# Basic Mechanical Engineering

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He has received more then 10 personal awards at the Regional, State and National level including the **Best Principal Award**. **Outstanding Engineer award**. Achiever Award etc. He is fellow of the Institution of Engineers (India), Calculta. He is a Life Member of I.S.T.E. Quality Form of India and Acoustic Society of India. At present, even at the age of 82, he is actively serving as **Advisor** at Kamaraj College of Engineering and Sri. Vidhya College of ^Engineering. He is also a member of Governing Council at Dhanalakshmi College of Engineering, Chennai. He has traveled to 17 countries so far and he is planning to visit some more countries.

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*Dedicated to my parents*

*Late Sri C Gurusamy Nadar*

*&*

*Late Smt. Sivahami Ammal*

***– G Shanmugam***

# CONTENTS

# PREFACE

This book is intended to serve as a textbook covering the syllabus for the course "Basic Mechanical Engineering", adopted in all the Universities in India. It covers the fundamentals of steam boilers, steam turbines, power plants, internal combustion engines, the process of casting, forming, joining and removal of metals, engineering materials, heat treatment, refrigeration and air conditioning, CAD/CAM/CIM, robots and transmission of power.

Also, it will be noted that even modern developments in the field of Mechanical Engineering like Computer Aided Design and manufacture Flexible manufacturing system (FMS) Micro Electro Mechanical Systems (MEMS) and Glimpse of Nanotechnology have been added in this text at the basic level. This book will be useful not only to the first year B.E. students, but also to diploma and AMIE students in all the technical institutions throughout the country.

Throughout the text, attempt has been made to present the subject matter in a simple, lucid and precise manner. Care has been taken in making the text student-friendly. Simple, neat and clear diagrams are provided in all the chapters to elucidate the concepts further.

The author considers it a great honour to have the foreword written by Prof. M. Salihu, former Vice-Chancellor of Madurai Kamaraj University, an eminent scholar and a successful administrator.

The author is indebted to Tata McGraw-Hill Publishing Company Limited, particularly to Mr. H.R. Nagaraja and Mrs. Vibha Mahajan for the speedy and quality publication of the book.

Any suggestions from the readers for the improvement of the book are welcome.

**G. Shanmugam**

**S. Ravindran**

# Chapter 1
# STEAM BOILERS AND STEAM TURBINES

## 1.1 INTRODUCTION

The function of a boiler is to evaporate water into steam at a pressure higher than the atmospheric pressure. Water free from impurities such as dissolved salts, gases and nonsoluble solids should be supplied to boilers. This is done by suitable water treatment. Steam is useful for running steam turbines in electrical power stations, ships and steam engines in railway locomotives. It is also useful for many other industrial applications. Boiler furnace can use either solid, liquid or gaseous fuel. Boilers are mainly classified as fire-tube boilers and water-tube boilers. In the fire-tube boilers, hot gases from the furnace pass through the tubes which are surrounded by water. In the water-tube boilers, the water circulates inside the tubes which are heated from outside by the hot gases from the furnace.

A steam turbine is a prime mover in which rotary motion is obtained by the gradual change of momentum of the steam. Steam turbines are primarily used to run alternators or generators in thermal power plants. It is also used to rotate the propeller of ships through reduction gearing. The design and manufacture of turbine blades are quite complicated due to which there are only a limited number of manufacturers of steam turbines.

## 1.2 FORMATION OF STEAM

Let us take 1 kg of water and heat at standard atmospheric pressure. Please refer to Fig. 1.1.

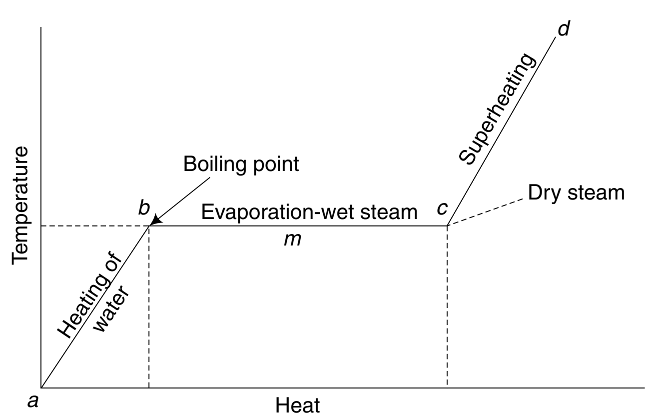



**Fig 1.1** *Formation of steam*

The temperature of water is raised to its boiling point.

***Boiling point of water*** At standard atmospheric pressure, the temperature is 100°C. It increases with pressure. The value can be obtained from steam tables. At 10 bar, the boiling point is 179.9°C.

***Evaporation of water*** The temperature remains constant. There will be mixture of water and steam till the point *C*. At the mid point *m*, only 0.5 kg of water would have been evaporated. Here, the dryness fraction of steam is 0.5.

All the water is evaporated and the steam is said to be dry at the point *C*. The dryness fraction becomes 1.

***Superheating*** The temperature is raised. In steam power plants, only superheated steam is used to run the turbines. Wet steam can be used for many industrial applications.

## 1.3 COCHRAN BOILER

This is a vertical fire-tube boiler as given in Fig. 1.2. The fuel is fed into the grate through the fuel door and lighted. The fuel is burnt in the grate and hot gases go to the combustion chamber through a short flue tube. The combustion continues in the combustion chamber. The fire brick

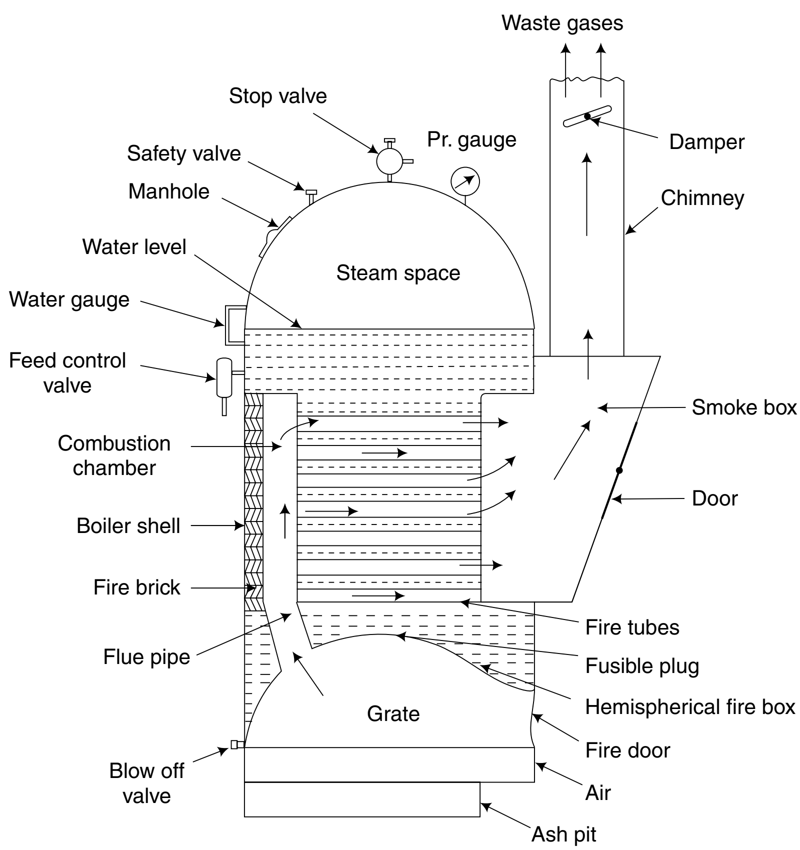



**Fig. 1.2** *Cochran boiler*

layer prevents the over-heating of the boiler shell. The hot gases pass through a large number of fire tubes and heat the surrounding water and convert it into steam. Since the steam is lighter, it goes up to the steam space. The fire tubes normally have 62.5 mm external diameter and are 165 in number. The crown of the boiler shell and grate are both hemispherical in shape. This boiler can evaporate upto 3800 kg of steam per hour, when the diameter is 3 m and the height is 6 m.

The waste gases enter the smoke box and are released through the chimney. The amount of waste gases leaving the chimney is controlled by means of a damper manually. When the damper is partly closed, amount of waste gases leaving the chimney will be reduced. Due to this action of the damper, the amount of air entering the grate will also be reduced and, obviously, only limited fuel can be burnt and the amount of steam generated also will be reduced. Thus, we find that the damper controls the rate of steam generated. Through the manhole, the boiler attender can enter inside the boiler shell for cleaning. By opening the door in the smoke box, the fire tubes and the smoke box can be cleaned with a wire brush.

The diameter of the boilers varies from 1–3 m. The height of the boiler varies from 2–6 m. The evaporative capacity of the boiler ranges from 20–3000 kg/h. The boiler is fitted with various mountings as detailed in the following section.

## 1.4 BOILER MOUNTINGS

### 1.4.1 Water Gauge

This *indicates the level of water inside the boiler*. For small-capacity boilers, this is made with a thick glass tube with necessary protection and safety devices. By automatic control using float mechanism, the water level will be kept constant, with the help of a feed pump or a water injector. According to boiler regulations, *two water gauges should be fitted* in each boiler.

In case the gauge glass breaks, the rush of water and steam will carry the *ball valves* to the position shown by dotted lines and prevent water or steam coming out of the boiler shell, as shown in Fig. 1.2(a).

### 1.4.2 Pressure Gauge

This is *to indicate the pressure of steam* inside the boiler. At atmospheric pressure, the gauge will read zero. Periodically, the pressure gauge should be tested with a standard gauge and *calibrated* if necessary.

Refer to Fig. 1.2(b). The flange will be fixed on the boiler shell or drum and connected to the steam pressure. Depending upon the pressure, the *spring tube will deflect*. This deflection will be *magnified* to the pointer through the link mechanism consisting of rod, toothed sector and pinion. The U-tube will be filled with water.

### 1.4.3 Safety Valve

This valve is *designed to open and let some steam out when the pressure exceeds the safe designed value*. In each boiler, there should be a *minimum of two safety valves*, as per the boiler regulations.

There are two types of safety valves. One is called *lever safety valve*. The other type is the *spring safety valve*, as shown in Fig. 1.2(c). In this valve, both the valves are kept closed by the spring. Pressure of the steam will be acting on the valve through the valve chest. If the pressure exceeds the designed value, the spring will be pushed up opening the valves and letting the steam out.

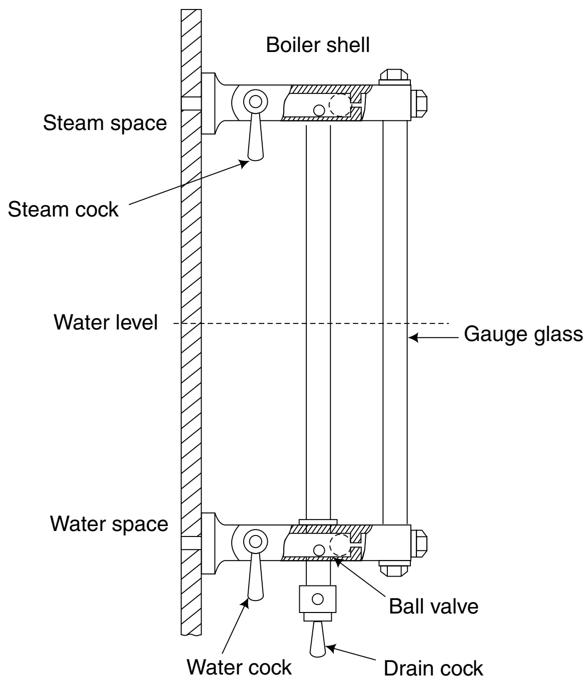



**Fig. 1.2 (a)** *Water-level indicator*

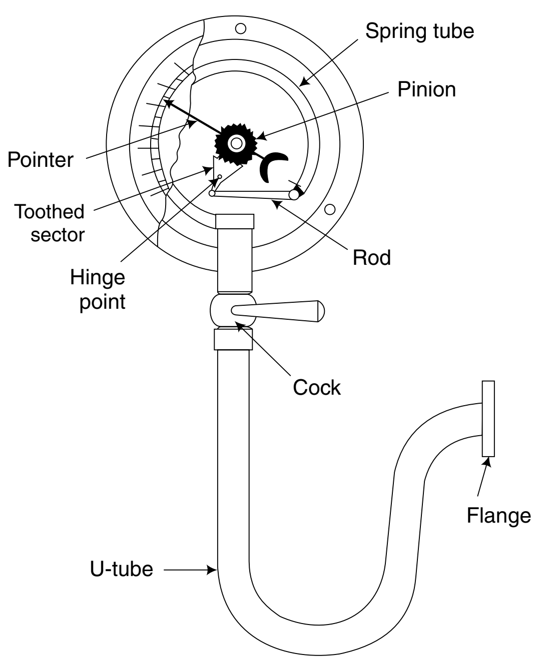



**Fig. 1.2 (b)** *Pressure gauge*

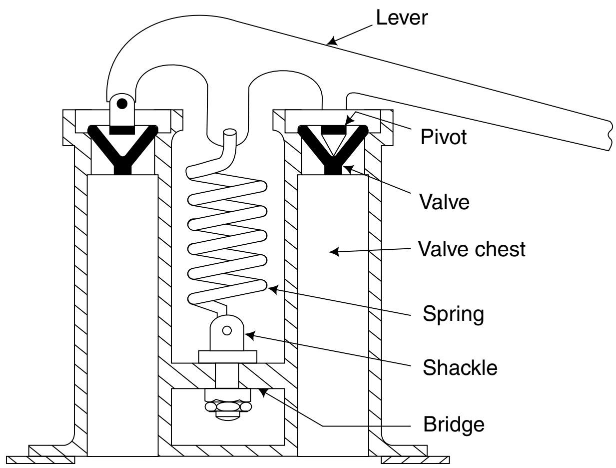



**Fig. 1.2 (c)** *Ramsbottom safety valve*

### 1.4.4 Main Steam Valve

This is to regulate or stop the flow of steam going out of the boiler to the turbine, engine, or process work.

### 1.4.5 Blow-off Valve

This valve is fitted at the lowest level of water. This helps to remove the salt deposits and other impurities accumulated in the bottom portion of the boiler shell or drum. This valve should be periodically opened keeping the steam under low pressure of about 2 bar.

### 1.4.6 Fusible Plug

This is one of the safety devices in many boilers. This prevents overheating of the fire box and other parts of the boiler. In case, the water level becomes too low due to the failure of the automatic control, the plug will melt and create an opening through which water and steam will be allowed to put out the fire in the grate. The plug is made of a special alloy which has a comparatively low melting point. The fusible plug is shown in Fig. 1.2(d).

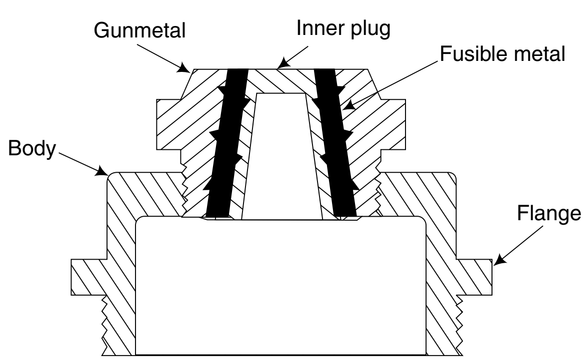



**Fig. 1.2 (d)** *Fusible plug*

## 1.5 LOCOMOTIVE BOILER

It is a horizontal fire-tube boiler. It is mostly used for railways. It consists of a shell or barrel having 1.5-m diameter and 4-m length. Fuel is fed into the fire box through the fuel door. Air enters through the damper and the slots in the grate plate. The rate of combustion and the amount of steam generated is controlled by the dampers. The fire brick arch deflects the hot gases and improves the combustion efficiency.

The hot gases pass through large number of fire tubes and enter the smoke box. The circulation of air and hot gases is improved by means of induced draft produced in the smoke box. Waste steam from the engine enters the smoke box through the blast pipe and expands. Due to the expansion, it produces a partial vacuum which improves the movement of hot gases and air. Waste gases go out through a short chimney. A door is provided in the smoke box for inspection and cleaning.

To remove the moisture from the wet steam and to increase the temperature of steam, it is superheated as shown as Fig. 1.4. The wet steam through the regulator enters the wet steam header and passes through large number of superheated tubes and finally comes to the superheater header. Then, the superheated steam goes to the engine. To accommodate the superheater tubes, some of the fire tubes are larger in diameter. There are about 157 fire tubes of 47.5 mm diameter and 24 fire tubes of 130 mm diameter. By superheating, the heat energy per unit mass of steam is increased and the thermal efficiency of the steam plant is considerably increased.

