* **combustion.**

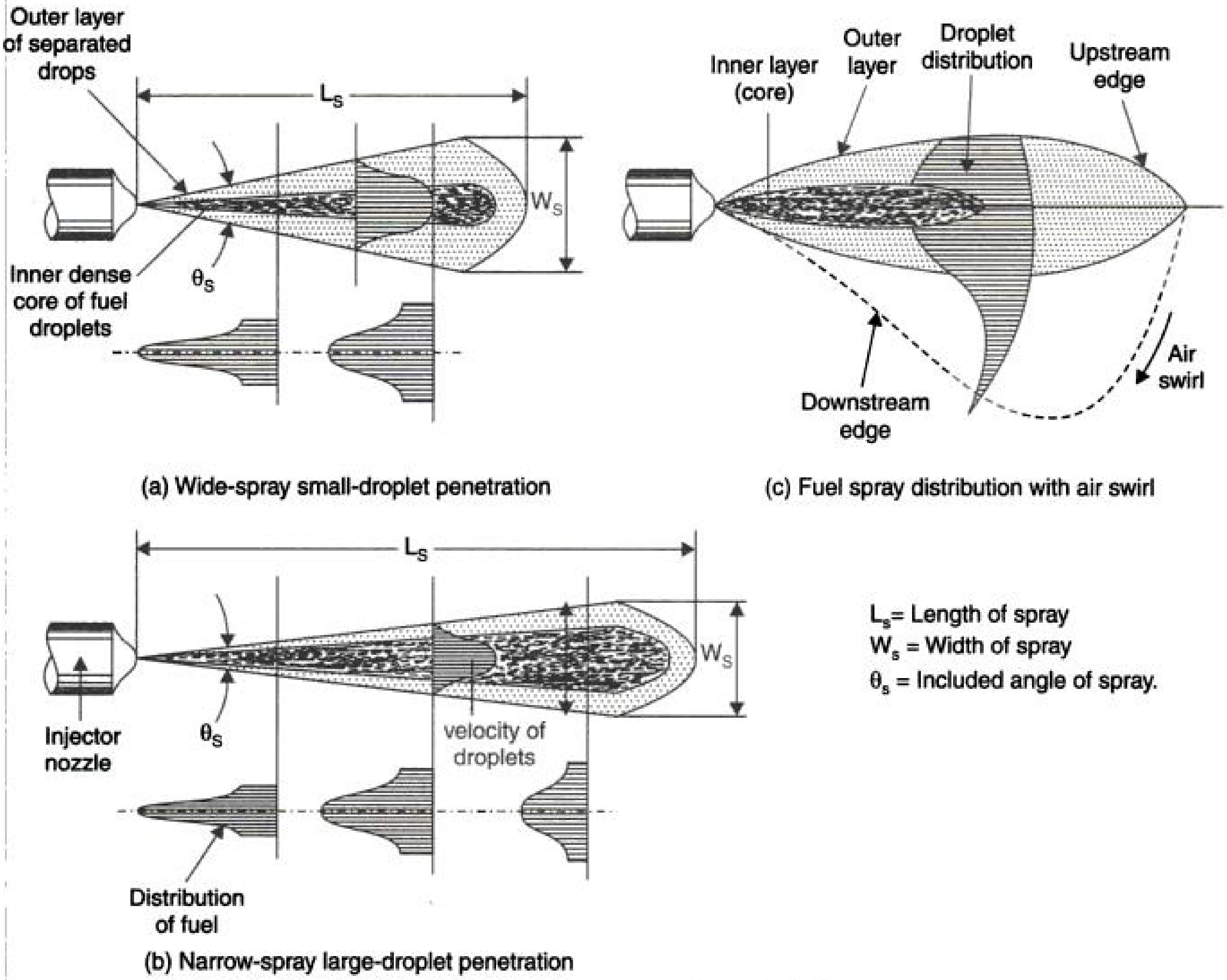


Fig. 2.70. Injected fuel spray characteristics.

- The liquid core, now surrounded by layers of heated vapour, oxidises burns as fast as it can ; that is it finds fresh oxygen to keep the chemical reaction going on.
- When the ***physical delay*** to convert the fuel spray into tiny droplets and the ***chemical reaction delay*** to establish ignition from the initial oxidation process are over, *the rate of burning is dependent on the speed at which the droplets are moving through the air or the air is moving past the droplets.*

Compression Ratio (r) :

Increase in compression ratio exercises the following *effects* :

- The cylinder compression pressure and temperature *increase* ; the ignition time lag between the point of injection to the instant when ignition first commences *reduces.*
- The density and turbulence of the charge *increase*, and this *increases the rate of burning and, accordingly the rate of pressure rise and the magnitude of the peak cylinder pressure reached.* The characteristics of the pressure rise relative to the piston stroke or crank-angle movement is illustrated in Fig. 2.71 and Fig. 2.72.

- Thermal efficiency and the specific fuel consumption are *improved* (Fig. 2.73)
- Raising compression ratio *results in reduction in the mechanical efficiency* as shown in Fig. 2.74 (since the higher cylinder pressures increase the pumping losses, friction losses and compression and expansion losses as more work is done in squeezing together the trapped air charge).

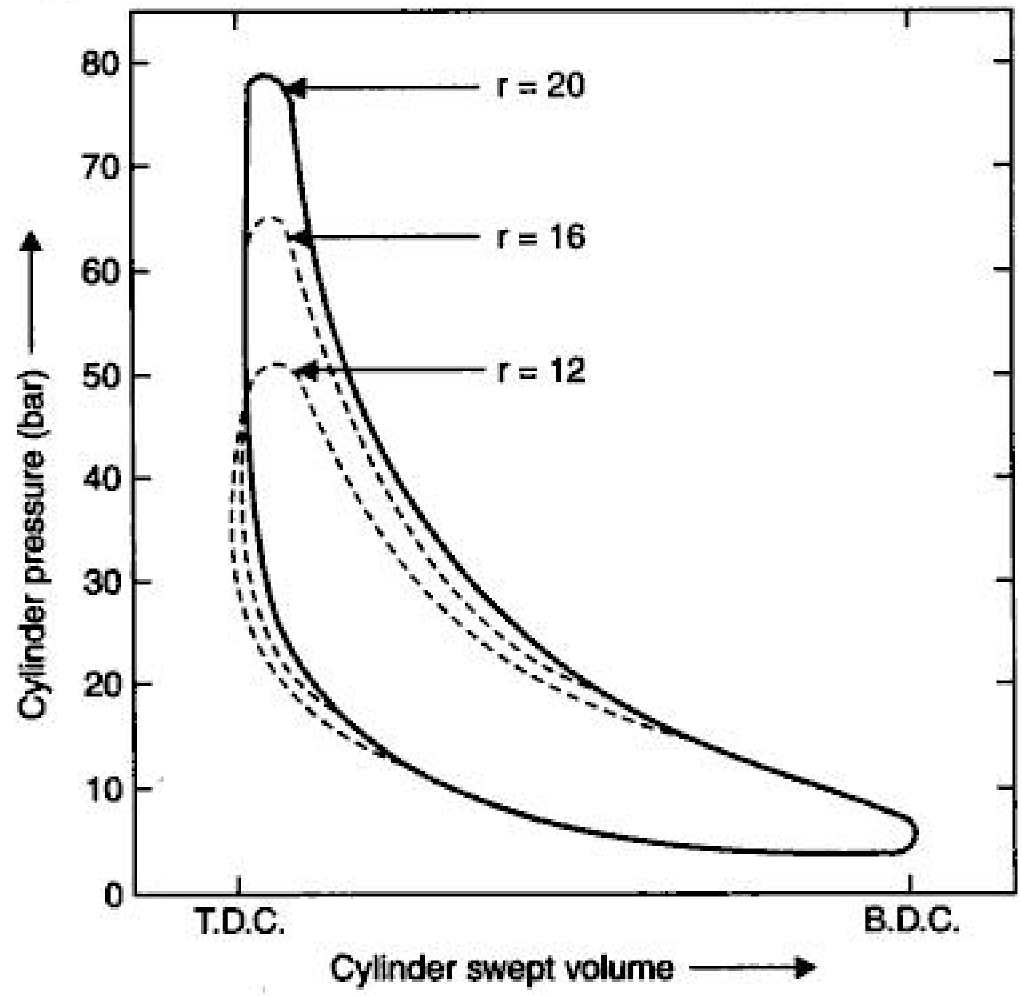


Fig. 2.71. Effect of compression ratio on the characteristic pressure—volume diagrams for a diesel engine.

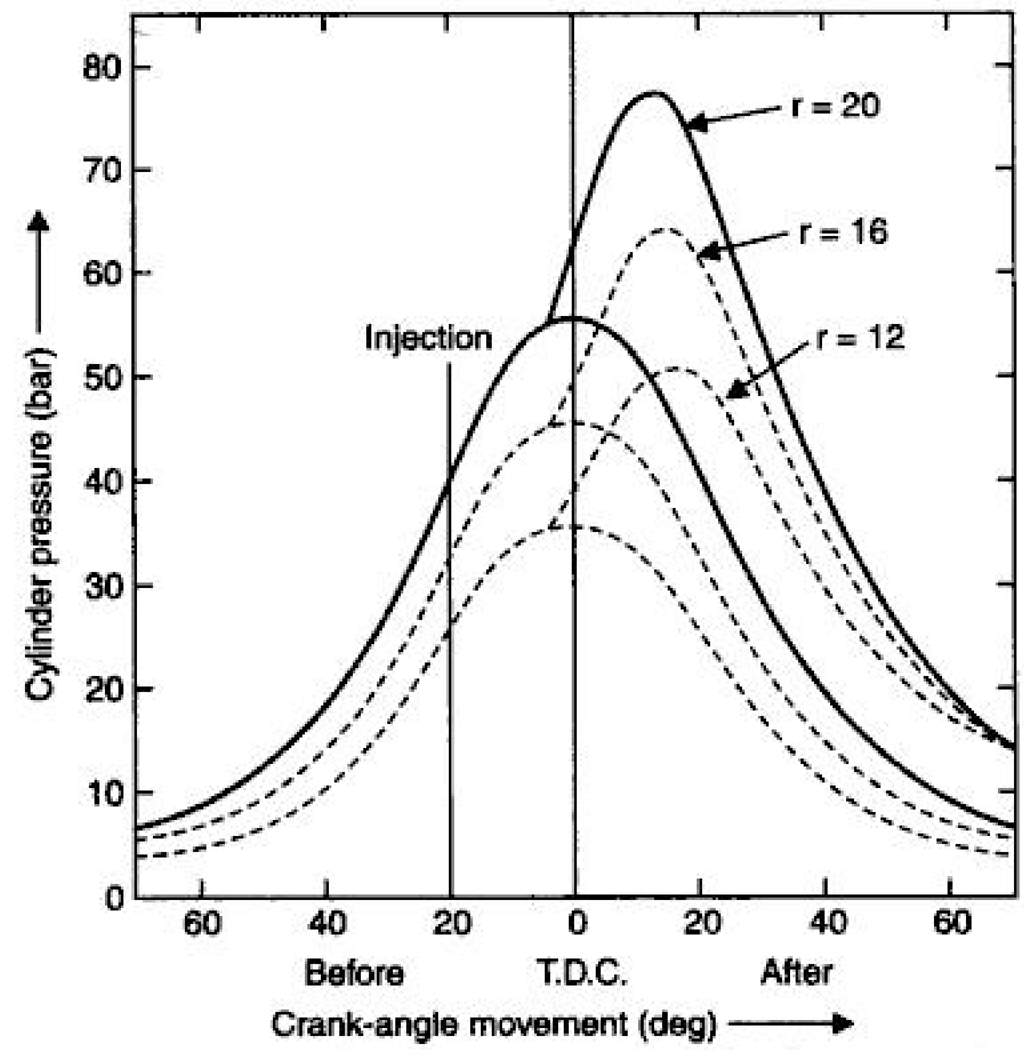


Fig. 2.72. Effect of compression ratio on the characteristic pressure–crank-angle movement diagrams for a diesel engine.

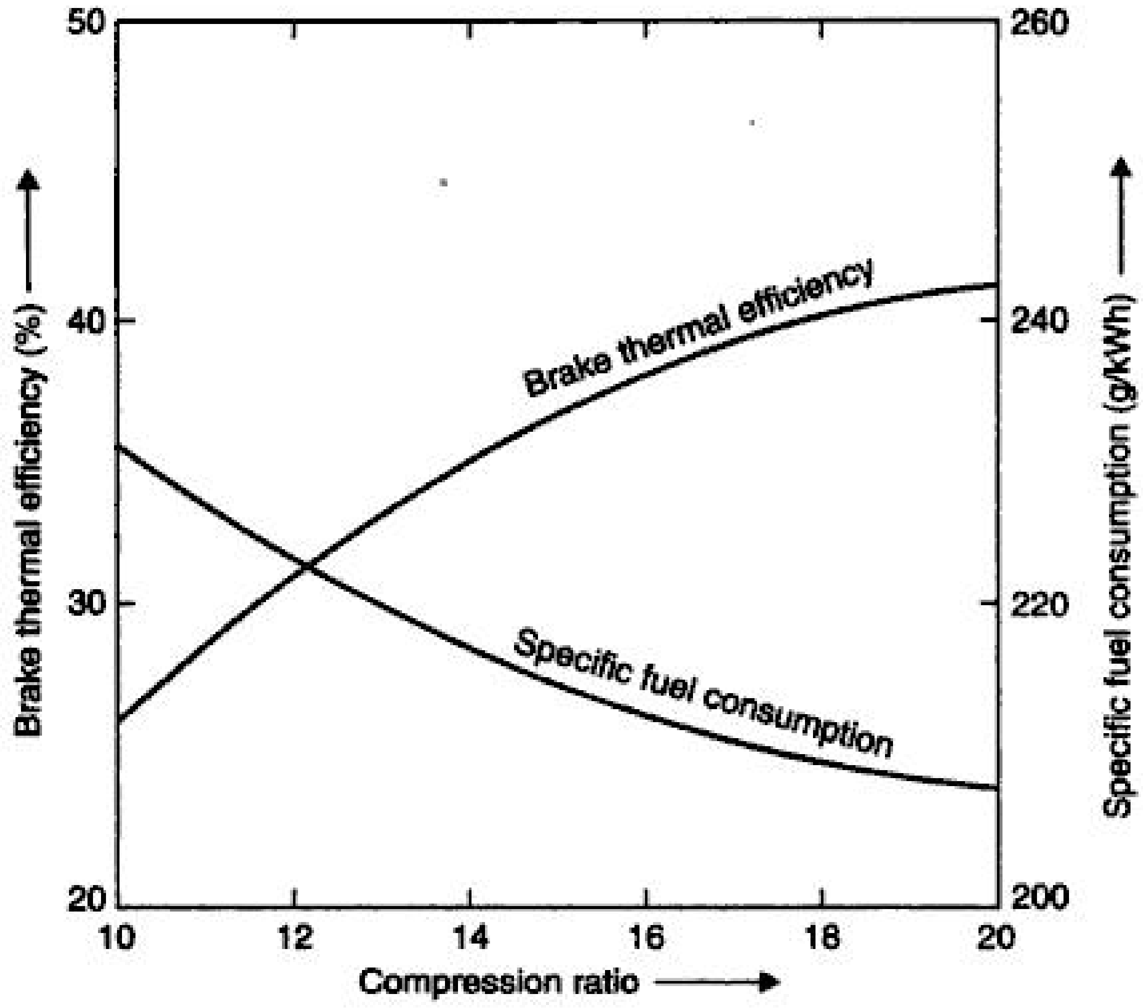


Fig. 2.73. Effect of compression ratio on the thermal efficiency and specific fuel consumption.

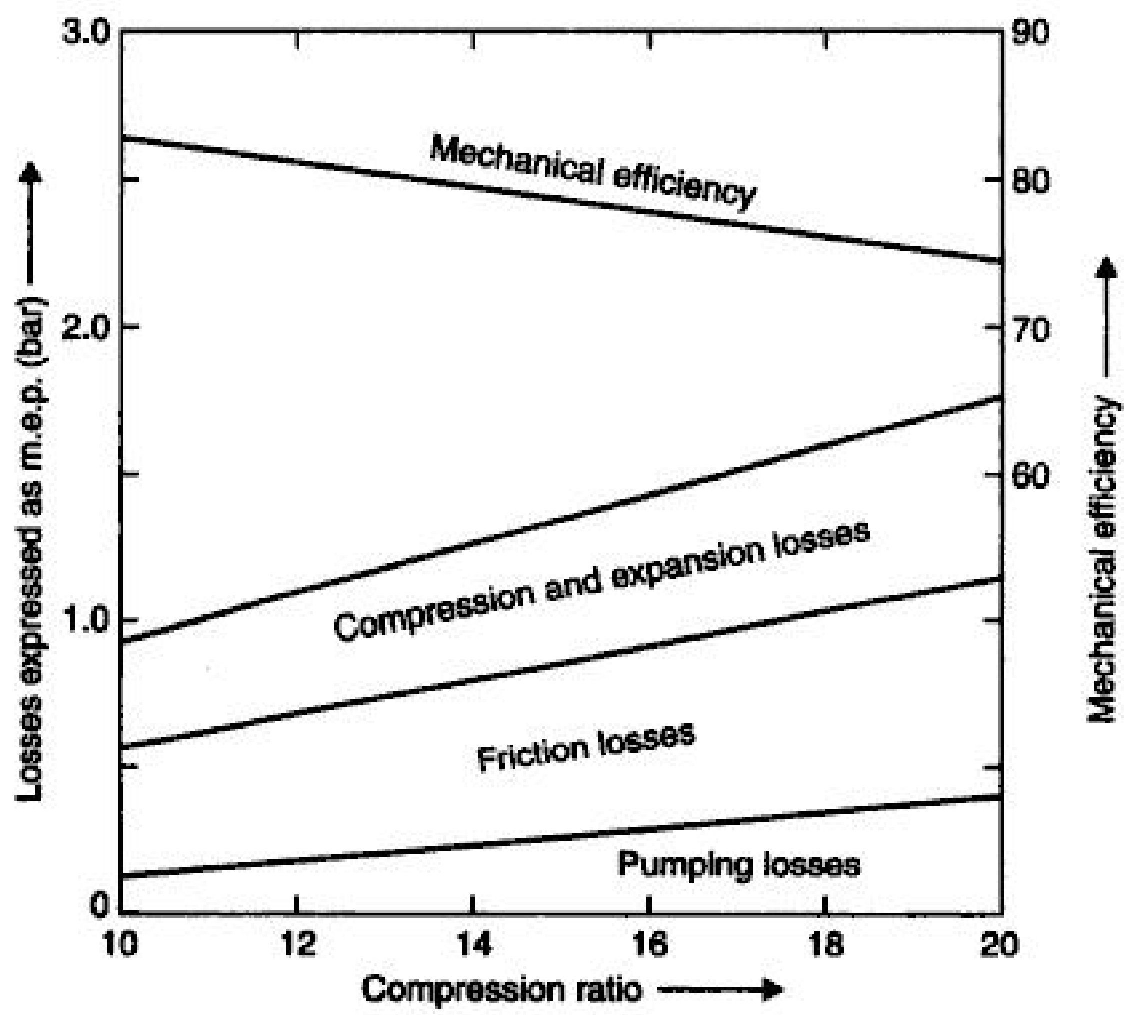


Fig. 2.74. Effect of compression ratio on the pumping, friction, compression and expansion losses and the resultant mechanical efficiency.

Injection Spray Droplet size :

- *The rate of burning depends on the relative movement of the burning droplets to the surrounding air charge.*
- The time taken to establish and ignite a film of vapour surrounding a liquid droplet is *practically independent of the size of the droplet*. However, the *rate of burning* and correspondingly the pressure rise following ignition, will be *dependent upon the exposed surface area of the vaporising liquid droplets.*
- A compromise must be made to *maintain sufficient droplet size* (and, therefore, momentum so that a fresh supply of air comes continuously into contact with the shrinking size of the unburnt portion of the liquid droplets) and to *have available sufficient numbers of small droplets which provide an adequate surface vapour area for rapid combustion.*
- It is possible, to some extent, to control the droplet size by the injection needle spring closing load. Generally the greater the injector spring load, the smaller and finer will be the droplet size, whereas a light spring needle load tends to produce coarse liquid droplets.

2.31. DELAY PERIOD (OR IGNITION LAG) IN C.I. ENGINES

- In C.I. (compression ignition) engine, the fuel which is in atomised form is considerably colder than the hot compressed air in the cylinder. Although the actual ignition is almost instantaneous, *an appreciable time elapses before the combustion is in full progress. This time occupied is called the* **delay period** or **ignition lag**. *It is the time immediately following injection of the fuel during which the ignition process is being initiated and the pressure does not rise beyond the value it would have due to compression of air.*
- The delay period extends for about 13°, movement of the crank. The time for which it occurs *decreases with increase in engine speed.*
- In C.I. engine, the length of the delay period plays a vital role. *This period serves a useful purpose in that it allows the fuel jet to penetrate well into the combustion space. If there were* ***no delay*** *the fuel would burn at the injector and there would be an oxygen deficiency around the injector resulting in incomplete combustion. If the* ***delay is too long*** *the amount of fuel available for simultaneous explosion is too great and the resulting pressure rise is too rapid.*
  - The delay period affects the rate of pressure rise and hence knocking. It also affects *startability.*
  - Some delay period is necessary otherwise the droplets would not be dispersed in air for complete combustion.

Factors on which the delay period depends :

The *delay period depends upon the following :*

(*i*) Temperature and pressure in the cylinder at the time of injection.
(*ii*) Nature of the fuel mixture strength.
(*iii*) Relative velocity between the fuel injection and air turbulence.
(*iv*) Presence of residual gases.
(*v*) Rate of fuel injection.
(*vi*) To small extent the finess of the fuel spray.

- *The delay period increases with load but is not much affected by injection pressure.*

- *The delay period should be as short as possible since a long delay period gives a more rapid rise in pressure and thus causes knocking.*

Effects of Various Factors on Delay Period :

Effects of various factors such as fuel properties, intake temperature, compression ratio, engine speed, type of combustion chamber, and injection advance are discussed below :

1. **Fuel properties :**

- The *Self-Ignition Temperature (S.I.T.)* is the most important property of the fuel which affects the delay period.
  - *A lower S.I.T. means a wide margin between it and the temperature of compressed air and hence lower delay period.*
  - *Higher cetane number means a lower delay period and smoother engine operation.* Cetane number depends on the *chemical composition of fuel.* The *more paraffinic hydrocarbons are contained in fuel, higher will be the cetane number.*
- The other fuel properties which affect delay period are :

  (*i*) Volatility ;

  (*ii*) Latent heat ;

  (*iii*) Viscosity ;

  (*iv*) Surface tension.
  - *Volatility and latent* heat affect the *time taken to form an envelope of vapour.*
  - The *viscosity and surface tension* influence the *fineness of atomisation.*

2. **Intake temperature :**

- *Increase in intake temperature* would result in increase in compressed air temperature which would *reduce the delay period.*

3. **Compression ratio :**

- *Increase in compression ratio reduces delay period as it raises both temperature and density.*
  - With increase in compression ratio, temperature of air increases. At the same time the minimum auto-ignition temperature decreases due to increased density of compressed air resulting in closer contact of molecules which thereby reduces the time of reaction when fuel is injected.
  - As *the difference between compressed air temperature and minimum auto-ignition temperature increases, the delay period decreases.*

4. **Engine speed :**

- Delay period can be given either in terms of *absolute time* (in milliseconds) *or crank angle rotation.*
  - At *constant speed*, delay period *is proportional to the delay angle.*
  - In *variable speed operation*, delay period may *decrease in terms of milliseconds but increase in terms of crank angles.*

5. **Type of combustion chamber :**

- *A pre-combustion chamber gives shorter delay compared to an open type of combustion chamber.*

6. **Injection advance :**

- *Delay period increases with increase in injection advance angle.* The reason for increase in delay period with increase in injection advance angle is that pressures and temperatures are lower when injection begins.

- When injection advance angles are small, delay period reduces and operation of engine is smoother but power is reduced because large amount of fuel burns during expansion.

Abnormal Combustion in C.I. engines :

In C.I. engines, abnormal combustion is not a great problem as in S.I. engines. The only abnormality is ***"diesel knock"***. *This occurs when the delay period is excessively long so that there is a large amount of fuel in the cylinder for the simultaneous explosion phase.* The rate of pressure rise per degree of crank angle is then so great that an *audible knocking sound occurs.* Running is rough and if allowed to become extreme the *increase in mechanical and thermal stresses may damage the engine.* ***Knock*** *is thus a function of the fuel chosen and may be avoided by choosing a fuel with characteristics that do not give too long a delay period.*

2.32. DIESEL KNOCK

- *Diesel knock is the sound produced by the very rapid rate of pressure rise during the early part of the uncontrolled second phase of combustion.* The primary cause of an excessively high pressure rise is due to a *prolonged delay period* (Fig. 2.75). An extensive delay period can be due to the following *factors* :
  - (*i*) A low design compression ratio permitting only a marginal self-ignition temperature to be reached.
  - (*ii*) A low combustion pressure due to worn piston rings or badly seating valves.
  - (*iii*) Poor fuel ignition quality ; that is a low cetane number fuel.
  - (*iv*) A poorly atomized fuel spray preventing early ignition to be established.
  - (*v*) An inadequate injector needle spring load producing coarse droplet formation.
  - (*vi*) A very low air intake temperature in cold wintry weather and during cold starting.

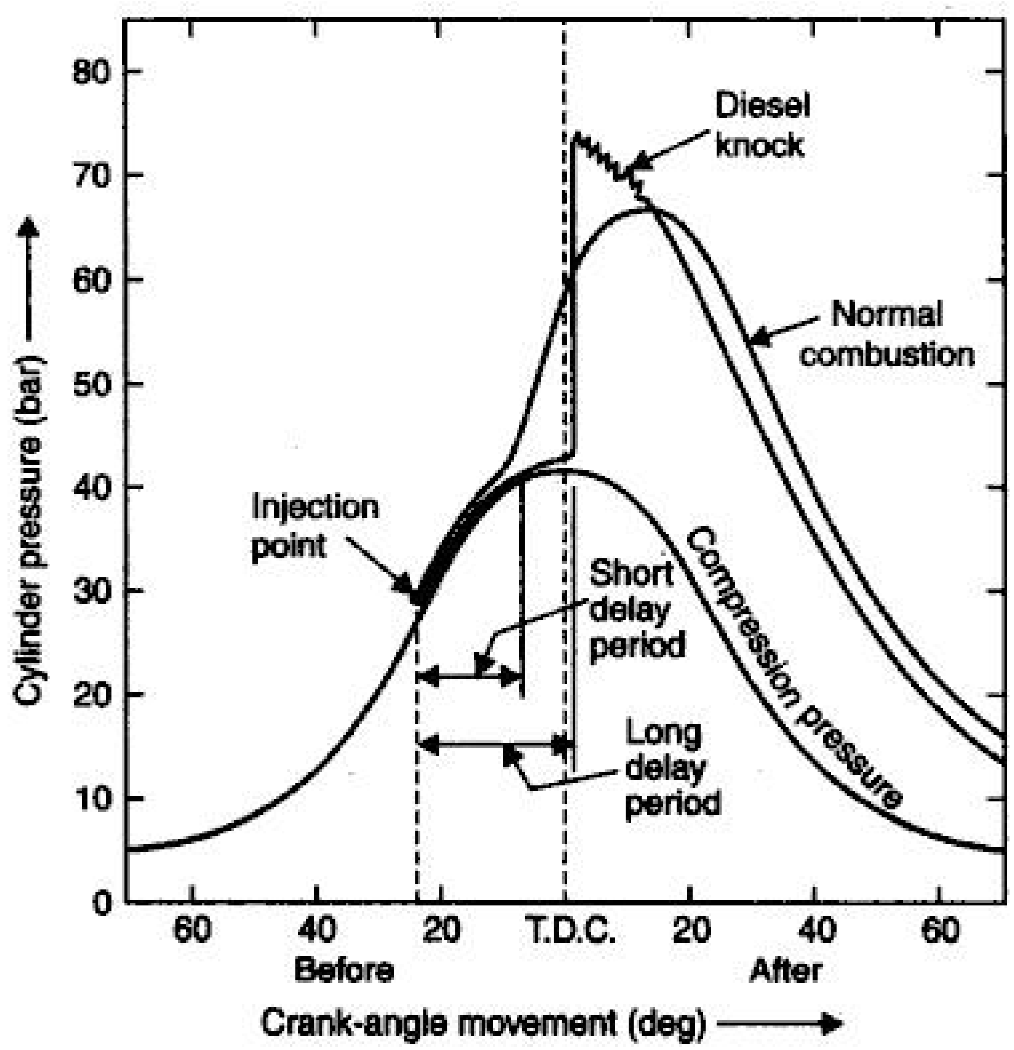


Fig. 2.75. Effect of short and long delay period on the characteristic p-θ diagram.

- A *very long ignition lag after injection causes a large proportion of the fuel discharge to enter the cylinder and to atomise before ignition and the propagation of burning actually occurs. Accordingly, when combustion does commence a relative amount of heat energy will be released almost immediately, this correspondingly produces the abnormally high rate of pressure rise, which is mainly responsible for rough and noisy combustion process under these condition (Fig. 2.75).*
- It has been observed generally, that provided the rate of pressure increase does not exceed 3 bar *per degree of crank-angle movement,* combustion will be relatively smooth, whereas *between a 3 and 4 bar pressure rise there is a tendency to knock and, above this rate of pressure rise, diesel knock will be prominent.*

Differences in the knocking phenomenon of the S.I. and C.I. Engines :

The following are the *differences in the knocking phenomena of the S.I. and C.I. engines* :

1. In the *S.I. engine,* the detonation occurs *near the end of combustion* whereas in the *C.I.* engine detonation occurs *near the beginning of combustion.*
2. The detonation in the S.I. engine is of a homogeneous charge causing very high rate of pressure rise and very high maximum pressure. In the C.I. engine, the fuel and air are imperfectly mixed and hence the rate of pressure rise is *normally lower than that in the detonating part of the charge in the S.I. engine.*
3. In the C.I. engine the fuel is injected into the cylinder only at the end of the compression stroke, *there is no question of pre-ignition as in S.I. engine.*
4. *In the S.I. engine, it is relatively easy to distinguish between knocking and non-knocking operation as the human ear easily finds the distinction.*
5. *Factors that tend to reduce detonation in the S.I. engine increase knocking in the C.I. engine.*

Methods of controlling diesel knock (Reducing delay period) :

The *diesel knock can be controlled by reducing delay period.* The delay is reduced by the following :

(*i*) High charge temperature.

(*ii*) High fuel temperature.

(*iii*) Good turbulence.

(*iv*) A fuel with a short induction period.

2.33. C.I. ENGINE COMBUSTION CHAMBERS

2.33.1. Primary Considerations in the Design of Combustion Chambers for C.I. Engines

In C.I. engines fuel is injected into the combustion chamber at about 15°C before T.D.C. during the compression stroke. For the best efficiency the combustion must complete within 15° to 20° of crank rotation after T.D.C. in the working stroke. Thus it is clear that injection and combustion both must complete in the short time. For best combustion mixing should be completed in the short time.

- In S.I. engine mixing takes place in carburettor, however in C.I. engines this has to be done in the combustion chamber. To achieve this requirement in a short period is an extremely difficult job particularly in high speed C.I. engines.
- From combustion phenomenon of C.I. engines it is evident that fuel-air contact must be limited during the delay period in order to limit $\frac{dp}{dt}$, the rate of pressure rise in the

second stage of combustion. This result can be obtained by *shortening the delay time. To achieve high efficiency and power the combustion must be completed when the piston is nearer to T.D.C., it is necessary to have rapid mixing of fuel and air during the third stage of combustion.*

- The design of combustion chamber for C.I. engines *must also take consideration of fuel injection system and nozzles to be used.*

The considerations can be summarized as follows :

1. High thermal efficiency.
2. Ability to use less expensive fuel (multi-fuel).
3. Ease of starting.
4. Ability to handle variations in speed.
5. Smoothness of operation *i.e.*, avoidance of diesel knock and noise.
6. Low exhaust emission.
7. Nozzle design.
8. High volumetric efficiency.
9. High brake mean effective pressure.

2.33.2. Basic Methods of generating Air Swirl in C.I. Engines Combustion Chambers

There are *there basic methods of generating swirl in a C.I. engine combustion chamber,* which are mentioned below :

1. By *directing the flow of air during its entry to the cylinder, known as* ***induction swirl.*** This method is *used in open combustion chamber.*

2. By *forcing the air through a tangential passage into a separate swirl chamber during compression stroke,* known as ***compression swirl.*** This method is used in *swirl chambers.*

3. By *use of initial pressure rise due to partial combustion to create swirl turbulence,* known as ***combustion induced swirl.*** This method is used in *pre-combustion chambers and air-cell chambers.*

Induction swirl : Refer Fig. 2.76.

- In a *four stroke engine* induction swirl can be obtained either by careful formation of air intake passages or masking or shrouding a portion of circumference of inlet valve. The angle of mask is from 90° to 140° of the circumference.
- In *two stroke engine,* induction swirl is *created by suitable inlet port forms.*

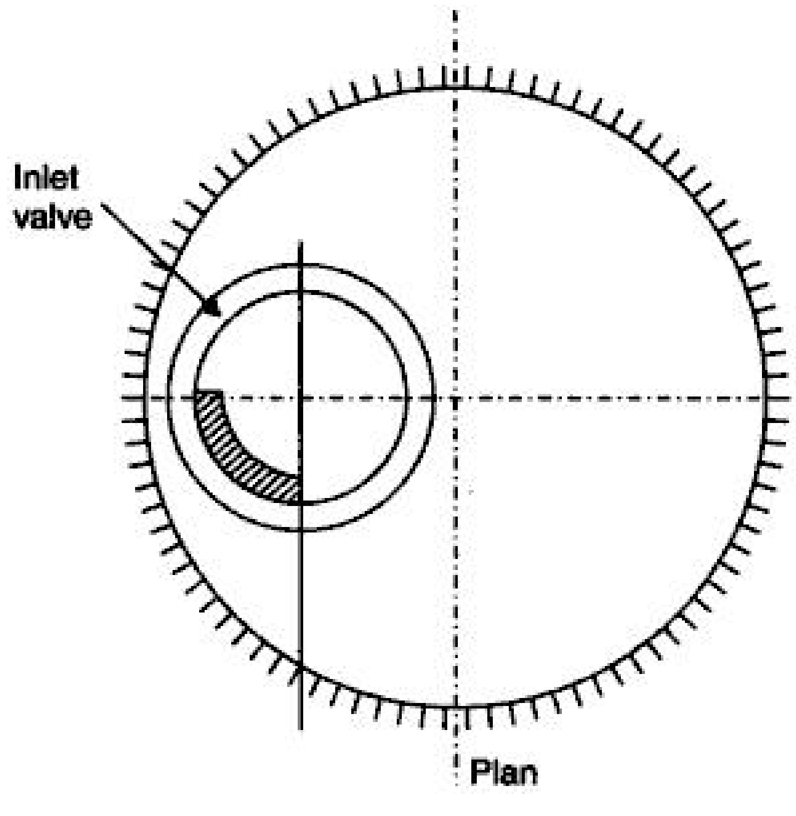


Fig. 2.76. Induction swirl by masking the inlet valve.

- The induction swirl generated by air intake passages is very weak. If a masked inlet valve is used, it provides an obstruction in the passage which reduces volumetric efficiency. Therefore *swirl generated is weak* even with this method. With a weak swirl, a single orifice injection cannot provide the desired air fuel mixing. Therefore, with induction swirl, *we have to use a multiple-orifice injector.*

Advantages of induction swirl :

1. Easier starting (due to low intensity of swirl).
2. High excess air (low temperature), low turbulence (less heat loss), therefore indicated thermal efficiency is high.
3. Production of swirl requires no additional work.
4. Used with low speeds, therefore low quality of fuel can be used.

Disadvantages :

1. Shrouded valves, smaller valves, low volumetric efficiency.
2. Weak swirl, low air utilisation (60%), lower m.e.p. and large size (costly) engine.
3. Weak swirl, multi-orifice nozzle, high induction pressure, clogging of holes, high maintenance.
4. Swirl not proportional to speed ; efficiency not maintained at variable speed engine.
5. Influence minimum quantity of fuel. Complication at high loads and idling.

Compression swirl : Refer to Fig. 2.77.

- The second method of generating swirl is by compression swirl in what is known as *swirl chamber*. A swirl chamber is a *divided chamber*. A divided combustion chamber is defined as one in which combustion space is divided into two or more distinct compartments, between which there are restrictions or throats small enough so that considerable pressure differences occur between them during combustion process.
- This swirl is maximum at about 15° before T.D.C. *i.e.*, close to the time of injection. The fuel is injected into the swirl chamber and ignition and bulk of combustion takes place therein. A considerable amount of heat is lost when products of combustion pass back through the same throat and this loss of heat is reduced by employing a heat insulated chamber. Thus, it serves as a thermal regenerator receiving heat during combustion and expansion and returning the heat to air during compression stroke. However the loss of heat to surface of combustion chamber is greater than induction swirl.

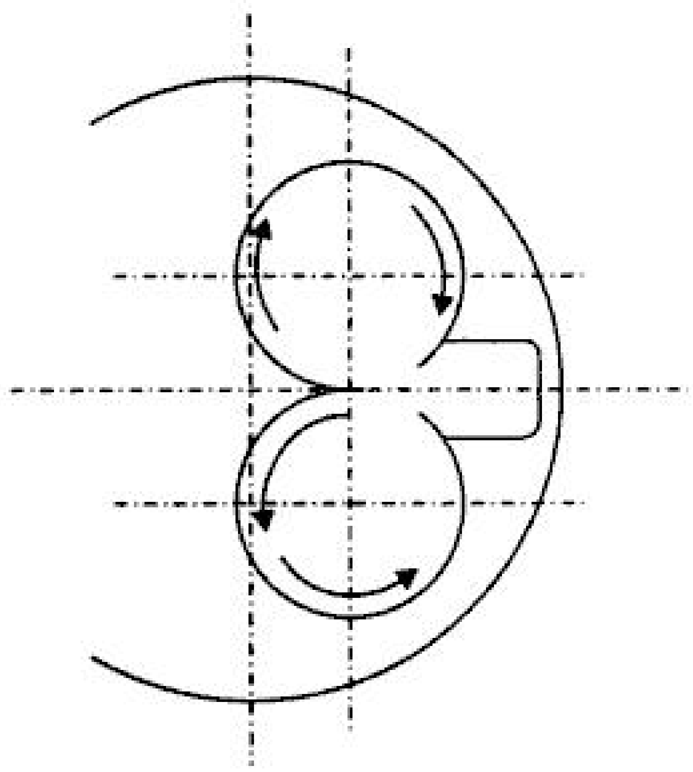


Fig. 2.77. Compression swirl.

- In *combustion swirl, a very strong swirl which increases with speed is generated.*

Advantage of compression swirl :

1. Large valves, high volumetric efficiency.
2. Single injector, pintle type (self cleaning), less maintenance.
3. Smooth engine operation.
4. Greater air utilization due to strong swirl. Smaller (cheaper) engine.
5. Swirl proportional to speed, suitable for variable speed operation.

Disadvantages :

1. Cold starting trouble due to high loss due to strong swirl, mechanical efficiency lower.
2. Less excess air ; lower indicated efficiency ; 5 to 8% more fuel consumption ; decreased exhaust valve life.
3. Cylinder more expensive in construction.
4. Work absorbed in producing swirl, mechanical efficiency lower.

Combustion induced swirl :

- This type of *swirl is induced by use of initial pressure rise due to partial combustion.*
- The combustion chambers which use this type of *swirl are not much favoured these days.*

2.33.3. Types of Combustion Chambers

In C.I. engines several types of combustion chambers are used. Each of these has its own peculiarities, and desirable, as well as undesirable features. Any one of these combustion chambers may produce good results in one field of application, but less desirable, or even poor results in another. No one combustion chamber design has yet been developed which will produce the best result is all types of engines. The particular design chosen, then, must be that which accomplishes the best performance for the application desired.

Four specific designs which find wide use in C.I. engines are discussed below :

A. The non-turbulent type
  (*i*) Open or direct combustion chamber.

B. The turbulent type
  (*i*) Turbulent chamber
  (*ii*) Pre-combustion chamber
  (*iii*) Energy cell.

1. **Open or direct combustion chamber :**

- Fig. 2.78 illustrates the usual design of *open combustion chamber*, which is representative of non-turbulent type.
- The fuel is injected directly into the upper portion of the cylinder, which acts as the combustion chamber. This type depends little on turbulence to perform the mixing. Consequently, the heat loss to the chamber walls is relatively low, and *easier starting results.* In order to obtain proper penetration and dispersal of the fuel necessary for mixing with the air, however, high injection pressures and multi-orifice nozzles are required. This necessitates small nozzle openings and results in more frequent clogging or diversion of the fuel spray by accumulated carbon particles, with consequent higher maintenance costs.

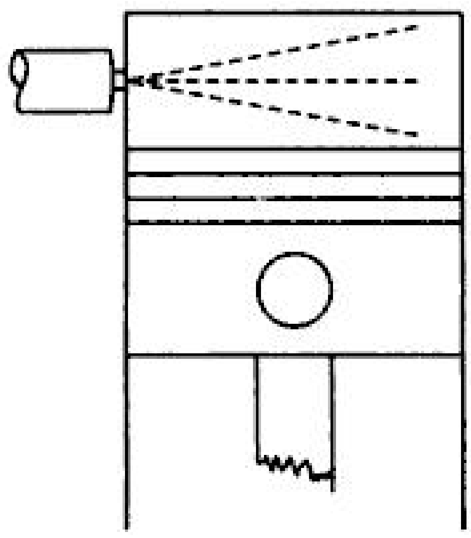
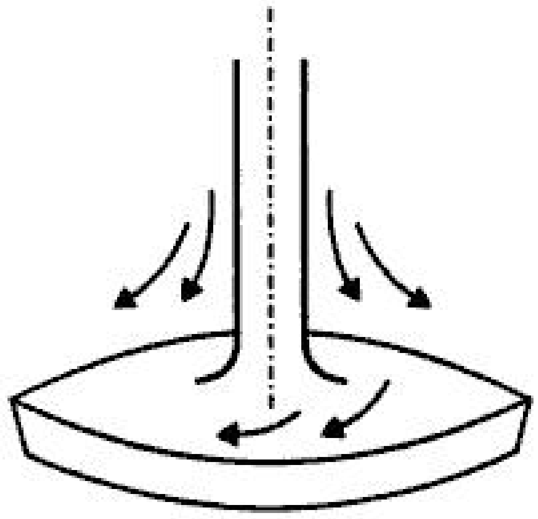


Fig. 2.78. Open or direct combustion chamber.

- This type of chamber is ordinarily used on *low speed engines,* where injection is spread through a greater period of time and thus ignition delay is a relatively less important factor. Consequently, *less costly fuels with longer ignition delay may be used.*
- Many attempts were made to improve the air motion in open chambers, the important are :
  (*a*) *by shrouding the inlet valve,* Refer Fig. 2.79 (*a*)
  (*b*) *by providing squish,* Refer Fig. 2.79 (*b*)



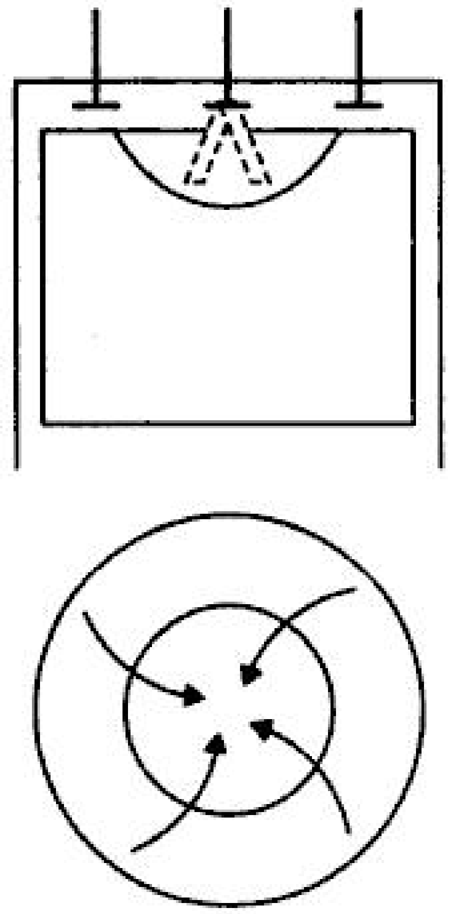


Fig. 2.79. (*a*) Air motion by shrouding the inlet valve. Fig. 2.79. (*b*) Squish air motion inside cylinder.

- By shrouding the inlet valve swirl motion is given to the air entering the cylinder which is believed to persist during compression stroke and the time of injection. This system gives better performance at low speeds, however volumetric efficiency reduces on account of reduction in inlet area due to shroud.
- Squish is provided by pushing the air at the end of the compression stroke in the space whose diameter is smaller than the cylinder bore. Because of the small clearance between the head and piston top when at T.D.C. air is pushed into combustion space providing air movement known as *squish*. The squish helps in mixing of fuel and air.

2. Turbulent chamber :

In the '*turbulent chamber*' (Fig. 2.80) the upward moving piston forces all the air (or 70–80% of all air) at a greater velocity into a small antechamber, thus imparting a rotary motion to the air passing the pintle type nozzle. As the fuel is injected into the rotating air, it is partially mixed with this air, and commences to burn. The pressure built up in the antechamber by the expanding burning gases force the burning and unburned fuel and air mixtures back into the main chamber, again imparting high turbulence and further assisting combustion.

Advantages :

(*i*) The insulated or hot running combustion chamber shortens the delay period and limits the rate of pressure rise, resulting in smoother running.

(*ii*) The turbulence is responsible for rapid mixing and burning of fuel during the third stage of combustion.

(*iii*) Suitable for high speeds as the amount of turbulence is proportional to piston or engine speed. The burning in the third stage will be completed early without resulting in late burning.

(*iv*) The demands on the fuel injection system are not severe as it is not to be depended upon for mixing, distribution, etc.

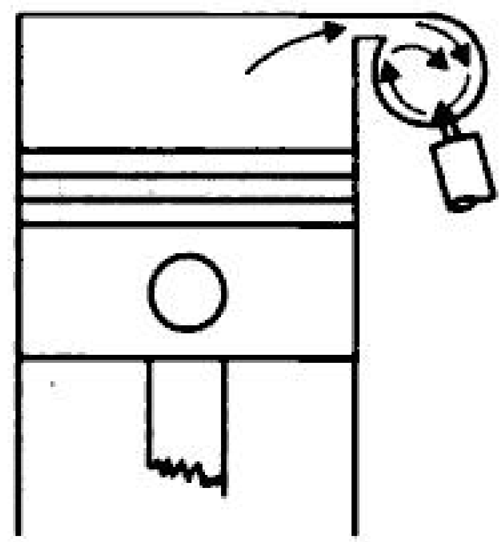


Fig. 2.80. Turbulent chamber.

The ***disadvantage*** is *that cold starting is difficult since air lose heat to combustion chamber walls during the compression stroke. The combustion chamber is relatively cool at the starting.*

3. **Pre-combustion chamber.** Refer to Fig. 2.81.

Here the combustion chamber is separated into *two chambers*. The smaller one of the chambers occupy about *30 per cent of total combustion space.* The communication between two chambers is a narrow restricted passage or a number of small holes. The air is forced into the pre-combustion chamber by piston during the compression stroke. Fuel is injected into the pre-combustion chamber. The chamber is designed to run hot and this results in shortening the delay period of fuel which is highly desirable. The products from this chamber rushes into main combustion space through restricted passages, creating violent air motion. This violent air motion helps in rapid mixing and burning in the main combustion space. The fuel reaching the main combustion space has practically no delay period as the temperature is already high due to combustion in pre-combustion chamber and combustion in main chamber is rapid and complete (*i.e.*, third stage of combustion) due to violent air motion.

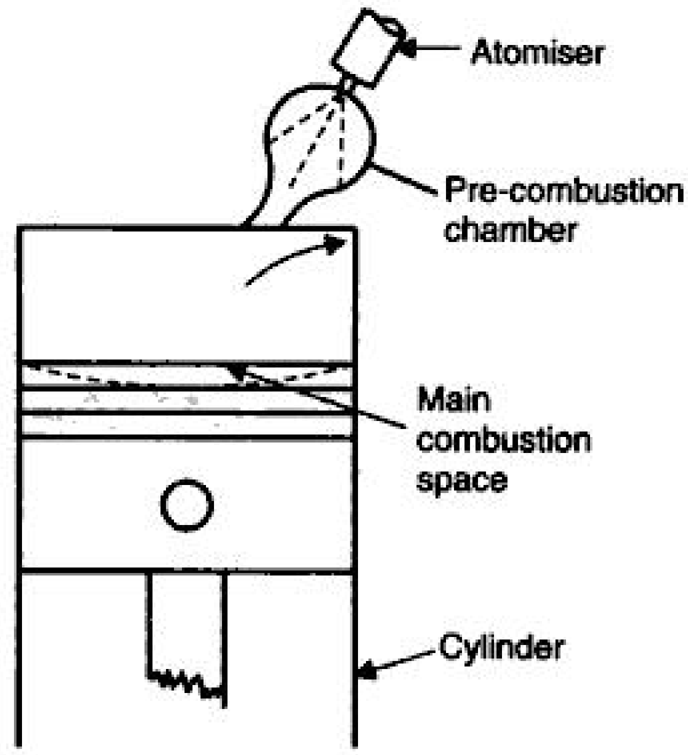


Fig. 2.81. Pre-combustion chamber.

Advantages :

(*i*) Due to short or practically no delay period for the fuel entering the main combustion space, *tendency to knock is minimum*, and as *such running is smooth.*

(*ii*) The combustion in the third stage is *rapid.*

(*iii*) As the mixing of fuel and air is thorough due to vialent projection of combustion products from pre-chamber, the *fuel injection system design need not be critical.*

Disadvantages :

(*i*) The velocity of burning mixture is too high during the passage from prechambers, so the heat loss is very high. This causes reduction in the thermal efficiency, which can be offset by increasing the compression ratio.

(*ii*) Cold starting will be difficult as the air loses heat to chamber walls during compression.

4. **Energy cell :**

The *'energy cell'* is more complex than the pre-combustion chamber. It is illustrated in Fig. 2.82. As the piston moves up on the compression stroke, some of the air is forced into the major and minor chambers of the energy cell. When the fuel is injected through the pintle type nozzle, part of the fuel passes across the main combustion chamber and enters the minor cell, where it is mixed with the entering air. Combustion first commences in the main combustion chamber where the temperature is higher, but the rate of burning is slower in this location, due to insufficient mixing of the fuel and air. The burning in the minor cell is slower at the start, but due to better mixing,

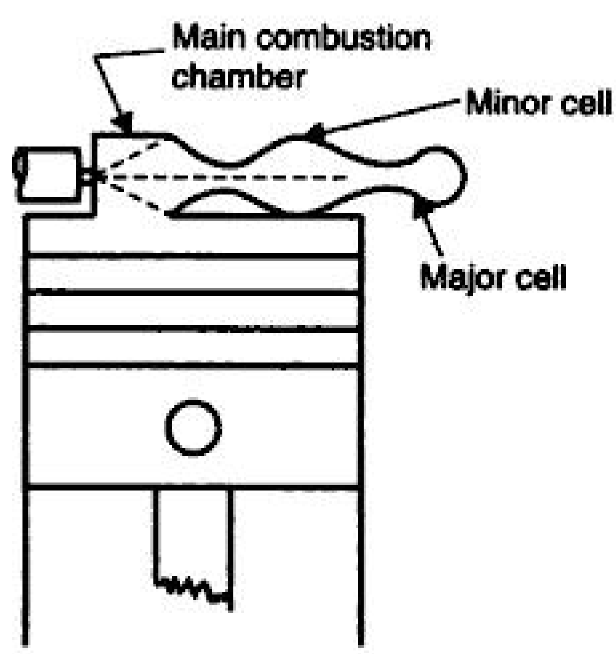


Fig. 2.82. Energy cell.

progresses at a more rapid rate. The pressures built up in the minor cell, therefore, force the burning gases out into the main combustion chamber, thereby creating added turbulence and producing better combustion in this chamber. In the mean time, pressure is built up in the major cell, which then prolongs the action of the jet stream entering the main chamber, thus continuing to induce turbulence in the main chamber.

5. **M. Combustion chamber :**

- After twenty years of research in 1954, Dr. Meuner of M.A.N., Germany developed M-process engine which ran without typical diesel combustion noise and hence it was named *'whisper engine'*.
- Fig. 2.83 shows a combustion chamber developed for small high speed engines. It differs from the other open combustion chamber engines in the respect that *fuel spray impinges tangentially on, and spreads over, the surface of a spherical space in the piston.* There is always some impingement of spray on the combustion chamber walls in all successful diesel engine designs. This impingement was not considered desirable till M.A.N. combustion system was experimented.
- The M.A.N. system's theory is that *enough of spray will ignite before impingement so that delay period will be normal while most of the fuel spray will evaporate from the hemispherical combustion space in piston prior to combustion.* Thus the *second stage of combustion is slowed down avoiding excessive rate of pressure rise.* Shrouded inlet valve is used to give air swirl in direction of arrow.

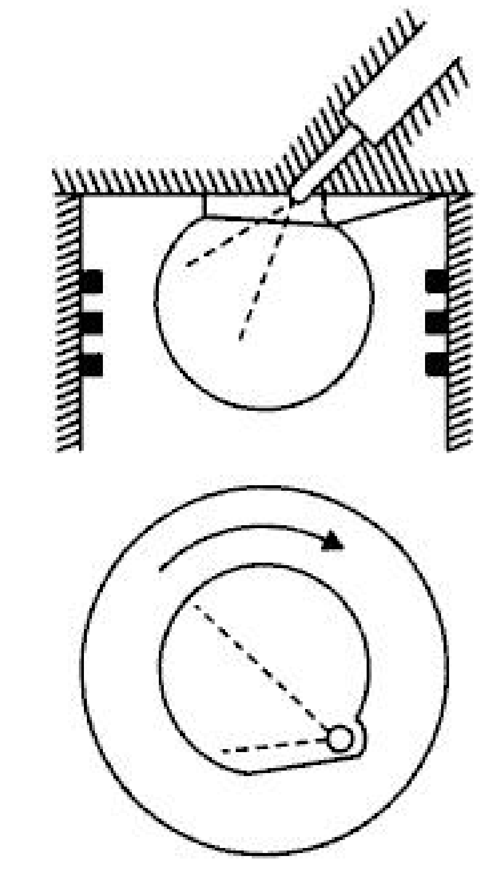


Fig. 2.83. M.A.N. 'M' combustion chamber.

Advantages :

'M-chamber' claims the following *advantages :*

(*i*) Low peak pressure.
(*ii*) Low rate of pressure rise.
(*iii*) Low smoke level.
(*iv*) Ability to operate on a wide range of liquid fuels (multi-fuel capability).

Disadvantages :

(*i*) Low volumetric efficiency.
(*ii*) Since fuel vaporisation depends upon the surface temperature of the combustion chamber, cold starting requires certain aids.
(*iii*) At starting and idling conditions hydrocarbon emissions may occur.

Table below gives *comparison between open combustion chambers and divided combustion chambers.*

S. No.	Aspects	Open combustion chamber	Divided combustion chamber
1.	*Fuel used*	Can consume fuels of good ignition quality, *i.e.*, of shorter ignition delay or higher cetane number.	Can consume fuels of poor ignition quality *i.e.*, larger ignition delay. or lower cetane number.
2.	*Type of injection nozzle used*	Requires multiple hole injection nozzles for proper mixing of fuel	It is able to use single hole injection nozzles and moderate injection

		and air, and also higher injection pressures.	pressures. It can tolerate greater degree of nozzle fouling.
3.	*Sensitivity to fuel spray characteristic*	Sensitive.	Insensitive.
4.	*Mixing of fuel and air*	Mixing of fuel and air is not so efficient and thus high fuel/air ratios are not feasible without smoke.	Ability to use higher fuel/air ratios without smoke, due to proper mixing and consequent high air utilization factor.
5.	*Cylinder construction*	Cylinder construction is simple.	More expensive cylinder construction.
6.	*Starting*	Easy cold starting.	Difficult cold starting because of greater heat loss through the throat.
7.	*Thermal efficiency*	Open combustion chambers are thermally more efficient.	Divided combustion chambers suffer from irreversibilities like throttling through the throat during the compression and expansion ; thus leading to pressure losses and available heat losses. Therefore, these engines are thermally less efficient comparatively.

Summarily it may be said that a particular combustion chamber design must be chosen to perform a given job. No one combustion chamber can produce an ultimate of performance in all tasks. In most engineering work, the design of the chamber must be based on a compromise, after full considerations of the following factors :

(*i*) Heat lost to combustion chamber walls.
(*ii*) Injection pressure.
(*iii*) Nozzle design.
(*iv*) Maintenance.
(*v*) Ease of starting.
(*vi*) Fuel requirement.
(*vii*) Utilisation of air.
(*viii*) Weight relation of engine to power output.
(*ix*) Capacity for variable speed operation.

2.34. COLD STARTING OF C.I. ENGINES

- The important requirement of a C.I. engine is its easy starting from cold. To fulfil this requirement frequently compression ratios higher than necessary are used. Cold work, even so, may become difficult under the following conditions :
  - When the cylinder liner is heavily worn ;
  - When the valves are leaky ;
  - Extreme cold climate (like Himalyan region).

Therefore, sometimes, it is necessary to provide some electrical aid for cold starting.

- *Open chamber direct injection engines are easiest to cold start because of the following reasons :*
  (*i*) They have smallest surface to volume (S/V) ratio, as a consequence heat loss is minimum.
  (*ii*) They have lowest intensity of swirl, due to which stagnant gas film remains on the cylinder walls which reduces heat transfer.

Cold starting aids for C.I. engines :

Several methods have been used in the past to *achieve easy cold starting*. Few of them are listed below :

1. *Preheating the engine cylinder by warm water.*
2. *Injection of a small quantity of lubricating oil or fuel oil.* This method temporarily raises the compression ratio, and seals the piston rings and valves.
3. *Provision of cartridges.*
4. *Modifying valve timings for starting.*
5. *Starting as petrol engine* by providing a carburettor and a spark-plug. At starting compression ratio is reduced by providing an auxiliary chamber.

Modern starting aids of high speed engines :

The following basic three types of starting aids are used on modern high speed diesel engines :

1. *Electric glow plugs* (in the combustion chamber)
2. *Manifold heaters* (which ignite a small feed of fuel)
3. Injection of ether.

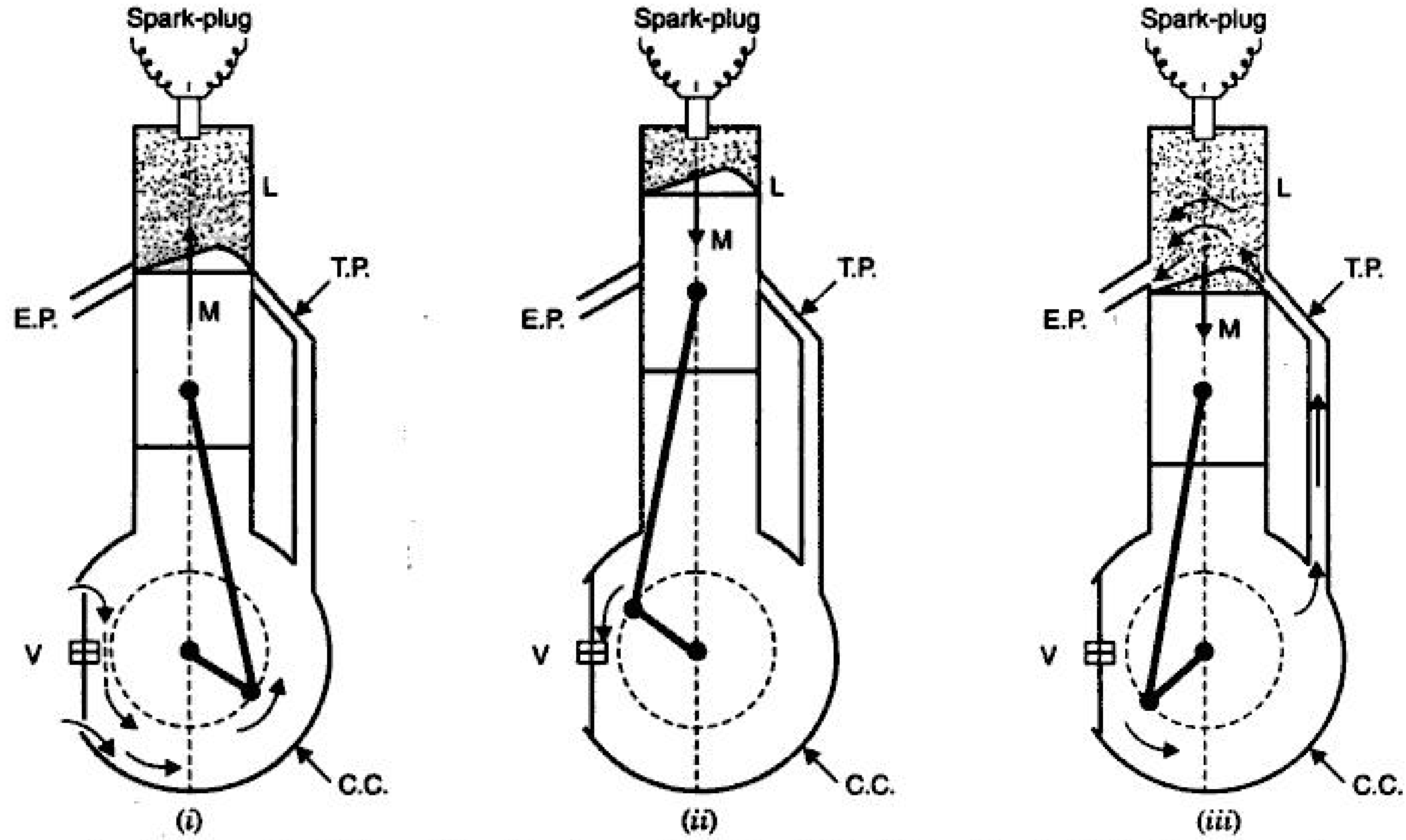
IV. Two Stroke Engines

2.35. GENERAL ASPECTS

2.35.1. Construction and Working

- In 1878, Dugald-clerk, a British engineer introduced a cycle which could be completed in two *strokes of piston rather than four strokes* as is the case with the four stroke cycle engines. The engines using this cycle were called *two stroke cycle engines*. In this engine suction and exhaust strokes are eliminated. Here *instead of valves, ports are used. The exhaust gases are driven out from engine cylinder by the fresh charge of fuel entering the cylinder nearly at the end of the working stroke.*
- Fig. 2.84 shows a two-stroke petrol engine (used in scooters, motor cycle etc.) Refer to Art. 2.12 also.
  - The cyclinder L is connected to a closed crankcase C.C.
  - During the upward stroke of the piston M, the gases in L are compressed and at the same time fresh air and fuel (petrol) mixture enters the crank chamber through the valve V.
  - When the piston moves downwards, V closes and the mixture in the crank chamber is compressed.
  - Refer Fig. 2.84 (*i*), the piston is moving upwards and is compressing an explosive charge which has previously been supplied to L. Ignition takes place at the end of the stroke. The piston then travels downwards due to expansion of the gases

(Fig. 2.84 (*ii*)) and near the end of this stroke the piston uncovers the exhaust port (E.P.) and the burnt exhaust gases escape through this port [Fig. 2.84 (*iii*)].



L = Cylinder ; *M* = Piston ; *C.C.* = Crankcase ; *V* = Valve ; *E.P.* = Exhaust port ; *T.P.* = Transfer port.

Fig. 2.84. Two stroke cycle engine (crankcase scavenged).

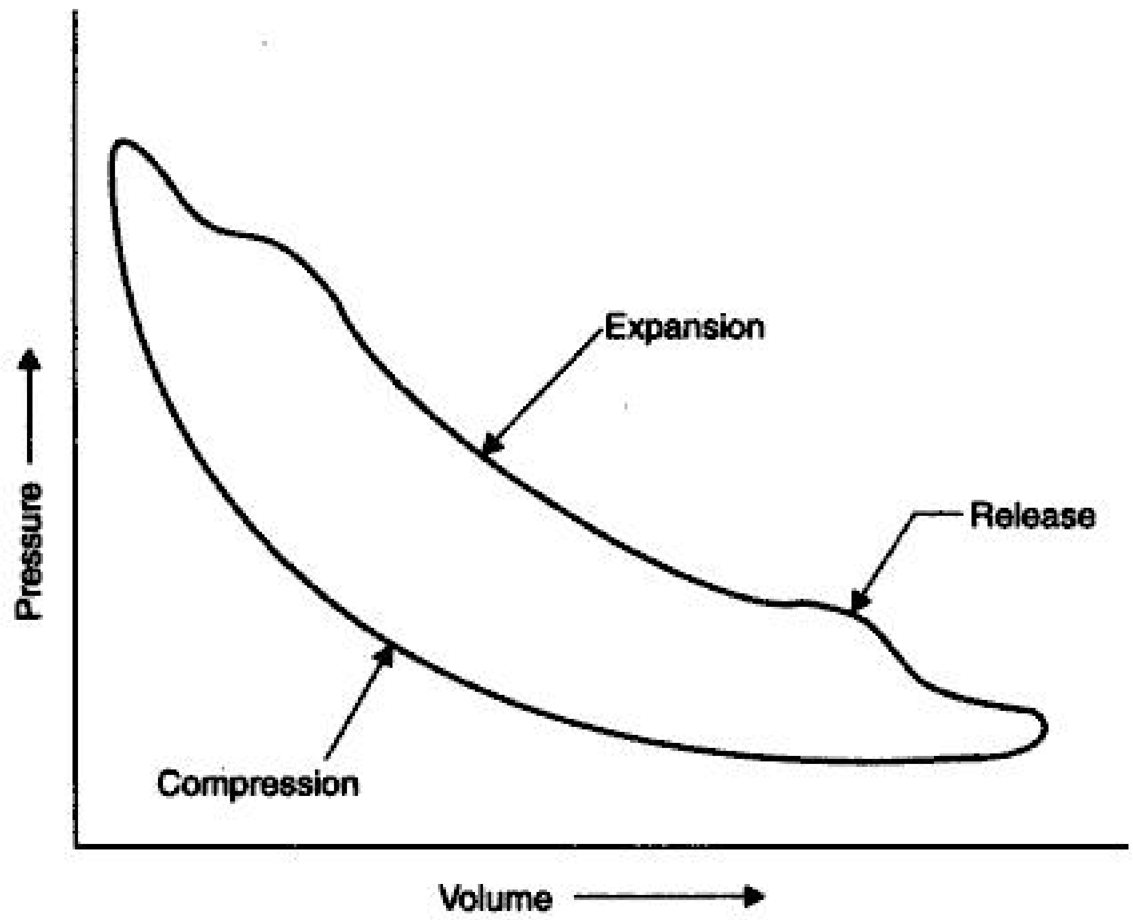


Fig. 2.85. *p-V* diagram for a two stroke cycle engine.

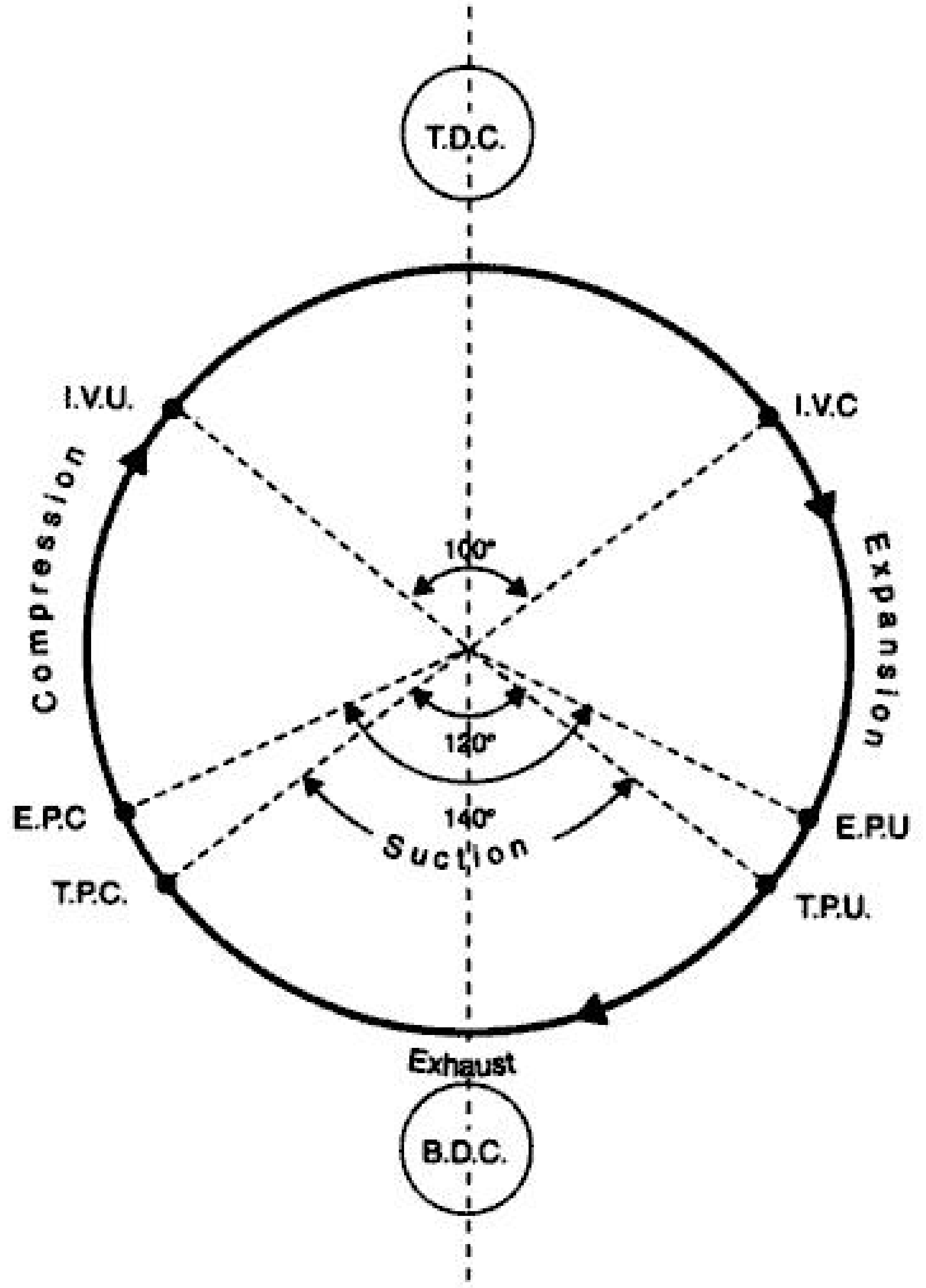


Fig. 2.86. Port timing diagram.

- The transfer port (T.P.) then is uncovered immediately, and the compressed charge from the crank chamber flows into the cylinder and is deflected upwards by the hump provided on the head of the piston. It may be noted that the *incoming air petrol mixture helps the removal of gases from the engine-cylinder ; if, in case these exhaust gases do not leave the cylinder, the fresh charge gets diluted and efficiency of the engine will decrease.*
- The piston then again starts moving from B.D.C. to T.D.C. and the charge gets compressed when E.P. (exhaust port) and T.P. are covered by the piston ; thus the *cycle is repeated.*

- Fig. 2.85 show the *p-V* diagram for a two stroke cycle engine. It is *only for the main cylinder or the top side of the piston.*
- Fig. 2.86 shows self-explanatory port timing diagram for a two stroke cycle engine.

In a **two stroke Diesel cycle** *engine all the operations are the same as in the spark ignition (Otto cycle) engine with the differences ; firstly in this case,* ***only air*** *is admitted into cylinder instead of air fuel mixture and secondly* ***fuel injector*** *is fitted to supply the fuel instead of a sparking plug.*

Note. The top of the piston usually has a projection/hump to deflect the fresh air to sweep up to the top of the cylinder before flowing to the exhaust ports. This serves the following two purposes :

(*i*) To scavenge the upper part of the cylinder of combustion products.

(*ii*) To prevent the fresh charge from flowing directly to the exhaust ports.

The same objective can be achieved *without piston deflector by proper shaping of the transfer port.*

2.35.2. Comparison between Two-stroke Cycle and F...-stroke Cycle Engines

- For comparison between 2-stroke cycle and 4-stroke cycle engines refer to Art. 2.14.
- *For all the petrol as well diesel two-stroke engines* a common **disadvantage** is *greater cooling and lubrication requirements due to one power stroke in each revolution of crankshaft. Due to higher temperature the consumption of lubrication oil is also high in two-stroke engines.*

2.35.3. Disadvantages of Two-stroke S.I. Engine Compared to Two-stroke C.I. Engine

Following are the two main disadvantages from which the two-stroke S.I. engines suffer :

1. Loss of fuel
2. Idling difficulty.

- In case two cylinders are supplied the fuel after the closure of the exhaust ports, the fuel loss will be nil and the indicated thermal efficiency of the two-stroke engine will be comparable as the four-stroke engine. However, in S.I. engine using carburettor, the scavenging is done with fuel-air mixture and only the fuel mixed with the retained air is used for combustion.
  - *In order to avoid the loss of fuel instead of carburettor fuel injection just before the exhaust port closure may be used.*
- At *low speeds* when m.e.p. (mean effective pressure) is reduced to about 2 bar, the two stroke S.I. engine *runs irregularly* and *may even stop.* This is owing to large amount of residual gas (more than in 4-stroke engine) mixing with small amount of charge. At low speeds there may be backfiring due to slow burning rate.
  - **Fuel injection** *improves idling and also eliminates backfiring as there is no fuel present in the inlet system.*

In case of C.I. engine there is neither fuel loss (as the charge is only air) nor difficulty in idling since there is no reduction in fresh charge (air).

2.35.4. Reasons for Use of Two-stroke C.I. Engines for Marine Propulsion

Two-stroke C.I. engines find wide use in marine propulsion for the following *reasons* :

1. More uniform torque, the ideal requirement for the propeller.

2. More cooling is required in two stroke engines, plenty of sea water is available for cooling.

3. In C.I. engines there in no loss of fuel in scavenging. Hence they have higher thermal efficiency.

4. *Propeller imposes the condition that maximum power must be developed at about 100 r.p.m. Two stroke engines may be made of slow speed, and with large displacement volume (over 60 cm bore) and of capacity 5000 kW and above. These slow speed engines can be coupled directly to the propeller of the ship, without the necessity of gear reduction.*

- For marine propulsion, *two-stroke C.I. opposed engine (cross-head type) is mainly used.*

2.35.5. Reasons for the Use of Two-stroke S.I. Engines for Low Horse Power Two Wheelers

- When applied to S.I. engines, the Two-stroke cycle engine has certain disadvantages which have restricted its use to small low horse power engines.
  - In S.I. engines the charge consists of a mixture of air and fuel. *During scavenging both, inlet and exhaust ports are open simultaneously for sometime. Some part of the fresh charge escapes with exhaust which results in higher fuel consumption and lower thermal efficiency.*

- For *small two-wheeler engines the* ***fuel economy is not a vital factor.*** Here ***light-weight and low initial cost are the main considerations,*** *which are the main characteristics of two-stroke S.I. engines.*

2.36. INTAKE FOR TWO STROKE CYCLE ENGINES

- *In two stroke cycle engines inlet air must be input at a pressure greater than atmospheric.* At the start of the intake process, following blowdown, the cylinder is still filled with exhaust gas at atmospheric pressure. There is no exhaust stroke. Air under pressure enters the cylinder and pushes most of the remaining exhaust residual out of the still-open exhaust port. This is called **scavenging.** When most of the exhaust gas is out, the exhaust port closes and the cylinder is filled with air.
  - *At part throttle inlet pressure is low, and this results in poorer scavenging.*
- Generally following two methods are used for putting air into the cylinders :
  (*i*) Through normal intake valves ;
  (*ii*) Through intake slots in the cylinder walls.
  - *The intake air is pressurised using a supercharger, turbocharger, or crankcase compression.*
- There are open combustion chambers in the two stroke cycle engines. It would be extremely difficult to get proper scavenging in a cylinder with a divided chamber.
- In some automobile engines *standard-type superchargers are used and the air is input through intake valves with no fuel added.* The compressed air scavenges the cylinder and leaves it filled with air and a small amount of exhaust residual. After the intake valve is closed, fuel is injected directly into the combustion chamber by injectors mounted in the cylinder head. This is done to avoid HC pollution from fuel passing into the exhaust system, when both exhaust and intake valves are open. *In some automobile engines, air is injected with the fuel. This speeds evaporation and mixing, which is required because of the very short time of the compression stroke.*
  - Fuel injection pressure is of order of 500 to 600 kPa, while air injection pressure is slightly less at about 500 kPa.
  - For *"S.I. engine" fuel injection occurs early in the compression stroke, immediately after the exhaust valve closes.* In *"C.I. engines" the injection occurs late in the compression stroke, a short time before combustion starts.*
- In just about all two stroke cycle engines, *due to cost, crankcase compression is used to force air into and scavenge the cylinders.*
  - In these engines, air is introduced at atmospheric pressure into the cylinder below the piston through a one-way valve when the piston is near T.D.C. The power stroke pushes the piston down and compresses the air in the crankcase, which has been designed for this dual purpose. The compressed air then passes through an input channel into the combustion chambers. In *modern automobiles engines* the fuel is then added with injectors, as with supercharged engines the fuel is then added with injectors, as with supercharged engines. In *small engines the fuel is usually added with a carburettor to the air as it enters the crankcase. This is done to keep the cost down on* small engines, simple carburettors being cheap to build. The fuel injectors will probably become more common as pollution laws become more stringent.
- In case of two stroke cycle engines *using crankcase compression, lubricating oil must be added to the inlet air.* The crankcase in these engines cannot be used as the oil reservoir as with most other engines. Instead, the surfaces of the engine components

are lubricated by *oil vapour carried by the intake air.* In some engines, lubricating oil is mixed directly with the fuel and is vaporised in the carburettor along with the fuel. Other engines have a separate oil reservoir and feed lubricant directly into the intake air flow. *Two negative results* occur beacuse of this method of lubrication : (*i*) Some oil vapour gets into the exhaust flow during valve overlap and contributes directly to HC exhaust emissions ; (*ii*) Combustion is less efficient due to the poorer fuel quality of the oil.

— *Engines which use superchargers or turbochargers generally use standard pressurised lubrication systems, with crankcase serving as the oil reservior.*

- *In order to avoid an excess of exhaust residual no pockets of stagnant flow or dead zones can be allowed in the scavenging process. This is controlled by :*
  (*i*) The size and position of the intake and exhaust slots or valves ;
  (*ii*) The geometry of the slots in the wall ;
  (*iii*) The contoured flow deflectors on the piston face.

2.37. SCAVENGING PROCESS

- In a two stroke engine because of non-availability of an exhaust stroke (unlike four-stroke engine) at the end of an expression stroke, its combustion chamber is left full of combustion products. *The process of clearing the cylinder after the expansion stroke is called* **scavenging process.** Scavenging process is the *replacement of combustion products in the cylinder from previous power stroke with fresh air charge to be burned in the next-cycle.* This process must be completed in a very short duration available between the end of the expansion stroke and start of the process of charging.
- The efficiency of a two stroke engine greatly depends on the effectiveness of the scavenging process.

  Inadequate/poor/bad scavenging leads to the following :
  (*i*) Low mean indicated pressure (m.e.p.) which *results in high weight and high cost per kW (shaft output) for the engine.*
  (*ii*) Low amount of oxygen availability which results in incomplete combustion leading to *higher specific fuel combustion.*
  (*iii*) Contamination of lubricating oil to a greater extent which *reduces the lubricating qualities* and eventually results in *increased wear of piston and cylinder liners.*
  (*iv*) *Higher mean temperature and greater heat stresses on the cylinder walls.*
- Scavenging process can be divided into the following *four distinct stages :*
  (*i*) **Pre-blowdown.** On the opening of inlet port, the gases expanding in the main cylinder tend to escape from it and to pre-discharge into the scavenge air mainfold. This pre-blowdown process ends with the opening of exhaust port.
  (*ii*) **Blowdown.** With the opening of exhaust ports, the gases existing in the cylinder at the end of expansion stroke discharge *simultaneously* into exhaust manifold ; consequently the pressure of main cylinder drops to a value lower than existing in scavenge air manifold. This blowdown process terminates at the moment the gas pressure inside the cylinder attains a value slightly less than air pressure inside scavenge manifold.
  (*iii*) **Scavenging.** This phase of the scavenging process starts at the moment the spontaneous exhaust of gases from cylinder terminates and ends at the moment the exhaust ports are closed. The *scavenge air sweeps out all residual gases remaining in the main cylinder at the end of spontaneous exhaust and replaces them as completely as possible with fresh charge.*

(*iv*) **Additional charging.** After the completion of scavenging phase, the fresh charge continues to flow till the scavenge ports are open and pressure in the cylinder rises. This last phase results in better filling of the cylinder.

- Fig. 2.87 shows a scavenging process on pressure-crank angle (p-θ) for a loop-scavenged cylinder of a typical two stroke engine.
  - It shows the adiabatic compression curve from B.D.C. when the exhaust pressure is 1.013 bar (atmospheric).
  - After the exhaust port opens at 70° before T.D.C., the pressure in the cylinder falls rapidly in the blowdown process (The ***blowdown*** is defined as *the crank angle from the point exhaust port opens to the point the cylinder pressure reaches exhaust pressure*). In practice due to inertia effect of the gases after the blowdown the pressure in the cylinder *normally falls below the exhaust pressure for a few degrees*. Immediately after the exhaust port opens, the inlet port also begins to open. The interval may be of the order of 20° of the crank angle. With the fall in cylinder pressure below scavenging pressure, the fresh charge gets introduced in the cylinder and continues as long as the inlet port is open, and the total inlet pressure becomes more than the pressure in the cylinder.

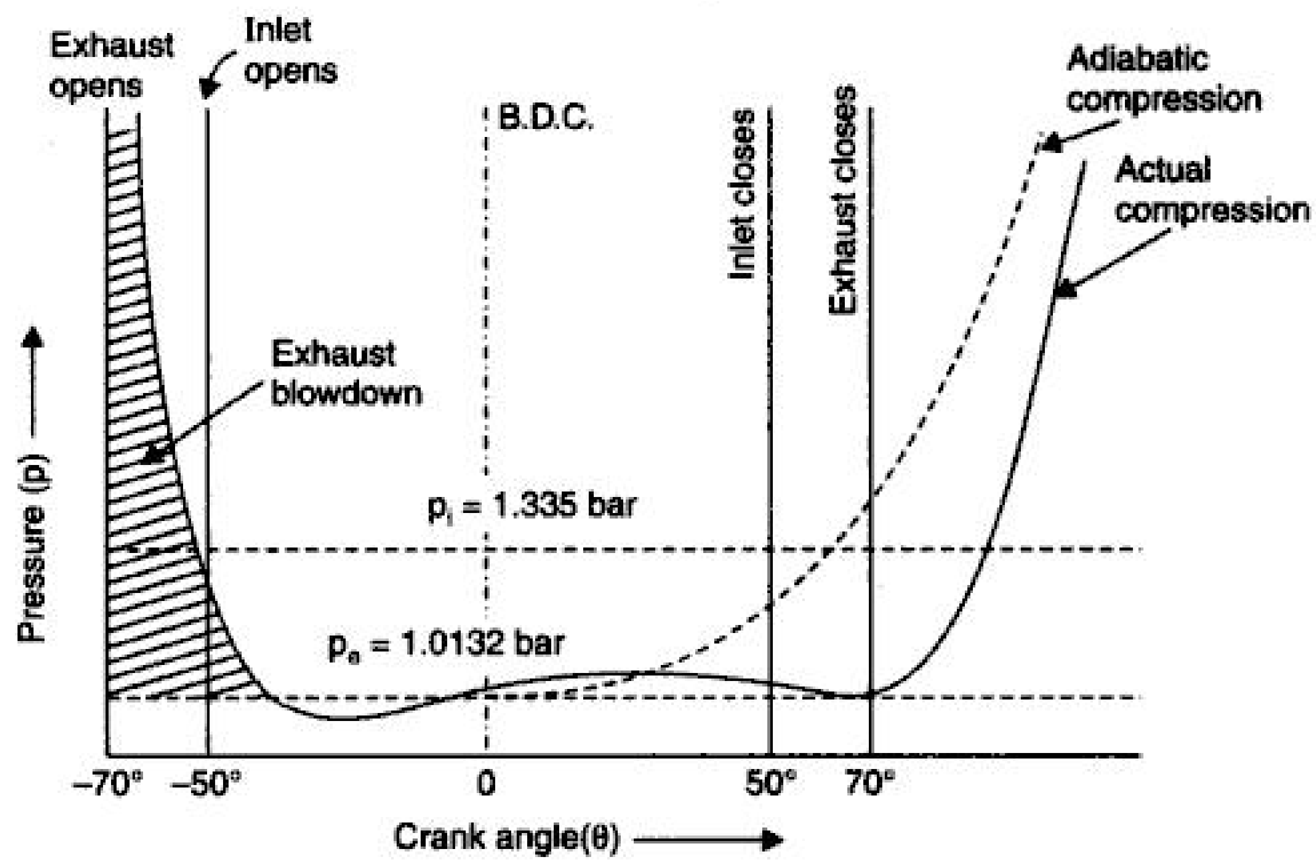


Fig. 2.87. Scavenging process on p-θ for a loop-scavenged cylinder of a typical two stroke engine.

  - Whereas the gases flow into the inlet ports, the exhaust gases continue to flow out of exhaust port, due to the fact that these started in this direction at high velocity during blow-down. Also due to the fresh mixture entering through inlet port there is building up of pressure in the cylinder higher than the exhaust system pressure.
  - **Scavenging angle.** It is defined as the *crank angle during which both inlet and exhaust ports are open.*
  - **Scavenging period.** It is the *time period taken for scavenging angle.*
- After the closure of the two ports, cycle is completed by compression, combustion and expansion in the cylinder as in four-stroke engine.

Theoretical Scavenging Processes :

Following are the three theoretical scavenging processes :

1. Perfect scavenging.
2. Perfect mixing.
3. Short circuiting.

1. Perfect scavenging :

- In this type of scavenging, fresh air pumped into the cylinder by the blower through the inlet ports at the lower end of cylinder pushes the combustion products ahead of itself and of the cylinder through the exhaust valve at the other end.
- The air and combustion products *do not mix together*.
- So long as any products remain in the cylinder, the flow through the exhaust valves consists of products only.

2. Perfect mixing :

- In this process, the *incoming fresh charge mixes completely and instantaneously with the cylinder contents and a portion of this mixture passes out of exhaust ports at a rate equal to that entering the cylinder.*
- The outgoing (homogeneous) mixture consists initially of combustion products only but then gradually changes to pure air.
- Since the result of this process closely approximates the result of many actual scavenging processes, therefore, it is *often used as a basis of comparison.*

3. Short-circuiting :

- In this process, the *fresh charge coming from the scavenge manifold directly goes out of exhaust ports without removing combustion products/gases.*
- It results in a dead loss and its occurence must be checked/avoided.

2.38. SCAVENGING PARAMETERS

- *For the same power generation, more air input is required in a two stroke cycle engine than in a four stroke cycle engine.* This is because *some of the air is lost in the overlap period of the scavenging process.*
- A number of different intake and performance efficiencies are defined for the intake process of two stroke cycle engine.
- Volumetric efficiency of a four-stroke cycle engine can be replaced by either **delivery ratio ($R_{del.}$)** or **charging efficiency ($\eta_{ch.}$)** :

$$\textbf{Delivery ratio} = R_{del.} = \frac{m_{mi}}{V_s \rho_a} \qquad ...(2.5)$$

$$\textbf{Charging efficiency} = \eta_{ch.} = \frac{m_{mt}}{V_s \rho_a} \qquad ...(2.6)$$

where, m_{mi} = Mass of air-fuel mixture *ingested* into the cylinder,

m_{mt} = Mass of air-fuel mixture *trapped* in cylinder after all valves are closed,

V_s = Swept volume, and

ρ_a = Density of air at ambient conditions.

Typical values : $0.65 < R_{del.} < 0.95$

$0.50 < \eta_{ch.} < 0.75.$

— *Delivery ratio is greater than charging efficiency* because some of the air-fuel mixture ingested into the cylinder is lost out of the exhaust port before it is closed.

— In case of those engines that inject fuel after the valves are closed, the *mass of mixture in these equations* (2.5 and 2.6) *should be replaced with the mass of ingested air. Sometimes, ambient air density is replaced by the density of air in the inlet runner downstream of the supercharger.*

Other efficiencies :

$$\textbf{Trapping efficiency} = \eta_{trap.} = \frac{m_{mt}}{m_{mi}} = \frac{\eta_{ch.}}{R_{del.}} \quad ...(2.7)$$

$$\textbf{Scavenging efficiency} = \eta_{sc.} = \frac{m_{mt}}{m_{tc}} \quad ...(2.8)$$

$$\textbf{Relative charge} = C_{rel.} = \frac{m_{tc}}{V_s\,\rho_a} = \frac{\eta_{ch.}}{\eta_{sc.}} \quad ...(2.9)$$

where, m_{tc} = Mass of total charge trapped in the cylinder, including exhaust residual.

Typical values : $0.65 < \eta_{trap.} < 0.80$

$0.75 < \eta_{sc.} < 0.90$

$0.60 < C_{rel.} < 0.90.$

Pressure loss coefficient. *It is defined as the ratio between the main upstream and downstream pressures during the scavenging period and represents the pressure loss to which the scavenge air is subjected when it crosses the cylinder.*

Excess air factor (λ). The value ($R_{del.}-1$) is called the excess air factor. Thus if the R_{del} (delivery ratio) is 1.3 the excess air factor is 0.3.

Measurement of Scavenging Efficiency :

The following procedure is adopted in *diesel engines for measuring the scavenging efficiency :*

- A small sample of the combustion products is drawn just before the exhaust valve opens or during the earlier part of blowdown.
- The sample is analysed.
- The results obtained are compared with standard curves of exhaust products *vs.* F/A ratio. This determines the F/A ratio that must have existed in the cylinder before combustion.
- Knowing the quantity of fuel injected per cycle, the quantity of fresh air retained in the cylinder per cycle is determined. Air present in the residual gas is not considered as it represent a constant quantity which does not participate in combustion process.

2.39. SCAVENGING SYSTEMS

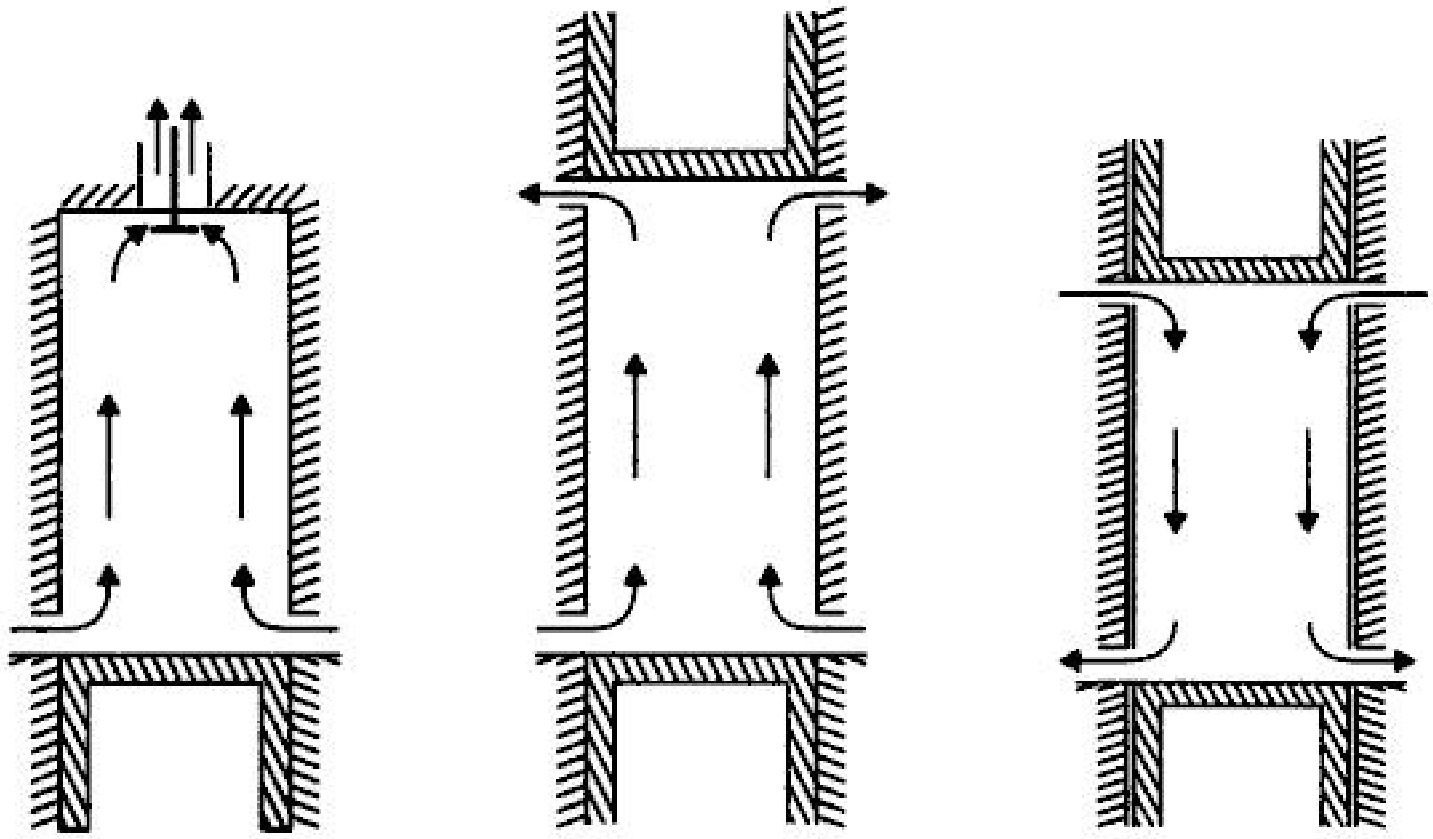
Different scavenging systems/arrangements *based on charge flow* are enumerated and described below :

1. Uniflow scavenging
2. Loop or reverse scavening
3. Cross scavenging.

1. **Uniflow scavenging :**

It is the *most perfect method of scavenging.*

- The fresh charge is admitted at one end of the cylinder and the exhaust escapes at the other end. The air flow is from end to end, and little short-circuiting between the intake and exhaust openings is possible.
- The three available arrangements for uniflow scavenging are shown in Fig. 2.88.



(a) (b) (c)

Fig. 2.88. Uniflow scavenging.

  - A *poppet valve* is used [Fig. 2.88 (*a*)] to admit the inlet charge or for the exhaust, as the case may be.
  - In Fig. 2.88 (*b*) the inlet and exhaust ports are both *controlled by separate pistons* that move in opposite directions (opposed piston engines).
  - In Fig. 2.88 (c) the inlet and exhaust ports are *controlled by the combined motion of piston and sleeve.*
- *All uniflow systems permit unsymmetrical port timings and supercharging.*
- Due to absence of any eddies or turbulence (at least theoretically) *it is easier in a uniflow scavenging system to push the combustion products out of the cylinder without mixing with it and short circuiting*. Thus this system ***has the highest scavenging efficiency.***
- Since this systems requires either opposed systems, poppet valves or sleeve valve (all of which increase the complication) its *construction is not simple.*

2. **Loop or reverse scavenging :**

In *loop or reverse scavenging, the fresh air first sweeps across the piston top, moves up and then down and finally out through the exhaust.* The system *avoids the short-circuiting of the cross-scavenged engine and thus improves upon its scavenging efficiency.*

- In the MAN type of loop scavenge, Fig. 2.89. (*a*), the exhaust and inlet ports are on the same side, the *exhaust above the inlet.*
- In the Schnuerle type, Fig. 2.89. (*b*), the ports are *side by side.*

  The Curtis type of scavenging, Fig. 2.89 (*c*), is similar to the Schnuerle type, except that *upwardly directed inlet ports are placed also opposite the exhaust ports.*

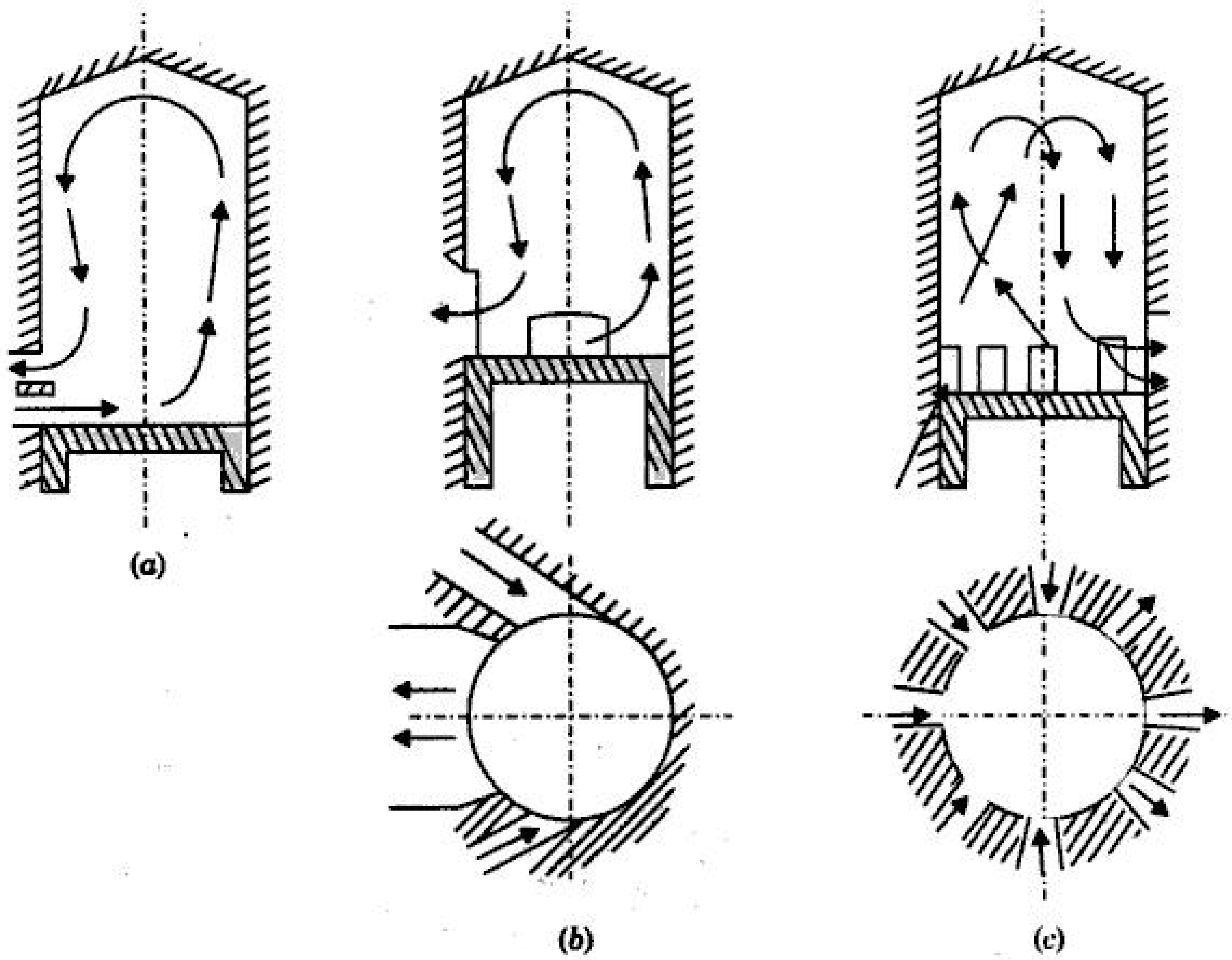


Fig. 2.89. Methods of loop scavenging.

- Owing to the absence of cams, valves and valve gear, loop or reverse scavenged *engines are simple and sturdy.* They have a *high resistance to thermal stresses and are thus much suited to higher supercharge.*
- In a loop scavenged two stroke engine, the *major mechanical problem* is that of obtaining an adequate oil supply to the cylinder wall consistent with reasonable lubricating oil consumption and cylinder wear.

3. Cross-scavenging

In this system the *inlet and exhaust ports are located on opposite sides of the cylinder (Fig. 2.90).*

The incoming flow is directed upwards by the deflector on the piston, and the cylinder head reverses the direction of flow, so that exhaust gases are forced through the exhaust port.

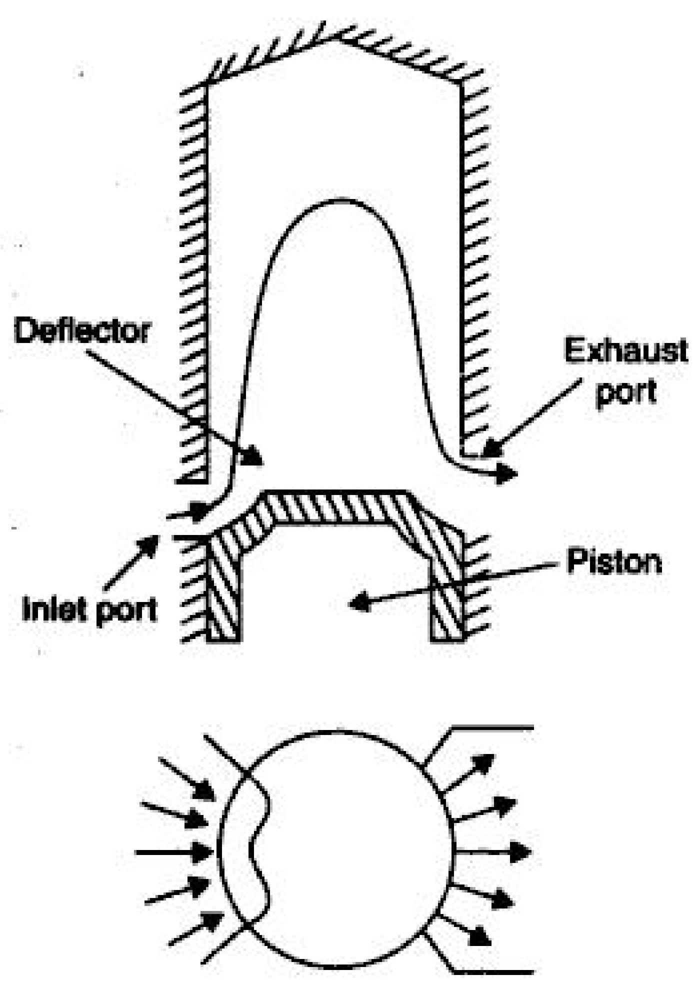


Fig. 2.90. Cross scavenging.

- In this type of arrangement the engine is structurally simpler than that with the uniflow scavenging (due to the absence of valves, distributors, and relative drive devices).
- The main *demerit* of this system is that *scavenging air is not able to get rid of the layer of exhaust gas near the wall resulting in poor scavenging.* A small portion of fresh charge

goes directly into the exhaust port. These factors contribute towards poor b.m.e.p. of the cross-scavenged engines.

2.40. CRANKCASE SCAVENGING

This type of scavenging arrangement is employed in the simplest type of two stroke engine, and is shown in Fig. 2.91.

In this engine, the charge (fuel-air mixture in S.I. engine and air in C.I. engine) is compressed in the crankcase by the underside of the piston during the expansion stroke. There are three ports in this engine-*intake port at the crankcase, transfer port and the exhaust port.* The compressed charge passes through the transfer port into the engine cylinder flushing the products of combustion. This process is called *scavenging*, and this type of engine is called *crankcase scavenged engine.*

- As the piston moves down, it first uncovers the exhaust ports, and the cylinder pressure drops to atmospheric level as the combustion products escape through these ports.
- Further downward motion of the piston uncovers the transfer ports, permitting the slightly compressed mixture or air (depending upon the type of engine) in the crankcase to enter the engine cylinder. The top of the piston and the ports are usually *shaped in such a way that the fresh charge is directed towards the top of the cylinder before flowing towards the exhaust ports.* This is for the *purpose of scavenging the upper part of the cylinder of the combustion products and also to minimize the flow of fresh charge directly through the exhaust ports.* The projection on the piston is called the *deflector.*

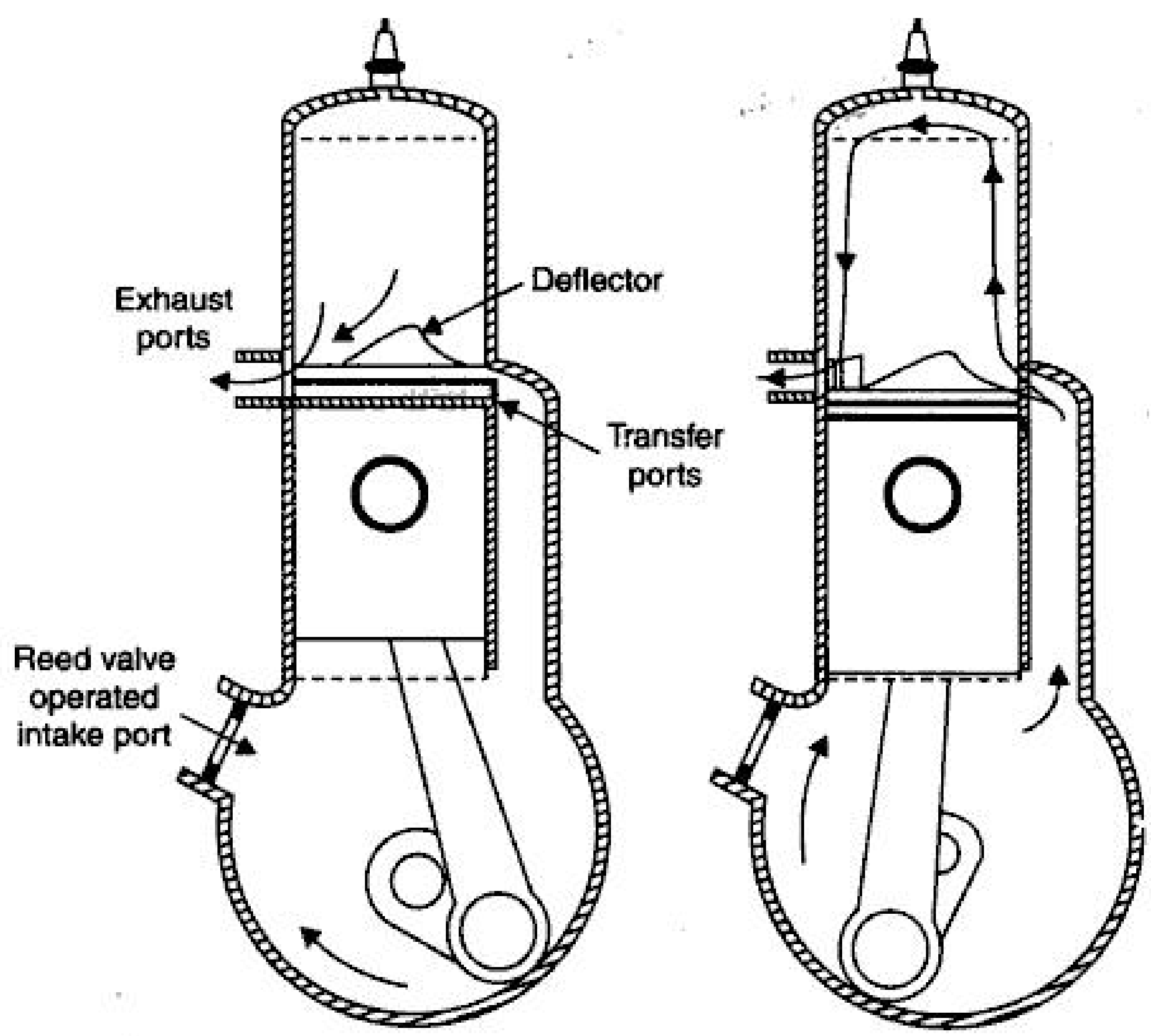


Fig. 2.91. Crankcase-scavenged two stroke engine.

- As the piston returns from B.D.C. the transfer ports and then the exhaust ports are closed and the compression of the charge begins. Motion of the piston during compression lowers the pressure in the crankcase so that the fresh charge is drawn into the crankcase through the inlet reed valve.

- Ignition and expansion take place in the usual way, and the *cycle is repeated*.

Demerits :

1. This system is *very uneconomical and inefficient in operation*. This is owing to the fact that amount of air which can be used for scavenging is less than the swept volume of the cylinder due to *low volumetric efficiency of the crankcase which contains a large dead space*. Thus the delivery ratio ($R_{del.}$) is always *less than unity* and as such it is not possible to scavenge the cylinder completely of the combustion products and some residual gases always remain in the cylinder. Consequently the crankcase-scavenged engine has a lower m.e.p., typical valves being 3 to 4 bar. Since the charge transferred through the transfer port is only 40-50 percent of the cylinder volume, the engine output is strictly limited.
2. Due to mixing of the oil vapours from the crankcase with the scavenging air, oil consumption is increased.

In view of the above demerits the *crankcase scavenging is not preferred and a scavenging pump is essential for a high output two stroke engine.*

2.41. SCAVENGING PUMPS AND BLOWERS

Since the piston of a two stroke engine cannot carry out the pumping action, therefore, a separate pumping mechanism, called the *scavenging pump*, is needed to supply scavenging air to the cylinder.

Following types of pumps are used : Crankcase compression (Refer to Art. 2.40), piston, roots and centrifugal blowers.

- **Piston type pump** shown in Fig. 2.92 is used for *low speed and single or two cylinder engines.*

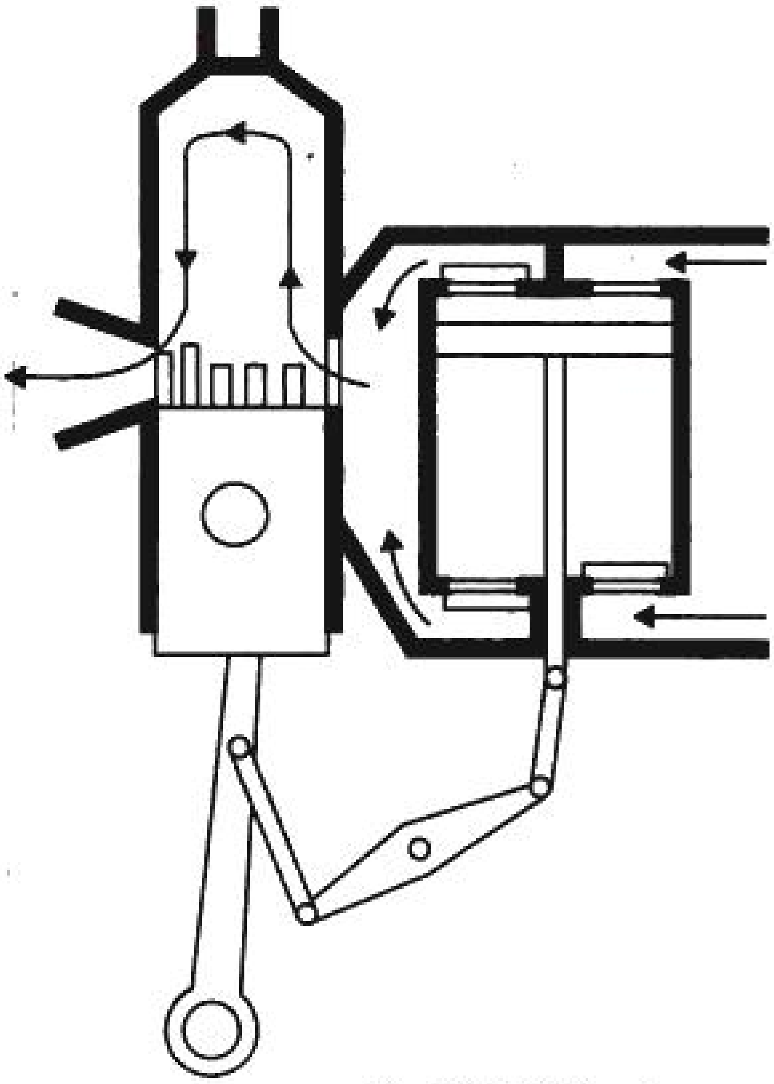


Fig. 2.92. Piston type pump.

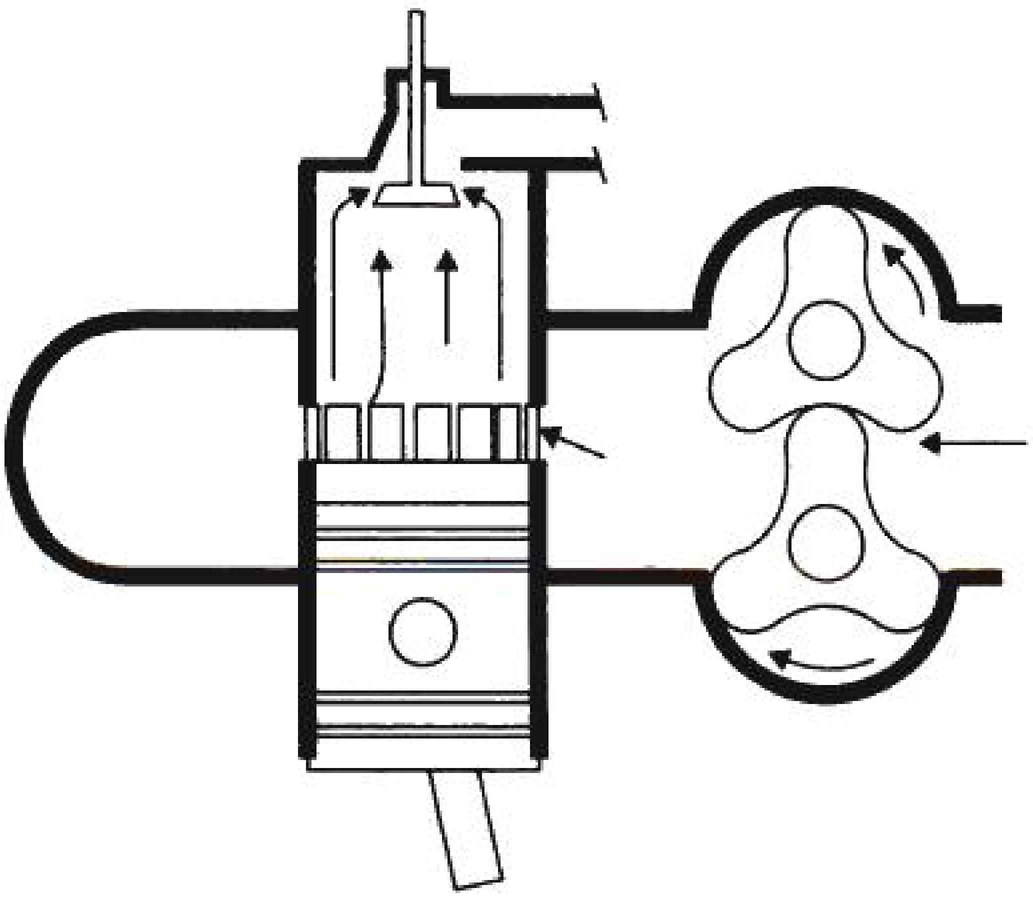


Fig. 2.93. Roots blower.

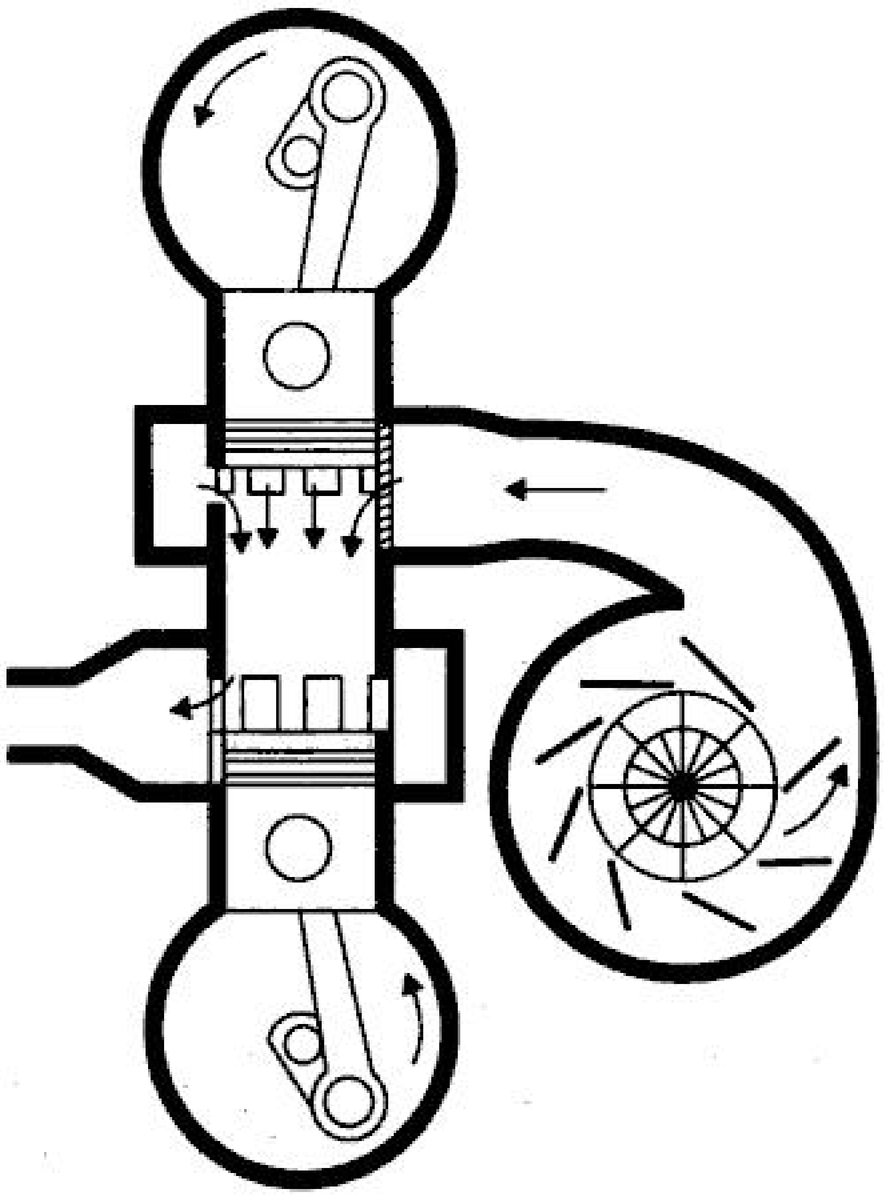


Fig. 2.94. Centrifugal blower.

- **Roots blower** shown in Fig. 2.93 is used for *small and medium engines.*
- **Centrifugal blower** shown in Fig. 2.94 is employed for *large and high output engines.*

V. Fuels for I.C. Engines

2.42. CONVENTIONAL FUELS (FOR I.C. ENGINES)

2.42.1. Introduction

- I.C. engines can run on different kinds of fuel, including liquid, gaseous and even solid fuels. The properties and the character of the fuel exercise profound influence on the design, power output, efficiency, fuel consumption and the reliability and durability of the engine.
- The use of *solid fuels* present problems of complicated injection systems, as well as difficulties associated with solid residual ash, and hence are *not popular, gaseous fuels* present problems of storage and handling of large volumes. Hence for mobile *use its use gets restricted.* But gaseous fuels do find *use for stationary power plants particularly when gas is readily available at the location nearby. Thus liquid fuels find abundant use in I.C. engines.*

2.42.2. Desirable Properties of Good I.C. Engines Fuels

The fuels used in I.C. engines are designed to satisfy the performance requirements of the engine system in which they are used. Thus fuel should possess the following **properties :**

1. High energy density (kJ/kg).
2. Good combustion qualities.
3. High thermal stability.
4. Low toxicity.
5. Low pollution.
6. Easy transportation/transferability and storage.
7. Compatibility with the engine hardware.
8. Good fire safety.
9. Low deposit forming tendency.
10. Economically viable in very large quantities.
11. Easy mixing with air and low latent heat of evaporation (h_{fg}).
12. No chemical reaction with engine components through which it flows.

2.42.3. Gaseous Fuels

These fuels are used in S.I. engines. The different gaseous fuels are enumerated and discussed below :

1. Natural gas
2. Manufactured gases
3. By-product gases
4. Sewage sludge gas
5. Biogas.

1. **Natural gas :**

- Its composition varies with source but mainly it contains CH_4 (75 to 95 percent) and remaining C_2H_6 and N_2. From some areas, the natural gas obtained contains H_2S which is much harmful to the engines.
- It is available with oil wells and is *colourless* and *odourless*.
- It is found in several parts of the world but particularly in U.S.A. It is also carried from the place of availability to the place of use through hundreds of kilometres pipeline.