The boiler is fitted with a water gauge, a pressure gauge, a steam regulator, a safety valve, a whistle, and a fusible plug as shown in the sketch. In a locomotive boiler, the water gauge and pressure gauge will be mounted in the driver's cabin. The steam regulator can be operated by the driver from the cabin by a hand wheel. It should be noted that in railways, the use of steam engine is being reduced gradually and it is replaced by electric and diesel engines which have many advantages.

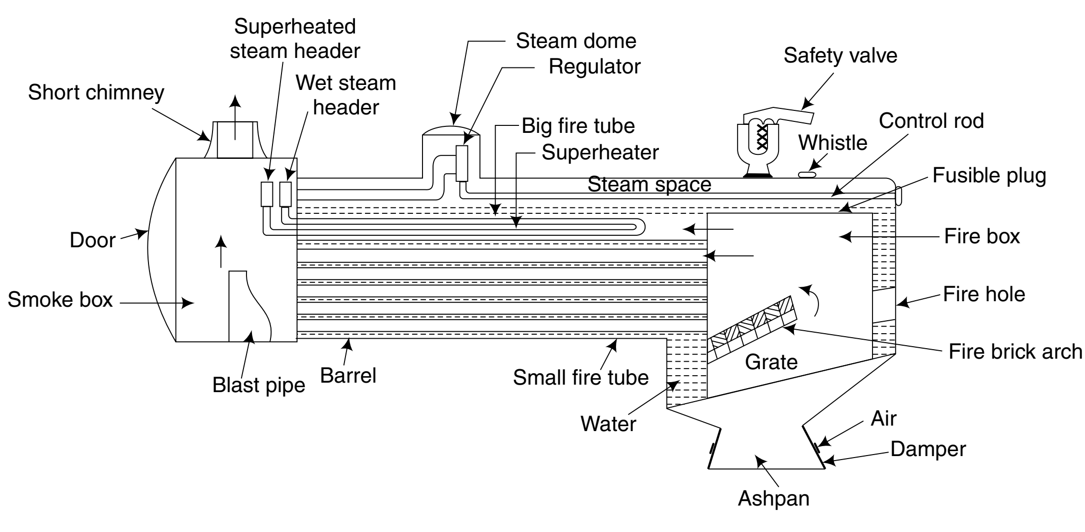



**Fig. 1.4** *Locomotive boiler*

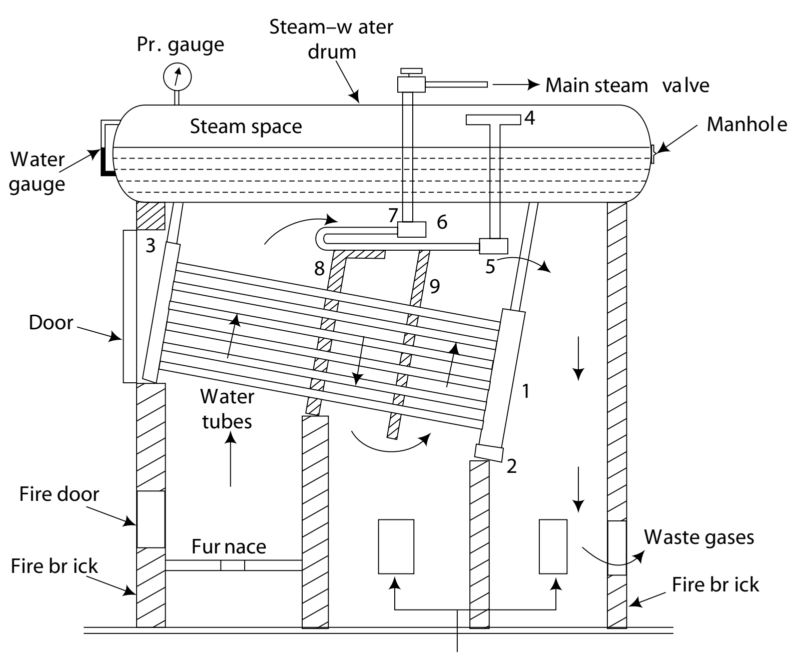
## 1.6 BABCOCK AND WILCOX BOILER

This is a water-tube boiler. It consists of a steam-water drum mounted on fire brick work. Hot gases from the furnace pass through a zigzag path through the fire brick baffles before going to the chimney through the damper. The damper controls the rate of burning and thereby the steam generation. The damper is operated by a chain passing through a set of pulleys. Water from the steam–water drum comes down to the downtake header and then goes to the uptake header through a large number of water tubes, inclined at about 14° for better circulation as shown in Fig. 1.5. It should be noted that there are many different types of Babcock and Wilcox boilers. One of the simpler types is shown in the sketch which is used for medium pressure and capacity.

The wet steam comes to the wet steam header through an antipriming pipe. The antipriming pipe removes some moisture from the steam. Then, it passes through a large number of superheater tubes and reaches the superheater header. From the superheated header, it goes to the main steam valve and finally to the steam turbine.

At the end of the downtake header, a mud drum is connected from where impurities can be removed. As shown in the sketch, the boiler is provided with two inspection doors and other mountings such as the water gauge, the pressure gauge and the safety valve.

Normally, the furnace is provided with a moving grate. In a boiler provided with a moving grate,the rate of fuel burning can easily be controlled by changing the thickness of the fuel bed and also by changing the speed of the moving grate, otherwise called chain grate. Compared to a fire-tube boiler; the evaporative capacity, the pressure of steam and the thermal efficiency of this boiler will be higher.




1. Downtake header 2. Mud drum 3. Uptake header 4. Antipriming pipe 5. Wet steam header
6. Superheater tubes 7. Superheater steam header 8. and 9. Fire brick baffles

**Fig. 1.5** *Babcock and Wilcox boiler*

## 1.7 LAMONT BOILER

This is one of the *high-pressure water-tube boilers working on forced circulation*. The circulation is maintained by a *centrifugal pump driven by a steam turbine using steam from the boiler*. *Due to forced circulation, the rate of heat transfer and the evaporative capacity of the boiler are increased*. This boiler is highly suitable for a power plant and this has a high thermal efficiency. Normally, in high-pressure boilers, either furnace oil or solid fuel in a pulverised form is used in the furnace. This boiler can produce steam upto a pressure of 150 atmosphere.

A simple layout sketch is given in Fig. 1.6. Water is circulated through the evaporator tubes. Hot gases from the furnace or the combustion chamber heat the water and evaporate into steam. Wet steam will come to the steam space in the steam-water drum. In the superheated tubes, the moisture from the wet steam is removed and also the temperature is raised considerably. In the economiser, the feed water is heated by means of waste gases before going to the chimney. Due to the feed water heating, thermal stress is reduced in various parts of the boiler. If any part is subjected to a large temperature difference suddenly, thermal stress will be induced in the part resulting in failure due to the development of cracks. Due to the use of heat in the waste gases, the thermal efficiency is further increased.

*Due to high pressure of steam, the temperature of steam is increased. So the temperature of the furnace should also be increased by pre-heating the air.* The method of pre-heating the air is shown in the sketch. The thickness of the drum and pipes should be more due to high pressure. In the boiler, bent tubes made of high quality steel are used. In the furnace, *wall pipes are used to increase the capacity of the boiler and also to cool the furnace wall.* This boiler is fitted with usual mountings such as

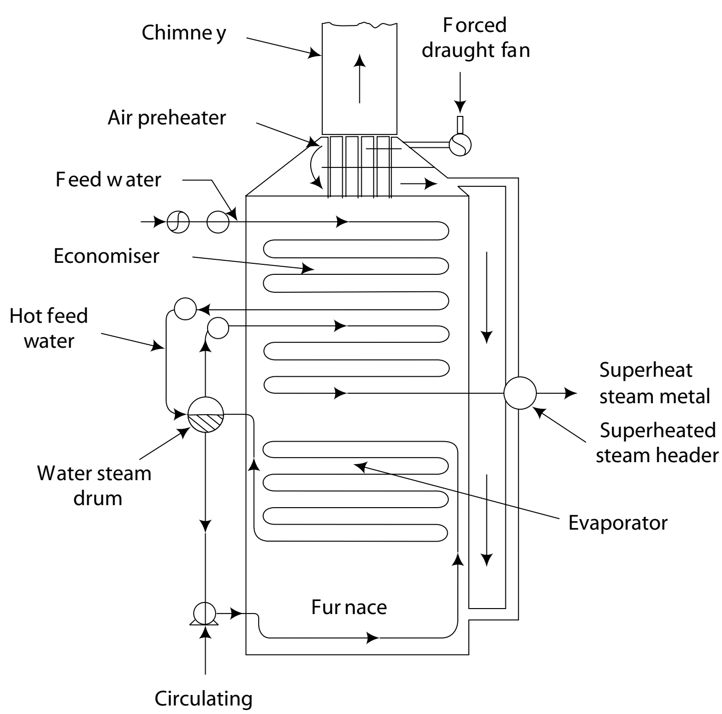



**Fig. 1.6** *High pressure Lamont boiler*

a *water gauge, a pressure gauge, safety valves and a blow-off valve.* Normally, *three safety valves* are fitted in high-pressure boilers. The design, manufacture and erection of such high-pressure boilers are very difficult. It needs a large number of skilled personnel, good team work and large investment.

## 1.8 BENSON BOILER

This is very similar to the Lamont Boiler, but *there is no drum.* This boiler can *withstand very high pressure,* even higher than critical pressure of steam. Absence of the drum *reduces the weight and cost.* The arrangement of various components is given in Fig. 1.7.

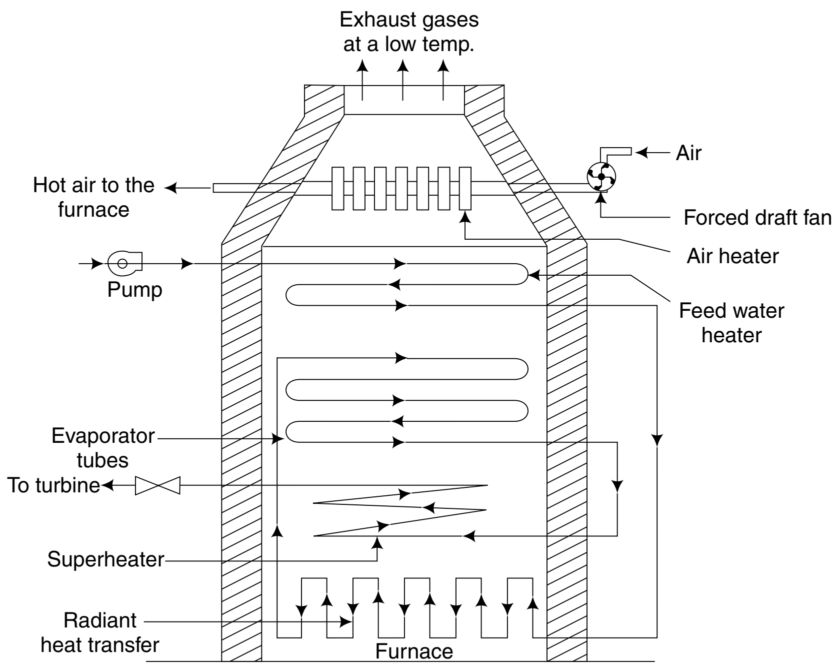



**Fig. 1.7** *Benson boiler*

## 1.9 ADVANTAGES OF HIGH PRESSURE BOILERS

1. High pressure steam out of the boiler will have higher heat energy per kg. So, power output from the turbine and the generator will be high.
2. The thermal efficiency of a high pressure boiler is much higher than the low pressure or medium pressure boilers.
3. Evaporative capacity of the boiler is high due to forced circulation of water.
4. The investment cost for each MW output will be less, by using a high pressure boiler.

## 1.10 CHARACTERISTICS OF A GOOD BOILER

1. The boiler should be able to evaporate steam at the designed capacity, pressure and temperature.

2. Total cost of the boiler with all mountings and accessories should be low.
3. By having a higher thermal efficiency, the operational cost should be low.
4. The boiler should have provision for inspection of all the parts for cleaning and maintenance.
5. The boiler should have provision for automatic control of water level, pressure and temperature.
6. The parts should be able to withstand the fluctuations in pressure and temperature.
7. Transport and erection of the boiler at site should be easy and at the minimum cost.
8. The boiler should conform to all the safety regulations, as laid down in the Indian Boiler Act.

## 1.11 INDIAN BOILER ACT

1. Unless the boiler is registered with the Chief Inspector of Boilers, it should not be put into operation.
2. Fitness Certificate should be obtained every year, from the Chief Inspector of Boilers.
3. The certificate should be displayed in the boiler room.
4. The boiler operator should be a trained person.
5. Any failure or accident should be immediately reported to the Chief Inspector.
6. Any violation of the act is punishable.

## 1.12 DIFFERENCES BETWEEN FIRE-TUBE AND WATER-TUBE BOILERS

**Table 1.1**

| | Fire-tube boiler | Water-tube boiler |
|---|---|---|
| 1. | Hot gases pass through the tubes with water surrounding them. | Water passes through the tubes with hot gases surrounding them. |
| 2. | Used for low-pressure steam as the diameter of the shell is large. The pressure is restricted to about 10 bar. | Drum diameter is less and it can be used for medium and high pressure. Pressure of steam can even go up to about 100 bar. |
| 3. | Used for industrial applications only due to low pressure. | *Used for power plants* where we need high pressure. |
| 4. | More steam space and so pressure fluctuation is less. | Less steam space; pressure fluctuation is more when the steam is taken out. |
| 5. | Transport is difficult due to large shell diameter. | Comparatively easier due to smaller drum. |
| 6. | Less number of parts. | More number of parts. |
| 7. | Fire tube will not be choked easily. Maintenance cost is less. | These boilers can be choked due to salt deposits. Maintenance cost is more. |
| 8. | Water circulation is poor. | Water circulation is better. |
| 9. | Thermal efficiency is low. | Thermal efficiency is high. |
| 10. | Heating surface is less. | Heating surface is more due to large number of water tubes. |
| 11. | Less skill is enough for the operation of the boiler. | More skill and controls are needed for the operation of the boiler. |

## 1.13 COGENERATION

It should be remembered that the thermal efficiency of any heat engine is rather low in the range of 15 to 35 percent. When a heat engine is not able to convert all the input heat energy into useful mechanical power, it would be obviously rejecting energy as waste heat. So, a system will become more efficient if the waste heat is utilised for some useful purpose. Any scheme which combines electrical power generation with utilisation of heat for industrial processes and/or space heating is referred to as Combined Heat and Power (CHP) or Cogeneration. In such a scheme, energy wastage is reduced to the minimum thereby increasing the overall thermal efficiency.

Refer to Fig. 1.8. This cogeneration power plant employs both the steam turbine and a gas turbine for generating electric power. Because of recovery of heat from the flue gases of the boiler and the exhaust gases from the gas turbine, we obtain high overall thermal efficiency.

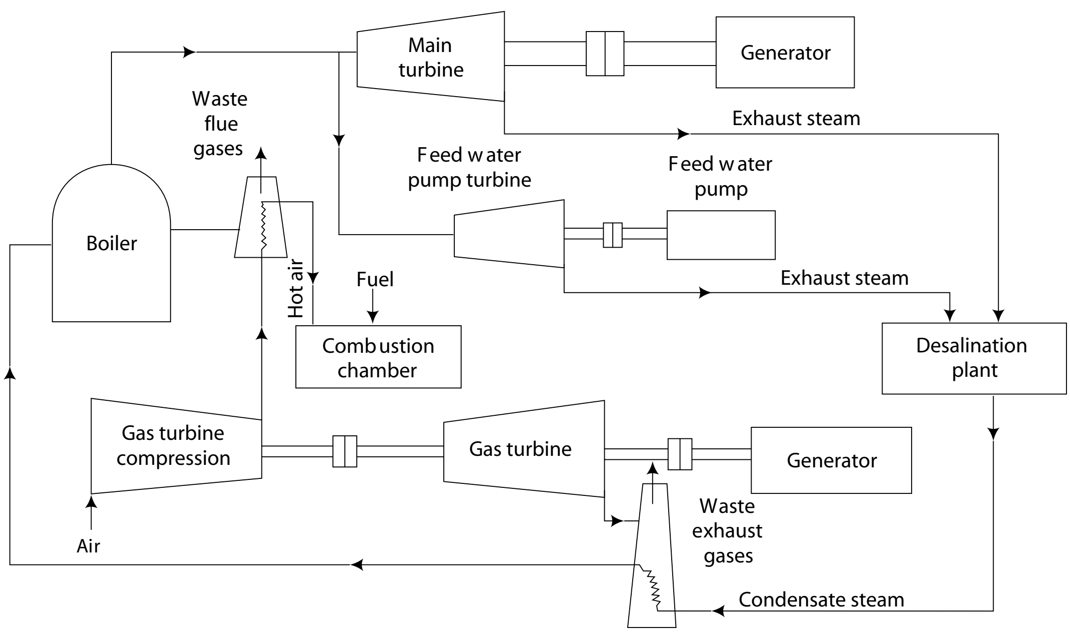



**Fig. 1.8** *Cogeneration*

Steam is generated at high pressure and temperature in the boiler. Steam from the boiler is fed to the main steam turbine for generating electric power and also to a small turbine which drives the feed water pump. Both the turbines are back pressure, non-condensing type and the steam in the last stages of the turbines is fed into the desalination plant to purify sea water for getting soft water. Thus, it is noted that the desalination plant is operated by using the heat from the exhaust or waste steam from the turbines.