2. **Manufactured gases :**

The gases are manufactured by various methods, discussed briefly below :

- ***Coal gas*** is manufactured by *heating soft coal in closed vessel*. The contents of the gas depend upon the type of coal and method of operation used in manufacturing.
  - A clean coal gas contains : 33% H_2 and 66% CH_4.
  - Its energy content is *50 percent of natural gas*.
- ***Water gas*** is *formed by using steam*. For its manufacture, the *water and air are passed alternately through a bed of hot carbon*.
  - It contains H_2, CO and N_2.

3. **By-product gases :**

- The gases produced during manufacture of other substances are known as *by-product gases*.
- ***Blast furnace gas*** is a by-product of steel plants. It contains CO and N_2. It contains large amount of dust particles ; therefore, it should be cleaned by an effective method before its use in the engine.

4. **Sewage sludge gas :**

- It contains CH_4 and CO_2 with very small percentage of H_2S.
- This gas is made available from present well developed sewage disposal plants.

5. **Biogas :**

- This gas is produced from the cow dung which is available in large quantities in India.
- It is easy to produce (with appropriate chemical reaction) and use locally.

Except natural gas, all other gases mentioned above are generally employed for running I.C. engines whose power is used locally to run different types of equipments like *small electric generators, pumps etc.*

Advantages of gaseous fuels :

(*i*) Easily compressed and stored.
(*ii*) Easily carried through pipes.
(*iii*) Easy starting of engines.
(*iv*) Easy to maintain A/F ratio in multi-cylinder engines, as compared to liquid fuels.

Disadvantages :

(*i*) High cost (on the basis of energy content)
(*ii*) High purifying cost.
(*iii*) Storage volume per unit energy very large.
(*iv*) As compared to engines using liquid fuels, the size and weight of the engine (kg/kW) is considerably large.
(*v*) The cost (capital and running) of the plants manufacturing gases is considerably high.

2.42.4. Liquid Fuels

Following are the three principal commercial types of liquid fuels :

1. Benzol ; 2. Alcohol ; 3. Refined products of petroleum.

1. **Benzol :**

- It consists of benzene (C_6H_6) and toulene (C_7H_8) and is obtained as a by-product of high temperature coal carbonization.
- It possesses anti-knock quality. As compared to gasoline, its heating value is low.

2. **Alcohol :**

- It has good anti-knock qualities.
- Its heating value is low as compared to gasoline.
- It is more expensive to produce.
- It is used as fuel blended with gasoline.
- It can be manufactured from grain, sugarcane and waste products.

3. **Refined products of petroleum :**

- It is the main source of liquid fuels for I.C. engines.
- It is used in the form of gasoline, kerosene, and diesel oil.

The liquid fuels are ***classified*** in two ***groups*** :

(*i*) *Liquid fuels which are vaporised easily : "Petrol"* and *"Alcohol"* . These are commonly used in S.I. engines.
(*ii*) *Liquid fuel which is directly injected in the combustion chamber :* "Diesel or fuel oil".

2.42.5. Structure of Petroleum

In I.C. engines the fuels which are usually used are *complex mixtures of hydrocarbons.* These fuels are obtained by *refining petroleum.*

Basically, petroleum is a mixture of hydrocarbons, compounds *made up exclusively of carbon and hydrogen atoms* ; it may also contain small quantities of other compounds having sulphur, oxygen and nitrogen (In some petroleum, metallic compounds such as derivatives of vanadium, iron, nickel, arsentic etc., are also found).

The constituents of petroleum are *classified* into the following four main groups :

	Constituents	General formula	
1.	*Paraffins*	C_nH_{2n+2}	(where n is the number of carbon atoms)
2.	*Olefins*	C_nH_{2n}	
3.	*Naphthenes*	C_nH_{2n}	
4.	*Aromatics*	C_nH_{2n-6}	

— Within each group also, the physical properties of individual compound differ according to the number of carbon and hydrogen atoms in the molecule.

— The physical differences between compounds, even in any group, influence the way fuel evaporates and hence the formation of combustible mixture.

— The difference in chemical properties of hydrocarbon from different groups affect the combustion process and hence the proportions of fuel and air requirements.

1. **Paraffins :**

(*i*) ***Straight chain or normal paraffins :***

- It consists of a straight chain molecular structure as shown in Fig. 2.95.
- The names of hydrocarbon in this series end with *ane* as in methane, propane, hexane etc.
- The straight chain paraffins are saturated compounds as valency of carbon is fully utilised and therefore, they are very *stable*.

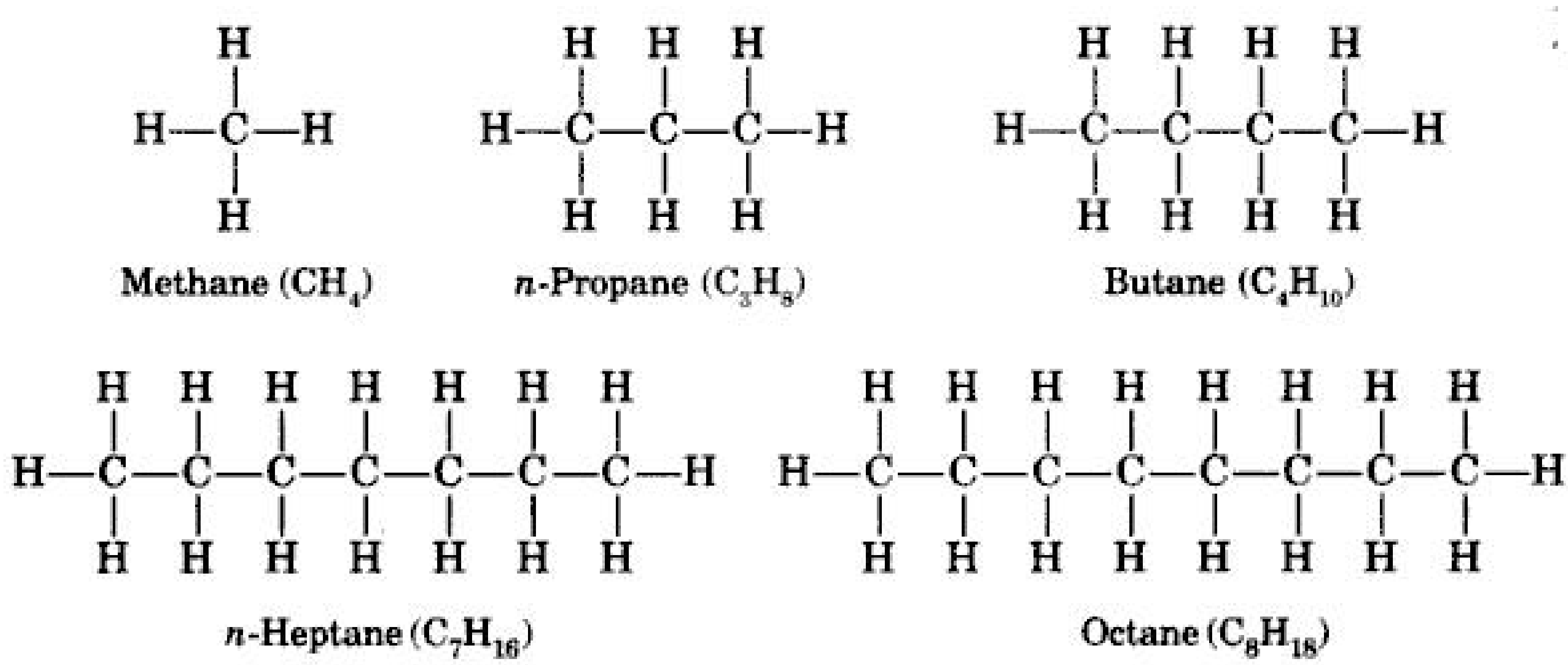
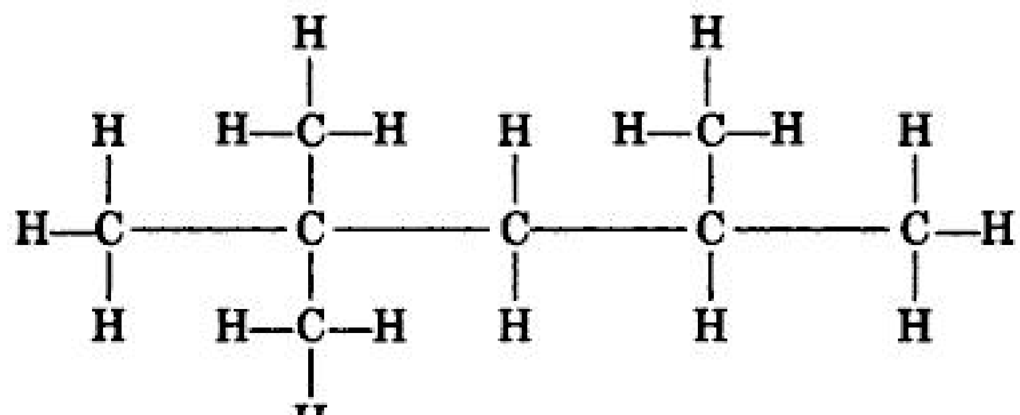


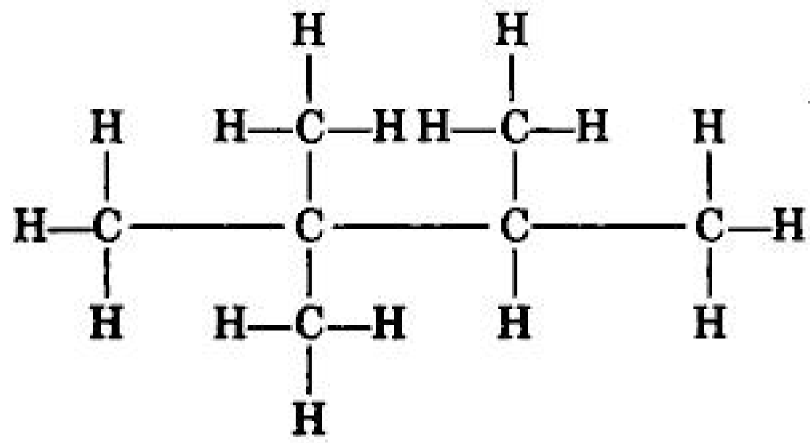
Fig. 2.95. Straight chain paraffin.

(*ii*) ***Branched chain or iso-paraffins :***

- The *carbon atoms are branched in these compounds.*
- Branched chain or iso-paraffins have an open structure which is branched as shown in Fig. 2.96. Iso-octane, triptane etc. are examples of this type.



Iso-octane



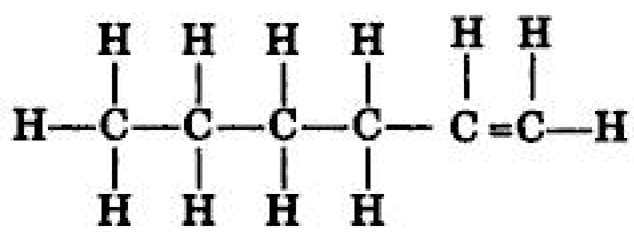
Triptane

Fig. 2.96. Branched chain or iso-paraffins.

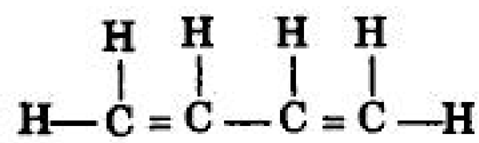
- Iso-paraffins are also *stable compounds* and *highly knock-resistant when used as S.I. engine fuels.*

2. **Olefins :**

- These are *compounds with one or more double bonded carbon atoms in straight chain.* The names end with *ene* for one double bond and *adiene* for two double bonds. The examples are : Hexene and Butadiene (Fig. 2.97)



Hexene, C_6H_{12} (mono-olefin)



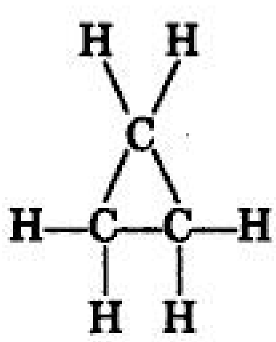
Butadiene, C_4H_6 (diolefin)

Fig. 2.97. Olefins.

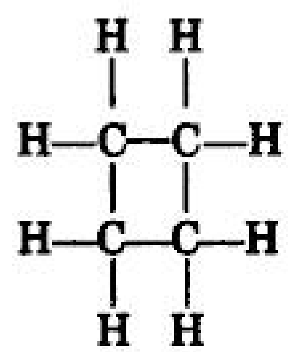
- The general formula for *mono-olefins* (single bond) is C_nH_{2n} and for *diolefins* (double bond) is C_nH_{2n-2}.
  — *Diolefins are more unstable than mono-olefins*
- Olefins are present in cracked gasoline. They form gummy deposits as they are readily oxidised in storage. Therefore, their percentages are kept low (less than 3%) in the fuels used in gas turbines.

3. **Napthenes :**

- These are *ring structured compounds.*
- The chemical formula for these compounds is the same as for olefins, C_nH_{2n} but have each carbon atom joined by single bond to two other C atoms, thus forming a ring of structure. The examples, (Fig. 2.98) are : Cyclo-propane (C_3H_6), Cyclobutane (C_4H_8) etc.



Cyclo-propane (C_3H_6)



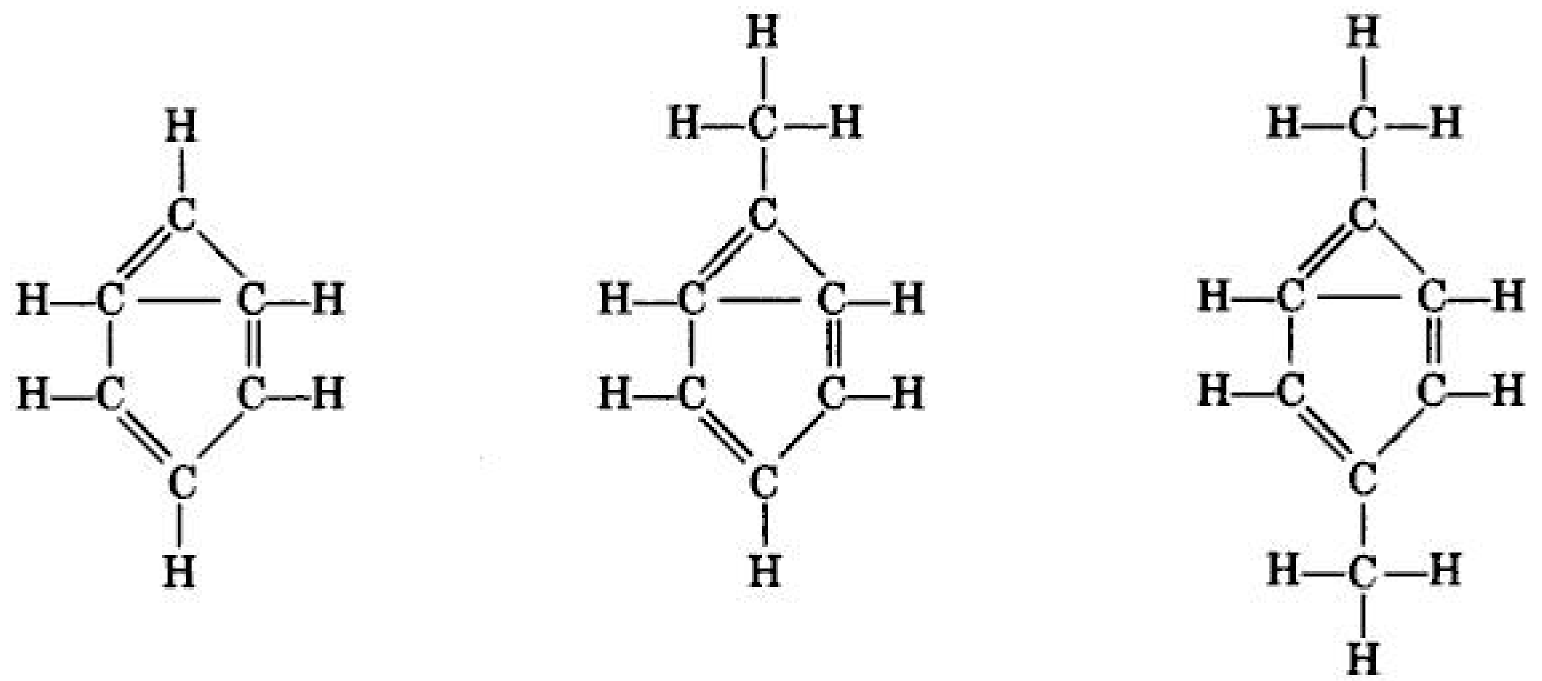
Cyclobutane (C_4H_8)

Fig. 2.98

- Although napthenes have the same formula as for olefins, the properties are *radically different.*
- The napthenes are *saturated* compounds whereas olefins are unsaturated.

4. **Aromatics :**

- These compounds (C_nH_{2n-6}) have a ring type structure for all or most of the carbon atoms, to which are attached H or group of C and H atoms ; the examples are shown in Fig. 2.99.
- In all aromatics, a *benzene, (C_6H_6) molecule exists as central structure* and other aromatics are formed by replacing one or more of the hydrogen atoms of the benzene molecule with an organic radical such as paraffins, napthenes and olefins. By adding a methyl group (CH_3) ; benzene is converted to toluene ($C_6H_5CH_3$). The three double bonds make aromatics very active and therefore they are *highly unsaturated compounds.*



(*a*) Benzene (C_6H_6) (*b*) Toluene (C_7H_8) or $C_6H_5CH_3$ (*c*) Xylene

Fig. 2.99. Structures of aromatics.

— In most unaltered gasolines, both benzene and toluene are present to a modest extent.

Following are a few *special properties of aromatics :*

(*i*) Offer highest resistance to knocking in S.I. engines.

(*ii*) Suitability of these fuels for C.I. engines is just reverse of their suitability for S.I. engines.

— Therefore, *"paraffins" are most suitable fuels for C.I. engines* and *"aromatics" are most suitable fuels for S.I. engines.*

(*iii*) With the increase in the number of atoms in the molecular structure, the boiling temperature of fuel generally increases.

(*iv*) As the proportion of H_2-atoms to C-atoms in the molecule increases the calorific value of fuel increases. Thus, paraffins have lower calorific value whereas *aromatics have highest calorific value.*

2.42.6. Petroleum and Composition of Crude Oil

- Petroleum is a dark viscous oily liquid known as *rock oil* (In Greek, *petra*—rock, *oleum*—oil). It is formed from the bacterial decomposition of the remains of animals and plants which got buried under the sea millions of years ago. When these organisms died, they sank to the bottom and got covered by sand and clay. Over a period of millions of years, these remains got converted into hydrocarbons by heat, pressure and catalytic action. The hydrocarbons formed rose through porous rocks until they were trapped by impervious rocks forming an oil trap.
- Natural gas is found above the petroleum oil trapped under rocks. The crude petroleum is obtained by drilling a hole into the earth's crust and sinking pipes into it. When the pipe reaches the oil deposit, natural gas comes out with a great pressure. After the pressure has subsided, the crude oil is pumped out of the oil well. *This process of obtaining crude oil from its sources* is called **mining.**
- The *crude oil is a mixture of hydrocarbons* such as alkanes, cycloalkanes and aromatic hydrocarbons. It also contains a number of compounds having oxygen, nitrogen and sulphur. The actual composition of petroleum depends upon its place of origin.

Fractional distillation of crude oil :

- The crude petroleum obtained by mining is a dark coloured viscous liquid called **crude** oil. Before petroleum can be used for different purposes, it must be separated into various components. *The process of separating petroleum into useful fractions and removal of undesirable impurities is called* **refining.**
- The refining of petroleum is carried out by the process of **fractional distillation** *as* described below :

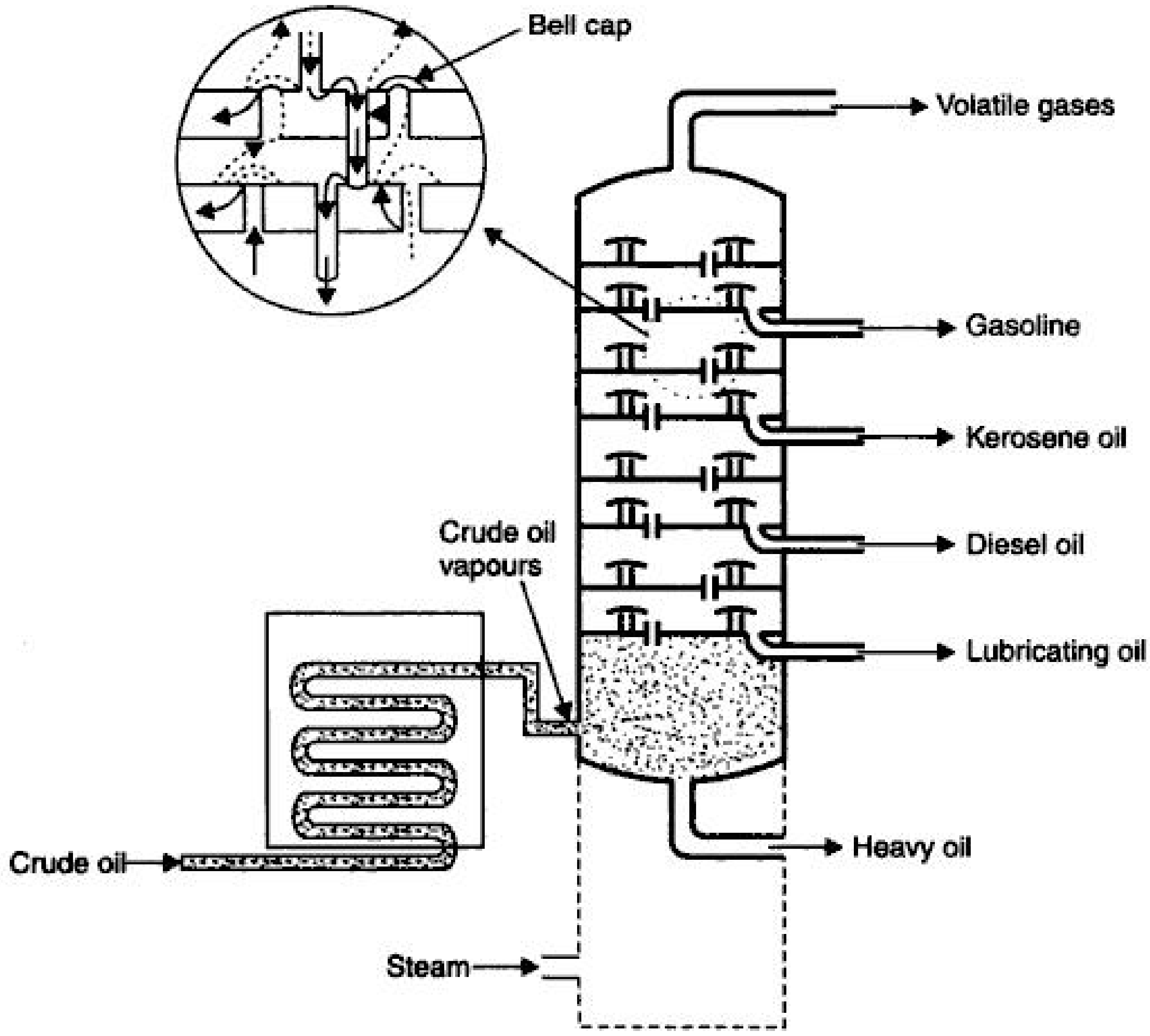


Fig. 2.100. Refining of petroleum.

— The refining of petroleum is done in big refineries. The first step in the refining process is neutralisation of crude oil by washing with acidic or basic solution as needed.

— Then the oil is heated in a furnace to about 675 K and the vapour thus obtained are introduced into a fractionating tower. The tower is divided into a number of compartments by means of shelves (trays) having holes (Fig. 2.100). The holes are covered with *bubble caps* which allow the lighter more volatile components to pass up the column while the heavier, less volatile components condense and flow into trays below. Each shelf is provided with an overflow pipe which keeps the liquid to a certain level and allows the rest to flow down to the lower shelf. Therefore, *during fractional distillation, the fractions with lower boiling points rise up the tower and condense at different levels depending upon the boiling points.* For example, the crude oil is fed at the base at about 675 K. At this temperature all the components except asphalt vapourise. As the mixture of hot vapour rises in the column, it cools. Therefore, the component with the highest boiling point liquefies first and is collected. Then a little, higher in the column, the component having slightly lower boiling point liquefies and so on. The residual gases which do not condense escape from the upper part of the tower. *The fractions are separated at different boiling points and are thus collected at different heights in the column.* The important fractions of petroleum refining are given in the table below.

Table. Different fractions of petroleum refining

Fraction (K)	Boiling range (K)	Approximate composition	Uses
1. Gaseous	113 to 303	C_1—C_5	As gaseous fuel, for producing carbon black and is also used for preparing ammonia, methyl alcohol and gasoline
2. Petroleum ether or ligroin	303 to 363	C_5—C_7	As a solvent for oils, fats, rubber and also in dry cleaning.
3. Gasoline or petrol (Sp. gravity = 0.7 to 0.8)	343 to 473	C_7—C_{12}	Mainly as a *motor fuel*.
4. Kerosene (Sp. gravity = 0.8 to 0.85)	448 to 548	C_{12}—C_{15}	As an illuminant fuel and for preparing *petrol gas*.
5. Gas oil, fuel oil, and diesel oil	523 to 673	C_{15}—C_{18}	In furnace oil, as a fuel for *diesel engines* and also in cracking.
6. Lubricating oils, greases and petroleum jelly	623 and higher	C_{16} and higher	Used mainly as *lubricants*.
7. Paraffin wax	melts between 325 to 330	C_{20} and higher	Used for manufacturing candles, waxed papers and for water proofing.
8. Petroleum coke	residue	C_{30} and higher	Used as artificial asphalt, fuel and also in making electrodes.

2.42.7. Fuels for Spark-Ignition Engines

Gasoline, a mixture of various hydrocarbons (such as paraffins, olefins, napthenes, and aromatics) is the major fuel used for S.I. engines. The composition depends upon the source of crude oil and the nature of refining process.

The following are the *requirements of an ideal gasoline* :

1. High calorific value.
2. Knock-resistance.
3. Easy to handle.
4. Easy availability at reasonable cost.
5. Quick evaporation (when injected by carburettor in the current of air).
6. Clean burning and no deposition of the residue.
7. No pre-ignition.
8. No tendency to decrease the volumetric efficiency of engine.

2.42.7.1. Volatility

- *"Volatility"* is commonly defined as *the evaporating tendency of a liquid fuel.*
- This quality of the fuel has great significance for carburetted engines. This will decide the fuel vapour to air ratio in the cylinder at the time of ignition. As $F_R = 0.6$ is the lowest limit for satisfactory ignition and flame propagation, therefore, volatility of fuel must ensure to give at least this *fuel vapour to air ratio* at the time of ignition under all conditions of operation including starting from cold.
- The volatility of gasoline is generally characterised by the following two laboratory tests.

  (*i*) ASTM distillation test (*ii*) Reid vapour test.

ASTM distillation test :

Fig. 2.101 shows the apparatus used for ASTM distillation test :

- 100 cubic centimetres of gasoline fuel is taken in the flask and heated. The flask is fitted with a thermometer to record the temperature of vapour being formed and collected in a graduated measuring cylinder.

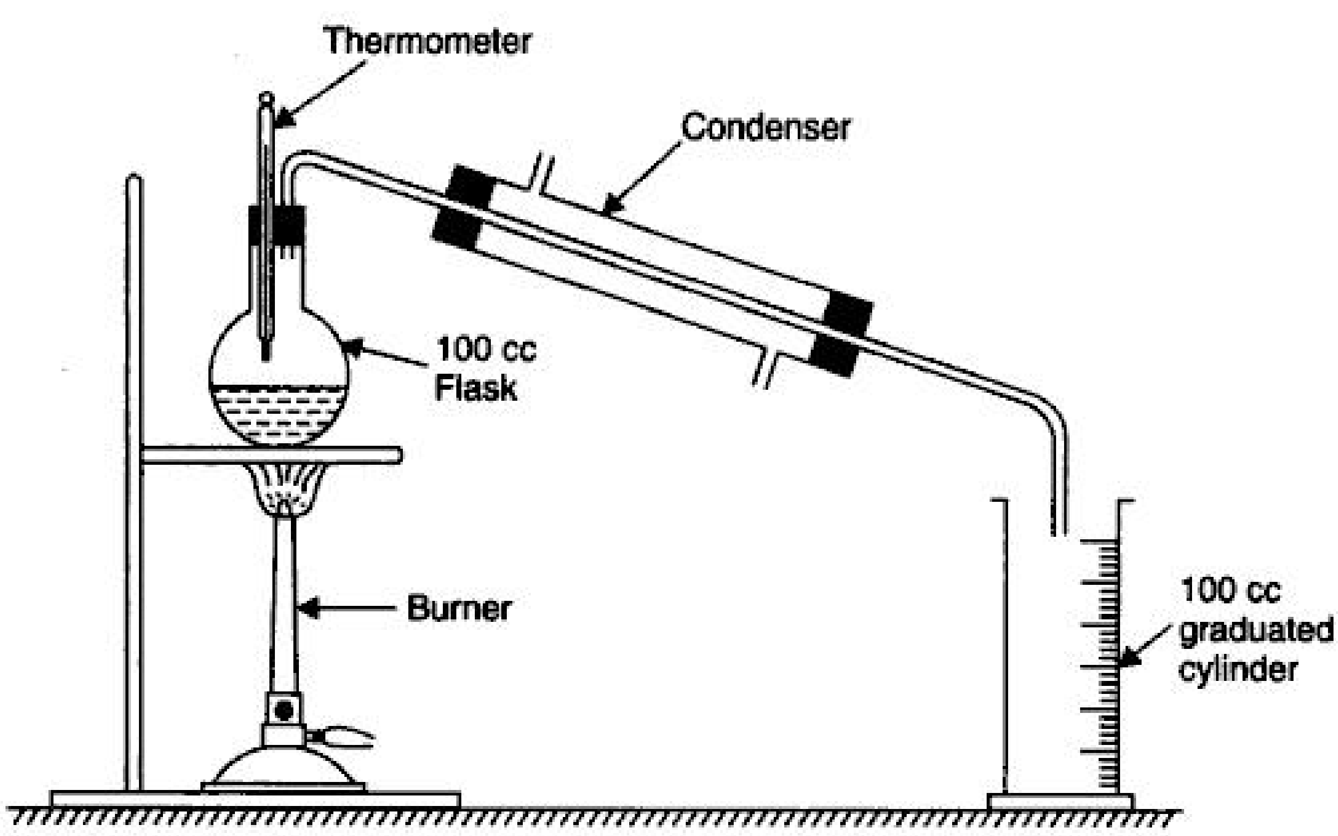


Fig. 2.101. ASTM distillation apparatus.

- When the first drop of condensed vapour drops from condenser, the temperature is recorded. This temperature is called *initial boiling point.*
- The vapour temperature is recorded at each successive 10 percent of condensed vapour collected. When 95 percent has been distilled the burner flame is increased and the maximum temperature is recorded as the *'end point'*. The mass of the residue in the flask is also recorded.

Fig. 2.102 shows distillation curves (ASTM) for various products of petroleum refining.

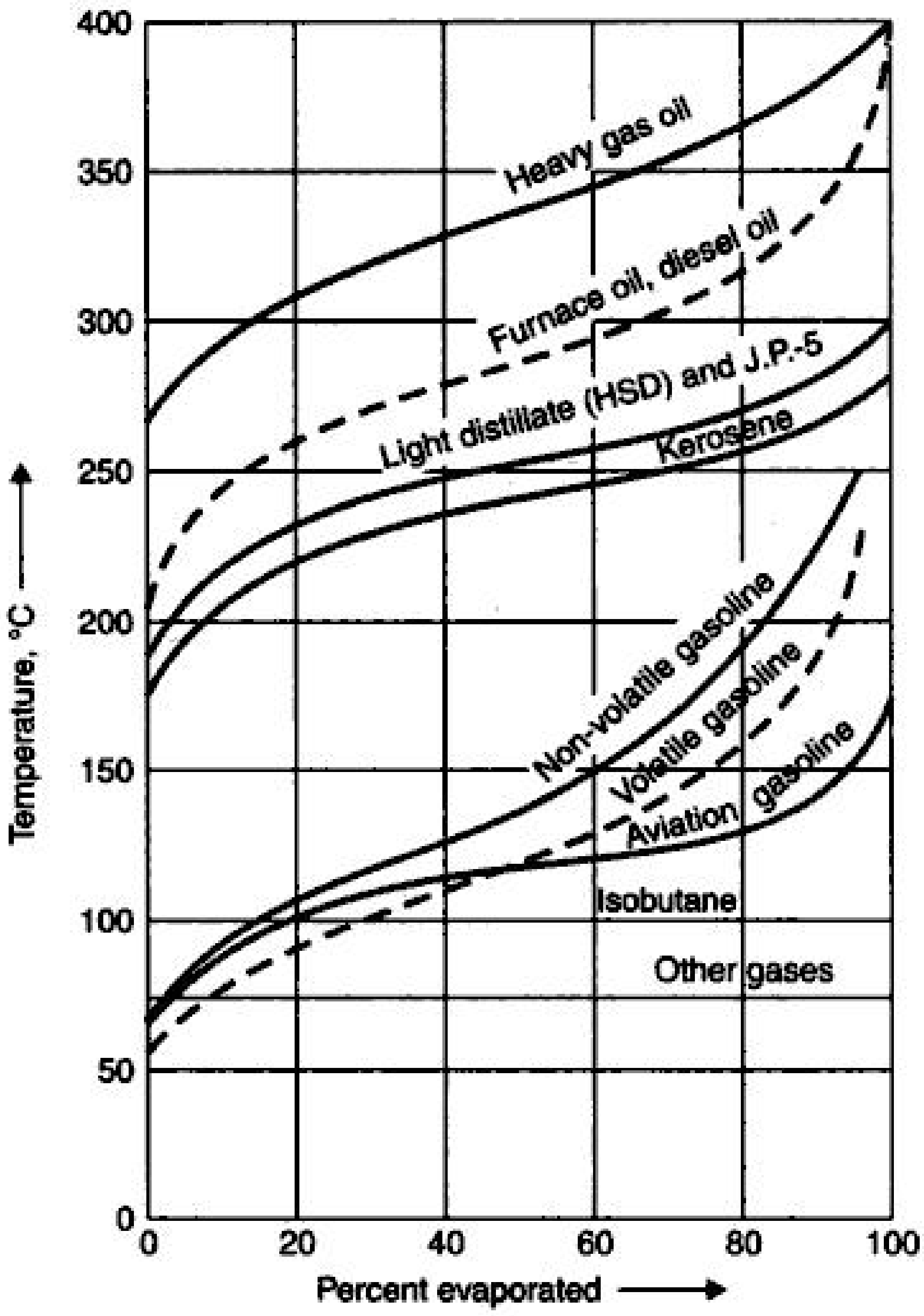


Fig. 2.102. Distillation curves (ASTM).

Reid vapour pressure :

- The *volatility* of petrol is also defined in *terms of Reid vapour pressure.* This is a measure of the vapour pressure of oil at 38°C expressed as millimetres of mercury or in pounds per square inch pressure and indicates initial tendency of a fuel to vapour-lock.
- The apparatus used for determination of Reid vapour pressure is shown in Fig. 2.103.
  - A chilled fuel sample is placed in the Reid bomb and then immersed in water bath held at 38°C ; the *air chamber contains an air volume equal to four times the volume of fuel.* The pressure indicated by the pressure gauge will indicate the *pressure rise due to vaporisation of fuel* and *increase in volume due to increase*

in temperature. If the latter is subtracted from the total pressure rise we get the Reid vapour pressure (the increase in pressure due to *vaporisation of a given quantity of fuel under a given quantity of fuel under given condition of temperature*).

Equilibrium air distillation (EAD) :

- The ASTM distillation curve is not a true boiling point curve of the fuel. Therefore, it cannot directly relate to fuel performance in the engine. In this case, the fuel is allowed to evaporate into an air stream moving through a long tube with low velocity. The exit *vapour-air* ratio is measured as a function of *fuel-air* ratio. The tube should be sufficiently long to attain equilibrium. The tube represents the intake manifold of the engine and equilibrium of vapour-air is reached before entering the engine.
- In ASTM-test, the vapourisation of fuel is carried out in the presence of vapour of fuel so these curves can not be used directly, as actual evaporation of fuel takes place in the current of air. Therefore, to correlate the fuel performance in the engine, EAD test apparatus is used as described above.

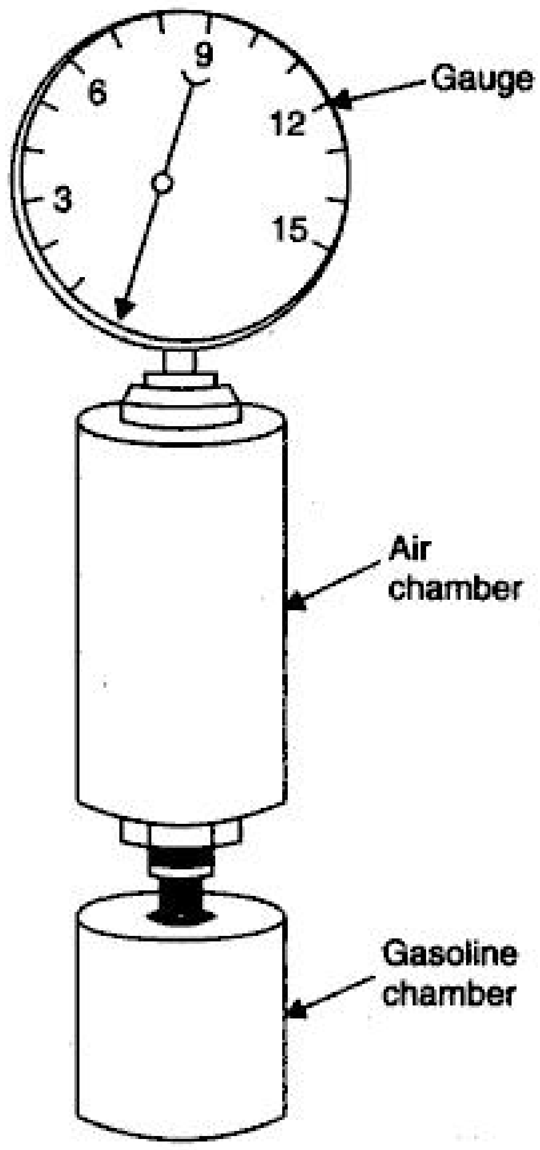


Fig. 2.103. Apparatus for determining Reid vapour pressure.

Fig. 2.104 shows the EAD test curves for a typical gasoline and also A/F ratio volatility curves.

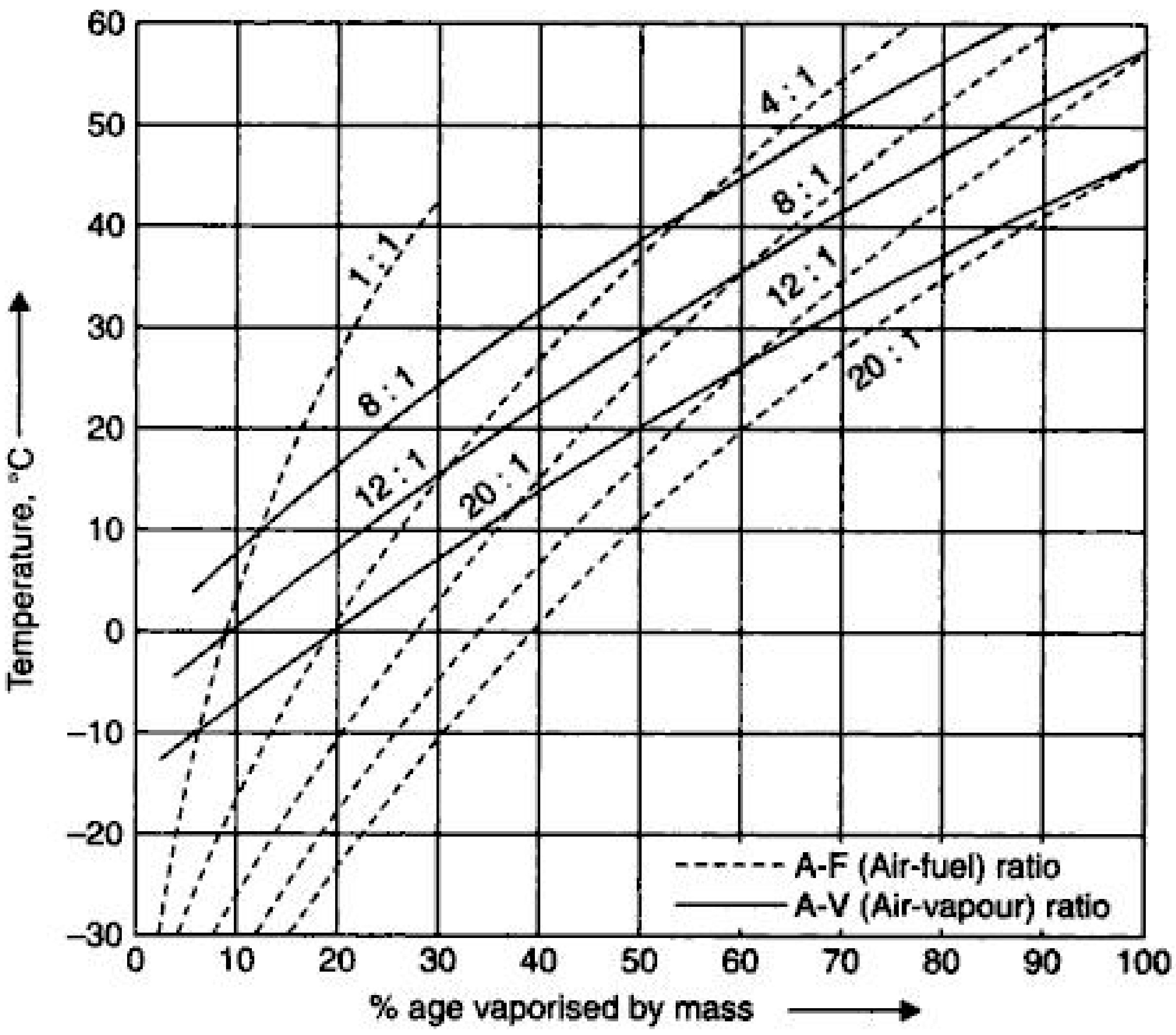


Fig. 2.104. EAD curves for a typical gasoline.

2.42.7.2. Effects of Volatility on S.I. Engine Performance

Volatility of a liquid is its tendency to evaporate under a given set of conditions. It is an extremely important characteristic of S.I. engine which affects engine performance and fuel economy characteristics.

- Cold starting of S.I. engine is improved if front end volatility is higher but it may lead to increased problems of hot starting and vapour lock.
- The *mid range* (20 to 80%) *portion* should be volatile enough to give satisfactory air-fuel ratios under a variety of operating conditions.
- *Low tail end volatility will help in good mixture distribution and hence good fuel economy.*

A few important effects of volatility on S.I. engine performance are enumerated and described below :

1. Starting and warm up.
2. Vapour lock.
3. Evaporation loss.
4. Crankcase dilution.
5. Operating range performance.
6. Spark-plug fouling.
7. Formation of sludge deposits.

1. **Starting and warm up :**

- For easy starting of the engine a certain part of the gasoline should vaporise at room temperature. To fulfil this condition 1 to 10 per cent of the distillation curve must have a low boiling temperature. With the warming up of the engine, the temperature gradually increases to the operating temperature.

- For best warm-up, low distillation temperatures are desirable throughout the range of distillation curve.

2. **Vapour lock :**

- Vapour lock is a situation where *too lean a mixture is supplied to the engine.* The automotive fuel pump should handle both liquids and vapours. If the amount of fuel evaporated in the fuel system is very high the fuel pump is mainly pumping vapour and very little liquid will go to the engine. This results in very weak mixture which can not maintain engine output.

  Vapour lock causes the following :

  (*i*) Uneven running of an engine ;
  (*ii*) Stalling while idling ;
  (*iii*) Irregular acceleration ;
  (*iv*) Difficult starting when hot ;
  (*v*) Momentary stalling when running.

- The vapour lock tendency of the gasoline is related to *front end volatility.* The vapour-liquid ratio (V/L) of a gasoline directly correlates with the degree of vapour lock likely to be experienced in the fuel system. At V/L ratio of 24 vapour lock may *start,* and at V/L ratio of 36 vapour lock may be *very severe.* Therefore, the *volatility of the gasoline should be maintained as low as practicable to prevent this type of difficulty.*

3. **Evaporation loss :**

- The evaporation loss (from carburettors and storage tanks) *depends on the vapour pressure which is a function of fraction components and initial temperature.* These losses can be as high as 10 to 15 per cent.
- The evaporation loss *not only decreases the fuel economy, but also decreases its anti-knock quality as the lighter fraction have higher anti-knock properties.*

  The evaporation loss is a *reason for restricting the low end volatility of the fuels.*

4. **Crankcase dilution :**

- If very frequent starting of the engine with low engine temperature is necessary, very rich mixtures have to be supplied and some of un-evaporated fuel leaks past the piston rings and goes to crankcase. Consequently lubricating oil gets diluted. *This dilution decreases the viscosity of the lubricating oil and also washes away the lubricating oil film on engine cylinder walls.* It is found that the tendency of fuels to dilute the lubricating oils lies in the order of 90% ASTM temperature. Thus control of 90% ASTM temperature combined with proper ventilation of cranckcase reduces the dilution of crank-case oil.
- In the engines using *heavier fuels* like kerosene and other distillates, the problem of dilution and poor lubrication of pistons and rings may be *severe.*

5. **Operating range performance :**

- The acceleration of an engine depends upon its ability to deliver suddenly to intake an extra supply of fuel air mixture in a sufficiently vaporised form to burn quickly. Good acceleration occurs when air-fuel vapour ratio of 12 : 1 is supplied.
- The ability to accelerate falls off as available mixture becomes lean.

6. **Spark-plug fouling :**

Spark plug fouling is caused due to deposition of some high boiling hydrocarbons. Lower the tail-end volatility less are the chances of spark-plug fouling.

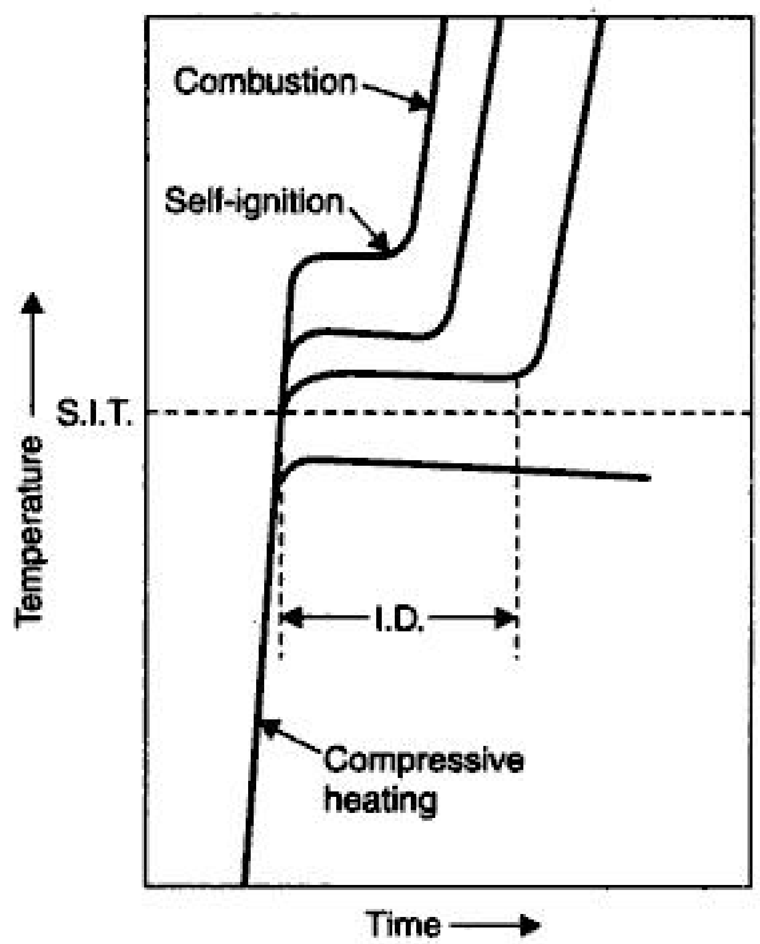
7. **Formation of sludge deposits :**

The sludge deposition inside an engine is caused by certain types of high boiling hydrocarbons. These deposits *can cause piston ring plugging and sticking and valve sticking resulting in poor operation and poor fuel economy.*

2.42.8. Knock Rating of S.I. Engines Fuels

2.42.8.1. Self-ignition characteristics of fuels

- When the temperature of an air-fuel mixture is raised high enough, the mixture will *self-ignite* without the need of a spark-plug or other external ignites. *The temperature above which this occurs is called the "Self-Ignition Temperature (S.I.T.)".* This is the basic principle of ignition in a compression ignition engine. The compression ratio is high enough so that the temperature rises above S.I.T. during the compression stroke. Self-ignition then occurs when the fuel is injected into the combustion chamber. On the other hand, self-ignition (or pre-ignition, or auto-ignition) is not desirable in an S.I. engine, where a spark-plug is used to ignite the air-fuel at the proper time in the cycle. *When self-ignition does occur in an S.I. engine higher than desirable, pressure pulses are generated. These high pressure pulses can cause damage to the engine and quite often are in the audible frequency range.* This phenomenon is often called **knock** or **ping.**
- Fig. 2.105 shows the basic process of what happens when self-ignition occurs.

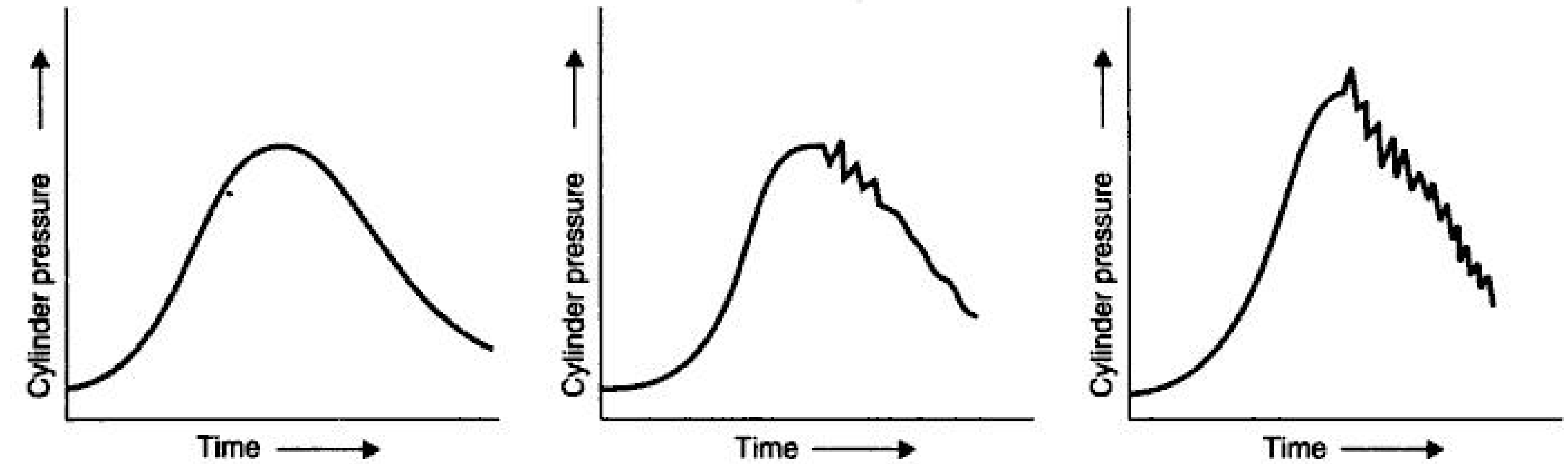


S.I.T. → Self-ignition temperature
I.D. → Ignition delay

Fig. 2.105. Self-ignition characteristics of fuels.

- If the temperature of a fuel is raised above the Self-Ignition Temperature (S.I.T.), the fuel will spontaneously ignite after a short Ignition Delay (I.D.). *The higher above S.I.T. which the fuel is heated, the shorter will be I.D.*
- **Ignition delay** is generally a very small fraction of a second (generally of the order of *thousandths of a second*). During this time, pre-ignition reaction occurs, including oxidation of some fuel components and even cracking of some large hydrocarbon components into smaller hydrocarbon molecules. These pre-ignition reactions raise the temperature at local spots, which then promotes additional reactions until, finally, the actual combustion reaction occurs.

• Fig. 2.106 shows the cylinder pressure as a function of time in a typical S.I. engine combustion chamber showing (*i*) normal combustion, (*ii*) combustion with light knock and (*iii*) combustion with heavy knock.



(*i*) Normal combustion with *no knock* (*ii*) Combustion with *light knock* (*iii*) Combustion with *heavy knock*

Fig. 2.106. Cylinder pressure as a function of time in a typical S.I. engine combustion chamber.

2.42.8.2. Highest Useful Compression Ratio (H.U.C.R.)

The ***highest useful compression ratio*** is the *highest compression ratio at which a fuel can be used without detonation in a specified test engine under specified operating conditions and the ignition and mixture strength being adjusted to give best efficiency.*

2.42.8.3. Octane number (ON) and Engine Knock

• *The property of a fuel which describes how fuel will or will not self-ignite is called the* **octane number or just octane**. This is a numerical scale generated by comparing the self-ignition characteristics of the fuel to that of standard fuels in a specific test engine at specific operating conditions. The *two standard reference fuels* are :

- **Iso-octane** (C_8H_{18}) which has a *very high resistance to knock* and therefore is given an octane number of *100* ; and
- **Normal heptane** (C_7H_{16}) which is *very prone to knock* and is therefore given a *zero* value.

Blends of these reference fuels define the knock resistance of intermediate octane numbers, and thus a blend of 10% *n*-heptane and 90% iso-octane by volume has an octane number of 90.

• *The higher the octane number of fuel, the less likely it will self-ignite. Engines with low compression ratios can use fuels with lower octane numbers, but high-compression engines must use high-octane fuel to avoid self-ignition and knock.*

Test procedure for finding octane number (ON) of fuel :

To find ON of a fuel, the following *test procedure* is used :

— The test-engine is run at specified conditions using the fuel being tested. (The *specified / fixed conditions* to give maximum knock response are : Air inlet temperature, coolant temperature, engine speed, ignition advance setting, mixture strength etc.)

— *Compression ratio is adjusted until a standard level of knock is experienced.* (Intensity of knock is measured *with a magnetostriction knock detector*).

— The test fuel is then replaced with a mixture of the two standard fuels. The intake system of the engine is designed such that the blend of the two standard fuels can be varied to any percent from all iso-octane to all *n*-heptane.

— The blend of fuels is varied until the same knock characteristics are observed as with the test fuel.

The percent of iso-octane in the fuel blend is the ON given to the test fuel. For instance, a fuel that has the same knock characteristics as a blend of 85% iso-octane and 15% *n*-heptane would have an ON of 85.

The relationship between octane number and compression ratio is approximately shown in Fig. 2.107.

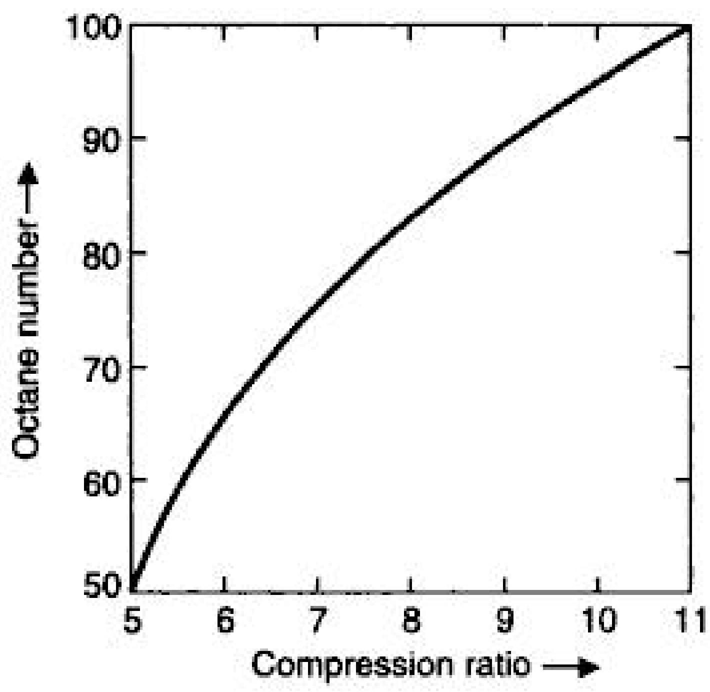


Fig. 2.107. Relationship between octane number and the highest useful compression ratio.

- There are several different tests used for rating octane numbers, each of which will give a slightly different ON value. The *two common methods* of rating gasoline and other automobile S.I. fuels are the **Motor method** and the **Research method.** These give the *Motor Octane Number* (MON) and Research Octane Number (RON). Another *less common method* is the **Aviation method** which is used for aircraft fuel and gives an Aviation Octane Number (AON).

— The engine used to measure MON and RON was developed in the 1930s. It is a single-cylinder, overhead valve engine that operates on the 4-stroke Otto cycle. It has a variable compression ratio which can be adjusted from 3 to 30.

Research Octave Number (RON) method :

— This method measures anti-knock performance under *relatively mild operating conditions.*

- It is considered to be similar to the detonation tendency of a fuel when the engine is *accelerating from 'low speed' in top gear with a wide open throttle under 'medium load'*. Inlet air temperature = 52°C ; coolant temperature = 100°C ; engine speed = 600 r.p.m. ; ignition advance setting = 13°C BTDC.

Motor Octane Number (MON) method :

- This method measures anti-knock performance under *relatively severe operating conditions.*
- It is considered to be similar to the detonation tendency of a fuel when the engine is driven at *'medium speed'* in top gear with a wide-open throttle under *'heavy load'*. Inlet air temperature = 150°C ; coolant temperature = 100°C ; engine speed = 900 r.p.m., ignition advance setting = 19–26° BTDC.

Fuel sensitivity (FS)

- *The difference in octane number between the Research method and the Motor method octane numbers is known as the fuel* ***sensitivity ;*** thus

$$\textit{Fuel sensitivity} = RON - MON$$

- Fuel sensitivity is a *good measure of how sensitive knock characteristics of a fuel will be to engine geometry.* A low FS number will usually mean that knock characteristics of that fuel are insensitive to engine geometry. FS numbers generally range from 0 to 10.

Antiknock index

- The average of the two octane number rating methods, RON and MON, is very good antiknock quality indicator which is known as the **antiknock index ;** thus

$$\textbf{Antiknock index} = \frac{\text{RON} + \text{MON}}{2}$$

Advantages of high-octane fuel :

The *advantages of high-octane fuel* are as follows :

1. The engine can be operated at high compression ratio and therefore, with high efficiency without detonation.
2. The engine can be supercharged to high output without detonation.
3. Optimum spark advance may be employed raising both power and efficiency.

- High octane fuels (upto 100) can be produced by *refining techniques*, but it is done more cheaply, and more frequently, by the use of anti-knock *additives,* such *as tetraethyl lead.* (An addition of 1.1 cm^3 of tetraethyl lead to one litre of 80 octane petrol increases the octane number to 90). Fuels have been developed which have a higher anti-knock rating than iso-octane and this has lead to an extension of the octane scale.

2.42.9. Miscellaneous Properties of S.I. Engine Fuels

Miscellaneous properties of S.I. fuels are described below :

1. **Gum content :**

- There is a tendency in some gasolines to deposit gum, a solid oxidation product, in fuel systems and on valve guides. Excessive gum formation often causes sticking of valves and plugging of fuel passages.
- The gum formation is reduced by mixing *inhibitors* (special chemicals) with gasoline.
- The *oxidised gasoline shows a loss of anti-knock quality.*

2. **Sulphur content :**

The presence of sulphur content in gasolines is objectionable since it may lead to the formation of sulphuric acid in the presence of moisture. The sulphuric acid has corrosive effect on engine parts.

3. **Tetra-ethyl lead :**

- It causes deposits on cylinder walls, spark-plug and valves etc. which lead to the corrosion of spark-plug and exhaust valves. These troubles are minimised by adding ethylene-dibromide ($C_2H_4Br_2$).
- It is a very dangerous poison acting on the skin and in vapour form, the lungs.

2.42.10. Diesel Fuel :

- Diesel fuel (diesel oil, fuel oil) is obtainable over a large range of molecular weights and physical properties. It is classified by various methods, some using *numerical scales* and some designating it for *various uses*. Generally speaking, the *greater the refining done on a sample of fuel, the lower is its molecular weight, the lower is its viscosity, and the greater is its cost.*
  - *"Numerical scales"* usually range from 1 to 5 or 6, with sub categories using alphabetical letters (*e.g.*, A1, 2D, etc.). *The lowest numbers have the lowest molecular weights and lowest viscosity. These are the fuels typically used in C.I. engines. Fuels with the largest numbers are very viscous and can only be used in large, massive heating units.* Each classification has acceptable limits set on various physical properties, such as viscosity, flask point, power point, cetane number, sulphur content etc.
  - *Another method of classifying diesel fuel* to used in I.C. engines is to *designate it for its intended use.* These designations include, bus, truck, railroad, marine and stationary fuel, going from lowest molecular weight to highest.
- For convenience, diesel fuels for I.C. engines can be divided into two *extreme categories* :

  (*i*) Light diesel fuel (molecular weight 170 appr.)

  (*ii*) Heavy diesel fuel (molecular weight 200 appr.)

  Most diesel fuel used in engines will fit in this range.
  - *Light diesel fuel* will be less viscous and easier to pump, will generally inject into smaller droplets, and will be more costly.
  - *Heavy diesel* fuel can generally be used in larger engines with higher injection pressures and heated intake systems.

Often an automobile or light truck can use a less costly heavier fuel in the summer, but must change to a lighter, less viscous fuel in cold weather because of cold starting and fuel line pumping problems.

2.42.10.1. Cetane Number (CN)

- *The cetane number of a diesel fuel is a measure of its ignition quality.* When a fuel is injected into the hot compressed air in the cylinder, it must first be raised to a temperature high enough to ignite the air-fuel mixture. This requires a certain amount of time, known as *ignition delay.*
- Though ignition delay is affected by several engine design parameters such as compression ratio, injection rate, injection time, inlet air temperature etc., it is also dependent on hydrocarbon composition of the fuel and to some extent on its volatility characteristic.
- *The cetane number is a numerical measure of the influence the diesel fuel has in determining the ignition delay.*

- *Higher the cetane rating of the fuel lesser is the propensity for diesel knock.*
- Ignition quality is usually determined by an **engine bench test** which *measures the ignition time delay under standard carefully controlled conditions.*
  - In such a test, the unknown fuel is rated on a scale between 0 and 100 against a pair of pure hydrocarbon reference fuels. **Cetane** ($C_{16}H_{34}$) (*n*-hexadecane) a straight chain paraffin which has a *very high ignition quality (short delay)* and *does not readily knock*, is assigned to the top of the scale by a *cetane number of 100*, whereas **heptamethylnonane** (HMN) which has a very low *ignition quality (long delay)* and *readily knocks*, is represented at the bottom end of the scale by a cetane number of 15. *Originally,* the low ignition quality reference fuel was *alpha methyl napthalane* ($C_{11}H_{10}$) which was given a cetane number of zero. However, *heptamethylnonane, a, more stable compound but with a slightly better ignition quality (CN = 15), now replaces it.*

    Hence, the cetane number (CN) is shown by,

    Cetane number (CN) = Percent cetane

    0.15 × percent heptamethylnonane
  - A standard single-cylinder pre-chamber variable compression ratio engine is used operating under fixed conditions : Inlet temperature = 65.5°C ; Jacket temperature = 100°C ; Speed = 900 r.p.m. ; Injection timing = 13° BTDC ; Injection pressure = 103.5 bar. The *engine is run on a supply of commercial fuel of unknown cetane number under standard operating conditions.* With the injection timing fixed to 13° BTDC, the compression ratio is varied until combustion commences at TDC (by observing the rapid rise in cylinder pressure) thereby producing a 13° delay period of 0.0024s at 900 r.p.m.. A *selection of reference fuel blends are then tested, where again the compression ratio is adjusted for each blend to obtain the standard 13° delay period. The percentage of cetane is one of the blends of reference fuels which gives exactly the same ignition delay (ignition quality) when subjected to the same compression ratio is called the* **cetane number** *of the fuel.* Thus, a commercial 40 cetane fuel would have an ignition delay performance equivalent to that of a blend of 40% cetane and 60% heptamethylnonane (HMN) by volume.
- *For higher speed engines the cetane number required is 50, for medium speed engine about 40, and for slow speed engines about 30.*
- Cetane number is the most important single fuel property which affects the exhaust emissions, noise and startability of a diesel engine. In general, *lower the cetane number higher are the hydrocarbon emissions and noise levels.* Low cetane fuels increase ignition delay so that start of combustion is near to top dead centre. This is similar to retarding of injection timing which is also known to result in higher hydrocarbon levels.
- In general, a *high octane value implies a low cetane value.*
- The relation between cetane number and delay period for a particular engine at a particular set of running conditions is illustrated in Fig. 2.108.

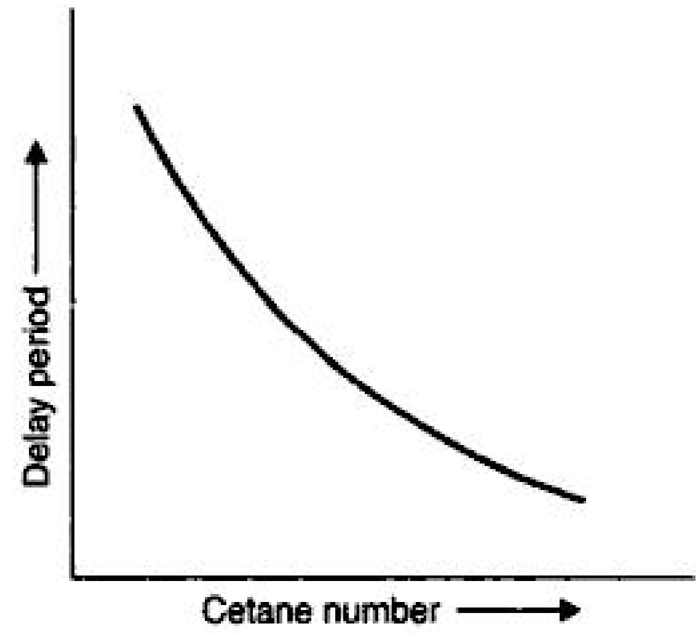


Fig. 2.108

- An approximate inverse relationship between cetane (CN) and octane (ON) number is given as :

$$CN = 60 - \frac{ON}{2}$$

(accurate within ± 5%)

2.42.10.2. Diesel Index (DI)

- The diesel index is a *cheap method of predicting ignition quality.*
- This scale is made possible because ignition quality is sensitive to hydrocarbon compositions ; that is, *paraffins have high ignition quality and aromatic and compounds have low ignition quality.*
- The *diesel index gives an indication of the ignition quality obtained from certain physical characteristics of the fuel as opposed to an actual determination in a test engine.* The index derived from the knowledge of aniline point American Petroleum Institute (API) gravity, which is put together as follows :

$$\text{Diesel index (DI)} = \text{Aniline point } (°F) \times \frac{\text{API gravity (deg)}}{100}$$

  — The **aniline point of the fuel** is *the temperature at which equal parts of fuel and pure aniline dissolve in each other.* It therefore gives an indication of the chemical composition of the fuel since the more paraffinic the fuel the higher the solution temperature. Likewise, a higher API gravity reflects a low specific gravity and indicates a high paraffinic content, which corresponds to a good ignition quality.

Note. The correlation between the diesel-index and cetane number is *not exact* and *with certain fuel consumption it is not reliable but, nevertheless, it can be a useful indicator for estimating ignition quality.*

2.43. ALTERNATIVE FUELS FOR I.C. ENGINES

2.43.1. General Aspects

- The *crude oil and petroleum products,* sometimes during the 21st century will *become very scarce and costly to find and produce.* At the same time, there will likely be an increase in the number of automobiles and other I.C. engines. Although fuel economy of engines is greatly improved from the past and will probably continue to be improved,

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2. The carburettor would *need modification*, as the stoichiometric *air-fuel ratio with alcohols is quite low* (of the order of 10 : 1)
3. The calorific value of alcohol fuels is *low* as compared to that of diesel or petrol.
   - The *m.e.p.* and power output from a given size engine will be low with coal *gas and biogas*.
   - The handling and transportation of natural gas is costly.
   - High compressor power is required to compress it for storage otherwise it will need large storage space.
   - Hydrogen is highly explosive, and its handling is risky.

2.43.3. Alcohol

Alcohol is an attractive alternative fuel because it can be obtained from a number of sources, both natural and manufactured. *Methanol* (methyl alcohol) and *ethanol* (ethyl alcohol) are two kinds of alcohol that seem most promising and have had the most development as engine fuel.

Advantages :

The advantages of alcohol as a fuel are :

1. It is high octane fuel with anti-knock index numbers (octane number on fuel pump) of over 100. High octane numbers result, at least in part, from the high flame speed of alcohol.
   - Engines using high-octane fuel can run more efficiently by using higher compression ratios.
2. It can be obtained from a number of sources, both natural and manufactured.
3. It has high evaporative cooling (h_{fg}) which results in *cooler intake process and compression stroke*. This *raises the volumetric efficiency of the engine and reduces the required work input in the compression stroke.*
4. Generally *less overall emissions* when compared with gasoline.
5. Low sulphur content in the fuel.
6. When burned, it forms *more moles of exhaust which gives higher pressure and more power in the expansion stroke.*
7. The contamination of matter in alcohols is less dangerous than petrol or diesel because alcohols are less toxic to humans and has a recognizable taste.

Disadvantages :

1. *Low energy content* of the fuel (Almost twice as much alcohol as gasoline must be burned to give the same energy input to the engine).
2. The exhaust contains more aldehydes. If as much alcohol fuel was consumed as gasoline, *aldehyde emissions would be a serious exhaust pollutions problem.*
3. As compared to gasoline, alcohol is much more corrosive on copper, brass, aluminium, rubber and many plastics. This puts some restriction on the design and manufacturing of engines to be used with this fuel.
   - Methanol is very corrosive on metals.
4. In general, the ignition characteristics are poor.
5. Vapour lock in fuel delivery system.
6. Owing to low vapour pressure and evaporation, the cold weathering starting characteristics are poor.
7. Due to low vapour pressure, there is a danger of storage tank flammability. Air can leak into storage tanks and create a combustible mixture.

8. Alcohols have almost invisible flames, which is considered dangerous when handling fuel. Again, a small amount of gasoline remove this danger.
9. Low flame temperatures generate less NO_x, but the resulting lower exhaust temperatures take longer to heat the catalytic converter to an efficient operating temperature.
10. When refuelling an automobile, headaches and dizziness have been experienced (due to the strong odour of alcohol).

Note :

- Alcohols are considered as clean burning renewable alternative fuels which can come to our rescue to meet the challenge of vehicular fuel oil scarcity and fouling of environment by exhaust emissions.
- Alcohols make very poor diesel engine fuels as their 'cetane number' is considerably lower.
  - Alcohols can be used in dual fuel engines or with assisted ignition in diesel engine. In a dual fuel mode, alcohol is inducted along with the air, compressed and then ignited by a pilot spray of diesel oil.

2.43.3.1. Methanol

- Of all the fuels being considered as an alternate to gasoline, methanol is one of the more promising and has experienced major research and development.
- Methanol can be obtained from many sources, both *fossil* and *renewable*. These include *coal, petroleum, natural gas, biomass, wood, landfills, and even the ocean*. However, any source that requires extensive manufacturing or processing raises the price of the fuel and requires an energy input back into the overall environmental picture, both unattractive.
- Methanol behaves much like petroleum and so, it can be stored and shifted in the same manner.
  - It is more flexible fuel than hydrocarbon fuels permitting wider variation from ideal A/F ratios.
  - It has relatively good lean combustion characteristics compared to hydrocarbon fuels. *Its wider inflammability limits and higher flame speeds have showed higher thermal efficiency and lesser exhaust emissions compared with petrol engines.*
- Depending on gasoline-methanol mixture, some changes in fuel supply are essential. Simple modifications to the carburettor or fuel injection can allow methanol to replace petrol easily.

Some important features of methanol as fuel :

1. The specific heat consumption with methanol as fuel is 50 percent less than petrol engine.
2. Exhaust CO and HC are decreased continuously with blends containing higher and higher percentage of methanol. But exhaust aldehyde concentration shows a reversed trend.
3. Methanol can be used as supplementary fuel in heavy vehicles powered by C.I. engines with consequent saving in diesel oil and reduced exhaust pollution.

Advantages of methanol :

1. Owing to its *excellent anti-knock characteristics, it is much suitable for S.I. engines.*
2. Methanol use maintains good air quality (Methanol emits less amount of CO_2 and other polluting gases as compared to gasoline fueled vehicles).

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– Two mixture combinations that are important are E 85 (85% ethanol) and E10 (gasohol). E 85 is basically an alcohol fuel with 15% gasoline added to eliminate some of the problems of pure alcohol (*i.e.*, cold starting, tank flammability, etc.). E 10 reduces the use of gasoline with no modification needed to the automobile engine. Flexible-fuel engines are being tested which can operate on any ratio of ethanol-gasoline.

Performance of engine using ethanol :

The effect of speed on power output, brake specific heat consumption and thermal efficiency of an engine using ethanol is compared with gasoline engine as shown in Fig. 2.116 to 2.118.

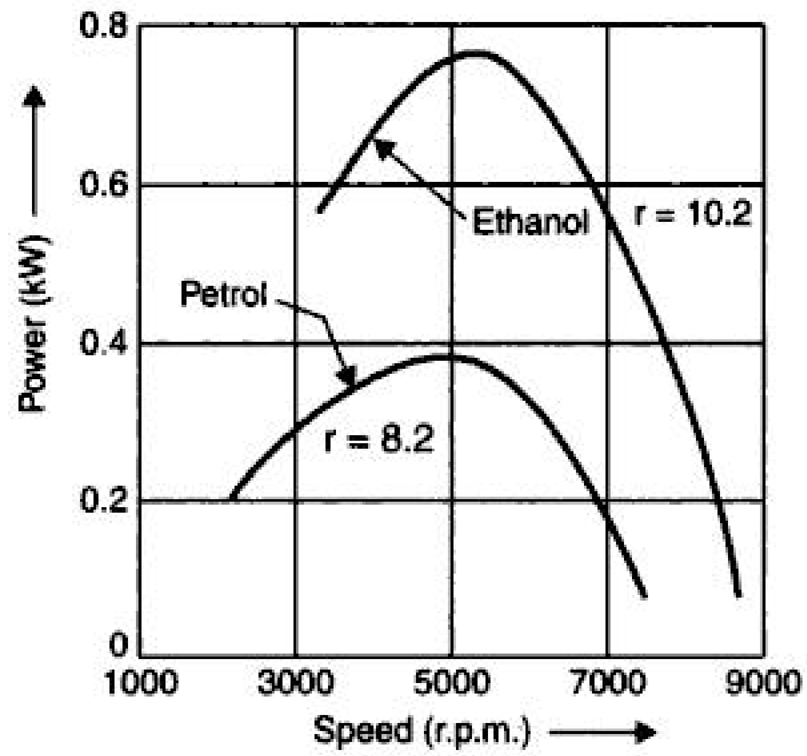

Fig. 2.116

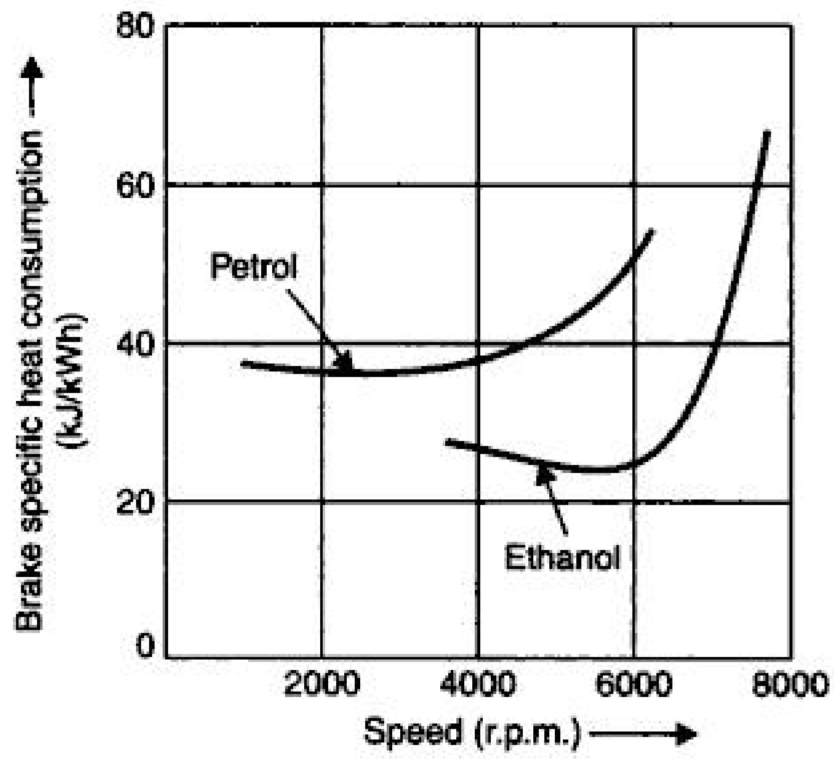

Fig. 2.117

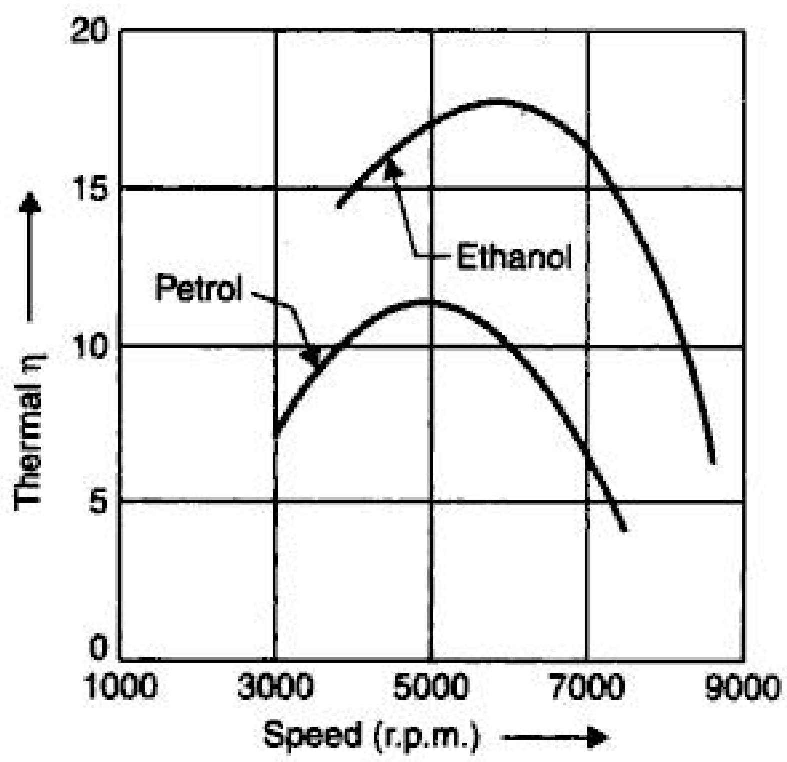

Fig. 2.118

- The *power output* of ethanol engine is *higher* compared to gasoline engine at all speeds.
- The *brake specific heat consumption* is *improved* with ethanol engine compared with petrol engine.

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amounts of N_2, CO_2, He and traces of other gases. Its sulphur content ranges from very little (sweet) to larger amounts (sour).

An *ideal composition of CNG* as an automative fuel is as follows :

Methane = 90% (minimum) ; *Ethane content* = 4% (maximum) ; *Propane content* = 1.7% (maximum) ; *C_4 and higher* = 0.7% (maximum) ; *C_6 and higher* = 0.2% (maximum) ; *(CO_2 + N_2)* = 0.2% (maximum) ; *Hydrogen* = 0.1% (maximum) ; *Carbon monoxide* = 0.1% (maximum) ; *Oxygen* = 0.5% (maximum) ; *Sulphur* = 10% ppm (maximum).

- It is stored as **Compressed Natural Gas (CNG)** at pressures of 7 to 21 bar and a temperature around –160°C.
- *As a fuel it works best in an engine system with a single-throttle body fuel injector. This gives a longer mixing time, which is needed by this fuel.*
- Tests using CNG in various sized vehicles continue to be conducted by government agencies and private industry.

Properties of CNG :

The properties of CNG are almost similar to that of methane :

- Methane has very good antiknock qualities which means it *does not ignite readily. Anti-knock Octane number of CNG is nearly 130, so it burns at much higher temperature compared with petrol unleaded (Octane No = 95) and diesel which have low octane number.*
- Owing to better antiknock quality of CNG it can be safely used in engines with a compression ratio as high as 12 : 1 compared with petrol (maximum 10 : 1).
  - *The CNG fuel used engines have higher thermal efficiencies than those fuelled by gasoline.* In addition to this, the reduction in the pollutants emitted by CNG engine is noticeable.
- CNG is *non-toxic* and *lighter than air so when leakage occurs it quickly disappears* unlike gasoline which paddles and evaporates.
- The presence of ethane and propane even in small percentages (5% and 2%, respectively) affect the burning properties of CNG. Both the gases try to lower the Octane characteristics and causes pre-ignition and reduced fuel efficiency.

Advantages of CNG :

(*i*) *High octane number* makes it a *very good S.I. engine fuel.*

(*ii*) *Low engine emissions.* Less aldehydes than with methanols.

(*iii*) It is cheap (It costs about 25 to 50% less than gasoline and more than 50% less than other alternative fuels, such as methanol and ethanol.

(*iv*) It is engine friendly.

(*v*) It is safe in operation.

(*vi*) Fuel fairly abundant world-wide. Natural gas is the second most abundant fuel available in India after coal.

(*vii*) Easy to tap.

(*viii*) It is odourless.

(*ix*) It is clean.

Disadvantages of CNG :

(*i*) Low energy density resulting in low engine performance.

(*ii*) Low engine volumetric efficiency because it is a gaseous fuel.

(*iii*) Need for large pressurised fuel storage tank.

Effects of supercharging on performance of the engine :

1. The *'power output'* of a supercharged engine is *higher* than its naturally aspirated counterpart.
2. The *'mechanical efficiencies'* of supercharged engines are *slightly better* than the naturally aspirated engines.
3. Inspite of better mixing and combustion due to reduced delay a mechanically supercharged otto engine almost always have *'specific fuel consumption' higher than a naturally aspirated engine.*

2.45. SUPERCHARGING OF S.I. ENGINES

The schematic arrangement for supercharging S.I. engine is shown in Fig. 2.122.

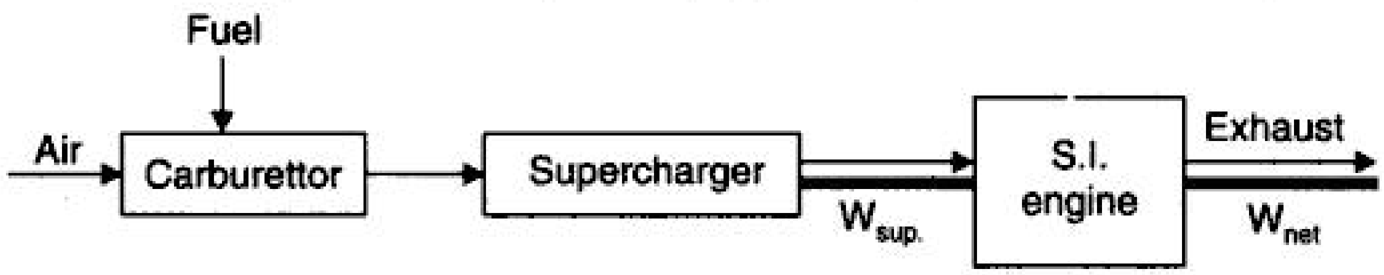

Fig. 2.122

The theoretical operating cycles for both the natural aspirated and supercharged petrol engines can be compared on pressure-volume (p-v) diagrams as shown in Fig. 2.123 and 2.124, respectively. *The larger upper loop is a measure of the positive power developed in the cylinder while the lower loop represents the negative power needed to fill the cylinder with fresh charge.*

2.45.1. Naturally Aspirated Cycle of Operation. Refer Fig. 2.123.

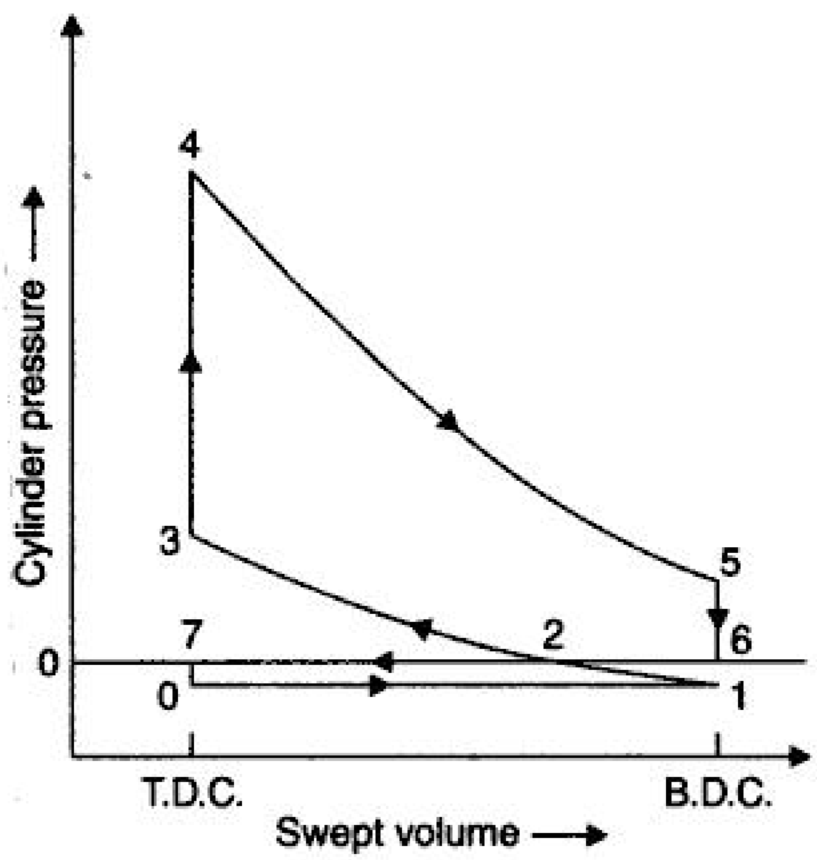

Fig. 2.123. Theoretical naturally aspirated petrol engine (constant volume) pressure-volume diagram.

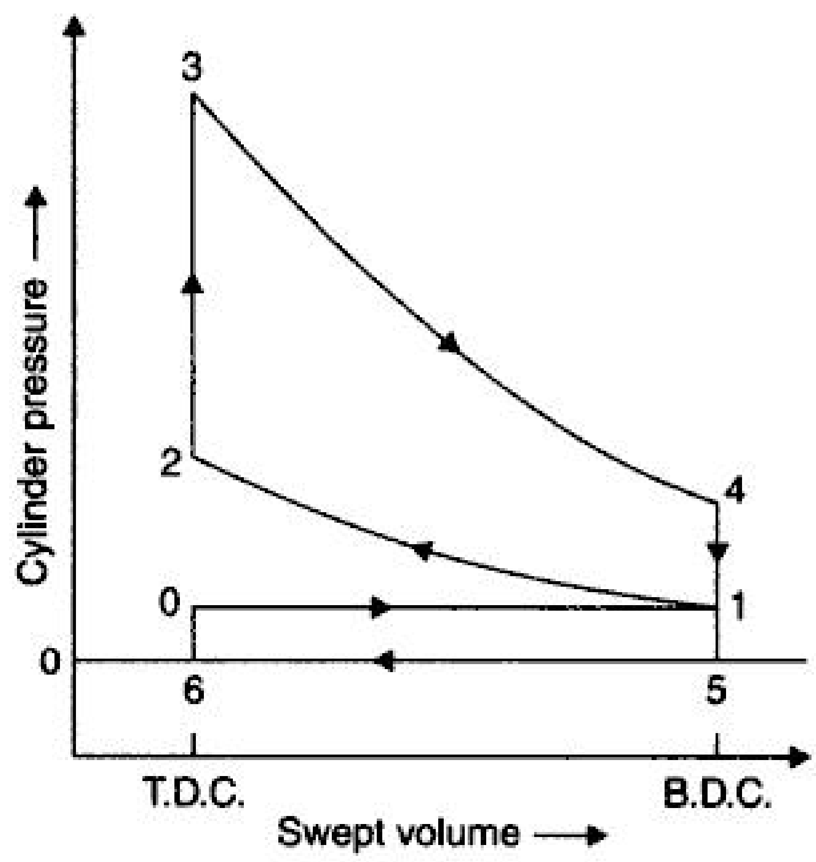

Fig. 2.124. Theoretical supercharged petrol engine (constant volume) pressure-volume diagram.

- The *large area* enclosed in the upper loop (2-3-4-5-6-2) is *proportional to the useful work* performed by combustion on the piston whereas the *small loop area* (0-1-2-7-0), which is

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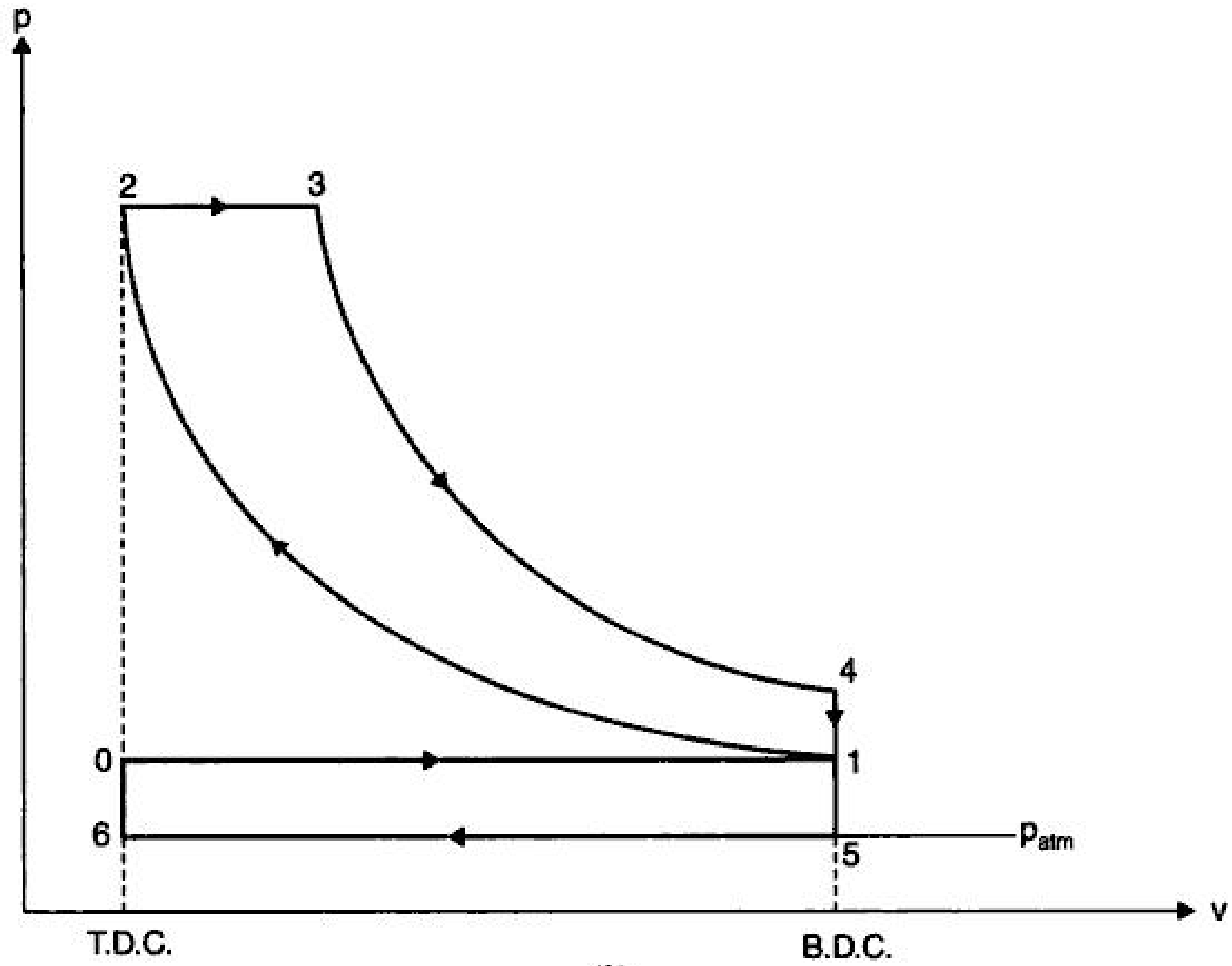

(b)

Fig. 2.129. Supercharging C.I. engine.

quieter and smoother combustion. This improvement in combustion allows a poor quality fuel to be used in a diesel engine and it is also not sensitive to the type of fuel used. *The increase in intake temperature reduces volumetric and thermal efficiency but increase in density due to pressure compensates for this and intercooling is not necessary except for highly supercharged engines.*

- *If an unsupercharged engine is supercharged it will increase the reliability and durability of the engine due to smoother combustion and lower exhaust temperatures. The degree of supercharging is limited by thermal and mechanical load on the engine and strongly depends on the type of supercharger used and design of the engine.*

2.46.1. Supercharging Limits of C.I. Engines

The supercharging limits for a C.I. engine (unlike S.I. engine where the limits of supercharging are due to combustion) is reached by ***thermal loading.*** The very high temperature of the piston and cylinder causes scuffing of piston rings and heavy liner wear.

It has been observed that load on bearing is increased due to increased pressure in the cylinder.

The *main considerations* in limiting the degree of supercharging of a C.I. engine are :

(*i*) Durability ;

(*ii*) Reliability ;

(*iii*) Fuel economy.

– The reliability of the engine decreases with the increase in maximum pressure in the cylinder. This also increases the thermal load on the engine due to the increase in the rate of heat release.

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- The *power developed by the turbocharger is sufficient to drive the compressor, and overcome its mechanical friction.* The turbocharger is independent of the engine, and it is only connected to it by a simple exhaust pipe. The speed range of the turbocharger is from 20000 to 30000 r.p.m.
- For supplying adequate energy to the turbocharger, the *exhaust valve is opened much before the B.D.C.* in contrast to a naturally aspirated engine. *This permits the exhaust gases to escape at a higher pressure and temperature, giving turbocharger enough energy to drive the compressor. The loss in piston work due to early opening of the exhaust valve is more than offset by better charging and scavenging of the engine.*

2.50.4. Methods of Turbocharging

The following are the main types of turbocharging methods :

1. **Constant pressure turbocharging :**

- The various cylinders discharge their exhaust into a common manifold at pressures higher than the atmospheric.

The exhaust gases (from all the cylinders) undergo expansion in the exhaust valves, without doing any work, to an approximately constant pressure in the common manifold and then enter the turbine. Thus the blow-down energy in the form of internal energy is converted into work in the turbine. The higher the pressure ratio of the turbine, the higher is the recovery of blow-down energy. During the whole of the cycle the exhaust gases are maintained at constant pressure to make use of a pure reaction turbine.

2. **Pulse turbocharging :**

- In this method of supercharging, as soon as the exhaust valve opens a considerable part of the blow-down energy is converted into *exhaust pulses.* These pulses enter the turbine (through narrow exhaust pipes by the shortest possible route) where a major proportion of the energy is recovered.
- In order that exhaust process of various cylinders do not interfere with one another, separate exhaust pipes are used.

3. **Pulse converter :**

This turbocharging method permits the advantages of the pulse and constant-pressure tubocharging methods simultaneously. The combination of these two systems is done by *connecting the different branches of exhaust manifolds together in a specially designed venturi junction, called "pulse converter", before the turbine.*

4. **Two-stage turbocharger :**

Two-stage turbocharging is defined as *the use of two turbochargers of different sizes in series, e.g.*, a high pressure stage operating on pulse system and low-pressure stage on constant pressure operation. This type of arrangement is employed for diesel engines requiring very high degree of supercharging, b.m.e.p. ranging from 25 to 30 bar, which can not be obtained in a single-stage turbocharger.

5. **Miller turbocharging :**

- The system of turbocharging is based upon the idea of *increasing the expansion ratio relative to compression ratio by means of early closure of inlet valve as the boost pressure is increased.*
- The Miller turbocharging is not very attractive unless two-stage turbocharging is necessary because of other reasons such as need to reduce exhaust valve failures.

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$$260 = \frac{p_{mb} \times V_s \times Nk \times 10}{6} \text{ kW} \qquad (\because \quad L \times A = V_s)$$

$$= \frac{p_{mb} \times 0.02488 \times 1500 \times \frac{1}{2} \times 10}{6}$$

$\therefore$ $\mathbf{p_{mb} = 8.36\ bar.}$ **(Ans.)**

Supercharged engine :

Increase of pressure required :

Gross power produced by the engine $= 260 + 0.08 \times$ gross power

$\therefore$ Gross power produced by the engine $= \dfrac{260}{(1 - 0.08)} = 282.6$ kW

$\therefore$ Mass of air required $= \dfrac{18.19 \times 282.6}{260} = 19.77$ kg

$$\eta_{vol.} = \frac{\text{Mass of air taken in per cycle}}{\text{Mass of air corresponding to swept volume measured at outlet conditions of supercharger}}$$

$$0.78 = \frac{\dfrac{19.77}{1500/2}}{\dfrac{(p_2 \times 10^5) \times 0.02488}{287 \times (32 + 273)}} = \frac{0.02636}{0.0284\, p_2}$$

or
$$p_2 = \frac{0.02636}{0.78 \times 0.0284} \text{ bar} = 1.19 \text{ bar}$$

$\therefore$ **Increase of pressure required** = 1.19 – 0.72 = **0.47 bar. (Ans.)**

VII. Testing and Performance of I.C. Engines

2.51. INTRODUCTION TO TESTING AND PERFORMANCE OF I.C. ENGINES

- The primary task of the development engineer is to reduce the capital and running cost of the engine. This involves trial of various design concepts. The parameters are so enormous and different in nature that it is almost physically impossible to take care of all of them during the design of the engine. Therefore, it is necessary to conduct the test on the engine and determine the measures which should be taken to improve the engine performance. The nature and the type of the test to be conducted will depend upon a great number of factors such as, the degree of development of the particular design, the accuracy required, the funds available, the nature of the manufacturing company etc.
- The testing of the engine is necessary to verify the performance of the engine as per the specification of the manufacturer.

2.52. PERFORMANCE PARAMETERS

Engine performance is an indication of the degree of success with which it does its assigned job *i.e., conversion of chemical energy contained in the fuel into the useful mechanical work.*

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Calorific value of fuel, $C = 43900$ kJ/kg

Brake power, B.P. = 28 kW

Speed = 2500 r.p.m.

$k = \frac{1}{2}$ .... for four-stroke cycle, engine.

(*i*) **Volumetric efficiency on the basis of air alone :**

Characteristic gas equation is written as

$$pV = mRT$$

or,
$$\frac{m}{V} = \frac{p}{RT} = \frac{1.0132 \times 10^5}{287 \times (20 + 273)} = 1.2 \text{ kg/m}^3$$

Also, 150 mm of $H_2O = \frac{150}{1000} \times 1000 = 150$ kg/m^2

Thus head of air column causing flow,

$$H = \frac{150}{1.2} = 125 \text{ m}$$

Thus air flow through the orifice

$$= \text{Air consumption} = C_d \times A \times \sqrt{2gH}$$

$$= 0.62 \times \frac{\pi}{4} \times (0.032)^2 \times \sqrt{2 \times 9.81 \times 125} = 0.0247 \text{ m}^3\text{/s}$$

Therefore, air consumption per stroke

$$= \frac{0.0247 \times 60}{\left(\frac{2500}{2}\right)} = 0.001185 \text{ m}^3$$

$\therefore$ *Volumetric efficiency,* $\eta_{vol.} = \frac{\text{Air consumption of stroke}}{\text{Piston displacement}}$

$$= \frac{0.001185}{0.00178} = \mathbf{0.665 \text{ or } 66.5\%.} \quad \textbf{(Ans.)}$$

(*ii*) **Air-fuel ratio :**

Mass of air drawn into the cylinder per min.

$$= 0.0247 \times 60 \times 1.2 = 1.778 \text{ kg/min}$$

$\therefore$ *Air-fuel ratio* $= \frac{1.778}{0.135} = \mathbf{13.67 : 1.}$ **(Ans.)**

(*iii*) **Brake mean effective pressure, p_{mb} :**

$$\text{B.P.} = \frac{n \times p_{mb} LANk \times 10}{6}$$

$$28 = \frac{1 \times p_{mb} \times 0.00178 \times 2500 \times \frac{1}{2} \times 10}{6} \qquad [\because LA = 0.00178 \text{ m}^3]$$

$$\therefore \quad p_{mb} = \frac{28 \times 6 \times 2}{0.00178 \times 2500 \times 10} = \mathbf{7.55 \text{ bar.}} \quad \textbf{(Ans.)}$$

(*iii*) The inherent knock resistance of TCP allows the use of higher compression ratio or turbocharging without imposing any octane requirement.

(*iv*) The lean overall mixture can be used.

(*v*) Low exhaust smoke.

- TCP system has proved very versatile as regards multi-fuel requirements and are *used in military vehicle engines.*

2.59.3. Advantages and Disadvantages of Stratified Charge Engines

The *advantages* and *disadvantages* of stratified charged engines are listed below :

Advantages :

1. Compact, lightweight design and good fuel economy.
2. Good part-load efficiency.
3. Exhibit multi-fuel capability.
4. The rich mixture near the spark-plug and lean mixture near the piston surface *provides cushioning to the explosive combustion.*
5. *Resist the knocking* and provide smooth combustion resulting in smooth and quiet engine operation over the entire speed and load range.
6. Low level of exhaust emissions ; NO_x is *reduced* considerably.
7. Usually *no starting problem.*
8. Can *tolerate wide quality of fuels.*
9. Can be manufactured by the existing technology.

Disadvantages :

1. For a given engine size, charge stratification results in *reduced power.*
2. These engines create *high noise level at low load conditions.*
3. *More complex design* to supply rich and lean mixture, and quantity is varied with load on the engine.
4. *Higher weight* than that of a conventional engine.
5. Unthrottled stratified charge engines *emit high percentage of HC* (due to either incomplete combustion of lean charge or occasional misfire of the charge at part load conditions).
6. Reliability is yet to be well established.
7. Higher manufacturing cost.

2.60. STIRLING ENGINE

2.60.1. Stirling Cycle

The Stirling cycle is ***superior*** *to the Carnot cycle because of the following reasons :*

1. The Stirling cycle is *practicable,* whereas the *Carnot cycle cannot be realised in practice* due to wide variation in speed during a cycle (alternately very high for adiabatic and very slow for the isothermal part of the cycle).

2. The work output per cycle and *m.e.p. of Stirling cycle are high. The Carnot cycle needs a very long stroke and produces a very narrow strip of work giving a low m.e.p.*

2.60.2. Working Principle of Stirling Engine

The basic principle of working of stirling engine is the same as that of conventional engine. *The alternate compression at low temperature and expansion at high temperature of a working fluid*

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- Major portion of the lead that enters the engine is emitted from the exhaust which forms very small particles of oxides and oxyhalides in the atmosphere. A portion of the lead particles falls to the ground very quickly, others are small enough to remain suspended in the atmosphere sometime, before they fall out, usually after coagulation with other dusty material in air.
- It may not be possible to eliminate lead completely from all petrols immediately because a large number of existing engines rely upon the lubrication provided by a lead film to prevent rapid wear of exhaust valve seats. However, a very small lead content would be adequate for the purpose.

Following points are worth noting :

- Both the *flow rate* and *pollutant concentration*, for exhaust emissions, can change with the mode operation. Both must be considered in determining emissions.
  - *Under constant high speed conditions, exhaust* HC *concentrations are low while the flow rates are high. During accelerations the flow rate is low but* HC *concentration is high.*
  - The *concentration* of HC in the crankcase and evaporative losses is virtually *independent* of operating conditions, but the *flow rates* from each of these sources *change* during various operations.

    Thus, on km basis CO and HC emissions decrease with increasing driving speed while NO_x emissions are relatively not affected.
- In *a poorly maintained engine the exhaust pollution is more.*
  - An automatic choke sticking in the closed position or a very dirty air cleaner element can reduce air-fuel ratio, generally increasing HC and CO emissions.
  - A misfire allows an entire air-fuel charge to be exhausted without combustion.

2.67. S.I. ENGINE EMISSION CONTROL

The main methods, among various methods, for S.I. engine emission control are :

1. Modification in the engine design and operating parameters.
2. Treatment of exhaust products of combustion.
3. Modification of the fuels.

2.67.1. Modification in the Engine Design and Operating Parameters

Engine design modification improves upon the emission quality. A few parameters which improve an emission are discussed below :

1. **Combustion chamber configuration :**

Modification of combustion chamber involves avoiding flame quenching zones where combustion might otherwise be incomplete and resulting in high HC emission. This includes :

- Reduced surface to volume (S/V) ratio ;
- Reduced squish area ;
- Reduced space around piston ring ;
- Reduced distance of the top piston ring from the top of the piston.

2. **Lower compression ratio :**

- Lower compression ratio reduces the quenching effect by reducing the quenching area, thus *reducing HC.*
- Lower compression ratio also *reduces NO_x* emissions due to lower maximum temperature.
- Lower compression, however, *reduces thermal efficiency and increases fuel consumption.*

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- Fig. 2.173 shows the arrangement of Exhaust Gas Recirculation (EGR) system. A portion (about 10% to 15%) of the exhaust gases is recirculated to cylinder intake charge, and this reduces the quantity of O_2 available for combustion. The exhaust gas for recirculation is taken (as shown in Fig. 2.173) through an orifice and passed through control valve for regulation of the quantity of recirculation.

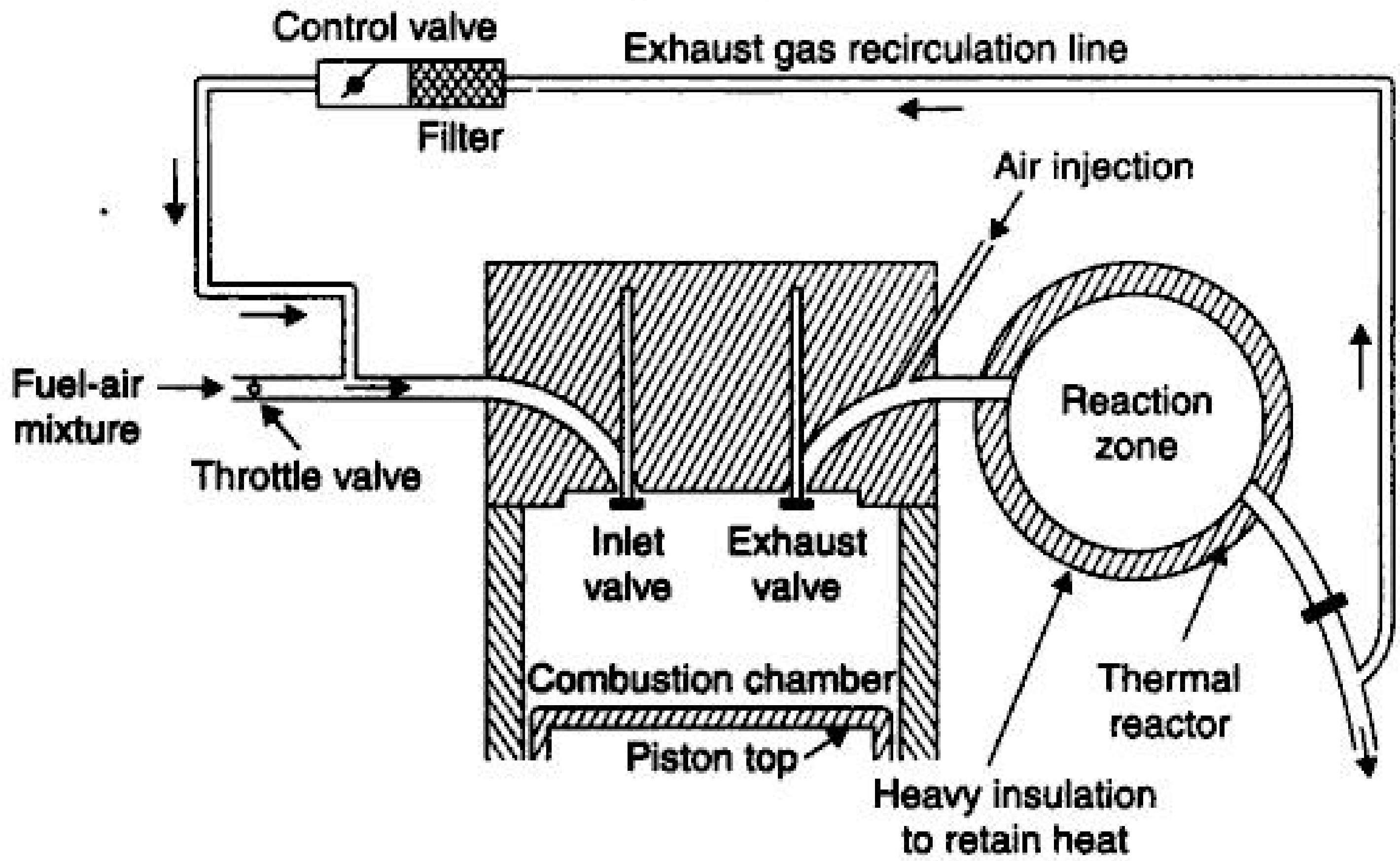

Fig. 2.173. EGR system.

- The effect of A/F ratio of NO_x emission taking EGR parameter is shown in Fig. 2.174.
  - It may be observed from the figure that, maximum emission of NO_x takes place during lean mixture limits when gas recirculation is least effective. Whereas, for emission of hydrocarbon (HC) and carbon monoxide (CO) lean mixture is preferred, 15 percent recycling reduces NO_x by 80 percent but increases HC and CO by 50 to 80%. These are two conflicting requirements of this emission control system and this problem has been solved by adopting package system which have both NO_x and HC/CO control devices.

2. **Catalyst.** A few types of catalysts have been tested to reduce the emission of NO_x; a copper catalyst has been used in the presence of CO for this purpose. The research is going on to develop a good catalyst.

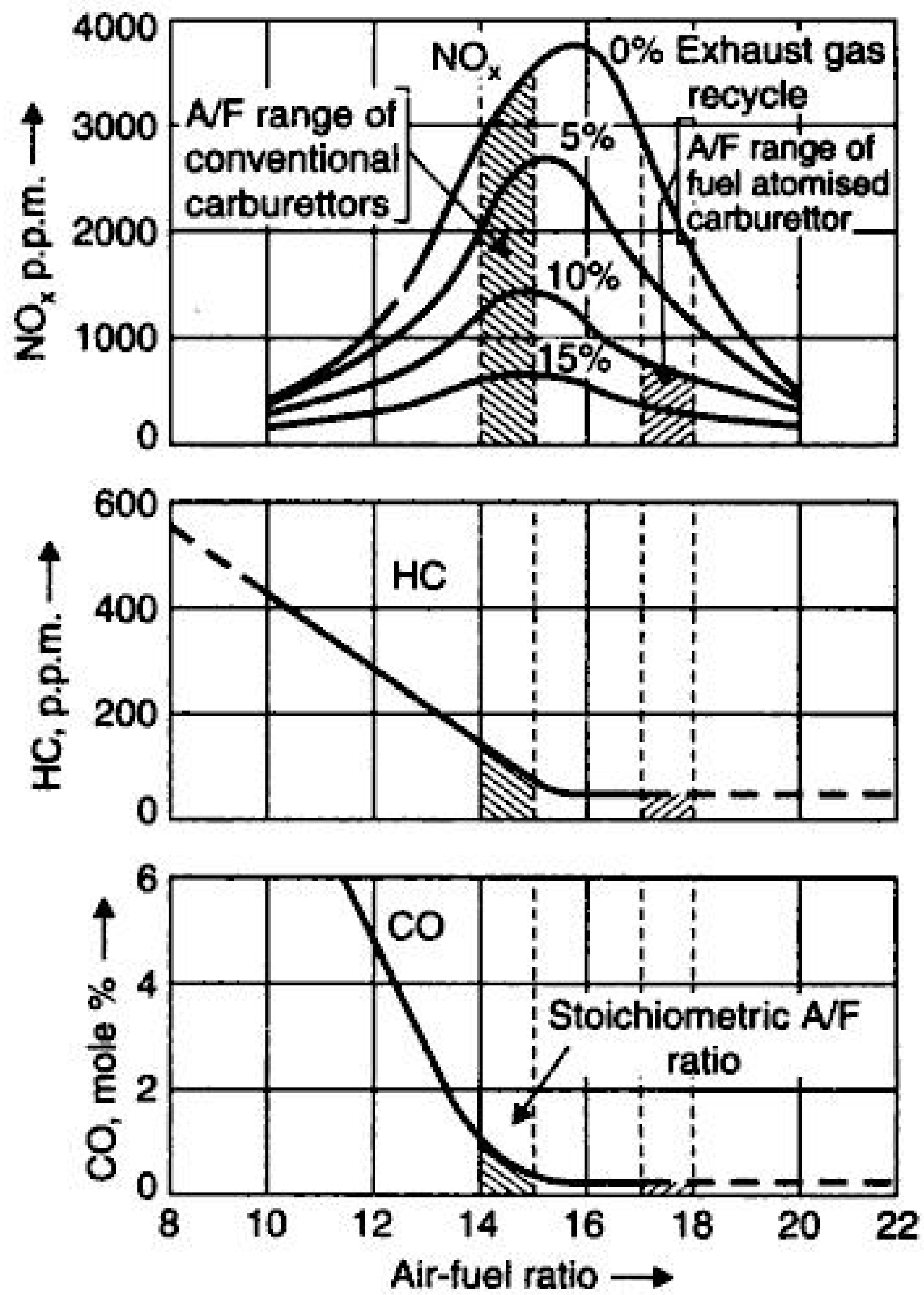

Fig. 2.174. Effect of recycling of gas on NO_x concentration.

2.69. DIESEL SMOKE AND CONTROL

2.69.1. Exhaust Smoke

In C.I. engines, any volume of the combustion chamber in which the fuel is burnt at a relatively F/A ratio greater than 1.5 ($F_R > 1.5$) at pressures developed in these engines produces **soot.** The quantity of soot formed depends on the following *factors* :

(*i*) The local F/A ratios ;

(*ii*) The type of fuel ;

(*iii*) The pressure.

If this soot is able to find *adequate air* (O_2) which on the whole is much in excess of the requirements of perfect combustion, it will *burn completely.* If it is unable to find air (O_2) in the combustion cycle, it will *pass* as *exhaust.* And if the *quantity is sufficient, it will be visible and that is called* **smoke.** The *colour of the smoke depends on the size of soot particles.*

— Formation of smoke is basically a process of conversion of molecules of hydrocarbon fuels into particles of soot. It should be noted that soot is not *carbon* but simply an aggomeration of very large polybenzenoid free radicals. It is also observed that soot formation during the early part of the actual combustion process is common to all diesel engines but it is consumed during later part of combustion.

— Pyrolysis of fuel molecules themselves is thought to be responsible for soot formation. Fuel heated with insufficient O_2 will give carbonaceous deposits. It is believed that the "heavy ends" of diesel fuel may pyrolyze to yield the type of smoke that is observed from the diesel engine. This is believed to be the path of formation of polycyclic aromatic hydrocarbons (benzo-pyrene) found in soot.

— Many theories have been put forward for the formation of smoke but the basic reactions leading to the formation of smoke are not fully known.

- The smoke of a diesel engine is, in general, of two basic types :

  (*i*) ***Blue-white smoke.*** *It is caused by liquid droplets of lubricating oil or fuel oil while starting from cold.*

  Owing to low lower surrounding temperatures the combustion products are at a relatively low temperature and intermediate products of combustion *do not burn.* This results in *bluish white smoke* when exhausted. This type of smoke is also formed when lubricating oil flows past piston rings.

  (*ii*) ***Black smoke :***

- It consists of carbon particles suspended in the exhaust gas and depends largely upon A/F ratio.
- It increases rapidly with the increase in load and available air is depleted.

2.69.2. Causes of Smoke

It is known that the *cause of smoke is incomplete burning of fuel inside the combustion chamber.* The *two major reasons for incomplete combustion are :*

(*i*) Incorrect A/F ratio.

(*ii*) Improper mixing.

These might result due to the design factors discussed below :

1. **Injection system :**

The following injection characteristics substantially *increase the smoke levels.*

- Unsuitable droplet size.
- Inadequate or excess penetration.

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Q. 33. What are the factors causing higher oil consumption ?

Ans. (*i*) Worn out piston rings, (*ii*) Leakage through gaskets, and (*iii*) Worn out valve guides.

Q. 34. What does the cetane number of diesel fuel indicate ?

Ans. Cetane number indicates its ability to ensure quiet operation or ignition quality.

Q. 35. How does turbulence aid combustion ?

Ans. By causing an effective thorough mixing of the hot compressed air with the injected fuel oil, thereby bringing about more complete combustion and uniform cylinder pressure.

Q. 36. How is an engine supercharged ?

Ans. An engine is supercharged by an air compressor or blower which supplies the excess air.

Q. 37. What is purpose of supercharging ?

Ans. To increase the power which may be required at intervals and give more power where space does not permit larger engines.

HIGHLIGHTS

I. Introduction to I.C. engines

1. Any type of engine or machine which derives heat energy from the combustion of fuel or any other source and converts this energy into mechanical work is termed as a **heat engine.**
2. The function of a carburettor is to atomise and meter the liquid fuel and mix it with air as it enters the injection system of the engine maintaining under all conditions of operation fuel air proportion approximate to those conditions.
3. The two basic ignition systems in current use are :
   (*i*) Battery or coil ignition system
   (*ii*) Magneto ignition system.
4. Following are the methods of governing I.C. engines :
   (*i*) Hit and miss method (*ii*) Quality governing
   (*iii*) Quantity governing.
5. Pre-ignition is the premature combustion which starts before the application of spark. Overheated spark plugs and exhaust valves which are the main causes of pre-ignition should be carefully avoided in engines.
6. A very sudden rise to pressure during combustion accompanied by metallic hammer like sound is called **detonation.** The region in which detonation occurs is farthest removed from the sparking plug, and is named the 'detonation zone' and even with severe detonation this zone is rarely more than that one quarter the clearance volume.
7. The **octane number** is the percentage of octane in the mixture [of iso-octane (high rating) and normal heptane (low rating), by volume] which knocks under the same conditions as the fuel.
8. **Delay period or ignition lag** is the time immediately following injection of fuel during which the ignition process is being initiated and the pressure does not rise beyond the value it would have due to compression of air.
9. Higher the cetane rating of the fuel lesser is the propensity for diesel knock. In general a high octane value implies a low cetane value.
10. The purpose of **supercharging** is to raise the volumetric efficiency above that value that which can be obtained by normal aspiration. Supercharging of petrol engines, because of its poor fuel economy, is not very popular and is used only when a large amount of power is needed or when more power is needed to compensate altitude loss.
11. **Dissociation** refers to disintegration of burnt gases at high temperatures. It is a reversible process and increases with temperature. Dissociation, in general, causes a loss of power and efficiency.

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28. The torque developed by the engine is maximum
(*a*) at minimum speed of engine (*b*) at maximum speed of engine
(*c*) at maximum volumetric efficiency speed of engine
(*d*) at maximum power speed of engine.

29. Iso-octane content in a fuel for S.I. engines
(*a*) retards auto-ignition (*b*) accelerates auto-ignition
(*c*) does not affect auto-ignition (*d*) none of the above.

30. Normal heptane content in a fuel for S.I. engines
(*a*) retards auto-ignition (*b*) accelerates auto-ignition
(*c*) does not affect auto-ignition (*d*) none of the above.

31. The knocking in S.I. engines increases with
(*a*) increase in inlet air temperature (*b*) increase in compression ratio
(*c*) increase in cooling water temperature (*d*) all of the above.