In addition, the heat energy in the flue gases from the boiler instead of being wasted is used to preheat the compressed air used in the gas-turbine combustion chamber. The hot exhaust from the gas turbine is made to heat the condensate feed water from the desalination plant. The above two waste heat recoveries help in increasing the thermal efficiency of the power plant by reducing the fuel burnt in the gas turbine combustion chamber and also in the boiler for the same output power.

To cite an example, in the case of a gas turbine power plant, heat from the exhaust gases could be made use of in the waste heat recovery boiler. Even after this, the gases could then be passed through an economiser to preheat the feed water for the boiler. Nowadays, this principle is made use of in many ways in thermal plants.

## 1.14 INTRODUCTION TO STEAM TURBINES

A steam turbine is a prime mover in which rotary motion is obtained by the gradual change of momentum of the steam. Steam turbines are primarily used to run alternators or generators in thermal power plants. It is also used to rotate the propeller of ships through reduction gearing. The design and manufacture of turbine blades are quite complicated due to which there are only a limited number of manufactures of steam turbines.

## 1.15. MAIN PARTS OF A STEAM TURBINE

***Nozzles*** In steam turbines, normally, convergent – divergent type of nozzles are used. When steam flows through the nozzle, there is a pressure drop which is converted into velocity or kinetic energy. The nozzle also guides the steam in the proper direction to strike the blades. The nozzles are kept very close to the blades to minimise the losses.

***Rotor*** The rotor or runner consists of a circular disc fixed to a horizontal shaft. The rotor is mounted on suitable bearings.

***Blades*** On the periphery of the rotor, a large number of blades are fixed. The steam jet from the nozzle impinges on the surface of the blades due to which the rotor rotates. The surface of the blades is made smooth to reduce frictional losses.

***Casing*** It is a steam tight steel casing which encloses the rotor, blades, etc. In a multistage turbine, the casing also accommodates the fixed blades. The casing helps the flow of steam and also protects the inner parts from any accident.

## 1.16 TYPES OF TURBINES

Steam turbines are classified as impulse turbines and reaction turbines. Differences between the terms impulse and reaction are explained below:

Impulse is the force imparted on an object when a jet of fluid strikes the object with great velocity as in Fig. 1.9(a). Reaction is the force imparted on an object when a fluid leaves the object with a higher relative velocity. Different examples of reaction are swimming, recoil of a gun, jet plane, ground wheel in fire works, lawn sprinkler, etc. In Fig. 1.9(b), the jet plane moves forward due to the reaction of the high velocity jet of hot gases from the nozzle. In Fig. 1.9(c), the lawn sprinkler rotates due to the reaction of the water jets.

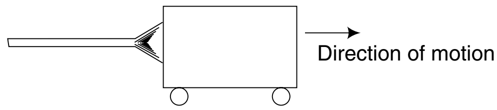



**Fig. 1.9(a)** *Impulsive force of a fluid jet*

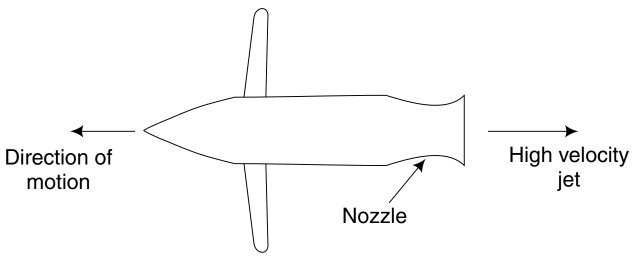



**Fig. 1.9(b)** *Jet Plane*

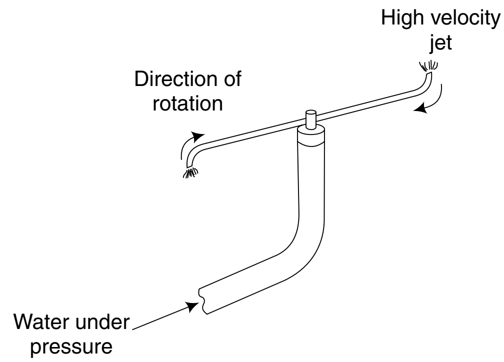



**Fig. 1.9(c)** *Lawn sprinkler*

## 1.17 WORKING OF A SINGLE-STAGE IMPULSE TURBINE (DE-LAVAL TURBINE)

First, the pressure energy is converted into kinetic energy by the expansion of steam through a set of nozzles. Normally, in steam turbines, we make use of convergent–divergent nozzles. The kinetic energy is converted into mechanical energy with the help of moving blades fixed on a rotor. The rotor is connected to the output shaft. All the above-mentioned parts are enclosed in a casing as shown in Fig. 1.10(a). The pressure–velocity diagram, given in Fig. 1.10(b), is for a single-stage impulse turbine.

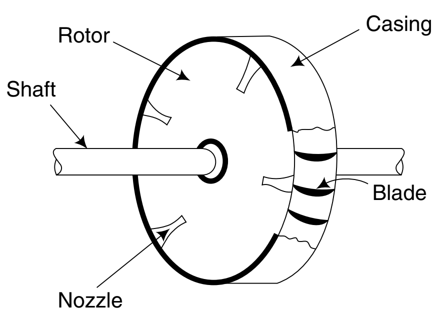



**Fig. 1.10(a)** *Single-stage impulse turbine*

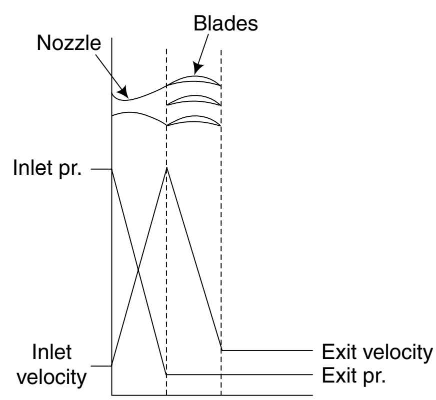



**Fig. 1.10(b)** *Pressure velocity diagram for a single-stage impulse turbine*

A simple or single-stage impulse turbine is only suitable for low-pressure steam. In case the steam pressure is high, when it expands in one set of nozzles, the outlet velocity of steam from the end of the nozzles will be too high. Due to the high velocity of the steam, the rotor will rotate at a very high speed. Such a high speed is not suitable for practical purposes. So, in practice, we make use of the multistage impulse turbines or compound impulse turbines.

## 1.18 COMPOUNDING OF IMPULSE STEAM TURBINES

In multistage impulse turbines, there are three types of compounding, namely, pressure compounding, velocity compounding and pressure velocity compounding. In this section, the three types are discussed.

### 1.18.1 Pressure Compounding

The pressure drop or expansion of steam is done in more than one set of nozzles and each set of nozzles is followed by a set of moving blades. The turbine is known as pressure compounded impulse turbine. A two-stage pressure compounding is shown in Fig. 1.11(a).

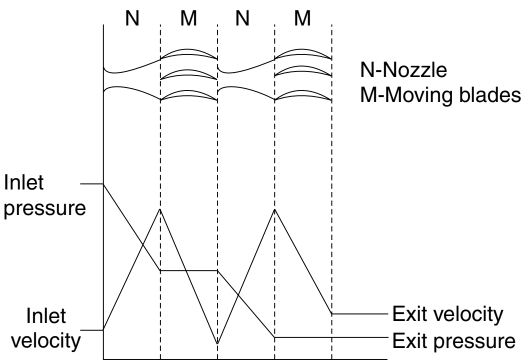



**Fig. 1.11(a)** *2-Stage pressure compounding*

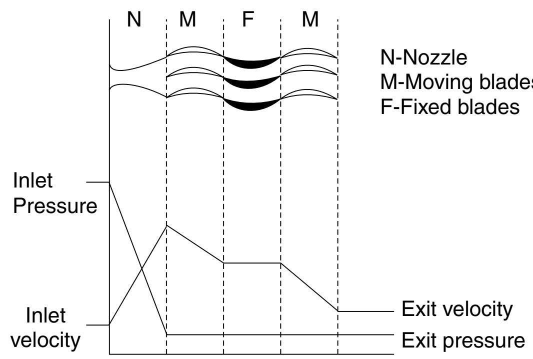



**Fig. 1.11(b)** *2-Stage velocity compounding*

### 1.18.2 Velocity Compounding

Here the entire expansion of steam occurs in one set of nozzles resulting in a very high velocity at the outlet. The steam is then passed through several sets of moving blades, followed by fixed blades. Moving blades are fitted on the rotor while the fixed blades are fixed on the casing. The function of the fixed blades is to change the direction of steam and guide the steam in the proper angle to the next set of moving blades. A two-stage velocity compounding is shown in Fig. 1.11(b).

### 1.18.3 Pressure Velocity Compounding

In power plants, pressure velocity compounding is more common. In this arrangement, for each pressure stage, there is a velocity staging. A two-stage pressure velocity compounding is shown in Fig. 1.11(c). In practice, there will be more than 20 stages in a power station.

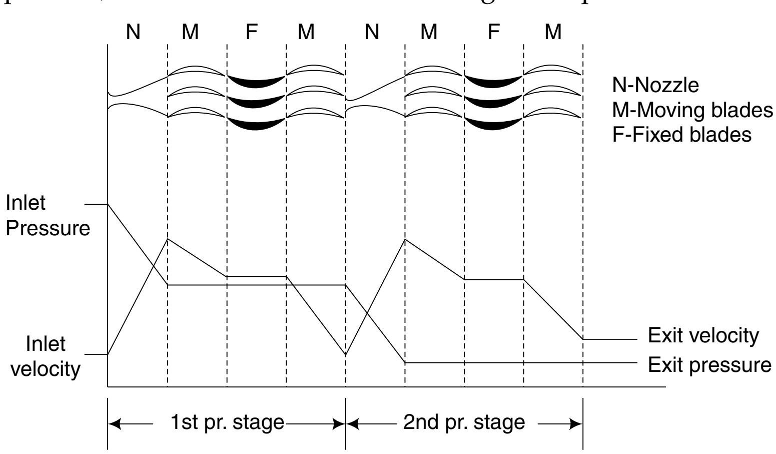



**Fig. 1.11(c)** *2-Stage pressure velocity compounding*

## 1.19 WORKING OF PARSON'S REACTION TURBINE

In this turbine, the power is obtained mainly by an impulsive force of the incoming steam and small reactive force of the outgoing steam. As shown in Fig. 1.12(a), this turbine consists of a rotor of a varying diameter. Moving blades are fixed on the rotor. The diameter of the casing also varies. Fixed blades are attached to the casing. Steam is admitted to the first set of moving blades through nozzles. The blades receive the impulsive force of the incoming steam. Then it goes to fixed blades which act as nozzles! Thus, steam flows alternatively through moving and fixed blades.

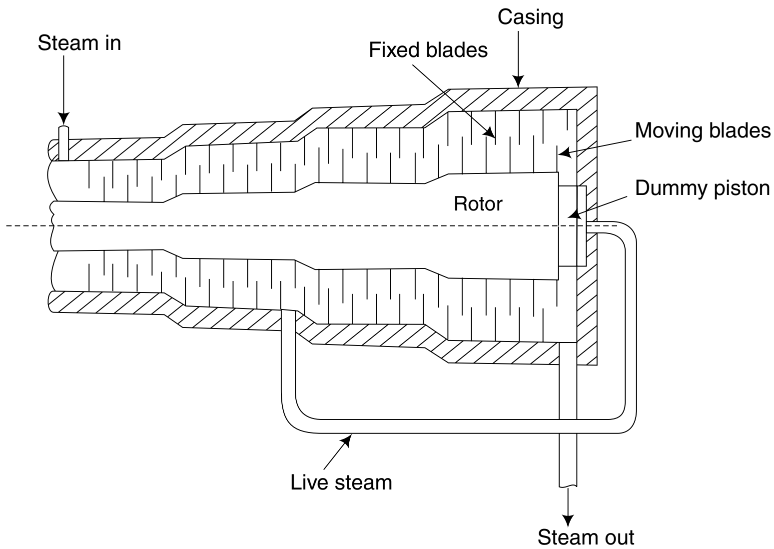



**Fig. 1.12(a)** *Parson's reaction turbine*

The shape of the moving blades is so designed to also have the reactive force when the jet of steam is leaving the blades. For this, area of the outlet between the two moving blades will be less than the area at the inlet. In addition, there will be also some pressure drop even in the moving blades. Thus, we have a continuous pressure drop in the fixed as well as in the moving blades as in Fig. 1.12(b), in reaction turbines.

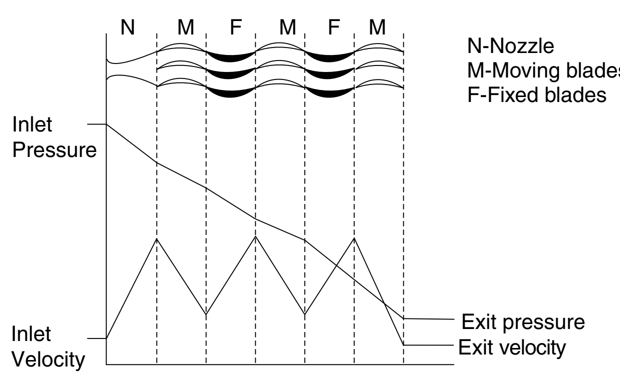



**Fig. 1.12(b)** *Pressure drop in a reaction turbine*

The diameters of the rotor and casing gradually increase to accommodate the increasing volume of steam at reduced pressure. The size of the blades also increases in the direction of flow. A dummy piston is used to balance the axial thrust of the rotor by allowing live steam to act on one side of the dummy piston, opposite to the direction of steam flow. In case the axial thrust is not balanced properly, there will be undue and uneven wear in the turbine shaft.

## 1.20 DIFFERENCES BETWEEN IMPULSE AND REACTION TURBINES

**Table 1.2**

| | Impulse turbine | Reaction turbine |
|---|---|---|
| 1. | Power is obtained only due to the impulsive force of the incoming steam. | Power is due to both the impulsive force of the incoming steam and due to the reactive force of the outgoing steam. |
| 2. | Pressure drop is only in the nozzle or in the fixed blades which act as nozzles. There is no pressure drop in moving blades. | Pressure drop is in the fixed and also in the moving blades. |
| 3. | The relative velocity of steam at inlet and outlet of the moving blades are equal. | The relative velocity of steam at outlet is higher to get the reactive force. |
| 4. | Blades are symmetrical. | Blades are not symmetrical. |
| 5. | Inlet area of moving blades is equal to the outlet area as in Fig. 1.13 (a). | Outlet area of the moving blades is smaller than the inlet area as shown in Fig. 1.13 (b), |

## Short-Answer Questions

1. *Answer the following questions:*
   (a) State some of the applications of steam boilers.
   (b) Classify different steam boilers.
   (c) What are the requirements of a good boiler?
   (d) What are water gauges?
   (e) What are the specific advantages of water-tube boilers?
   (f) Give three examples each of boiler mountings and boiler accessories.
   (g) What are the aims of pre-heating of air in a boiler?
   (h) How does a fusible plug function as a safety device?
   (i) What is meant by superheated steam?
   (j) What are the commercial fuels used in boilers?
   (k) What is meant by cogeneration?
   (l) What are the essential components of a cogeneration plant?

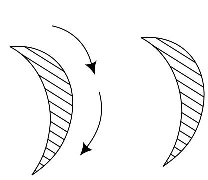


**Fig. 1.13 (a)** *Moving blades of impulse turbine*

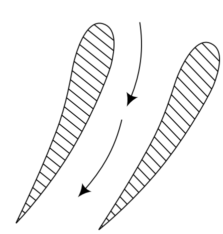


**Fig. 1.13 (b)** *Moving blades of reaction turbine*

(m) What are the main parts of a steam turbine?
(n) What is the function of a steam nozzle?
(o) Define the terms impulse and reaction with examples.
(p) Draw pressure-velocity diagram for a single stage impulse turbine.
(q) What are the three types of compounding in impulse steam turbines?
(r) Define the terms:
  (i) pressure compounding  (ii) velocity compounding
(s) State any two important differences between the impulse and reaction steam turbines.