32. The knocking in S.I. engines gets reduced
(*a*) by increasing the compression ratio (*b*) by retarding the spark advance
(*c*) by increasing inlet air temperature (*d*) by increasing the cooling water temperature.

33. Increasing the compression ratio in S.I. engines
(*a*) increases the tendency for knocking (*b*) decreases tendency for knocking
(*c*) does not affect knocking (*d*) none of the above.

34. The knocking tendency in petrol engines will increase when
(*a*) speed is decreased (*b*) speed is increased
(*c*) fuel-air ratio is made rich (*d*) fuel-air ratio is made lean.

35. The ignition quality of fuels for S.I. engines is determine by
(*a*) cetane number rating (*b*) octane number rating
(*c*) calorific value rating (*d*) volatility of the fuel.

36. Petrol commercially available in India for Indian passenger cars has octane number in the range
(*a*) 40 to 50 (*b*) 60 to 70 (*c*) 80 to 85 (*d*) 95 to 100.

37. Centane number of the fuel used commercially for diesel engines in India is in the range
(*a*) 80 to 90 (*b*) 60 to 80 (*c*) 60 to 70 (*d*) 40 to 45

38. The knocking tendency in C.I. engines increases with
(*a*) decrease of compression ratio (*b*) increase of compression ratio
(*c*) increasing the temperature of inlet air (*d*) increasing cooling water temperature.

39. Desirable characteristic of combustion chamber for S.I. engines to avoid knock is
(*a*) small bore (*b*) short ratio of flame path to bore
(*c*) absence of hot surfaces in the end region of gas (*d*) all of the above.

40. Accumulation of carbon deposits on the cylinder head of an I.C. engine leads to increase in ...
(*a*) piston displacement (*b*) clearance volume
(*c*) compression ratio (*d*) swept volume.

41. Which of the following motor cycles has more than one cylinder ?
(*a*) Bullet (*b*) Yezdi (*c*) Rajdoot (*d*) Yamah.

42. A diesel engine is generally more efficient than a petrol engine because of
(*a*) proper air-fuel mixing and combustion (*b*) high calorific value of diesel fuel
(*c*) knock-free operation (*d*) high compression ratio.

43. Vapour lock refers to which of the following ?
(*a*) excess supply of fuel to engine (*b*) blocking of carburettor jets
(*c*) complete or partial stoppage of fuel supply due to vaporisation of fuel in the supply line
(*d*) supply of air-fuel mixture containing liquid particles.

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93. Hunting occurs due to which of the following ?
(*a*) Faulty governor
(*b*) Poor-control by the governor
(*c*) Over-control by the governor
(*d*) Bad engine design.

94. Maximum torque is generated by an engine when
(*a*) it runs at lowest speed
(*b*) it develops maximum power
(*c*) it consumes maximum fuel
(*d*) it runs at maximum speed.

95. With an increase of the number of cylinders in a multicylinder engine the power to weight ratio
(*a*) decreases
(*b*) increases
(*c*) remains unaffected
(*d*) none of the above.

96. What will happen if petrol is used in diesel engine ?
(*a*) Black smoke will be produced.
(*b*) Low power will be produced.
(*c*) Higher knocking will occur.
(*d*) Efficiency will be low.

97. What will happen if diesel is fed by mistake in the oil tank of a petrol engine ?
(*a*) The engine will not run.
(*b*) The engine will knock.
(*c*) The engine will detonate.
(*d*) The engine will give lot of smoke.

98. With which of the following tendency of detonation is S.I. engines increases ?
(*a*) Increase of compression ratio
(*b*) Decrease of compression ratio
(*c*) Increase of engine speed
(*d*) Decrease of engine speed.

99. Performance numbers are ...
(*a*) indicative of the fuels having anti-knock qualities superior to iso-octane
(*b*) indicative of the fuels having anti-knock qualities superior to cetane
(*c*) indices of efficiency of petrol engines
(*d*) indices of efficiency of diesel engines.

100. The bi-fuel engine uses which of the following ?
(*a*) Gas fuel during start up and liquid fuel as the basic fuel.
(*b*) Liquid fuel during start up and gas as the basic fuel.
(*c*) Two fuels used in two combustion chambers.
(*d*) None of the above.

101. Lean air-fuel mixture is required for
(*a*) idling (*b*) acceleration (*c*) starting (*d*) cruising.

102. ...... is not a part of petrol engine.
(*a*) Air filter (*b*) Induction coil (*c*) Value mechanism (*d*) Fuel injector.

103. Regarding two-stroke engines which of the following statements is *correct* ?
(*a*) There is only one valve for inlet and exhaust.
(*b*) Charge enters the engine cylinder through ports only.
(*c*) A diesel engine cannot operate on two-stroke cycle.
(*d*) Compression ratio is always lower than that of four-stroke cycle engine.

104. Which of the following statements is *incorrect* ?
(*a*) Choke is kept open when cranking a cold engine for starting.
(*b*) A carburettor prepares a homogenous air-fuel mixture by atomising and vaporising the fuel.
(*c*) Throttle valve controls the supply of air-fuel mixture.
(*d*) Vacuum at the throat of venturi sucks the fuel through the fuel-jet.

105. ...... of heat supplied in the form of fuel in a four-stroke engine is carried away by exhaust gases.
(*a*) 3-7 percent (*b*) 8-12 percent (*c*) 20-35 percent (*d*) 45-55 percent

106. Petrol engines are adjusted to give minimum brake specific fuel consumption at
(*a*) no load
(*b*) 20-30 percent of full load
(*c*) about 70 percent of full load
(*d*) near full load.

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10. Explain briefly crankcase scavenging.
11. Explain the scavenging process in two-stroke engine. Disucss three scavenging processes used in two-stroke engine.
12. Define scavenging and scavenging efficiency. Explain with sketches different scavenging arrangements based on charge flow.
13. How the valve timings of a two-stroke engine differ from that of four-stroke cycle engine ?
14. What is the difference between the valve timing of a crankcase-scavenged and supercharged two-stroke engine ?
15. Compare the relative merits and demerits of different scavenging systems.
16. How is the supercharging of two-stroke engines done ?

V. Conventional fuels

1. What are the desirable properties of good I.C. engines fuels ?
2. Enumerate and describe briefly the gaseous fuels.
3. How are constituents of petroleum classified ?
4. Explain briefly the chemical structure of petroleum.
5. What are five primary hydrocarbon families found in petroleum ? Which are chain types ? Which are ring types ? Which of primary families tends to be better S.I. engine fuel and C.I. engine fuel ?
6. What are different kinds of fuels used in an I.C. engine ?
7. What are the important properties which S.I. engine fuel possess ?
8. What are requirements of an ideal gasoline fuel ?
9. What is volatility ?
10. Discuss the significance of distillation curve.
11. Why volatility is an important quality of S.I. engine fuels ?
12. Explain briefly the following in regard to a fuel :
    (*i*) Vapour lock characteristics.
    (*ii*) Crankcase dilution.
13. "While volatility of the fuel is a determining factor in the selection of fuels for S.I. engines, ignition quality of the fuel is the primary deciding factor for C.I. engines". Discuss briefly the statements.
14. Distinguish clearly between 'Octane Numbers' and 'Cetane Number'. What is their significance in rating of fuels for S.I. and C.I. engines ?
15. What are the reference fuels for 'Octane Number' ?
16. What are the reference fuels for 'Cetane Number' ?
17. What is performance number (PN) ?
18. What is the significance of ASTM distillation curve ?
19. Explain the effect of fuel viscosity on diesel engine performance.
20. What qualities are desired in fuels to inhibit detonation ?

VI. Supercharging of I.C. engines

1. What is supercharging ?
2. Enumerate the main objects of supercharging.
3. What is a supercharger ?
4. Explain briefly supercharging of S.I. engines.
5. Give the comparison of 'Actual naturally aspirated' and 'supercharged engine' pressure-volume diagrams.
6. Define the terms 'Boost pressure' and 'Pressure ratio'.
7. Explain briefly the effect of pressure ratio on air charge temperature.
8. Explain briefly the thermodynamic cycle of supercharged engine on p-v diagram for an ideal otto cycle.

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Determine : (*i*) Indicated mean effective pressure

(*ii*) Indicated power. **[Ans.** (*i*) 8.43 bar ; (*ii*) 3.1 kW]

5. A four-cylinder, four-stroke diesel engine runs at 1000 r.p.m. The bore and stroke of each cylinder are 100 mm and 160 mm respectively. The cut-off is 6.62% of the stroke. Assuming that the initial condition of air inside the cylinder are 1 bar and 20°C, mechanical efficiency of 75%, calculate the air-standard efficiency and brake power developed by the engine.

6. A V-8 four-stroke petrol engine is required to give 186.5 kW at 440 r.p.m. The brake thermal efficiency can be assumed to be 32% at the compression ratio of 9 : 1. The air/fuel ratio is 12 : 1 and the volumetric efficiency at this speed is 69%. If the stroke to bore ratio is 0.8, determine the engine displacement required and the dimensions of the bore and stroke. The calorific value of the fuel is 44200 kJ/kg, and the free air conditions are 1.013 bar and 15°C. **[Ans.** 5.12 litres ; 100.6 mm ; 80.5 mm]

7. During the trial (60 minutes) on a single-cylinder oil engine having cylinder diameter 300 mm, stroke 450 mm and working on the four-stroke cycle, the following observations were made :

Total fuel used = 9.6 litres, calorific value of fuel = 45000 kJ/kg, total number of revolutions = 12624, gross indicated mean effective pressure = 7.24 bar, pumping i.m.e.p. = 0.34 bar, net load on the brake = 3150 N, diameter of brake wheel drum = 1.78 m, diameter of the rope = 40 mm, cooling water circulated = 545 litres, cooling water temperature rise = 25°C, specific gravity of oil = 0.8.

Determine : (*i*) Indicated power. (*ii*) Brake power.

(*iii*) Mechanical efficiency.

Draw up the heat balance sheet on minute basis. **[Ans.** (*i*) 77 kW ; (*ii*) 61.77 kW ; (*iii*) 80.22%]

8. Air enters an air compressor (run by a supercharged diesel engine) at 27°C and is passed on to a cooler where 1160 kJ/min. are rejected. The air leaves the cooler at 67°C and 1.7 bar. Some air from the compressor is bled after the cooler to supercharge the engine. The volumetric efficiency of the engine is 75 percent based on the intake manifold temperature of 67°C and pressure of 1.7 bar.

The engine has the following specifications :

B.P. = 30 kW ; Speed = 2000 r.p.m. ; Number of cylinders = 4 ; Bore = 100 mm ;

Stroke = 110 mm ; Mechanical efficiency = 80 percent.

Assuming the internal efficiency of the compressor as 90 percent, determine the following :

(*i*) The indicated mean effective pressure of the engine ;

(*ii*) The air consumption rate of the engine ;

(*iii*) The air handling capacity of the compressor. **[Ans.** (*i*) 6.5 bar ; (*ii*) 4.53 kg/min. ; 11.57 kg/min.]

9. The average indicated power developed in I.C. engine is 12.9 kW/m^3 of free air induced per minute. The engine is three-litre four-stroke engine running at 3500 r.p.m., and has a volumetric efficiency of 80%, referred to free conditions of 1.013 bar and 15°C. It is proposed to fit a blower, driven mechanically from the engine. The blower has an isentropic efficiency of 75% and works through a pressure ratio of 1.7, at the pressure and temperature of the delivery from the blower. Calculate the increase in B.P. to be expected from the engine. Take all the mechanical efficiencies as 80%. **[Ans.** 25.3 kW]

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3.3. INDUCTION SYSTEM

The schematic arrangement of induction system is shown in Fig. 3.5.

- The pipe that carries the prepared mixture to the engine cylinders is called the *intake manifold*.
- The carburettor is the focal point of the induction system.
- The fuel system, comprising the fuel supply tank and necessary fuel pumps, lines and filters supply liquid fuel to the carburettor.
- During the motion stroke vacuum is created in the cylinder which causes the air to flow through the carburettor and the fuel to be sprayed from the fuel jets. Due to the volatility of the fuel, most of the fuel vaporises and forms a combustible fuel-air mixture. However, some of the larger drops may reach the cylinder in the liquid form and must be vaporised and mixed with air during the compression stroke before the electric spark ignites the mixture.

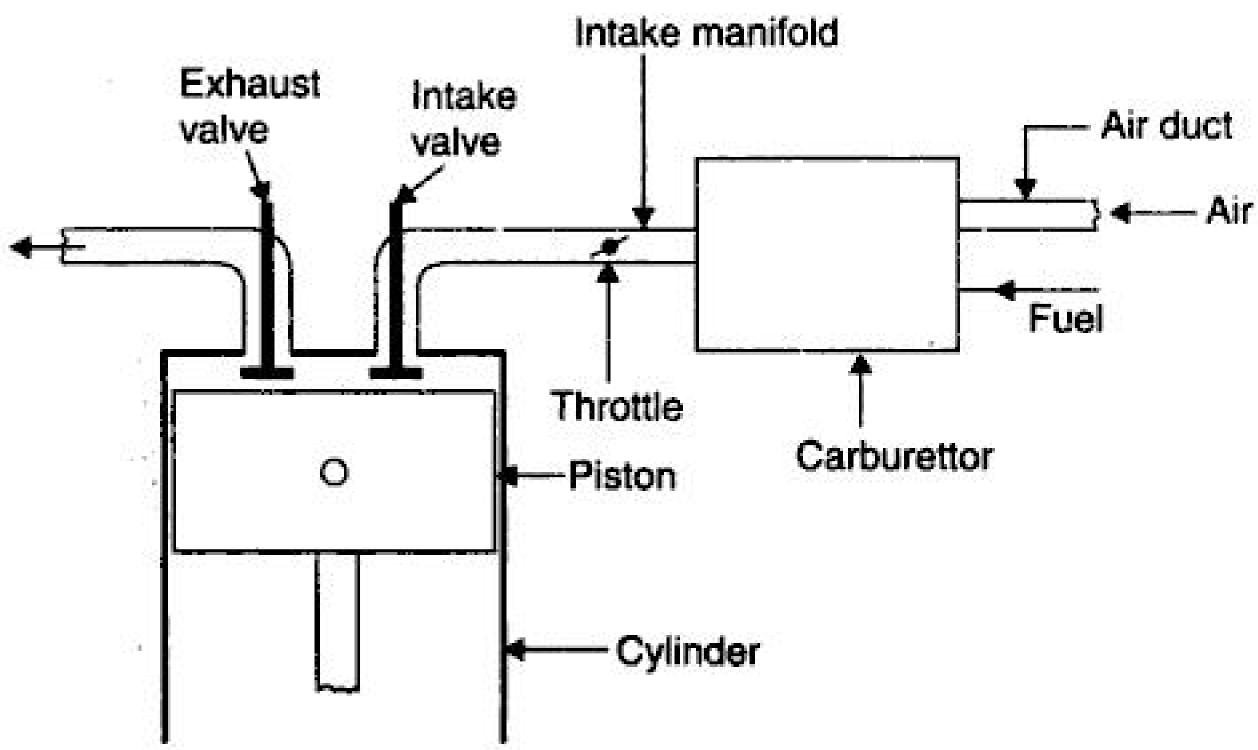

Fig. 3.5. Schematic arrangement of the 'Induction System'.

- The throttle located in the carburettor, regulates the quantity of the mixture.
- There is a limited range of A / F ratio in a homogenous mixture within which combustion in S.I. engines is sustainable. Outside this range, the ratio is too rich or too lean to sustain flame propagation. This range of useful A /F ratio is from approx. 20 : 1 (lean) to 8 : 1 (rich).

3.4. FACTORS INFLUENCING CARBURETION

The *various factors which influence the process of carburetion are as follows :*

1. The engine speed ; the time available for the preparation of the mixture.
2. The vaporisation characteristics of fuel.
3. The temperature of the incoming air.
4. The design of the carburettor.

- In case of modern high speed engines, the time duration available for the formation of mixture is very small and limited. The time duration for mixture formation and induction may be of the order of 10 to 5 milliseconds.
- Atomisation, mixing and vaporisation are the processes which require a finite time to occur. The time available for mixture formation is very small in high speed engines (For

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engine there is an increase in the amount of evaporated fuel and hence the mixture ratio should be progressively made leaner, too rich *evaporated* F/A ratio is avoided.

2. **Acceleration requirements :**

- With regard to engines, the terms acceleration generally refers to an increase in engine speed resulting from opening the throttle. The main object of opening the throttle, however, is *to provide an increase in torque* and whether or not an increase in speed follows depends on the nature of load.
- Under steady running conditions, the fuel evaporated in the intake manifold moving much faster than the liquid film formed on the induction system walls, does not cause any problem. But when the throttle is *suddenly* opened *e.g.*, during acceleration, the liquid fuel lags behind and, the cylinder receives temporarily a lean mixture whilst actually, to produce more instantaneous power for acceleration, a rich mixture is needed. Hence, a suitable mechanism (acceleration pump) is required to provide rich mixture during the acceleration period.

Note. The petrol to be used should be carefully made to suit the engine and the climate of the place since too high volatility or too low volatility, both create difficulties in operation.

— *Too high volatility* may form bubbles in the carburettor and fuel lines particularly when the engine temperature are high, which interfere with the supply and metering of the fuel and may disturb the F/A ratio so seriously that engine may stop working.

— *Too low volatility* may cause petrol to condense on the cylinder walls, diluting and removing the lubricating oil film ; ultimately the petrol may reach the cranckcase past the piston rings and dilute the engine oil. Condensation of petrol on cylinder walls also causes carbon deposits.

3.8. A SIMPLE OR ELEMENTARY CARBURETTOR

In order to understand a modern carburettor (a very complex device) it helps first to study a *simple carburettor* which supplies fuel-air mixture for cruising or normal range of speed and then to add other devices or attachments to take care of other function like *starting, idling, accelerating,* decelerating and other variable load and speed operations.

Fig. 3.9, shows a schematic diagram of a simple or elementary carburettor.

- It consists of a *float chamber, nozzle with metering orifice, venturi* and *throttle valve.*
  — The **float chamber** is meant for storage of fuel. The fuel supplied under gravity action or by fuel pump enters the float chamber through a filter. The arrangement is such that when oil reaches a particular level the *needle/float valve* blocks the inlet passage and thus cuts off the fuel oil supply. On the fall of oil level, the *float* descends down, consequently intake passage open and again the chamber is filled with oil. Then the float and the needle/float valve maintains a constant fuel oil level in the float chamber. There is a *nozzle (discharge jet)* from which the fuel is sprayed into the air stream as it enters the inlet and passes through the venturi or throat. *The fuel level is slightly below the outlet of the jet when the carburettor is inoperative.*
- As the piston moves down in the engine cylinder, suction is produced in the cylinder as well as in the induction manifold as a result of which air flows through the carburettor. *The velocity of air increases as it passes through the constriction at the venturi and the pressure decreases due to conversion of a portion of pressure head into kinetic energy.* Due to decreased pressure at the venturi and hence by virtue of difference in pressure (between the float chamber and the venturi) the jet issues fuel oil into air stream. Since the jet has a fine bore, the oil issuing from the jet is in the form of *fine spray* ; it vaporises quickly

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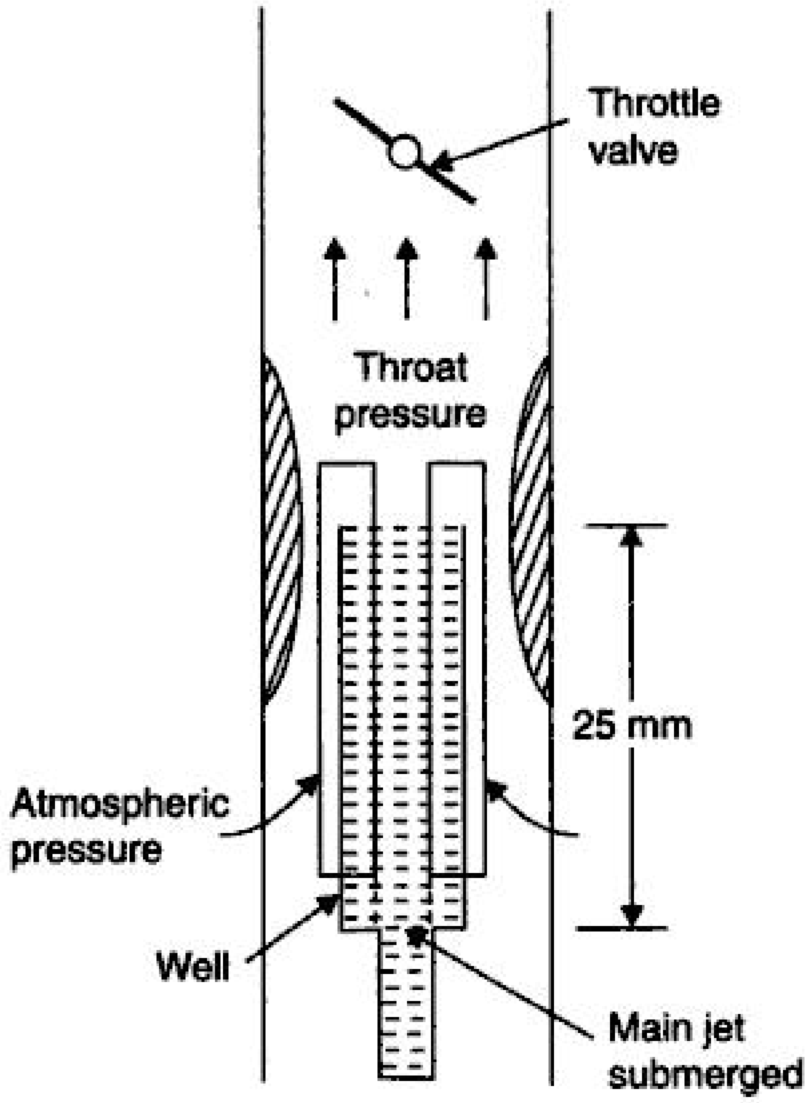

Fig. 3.12. Correction in modern carburettors by air bleeding.

(*iii*) ***Back suction control or pressure reduction method :***

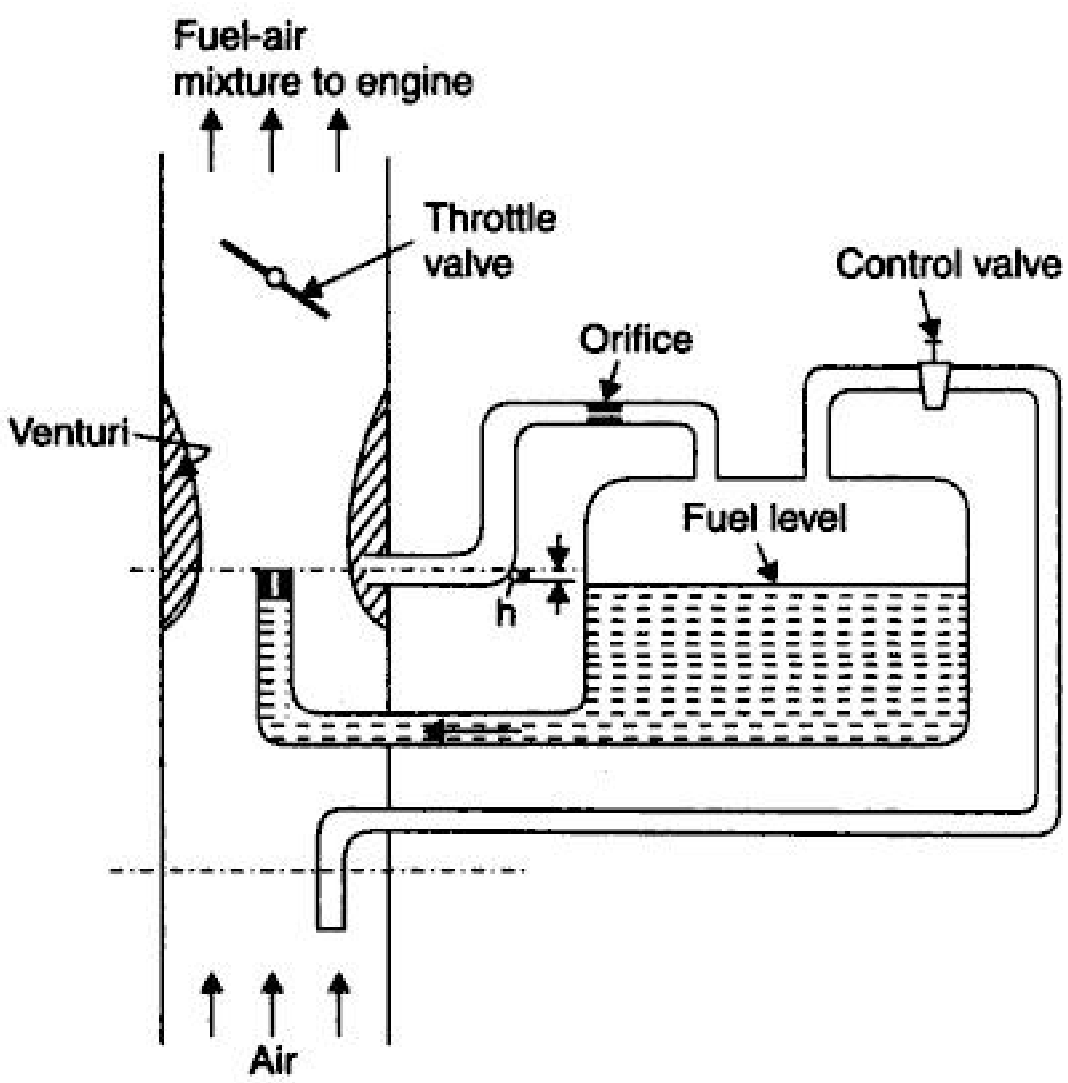

Fig. 3.13. Back-suction control or pressure reduction method.

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— In some carburettors, instead of providing mechanical linkages, an arrangement is made so *that the pump plunger is held up by manifold vacuum*. Whenever this vacuum is reduced by rapid opening of throttle a spring forces the plunger down pumping the fuel through the jet.

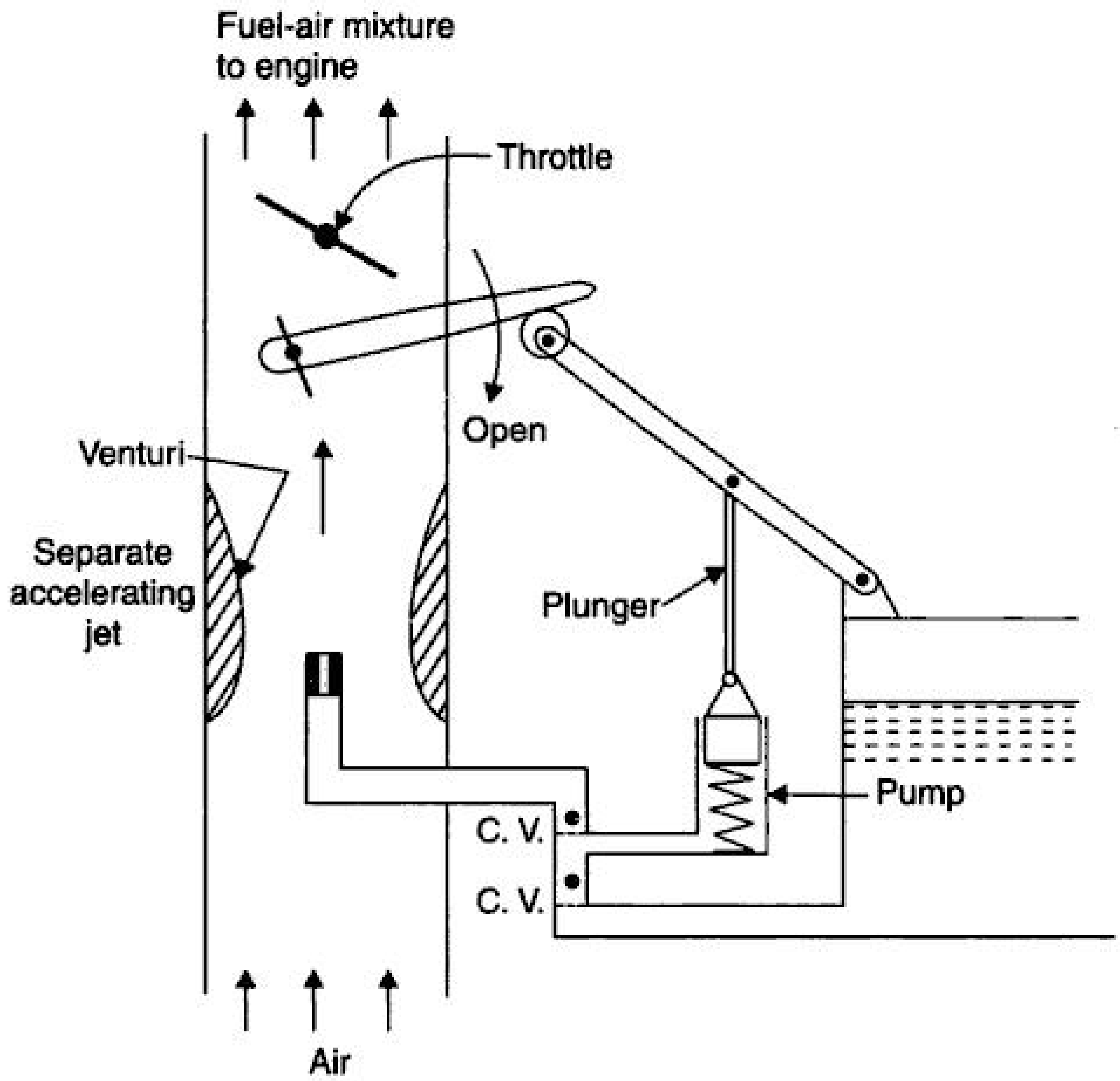
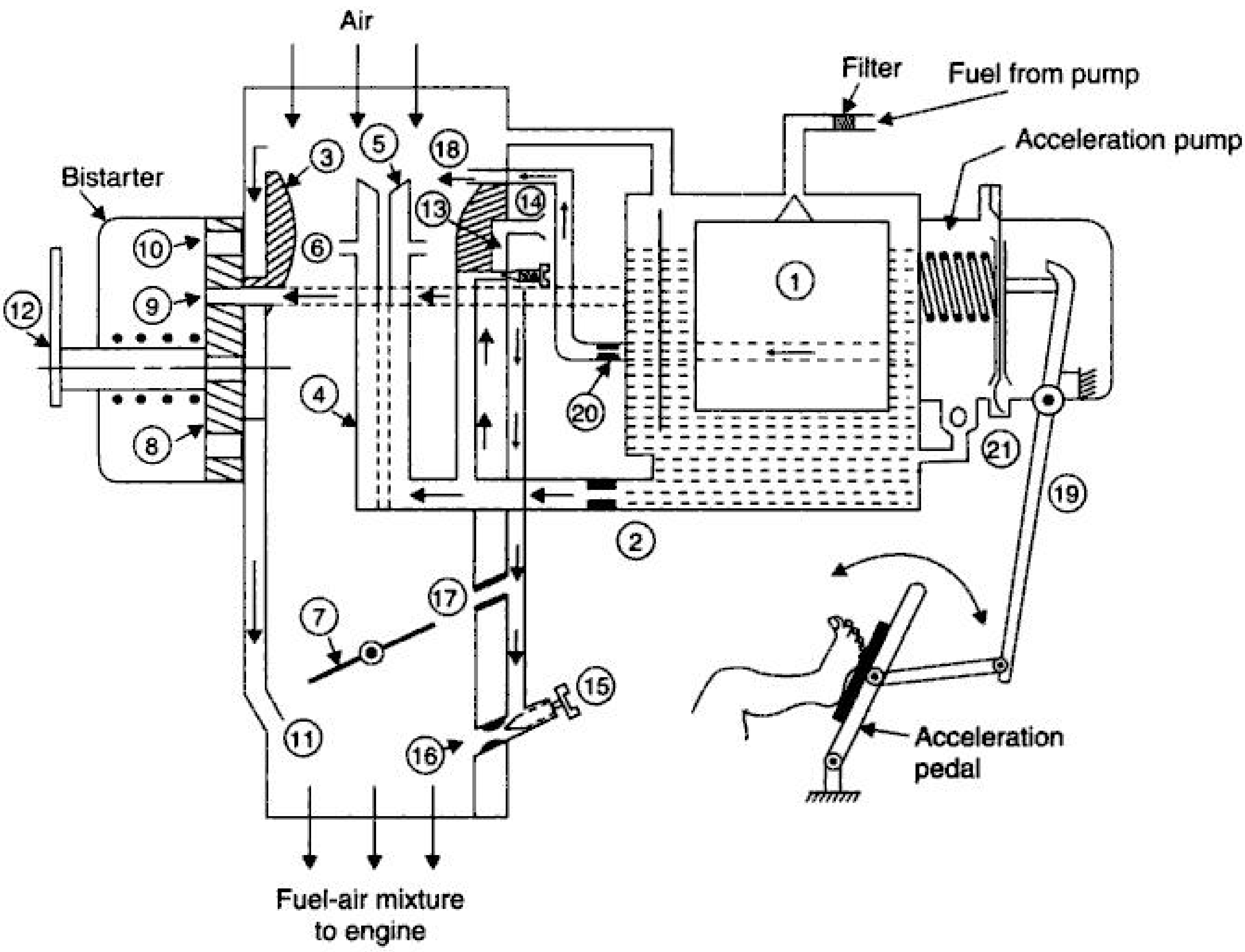


Fig. 3.18. Acceleration pump.

5. **Choke :**

- Starting of a vehicle which is kept stationary for a long period (may be overnight.) during cool winter seasons, is often more difficult. At low cranking speeds and intake temperatures a very rich mixture is required to initiate combustion. Sometimes as high as *five to ten times* more fuel (than usual mixtures) is required. The main reason is that very large fraction of fuel may remain liquid suspended in air even in the cylinder, and only the vapour fraction can provide a combustible mixture with air. The most popular method of providing such mixture is by the use of *choke*.
- A *choke* is simply butterfly valve located between the entrance to the carburettor and the venturi throat as shown in Fig. 3.19.
  — When the choke is partly closed, large pressure drop occurs at the venturi throat, would normally result from the amount of air passing through the venturi throat. The very large carburettor depression at the throat inducts large amount of fuel from the main nozzle and provides a very rich mixture so that the ratio of the evaporated fuel to air in the cylinder is within the combustible limits.
- Sometimes the choke valves are made with spring-loaded by-pass to ensure that large carburettor depression and excessive choking does not persist after the engine has started,



1. Conventional float
2. Main jet
3. Choke tube or venturi
4. Emulsion tube
5. Air correction jet
6. Spraying orifice or nozzles
7. Conventional butterfly valve
8. Flat disc with holes of different sizes
9. Starter petrol jet
10. Jet
11. Starting passage
12. Starter lever
13. Pilot jet
14. Small pilot air bleed orifice
15. Idling volume control screw
16. Idle port
17. By-pass orifice
18. Pump injector
19. Pump lever
20. Pump jet
21. Pump inlet valve.

Fig. 3.21. Schematic arrangement of a solex carburettor.

2. Cold starting and warming :

The *provision of a bi-starter or a progressive starter is the unique feature of solex carburettors.*

- The starter valve is in the form of a flat disc (8) with holes of different sizes. These holes connect the starter petrol jet (9) and starter air jet sides to the passage which opens into a hole just below the throttle valve at (11). Either bigger or smaller holes come opposite the passage, depending upon the position of the starter lever (12). The starter lever is operated by flexible cable from the dash board control. Initially, for starting richer mixture is required and after the engine starts, the richness required decreases. In the start position when the starter control is pulled out fully, bigger holes are the connecting holes. The throttle valve being in closed position the whole of the engine suction is

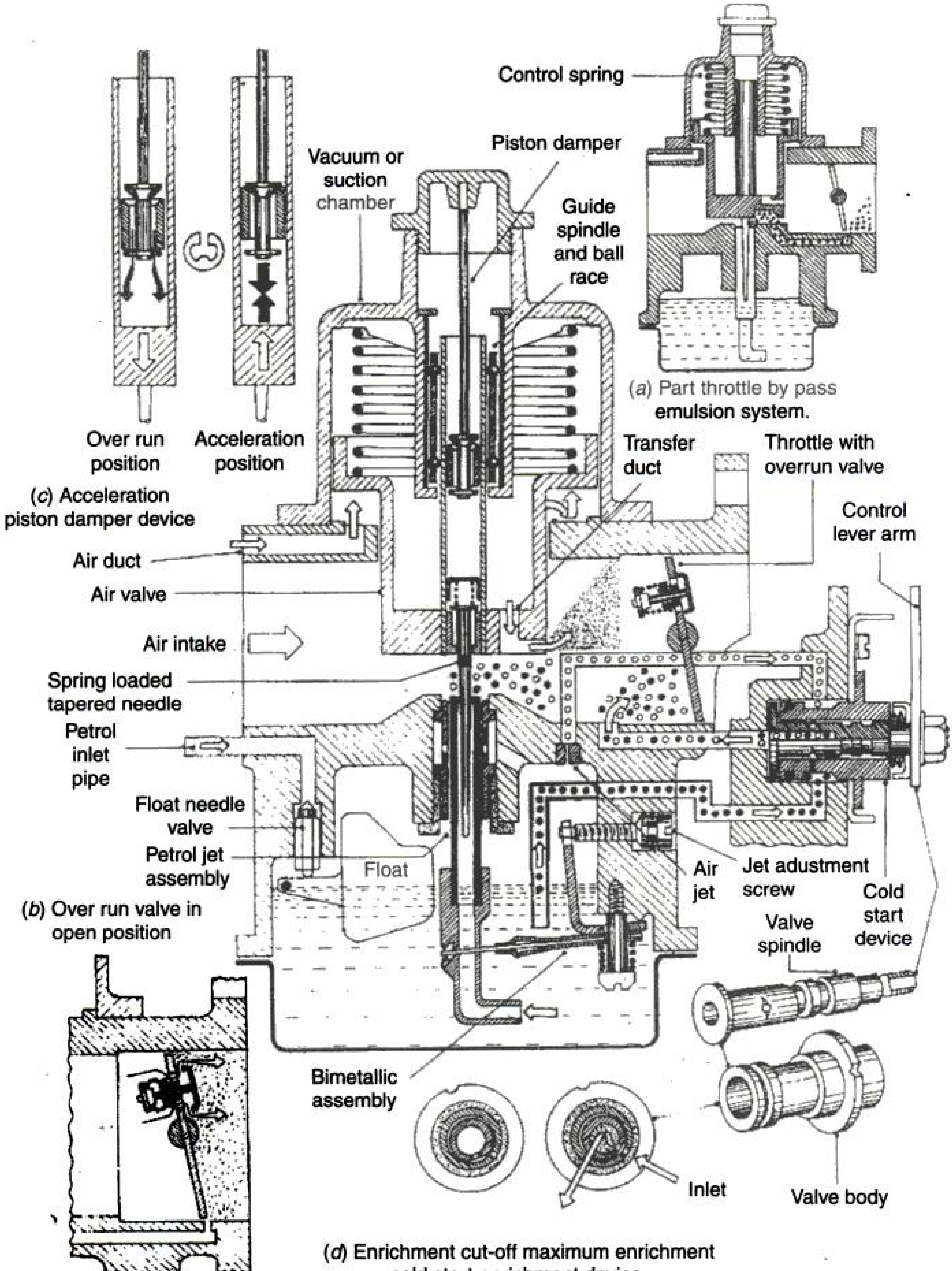


Fig. 3.23. S.U. carburettor (constant vacuum variable choke).

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1. Fuel delivery system
2. An induction system
3. Sensors and air flow control system
4. Electronic control unit.

1. **Fuel delivery system :**

- It consists of an electrically driven fuel pump which draws fuel from a *fuel tank*. The pump forces the oil through a *filter* into a line at the end of which is situated a *pressure regulator*, which in turn is connected to intake manifold.
- The pressure regulator keeps the pressure difference between the fuel pressure and the manifold pressure constant, so that the quantity of fuel injected is dependent on the injector open time only.

2. **Air induction system :**

- After passing the air filter, the incoming air flows through an air flow meter, which generates a voltage signal (depending on the quantity of air flow).
- Just behind the *throttle valve* is fitted a cold start *magnetic injection valve,* which injects additional fuel for cold start. This valve also supplies the extra fuel needed during warm-up period.
- An *auxiliary valve* (which by-passes the throttle valve) supplies the extra air required for idling (in addition to rich-air-fuel mixture). This extra air increases the engine speed after cold start to acceptable idling speed.
- To the throttle valve is attached a *throttle switch* equipped with a set of contacts which generate a sequence of voltage signals during the opening of throttle valve. The voltage *signals result in injection of additional fuel required for acceleration.*

3. **Electric control unit :**

- The *sensors* are incorporated to measure the operating data at different locations. The data measured by the sensors are transmitted to the *electronic control unit which computes the amount of fuel injected during each engine cycle. The amount of fuel injected is varied by varying the injector opening time only.*
- The *sensors* used are :
  - Manifold pressure ;
  - Engine speed ;
  - Temperature at the intake manifold.

4. **Injection time :**

- For every revolution of the camshaft, the fuel is injected twice, each injection contributing half of a fuel quantity required for engine cycle.
- The injectors, at different phases of the operating cycle, are operating simultaneously.

3.12. THEORY OF SIMPLE CARBURETTOR

During the induction stroke, the air is sucked through the carburettor by the pressure difference across it created when the piston moves. As the air passes through the venturi, its velocity increases and reaches maximum (section 2-2, see Fig. 3.26) at venturi throat, this being the minimum area in the induction track (unless the throttle is sufficiently closed to provide a smaller area). As a result of suction created in the venturi fuel is sucked through the nozzle. The tip of the nozzle is z metres above the float chamber level ; this arrangement prevents spilling of petrol when vehicle is stationary. Let us find expressions for air flow neglecting and considering the compressibility of air.

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WORKED EXAMPLES

Example 3.12. *A six-cylinder, four-stroke diesel engine develops 125 kW at 3000 r.p.m. Its brake specific fuel consumption is 200 g/kWh. Calculate the quantity of fuel to be injected per cycle per cylinder. Specific gravity of the fuel may be taken as 0.85.*

Solution. *Given* : $n = 6$; B.P. = 125 kW ; N = 3000 r.p.m. ; b.s.f.c. = 2.00 g/kWh ;

Sp. gr. of fuel = 0.85.

Fuel consumption per hour = b.s.f.c. × B.P.

$$= \frac{200}{1000} \times 125 = 25 \text{ kg}$$

$\therefore$ Fuel consumption per cylinder $= \dfrac{25}{n} = \dfrac{25}{6} = 4.167$ kg/h

$$\text{Fuel consumption per cycle} = \frac{\text{Fuel consumption per cylinder per min.}}{\text{No. of cycles per min.}}$$

$$= \frac{(4.167/60)}{(3000/2)} = 4.63 \times 10^{-5} \text{ kg} = 0.0463 \text{ g}$$

$\therefore$ Volume of fuel injected per cycle

$$\therefore \quad = \frac{\text{Fuel consumption per cycle}}{\text{Specific gravity of fuel}}$$

$$= \frac{0.0463}{0.85} = \mathbf{0.05447 \text{ c.c.}} \quad \textbf{(Ans.)}$$

Example 3.13. *A 6-cylinder 4-stroke C.I. engine develops 220 kW at 1500 r.pm. with brake specific fuel consumption of 0.273 kg/kWh. Determine the size of the single hole injector nozzle if the injection pressure is 160 bar and the pressure in the combustion chamber is 40 bar. The period of injection is 30° of crank angle. Specific gravity of fuel = 0.85 and orifice discharge coefficient = 0.9.*

Solution. *Given* : $n = n_0 = 6$; N = 1500 r.p.m. ; B.P. = 220 kW, b.s.f.c. = 0.273 kg/kWh

$\theta = 30°$, Sp. gr. of oil = 0.85, $C_f = 0.9$, $\Delta p = p_1 - p_2 = 160 - 40 = 120$ bar.

Diameter of the nozzle orifice, d_0 :

We know that, *actual* fuel velocity of injection,

$$V_f = C_f \sqrt{\frac{2(p_1 - p_2)}{\rho_f}} = C_f \sqrt{\frac{2\Delta p}{\rho_f}} \quad \text{...(Eqn. 3.23)}$$

$$= 0.9 \times \sqrt{\frac{2 \times 120 \times 10^5}{(0.85 \times 1000)}} = 151.23 \text{ m/s}$$

Volume of fuel injected per second,

$$Q_f = \frac{0.273 \times 220}{(0.85 \times 1000) \times 3600} = 1.963 \times 10^{-5} \text{ m}^3/\text{s}$$

Also, volume of fuel injected per second,

$$Q_f = \left[\frac{\pi}{4} d_0^{\,2} \times n_0\right] \times V_f \times \left[\frac{\theta}{360} \times \frac{60}{N}\right] \times \frac{N_i}{60} \quad \text{...(Eqn. (3.24)}$$

(where, N_i = No. of injection/min. $= \dfrac{1500}{2} = 750$)

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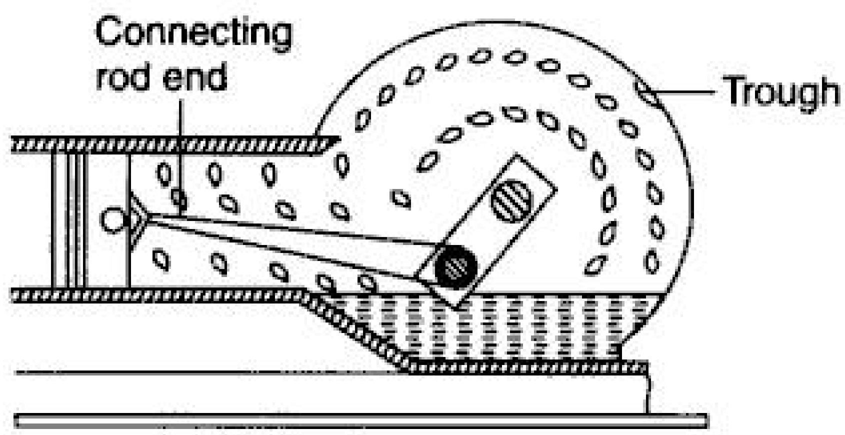

Fig. 4.13. Splash lubrication system.

Note. *Grease cup method* is used for lubricating rocker arms and reciprocating parts with a jerkey motion. It is also employed on parts that are not readily accessible and can be lubricated only at fairly long intervals.

4.6.6. Lubrication of Ball and Roller Bearings

The ball and roller bearings are lubricated for the following purposes :

1. To reduce friction and wear between the sliding parts of the bearing.
2. To prevent rusting or corrosion of bearing surfaces.
3. To protect the bearing surfaces from water, dirt etc.
4. To dissipate the heat.

For lubricating the ball and roller bearings, *generally oil or light grease is used*. Only pure mineral oil or a calcium-base grease should be used. If there is a possibility of moisture contact, then potassium or sodium base greases may be used. Another additional advantage of the grease is that it forms a seal to keep out dirt or any other foreign substance. The temperature should be kept below 90°C and in no case a bearing should operate above 150°C.

4.6.7. Oil Filters

All the lubricating oil (used for lubrication purpose) from the oil sump, must pass through an oil filter before it is supplied to the engine bearings. Bearings maintain very close tolerances and are likely to be damaged by any foreign abrasive material entering the lubrication line.

The filter arrangement may be of the following two types : (*i*) *By-pass type* ; (*ii*) *Full-flow type*.

1. **By-pass type filter arrangement :**

- In this arrangement only a small portion of the lubricating oil is passed through the filter and the remaining lubricating oil is directly supplied to the bearings by the oil pump at pre-set pressure, determined by the pressure regulating valve. Consequently a portion of the oil is continuously filtered.
- Since quantities of oil flowing through filter are *small*, a *very fine filter or a special filter impregnated with resin to avert disintegration due to moisture is used*. Such a fine paper/filter will remove all harmful contaminants.

2. **Full-flow type filter arrangement :**

- In this filter arrangement *whole of the oil is filtered* before it is supplied to various-bearings. Thus, the size of the filter is comparatively large.
- In this case, it is hardly possible to remove very fine particles because of high pressure required to pump oil through such filters.
- All the lubricating oil, in normal course, should be filtered approximately every half minute. A pressure relief valve is used to prevent excessive pressure build up after a cold start.

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39. In .... crankcase ventilation system fresh air supply is inducted into the crankcase during the compression stroke.
40. Lubricating grease is a solid to semi-solid dispersion of a thickening agent in liquid lubricant.

ANSWERS

1. B.P.	2. No	3. Blowby	4. No	5. Yes
6. decrease	7. Yes	8. Yes	9. Yes	10. increases
11. reduces	12. Yes	13. No	14. lubrication	15. Film
16. elasto-hydrodynamic		17. viscosity	18. viscosimeter	19. Yes
20. viscosity index	21. No	22. Flash	23. Fire	24. Pour
25. Oiliness	26. emulsification	27. Adhesiveness	28. Yes	29. mineral
30. Yes	31. Yes	32. Sludge	33. Yes	34. Yes
35. Yes	36. Dry	37. Mist	38. closed	39. open
40. Yes.				

THEORETICAL QUESTIONS

1. How is 'engine friction' defined ?
2. State the importance of engine friction.
3. Enumerate the factors on which the frictional resistance between two moving parts having relative motion is dependent.
4. Discuss the components into which the total engine friction can be divided.
5. Explain briefly the following :
   (*i*) Direct frictional losses
   (*ii*) Valve throttling losses
   (*iii*) Combustion chamber pump loss
   (*iv*) Blowby losses.
6. State the effect of the following engine parameters on engine friction :
   (*i*) Stroke-to-bore ratio
   (*ii*) Cylinder size and number of cylinders
   (*iii*) Piston rings
   (*iv*) Compression ratio
   (*v*) Engine speed
   (*vi*) Engine load
   (*vii*) Cooling water temperature
   (*viii*) Oil viscosity.
7. Enumerate the methods by which engine friction can be determined.
8. Define the term 'lubrication'.
9. What are the objects of lubrication ?
10. Discuss the behaviour of a journal in its bearing.
11. Explain briefly the following :
    (*i*) Film lubrication
    (*ii*) Elasto-hydrodynamic lubrication
    (*iii*) Boundary lubrication.
12. Enumerate and discuss the chief qualities to be considered in selecting oil for lubrication.
13. Explain briefly the following properties of a lubricant :
    (*i*) Viscosity
    (*ii*) Flash point
    (*iii*) Oiliness
    (*iv*) Emulsification
    (*v*) Neutralisation number
    (*vi*) Adhesiveness.
14. What are additives ?

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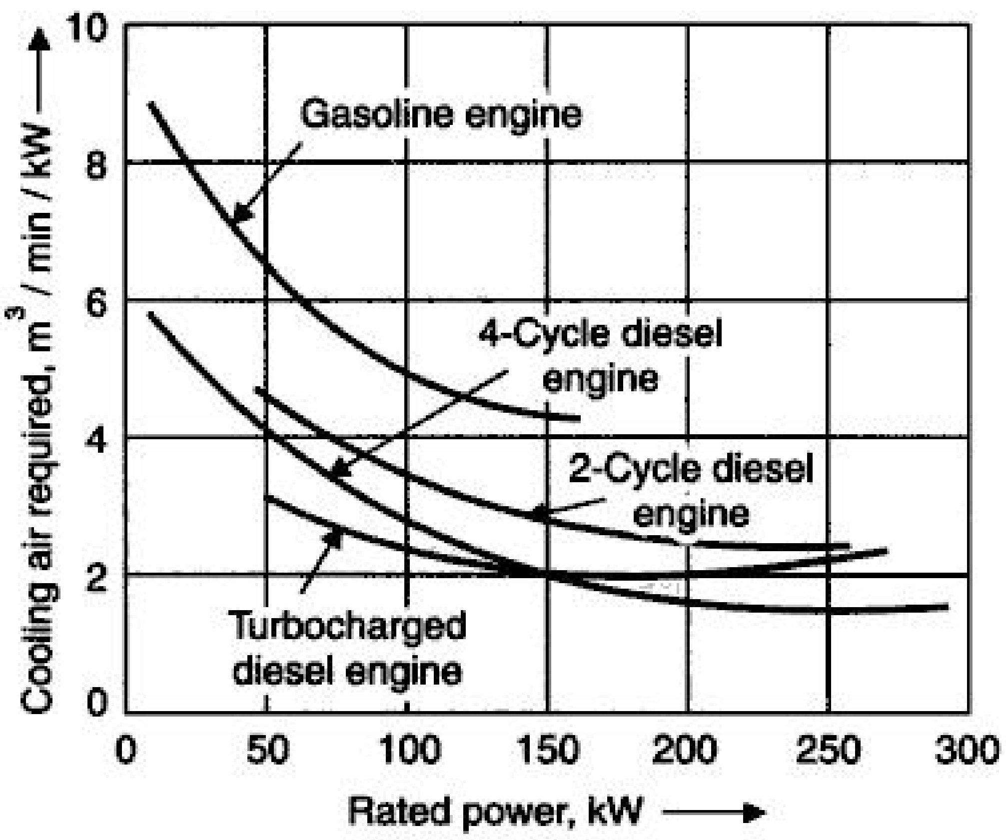

Fig. 5.11. Cooling air requirements.

Cooling water requirements. As is evident from Fig. 5.10, the heat rejected to the coolant greatly depends on the type of the engine. It can be seen that for a small high speed engine the heat rejected in the coolant can be as high as 1.3 times the B.P. developed, while for an open chamber engine it is only about 60% of the B.P. developed.

The quantity of water (Q_w) required for cooling is given by

$$Q_w = \frac{Z \times \text{B.P.}}{\Delta t_w} \qquad \text{...(5.5)}$$

where, Δt_w = *Permissible increase of temperature of cooling water, and*

Z = *Constant which depends upon fuel consumption and the compression ratio.*

- The heat flow to water jackets, on an average, is about 4200 kJ/kW-h for large engines and 500 to 5700 kJ/kW-h for small engines.
- Large heat stress is avoided if the temperature rise is limited to 10°C–12°C.
- The *outlet cooling water temperature* for various types of engines is as follows :

  For large engines .... about 50°C

  For medium engines .... 60 to 65°C

  For automobile engines .... 80°C.

5.7. COOLING SYSTEMS

There are mainly following two methods/systems of cooling I.C. engines :

1. Air cooling
2. Water liquid cooling.

5.7.1. Air-Cooling System

- In this system, heat is carried away by the air flowing over and around the cylinder.
- Here fins are cast on the cylinder head and cylinder barrel which provide additional conductive and radiating surface (See Fig. 5.12). The fins are arranged at right angles to cylinder axis. The number and dimensions should be adequate to take care of the surplus heat dissipation. From all points of view, the truncated conical fin with rounded edges, as shown in Fig. 5.13, accomplish the purpose.

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Advantages of pressurised engine cooling over conventional thermo-syphon cooling system :

Following are the *advantages* of pressurised engine cooling over conventional thermo-syphon cooling system :

(*i*) Effective and positive cooling of all parts. Local overheating is avoided.

(*ii*) It can take overload easily because as the engine speed increases the water circulation also increases, and same effective cooling can be maintained at all the speeds.

(*iii*) In thermo-syphon system, the radiator should be kept well above the engine, to provide a height for natural circulation. There is no such requirement for pressurised forced pump system.

(*iv*) With pressurised system the coolant temperature is maintained higher. This reduces corrosion.

(*v*) Smaller coolant passages can be used. This reduces weight and bulk of the engine.

(*vi*) No loss of water by boiling and evaporation.

5. Evaporative cooling :

- In this system, also called steam or vapour cooling, the temperature of the cooling water is allowed to reach a temperature of 100°C. This method of cooling *utilises the high latent heat of vapourisation of water to obtain cooling with minimum of water.* Fig. 5.20 shows such a system. The cooling circuit is such that *coolant is always liquid but the steam formed is flashed off in the separate vessel.* The make up water so formed is sent back for cooling.
- This system is used for cooling of many types of *industrial engines.*

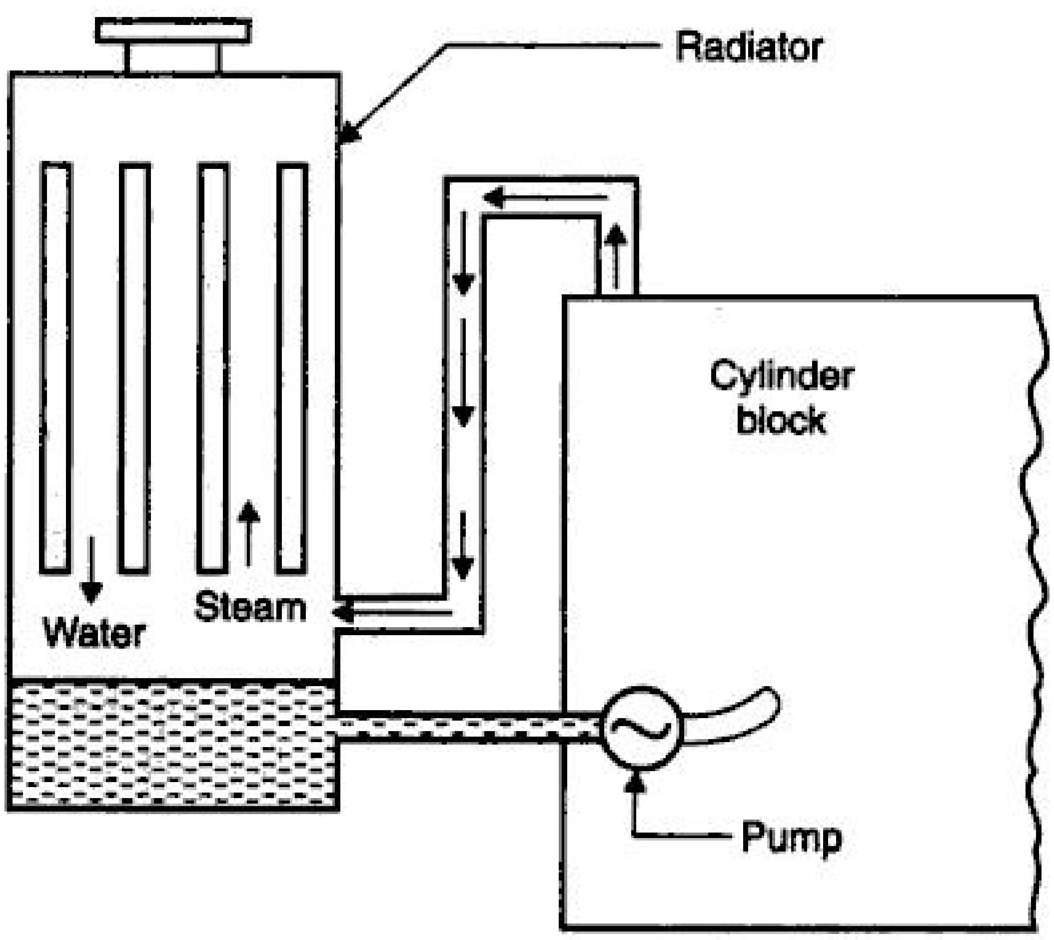

Fig. 5.20. Evaporating cooling.

Advantages and Disadvantages of liquid cooling :

Advantages :

1. Compact design of engine with appreciably smaller frontal area is possible.
2. The fuel consumption of high compression liquid-cooled engine is rather lower than for air-cooled one.