2. *Fill up the blanks with suitable word/words:*
(a) Cochran boiler is a __________ boiler and Babcock and Wilcox boiler is a __________ boiler.
(b) The two types of draught employed in boilers are __________ and __________ .
(c) __________ and __________ are modern high pressure boilers.
(d) The two types of superheaters used in high pressure boilers are __________ and __________ .
(e) Rotary motion of a turbine is obtained by the gradual change of _________ of steam.
(f) When steam flows through nozzle, _________ is converted into _________.
(g) Pressure energy is converted into kinetic energy by the _________ of steam through a nozzle.
(h) _________ is converted into _________ with the help of moving blades.

3. *Choose the correct answer from the following:*
(a) The water tubes in a Babcock and Wilcox boiler are
  (i) vertical  (ii) horizontal
  (iii) inclined  (iv) none of the above
(b) The condition of steam in the boiler drum is usually
  (i) superheated  (ii) super saturated
  (iii) wet  (iv) none
(c) In an impulse turbine, when steam flows through the moving blades,
  (i) velocity decreases  (ii) velocity increases
  (iii) pressure decreases  (iv) pressure increases
(d) In reaction turbine, when steam flows through the fixed blades,
  (i) pressure and velocity both increase
  (ii) pressure and velocity both decrease
  (iii) pressure decreases, while velocity increases
  (iv) pressure decreases, while velocity decreases
(e) In pressure compounded impulse turbine
  (i) pressure drop for each stage is equal
  (ii) pressure drop takes place in nozzle

(iii) both (i) and (ii)
(iv) none of the above

(f) In velocity compounded impulse turbine, when steam flows through the second row of moving blades,
(i) velocity increases
(ii) velocity decreases
(iii) velocity remains constant

(g) In steam turbines, blades are
(i) straight
(ii) curved
(iii) circular
(iv) none of the above

4. *State whether the following statements are true or false:*

(a) Heating of steam above saturation temperature is called superheating.
(b) Cochran boiler is a horizontal water-tube boiler.
(c) Fusible plug is employed to make a spark.
(d) All fire-tube boilers are high pressure boilers.
(e) Formation of scale on a boiler tube decreases its life.
(f) Pressure drop is converted into mechanical energy in nozzle.
(g) Pressure falls gradually in reaction turbines in fixed and moving blades.
(h) Turbine blades are circular.
(i) Steam nozzle converts heat energy of steam into pressure energy.
(j) When the cross section of a nozzle first decreases from its entrance to throat and then increases from its throat to exit, the nozzle is known as convergent nozzle.
(k) Steam enters the steam nozzle at high pressure and high velocity.
(l) Steam leaves the nozzle at high pressure and high velocity.
(m) In reaction turbine, the driving force is only reaction force.

## Long-Answer Questions

1. Describe the working of Parson's reaction turbine.
2. What is meant by cogeneration? What are the essential components of a cogeneration plant?
3. What is meant by pressure compounding and velocity compounding?
4. Explain the formation of steam with a graph.
5. What is specified in the Indian Boilers Act.
6. What are the differences between the impulse and reaction steam turbines.

# Chapter 2
# POWER PLANTS

## 2.1 INTRODUCTION

Power plants are used for the generation of electric power. To improve the standard of living, rapid industrialisation is necessary for which adequate electrical power is essential. In India, there has been considerable increase in power development under various five-year plans.

## 2.2 CLASSIFICATION OF POWER PLANTS

Power plants can be mainly classified as follows:

1. Steam power plant
2. Nuclear power plant
3. Gas-turbine power plant
4. Diesel power plant
5. Hydroelectric power plant
6. Power from alternate sources of energy

A description of the above power plants and alternate sources of energy is provided in this chapter.

## 2.3 STEAM POWER PLANTS

The layout of a steam power plant is given in Fig. 2.1(a). Steam from the boiler is taken to the turbine through the steam pipe fitted with an *expansion joint*. The joint provides a flexible connection to prevent any crack in the steam pipe which is subjected to expansion and contraction due to the variation in temperature. From the turbine, the steam enters a condenser, details of which are shown in Fig. 2.1(b). In the condenser, the exhaust steam from the turbine is condensed due to which a high vacuum is produced. Due to the vacuum, the power output and the thermal efficiency of the turbine are considerably increased. Also, the condensed water can be recirculated in the system. In the condenser, cooling water is circulated by a pump through the water tubes to condense the exhaust steam. The cooling water at the outlet becomes hot and it is taken to a cooling pond or a cooling tower to cool and to recirculate the same water if the power plant is not located on the bank of a river or a lake.

The condensate from the condenser before entering the boiler is subjected to the following treatments.

1. Removal of air and oxygen.

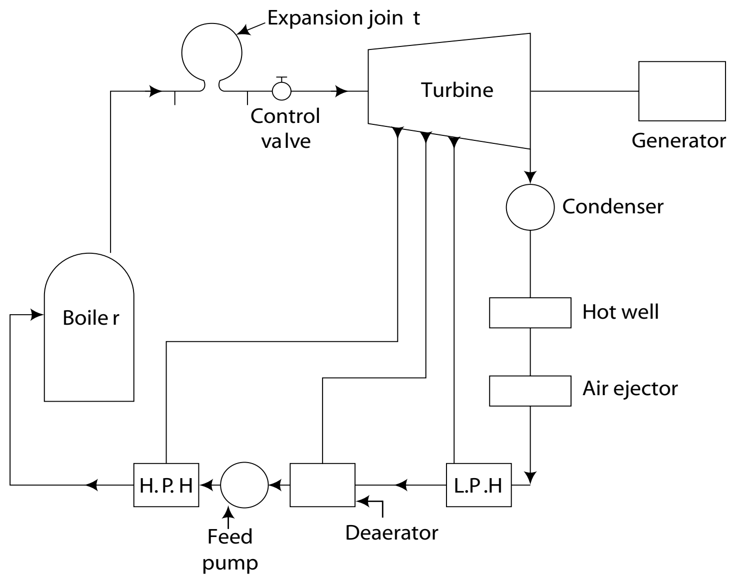



**Fig. 2.1 (a)** *Layout of a steam power plant*

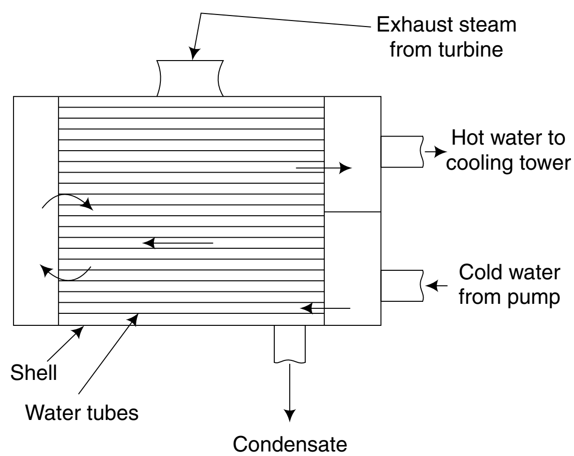



**Fig. 2.1 (b)** *2-Pass steam condenser*

2. Preheating the feed water in different stages using a low-pressure heater (LPH), a deaerator and a high-pressure heater (HPH).

Air and oxygen are removed at the air ejector and the deaerator. In case, air and oxygen are not removed from the feed water, the vacuum cannot be maintained in the condenser, resulting in loss of power and thermal efficiency.

### *Factors to be Considered in the Selection of a Site for a Steam Power Plant*

1. The location of the plant should be at a minimum distance from the load centre (consumer) to avoid transmission losses.

2. Availability of water is a desirable factor.
3. The water should be preferably free from salt to reduce the cost of water treatment.
4. The soil should be satisfactory for a strong foundation.
5. The site should be away from thickly populated areas to reduce the effect of pollution.
6. Adequate transport facility is desirable.
7. Space should be available to store coal and ash.

### 2.3.1 Electrostatic Precipitator

The electrostatic precipitator is extensively used to remove dust and flyash from chimney gases in a power plant using solid fuel. Use of this unit is growing rapidly, because of the strict air quality code. This equipment was first introduced by Dr. F.G. Cottell in 1906 and came to use in 1937 for the removal of dust and ash particles carried with the chimney gases, in thermal power plants.

The general arrangement of an electrostatic precipitator is given in Fig. 2.1.(c). The waste gas with dust and ash is passed between oppositely charged wires and it becomes ionized, as the voltage applied between the wires is quite high in the range of 40,000 to 50,000 volts. The ionized gas is also passed thought vertical metal plates, alternate plates are positively charged and earthed. As the alternate plates are grounded, high intensity electrostatic field exerts a force on positive charged dust particles and drives them towards the grounded plates. The deposited dust particles are removed from the plates, by giving shaking motion to the plates, with the help of cams.

As direct current is not readily available in a power station, it becomes necessary to convert 400 Volts A.C. to high D.C. voltage of about 50,000V. Obviously, this increases the capital cost.

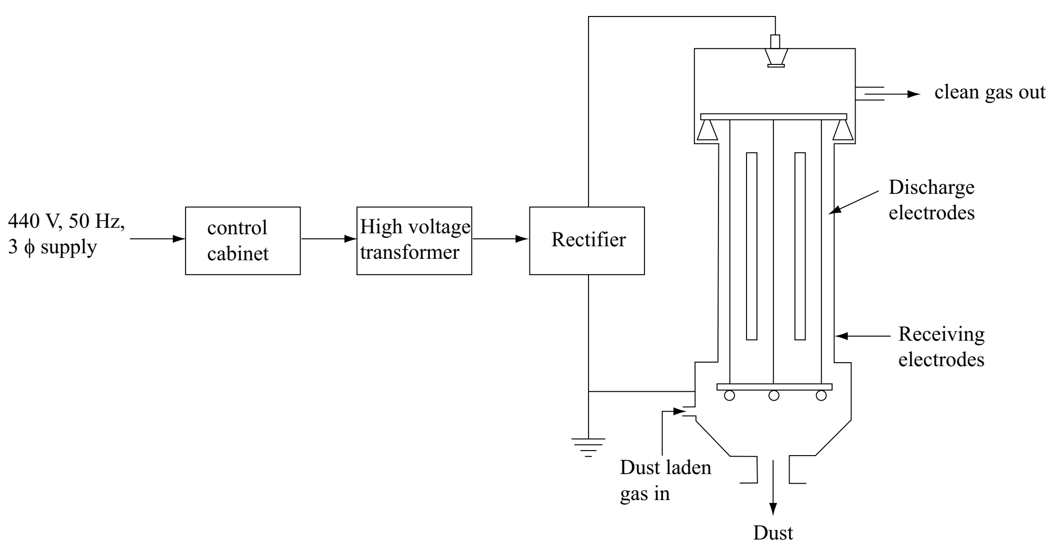



**Fig. 2.1(c)** *Electrolytic precipitator*

## 2.4 NUCLEAR POWER PLANT

A nuclear power plant is very similar to a conventional steam power plant except for the furnace. The nuclear reactor becomes the furnace in this case. It has been estimated that complete fission of 1 kg of Uranium $U^{235}$ produces heat energy equivalent to 4500 tons of coal or 1700 tons of oil.

***Dalton's Atomic Theory*** John Dalton, an English scientist, discovered that an element is made up of extremely small particles called atoms. An atom is the smallest particle of an element. According to Dalton's theory, an atom cannot be split. But, this theory is no longer valid.

***Nuclear Fusion and Fission*** Nuclear reactions of importance to energy production are fusion and fission. In fusion, two or more light nuclei fuse to form a heavier nucleus. In fission, a heavy nucleus is split into two or three ligher nucleus. In both, there is a decrease in mass resulting in the release of exothermic energy.

***Nuclear Fusion*** Energy is produced in the sun and stars by continuous fusion reaction. To cause fusion, it is necessary to accelerate the positively charged nuclei to high kinetic energy by raising the temperature to hundreds of millions of degrees, resulting in a plasma. Fusion reactions are also called thermonuclear, because very high temperature is required. Further details on fusion are beyond the scope of this text.

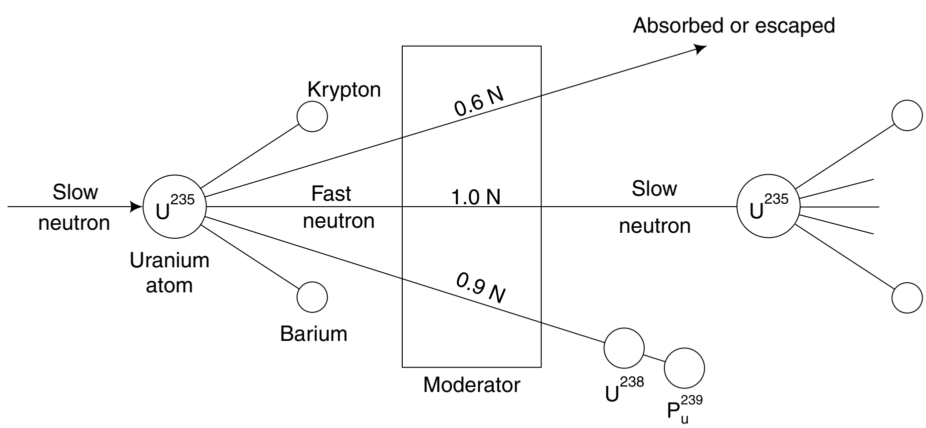



**Fig.2.1(d)** *Nuclear reaction*

***Nuclear Fission*** Contrary to the Dalton's Atomic Theory, it has now been established that a large amount of heat energy is derived by fissioning of the nucleus of a fissionable material like Uranium $U^{235}$. When a neutron bombards the nucleus of $U^{235}$, the atom splits into Krypton and Barium and releases 2.47 fast moving neutrons and also produces a large amount of heat energy.

As in Fig. 2.1(d), one of the neutrons released during the fission continues to fission another nucleus of $U^{235}$ causing a chain reaction which produces enormous amount of heat energy. About 0.9 neutron is captured by $U^{235}$ which gets converted into fissionable material $P_U^{239}$

and about 0.6 neutrons is partly absorbed by the moderator and a part escapes from the reactor. $Pu^{239}$ is a fissionable material and is called secondary nuclear fuel.

***Nuclear Reactor*** Fig 2.1(e) gives the important components of a nuclear reactor.

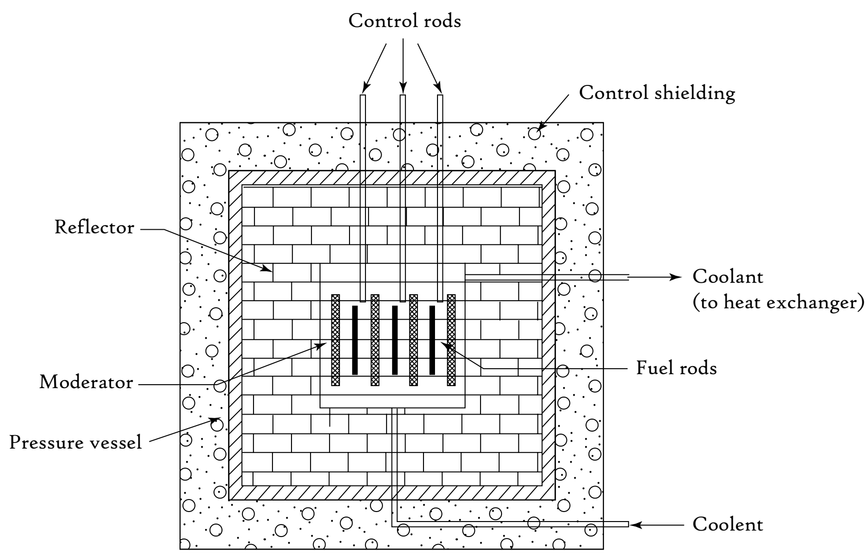



**Fig. 2.1(e)** *Nuclear Reactor*

### *I. Fuel*

1. Natural Uranium $U^{235}$
2. Enriched Uranium
3. Plutonium $Pu^{239}$
4. Plutonium $Pu^{233}$ (Man Made)

### *II. Control Rods*

Control rods absorb neutrons and control the rate of chain reaction. Materials like boron, cadmium act as control rods. To initiate the operation of the reactor, the control rods can be lifted up.

### *III. Moderator*

In any chain reaction, the neutrons produced are fast moving. They are less effective in causing fission of $U^{235}$. So, speed of these neutrons should be reduced. This is done by making these neutrons collide with lighter nuclei of materials like graphite.

***Reflector*** Some of the neutrons produced during fission will try to escape from the reactor and will be lost. Such losses are minimized by surrounding the reactor with a material called reflector which will reflect the neutrons back to the core. Beryllium acts as a reflector.