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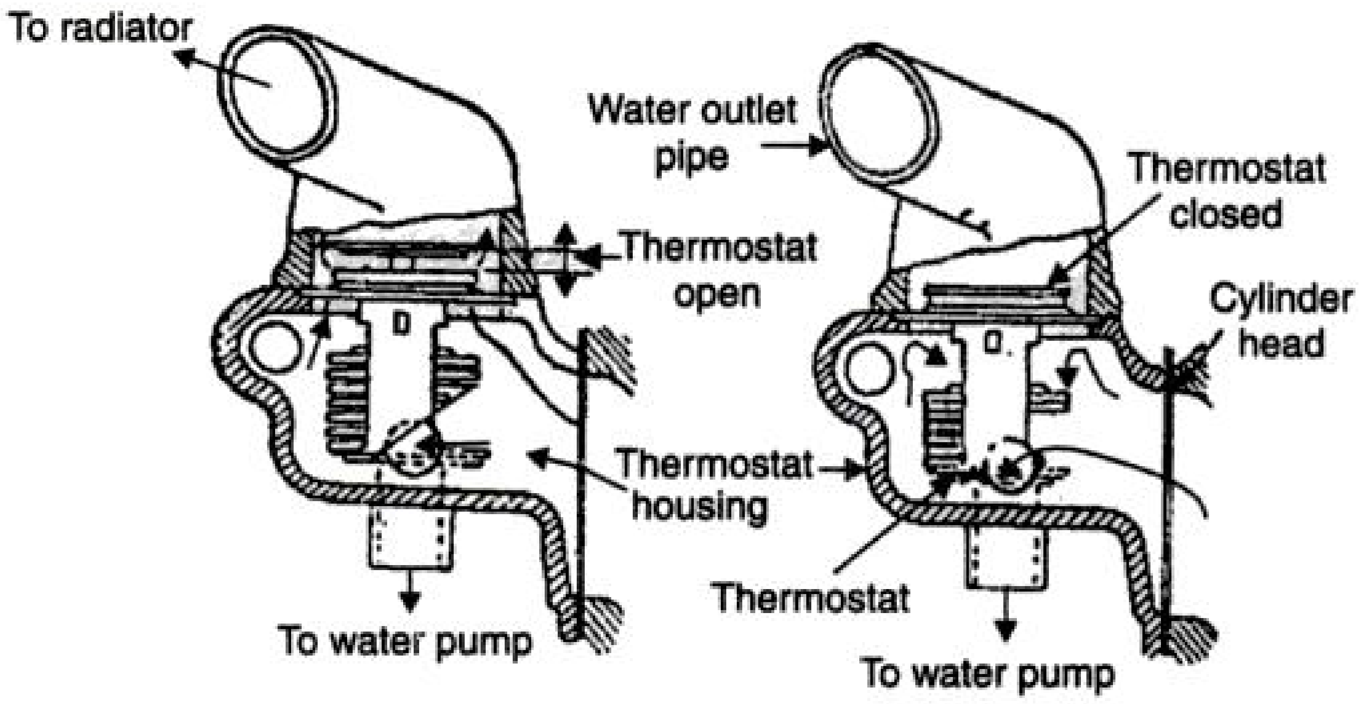

Fig. 5.23. Thermostat.

5. **Connecting hoses :**

- For convenience of connection and to isolate the radiator from engine movement and vibration, flexible hoses are used.
- They were originally of rubber, reinforced with canvas like large diameter garden hose- Neoprene and various plastics are now more suitable and are premoulded to the shapes and curves required for the installation.
- The ends of the hose are forced over the connecting spigots on the radiator and engine held in place by bore clamps or spring clips.

6. **Radiators :**

- The basic requirement of a radiator is to *provide a sufficiently large cooling area for transmission of heat from the coolant to the air.* The construction of the centre of the radiator or core varies, but in general the water passages terminate at a header tank at the bottom. In addition to an opening which enables the cooling system to be topped up the header tank allows for expansion and contraction of the coolant within the system.
- The principle types of radiator core are :
  (*i*) Film type
  (*ii*) Fin and tube
  (*iii*) Pack type.

Fig. 5.24 shows a radiator made of thin sheet brass and is typical of most cooling systems. As the water descends through hundreds of tubes or passage it is cooled by radiation to the air and returns to the engine via the bottom tank and the lower left connection. An overflow pipe from the filter neck can be clearly seen.

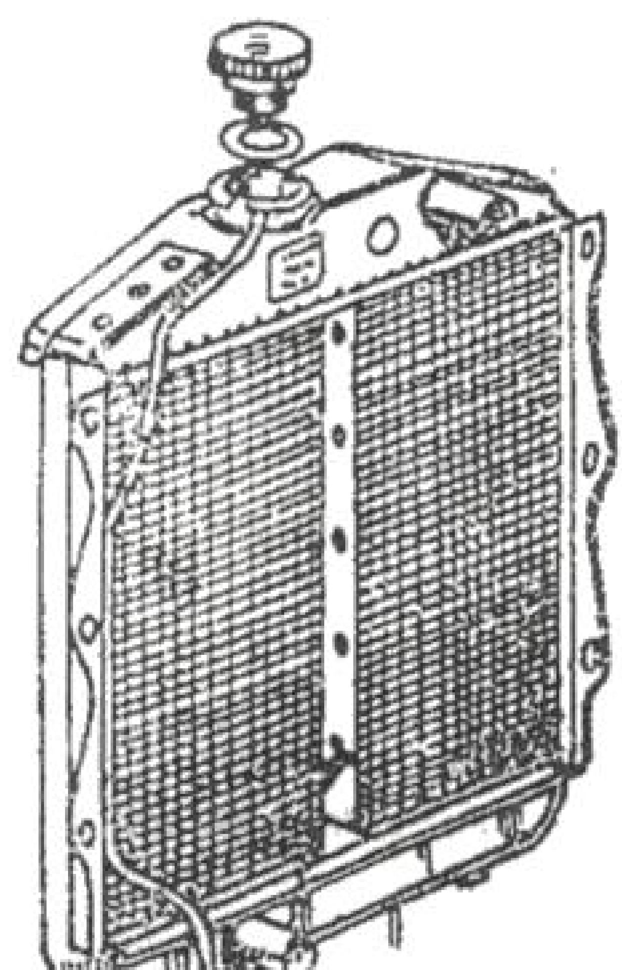

Fig. 5.24. Radiator.

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6.	*Ashok Leyland*	Water cooling	–	Tube and fin	25	Centrifugal type	Bellow type	Ethylene glycol
7.	*Tata Truck*	Water cooling	–	Tube and fin	13	Centrifugal type	Bellow type	Ethylene glycol
8.	*Santro*	Water cooled pressurized, forced circulation 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

SHORT ANSWER QUESTIONS

Q. 1. What is the distinct advantage of an air-cooled engine ?

Ans. Rapid warm up in the distinct feature in an air-cooled engine. Moreover there is no water jacket or radiator. The rapid warm up is used in avoiding sludge and crankcase dilution.

Q. 2. What are the advantages of water cooling system ?

Ans. (*i*) Less engine sound, (*ii*) Quick transfer of heat, and (*iii*) Easier method to control temperature.

Q. 3. What are the disadvantages of water cooling system ?

Ans. (*i*) Corrosion of metal part, (*ii*) Increase in weight of the vehicle, and (*iii*) Freezing difficulties in cold weather.

Q. 4. What is the purpose of a fan in the radiator ?

Ans. To assist the flow of air through the radiator, particularly when the vehicle is moving slowly.

Q. 5. Why is it desirable to flush out the radiator occasionally ?

Ans. If the radiator is not flushed out occasionally, particles or dirt may choke the radiator tubes.

Q. 6. What is the function of the thermostat valve in the cooling system ?

Ans. To reduce the cooling temperature of water by allowing some water to the radiator and bypassing the excess to the circulating pump.

Q. 7. How does the thermostat work ?

Ans. When the engine is too cold the thermostat closes the main valve, thus stopping the flow to the radiator. When the engine is too hot, it opens the main valve for normal circulation through radiator.

Q. 8. How is thermostat valve controlled ?

Ans. (*i*) By a heat sensitive spring, or (*ii*) A coil containing a liquid such as acetone.

Q. 9. What is a radiator ?

Ans. A very effective form of cooling surface in which heat is absorbed and transmitted by the circulating water.

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6

Chassis and Suspension

A. CHASSIS

6.1. INTRODUCTION TO CHASSIS

Chassis (also known as *carrying unit*) is a french term and was *initially used to denote the frame or main structure of a vehicle.*

The term **chassis** is now extensively used *to denote the complete vehicle except the body for the heavy vehicle having a separate body.* The chassis contains all the major units necessary to propel the vehicle, direct its motion, stop it, and allow it to run smoothly over uneven surfaces.

The chassis of an automobile *consists of the following components* suitably mounted (Fig. 6.1) :

(*i*) Frame
(*ii*) Front axle
(*iii*) Steering system
(*iv*) Rear-axle
(*v*) Suspension system
(*vi*) Transmission
(*vii*) Brake system
(*viii*) Engine
(*ix*) Electrical system.

The chassis is sub-divided into :

(*i*) Power plant
(*ii*) Running gear.

The ***power plant*** includes the *engine assembly and power transmission assembly.*

The ***running gear*** includes the *frame, steering system, suspension system, brakes, wheels and tyres.*

— The *electrical system is part of both chassis and body.*

All the above mentioned components are mounted in either of the following two ways :

1. ***Conventional construction.*** In this case a *separate frame* is used.
2. ***Frameless or unitary construction.*** Here *no separate frame* is employed.

(*iv*) ***6 × 4 drive chassis vehicle.*** Refer Fig. 6.9.

- It consists of 6 wheels out of which 4 wheels are the driving wheels.

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*.

4. **According to wheel base size :** Refer to Fig. 6.10.

- 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 passengers and goods*.
- In this type of chassis, the front overhang and particularly the rear overhang are also more.

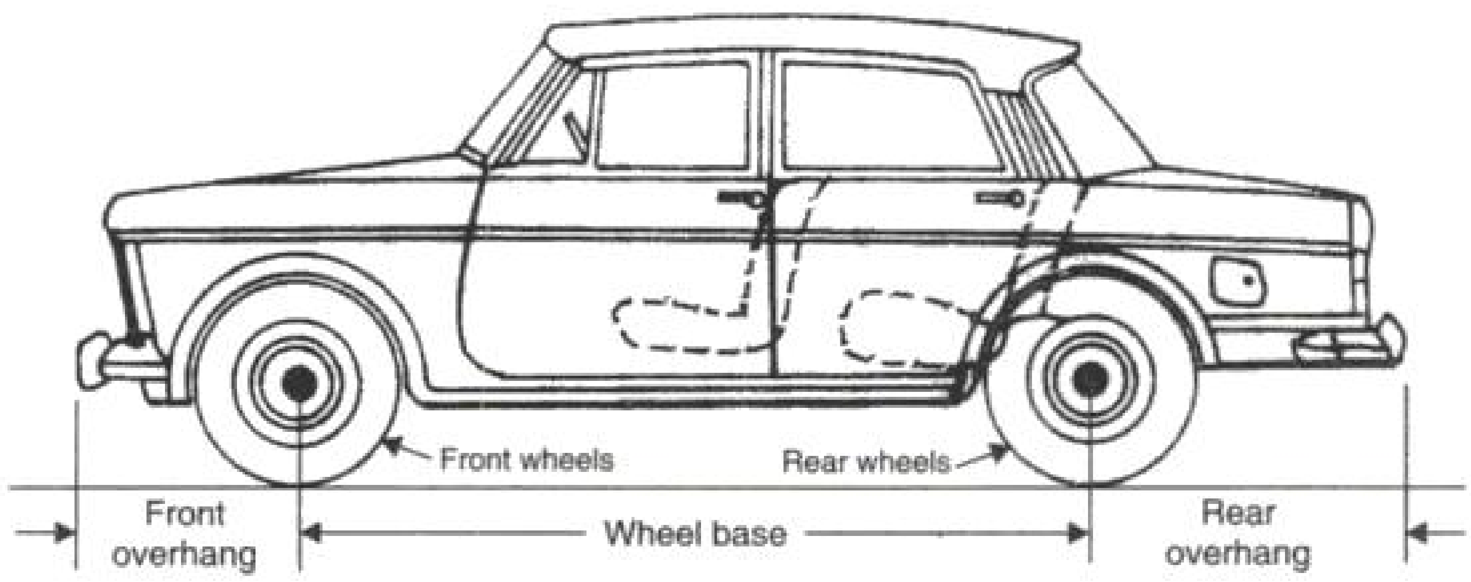

Fig. 6.10

6.3. FRAME

6.3.1. Introduction

- *The* ***frame*** or ***under body*** is *the main part of the chassis on which the remaining parts of the chassis are mounted.* It is a rigid structure that forms a skelton to hold all the major parts together.
  - The *engine* is mounted in the forward end of the frame and is connected to the clutch and transmission unit to form a complete power assembly.
  - At the rear end of the frame, the *rear axle* housing is attached through the rear spring.
  - The *wheel* and *tyre* assemblies support the frame.
  - The *steering system* has some parts bolted to the frame and some to the body.
  - The *petrol tank* is fastened to the rear of the frame.
- **Chassis frames** *are made of* ***"steel section"*** *so that they are strong enough to withstand the load and at the same time are also light in weight to reduce dead weight on the vehicle.*

The long sections which are right and left members of frame are called *long members*. There are joined together with cross members with the help of rivets or bolts or nuts. There are 5 to 6 cross members joining the long member to give the chassis frame a good strength. *In some of the models the long members are bent both at the front and rear to accommodate jumping of front and rear axels.*

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The following methods are used *to avoid rust formation* :

(*i*) Use of galvanised sheets.

(*ii*) Use of zinc enriched primer paint.

(*iii*) Use of plastic coating on panels.

(*iv*) Use of rubberised solution.

(*v*) Avoiding tight corners so that the moisture cannot get settled.

(*vi*) Providing plenty of drain holes to allow trapped water to run out.

- It is important that the chassis frame is *properly aligned*. After some repair is carried out on the frame, the alignment should be checked with the original measurements.

6.4. BODY

Body *is the super-structure of the vehicle. The chassis and body make the complete 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.*

The body of motor vehicle should fulfill the following *requirements* :

(*i*) Light in weight.

(*ii*) Cheap and easy in manufacturing.

(*iii*) Attractive in shape and colour.

(*iv*) Minimum number of components.

(*v*) Clear all-round vision through glass area.

(*vi*) Long fatigue life.

(*vii*) Minimum resistance to air.

(*viii*) Good access to the engine and suspension system.

(*ix*) Minimum vibrations during running of the vehicle.

(*x*) Adequate space for passengers and luggage.

All steel sections of the body are stamped out by dies separately and welded together. Decorative moulds and bands are formed around the window and door openings. The tendency of all steel body to drum or rumble is overcome by using insulating and sound deadening materials.

- The closed car body provided roof which may be used for luggage.
- The closed bus provides a large space for luggage.
- The open truck body does not have roof. It consists of surrounding side only. The rear side is only a half panel which may be opened down for loading and unloading. In some good trucks, the lower side panels may also be opened down for unloading.

- A car body is formed by a number of pressed steel panels welded together. For attaching the door, instrument panel, hood, truck lid, head lining etc. attachment brackets are welded to the body.

Different types of bodies for various vehicles are listed below. Refer to Fig. 6.14.

1. Two-door sedan	2. Four-door sedan
3. Convertible	4. Van
5. Truck Punjab body or Straight truck	6. Truck half-body

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6.9. ELEMENTS OF A SUSPENSION SYSTEM

Fig. 6.17 shows the schematic form of a suspension system. The **sprung weight** is *the weight of passenger carriage whereas the* **unsprung weight** *is the weight of the wheel-axle system.*

The important *elements of a suspension system* are :

1. Springs.
2. Dampers (or shock absorbers).

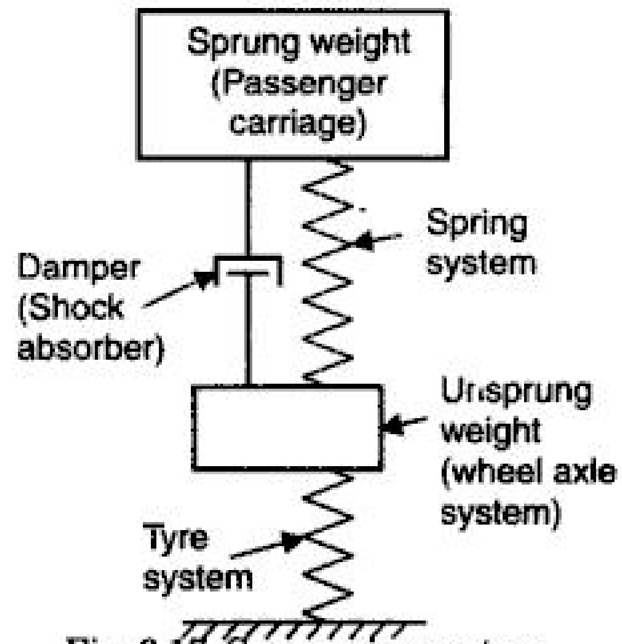

Fig. 6.17. Suspension system.

- The *springs* provide spring effect to a large extent ; the tyre, however, provides the spring effect to a smaller extent.
- The *dampers* (or shock absorbers) provide the damping effect to a large extent. However in case of leaf springs, the friction between the leaves in motion does generate some damping effect. Dampers perform the following *two functions* :

(*i*) They *reduce the tendency of the carriage unit to continue to "bounce"* [Fig. 6.18 (*a*)] *up and down* on its springs after the disturbance that caused the linear motion has ceased.

(*ii*) *They prevent excessive built 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.

Besides a simple bounce or vibration of the carriage unit as a whole, following two more types of vibration also exist :

(*i*) Rolling (*ii*) Pitching.

In **"rolling"**, [Fig. 6.18 (*b*)] *the carriage unit rolls about the longitudinal axis of the vehicle* while in **"pitching"**, *the carriage unit rolls about a transverse axis.*

– In rolling one side of the car goes down and the rear goes up and *vice versa*. The tendency to roll is checked by a *stabilizer*.

– *Pitching* [Fig. 6.18 (*c*)] is a more complex phenomenon and is affected by what is known as *"vibration coupling effect" i.e., interaction between front and rear suspension.* Since the picthing persists for a longer duration if the rear suspension has a lower natural frequency than the front suspension, therefore, the natural frequency of the rear suspension is normally made higher than that of the front.

– The pitching, in general, depends upon the following factors.

(*i*) The frequency of disturbances ;
(*ii*) Bumps over which the car rolls ;
(*iii*) Spacing of bumps ;
(*iv*) Speed of the vehicle ;
(*v*) Mass moment of inertia of the vehicle about the axis of pitch and its wheel base.

- *A combination of roll and pitch is called* ***diagonal pitch.***

In order to control the above mentioned suspension movements, *antisway bars, stabilizers, pitch and roll control bars, mechanical levelling devices, hydroelastic systems etc. are employed.*

(*iii*) Require less space for a given load as compared to a leaf spring.

(*iv*) Lighter for a given load as compared to leaf spring.

(*v*) Compact as a unit.

(*vi*) Since there is no friction damping effect as in leaf spring, they are more lively in action. As such good and powerful shock absorbers are required with coil springs.

The coil springs are **used** *mainly with independent suspension, though they have also been used in the conventional rigid axle suspension as they can be well accommodated in restricted spaces.*

- The *springs take the shear as well as bending stresses.* The coil springs, however, *cannot take torque reaction and side thrust*, for which alternative arrangements have to be provided.
- 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.

3. **Torsion bars :**

Torsion bar is simply a *rod acting in torsion and taking shear stresses only.* These bars are made of *heat-treated alloy spring steel.* The *amount of energy stored per unit weight of material is nearly the same as for coil springs.*

The torsion bar performs the spring's action by its resistance to twisting. The bar is mounted transversally in some of the vehicles, whereas in other constructions, it is employed lengthwise along the frame.

Fig. 6.22 shows a frame and axle.

— The axle is supported by a lower plate and another plate fixed to the frame. The lower plate is connected to a torsion bar. The end of the torsion bar is fitted to the chassis frame.

— When the wheel moves up or down, the torsion bar gets slightly twisted. In this position it absorbs the vibrations. When the wheel is coming down, the torsion bar reaches its original position. It absorbs vibrations and shocks. By this arrangement it acts like a spring and maintains the stability of the vehicle.

- As in coil springs, shot peening and anticorrosion treatment is also given to the torsion bar to improve fatigue life.

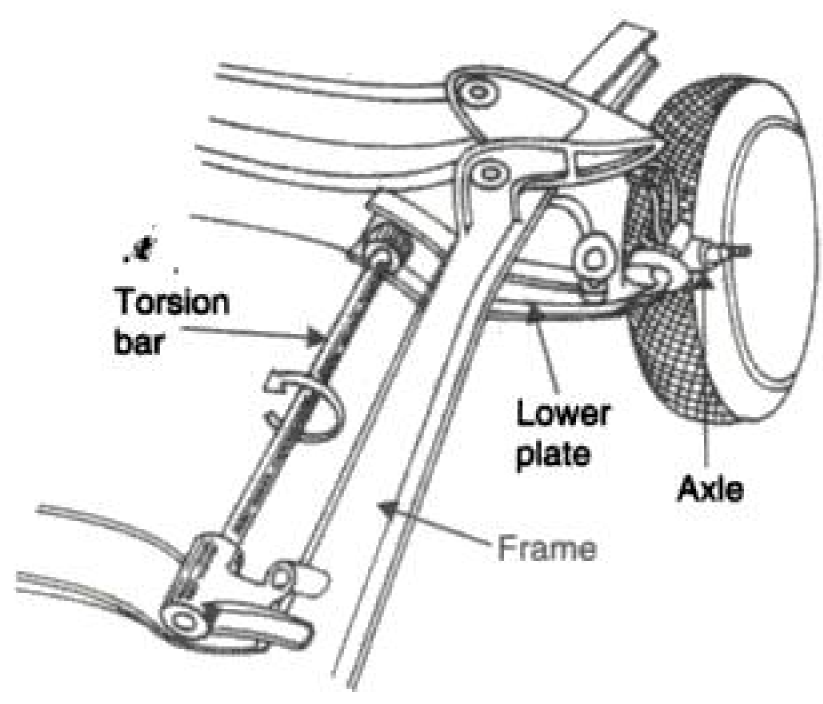

Fig. 6.22. Torsion bar.

- 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.* These are however used as *antiroll devices.*

4. **Air and gas springs :**

In these 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 passes over a road irregularity the compressed air pressure returns the system to its original position.

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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.

Maintenance of damper/shock absorber :

When a shock absorber does not function properly it is better to remove it and replace it with a new one.

Sometimes an old *shock absorber can be properly serviced again, as per procedure given below* :

- Remove the shock absorber and dismantle its parts in a systematic manner.
- Clean these parts thoroughly.
- Fit new rubber gaskets.
- Then properly reassemble the parts.
- Pour in the fluid as recommended by the manufacturer for that particular shock absorber.

6.12. SUSPENSION SYSTEMS

6.12.1. Components of a Suspension System

A suspension system consists of the following *principle components* :

1. *Springs*. There neutralise the shocks from the road surface.

2. *Dampers (Shock absorbers)*. They act to improve comfort by limiting the free oscillation of the springs.

3. *Stabilizer (Sway bar or antiroll bar)*. It prevents lateral swaying of the car.

4. *A linkage system*. It acts to hold the above components in place and to control the longitudinal and lateral movements of the wheels.

Suspension may be *rigid axle suspension* or *independent suspension*.

6.12.2. Rigid Axle Front Suspension

A rigid axle suspension has the following *characteristics :*

1. It is durable enough for heavy-duty use.

2. The number of parts composing the suspension is small and the construction is simple ; therefore maintenance is simple.

3. While turning, there is a little tilting of the body.

4. Less tyre wear since there is little change in the alignment due to the up-and-down movement of the wheels.

5. Riding comfort is poor due to great unsprung weight.

6. Vibrations and oscillations occur rather easily since the movements of the left and right wheels mutually influence one another.

Fig. 6.26 shows a typical rigid axle front wheel suspension. This type of suspension was universally used before the introduction of independent front wheel suspension. It may use either two longitudinal leaf springs or transverse springs, usually in conjunction with shock absorbers. These assemblies are mounted similarly to rear leaf spring suspensions.

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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 term carries the wheel. The steering motion is supplied to the lower part of the strut and it turns the whole strut. A coil and a hydraulic damper/shock absorber surround the upper part of the strut which takes care of the road irregularity shocks and vibrations.

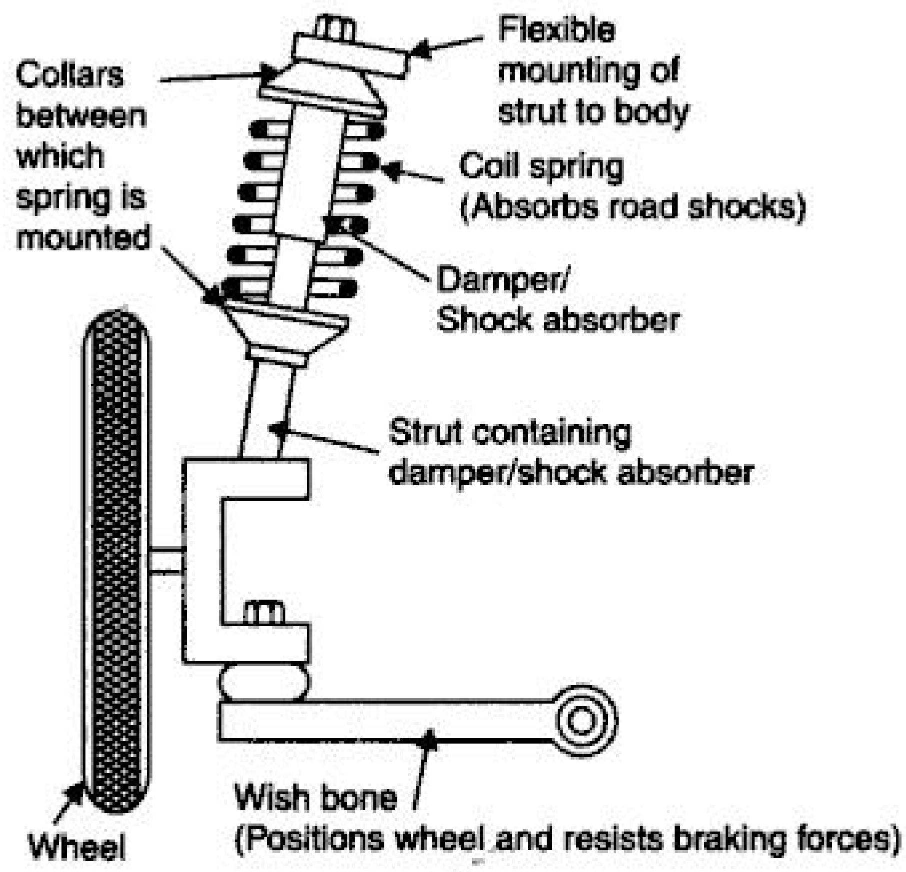

Fig. 6.28. MacPherson strut assembly.

Advantages of MacPherson system :

(*i*) Very easy maintenance.

(*ii*) Simple in mechanical construction.

(*iii*) Less variations in wheel camber.

(*iv*) Its light moving parts help the wheels to follow the road irregularities.

(*v*) Distinct advantages in case of transverse engines, since in that case there is no space or very little space for upper links to fit.

Disadvantages :

(*i*) During cornering and brake torque the radial loading comes on the piston due to the lateral forces.

(*ii*) In order to absorb the full suspension loads the body structure has to be really strong above the wheel arches where the struts are attached.

Maruti-800 suspension system :

Maruti-800 car incorporates the MacPherson type independent suspension system. It consists of *coil springs, front suspension struts, steering knuckles, a stabiliser bar and front suspension arms*. In this type of construction, shocks applied to wheels are distributed through steering knuckles from front suspension struts, coil springs, to front suspension arms and are absorbed.

- The spring rate of front coil spring and it's free length = 1.8 kg/mm and 336 mm respectively.
- The attenuation force of the suspension struts = 50 kg (extending side) and 24 kg (contracting side).
- The stroke of suspension struts = 135 mm.

is one that either rotates or houses the shafts that rotate, while a **"dead axle"** *simply carries at its ends the stub axles on which the wheels rotate.* A live axles performs the following *two functions* :

(*i*) It houses and supports the final drive, differential and shafts to the road wheel and reacts to the torques in both the input and output shafts.

(*ii*) It works as a beam that *carries* through the medium of springs and other suspension system, the weight of passenger compartment and its contents, and *transmits* these loads under dynamic conditions through the road wheels (rotating on its ends) to the ground.

The rear axle suspension system needs to be designed for overcoming the following forces :

(*i*) The weight of carriage unit (including contents).

(*ii*) Brake drag.

(*iii*) Torque reaction (both drive line and brakes).

(*iv*) Lateral forces.

(*v*) Driving thrust.

Both rigid suspension and independent rear wheel suspension have been designed in several ways and some are specifically known by the names of the car models in which they are used. Some of these are discussed below :

1. **Leaf-spring rear-suspension system (Rigid suspension) :**

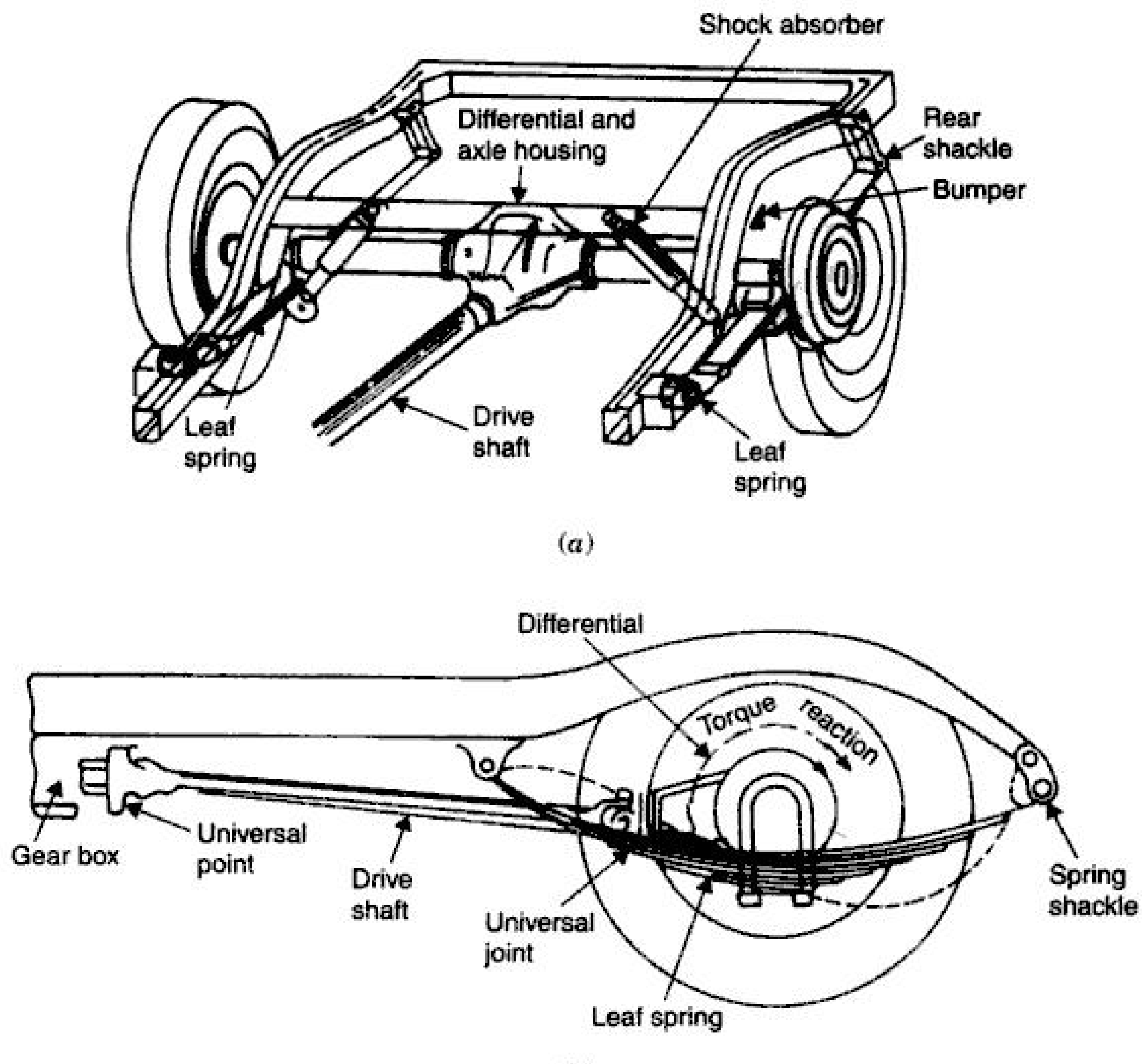

Fig. 6.37. Rear end rigid suspension (Hotchkiss drive).

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which is beneath and in the centre of the rubber spring. This upward movement of the tapered piston also forces the fluid up through the interconnecting pipe to the other unit on the same side of the car. The other side of the car also gets lifted, thereby distributing the shock of the bump between the front and rear wheels of the car.

3. **Hydragas suspension system :**

This system uses *gas-filled spring units* (called *Hydragas springs*), one at each wheel. Each unit has a sealed chamber containing a quantity of nitrogen gas at high pressure. Below this chamber is a displacement chamber filled with water-based fluid (Fig. 6.42). When the wheel meets a bump, the fluid is pushed, compressing the gas. This action provides the springing effect.

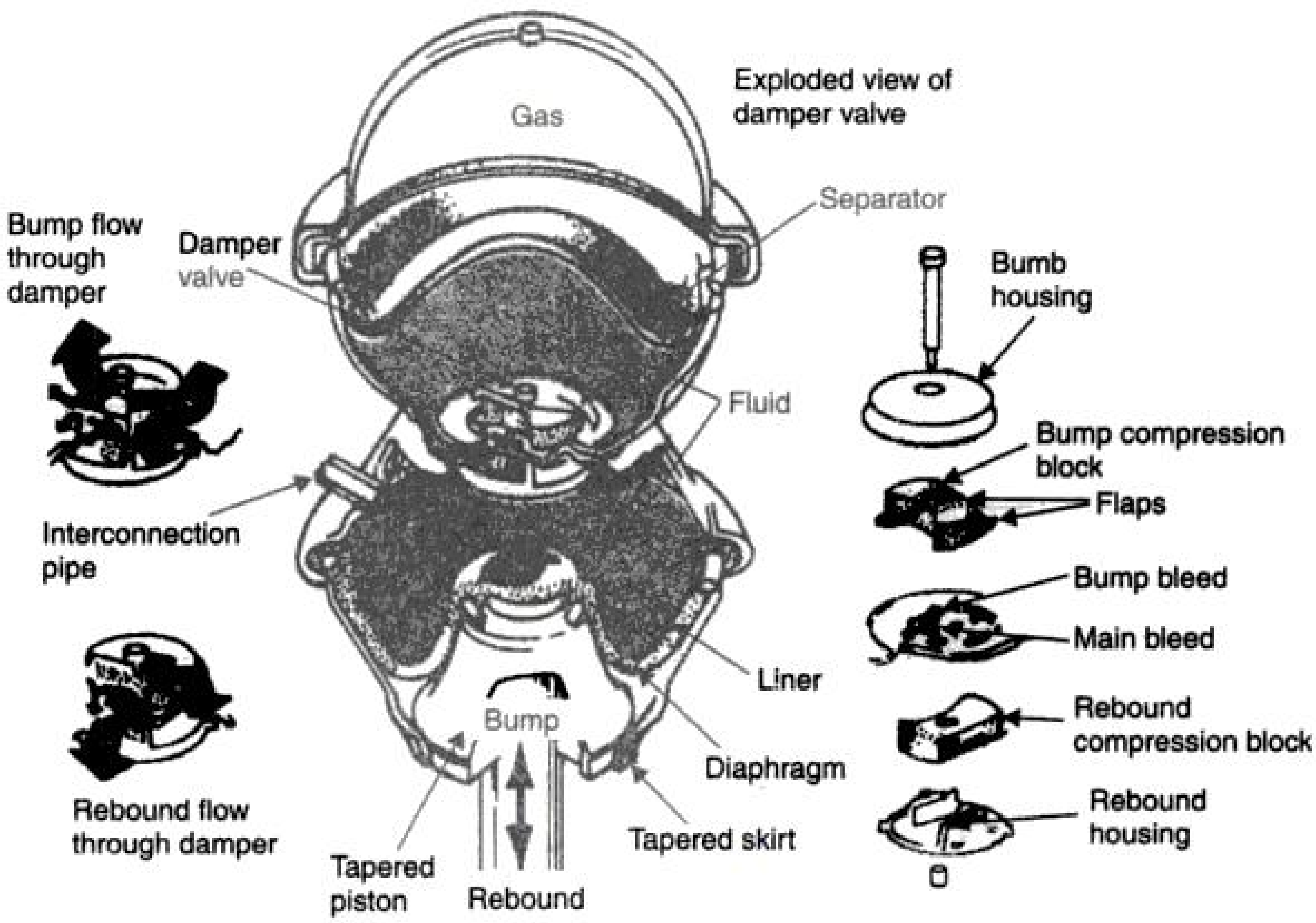

Fig. 6.42. Partly cut-away hydragas spring.

The two units on each side of the car are also interconnected front to back. Thus, when the left front wheel meets a bump, *for example*, a part of the fluid from the left front unit is forced through a pipe to the left rear unit. This action raises the left rear wheel also. Therefore the shock is distributed between the left front and left rear wheels and consequently the side is improved.

4. **The Daimler-Benz vehicle suspension :**

This suspension system (devised by Daimler-Benz A.G. of Germany) consists *primarily of one spring and incorporates resilient hydro-mechanical couplings to cause opposite wheels rise and fall together.*

Each wheel hub is attached to a piston and cylinder arrangement, by means of which vertical displacements of the wheel are transmitted hydraulically to a hydro-pneumatic spring containing an air chamber. Diagonally opposed wheels are served by pipe lines which pass through gear type hydraulic motor pumps, interconnected by torsion rods. The hydraulic pipes are themselves connected by a pipe that runs upto the spring.

2. **Wire wheels :**

The wire wheel is the earliest type of wheel but presently its *use is limited to certain vintage sports and racing cars.* It is higher, heat dissipation is better and it can be fitted and removed very easily. However, tubeless tyres cannot be fitted over wire wheels which are also difficult to clean.

A wire wheel consists of a separate hub connected to the rim with a number of wires or spokes. The headed inner ends of the spokes fit in the hub holes and the threaded outer ends fit in the rim holes, where mushroom-headed tubular nuts are screwed through the rim holes to tighten the spokes. All the spokes must be of correct length and at correct tension to hold the rim, centrally around the hub. The spokes do not stick straight out as radii from the hub, but alternate spokes are screwed to slope forwards and backwards towards the rim (Fig. 6.45). This arrangement of spokes serves special purpose of the wheel.

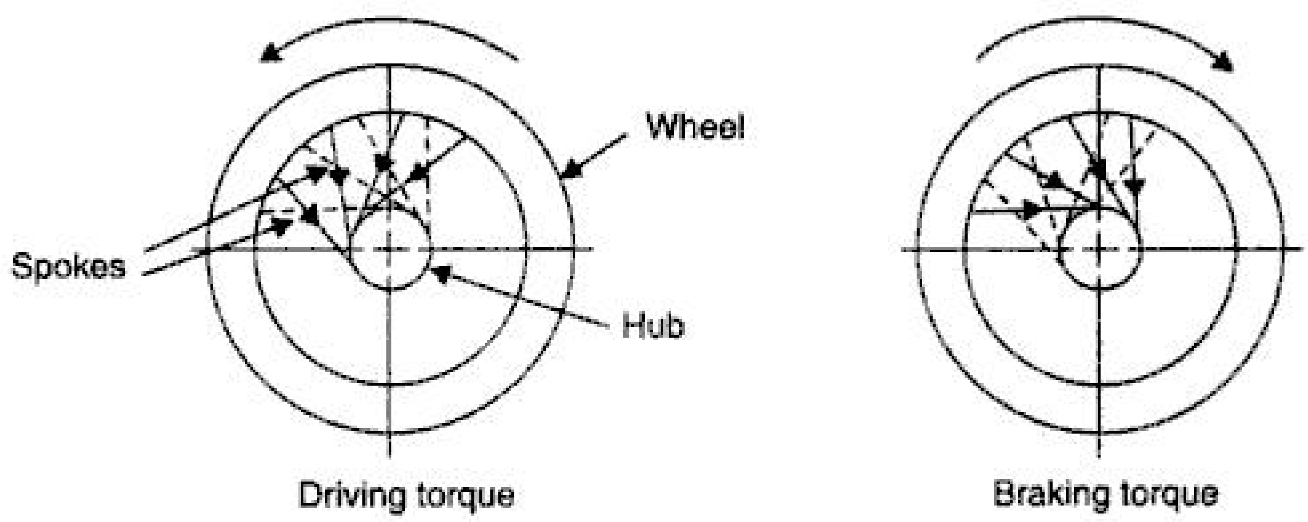

Fig. 6.45. Arrangement of spokes.

The forward-sloping spokes absorb braking torque and the rearward-sloping spokes convey driving torque.

The holes in the hub are arranged in inner and outer rows so that one set of spokes slope towards the rim from the outer row of the hub and the other set slopes outwards to the rim from the inner row of the hub. *These sideways inclinations of the spokes hold the wheel upright against cornering loads and side thrusts.* A rubber chafing band is fitted in the well of the rim to keep tube touching the spoke nuts.

The wire wheels allow free circulation of air around the brake drum.

3. **Light alloy casting wheels :**

The light alloy cast or forged wheel is the most recent type, whose use in ever increasing in both road-and sports cars. The use of light alloys (aluminium and magnesium alloys) makes it possible to *use wider rims, which allow low aspect ratio (i.e., wider tyres to be fitted), thus improving good adhesion, especially on corners.*

The advantages and disadvantages of such wheels may be summed up as follows :

Advantages :

(*i*) Light in weight.

(*ii*) Light alloys being good heat conductors dissipate heat produced by tyres and brakes more efficiently than steel.

(*iii*) Heavier sections can be used which improve the wheel stiffness and better stress distribution is obtained.

(*iv*) Rims with larger area can be used which results in the use of wider tyres with less diameter.

2. **Radial ply construction :**

These tyres have plies running from bead to bead across the crown at right angles to the rotation (Fig. 6.50). On the side walls the direction of these piles 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 depend upon the material used, the lateral stiffness needed and the load the tyre is required to carry.

Radial ply construction tyres are the most modern type and gradually replacing the other two.

Advantages and disadvantages :

Radial ply tyres possess the following *advantages over the bias-ply tyres* :

Advantages :

(*i*) They can absorb more bounce of rough roads and thus the ride is more comfortable at high speeds.

(*ii*) Improved acceleration and braking, operations (due to continuous flat contact–patch area with the road surface).

(*iii*) Lower rolling resistance and hysteresis loss, which ultimately means reduced fuel consumption.

(*iv*) Longer tread-life.

(*v*) For similar tread design the water removal efficiency and hence the braking efficiency on wet-roads is better in case of radial ply tyres.

(*vi*) Better steering characteristics.

(*vii*) Larger resistance to punctures, cuts and impacts in the tread area on account of the breaker belts.

(*viii*) Less tendency to distort and lift off the road from one side.

Disadvantages :

(*i*) Higher initial cost (about 20% more than cross-ply tyres).

(*ii*) At low speeds the ride is uncomfortable harsh.

(*iii*) Heavier steering at low speeds.

3. **Belted bias construction :**

This type of tyre construction is combination of the above two types. The basic construction is the bias-ply over which run a number of breaker belts. The belts improve the characteristics of the bias-ply tyre to a large extent. By keeping the tread shape these tyres show the following *advantages over cross ply* :

(*i*) Improved traction.

(*ii*) Run cooler.

(*iii*) Show greater road mileage.

However since they do not flex as easily as cross ply, the rider is harder because all road shocks are transmitted to the body. Therefore, for comfort, designed springs and suspension systems have to be employed to reduce road shock transfer to the passenger compartment.

6.13.2.6. Tyre materials

The various materials used for construction of tyres are as follows :

- *"Rubber" used in* ***tyres*** *is a blend of the natural and synthetic rubbers* to which various chemicals (carbon, sulphur etc.) are added *to obtain desired properties like wear resistance, less internal friction, reduced hysteresis etc.*

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6.13.2.14. Tyre maintenance

The systematic and correct tyre maintenance is one of the most important factors of safe vehicle operation. *Tyres must sustain the weight of a loaded vehicle, withstand more than ordinary rough service, provide maximum safety over all types of terrain, and furnish the medium on which the vehicle can be moved with ease.*

Besides other elements of tyre service, *inflation maintenance* is the most important and in many cases the most neglected. *The tyre pressure should be constantly maintained for safe operation.* An '*Under inflated*' tyre is dangerous as too much flexing causes breakage of the casing resulting in failure. '*Over inflation*' sometime may cause a blow-out.

The extent of tyre life and the ease and safety of vehicle control are influenced by the following *four factors* :

(*i*) Tyre pressure (*ii*) Tyre rotation

(*iii*) Wheel balance (*iv*) Wheel alignment.

Four of the most common tyre troubles are :

(*i*) Excessive wear around the *outer edges* resulting from under inflation.

(*ii*) Excessive wear in the *centre* of the tread resulting from over inflation.

(*iii*) Tyre tread worn on one side indicating wheels need *realigning.*

(*iv*) Cuplike depressions on one side of the tread indicating wheels need *balancing.*

In order to have a satisfactory four-wheel drive operation, a four-wheel drive vehicle *must be equipped with the same size tyres of equal circumference on all four wheels.* The tyres *must then be inflated to proper factory recommended pressures at all times.*

The practice of *cross-switching* the tyres every 10000 km evens out differences in wear and make a set of tyres last longer than they would without cross-switching.

Fig. 6.54 shows the actual *procedure for rotation of tyres of a car.*

- Rear right wheel (1) is changed to the front left.
- Wheel (2) is changed to the rear left.
- Wheel (3) is changed to the front right.
- Wheel (4) is kept as a spare wheel.
- Spare wheel (5) is fitted to the rear right.

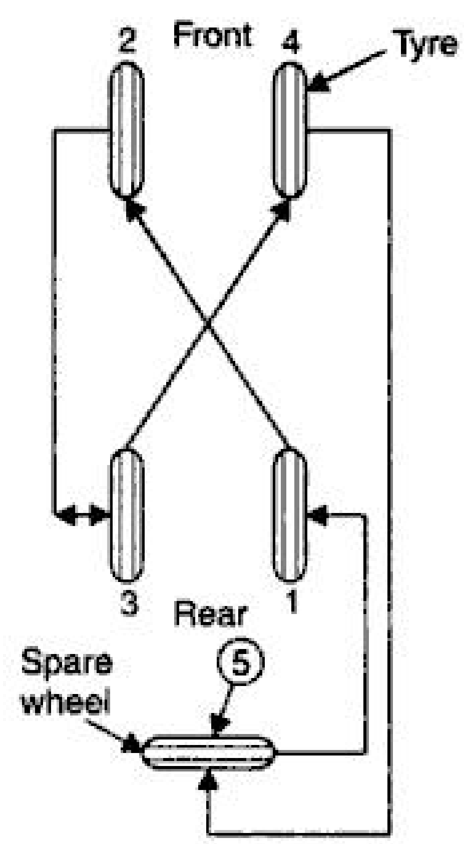

Fig. 6.54. Rotation of tyres.

6.13.2.15. How to enhance the tyre life ?

The life of a tyre can be enhanced/increased by following the basic maintenance rules given below :

1. Load the vehicle to the extent of its capacity fixed by the manufacturer.

2. During loading of the vehicle specially trucks, care should be taken to place the load in the centre of the body.

3. Tyres should neither be under inflated nor over inflated. They should be inflated to their proper capacity.

4. Air should never be bled from a hot tyre to set the pressure right.

5. Proper driving habits should be ensured.

6. In trucks and buses where dual wheels are fitted on the rear axle, the *height of both the tyres should be the same.* In case it is not possible then the difference in height should not be more

Q. 5. What are the types of sections used to make the frames ?

Ans. The frames are made of the following *sections* :

(*i*) Channel section (*ii*) Box section

(*iii*) Tubular section.

Q. 6. What is meant by 'dumb iron' in frame work ?

Ans. Lateral bending of the frame is taken by extra stiff to front and rear extension of the side members of the frame. These extensions are called as *dumb iron.*

Q. 7. What is an "X" frame ?

Ans. It is a frame consisting of large channels joined by a cross member at the middle.

Q. 8. What is the "backbone frame" ?

Ans. It is a frame in which heavy sections are run down at the centre.

Q. 9. Why is the frame narrowed at the front ?

Ans. The frame is narrowed at the front to have better steering lock, which gives *a smaller turning circle.*

Q. 10. Why is box section preferred in the design of chassis member to an open channel section ?

Ans. The box section has *greater torsional stiffness.*

SUSPENSION

Q. 11. What is a helper spring ?

Ans. A keeper spring is an additional spring to allow a wide range of loading and to provide progressive stiffness against increasing load. These are used *in rear suspension only.* They take a part of the load when it exceeds the maximum on the main spring.

Q. 12. What is the sprung weight ?

Ans. The sprung weight is the weight of *passenger carriage.*

Q. 13. What is unsprung weight ?

Ans. The unsprung weight is weight of the *wheel-axle system.*

Q. 14. What are the causes of rough ride ?

Ans. A *rough (or hard) ride* is due to excessive friction in spring suspension and/or improper operation of shock absorber.

Q. 15. What is bouncing in the suspension system ?

Ans. *Bouncing* is a vertical vibration of the complete body when the vehicle crosses an up and down surface of the road.

Q. 16. What is rolling in the suspension system ?

Ans. *Rolling* is the movement about a longitudinal axis, caused by a centrifugal force while turning a corner.

Q. 17. What is pitching in the suspension system ?

Ans. *Pitching* is a rocking action about a transverse axis through the vehicle, parallel to the ground. The front suspension moves out of phase with the rear, experiencing the rocking effect due to pitching.

Q. 18. What is the type of suspension used in heavy duty trucks ?

Ans. Longitudinal leaf spring rear suspension is used in heavy duty trucks.

Q. 19. What is the purpose of the tie rod in the rear end suspension ?

Ans. The tie rod is used to control fore-and-aft wheel movement and to position the spindle to provide toe setting in the rear end suspension.

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Q. 67. State three causes which reduce tyre life.

Ans. (*i*) High speeds, (*ii*) Running the tyres with underinflation, and (*iii*) High rates of cornering.

HIGHLIGHTS

1. The term *Chassis* is used to denote the complete vehicle except the body for the heavy vehicle having a separate body.
2. The *power plant* includes the engine assembly and power transmission assembly.
3. The *frame* or *underbody* is the main part of the chassis on which the remaining parts of the chassis are mounted.
4. The *channel section* is good in bending, *tubular* in torsion and *box* in bending and torsion.
5. *Body* is the superstructure of the vehicle.
6. The *suspension system* of an automobile is one which separates the wheel/axle assembly from the body.
7. The important elements of a suspension system are :
   (*i*) Springs (*ii*) Dampers (or shock absorbers).
8. The various tyres of automotive springs are :
   Leaf (or laminated) springs, Coil springs, Torsion bars, Air and gas springs and Rubber springs.
9. *Dampers* (or *shock absorbers*) are used in the suspension system to check any continuous vibration which may follow the initial force on the system.
10. Modern cars mostly have the following two types of hydraulic dampers :
    (*i*) Telescopic dampers (*ii*) Rocking lever dampers.
11. In a gas-filled shock absorber, instead of only oil, mixture of oil and gas is used for the damping effect.
12. The components of a suspension system are :
    Springs, Dampers (or shock absorbers), Stabilizer and a Linkage system.
13. Suspension may be *rigid axle suspension* or *independent suspension*.
14. "*Independent suspension*" is the 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.
15. The *MacPherson system* consists of a telescopic strut, a single arm and a diagonal stay.
16. A *stabilizer* or *sway bar* is simply a bar of alloy steel with arms at each end connected to the lower wishbone of the independent suspension or axle.
17. The primary advantage of an interconnected system is that tendency of the vehicle to bounce, pitch or roll is reduced and constant desired altitude of the wheel can be maintained.
18. In *air suspension systems*, the four steel springs are replaced by four rubber cylinders or air springs.
19. *Hydrostatic suspension* works on compression of fluid with the help of rubber washers or cups.
20. *Hydragas suspension system* uses gas-filled spring units (called Hydragas springs), one at each wheel.
21. *Wheels* are legs of the vehicle which carry it to far-off distances.
22. A *tyre* is a cushion provided with an automobile wheel.
23. *Aspect ratio* in reference to tyre shape is numerically equal to the ratio of the section height to section width.
24. The *balance of a tyred wheel* is essentially required to avoid front wheel wobble which affects steering and increases tyre wear rates.

OBJECTIVE TYPE QUESTIONS

Choose the Correct Answer :

1. The most effective section against bending is
   (*a*) rectangular bar (*b*) round bar
   (*c*) round hollow tube (*d*) square hollow section.

63. State the requirements of a good tyre.

64. Explain briefly the following types of tyres :

(*i*) Conventional tube tyre (*ii*) Tubeless tyre.

65. What are the advantages of a tubeless tyre ?

66. Describe tyre construction in brief.

67. What are the results of under-inflation and over-inflation ?

68. List down the advantages of radial ply tyres over the bias-ply tyres.

69. Describe briefly 'tyre materials'.

70. Explain briefly 'tyre shape'.

71. What do you mean by 'Tyre marking' ? Explain briefly.

72. State the factors on which 'Tyre selection' depends.

73. What are the causes of tyre wear ?

74. List the factors which affect tyre life.

75. Explain the importance of tyre maintenance.

76. Enumerate the four most common tyre troubles.

77. What is tyre rotation and its purpose ?

78. How can the life of a tyre enhanced ?

79. Write a short note on 'Wheel balance'.

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3. It should be *dynamically balanced* (particularly required in case of high speed engine clutches).

4. It should be *free from slip* when engaged.

5. It should be as small as possible so that it will *occupy minimum space.*

6. The wearing surfaces should have *long life.*

7. It should be *easily accessible* and have *simple means of adjustment.*

8. It should have suitable mechanism to *damp vibrations* and to *eliminate noise* produced during the power transmission.

9. It should be able to *dissipate large amount of heat* which is generated during the clutch operation due to friction.

10. The driven members of the clutch should be made as light as possible so that they *will not continue to rotate for any length of time* after the clutch has been disengaged.

11. The clutch should have *free pedal play* in order to *reduce effective clamping load on the carbon thrust bearing and wear on it.*

7.2.4. Principle of Operation of a Clutch

The clutch principle is based on *friction*. When two friction surfaces are brought in contact with each other and pressed they are united due to friction between them. If now one is revolved, the other will also revolve. The friction between the two surfaces depends upon, (*i*) Area of the surface, (*ii*) Pressure applied upon them, and (*iii*) Coefficient of friction of the surface materials. One surface is considered as *driving* member and the other as *driven member*. The driving member is kept rotating. When the driven member is brought in contact with the driving member, it also starts rotating. When the driven member is separated from the driving member, it stops revolving. This is how, a clutch operates.

- The driving member of a clutch is the *flywheel* mounted on the crankshaft, the driven member is *pressure plate* mounted on the transmission shaft. Friction surfaces (clutch plates) are between the two members (driving and driven). On the engagement of the clutch, the engine is connected to the transmission (gear box) and the power flows from the engine to the rear wheels through the transmission system. When the clutch is disengaged by pressing a clutch pedal, the engine is disconnected from the transmission and consequently the power does not flow to the rear wheels while the engine is still running.

7.2.5. Friction Materials

There are three types of friction materials/linings, namely :

1. Woven type 2. Moulded or compression type 3. Mill board type.

1. The "*woven type*" is made by spinning threads from *asbestos fibres*, sometimes on brass wire, weaving this thread into a cloth and then impregnating it with a bonding material (such as vegetable grins, rubber, synthetic resins etc.).

2. The "*moulded* or *compression*" type of lining is composed of *asbestos fibres* in their natural state mixed with a *bonding material* and then moulded in dies under pressure and at elevated temperatures. Metallic wires are sometimes included but only to increase the wearing qualities and to eliminate scoring of the metal faces against which the lining rubs.

3. "*Mill board*" type friction materials mainly include asbestos sheets treated with different types of impregnants. They are cheap as well as quite satisfactory in operation.

"*Cotton*" is occasionally used instead of, or mixed with, asbestos and such fabrics can be made to give high co-efficients of friction (up to 0.6) but materials containing cotton cannot withstand a temperature exceeding about 150°C without being charred and ruined.

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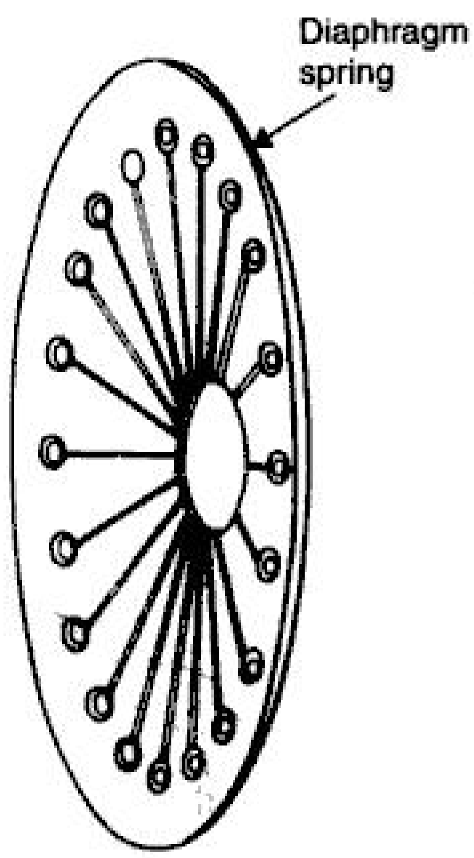

Fig. 7.4. Diaphragm spring used in diaphragm spring clutch.

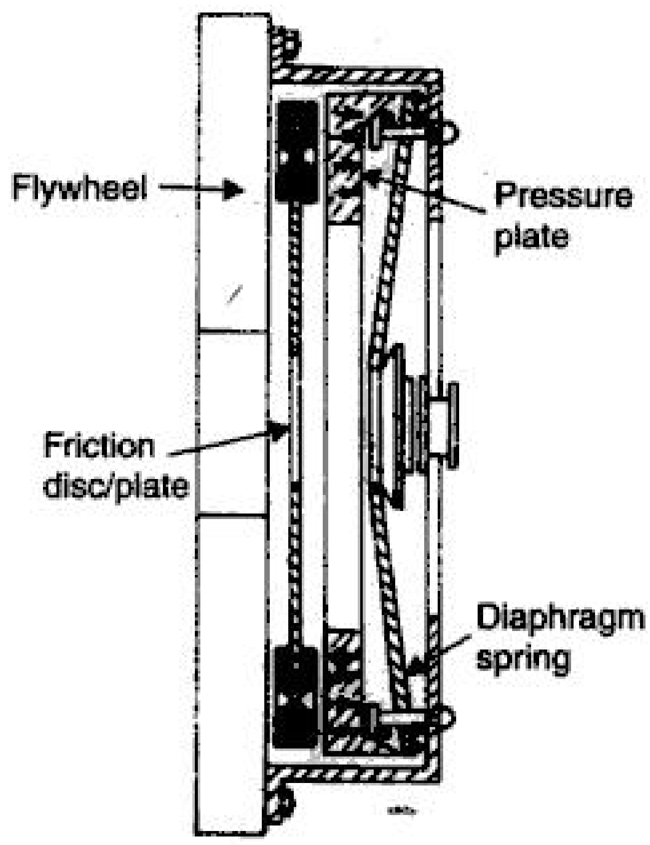

Fig. 7.5. Diaphragm spring clutch (disengaged)

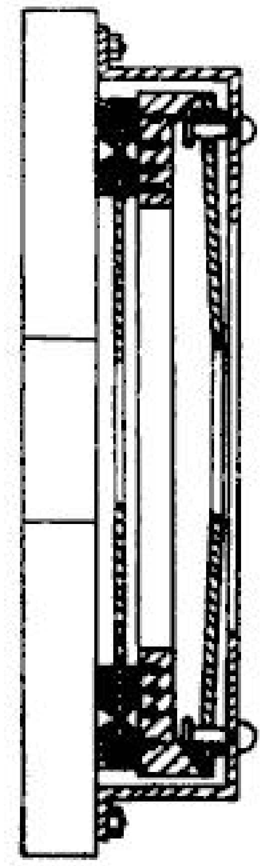

Fig. 7.6. Diaphragm spring clutch (engaged)

Diaphragm spring is shown in 'disengaged' and 'engaged' conditions in Fig. 7.5 and 7.6 respectively.

The diaphragm spring offers the following *advantages* :

(*i*) The operating load is practically uniform and constant on the driven plate.

(*ii*) It has a compact design, which results in smaller clutch housing.

(*iii*) Release levers are not required, since the diaphragm itself acts as a series of levers.

(*iv*) Squeaks, rattles and vibrations are mostly eliminated.

(*v*) It can withstand higher rotational speeds since the diaphragm is comparatively less affected by the centrifugal forces. On the other hand, coil springs have tendency to distort in the transverse direction at higher speeds.

7.2.9. Multiplate Clutch

When a great amount of torque is to be transmitted instead of single plate we can employ a *number of friction plates*. This will increase the number of mating friction surfaces, hence it is called "*multiplate clutch*".