***Shielding*** During nuclear fission, Alpha, Beta and Gamma particles are produced. They are very harmful to human life. So, it becomes necessary to shield the reactor with thick layer of concrete. The minimum thickness of concrete should be one meter The shell thickness of KAMINI fast breader reactor at Indira Gandhi Center for Atomic Research (IGCAR) is 1.85m.

### 2.4.1 Pressurised Water Reactor (PWR)

The schematic diagram of a pressurised water reactor is shown in Fig. 2.2(a). It is also a water-cooled reactor. The system has primary and secondary loops. In the primary loop, the pressuriser maintains a high pressure in the water in the range of 150 bar. Due to the high pressure of water in the reactor, the water does not boil. The coolant gets heated in the reactor and the hot water goes to the boiler and transfers the heat to the feed water in the boiler in the secondary loop. The feed water evaporates and becomes steam and runs a turbogenerator from which power is obtained. Functions of various parts of the reactor are the same as those of a boiling water reactor.

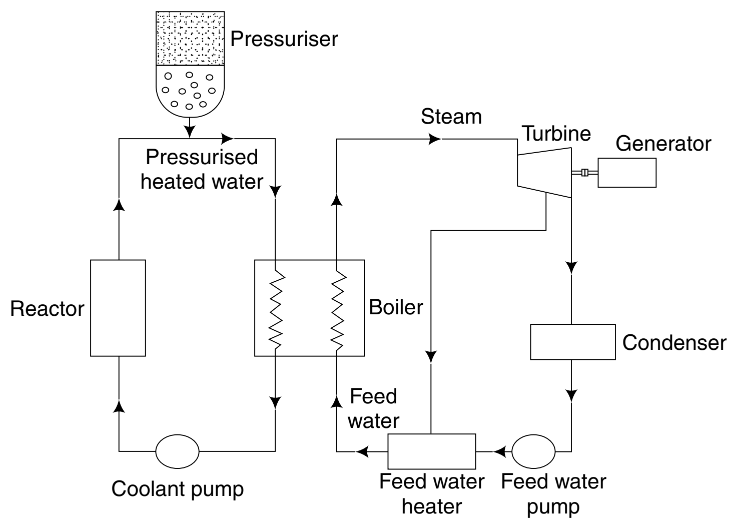



**Fig. 2.2(a)** *Pressurised water reactor*

### 2.4.2 Gas-Cooled Reactor

The schematic diagram of a gas-cooled reactor is shown in Fig. 2.2(b). In this, $CO_2$ is employed as coolant and the heat carried by the gas from the reactor is either used for steam generation in the secondary circuit like pressurised water reactor or is directly used as the working fluid in a gas-turbine plant. Usually, the gas used is $CO_2$ and graphite is the moderator.

$CO_2$ gas gets heated in the reactor and loses its heat to the superheater, evaporator and economiser tubes in the secondary loop. The cooled gas is recirculated again in the primary loop by means of a gas blower. The superheated steam is expanded in the turbine to run the generator to produce electrical power.

### 2.4.3 Safety Precautions for Nuclear Power Plant

The first level of safety in nuclear reactor is the careful design of the reactor and other components of the system with a high degree of reliability, and the chances of malfunction are very small. Apart from the controlling devices like control rods, moderator and coolant in the reactor, some auxiliary safety devices are also provided.

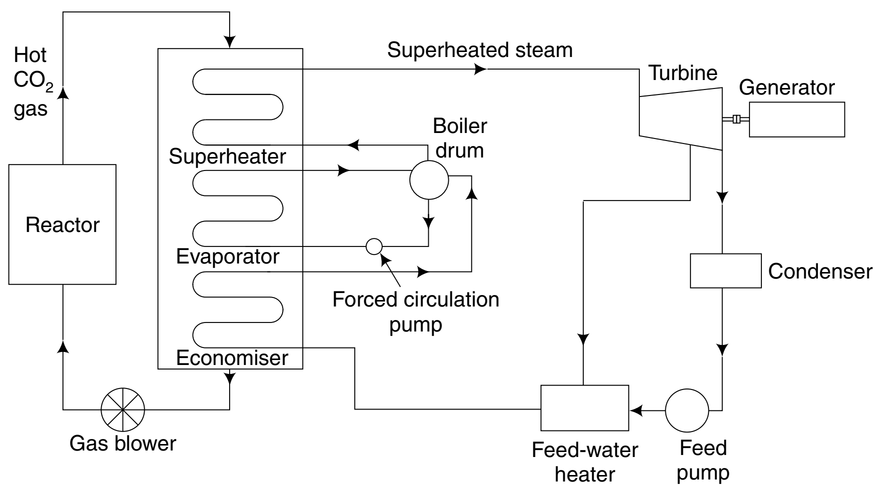



**Fig. 2.2(b)** *Gas-cooled reactor*

When the primary protection system fails, each reactor is provided with some type of back-up protection. One important device is *gas fuse*. The gas used is boron trifluoride. This is filled in a container at high pressure and sealed with a plug which melts when the temperature in the reactor exceeds the safe value. If the temperature rises above the safe value, sufficient volume of gas enters the reactor core and reactivity decreases, due to which the temperature automatically comes down.

### 2.4.4 Nuclear Waste Disposal

The radioactive wastes produced in different stages of nuclear fuel cycle must be disposed off without any hazard to human and plant life. Gaseous wastes are discharged to the atmosphere through high stacks. Moderate liquid wastes, after a preliminary treatment are discharged into deep pits. Active liquids are kept in concrete tanks. These tanks are buried in the ground till their radioactivity decays up to a safe level for disposal.

Solid wastes can be classified as combustible wastes and noncombustible wastes. Combustible solid wastes can be reduced to ashes by putting them into fire (incineration). The noncombustible wastes include incinerator ash. Land burial is the best method employed for solid waste materials.

### 2.4.5 Advantages of a Nuclear Power Plant

1. Very large amount of heat is liberated by a very small quantity of fuel.
2. It is suitable for large power generation.
3. Cost of fuel transportation and storage is less.

### 2.4.6 Disadvantages

1. Installation cost is very high.
2. Availability of nuclear fuel is scarce and cost is high.

3. Large number of trained and qualified personnel are required to operate the plant.
4. Maintenance cost is higher.
5. Problems are involved in waste disposal and there is also a risk of radiation hazards.

### 2.4.7 Atomic Power Stations in India

1. The Tarapur Atomic Power Station in Maharashtra was initially constructed with two boiling water reactors of 160 MW, each under the agreement between India, the United States and the International Atomic Energy Agency. These were the first of their kind in Asia. Recently, an additional two units of 540 MW each have been constructed.
2. The Madras Atomic Power Station at Kalpakkam, about 80 km south of Chennai has two units producing 170 MW each, operative from 1984 and 1986 respectively. Additional reactors are under construction with a capacity of 500 MW This station has been named as the Indira Gandhi Centre for Atomic Research (IGCAR). So, in addition to power production, the station is engaged in active research and development.
3. The Koodenkulam Nuclear Power Plant is under construction in the Tirunelveli district of Tamil Nadu with an agreement with the Soviet Union and will have 8 units with the total capacity of 9200 MW. When completed, they will become the largest nuclear-power generation complex in India. The first unit is scheduled to start operations in December 2009 and the second unit during March 2010.

## 2.5 GAS TURBINES

Gas turbines are used mainly for electric-power generation and also in jet engines of aircraft and in turbochargers of internal combustion (IC) engines. They have limited application in marine engines. Gas turbines have the unique advantage of using any type of fuel, i.e., solid, liquid or gas. Gas turbines operate either on an open cycle or in a closed cycle.

### 2.5.1 Working of an Open-Cycle Single-Stage Gas Turbine

A simple open-cycle gas turbine is represented in Fig. 2.3(a). It consists of a compressor, a combustion chamber and a turbine. The compressor and turbine are connected by a common shaft with a suitable flange. Air from the atmosphere is taken and compressed to a pressure ratio ranging from 2 – 8 before passing to the combustion chamber where the fuel is injected. The fuel

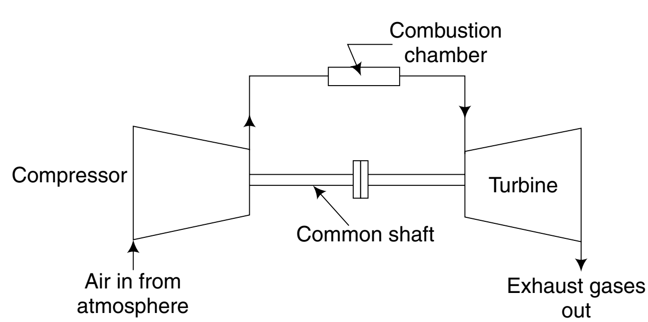



**Fig. 2.3 (a)** *Simple gas turbine*

burns and the temperature is raised at constant pressure. It then passes to the turbine where it expands to its original pressure before being exhausted to the atmosphere. A major portion of the power developed in the turbine is used to drive the compressor and the remainder is available as the net power output. A simple gas turbine works on a Brayton Joule cycle as shown in Fig. 2.3 (b).

***Advantages of Gas Turbines***

1. Possibility of using any type of fuel.
2. Compact size, less weight and low space requirement.
3. Simple foundation and low installation cost.
4. Less requirement of lubrication oil, water, etc.
5. Less vibration.

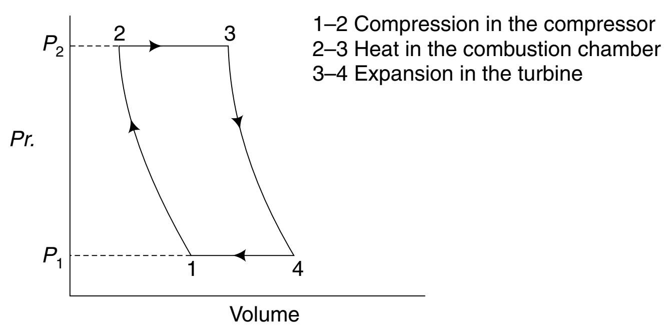



**Fig. 2.3 (b)** *Brayton Joule cycle*

***Disadvantages of Gas Turbines***

1. There is high operating temperature in the combustion chamber and in the turbine. Special high-temperature alloys are therefore needed.
2. Thermal efficiency is very low in the case of simple gas turbine due to high temperature of about 450°C in the waste exhaust gases. So, a single-stage gas turbine is not suitable for electric-power generation.
3. It exudes high-pitch noise due to very high speed in the order of 50,000 rpm.
4. Gas turbines are not suitable for low capacity. In the world market, experimental gas turbines are available operating on a single stage giving an output of 45 kW. Such a turbine can only give the maximum thermal efficiency of about 6 per cent.
5. Large-size exhaust duct due to increased requirement of air for combustion and also for cooling.

***Methods to Improve the Thermal Efficiency of Gas Turbines in Power Plants***

1. By using a multistage compressor with intercooling to reduce the work of compression, as in Fig. 2.4.
2. By using a multistage turbine to reduce the temperature of exhaust gases before leaving the turbine.
3. By using a regenerator, to further reduce the temperature of waste gases.

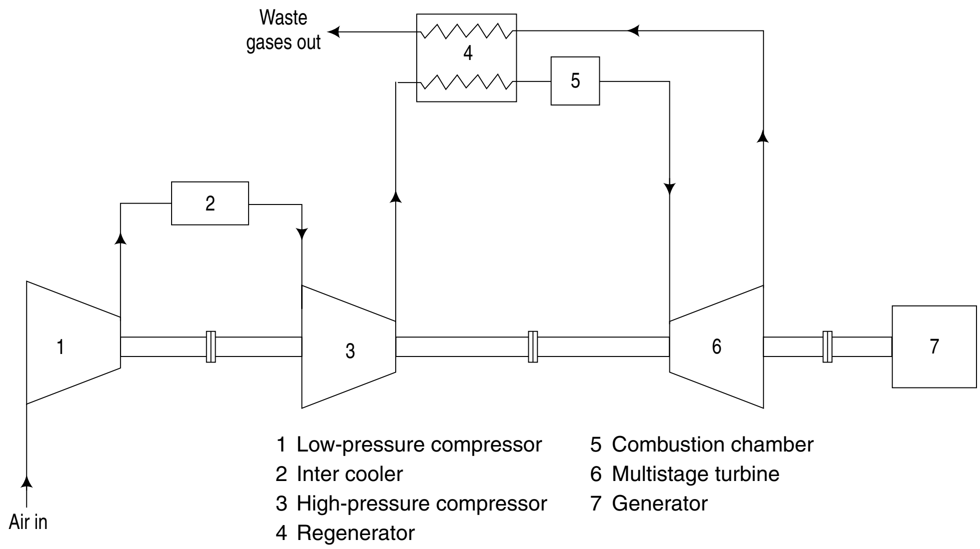



**Fig. 2.4** *Multistage turbine*

## 2.5.2 Closed-Cycle Gas Turbine

The closed-cycle plant can use some stable gas with a higher specific heat as the working medium. Instead of burning the fuel directly in the air stream, an externally fired combustion chamber or furnace is used and heat is transferred to the working medium through a heat exchanger as in Fig. 2.5. Thus, the working medium is uncontaminated by the products of combustion and is constantly recirculated. A cooler is provided for the recirculated working medium before it enters the low-pressure compressor in order to minimise the compressor work. Similarly, an intercooler is also provided to improve the overall efficiency of compression. As a multistage turbine is used, the temperature of exhaust gases leaving the turbine is considerably reduced resulting in a higher thermal efficiency. The regenerator preheats the gas before entering the furnace. By these provisions, the thermal efficiency is further increased to about 30 per cent.

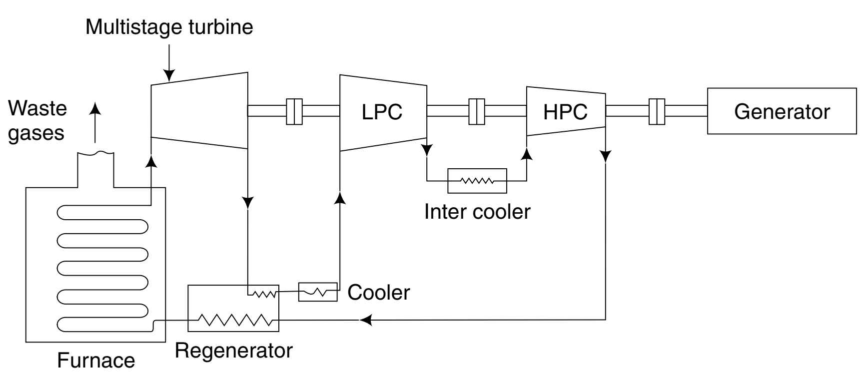



**Fig. 2.5** *Closed-cycle gas-turbine plant*

The closed cycle gas-turbine plant has the following advantages:

1. Flexibility as to the type of fuel.
2. Uncontaminated working medium, and hence maintenance is easier.
3. Possibility of using a gas having better thermal properties as the working medium. By using an inert gas with high specific heat, the unit will become compact.

## 2.6 DIESEL POWER PLANT

The layout of a diesel power plant is given in Fig. 2.6. Normally, multicylinder 2-stroke turbocharged diesel engines are used in power plants. In a turbocharged engine, the atmospheric air is compressed by a compressor run by an exhaust-driven gas turbine and the compressed air is taken inside the cylinder. Due to this, mass of air intake and amount of fuel burnt will be considerably increased giving rise to increased output power and higher thermal efficiency.

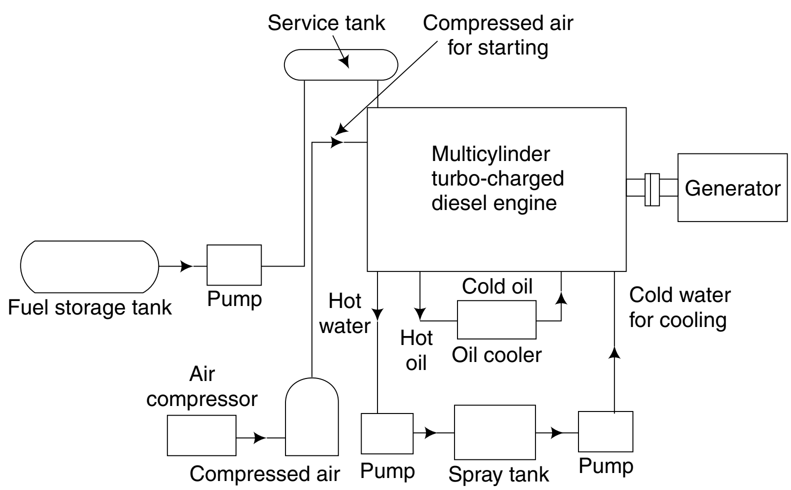



**Fig. 2.6** *Layout of diesel power plant*

Due to turbocharging, the operating temperature of the engine is increased. So, the lubricating oil coming out of the engine should be cooled in an oil cooler. The cooling water from the engines is normally cooled in a spray tank and recirculated. Due to high capacity, the engine is started by using compressed air.