These clutches are **used** in *heavy commercial vehicles, racing cars and motor cycles for transmitting high torque.*

Fig. 7.7 shows a multiplate clutch in which friction rings are splined on their outer circumferences to mate with corresponding splines on the bore of the housing and are free to slide on the splines. The friction material therefore rotates with the housing and engine shafts. Discs or plates are free to slide on the splines on the driven shaft and rotate with it. The disc on the right can be moved to the right against a powerful spring which, when the actuating force is removed, presses the disc into contact with friction rings. Torque is therefore transmitted between the engine shaft and the driven shaft.

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comparable to an electric transformer. Usually the *torque converters are used for increasing the torque.*

When a large reduction in speed ($\omega_t << \omega_p$), and a large torque is required, the hydraulic torque converters are designed which utilize two or more sets of turbine runners, and fixed guide vanes located between the turbine runners.

Fig. 7.15, shows the efficiency versus speed ratio curve for a torque converter ; maximum value of efficiency occurs where speed ratio is approximately 0.5 ; at higher speed ratios the efficiency drops. From the efficiency curve, it is apparent that the efficiency of the torque converter is better at smaller speed than that of hydraulic coupling. The advantages of the hydraulic coupling and the torque converter can be obtained by *designing the system in such a way that at low speed ratios it acts as a converter and at high speed ratios as a coupling.*

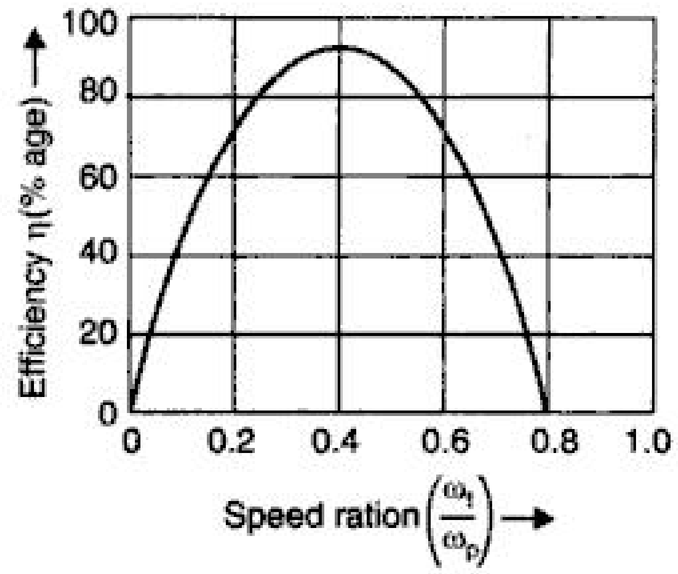

Fig. 7.15. Efficiency vs. speed ratio curve for the hydraulic torque converter.

Comparison between the "fluid coupling" and "hydraulic torque converter" :

The comparison between the fluid coupling and hydraulic torque converter is given below :

S. No.	Aspects	Fluid coupling	Hydraulic torque converter
1.	*Means of power transmission*	Through fluid.	Through fluid
2.	*Type of device*	Automatic.	Automatic
3.	*Main components*	Impeller and runner.	Pump, stator and turbine.
4.	*Type of unit*	It is simply a means to connect driving and driven members.	It is a torque multiplication unit.
5.	*Flow of oil*	Impeller and runner are locked up and movement of oil stops during engagement when centrifugal force is approximately the same on both members.	It never locks up and flow of oil never stops but continues.
6.	*Types of blades*	Merely fins.	The turbine blades are inclined having pitch.
7.	*Purpose served*	It serves the purpose of an automatic clutch.	It acts as an automatic clutch and serves the purpose of automatic gear box to increase torque.
8.	*Performance at highway speeds*	It is efficient at highway speeds.	It is not as efficient as fluid coupling at highway speeds but is slightly more efficient under load.
9.	*Assistance by a clutch*	It is not assisted by friction clutch.	It is usually used in conjunction with automatic clutch (mostly fluid flywheel) to eliminate the slight loss of efficiency at highway speeds.

7.2.16. Clutch Adjustment

The following four adjustments are made on most of the vehicles :

1. **Floor board clearance adjustment :**

This adjustment is required *to prevent the pedal arm from resting against the floor board when the clutch is engaged.*

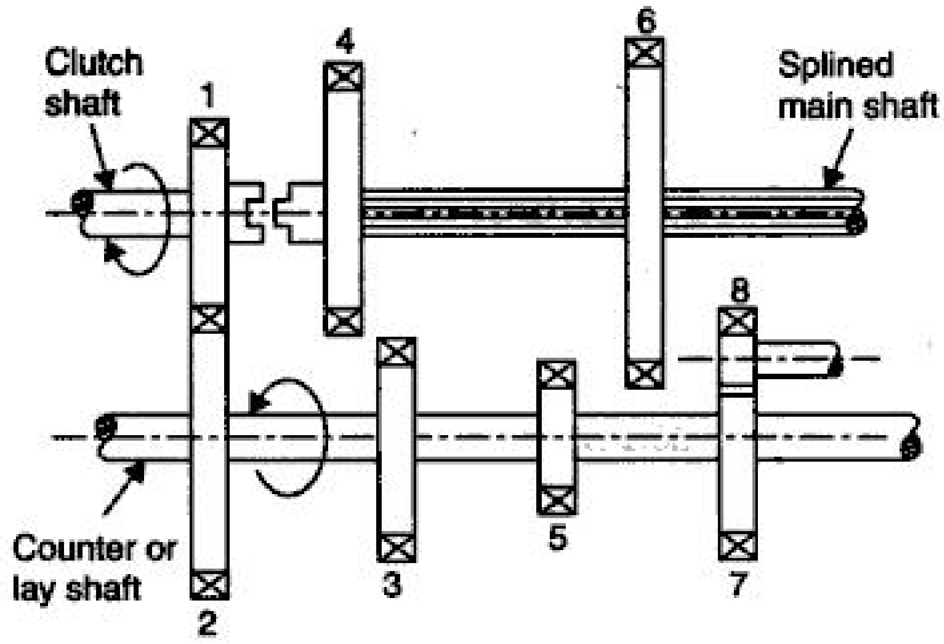

Fig. 7.22. Neutral gear position.

2. Constant mesh gear box :

Refer Fig. 7.23. It is that gearbox in which all the gears are in constant mesh with each other (hence the name constant mesh gear box) all the time and this gives a silent or *quiet operation*. Here, helical gears are used to make gear changing easier. The gears on the main shaft which is splined, are *free*. The gears on the counter or layshaft are, however, *fixed*. Two dog clutches are provided on the main shaft-one between the clutch gear and the second gear and the other between the low/first gear and reverse gear. Dog clutch can slide on the main shaft and rotates 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. 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 handing 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.

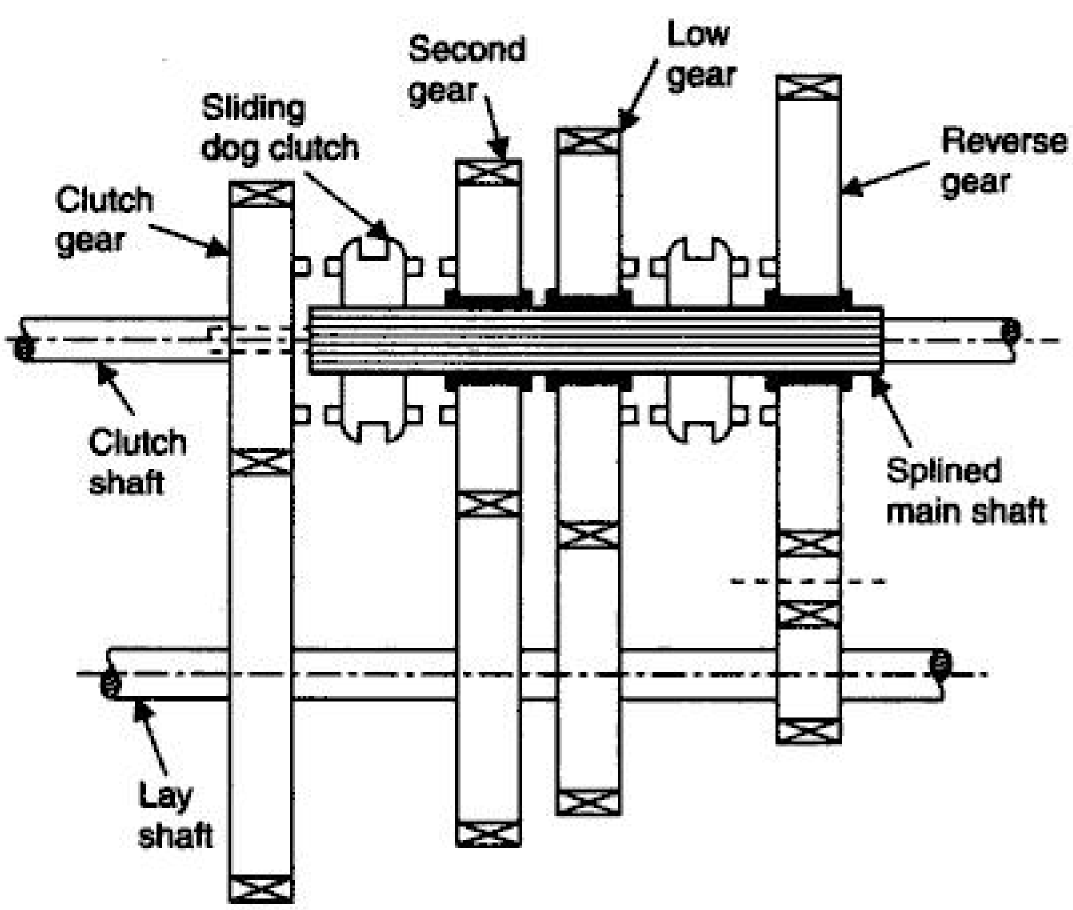

Fig. 7.23. Constant mesh gear box.

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6. Owing to distribution of loads, a generate area of *gear tooth contact can be used.*

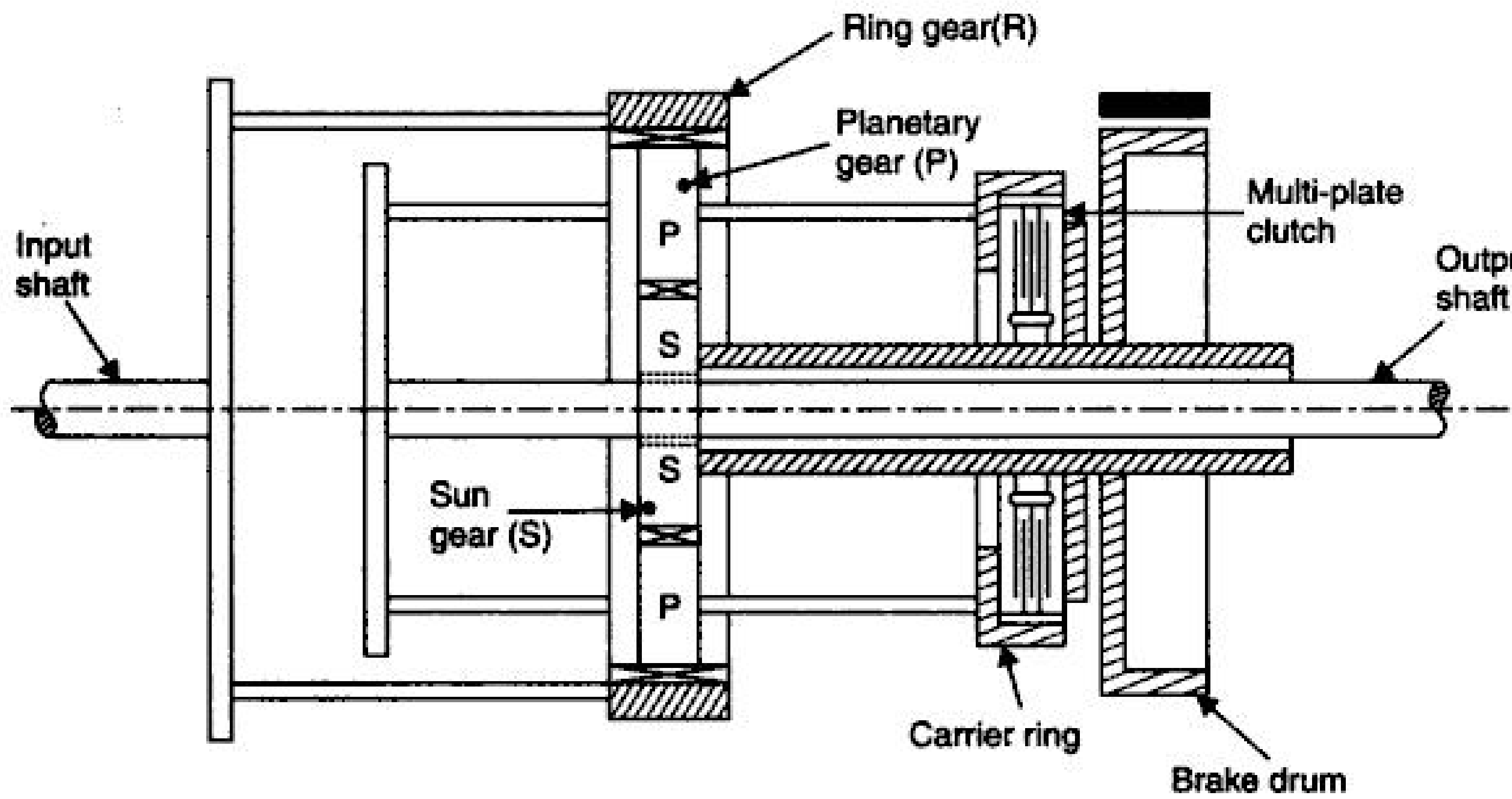

Fig. 7.30. Two-speed epicyclic gear box.

7.3.7. Maruti-800 Gear Box

Fig. 7.31 shows the layout of a Maruti-800 car gear box along with the differential.

It is fully synchronized and provides four forward speeds and one reverse speed by means of two synchronizers and two shafts—input shaft and 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, and the *high speed synchronizer* is engaged with 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 made in two parts-*upper case* and *lower case* :

— The *upper case* houses the reverse shaft.

— The *lower case* has three fork shifting mechanisms, built into it.

In automobiles, transmission from engine to rear wheel flow through some forward and reverse gears, which are enumerated below :

1. **Low speed drive** —The drive is transmitted through the low drive gear on the input shaft and the low-driven gear on the countershaft to the gear of the final differential.

2. **Second speed drive** —The drive is transmitted through the second drive gear on the input shaft and second driven gear on the countershaft to the final gear of the differential.

3. **Third speed drive** —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** —The drive is transmitted through the top drive gear on the input shaft and top driven gear on the countershaft to the final gear of the differential.

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lights. This *speed at which the overdrive can be engaged* (in other words, the speed at which the indicator lamp lights) is called the ***"cut-in-speed"***.

- When the engine speed is dropping, the overdrive will not disengage at 50 km/h. There will be a difference of about 8 km/h, in other words, the overdrive will not disengage automatically until the speed drops to 42 km/h. This *speed at which the overdrive disengages automatically* is called the ***"cut-out speed"***.

There is a difference of 8 km/h between the cut-in and cut-out speeds and this difference is called "***hystresis***". Unless this difference is provided, a car running at 50 km/h will be subjected to complicated gear changes, alternating continuously between overdrive and normal top speed.

- When the control lever in front of the driver is pulled out, the lockout switch actuates. The overdrive electric circuit will be switched off and the overdrive will not be engaged even if the car speed rises above the cut-in-speed. The car will be running under normal direct drive.
- If while driving under overdrive, quick acceleration is desired or a hill has to be climbed, that is, if a large drive power is required, depressing the accelerator pedal all the way down will enable going out of overdrive automatically and allow the car to run under direct drive. This is called ***kick-down.***
- If the accelerator pedal is depressed all the way down while driving at high speed (about 110 km/h), the overdrive *will not disengage* because of the anti-kick-down device provided in the overdrive relay. The *purpose of this is to prevent the engine from over-running.*

Freewheel unit :

Freewheel unit, also known as *over running clutch, sprang clutch or one way clutch*, *is an essential part of every overdrive*. It transmits power in *one direction only*–from the transmission main shaft to the output shaft.

It enables the vehicle to freewheel or overrun while going doing a gradient or when the accelerator is released. It does not prevent the vehicle to be driven positively in forward direction. It is fitted at the back of the gear box and in case an overdrive is attached to the gear box, it is either incorporated in the overdrive or attached at its back. In every case, it is fitted between the transmission and the propeller shaft.

It works on the same principle as the freewheel in a bicycle.

Fig. 7.38 shows a free-wheeling device. It consists of a central *driving member* which is attached to the splined shaft forming rear end of the gearbox output shaft. An annular outer *driven member* is mounted over the driving member. The driven member is connected to the propeller shaft.

– In the *positive drive, the roller are forced to the right by the spring pad*. They become *wedged* between the driving and driven members as a result of spring pressure and driving effect of driving member.

– When the *driven member over-runs the driving member*, the rollers move to the *left* and the drive between them is disconnected.

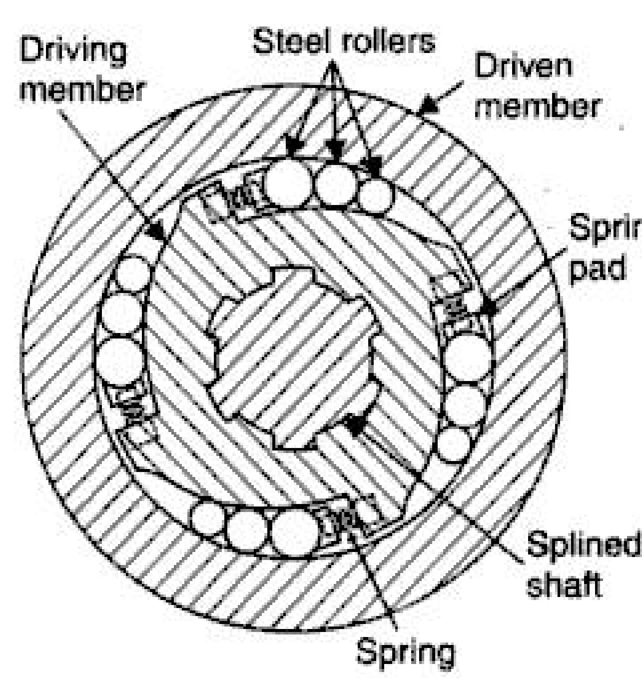

Fig. 7.38. Freewheel unit.

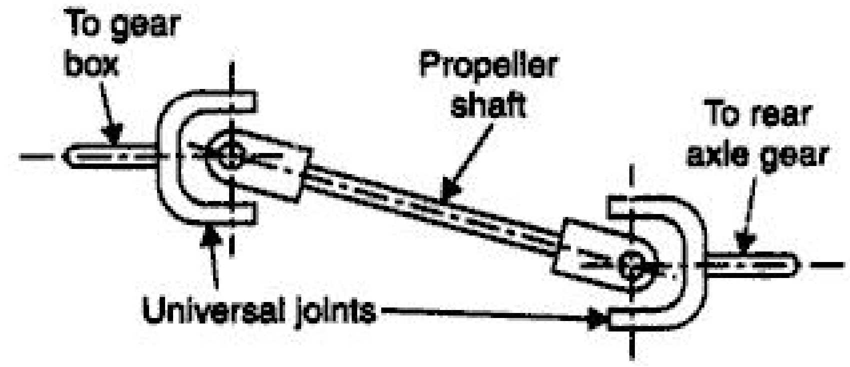

Fig. 7.45. Use of two universal joints.

7.5.3. Types of Universal Joints

Universal joints can be classified as under :

1. *Variable velocity joints :*

(*i*) Cross or spider type.

(*ii*) Ring type.

(*iii*) Ball and trunion type.

2. *Constant velocity joints :*

(*i*) Rzeppa

(*ii*) Bendix Weiss

(*iii*) Tracta.

1. **Variable velocity joints :**

- In these joints, the driving and driven shafts do not turn at the same speed through each part of a revolution although they turn at the same r.p.m. The driving and driven shafts should therefore be in a straight line so that they may turn at the same speed through each part of a revolution. But in an automobile, it is not feasible as the drive shaft is inclined. When there is an angle between the driven and driving shafts, the driven shaft turns lower than the driving shaft through half a revolution and faster than the driving shaft through the other half revolution. Thus the average speed of the driven shaft is equal to the driving shaft. *The speed variation in the driven shaft increases when the flex of angle of the universal joint is increased.* It is owing to this fact that *variable velocity joints are usually employed when the flex angle is small.*
- When two variable velocity universal joints are used in one drive line, the *yokes on the shafts connecting the universal joints should be in the same plane. It helps in balancing the speed variation.*

(*i*) ***Cross or spider type (Hooke's joint)*** **:**

Refer to Figs. 7.42 and 7.43.

- It consists of a cross piece or spider and two yokes, therefore, it is known as cross type of spider and two-yoke type universal joint. There are four needle bearings, one for each trunion of the spider. The bearings are held in place by rings heat drop into under cuts in the yoke-bearing holes.
  - One commercial design of the cross type universal joint incorporates a *slip joint.* One yoke is integral with the hub that holds the female end of the slip joint. When the joint is used between the propeller shaft and rear axle gear shaft, the slip joint is omitted so that a direct connection is made between the two units.
- These types of joints are *mostly used with the drive shafts—"Hotchkiss drive'.*

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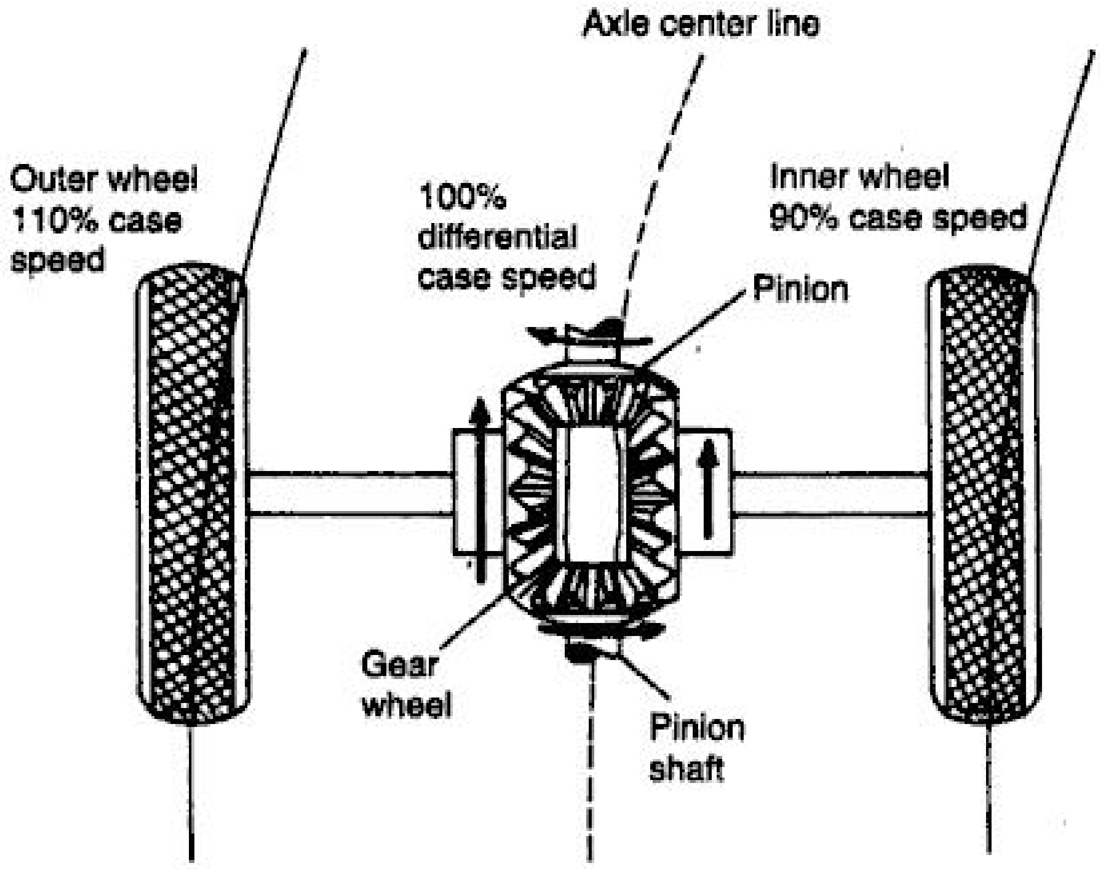

Fig. 7.50. Differential action on turns.

Whenever the car goes round a turn, the outer drive wheel travels a greater distance than the inner drive wheel. The two pinion gears rotate on their shaft and send more rotary motion to the outer wheel.

- The gear ratio in the differential is usually referred to as the *axle ratio*. However it would be more accurate to call it the *differential ratio*.

Types of differential :

Differential is of the following types :

1. Conventional.
2. Power-lock or Non-slip.
3. Double reduction type.

1. ***Conventional.*** Already discuss above.

2. ***Power-lock or Non-slip :***

The conventional differential delivers the same amount of torque to each wheel on the drive axle. If one wheel slips on a slippery road, mud or ice, the wheel becomes stationary, all the power being flowing to the slipping wheel. This results in no movement to the vehicle. In order to overcome this drawback, the vehicles are now *provided with a non-slip or self-locking differential*.

Non-slip differential is very much similar in construction to conventional type except that *it has two sets of clutch plates in addition*. Furthermore, the ends of pinion shafts lay loosely in notches, in two halves of the differential cage.

- *Straight head drive*. The rotating differential cage carries the sun gear shafts around with it. Since there is a considerable side thrust, the axle shafts in sun gears tend to slide up the sides of the notches in the two halves of the differential cage. As they slide up, they are forced outward and this force is transmitted to the clutch plates. Clutch plates thus lock the sun gears and the axle shafts to the differential cage. In this case, if one wheel encounters a muddy or slippery surface, *that causes it to lose traction temporarily avoiding it from slipping or spining* since it cannot turn faster than the other wheel as the half shaft is locked with differential cage by means of clutch plates.
- *Rounding a corner*. While taking a turn, the non-slip differential functions in the conventional way to tend the outer wheel to run faster than the inner wheel and thus to cover

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7.7.7. Comparative Rear Axle Data of Some Indian Automobiles :

S. No.	Vehicle make	Type	Type of drive	Ratio
1.	*Hindustan Ambassador Mark-II*	Three-quarter floating	Hypoid	4.875 : 1
2.	*Fiat 1100*	Semi-floating	Hypoid	4.3 : 1
3.	*Jeep CJ Series*	Semi-floating	Hypoid	4.38 : 1
4.	*Ashok Leyland Comet Passenger*	Fully-floating	Spiral-bevel	6.216 : 1
5.	*Ashok Leyland Viking*	Fully-floating	Spiral-bevel	6.167 : 1
6.	*Dodge/Fargo Model 89M4*	Fully-floating	Hypoid	6.166 : 1
7.	*Tata 1210E Vehicles*	Fully-floating	Hypoid	6.857 : 1
8.	*Standard 20*	Semi-floating	Hypoid	4.625 : 1 (normal duty) 5.375 : 1 (heavy duty)
9.	*Swaraj Mazda*	Fully-floating		6.571 : 1
10.	*Eicher Mitsubishi 'Canter'*	Fully-floating	Hypoid	6.166 : 1
11.	*Ford FS 16C*	Fully-floating	-	6.5 : 1

7.7.8. Troubleshooting of Rear Axle

S. No.	Fault	Causes	Remedies
1.	*Axle noisy on acceleration.*	(*i*) Heavy heat contact on ring gear. (*ii*) Improper adjustment of pinion and ring gear. (*iii*) Rough pinion bearings. (*iv*) Loose pinion bearings.	(*i*) Correct it (*ii*) Re-adjust (*iii*) Replace (*iv*) Adjust.
2.	*Axle noisy on coast.*	(*i*) Excessive backlash in ring gear and pinion. (*ii*) End play in the pinion shaft. (*iii*) Heavy toe contact on ring gear. (*iv*) Rough bearings.	(*i*) Adjust (*ii*) Re-adjust (*iii*) Re-adjust (*iv*) Replace.
3.	*Axle noisy on both coast and acceleration.*	(*i*) Worn differential gears. (*ii*) Worn pinion and ring gears. (*iii*) Defective bearings. (*iv*) Excessive backlash between ring gear and pinion. (*v*) Pinion set too deep in ring gear. (*vi*) Pinion and ring gear too tight.	(*i*) Replace (*ii*) Replace (*iii*) Replace (*iv*) Adjust (*v*) Adjust (*vi*) Adjust.
4.	*Back lash.*	(i) Axle shaft splines worn. (*ii*) Axle shaft nut loose. (*iii*) Worn universal joints. (*iv*) Worn differential bearings. (*v*) Worn differential side gear thrust washers.	(*i*) Replace axle shaft (*ii*) Tighten as necessary (*iii*) Replace (*iv*) Replace (*v*) Replace.

2. Progressive type

3. Epicyclic or planetary type.

15. *Synchromesh gear devices* 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.

16. *Epicyclic or planetary type gear box* uses no sliding dogs or gears to engage but different gear speeds are obtained by merely tightening brake-bands on gear drums.

17. *Gear shifting* is the moving of the gears in transmission by means of the gear shift lever to change the gear mesh.

18. *Transfer case* is a two-speed transmission located at the rear of the standard transmission which provides a low and direct gear (as in jeep).

Propeller shaft, Universal joint, Final drive and differential, Rear axles

19. The *propeller shaft* is a driving shaft that connects the transmission main or output shaft of the gear box to the differential of the rear axle.

20. *Universal joint* is the joint which enables the drive shaft to transmit power at varied angles. It permits the torque transmission not only at angle, but also while this angle is changing.

21. Types of universal joints :

(*a*) Variable velocity joints : Cross or spider type ; Ring type ; Ball and trunion type.

(*b*) Constant velocity joints : Tracta ; Bendix Weiss ; Rzeppa.

22. The *final drive* is the last stage in transferring power from the engine to the road wheels. It provides a fixed reduction between the drive shaft and the driving axles.

23. *Classes of final drive :*

1. Chain type

2. Gear type : Worm and wheel type ; Bevel and hypoid bevel gear type.

24. *Differential* is the mechanism by means of which outer wheel runs faster than the inner wheel while taking a turn or moving over upheaval road.

25. *Types of differential :*

1. Conventional ; 2. Power lock or non-slip ; 3. Double reduction type.

26. A *rear axle* lies between the differential and the driving wheels and transmits power from the differential to the driving wheels.

27. *Types of rear axles :*

1. Half-floating ; 2. Three-quarter floating ; 3. Fully floating rear axles.

OBJECTIVE TYPE QUESTIONS

Choose the Correct Answer :

Clutch

1. A clutch is usually designed to transmit maximum torque which is :

(*a*) 90 percent of the maximum engine torque (*b*) equal to the maximum engine torque.

(*c*) 150 percent of the maximum engine torque (*d*) none of the above.

2. The inertia of the rotating parts of the clutch should be

(*a*) minimum (*b*) maximum (*c*) zero (*d*) none of these.

3. The coefficient of friction for the clutch facing is approximately

(*a*) 0.1 (*b*) 0.4 (*c*) 0.8 (*d*) 1.2.

4. In a clutch with coil springs, the wear of the clutch facing will cause the clamping load to

(*a*) increase (*b*) decrease (*c*) remain constant (*d*) become infinite.

5. Clutch facings are usually attached to the plate by

(*a*) steel rivets (*b*) brass rivets (*c*) aluminium screws (*d*) steel screws.

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8

Steering and Front Axle

A. STEERING SYSTEM

8.1. PURPOSE OF A STEERING SYSTEM

The **steering system** *allows the driver to guide the car along the road and turn left or right as desired.*

The system includes the following :

(*i*) *The steering wheel* ...... which the driver controls.

(*ii*) *The steering gear* ...... which changes the rotary motion of the wheel into straight line motion, and

(*iii*) *The steering linkages* ...... which transmit the steering gear movement to the front wheels.

- The steering system configuration depends on vehicle design (the drive train and suspension system used, whether it is a passenger car or a commercial vehicle etc.). At present, the rack-and-pinion type and the recirculating-ball types are in use.
- Most steering systems were *manual* until a few year back. Then *power steering* became popular. It is now installed on almost all costly cars.

8.2. FUNCTIONS OF A STEERING SYSTEM

Following are the *functions* of a steering system :

1. The primary function of the steering system is *to achieve angular motion of the front wheels to negotiate a turn.*

2. To provide directional stability of the vehicle when going straight ahead.

3. To facilitate straight ahead recovery after completing a turn.

4. To minimise wear and tear of tyres.

5. To absorb a major part of the road shocks thereby preventing them to get transmitted to the hands of the driver.

6. To provide perfect rolling motion of the road wheels at all times.

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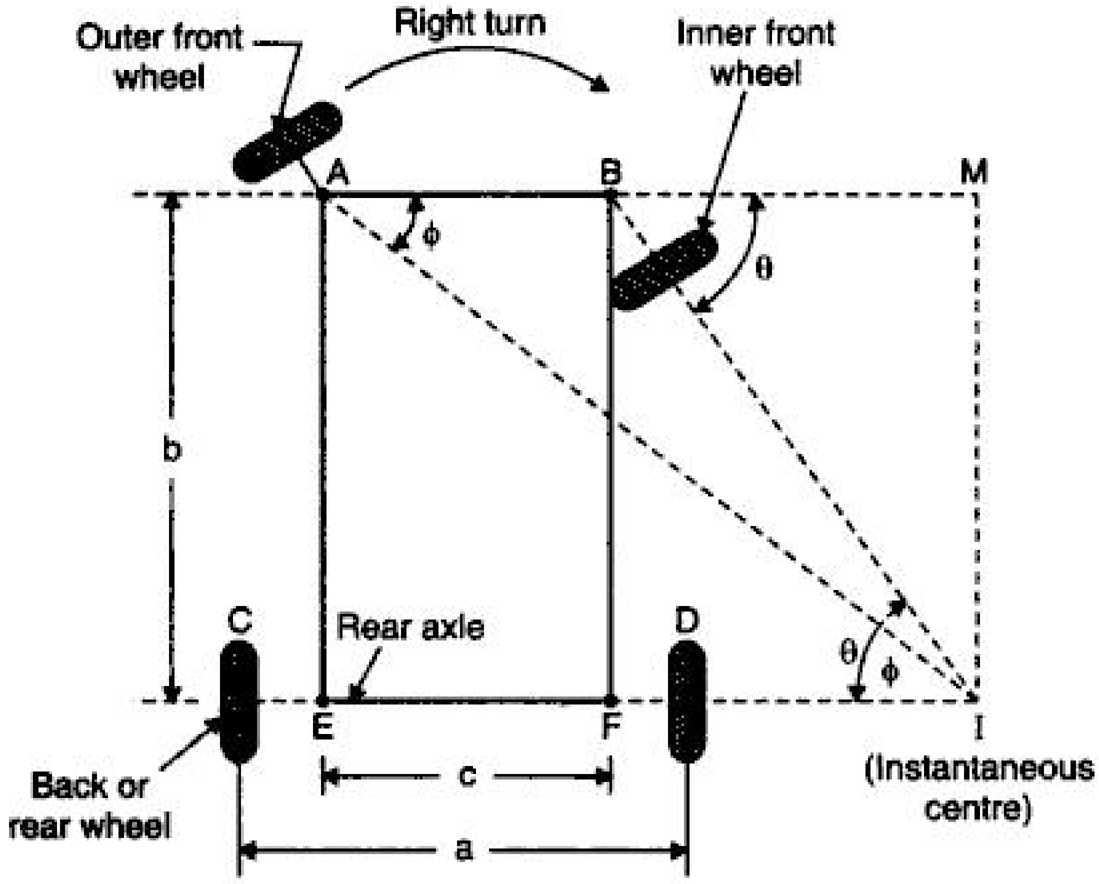

Fig. 8.15. Steering gear mechanism.

In automobiles, the front wheels are placed over the front axles, which are pivoted at the points A and B, as shown in Fig. 8.15. These points are fixed to the chassis. The back or rear wheels are placed over the back axle, at the two ends of the differential tube. When the vehicle takes a turn, the front wheels along with the respective axles turn about the respective pivoted points. The rear wheels remain straight and do not turn. Therefore, the steering is done by means of front wheels only.

In order to avoid skidding (*i.e.*, the slipping of the wheels tyres), the two front wheels must turn about the same instantaneous centre I which lies on the axis of the rear wheels. If the instantaneous centre of the two front wheels do not coincide with the instantaneous centre of the rear wheels, the skidding on the front or rear wheels will definitely take place, which will cause more wear and tear of the tyres.

Thus, the *condition for the correct steering is that all the four wheels must turn about the same instantaneous centre.* The axis of the inner wheel makes a larger turning angle θ than the angle ϕ subtended by the axis of outer wheel.

Let, a = Wheel track

b = Wheel base, and

c = Distance between the pivots A and B of the front axle.

Now, from ΔIBM, $$\cot\theta = \frac{BM}{IM}$$

and, from ΔIAM, $$\cot\phi = \frac{AM}{IM} = \frac{AB + BM}{IM} = \frac{AB}{IM} + \frac{BM}{IM} = \frac{c}{b} + \cot\theta \qquad (\because\ IM = b)$$

$$\therefore \qquad \cot\phi - \cot\theta = \frac{c}{b} \qquad \text{...(8.1)}$$

This is the *fundamental equation for correct steering*. If this condition is satisfied, there will be no skidding of wheels, when the vehicle takes a turn.

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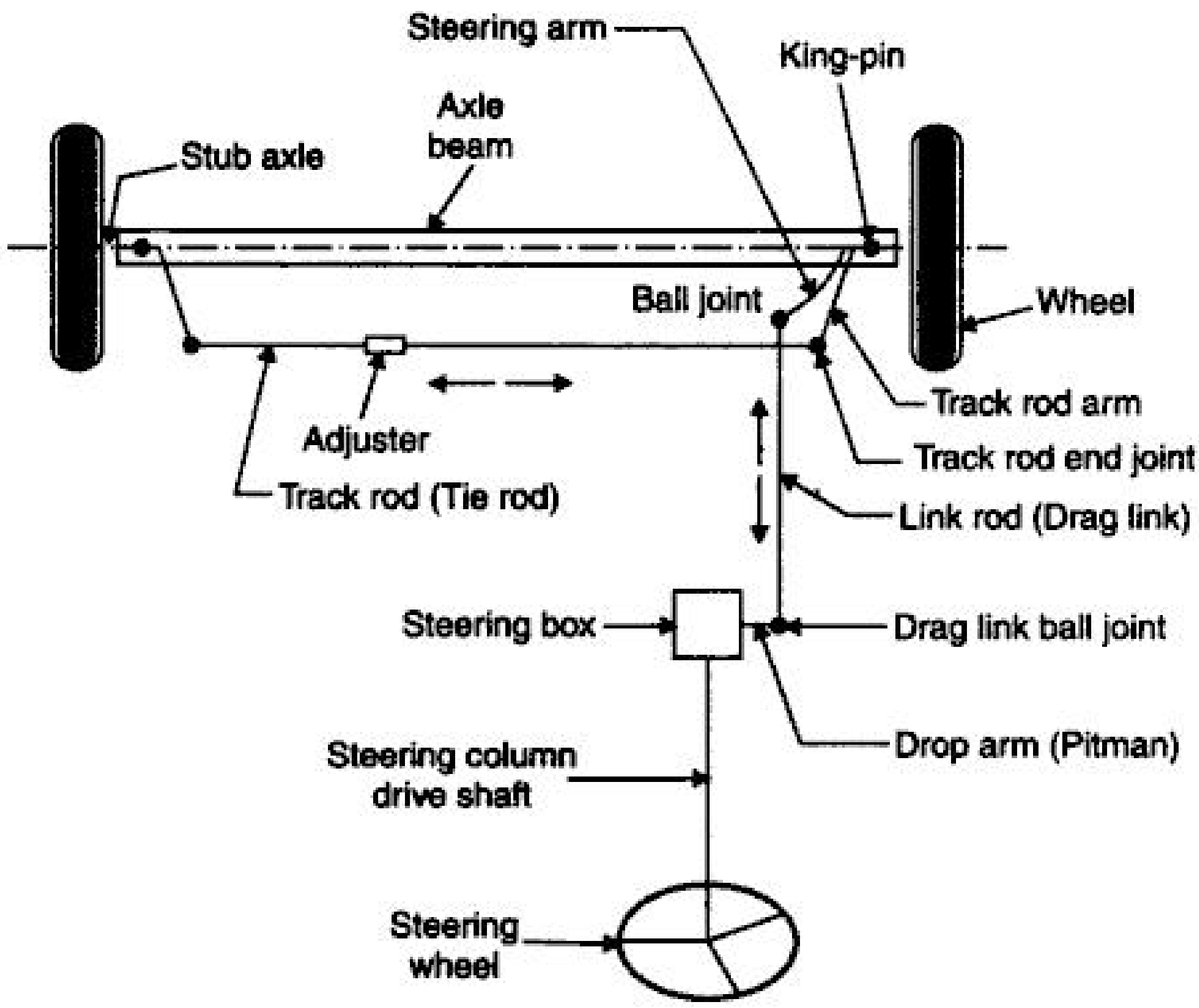

Fig. 8.19. Steering linkage for a conventional rigid axle suspension.

– **Each stub axle has a forged track rod arm rigidly bolted to the wheel axis. The other ends of the track rod arms are connected to the track rod by means of ball joints. An adjuster is also provided in the track rod to change its length for adjusting wheel alignment.**

Working. When the steering wheel is turned, the swinging action of the drop arm imparts a near linear movement to the link rod. This movement is transmitted through the link rod arm to the stub axle so as to turn the later about its pivot, which may be a king-pin or ball joints. The other wheel is steered through the track rod. Thus only one wheel is positively steered.

Steering linkages for independent front suspension :

Some steer linkages for independent front suspension are shown in Fig. 8.20. In these linkages, the ball joints are fitted between the linkage and the steering arms to allow for the independent movement of the wheels.

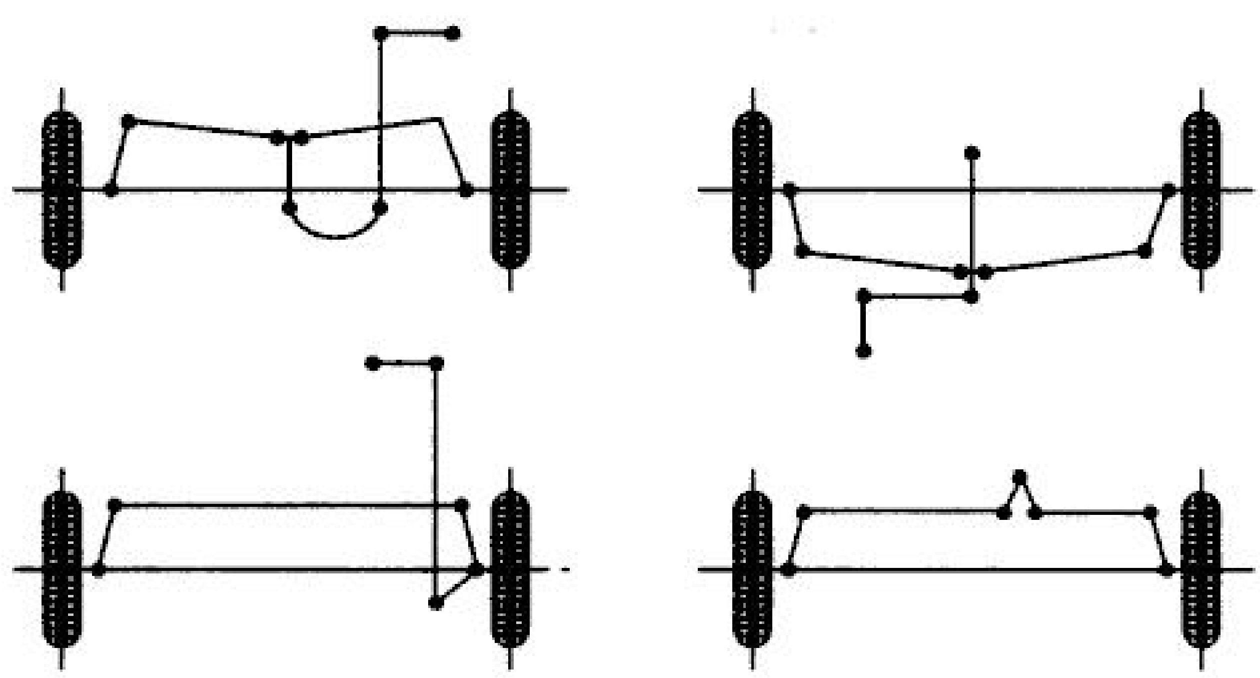

Fig. 8.20. Various types of steering linkages.

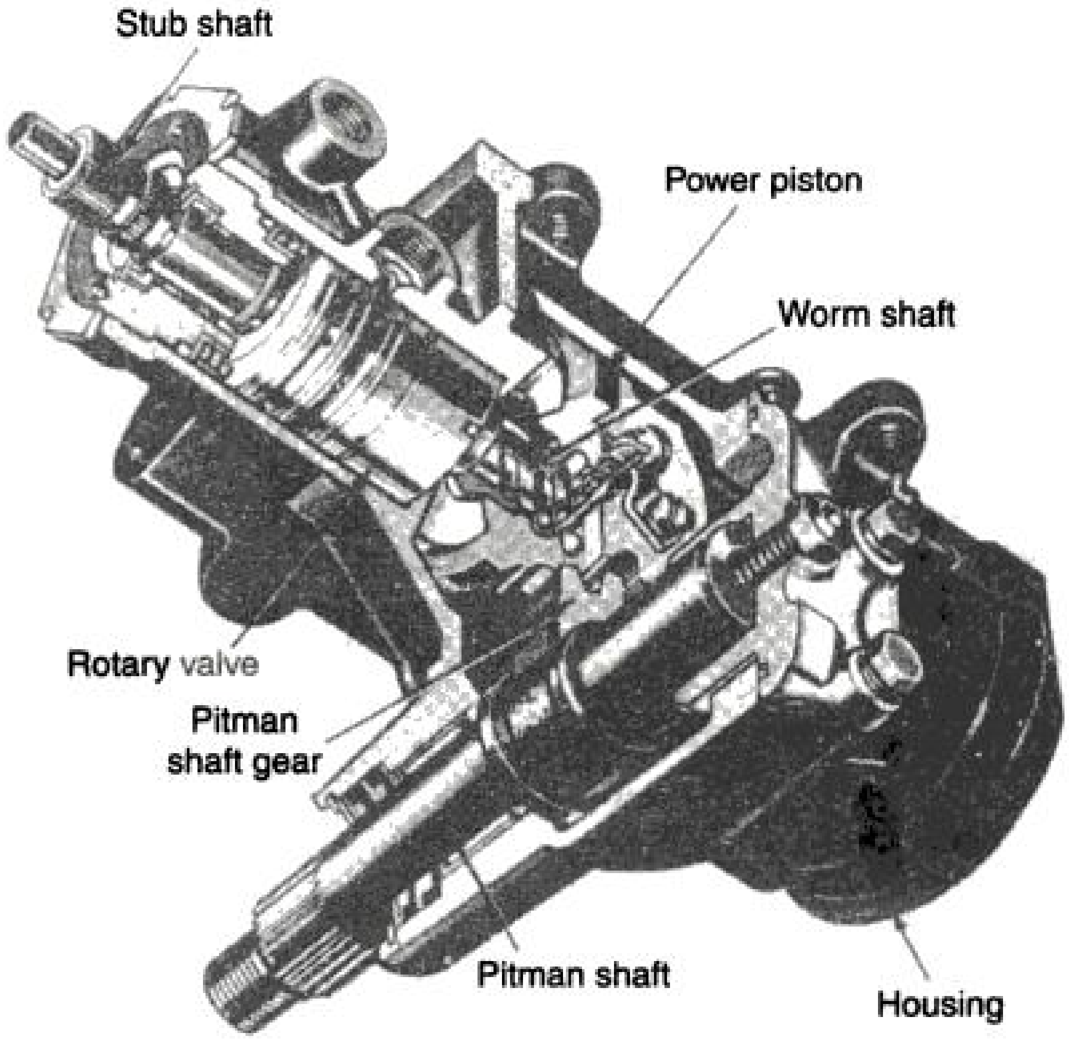

Fig. 8.24. Cut away rotary valve integral power steering gear.

2. **Linkage power steering :**

In this type of steering (Fig. 8.25) the *power system is attached between the frame of the vehicle and the steering linkage.* Usually it must be installed at the factory as the vehicle is built. The integral type is *more widely used.*

The *linkage type is widely used on trucks.*

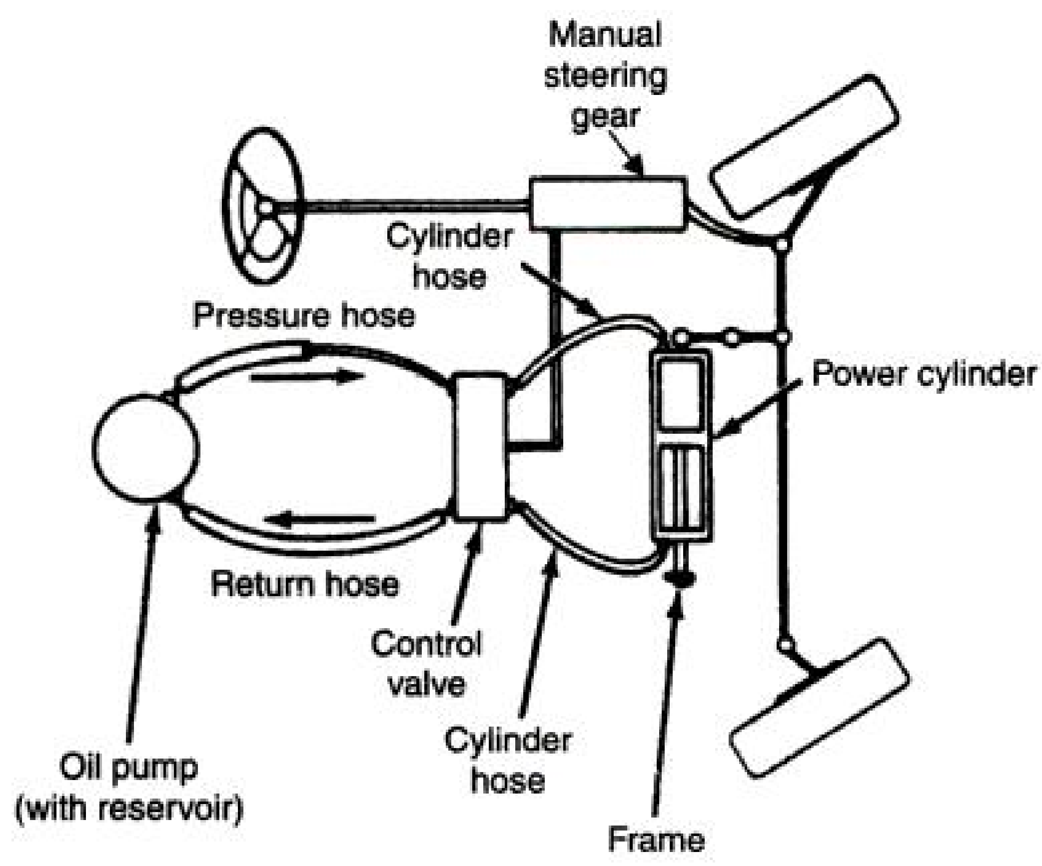

Fig. 8.25. Linkage power steering (simplified diagram)

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9

Braking System

9.1. INTRODUCTION TO BRAKING SYSTEM

This chapter deals with the construction and operation of the various types of braking systems used in automotive vehicles.

Brakes are one of the most important control components of the vehicle. They contribute very much in the running and control of the vehicle. On the efficiency of brakes depends the lives and comfort not only of driver and passengers but other persons moving on the road. Furthermore it is a fact that owing to recent improvements in the braking mechanism it has been possible to have increased speeds of the modern cars on the road.

The braking system used *most frequently operates hydraulically, by pressure applied through a liquid.* These are the foot-operated brakes that the driver normally uses to slow or stop the car. They are called the "*service brakes*". In addition all cars have a *parking-brake system* which is mechanically operated by a *separate foot or hand lever.* On some trucks and buses, the braking system is operated by air pressure (*pneumatically*). This type of brake is an *air brake*. Many boat and camping trailers have *electric brakes*.

- *All the braking systems depend upon friction between moving parts and stationary parts for their stopping force.*
- ***Braking efficiency** is the ratio between the retarding force (or force of friction between the linings and the drum) and the weight of the vehicle.* It is expressed as percentage.

9.2. NECESSITY OF A BRAKING SYSTEM

In an automobile, if the pressure from accelerator pedal is removed, the vehicle tends to slow up because of wind resistance, drag of engine and road friction. These forces, of course, would stop the vehicle but in the present day traffic, this would be quite unpracticable and dangerous. *The*

The *advantages* and *disadvantages* of *disc brakes compared with drum brakes* are as follows :

Advantages :

(*i*) Lighter than drum brakes.

(*ii*) Better cooling (since the braking surface is exposed directly to air).

(*iii*) Offer better resistance to fade.

(*iv*) Uniform pressure distribution (since disc brakes have no self-servo effect).

(*v*) Brake pads can be easily replaced.

(*vi*) These brakes are self adjusting by design.

Disadvantages :

(*i*) Costlier than drum brakes.

(*ii*) For stopping the vehicle higher pedal pressure is required.

(*iii*) There is no servo action in these brakes.

(*iv*) It is difficult to install an adequate parking attachment.

- The *major drawback of a "mechanical brake system" is that it is very difficult to get simultaneous brake action on all the four wheels. Also lengths of various rods and cables vary and this causes unequal braking action.*

9.7. HYDRAULIC BRAKES

9.7.1. Introduction

Brakes which are operated by means of hydraulic pressure are known as **hydraulic brakes.**

In a *hydraulic system*, when the brakes are applied, the pressure in increased sufficiently in the system to produce equal and uniform backing action on all the four wheels. The hydraulic brakes function on the principle of *Pascal's law* which reads as follows :

"Pressure applied to a liquid is transmitted equally in all directions."

9.7.2. Hydraulic Braking System

The hydraulic braking system consists of *four wheel cylinders*, one at each of the four wheels of the vehicle as shown in Fig. 9.4. The system also consists of one *master cylinder*, which is connected

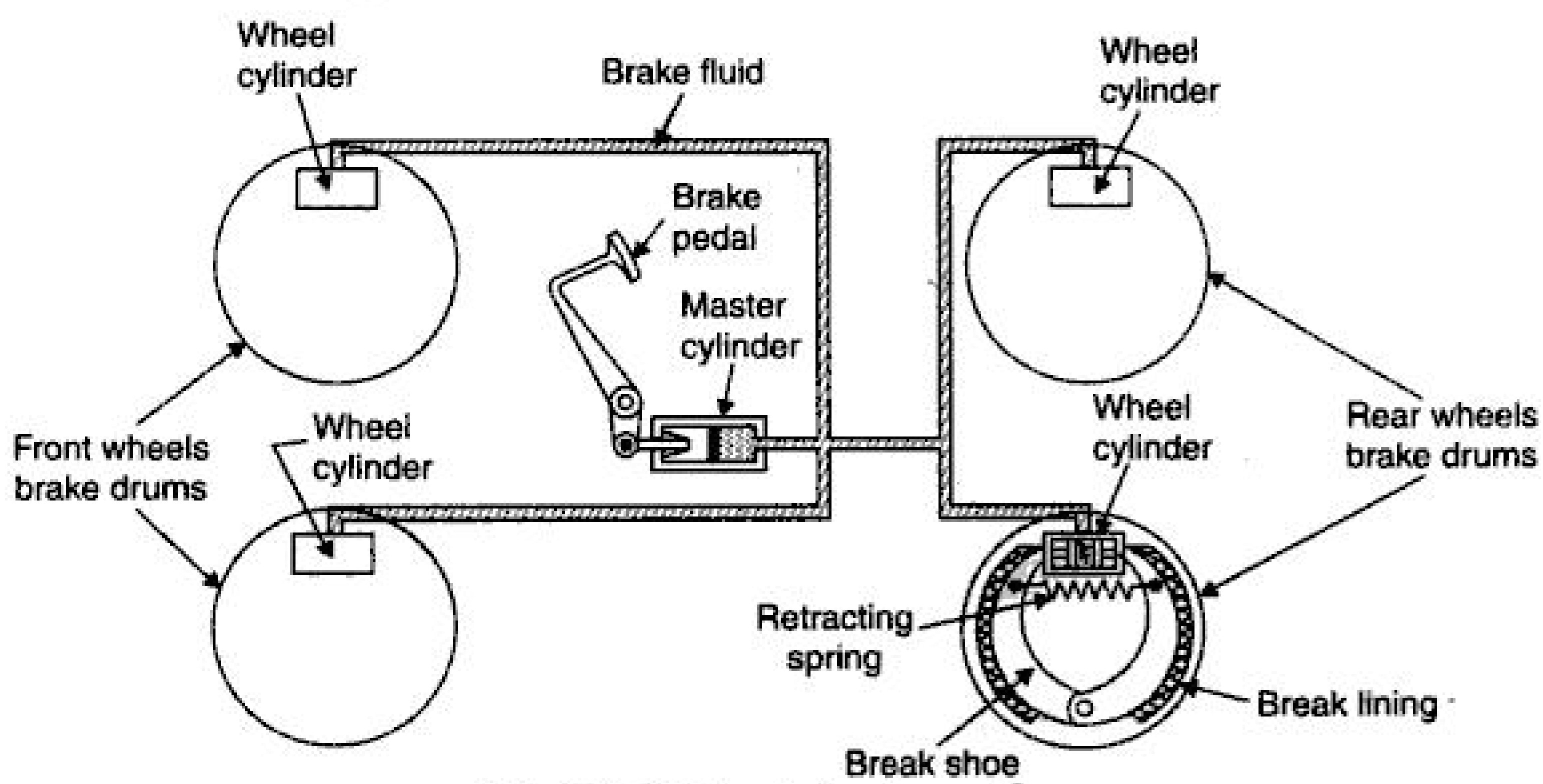

Fig. 9.4. Hydraulic brake system.

to the wheel cylinders by steel tubing. Each wheel cylinder contains *two pistons*, which will move out when the pressure will be applied through *brake fluid*. When the brakes are not in operation, the

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come closer, the liquid is forced into the master cylinder. The spring between the two pistons holds the rubber cups in position.

- The copper-coated, tin-plated annealed steel tubing and flexible hoses are used to connect the master cylinder to the wheel cylinders. The hoses are used to connect the lines to the front wheel cylinder to permit the front wheel to be turned. Rear wheel cylinders are generally connected directly to a line fastened to the rear axle housing. The brake lines are attached directly or by means of brackets to the frame or axle housings.

9.7.3. Advantages and Disadvantages of Hydraulic Brakes

Advantages :

1. Equal braking effort to all the four wheels (since fluid exerts equal pressure every where in the circuit).

2. The system is simple in construction.

3. Less rate of wear (due to absence of joints compared to mechanical brakes).

4. The system is mostly self-lubricating.

5. Increased braking effort.

6. High mechanical advantage.

7. Flexibility in brake lines.

8. The hydraulic brakes can also provide differential braking action between the front and rear brakes by using the wheel cylinder of different size for the front and rear wheels.

Disadvantages :

1. Even slight leakage of air into the braking system makes it useless.

2. The brake shoes are liable to get ruined if the brake fluid leaks out.

3. This system is suitable only for applying brakes *intermittently*. For parking purpose separate mechanical linkage has to be employed.

9.7.4. Hydraulic Brake Fluid

The fluid used in the braking system is a special kind of fluid which has to be satisfactory under all conditions. Most fluids are based on *polyglycols* and *additives are added* to achieve the required properties. A 50 percent solution of caster oil in alcohol to which a neutraliser is added, meets the above mentioned requirements satisfactorily. The neutraliser is added to counter act the effect of any free acids which may be present in caster oil or alcohol.

The hydraulic brake fluid should possess the following ***characteristics :***

1. Should be non-compressible.

2. Must remain fluid at low temperature.

3. Should not rust corrode or rust metallic parts in the brake system.

4. Mix satisfactorily with other makes of hydraulic fluids.

5. Must be chemically stable.

6. Should not soften the rubber parts used in the hydraulic brake system.

7. Must act as a lubricant to the moving parts inside the system.

8. Must retain all its characteristics for a maximum long period.

9.7.5. Bleeding of Hydraulic Brakes

The *process of eliminating or removing air out of the braking system of an automobile is called* **"bleeding"**.