## 2.7 HYDROELECTRIC POWER PLANT

In a hydroelectric power plant, the potential energy of water stored in a dam is made use of in running a water turbine coupled to an electrical generator. It is estimated that about 23 per cent of the total electric power in the world comes from hydro power. In Tamil Nadu, the total generation of power from hydroelectric plants amounts to 1950 MW and in an all-India level, it amounts to about 18000 MW.

### 2.7.1 Layout of a Hydroelectric Power Plant

The layout of a hydroelectric power plant is given in Fig. 2.7. The water from the dam is brought to the water turbine by a large diameter penstock pipe. The penstock pipe is made of steel or reinforced concrete. It is desirable to eliminate sharp bends in the penstock pipe to avoid the loss of head and special anchoring.

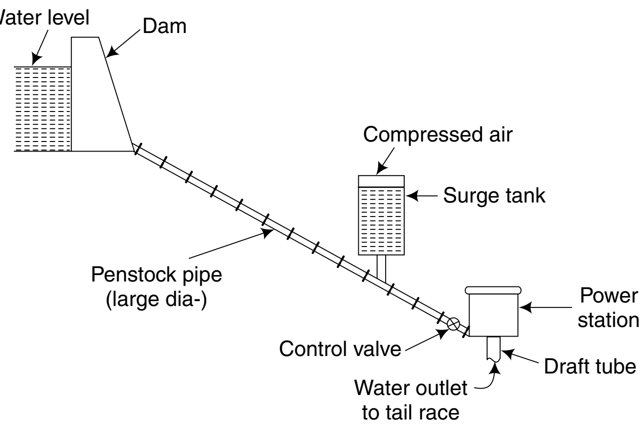



**Fig. 2.7** *Hydroelectric power plant*

Depending upon the load on the turbine, the amount of water needed is controlled automatically by a valve operated by a centrifugal governor. In case, the amount of water is suddenly reduced or stopped by the governor mechanism, water coming down with a high velocity will produce turbulence resulting in a water hammer in the pipe. The penstock pipe may be damaged due to the water hammer. To prevent this, a surge tank is provided. From the turbine, water is allowed to pass through a draft tube to the tail race. The tail race is the water path leading the discharge water from the turbine to the river or canal.

### 2.7.2 Types of Water Turbines

Depending upon the head of water available, different types of water turbines are used as given below:

***1. Pelton Wheel*** It is an impulse turbine used for high head. A pelton wheel is used at Pykara Power House where a head of more than 900 m is available. The turbine is named after Lester A Pelton (1829–1908), an American engineer, who developed it in about 1880.

Figure 2.8(a) shows the Pelton wheel installation. The runner consists of a circular disc with large number of buckets or blades fixed on its periphery. The buckets have the shape of a double semi-ellipsoidal cup. These buckets are made by cast steel, bronze or stainless steel. Water can be controlled by rotating the hand wheel by moving the spear in the case of a small unit. In bigger units, it will be controlled automatically by a governor. The casing is made of cast iron or fabricated steel plates.

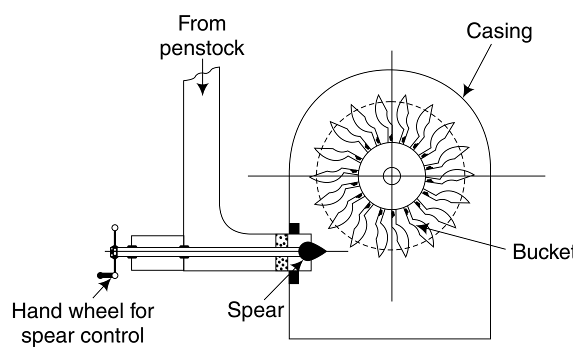



**Fig. 2.8(a)** *Pelton wheel*

***2. Francis Turbine*** It is a mixed-flow type reaction turbine. It is used for medium heads ranging from 50–400 m. Francis turbine is used at the Periyar Hydroelectric Project where a head of about 374 m is available. The main components are a spiral casing, guide blades and a runner as shown in Fig. 2.8(b). This turbine was developed by the American Engineer JB Francis in 1849.

Water from the penstock pipe enters the casing and flows radially towards the centre of the runner. The casing is usually made of steel. The water is guided to the runner by guide vanes. Guide vanes are made of steel or stainless steel. The runner consists of a series of curved vanes numbering 16 to 24. The vanes are so shaped that water enters the runner radially and leaves it axially. It is usually made of mild steel or stainless steel.

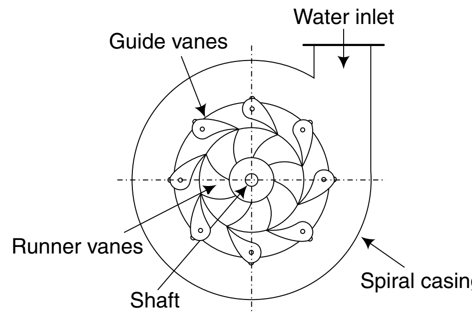



**Fig. 2.8(b)** *Francis turbine*

***3. Kaplan Turbine*** Kaplan turbine is an axial flow reaction turbine. The German engineer V Kaplan developed this turbine in 1916. This is suitable for low heads ranging from 1.5 m. It is similar to the Francis turbine in construction, except for the runner. The runner has only 3, 4 or 6 blades. The four blades or vanes are shown in Fig. 2.8(c). The blades are adjustable only in a Kaplan turbine.

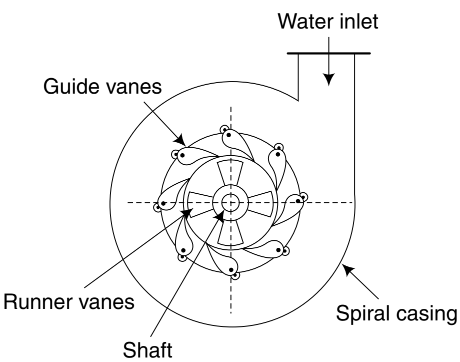



**Fig. 2.8(c)** *Kaplan turbine*

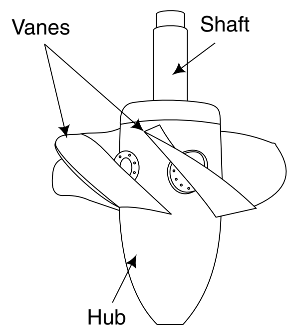



**Fig. 2.8(d)** *Kaplan turbine runner*

**Table 2.1** Comparison of Thermal and Hydroelectric Power

| | **Thermal power** | **Hydroelectric power** |
|---|---|---|
| 1. | Not affected by seasons. | Affected by seasons. |
| 2. | Can be installed at any place. | Only near a dam. |
| 3. | Operating cost is high. | Negligible as there is no fuel cost. |
| 4. | Transmission of power is comparatively easier. | Not so economical as transmission towers should be erected in hill area. |
| 5. | Capital cost is comparatively less. | Cost including dam is much higher. |
| 6. | Fuel may be exhausted in due course of time. | Water will not be exhausted. |
| 7. | There is a problem of pollution of environment. | Free from pollution. |

## 2.8 ENVIRONMENTAL CONSTRAINTS OF POWER GENERATION

Raw energy is processed and transformed into usable energy forms by means of energy- conversion processes. These energy-conversion processes create pollution problems which disturb the ecological balance.

Power plants are used for transforming raw energy into electrical energy. The power generation in coal-fired power plants emits solid particles, $SO_x$, $NO_x$, CO, $CO_2$ and waste chemicals into the environment. Nuclear power plants, thermal power plants, chemical conversion plants, etc., also emit solid, liquid and gaseous pollutants in the environment. The gaseous pollutants cause global environmental problems like global warming and greenhouse effect. Some important environmental constraints of power generation are given below:

***(i) Particulate Matter*** Solid or liquid particles present in the air are called particulate matter. Their size varies from 1 mm to 500 mm. Dust and fly ash emitted from the power plants are the significant sources of particulate matter in air.

***(ii) Acid Rain, Acid Snow, Acid Fog and Dry Acidic Deposition*** Increased concentrations of sulphur oxides ($SO_x$) and nitrogen oxides ($NO_x$) in the atmosphere cause these global environmental effects.

***(iii) Greenhouse Effect*** A greenhouse has transparent glass panes which allow sunlight to enter and prevent exit of heat, $CO_2$ and moisture. The climate inside the greenhouse is warm due to high concentration of $CO_2$ and moisture. A similar effect is created by higher concentration of $CO_2$ in the atmosphere and is called the greenhouse effect.

***(iv) Global Warming*** The warming up of earth due to the greenhouse effect is called global warming. In this process, $CO_2$ in the air allows the entry of radiation heat of sunlight which contains short wavelength waves and the visible portion of the spectrum. This heat is then absorbed by the earth and the atmosphere.

## 2.9 SOLAR ENERGY

From the consumption pattern of various fossil fuels (natural gas, fuel oil, coal, etc.), it has been estimated that petroleum products and coal are not going to last beyond 50 and 100 years respectively. As a result, every country needs to develop technologies which make use of non-conventional sources of energy such as solar, wind, tidal and geothermal.

In spite of the enormous distance between the sun and earth, the radiation output by the sun is very powerful. The earth is shielded from harmful effects of radiation by the atmosphere which surrounds the earth and particularly by the ozone layer in the stratosphere. It has been estimated that the earth receives about $10^{18}$ kWh of solar energy every year. The total worldwide annual energy requirement is about $80 \times 10^{12}$ kWh. This shows that the world energy consumption can be met if a small percentage of sunlight incident on the earth is effectively utilised.

### 2.9.1 Solar Heaters

By using solar radiation, water or any fluid can be heated by using a flat plate collector or a parabolic reflector. Solar water-heating systems have many applications in the domestic and industrial sectors. Such systems can provide hot water for different applications in industries directly or as boiler feed and also in hostels, hotels and canteens.

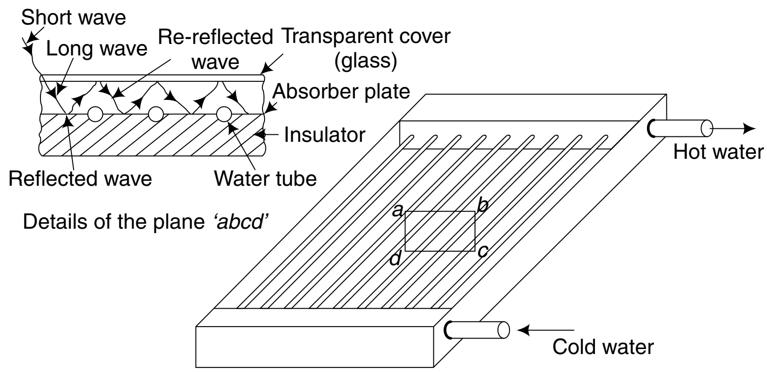



**Fig. 2.9** *Solar flat-plate collector*

***Solar Flat-Plate Collector*** The arrangement of a solar flat-plate collector is shown in Fig. 2.9. The absorber plate normally is metallic. It is usually coated black to absorb more thermal energy. Tubes, passages or channels integral with the collector carry water, air or other working fluids. Insulation should be provided at the back and at the sides to minimise the heat losses. Usually, glass wool is used as insulating material.

A transparent cover (usually glass) should be provided on the top. This cover will permit the radiation from the sun on to the metal plate since it is at a shorter wavelength. When the radiation strikes the plate, a part of the energy is reflected back to the cover. As the radiation is at a higher wavelength, it will not go out to the atmosphere. Instead, the cover will reflect the energy back to the absorber plate and thereby increase the heat transfer. If there is no transparent cover, the reflected energy would have been lost. If the circulating fluid is water, the hot water can be collected in a tank and recirculated. A small water-circulating pump can also be introduced at the inlet side of the collector. Such a system gives a better result due to improved heat transfer.

***Parabolic Reflector*** The parabolic reflector is shown in Fig. 2.10. Highly polished metallic surfaces are used as reflectors. The reflector will normally have a parabolic shape so that the sun rays striking the profile will be reflected on its focal point. If a tube carrying a fluid is kept along the focal line, the fluid will be heated to a very high temperature.

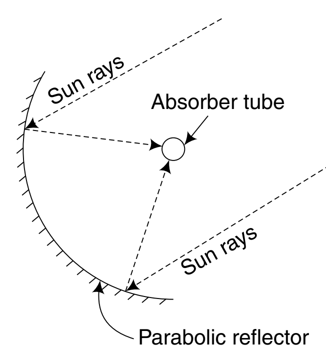



**Fig. 2.10** *Parabolic concentrator*

### 2.9.2 Solar-Power Generation

The World Energy Council predicts a 75% per cent growth in demand for energy by 2020. Most of the electricity is generated from coal, leading to the emission of greenhouse gases such as $CO_2$ which contribute to global warming. The world is trying to reduce greenhouse gas emissions after the Kyoto Summit on Climate Change in 1997 and the ministerial meeting in Buenos Aires in 1998. Today, the use of solar energy for power generation is getting intense attention because it is eco-friendly. At present, the cost of converting solar power into electricity may be high, but it is expected to come down in future.

Recently, a British company has developed a system which uses fixed concave mirrors to trap and concentrate the solar energy which heats the air to about 1000°C. This hot air in turn drives a gas turbine generating electricity. One such system built on the Mediterranean island of Crete employs 800 $m^2$ of mirrors fixed at ground level producing 35 kW of power. This system can be installed in remote villages, hospitals and hotels. It can also be used to desalinate water for air-conditioning and cooking.

The direct conversion of solar energy into electricity is made possible by using the photovoltaic effect in certain materials. The basic unit of photovoltaic system is the solar cell. The first practical solar cell was produced in 1954 by Bell Telephone Laboratories in USA. This cell was made from a single crystal silicon. A solar cell is a semiconductor device processed and fabricated in a manner which permits the generation of voltage when light falls on it. The voltage is capable of driving an electric current through an external circuit.

The power from the solar cells can be used for the operation of a calculator, pump set, radio station, TV station, satellite, etc. The power obtained in the day time can be stored in solar batteries. At present, the cost per unit power is quiet high which can be expected to come down in the future.

### 2.9.3 Solar Power Plant using Butane Boiler

Water in the flat-plate collector is heated to 70 to 80°C due to solar radiation. The hot water heats the butane liquid in the butane boiler. As butane vaporizes at 50°C, water at 70 to 80°C is able to vaporize butane. Hot water after transfering the heat to butane is pumped by a circulating pump to the flat-plate collector where it is again heated.

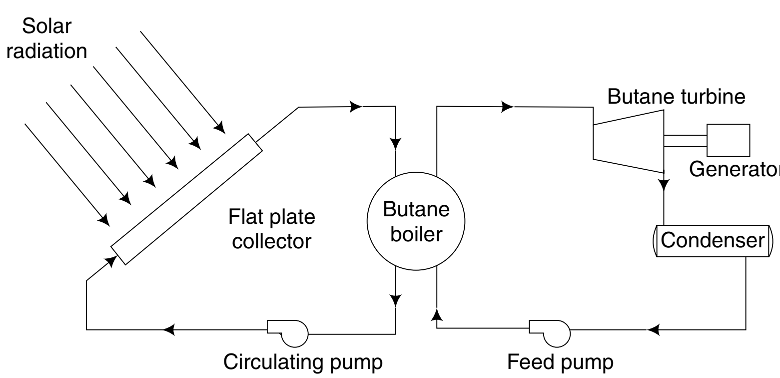



**Fig. 2.11** *Solar power plant using butane boiler*

Butane vapour from the boiler is taken to the butane turbine which is connected to an electric generator. Exhaust vapour from the turbine is condensed in a condenser and the liquid butane is pumped by a feed pump to the butane boiler. The cycle will be repeated.

***Advantages of Solar Power Plant***

- Heat energy from the sun is freely available so there is no pollution problem.
- No transport and storage problem of any fuel.
- Easy to construct and erect.

***Disadvantages***

- Solar energy is not available during night.
- Power produced is rather small.

## 2.10 WIND ENERGY

A total of $10^{11}$ gigawatts of wind power is available around the earth surface. Hence, a successful harnessing of even a small fraction of this substantial energy source can bridge the gap between the energy demand and supply. The potential of wind energy in India is 20000 MW. Large areas having annual average wind speeds of above 20 kmph are available in Tamil Nadu, Andhra Pradesh, Kerala, Karnataka and coastal areas of Gujarat and Maharashtra. At present, about 970 MW of electric power from wind energy is produced in India.

Tamil Nadu stands first in the generation of wind electric power in our country. The total wind electric-power generation in Tamil Nadu in 1995 was about 300 MW which was expected to touch the 1000 MW mark by the beginning of the 21st century. With the assistance of the Ministry of Nonconventional Energy Sources (MNES), the Tamil Nadu Energy Development Agency (TEDA) has erected several windmills in Kayathar, Kethanpur, Muppandal, Puliankulam, Sultanpet and Tuticorin. Muppandal in the Kanyakumari district has the highest average wind speed in Tamil Nadu.