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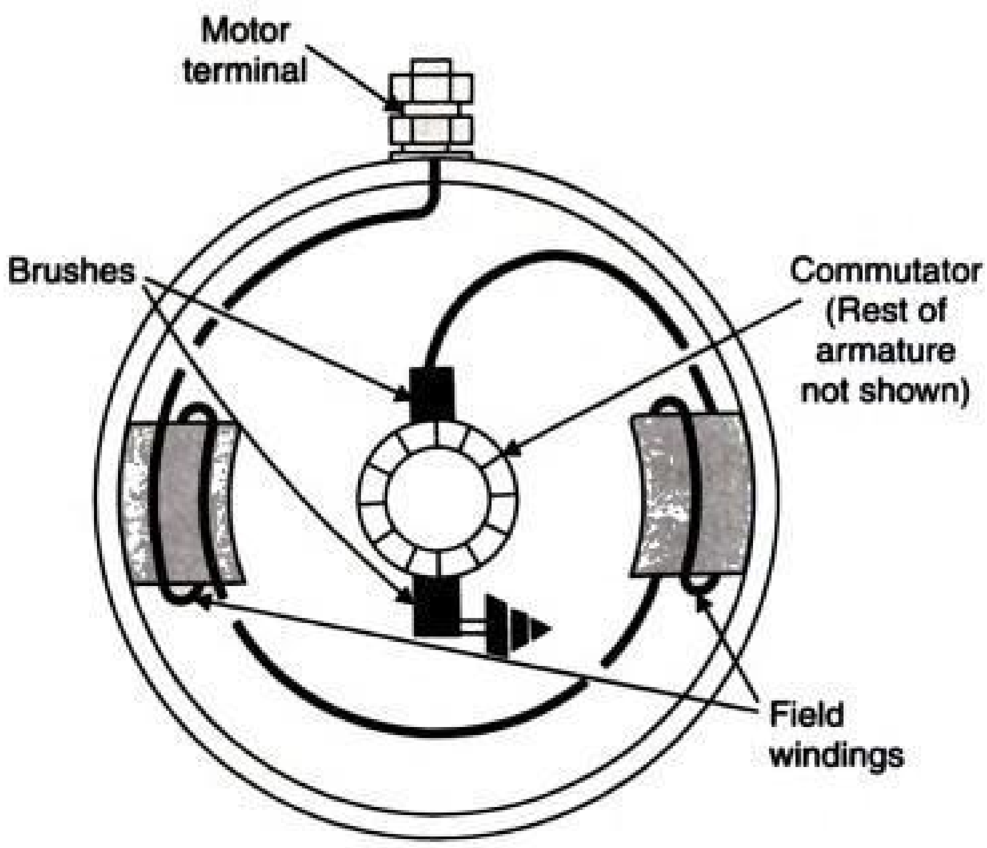
connected to the commutator in such a way so that the current from the brushes may flow through all the coils at one time. This creates a magnetic field around each conductor due to which a repulsive force is produced all around the armature and the armature is rotated.

Fig. 10.15 shows the armature and field frame assembly.

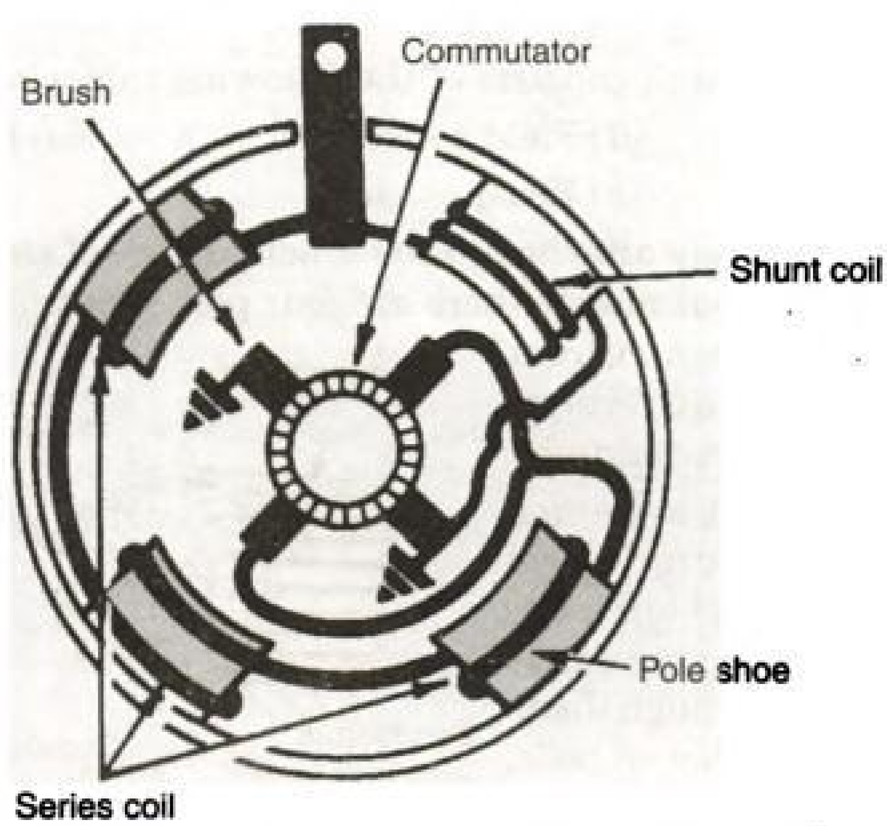
Field coil windings are also of heavy flat copper wire to carry heavy current. The coils on adjacent pole shoes are wound in apposite directions giving their respective pole shoes a north and south magnetic polarity. The starter housing acts as a return circuit for the magnetic lines of force. The field coils are connected together in *series with the armature*. One end is connected with starter terminal and other to the insulated bushes. In case the starter is having four brushes, two opposite brushes are insulated from the end frame and are connected with the field coils. The other two are earthed to the end frame through the commutator and armature conductors.

Fig. 10.16 (*i*) shows wiring diagram for a *two-pole series-wound* starting motor.

Fig. 10.16 (*ii*) shows wiring diagram for a *four-pole series-shunt* or *compound*, starting motor.



(*i*) Two-pole series wound starting motor.



(*ii*) Four-pole series-shunt, or compound starting motor.

Fig. 10.16. Electric circuits in starting/cranking motor.

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engine through a belt pulley or sprocket and chain. It replaces in the battery the current used in starting the engine and also supplies current for operation of electrical devices such as ignition system, lights, radio etc.

- The automobile generator is a low voltage generator producing *direct current only* because the use of battery requires direct current.
- *Shunt wound type of "D.C. generator or dynamo"* is the one that has been used for automotive purposes till recently when it has given way to the **A.C. generator** or **Alternator** *whose output is rectified by in-built semiconductor rectifier diodes.*

In modern cars, the charging system consists of an alternator only.

10.6.2. Working Principle of D.C. Generator or Dynamo

The automobile generator or dynamo works on the following principle :

"When a conductor is moved in a magnetic field, a current is produced, the direction of which is determined by Fleming's right-hand rule".

The amount of current induced in a conductor depends upon the strength of magnetic field, the number of turns, cutting the field and speed with which they pass through the field.

Fig. 10.22 shows the principle of the dynamo.

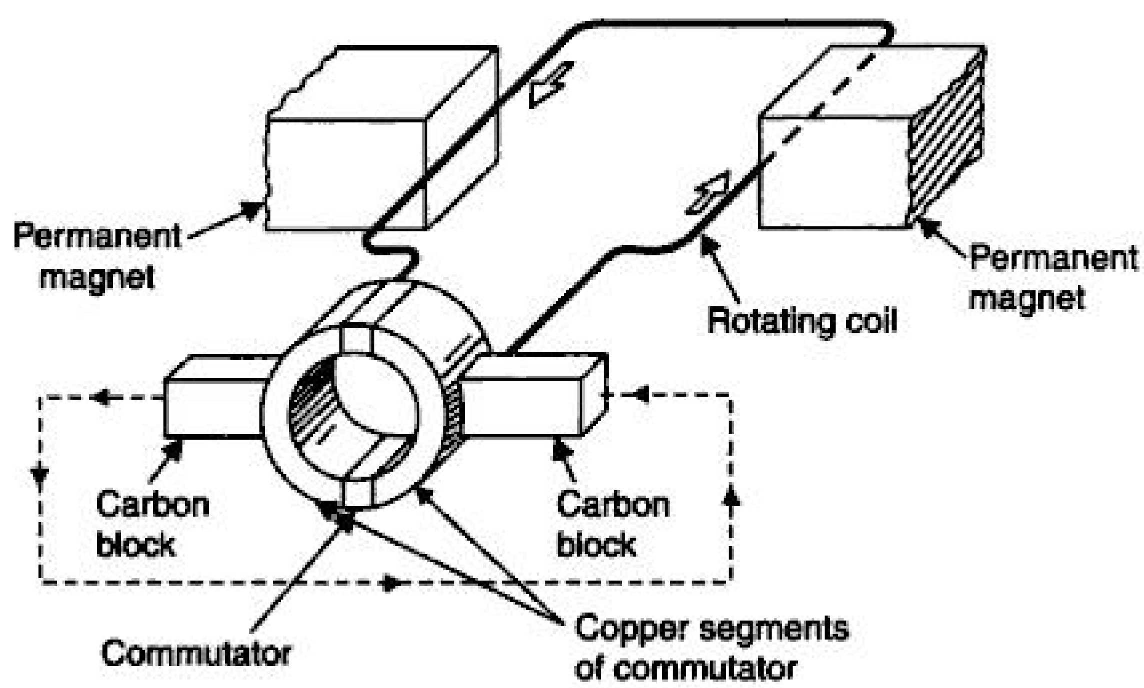

Fig. 10.22. Principle of a D.C. generator or dynamo.

Let the coil is rotated by half a revolution. Then the current will flow in the direction as shown in the figure. This current is in contact with the copper segments of the commutator. These segments come into contact with the carbon brushes, which are connected by an external circuit. Therefore the generated current is completed as shown in the figure. When the *coil is changed by another half revolution, the direction of flow of the current changes. But the contact of the commutator and brushes allows the current in the external circuit to flow in the same direction.* This principle is adopted in the dynamo system.

The permanent magnets in the dynamo are *replaced by electromagnets,* which provide the necessary magnetic field for generating current in the coils.

Parts of a dynamo :

The *main parts of a dynamo* are shown in Fig. 10.23 and are as under :

1. Armature
2. Field windings/coils
3. Frame
4. Brushes and brush gear.

Fig. 10.29. Stator of an alternator.

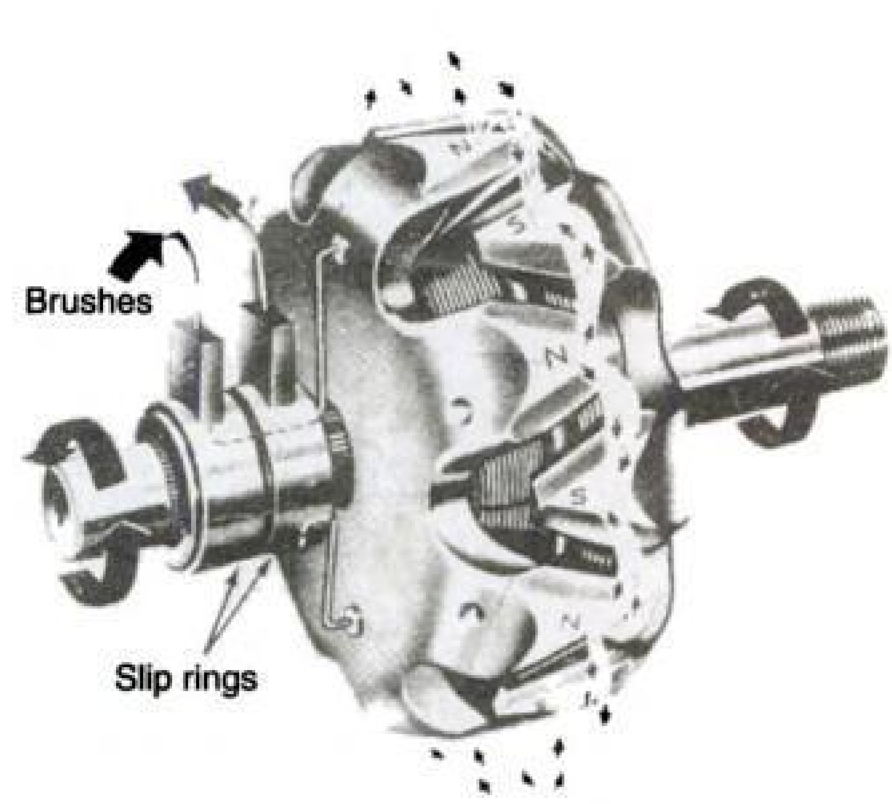

Fig. 10.30. Rotor of an alternator.

– The '*housing*' is usually made of two pieces of die cast aluminium (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 '*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.

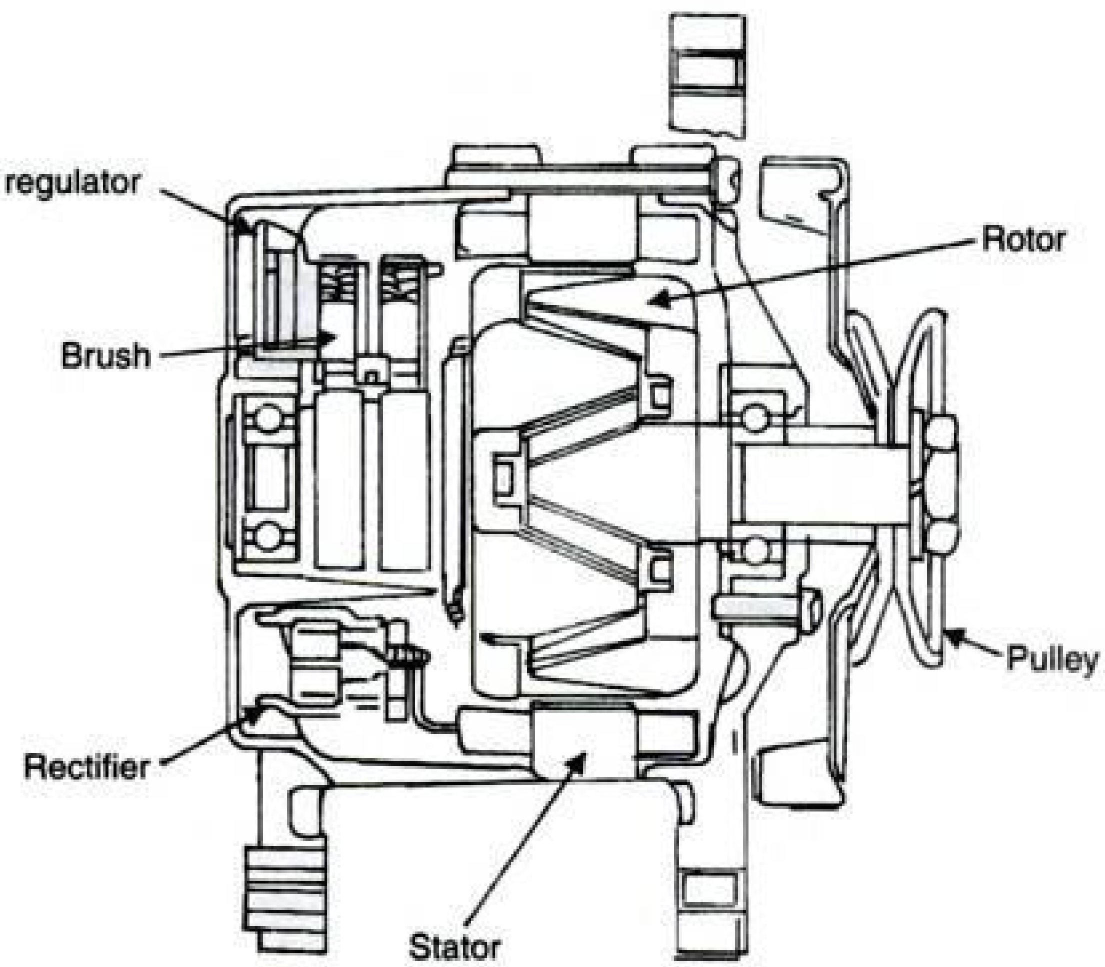

Fig. 10.31. Alternator.

– The '*rectifiers*' (*diodes*) are pressed in the slip end ring head or heat sinks (rectifier mounting plates) and are connected to the stator leads. The heat sink takes heat from the diodes,

- A small cam, with a lobe for each time the breaker is required to open per revolution, revolves and pushes the movable breaker arm so that the contact points are separated. In this way, the current in the primary winding of the coil is interupted every time a spark is required in one of the cylinders.
- The usual circuit breaker used on modern vehicles is the closed-circuit type (Fig. 10.39). The contact points normally remain in the closed position, *being separated only when the breaker arm is lifted by a lobe of the breaker arm*. The closed circuit type is more adaptable to high speed engines because the points are in contact long enough to allow complete magnetisation of high tension coil. This results in especially good sparks at slow starting speeds, with less intense sparks at higher speeds when the time of the contact is shortened.

4. **The distributor :**

- In order for the coil to produce a high voltage from a low voltage supply the flow of electricity must be interrupted (switched off and on). The distributor contains the contact breaker and a cam, which is of rotary switch, that interrupts the supply. The *distributor cap* has a centre terminal which connects with the high tension terminal of the induction coil, and as many terminals equally spaced around it as there are spark plugs to fire. The cap is usually moulded of a highly resistant insulating material, such as bakelite which is moisture proof and possesses high insulating properties even under excessive heat. The terminals are of brass or metal alloy moulded in position, terminating on the underside either in the form of a button flush with the surface or in the form of a pin. The distributor head is usually held in place by two spring clips which snap on only when the head is in its proper position. Thus the head can be easily removed to inspect and adjust the rotor and breaker mechanism with no chance of replacing it incorrectly. The *rotor* or *distributor arm* is mounted on the upper end of the distributor shaft, on which the breaker cam is also located. The inside end of rotor makes contact with the centre terminal of the head, while the outside end in its rotation completes the circuit successively with the terminals leading to the spark plugs.
- The distributor may be considered as a revolving switch located in the secondary circuit, which connects the high-tension wire from coil to the proper spark plug at proper time.
- The distributor rotor must be well insulated to prevent grounding of the high-tension current, consequently it is usually moulded from an insulating material similar to that used in the distributor cap.
- It is designed to fit over the end of the liner shaft in one position only, to prevent its installation in a position which would throw it out of time with the breaker.
- The distributor may be of gap type or contact type ; classified according to the method used in completing the circuit between the rotor and the distributor head terminals.

5. **The condenser :**

- When the primary circuit is broken the current tends to continue flowing and a spark jumps across the separated contact breaker points. This effect is characteristic of an inductive circuit and is undesirable for the following *reasons* :

  (*i*) *It causes arcing, burning of the contact breaker points.*

  (*ii*) *The effectiveness of the coil is reduced since a sudden interruption of the circuit is essential to produce a high voltage.*

- The condenser absorbs and stores this inductive flow of current and causes the current in the coil to die away rapidly which increases the voltage in the secondary coil.
- A condenser is constructed strips of sheets of tin foil insulated by thin sheets of paraffined paper or mica. The alternate layers of tin foil are connected in parallel, forming two

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- When ignition occurs early in the compression stroke, the engine is said to be *advanced*. A *retarded ignition takes place when the piston is just near the compression stroke.*

– If the ignition is **advanced to much**, it will be complete before the end of the compression stroke. Under these conditions, the crankshaft and connecting rod will have to push the piston upward compressing the gases. In such a case the force might not be sufficient to overcome the pressure and the *engine would stop or stall.*

– If the ignition is **retarded too much**, the combustion of fuel will continue, during the power stroke of the piston (working stroke) and the *maximum pressure will not be developed and less work will be obtained from heat energy. Under these conditions comparatively more exhaust gases will be going out of the engine cylinder overheating the exhaust valve.*

Spark Advance Mechanisms :

It is of significance importance that the point in the cycle where the spark occurs must be regulated *automatically to ensure maximum power and economy at different loads and speeds.* Most of the engines are fitted with a mechanism which is integral with the distributor and automatically regulates the optimum spark advance to account for change of load and speed.

There are two general methods used in modern engines to advance and retard the ignition timing automatically in relation to engine speed and operating condition after initial timing is set manually, most manufacturers call these methods as "*Automatic advance mechanisms*".

1. Centrifugal spark advance mechanism.
2. Vacuum spark advance mechanism.

1. **Centrifugal spark advance mechanism :**

- The centrifugal spark advance is essential to compensate for the increase in speed of the engine.
- This mechanism consists of *two flyweights (advance weights), cam, spring,* and *base plate* (Fig. 10.43). The flyweights are carried by the distributor drive shaft through the base plate which is fixed to the drive shaft. The flyweights are pivoted on the base plate, and attached to the cam through springs. The cam is connected with the distributor drive shaft through the springs, flywheel and base plate.

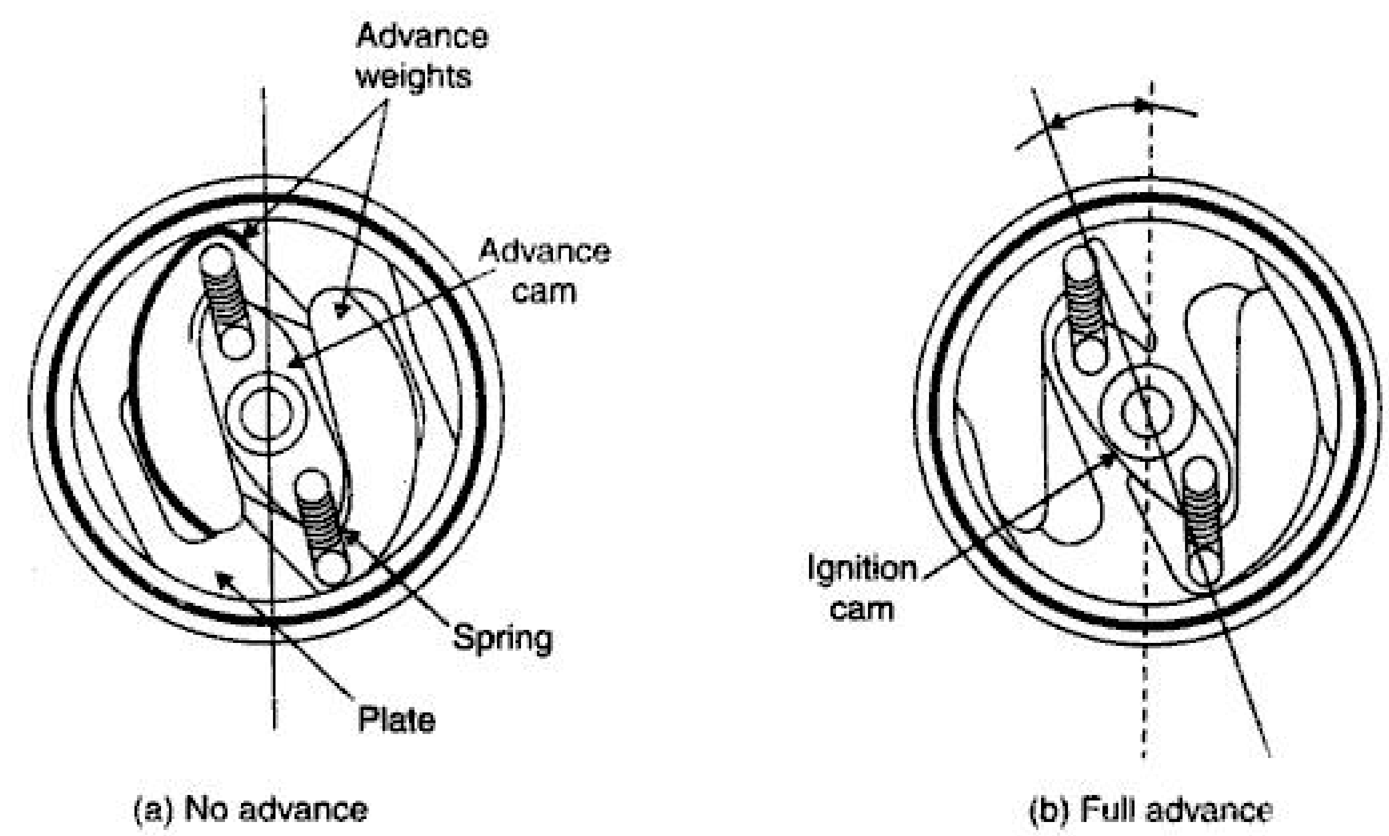

Fig. 10.43. Centrifugal spark advance mechanism.

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– When the water in the engine gets heated up, the plug being in direct contact with engine water also gets heated up. The bimetallic strip gets straightened and point attached to it open and close with the result less current can flow through it. This current is read through the gauge which is calibrated to show temperature.

6. **Speedometer and odometer :**

The mechanical speedometer and odometer are not electrical devices. However they are mounted on the car instrument panel, alongwith the other instruments :

– The "*speedometer*" tells the driver *how fast the car is running*.

– The "*odometer*" tells the driver the *distance the car has travelled.*

Fig. 10.72 shows the *working principle of a speedometer.*

There is a small magnet mounted on a shaft inside the speedometer. This magnet is driven by a flexible cable from the transmission. The faster the car goes, the faster the magnet *spring*. This action produces a rotating magnetic field that *drags* on the metal ring surrounding the magnet (the metal ring does not have any mechanical connection with the magnet). The faster the spinning, the more drag on the ring. The spinning causes the ring to swing around against the tension of a hair spring. This is turn, moves a pointer attached to the ring, which indicates car speed. The hair spring also serves to bring the pointer to zero and keep it there when the vehicle is brought to rest.

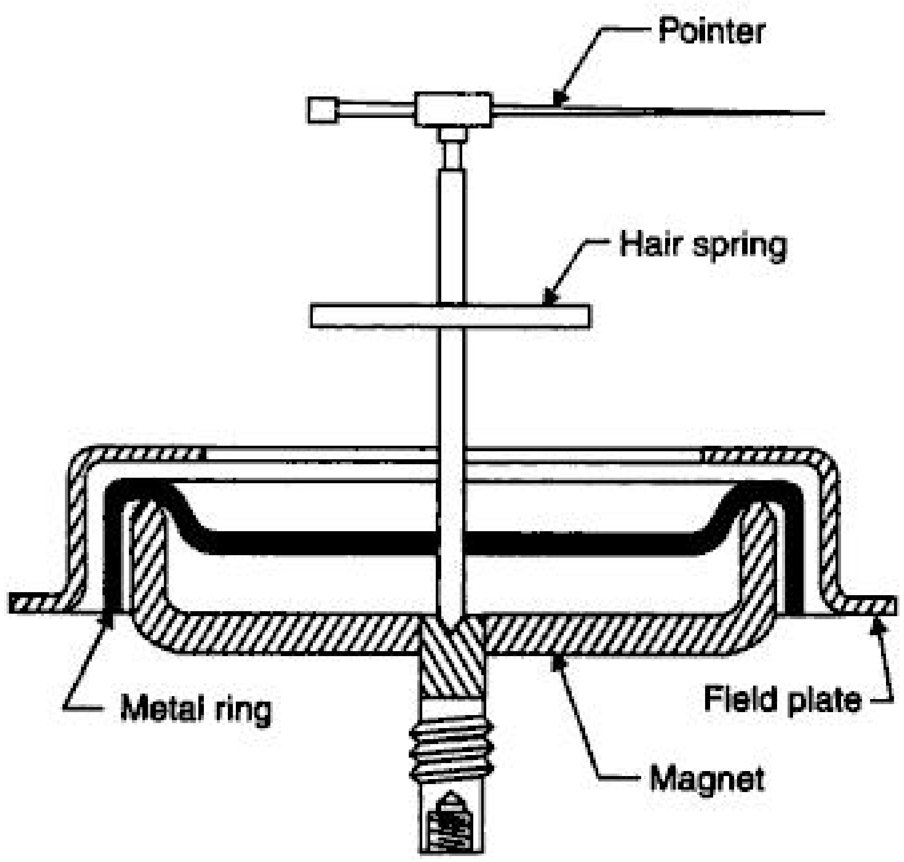

Fig. 10.72. Working principle of speedometer.

The **odometer** *is operated by a pair of gears from the same rotating flexible cable that drives the speedometer.* The motion is carried through the gears to the mileage/km rings on the odometer indicator. These rings turn to show how many miles/km the car has been driven.

The cable is usually driven from a pair of gears in the rear extension housing of the transmission. One of the these gears is the main shaft of the transmission. The other is on the end of the flexible cable.

The *speedometer and odometer assembly* is shown in Fig. 10.73.

		(*iii*) Restriction in condenser or receiver liquid indicator. (*iv*) Condenser air flow blocked. (*v*) Evaporator pressure too high.	stop depressurizing and recheck operational pressures. If pressures are satisfactory, depressurize until bubbles appear. Then add one-half pound refrigerant. Recheck operational pressures. ● 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.* (*iii*) Remove parts, inspect, and clean or replace. (*iv*) Clean condenser and radiator core surfaces as well as the space between the condenser and radiator. See 5. Evaporator pressure too high.
3.	*Compressor discharge pressure too low.*	(*i*) Insufficient refrigerant. (*ii*) Low suction pressure. (*iii*) Defective compressor and/or broken compressor reed valves.	(*i*) 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 1/2 lb. (*ii*) See 4. Evaporator pressure too low. (*iii*) Repair compressor.
4.	*Evaporator pressure too low.*	(*i*) Valve capillary tube broken, inlet screen plugged, or valve otherwise failed. (*ii*) Restriction in system tubes or hoses. (*iii*) Suction throttle valve adjusted improperly or defective.	(*i*) Replace valve or clean inlet screen of valve. (*ii*) Replace kinked tube or restricted hose. (*iii*) Check operation of suction throttle valve. Repair if necessary.

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Q. 73. What are the major components included in automobile air-conditioning ?

Ans. Compressor, condenser, receiver-driver-thermostatic expansion valve and evaporator.

Q. 74. What refrigerant is used in an automobile air-conditioner ?

Ans. R-12.

Q. 75. What is a thermostatic expansion valve ?

Ans. It is a metering device which removes pressure from the liquid refrigerant so that it can expand and become refrigerant gas in the evaporator.

Q. 76. What is the function of evaporator ?

Ans. It absorbs heat from the passenger compartment.

Q. 77. What is purpose of the receiver-drier in automobile air-conditioning ?

Ans. It is a storage tank for liquid refrigerant. It also removes the foreign particles and moisture from the circulating refrigerant.

Q. 78. What is meant by "purging" the automobile air-conditioning ?

Ans. Purging is the process of discharging by releasing the refrigerant from the heigh and low sides of the system until no pressure exists.

HIGHLIGHTS

Battery

1. The major components of the electrical system are :
   (*i*) Starting system (*ii*) Charging system
   (*iii*) Ignition system (*iv*) Accessory system.
2. The battery is an electrochemical device.
3. The batteries are of the following types :
   (*i*) Lead acid battery (*ii*) Alkaline battery
   (*a*) Nickle-iron type (*b*) Nickle-cadmium type
   (*iii*) Zinc-air battery.
4. The *capacity* of a battery is given in terms of *ampere-hours* on discharge.
5. The *efficiency* of a battery is defined as, "The ratio of the output of a cell or a battery to the input required to restore the initial state of charge under specified conditions of temperature, current rate and final voltage."
6. The storage batteries are rated in the following ways :
   (*i*) 20-hour rating. (*ii*) 25-ampere rating.
   (*iii*) Cold-cranking rate.
7. The batteries can be *charged* by the following three methods :
   (*i*) Constant current charging. (*ii*) Constant voltage or potential charging
   (*iii*) Quick charging.
8. *Factors affecting battery life :*
   (*i*) Overcharging (*ii*) Undercharging
   (*iii*) Lack of water (*iv*) Loose hold-downs
   (*v*) Excessive loads (*vi*) Freezing of electrolyte.
9. *Battery faults/troubles :*
   (*i*) Rapid loss of electrolyte (*ii*) Sulphate plates
   (*iii*) Internal short-circuit (*iv*) Open circuit
   (*v*) Reversed polarity (*vi*) Cracked container or jar
   (*vii*) Deterioration of plates of the cells (*viii*) Mechanical faults.

Ignition system

38. A spark plug may be fouled by
(*a*) petrol (*b*) oil
(*c*) lead (*d*) all of the above.

39. Spark plug having white insulator tip indicates
(*a*) overadvanced ignition (*b*) retarded ignition
(*c*) leaded fuel (*d*) gas leak.

40. A spark plug with a black centre insulator indicates
(*a*) over advanced ignition (*b*) retarded ignition
(*c*) stuck-up choke valve in the carburettor (*d*) excessive dwell.

41. The primary winding of ignition coil consists of
(*a*) a few turns of thin wire (*b*) many turns of thin wire
(*c*) a few turns of thick wire (*d*) many turns of thick wire.

42. Contact breaker points are generally made of
(*a*) plastic (*b*) steel
(*c*) copper (*d*) tungsten.

43. The 'dwell' is
(*a*) the time for which the points remain closed (*b*) the distance between the cam lobes
(*c*) the angle at which the heat contacts the cam (*d*) none of the above.

44. The capacity of an automotive engine condenser is approximately
(*a*) 0.2 microfarads (*b*) 2 microfarads
(*c*) 20 microfarads (*d*) 2 millifarads.

45. The ratio of the distributor shaft and the crankshaft speeds is
(*a*) one (*b*) one-half
(*c*) one-fourth (*d*) two.

46. The centrifugal advance mechanism provides ignition advance proportional to
(*a*) engine load (*b*) engine speed
(*c*) both (*a*) and (*b*) (*d*) none of the above.

47. Excessive contact breaker gap results in
(*a*) advanced timing (*b*) increased dwell
(*c*) rapid burning of points (*d*) all of the above.

48. The spark occurs when the
(*a*) points close (*b*) points open
(*c*) ignition switch is on (*d*) none of the above.

49. Contact breaker points are opened by the cam and closed by the
(*a*) same cam (*b*) centrifugal force
(*c*) magnetic force (*d*) spring tension.

50. Vacuum advance mechanism operates at
(*a*) light engine load (*b*) heavy engine load
(*c*) high engine speed (*d*) any of the above.

51. Ignition timing can be adjusted by an
(*a*) accurate clock (*b*) stop watch
(*c*) stroboscopic light (*d*) vacuum gauge.

52. The commonly used material for insulator of spark plug is
(*a*) bakelite (*b*) asbestos
(*c*) alumina (*d*) copper.

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Solution. Refer Fig. 12.3.

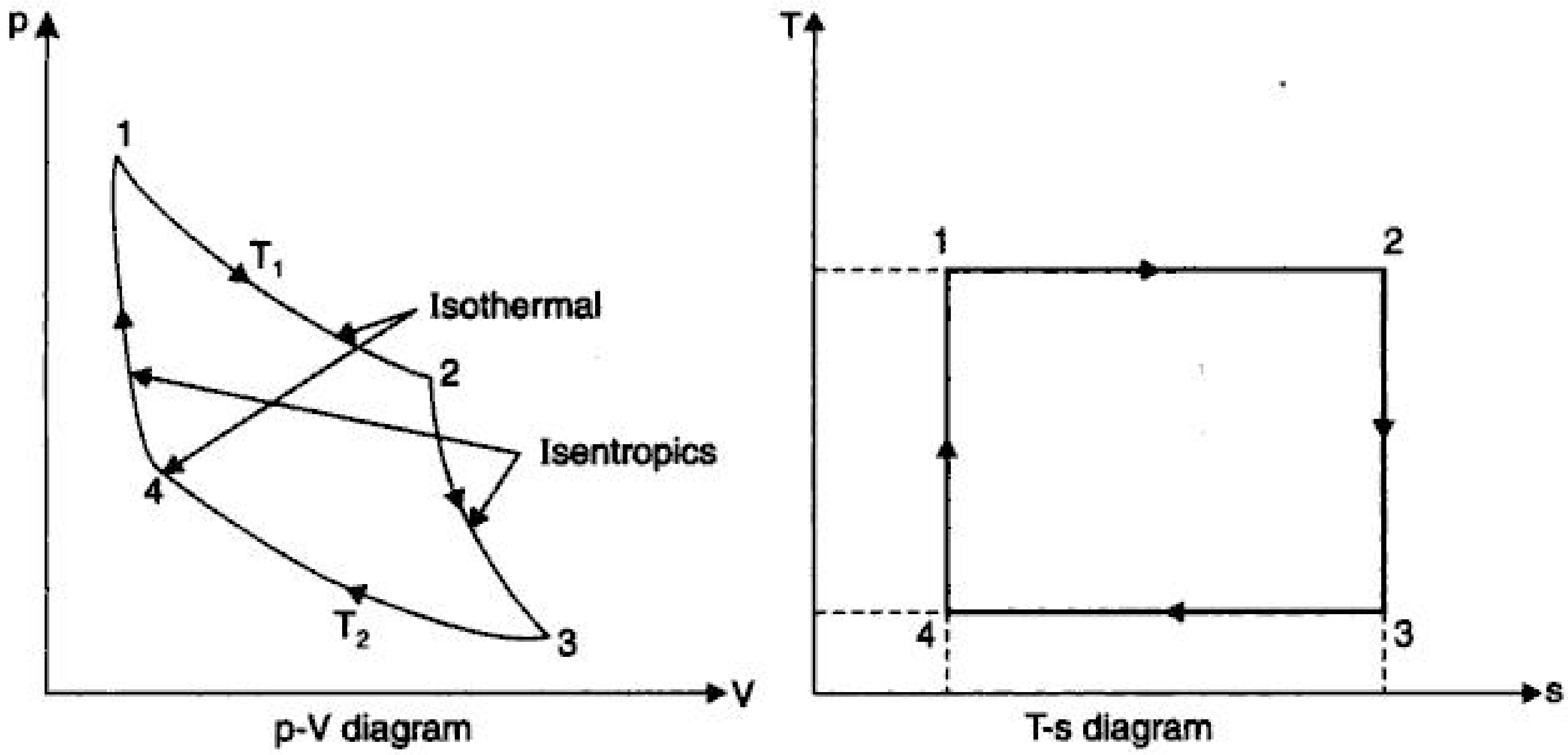

Fig. 12.3. Carnot cycle.

Given : $m = 0.5$ kg ; $\eta_{th} = 50\%$; Heat transferred during isothermal expansion = 40 kJ ;
$p_1 = 7$ bar, $V_1 = 0.12$ m^3 ; $c_v = 0.721$ kJ/kg K ; $c_p = 1.008$ kJ/kg K.

(*i*) **The maximum and minimum temperatures, T_1, T_2 :**

$$p_1V_1 = mRT_1$$

$$7 \times 10^5 \times 0.12 = 0.5 \times 287 \times T_1$$

$\therefore$ Maximum temperature, $\mathbf{T_1} = \dfrac{7 \times 10^5 \times 0.12}{0.5 \times 287} = \mathbf{585.4\ K.}$ **(Ans.)**

$$\eta_{cycle} = \frac{T_1 - T_2}{T_1}, \quad \text{or,} \quad 0.5 = \frac{585.4 - T_2}{585.4}$$

$\therefore$ Minimum temperature, $\mathbf{T_2} = 585.4 - 0.5 \times 585.4 = \mathbf{292.7\ K.}$ **(Ans.)**

(*ii*) **The volume at the end of isothermal expansion, V_2 :**

Heat transferred during isothermal expansion

$$= p_1V_1 \ln (r) = mRT_1 \ln \left(\frac{V_2}{V_1}\right) = 40 \times 10^3 \qquad \text{...(Given)}$$

or,
$$0.5 \times 287 \times 585.4 \ln \left(\frac{V_2}{0.12}\right) = 40 \times 10^3$$

or,
$$\ln \left(\frac{V_2}{0.12}\right) = \frac{40 \times 10^3}{0.5 \times 287 \times 585.4} = 0.476$$

or,
$$\mathbf{V_2} = 0.12 \times (e)^{0.476} = \mathbf{0.193\ m^3}. \quad \textbf{(Ans.)}$$

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1 on the T-s diagram. As is evident from the eqn. (12.13) the cycle which has the least heat rejected will have the highest efficiency. Thus, otto cycle is the most efficient and diesel cycle is the least efficient of the three cycles.

i.e., $$\eta_{otto} > \eta_{dual} > \eta_{diesel}.$$

12.1.7.3. For constant maximum pressure and heat supplied

Fig. 12.13 shows the otto and diesel cycles on *p-v* and *T-s* diagrams for constant maximum pressure and heat input respectively.

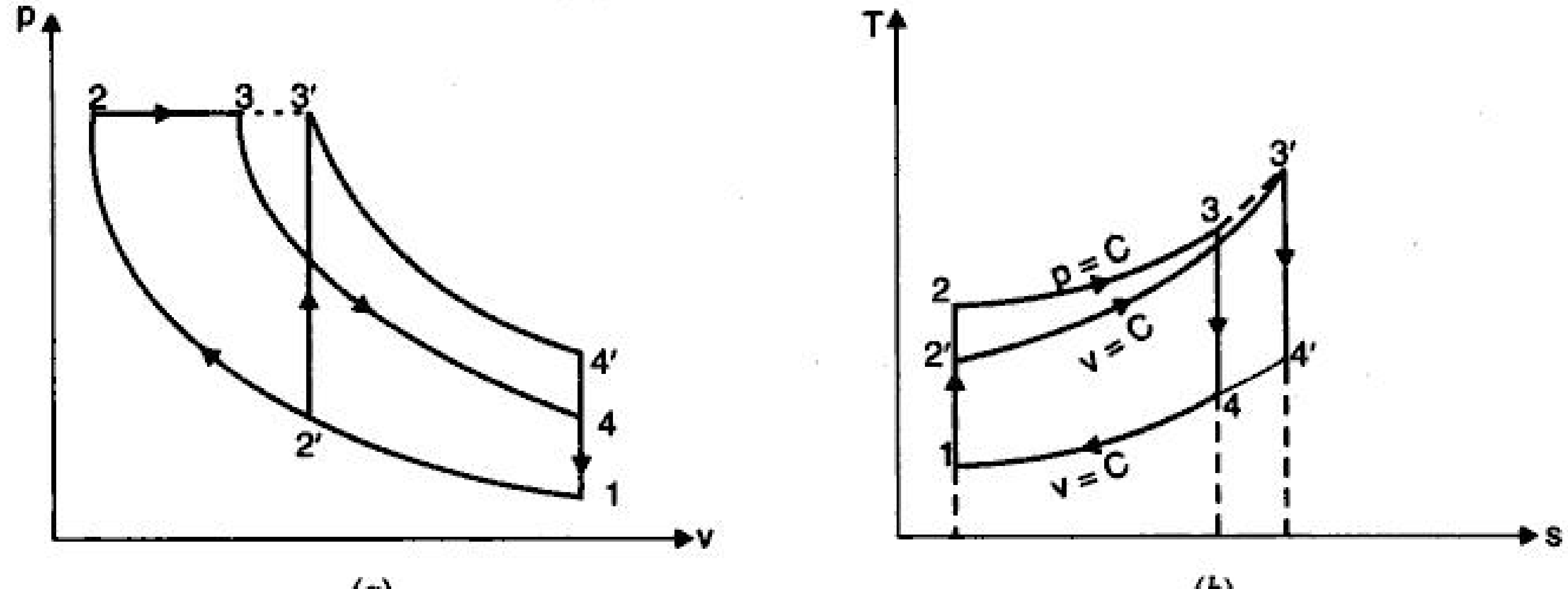

Fig. 12.13. (*a*) *p-v* diagram, (*b*) *T-s* diagram.

– For the maximum pressure the points 3 and 3′ must lie on a constant pressure line.
– On *T-s* diagram the heat rejected from the diesel cycle is represented by the area under the line 4 to 1 and this area is less than the otto cycle area under the curve 4′ to 1 ; hence the *diesel cycle is more efficient than the otto cycle for the condition of maximum pressure and heat supplied.*

Example 12.10. *With the help of p-v and T-s diagrams compare the cold air standard otto, diesel and dual combustion cycles for same maximum pressure and maximum temperature.*

Solution. Refer to Fig. 12.14 (*a, b*).

The air-standard otto, dual and diesel cycles are drawn on common *p-v* and *T-s* diagrams for the same maximum pressure and maximum temperature, for the purpose of comparison.

otto 1-2-3-4-1, dual 1-2′-3′-3-4-1, diesel 1-2″-3-4-1 (Fig. 12.14 (*a*)).

Slope of constant volume lines on *T-s* diagram is higher than that of constant pressure lines. [Fig. 12.14 (*b*)].

Here the otto cycle must be limited to a low compression ratio (*r*) to fulfill the condition that point 3 (same maximum pressure and temperature) is to be a common state for all the three cycles.

The construction of cycles on *T-s* diagram proves that for the given conditions the heat rejected is same for all the three cycles (area under process line 4-1). Since, by definition,

$$\eta = 1 - \frac{\text{Heat rejected, } Q_R}{\text{Heat supplied, } Q_S} = 1 - \frac{\text{Const.}}{Q_s}$$

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– Lightweight aluminium transforms this delightful hatchback, capable of returning a fuel average in the high twenties per litre or even more.
– The powerful and efficient 1500 cc diesel unit is renowned Peugeot design and returns excellent fuel consumption figures.

- **Cheap to run :**

– The car's price tag may seem a bit exaggerated but given its ability to return excellent fuel averages, be it petrol or diesel, it is cheap to run.
– The engine and other mechanicals are reliable with regular service.

- **Good build quality :**

– The Zen is a new generation design and a result of modern engineering, which makes cars very reliable.
– The body is a monocoque construction, uses thinner gauge metal but exhibits good resistance to corrosion, thereby ensuring long life.

- **Ease of service :**

– On the road from 1994, the Zen is a familiar car to deal with. Spares are available at reasonable cost and almost anywhere.
– A MPFI system model is instrumental in elevating its appeal even more while equipping it to tackle emission norms.

- **Resale value :**

– The Zen commands a good resale value, due to its reliability, efficiency and light controls.

Technical Specifications :

	Petrol	**Diesel**
Engine :	Four-cylinder, in-line	Four-cylinder, in-line
Displacement :	993 cc	1527 cc
Maximum power :	50 bhp @ 6500 rpm	57 bhp @ 5000 rpm
Maximum torque :	7.2 kgm @ 4500 rpm	9.69 kgm @ 2250 rpm
Transmission :	Five-speed manual	Five-speed manual
Length :	3495 mm	3495 mm
Width :	1495 mm	1495 mm
Wheelbase :	2335 mm	2335 mm
Weight :	730 kg	830 kg

3. **Maruti-"Esteem" :**

- **Efficient engine :**

– The engine is punchy, catapulating the car ahead with the lightest touch of foot on pedal.
– The all-aluminium unit of 1200 cc displacement with its hollow camshaft is very light and extremely responsive.

- Its free-rewing character makes it a very refined unit giving the car phenomenal acceleration.

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ADDITIONAL OBJECTIVE TYPE QUESTIONS' BANK

A. Choose the Correct Answer.

B. Match List I with List II.

C. Competitive Examinations Questions (With Solutions-Comments).

D. Fill in the Blanks.

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267. Due to which of the following, the tendency of a diesel engine to knock increases ?
(*a*) Increase in engine speed (*b*) Increase in compression ratio
(*c*) Increase in octane value of fuel (*d*) Increase in engine power.

268. The part load efficiency of a carburettor is
(*a*) constant (*b*) maximum (*c*) optimum (*d*) poor.

269. ... can work on very lean mixture.
(*a*) C.I. engine (*b*) S.I. engine
(*c*) Two stroke engine (*d*) Four stroke engine.

270. Thermal efficiency of I.C. engine on weak mixture is
(*a*) lower (*b*) higher (*c*) unaffected (*d*) unpredictable.

271. Cetane number is the measure of
(*a*) viscosity of fuel (*b*) ignition quality
(*c*) calorific value of fuel (*d*) auto-ignition temperature.

272. In a S.I. engine an ignition coil performs which of the following functions ?
(*a*) Regulates battery voltage (*b*) Avoids sparking
(*c*) Controls spark (*d*) Supplies high voltage to the spark plug.

273. ... does not assist in getting higher output from diesel engine.
(*a*) High fuel air ratio (*b*) High compression ratio
(*c*) High excess air (*d*) Fine atomisation of fuel.

274. Which of the following factors does not promote detonation in S.I. engines ?
(*a*) High self ignition temperature of fuel
(*b*) Increase in inlet pressure and temperature of charge
(*c*) Higher compression ratio (*d*) Advanced spark timing.

275. Which of the following statements is correct ? The phenomenon of pre-ignition
(*a*) always occurs in petrol engines (*b*) always occurs in diesel engines
(*c*) never occurs in diesel engines (*d*) increases the power output of an engine.

276. The octane rating of the commercially available petrol in India is
(*a*) 15-35 (*b*) 45-55 (*c*) 60-70 (*d*) 85-90.

277. .... lubrication technique is used for lubrication of the cylinder of a scooter engine.
(*a*) Petrol (*b*) Splash (*c*) Gravity feed (*d*) Forced feed.

278. In 4-stroke engines the camshaft rotates at ... the crankshaft speed
(*a*) half (*b*) three-fourth (*c*) equal (*d*) double.

279. Which of the following is the distinctive features of an I.C. engine ?
(*a*) Easy and instantaneous starting (*b*) High overall efficiency
(*c*) Low weight to power ratio
(*d*) Combustion and conversion of heat energy into mechanical work occur inside a cylinder
(*e*) All of the above.

280. The minimum number of rings in a piston are
(*a*) two (*b*) three (*c*) four (*d*) six.

281. ... process is not associated with Diesel cycle.
(*a*) Constant pressure (*b*) Constant volume
(*c*) Adiabatic (*d*) Isothermal.

282. Highest useful compression ratio is the compression ratio at which
(*a*) the engine consumes minimum fuel for a particular power output
(*b*) the engine gives maximum power output

363. An engine indicator is used to determine
(*a*) temperature (*b*) m.e.p. and I.P.
(*c*) speed (*d*) volume of cylinder.

364. The camshaft of a 4-stroke I.C. engine running at 2000 r.p.m. will run at
(*a*) 2000 r.p.m. (*b*) 1500 r.p.m. (*c*) 1000 r.p.m. (*d*) 500 r.p.m.

365. In a cycle the spark lasts for
(*a*) 0.001 s (*b*) 0.01 s (*c*) 0.1 s (*d*) 1 s.

366. By which of the following is the air pressure produced in the crankcase method of scavenging ?
(*a*) Natural aspiration (*b*) Movement of engine piston
(*c*) Supercharger (*d*) None of the above.

AUTOMOBILE ENGINEERING

367. .... is not the material for automobile pistons.
(*a*) Cast iron (*b*) Cast steel
(*c*) Steel forgings (*d*) Aluminium alloys.

368. By which of the following methods are automobile connecting rods mass produced ?
(*a*) Die casting (*b*) Forging
(*c*) Cold heading (*d*) Fine sand casting.

369. Most cars have ...... engine.
(*a*) free piston (*b*) rotary Wankel
(*c*) two stroke cycle (*d*) four stroke cycle.

370. Which of the following types of car batteries are generally used in India ?
(*a*) Lead-acid battery (*b*) Dry battery
(*c*) Nickel-cadmium battery (*d*) Nickel-iron battery.

371. An automobile engine is usually mounted at
(*a*) two points (*b*) three points
(*c*) four points (*d*) five points.

372. Which of the following statements regarding four-wheel drive is *correct* ?
(*a*) All the four wheels are powered (*b*) All the four wheels can be steered
(*c*) Vehicle has four wheels (*d*) None of the above.

373. In the differential unit of a passenger car the gear ratio is of the order of
(*a*) 3 : 1 (*b*) 6 : 1 (*c*) 8 : 1 (*d*) 10 : 1.

374. ...... batteries are generally used in automobiles.
(*a*) 6 V (*b*) 12 V (*c*) 24 V (*d*) 48 V.

375. Which of the following acids is used in automobile battery ?
(*a*) Hydrochloric acid (*b*) Nitric acid
(*c*) Sulphuric acid (*d*) Any of the above.

376. Due to which of the following reasons automobile engines are usually designed as multicylinder engines ?
(*a*) High efficiency (*b*) Lower fuel consumption
(*c*) Better balance, uniform torque output (*d*) None of the above.

377. Due to which of the following reasons engines are usually rubber mounted ?
(*a*) To prevent road shocks from reaching the engine
(*b*) To reduce the transmission of vibration between the engine and body

435. The brake bleeding system serves to free the system from
(*a*) excess pressure (*b*) excess fluid (*c*) air (*d*) none of the above.

436. Circumferential grooves are provided on automobile tyres to
(*a*) reduce danger of skidding (*b*) increase load carrying capacity
(*c*) prevent good traction (*d*) all of the above.

(B) Match List I with List II and select the correct answer using the codes given below the lists.

437.

List I	List II
A. Farm equipment	1. Maruti
B. Public conveyance	2. Tata
C. Passenger car	3. HMT
D. Good transportation	4. Hero

Codes :

	A	B	C	D
(*a*)	2	4	3	1
(*b*)	3	4	1	2
(*c*)	1	2	3	4
(*d*)	1	3	4	2

438.

List I	List II
A. Combustion process at constant volume occurs in	1. Auto-ignition
B. Combustion process at constant pressure occurs in	2. Combustion knock
C. ....in the I.C. engines is produced by the spontaneous combustion or auto-ignition of an appreciable portion of the charge	3. S.I. or otto cycle
D. ......temperature of an air fuel mixture is the lowest temperature at which chemical reaction proceeds at a rate sufficient to result eventually in inflammation	4. C.I. or diesel cycle

Codes :

	A	B	C	D
(*a*)	3	4	2	1
(*b*)	1	2	4	3
(*c*)	1	3	2	4
(*d*)	4	2	3	1

439.

List I	List II
A. The principal source of exhaust CO is...combustion	1. Nozzle
B. ...distribute the air or the air and fuel to the various cylinders of multicylinder engines	2. Engine power
C. Supercharging permits more fuel to be burned and is practical means to greater......	3. Intake manifolds

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445. Statement I is false since the performance of an S.I. engine *cannot* be improved by increasing the compression. Statement II is true ; since high octane number tends to suppress detonation, therefore, to some extent fuels of higher octane number will prove useful at higher compression ratio. Thus (*d*) is the correct choice.

446. The formula indicated of power (I.P.) involves p_mLAN ; *i.e.*, I.P. depends upon mean effective pressure (p_m), length of stroke (L), piston diameter $\left(\text{Area A} = \frac{\pi}{4} D^2\right)$, and speed rotation ($n$). Thus (*c*) is the correct choice.

447. $\Delta p \propto v^2$, this relationship is shown in curve (*c*).

451. **Idling System** compensates dilution of charge ; economiser is used for meeting maximum power range of operation ; **acceleration pump** for meeting rapid opening of throttle, and choke for cold starting, thus (*b*) is the correct choice.

454. Because four-stroke engines require heavier flywheels as power stroke comes only once every four strokes and also petrol engine is running at the highest r.p.m.

D. Fill in the Blanks

1. Detonation in S.I. engines is caused by the .... of the charge to burn, while knock in C.I. engines is caused by the .... of the charge to burn.

2. Of all the three-phases of combustion process in a C.I. engine, the .... is the most important.

3. While volatility of the fuel is a determining factor in S.I. engines, the .... of the fuel is the determining factor in C.I. engines.

4. Octane number of fuel means the percentage of .... in a mixture of .... and ....

5. .... and .... are reference fuels for measuring octane number of S.I. engine fuels.

6. .... and .... are reference fuels for measuring cetane number of C.I. engine fuels.

7. .... is done for increasing the .... efficiency of a diesel engine.

8. The quantity of fuel in a .... engine is controlled by the rotation of fuel pump plunger by .... and .... arrangement.

9. The function of a carburettor is to control .... ratio and .... of mixture.

10. Crankcase dilutation is caused if the S.I. engine fuels are ...... volatile and vapour lock characteristics are caused if the S.I. engine fuels are .... volatile.

11. The Stirling engines are .... combustion engines and would be popular in......... sector.

12. Wankel rotary engines are of very .... speed but have some .... problem.

13. Engine exhaust emissions can be measured accurately by an .... exhaust gas ....

14. Chemically correct air-fuel ratio is called .... ratio and the ratio of actual mass of air to the theoretical mass of air in a diesel engine is called .... efficiency.

15. Ignition delay of fuel .... as the carbon-hydrogen ratio in the molecules increases.

16. The general formulae for paraffins is ....

17. I.C. engine .... is designed to remove about 30 per cent of the heat produced in the .... chamber.

18. The most commonly used firing order for a six-cylinder four-stroke engine is ....

19. The vibration of the .... induced by a variable torque is called .... vibration.

20. The chemically correct air-fuel ratio is called ....

21. Iso-octane is arbitrarily rated .... octane number.

22. The efficiency of a 4-stroke engine is .... than that of a 2-stroke engine.

23. By supercharging the .... and .... of a Diesel engine can be increased.

APPENDICES

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APPENDIX-VI
REQUIREMENTS FOR MOTOR GASOLINES (IS : 2796-1971)

S.No.	*Characteristics*	*Requirements*	
		83 Octane	*93 Octane*
(*i*)	Colour, visul	Orange	Red
(*ii*)	Copper-strip corrosion for 3 hours at 50°C	Not worse	No. 1
(*iii*)	Density at 150°C	Not limited but to be reported	
(*iv*)	Distillation :		
	(*a*) Initial boiling point	Not limited but to be reported	
	(*b*) Recovery up to 70°C, per cent by volume, *Min*	10	10
	(*c*) Recovery up to 125°C, per cent by volume, *Min*	50	50
	(*d*) Recovery up to 180°C, per cent by volume, *Min*	90	90
	(*e*) Final boiling point, *Max*	215°C	215°C
	(*f*) Residue, per cent by volume, *Max*	2	2
(*v*)	Octane number (Research method), *Min*	83	93
(*vi*)	Oxidation stability, in minutes, *Min*	360	360
(*vii*)	Residue on evaporation, mg/100 ml. *Max*	4.0	4.0
(*viii*)	Sulphur, total, per cent by weight, *Max*	0.25	0.20
(*ix*)	Lead content (as Pb), g/1, *Max*	0.56	0.80
(*x*)	Reid vapour pressure at 380°C, bar, *Max*	0.70	0.70

APPENDIX-VII
REQUIREMENT FOR DIESEL FUELS (IS : 1460-1974)

S.No.	*Characteristics*	*Requirements*	
		HSD	*LDO*
(*i*)	Acidity, inorganic	NIL	NIL
(*ii*)	Acidity, total mg of KOH/g (max)	0.50	—
(*iii*)	Ash, per cent by mass, max	0.01	0.02
(*iv*)	Carbon residue (Ramsbottom), per cent by mass (max)	0.20	1.50
(*v*)	Cetane number (min)	42	—
(*vi*)	Pour point (max)	6°C	12°C for winter 18°C for summer
(*vii*)	Copper strip corrosion for 3 hrs at 100°C	90	—
(*viii*)	Flash point :		
	(*a*) Abel, °C (min)	38	—
	(*b*) Pensky-Martens (closed), °C, (min)	—	66
(*ix*)	Kinematic viscosity, CS, at 38°C	20 to 7.5	2.5 to 15.7
(*x*)	Sediment, per cent by mass, (max)	0.05	0.10
(*xi*)	Total sulphur, per cent by mass, (max)	1.0	1.8
(*xii*)	Water content, per cent by volume, (max)	0.05	0.25
(*xiii*)	Total sediments, mg per 100 ml, (max)	1.0	—

About the Book

This book on "**Automobile Engineering**" has been written for the students preparing for B.E./B.Tech., A.M.I.E. (Section B), Diploma and Competitive examinations. It consists of twelve chapters in all, covering the various topics systematically and exhaustively; and an "*Additional Objective Type Questions' Bank*" at the end.

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- A large number of solved examples, properly graded, have been added in various chapters to enable the students to attempt different types of questions in the examination without any difficulty.
- At the end of each chapter ***Short Answer Questions,*** *Highlights, Objective Type Questions, Theoretical Questions* and *Unsolved Examples* have been added to make the book a complete unit in all respects.

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* ***Jawahar Lal Nehru Memorial Gold Medal for an outstanding research paper (Institution of Engineers).***
* ***Distinguished Author Award.***
* ***Man of Achievement Award.***

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