### 2.10.1 Theory of Wind Power

The power available in the wind can be expressed by the following formula.

$$P = \frac{\pi}{8} \rho d^2 V^3$$

where $P$ = power, W

$\rho$ = density of air, kg/m$^3$

$d$ = diameter of blades, m

$V$ = Wind velocity, m/s

The major problem with wind power is that large windmills are required for generating power especially in low wind-velocity regions. The unsteady nature of wind with respect to direction and velocity is an additional problem. For economic viability of wind electric generation, wind velocity should be in the range of 7 m/s to 10 m/s. However, winds at lower velocities can operate positive displacement pumps to lift water from wells for domestic use and minor irrigation.

### 2.10.2 Types of Windmills

The following types of windmills are available.

1. High-speed two-blade windmill
2. Medium-speed three-blade windmill
3. Savonius rotor windmill
4. Darrieus rotor windmill
5. Propeller windmill

A location having the following features can be considered desirable for windmills.

1. The site should have a high annual wind speed.
2. There should be no tall obstructions in the neighbouring area such as
   - Top of a hill with gentle slopes
   - An open shore line
   - A mountain gap which produces wind funnelling

### 2.10.3 Utilisation of Wind Energy

A windmill for generating electricity is shown in Fig. 2.12(a). It consists of a tower-mounted, two-bladed or multi-bladed rotor facing the wind, rotating around a horizontal axis and turning an electrical generator. The power in the wind increases with the cube of the wind speed. Such windmills are manufactured with a capacity from a few kW to several MW in Europe, US and other parts of the world including India. They are either linked to a grid or function in an autonomous mode. For a capacity of 100 kW, the diameter is in the range of 20 m and for 250 kW, the diameter is about 32 m. The total cost of a windmill set-up having a capacity of 250 kW is in the range of Rs 1 crore.

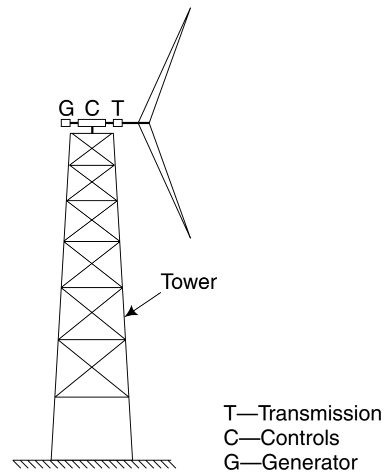



**Fig. 2.12(a)** *Windmill for generating electricity*

Figure 2.12(b) shows the side view of a horizontal axis, multi-bladed windmill for pumping water from wells for domestic use or for minor irrigation. The head against which water is pumped ranges from 3 m to 15 m with a seasonal variation of the order of 5 m. Considering the low speed of windmills, it is most convenient to couple it with positive displacement pumps which can operate efficiently at these speeds. The rotor speed has to be stepped up when it is connected with rotor dynamic pumps. The excess water pumped can be stored in overhead tanks and can be used in nonwindy periods. The tailvane helps the blades to change in the direction of wind. Anemometer can indicate the velocity of wind.

A modern application of windmill water-pumping operation involves pumping water under high pressure to irrigation sprinklers. In another application, the water-pumping windmill drives a small air compressor and the compressed air pumps the water. An advantage of this system is that the windmill can be located at a convenient site away from the well.

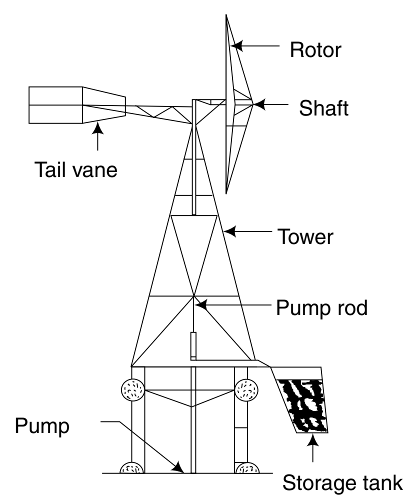



**Fig. 2.12(b)** *Horizontal-axis multi-blade water-pumping wind mill*

## 2.11 TIDAL POWER

The rise and fall of tides in an estuary (river mouth into which the tide flows from the sea) can be made use of to drive specially designed low-head water turbines. These turbines can operate even

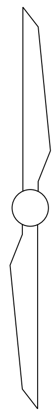


**Fig. 2.12(c)** *Two-blade rotor*

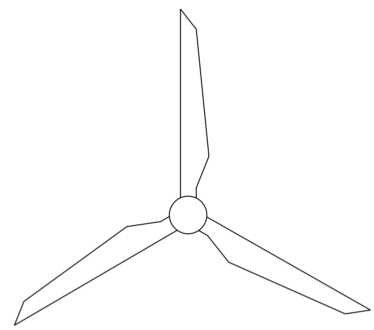


**Fig. 2.12(d)** *Three-blade rotor*

at very low heads as 0.5 m. Several tidal power plants already exist in many parts of the world. At the mouth of the Rance river in France, a tidal plant with a capacity of 240 MW is producing electricity for commercial use since 1966.

India's first tidal power plant, the Kachchh Tidal Power Project, the biggest project of its kind in the world, is to be built at Navlakhi near Kandla port in Gujarat. The expected power to be generated in this project is about 850 MW from 34 generating sets of 25 MW each. As per the estimate in 1991, the cost of the project is about Rs 1150 crore.

A tidal power plant mainly consists of the following:

1. A barrage with gates and sluices
2. One or more basins
3. A powerhouse

A *barrage* is a barrier constructed across the tidal reach to create a basin for storing water. The barrage has to withstand the pressure exerted by the water head and should also resist the shock of the waves. So the side slope of the barrage should not be steep.

A *basin* is the area where water is retained by the barrage. A tidal power scheme can have a single basin or multiple basins. Low-head reversible water turbines are installed in the barrage separating the sea from the basin. The electric generator and a number of turbine components are enclosed in a water-tight compartment with the whole hydroelectric unit submerged in water. The simple arrangement of a tidal power plant is given in Figs. 2.13(a) and 2.13(b) which also indicate the level of water during high tides and low tides.

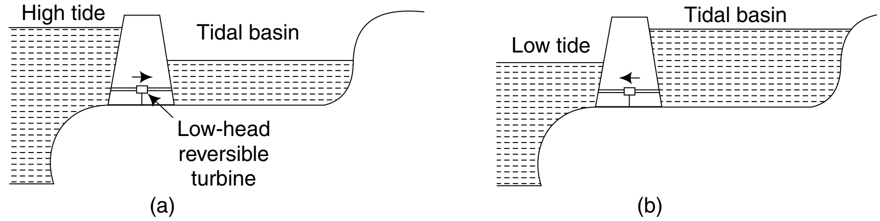



**Fig. 2.13(a) and (b)**

***Advantages of a Tidal Power Plant***

1. It is an inexhaustive source of energy.
2. There is no problem of pollution.
3. After the capital cost, the cost of power generation is quite low.
4. A high output can be obtained compared to solar or wind energy.

***Disadvantages of a Tidal Power Plant***

1. Capital cost is very high compared to a thermal or a hydroelectric power plant.
2. As the head is not constant, variable output is obtained.
3. As the head is only low, a large amount of water is necessary for the turbine.
4. The operation of the turbine will have to be stopped when the available head is less than 0.5 m.

## 2.12 GEOTHERMAL POWER

Geothermal power plants derive energy from the heat of the earth's interior. The average increase in temperature with depth under the earth is 1°C for every 30–40 m. At a depth of 10–15 km, the earth's interior is as hot as l000–1200°C. In certain areas of our planet, the underground heat has raised the temperature of water to over 200°C which bursts out as hot steam through the cracks in the earth's crust. These are called *thermal springs*. This steam can be used for the generation of electric power. Boreholes are normally sunk with a depth up to 1000 m releasing steam and water at temperatures ranging from 200–300°C and pressure up to 30 bar. Steam is transmitted by pipelines to the power station. Due to low steam pressure, the station efficiency is only 10 to 15 per cent.

In New Zealand, geothermal power plants account for 40 per cent of the total electric output, and in Italy for 6 per cent. Several installations for output, up to about 20 MW are in use in various parts of the world, but the chief installations are the 500 MW station near Lardarele, Italy, and the 250 MW station at Wairaki, New Zealand.

Even in India, hot springs are available. Manikaran in Himachal Pradesh and Pugger Valley in Jammu and Kashmir have good potential for generation of energy. These areas have been surveyed and recommended for the installation of geothermal power plants with a capacity of 25 MW.

## 2.13 OCEAN THERMAL ENERGY CONVERSION (OTEC)

The heat contained in the ocean could be converted into electricity by utilising the temperature difference of 20–25 K between the warm water on the surface and the cold water at a depth of about 600 m. The high temperature of surface water could be used to heat some low-boiling organic fluid, the vapour of which could run a heat engine. The exit vapour would be condensed by pumping cold water from the deeper regions. The amount of energy available for ocean thermal power generation is enormous.

The first OTEC plant was built by the Frenchman Georges Claude in 1929 at the Mantanzas Bay in Cuba. The warm surface water was at 25°C. The cold water at 11°C was tapped by a long pipe. As the Claude plant used an open cycle in early times, the open cycle system is sometimes referred to as '*Claude cycle*'. In the open cycle, the condensate need not return to the evaporator. A schematic diagram of the open cycle OTEC system is shown in Fig. 2.14.

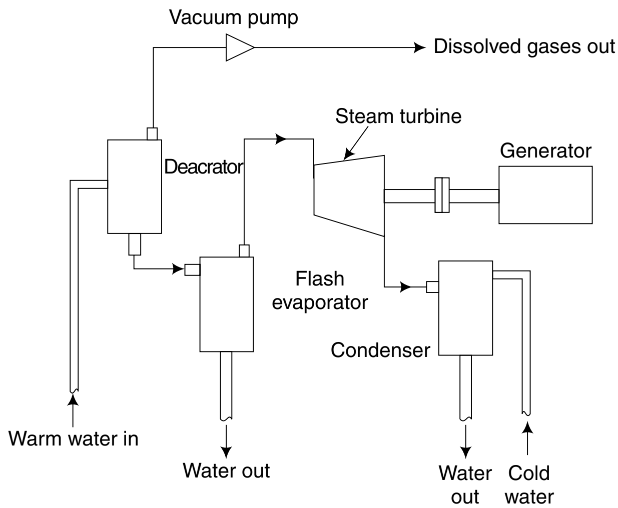



**Fig. 2.14** *Schematic diagram of an open-cycle OTEC system*

### 2.13.1 Open-Cycle OTEC System

The open cycle uses sea water as the working fluid. The warm water is first sent to the deaerator where the dissolved gases are removed by means of a vacuum pump. Then, the warm water is flash evaporated under a partial vacuum in the flash evaporator. The low pressure steam is then passed through a turbine which extracts energy from it and runs a generator. The vapour, after expansion in the turbine, is then cooled in the spray condenser (direct contact) where the condensate is mixed with the cooling water, and the mixture is discharged into the ocean.

It is to be noted here that since we have to obtain energy from low-pressure steam, extremely large-sized turbines must be used.

The cost of an open-cycle system for producing electric power is significantly greater than that of a closed-cycle system. The turbine cost alone amounts to almost half the cost of the entire power system.

### 2.13.2 Closed Cycle OTEC System

The first published work on OTEC by d' Arsonvol in 1881 actually suggested a closed cycle, and that article proposed sulphur dioxide as the working fluid. Later, in the closed cycle, working fluids such as ammonia, propane or freon with higher vapour pressures at the temperatures available were used.

The most recent design on the closed-cycle OTEC system was done by Anderson and Anderson in the l960s. Hence, the closed cycle is sometimes referred to as '*Anderson cycle*'. They used propane as the working fluid, with a 20°C temperature difference between the warm surface and cold water. The cold water was taken from a depth of about 600 m. Roughly, 14 per cent of the gross power was expected to be consumed internally. The size of the plant was gigantic. A schematic diagram of the closed cycle OTEC power plant is shown in Fig. 2.15.

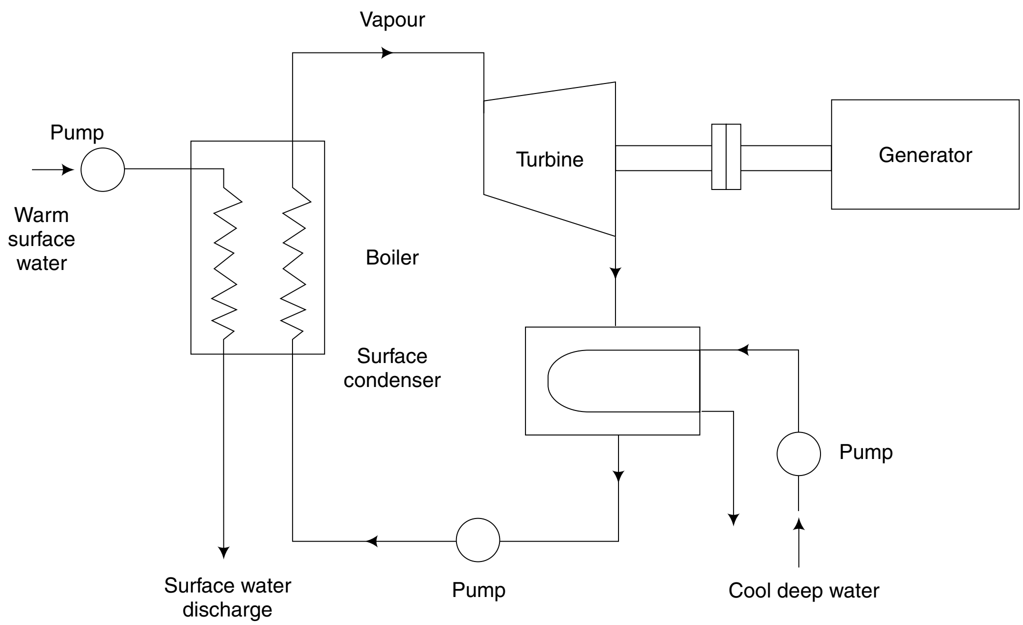



**Fig. 2.15** *Schematic diagram of a closed-cycle OTEC power plant*

In boilers and condensers, extensive areas are needed to transfer significant amounts of heat due to low temperature differences. In other words, large volumes of water must be circulated through the OTEC power plant, requiring large heat exchangers.

The warm water from the surface of the sea is pumped into the boiler where it loses its heat to the propane and is discharged out. The propane gets vaporized and is expanded in the turbine coupled to a generator producing the electrical power. The vapour after expansion is condensed in the surface condenser by means of cool deep-sea water. The condensed propane is again sent to the boiler by means of a pump.

***Recent development of OTEC systems*** In the international scenario, large number of countries have recently been active in OTEC research and development. These include Japan, Sweden, Germany and Netherlands.

## Short-Answer Questions

1. *Answer the following questions:*
   (a) List the conventional power plants.
   (b) What are the main purposes of a condenser in a steam power plant?
   (c) Write three factors to be considered for the selection of a steam-power-plant site?
   (d) State two advantages and disadvantages of a nuclear power plant.
   (e) Briefly write the working principle of a gas turbine.
   (f) List the main components of an open-cycle gas turbine.

(g) Give two advantages and disadvantages of a gas turbine.
(h) State the methods of improving the thermal efficiency of a gas-turbine cycle.
(i) Give two examples for reaction hydraulic turbine.
(j) What is the use of a surge tank in a hydraulic power plant?
(k) What are the alternate sources of energy to fossil fuel?
(l) What is a 'solar cell'?
(m) Describe a solar heater with an example.
(n) Give two locations of windmill power plants in Tamil Nadu.
(o) What are the main components used in a tidal power plant?
(p) Explain greenhouse effect.
(q) What is global warming?
(r) What is meant by Nuclear Fusion?
(s) Compare Nuclear Fission & Nuclear Fusion.
(t) Mention different types of Nuclear fuels.
(u) What are thermal springs?
(v) What are the major parts of a tidal power plant?
(w) What is a basin?
(x) For a wind velocity of 9m/s, how much should be the ideal diameter of the blades?
(y) What are the functions of Electrolytic Precipitator?

2. *Fill up the blanks with suitable word/words:*
(a) A nuclear power plant is similar to a steam power plant, except that ________ is replaced by ________.
(b) Thermal shielding reduces ________ and the concrete shielding prevents ________ in a nuclear power plant.
(c) In a diesel power plant, turbocharging is used to increase ________.
(d) ________ turbine is used in a hydroelectric power plant.
(e) The Pelton wheel is an example of ________ turbine.
(f) A windmill converts ________ energy of ________ to electricity.

3. *Choose the correct answer from the following:*
(a) Heat energy released by 1 kg of uranium is equivalent to
(i) 3000 tons of coal (ii) 4500 tons of coal
(iii) 450 tons of coal (iv) 1 kg of coal
(b) In an open-cycle gas turbine, the fuel is injected in the
(i) compressor (ii) turbine
(iii) combustion chamber (iv) condenser
(c) An axial-flow hydraulic turbine is the
(i) Francis turbine (ii) Kaplan turbine
(iii) Pelton wheel

(d) A solar cell works on

(i) photovoltaic effect (ii) Thomson effect

(iii) Zeebeck effect (iv) solar effect

(e) In a Nuclear Reactor, what are the functions of

(i) Control rods (ii) Moderator

(iii) Reflector (iv) Concerete shell.

4. *State whether the following statements are true or false:*

(a) A deaerator is used to remove air and oxygen from the condensate in a steam powerplant.

(b) Thermal efficiency of a simple gas turbine is very low.

(c) In a hydroelectric power plant, a centrifugal governor is used to control the amount of water, depending upon the load on the turbine.

(d) A solar cell converts electrical energy into solar energy.

(e) The fluid will be heated to a very high temperature in a parabolic reflector compared with flate-plate collector.

## Long-Answer Questions

1. What are the functions of Electrolytic Precipitator?
2. Explain with a neat sketch, the working of a closed cycle gas turbine.
3. Explain with a neat sketch the working of a nuclear reactor.
4. Describe the 'Open Cycle OTEC System'
5. Describe the 'Closed Cycle OTEC System'
6. List the advantages and disadvantages of Tidal power plants.
7. List the types of windmills and describe how they utilize wind energy.
8. Describe the working of solar flat plate collectors.

# Chapter 3
# PUMPS

## 3.1 APPLICATIONS OF PUMPS

Pumps have wide applications in pumping water, fuel, chemical and viscous fluids like lubricants. Water pumps are used to pump water from borewells or open wells for residential buildings and agricultural purposes. They are also used for cooling of petrol engines, diesel engines, gas turbines, exhaust steam in condensers in power plants. Special high-pressure injector pumps are used to pump water in steam boilers, during operation.

Fuel pumps and lubricating oil pumps are used for the operation of IC engines, gas turbines, steam power plants, etc. They also have immense industrial applications.

To name a few, in automobile industry, pumps are used for automatic transmission, power steering, hydraulic brake, etc. In the field of agriculture, pumps are used for hydraulic-driven farm equipment. Also, in the field of material handling, pumps are used in earth-moving equipment, cranes, lifts, etc.

In municipalities and corporations, special pumps are used for sewage disposal.

**Table 3.1** 3.1.1(unitalicize)

| | Types of Pumps | Applications |
|---|---|---|
| 1. | Reciprocating pumps | To pump water to overhead tanks in buildings and also for agriculture |
| 2. | Centrifugal pump | |
| 3. | Compressor pumps | |
| 4. | Submergible pumps | |
| 5. | Vane pumps | To pump semi-viscous liquids |
| 6. | Gear pumps | To pump viscous oil for lubrication |
| 7. | Injector pump | To pump boiler feed water during its operation |
| 8. | Different types of fuel pumps | To pump petrol or diesel oil in IC engines |
| 9. | Screw pumps | To pump liquid mixed with solid materials. |

In this text, however, only the first two types will be dealt with.

### 3.1.2 Classification

Broadly, pumps are classified as

1. Reciprocating pumps
2. Centrifugal pumps
3. Compressor pumps
4. Submergible pumps

In this textbook, only the first two types will be dealt with.

## 3.2 RECIPROCATING PUMPS

The reciprocating pumps are classified as

1. Single acting
2. Double acting

### 3.2.1 Working of a Single-Acting Reciprocating Pump

As in Fig. 3.1, it consists of the following parts:

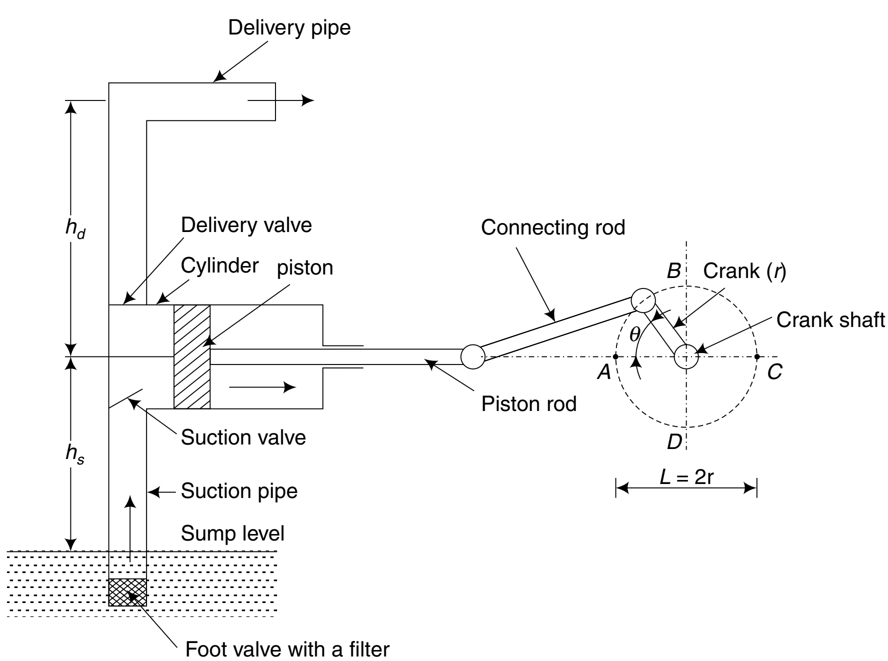



**Fig. 3.1** *Single-acting reciprocating pump*

1. Cylinder with a piston
2. Piston rod, connecting rod, crank and crank shaft

3. Suction pipe with a foot valve (one-way valve) and filter
4. Delivery pipe
5. Suction valve
6. Delivery valve

The crankshaft is coupled to an electric motor or a diesel engine. When the motor or engine is started, the piston moves to and fro inside the cylinder. When the piston moves right in the direction of arrow, a vacuum will be produced in the cylinder due to which the suction valve opens and the water is sucked up from the sump and enters the cylinder through the suction pipe.

When the piston moves in the left direction, pressure is created in the water due to which the delivery valve is opened and water is forced into the delivery pipe and finally to the required height.

### 3.2.2 Working of a Double-Acting Pump

In the double-acting pump, water acts on both sides of the piston. There are two suctions pipes and two delivery pipes, as shown in Fig. 3.2. When there is a suction stroke on one side of the piston, there will be a delivery stroke on the other side of the piston. Thus, for each revolution of the crankshaft, there will be two delivery strokes and so, double the amount of water is delivered by this type of pump.

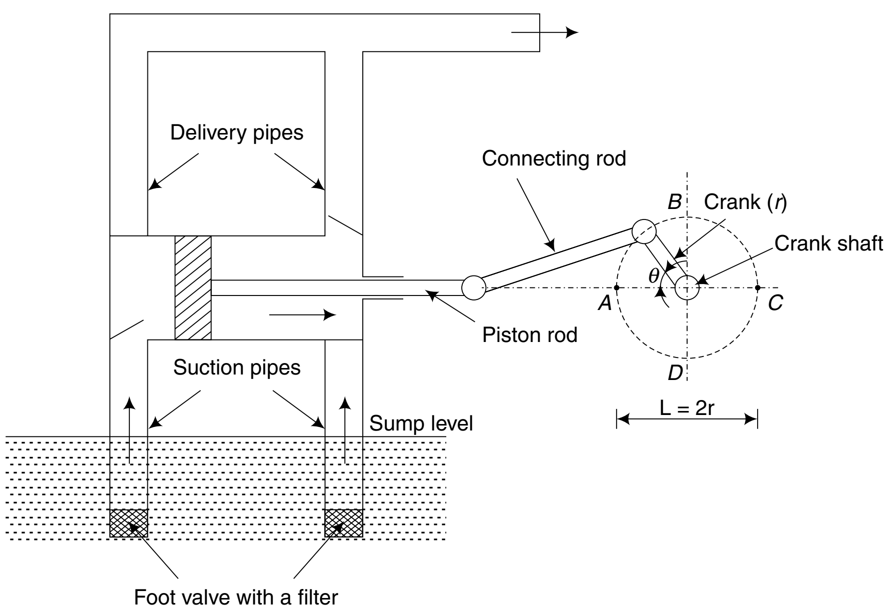



**Fig. 3.2** *Double-acting reciprocating pump*

### 3.2.3 Differences between Single-Acting and Double-Acting Pumps

**Table 3.2**

| | Single Acting | Double Acting |
|---|---|---|
| 1. | One suction pipe only | Two suction pipes |
| 2. | One delivery pipe only | Two delivery pipes |
| 3. | Water acts on one side of the piston | Water acts on both sides of the piston |
| 4. | During one rotation of the shaft, there is only one delivery stroke | Two delivery strokes |
| 5. | Water pumped will be less | Double the amount |
| 6. | Power of the motor or engine is less | Higher power is required |
| 7. | Cost is less | Cost is more |

## 3.3 CENTRIFUGAL PUMPS

The main parts of a centrifugal pump are given in Fig. 3.3. It consists of

1. Impeller
2. Casing
3. Suction pipe fitted with a foot valve (one-way valve) and filter; the foot valve will not allow the water to come down
4. Delivery pipe

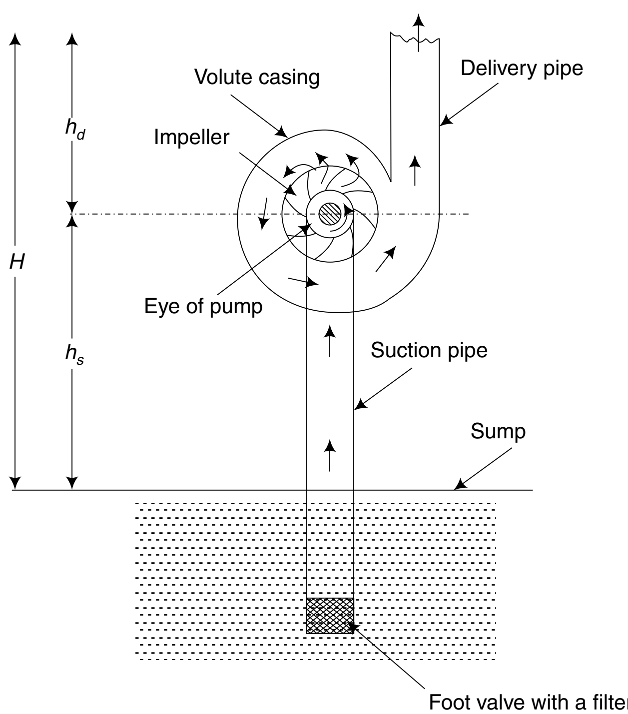



**Fig. 3.3** *Main parts of a centrifugal pump with volute casing*

### 3.3.1 Impeller

The impeller is a metallic disc fitted with a number of curved vanes. Initially, water will be poured inside the casing and the process is called priming. So, after priming, the impeller will be immersed in water inside the casing. When the impeller is rotated by an electric motor or an engine, it will produce centrifugal force due to which kinetic energy or velocity energy will be produced in the water. This is finally converted into pressure energy due to which water is pumped up.

### 3.3.2 Casing

The casing surrounds the impeller. The area between the impeller and casing is gradually increasing till the delivery pipe. Due to this, the velocity of flow of water will be gradually decreased. Due to the reductions in kinetic energy, the pressure energy of water is increased. The following three types of casings are normally used.

***Volute Casing*** The gap between the impeller and the casing is comparatively less, as in Fig. 3.3. So, eddies or turbulence will be formed which reduces the efficiency of the pump. However, the size of the casing will be small and the cost will be less.

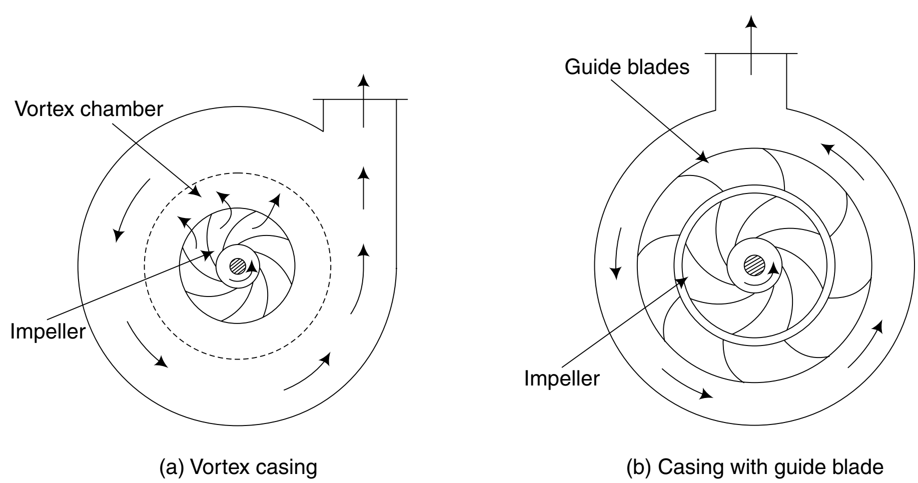



**Fig. 3.4** *Different types of casing for centrifugal pumps*

***Vortex Casing*** As shown in Fig. 3.4(a), the space between the impeller and the casing is increased by introducing a circular chamber. As eddies are reduced, the efficiency of the pumps with vortex casing is increased.

***Casing with Guide Vanes or Diffuser Casing*** In this type, the impeller is surrounded by a set of guide vanes or diffuser as in Fig. 3.4(b). The shape of the guide vanes should be carefully designed to ensure that the water flow from the impeller enters the guide vanes without shock. Gradual increase in area of guide vanes reduces the velocity of flow resulting in pressure increase.

### 3.3.3 Differences between Reciprocating Pump and Centrifugal Pump

**Table 3.3**

| | Reciprocating pumps | Centrifugal Pump |
|---|---|---|
| 1. | Can be used for high head | Medium head |
| 2. | Can pump less quantity only | Large quantity can be pumped |
| 3. | Discharge is not continuous | Continuous flow |
| 4. | Cost is high | Cost is low |
| 5. | Cannot run at high speed | Can run at high speed |
| 6. | Cannot pump viscous fluid | Can pump viscous fluid. |

## Short-Answer Questions

1. What is the function of a foot valve in the suction pipe?
2. Tabulate the differences between single-acting and double-acting reciprocating pumps.
3. In a centrifugal pump, compare volute casing and vortex casing.
4. What is priming?
5. Tabulate the differences between the reciprocating pump and centrifugal pump.

## Long-Answer Questions

1. Describe the different types of pumps and their applications
2. Explain the working of a single-acting reciprocating pump with a neat sketch.

# Chapter 4
# IC ENGINE

## 4.1 INTRODUCTION

Petrol engines and diesel engines are classified as internal combustion engines, abbreviated as IC engines. These engines have extensive applications in transport by road, rail, sea and air. These are made use of in motorcycles, scooters, cars, buses, lorries, railway engines, ships and aero engines. IC engines have led to a major revolution in transport. These engines have also contributed to the development of agriculture through tractors, harvesters, etc. IC engines also play a vital role in major construction work through bulldozers and other equipment. Thus, development of IC engines has made a great contribution to human comfort and to the tremendous progress of agriculture and industry. It is surprising and rather unbelievable that about 120 years back, there was no IC engine at all in any part of the world. Obviously, due to the rapid development in science and technology in the recent years, the present generation enjoys more comfort than our ancestors.

But, the world is going to face a crisis for fuel in about 75 years when the crude oil in the Gulf countries is expected to be exhausted. Under these circumstances, leading automobile companies in the world are investing huge amounts in research and development to find alternate fuel to replace diesel and petrol.

## 4.2 CLASSIFICATION OF IC ENGINES

IC engines can be classified as follows:

1. According to the type of fuel used
   (a) Petrol engine
   (b) Diesel engine
2. According to the cooling system
   (a) Air-cooled engine
   (b) Water-cooled engine
3. According to the cycle of operation
   (a) Four-stroke cycle engine
   (b) Two-stroke cycle engine
4. According to the charge pressure
   (a) Naturally aspirated engine
   (b) Supercharged/turbocharged engine for higher capacity

5. According to the number of cylinders
   (a) Single-cylinder engine
   (b) Multicylinder engine

## 4.3 MAIN COMPONENTS OF IC ENGINES

A simple sectional elevation of a 4-stroke engine is given in Fig. 4.1(a) indicating the various components.

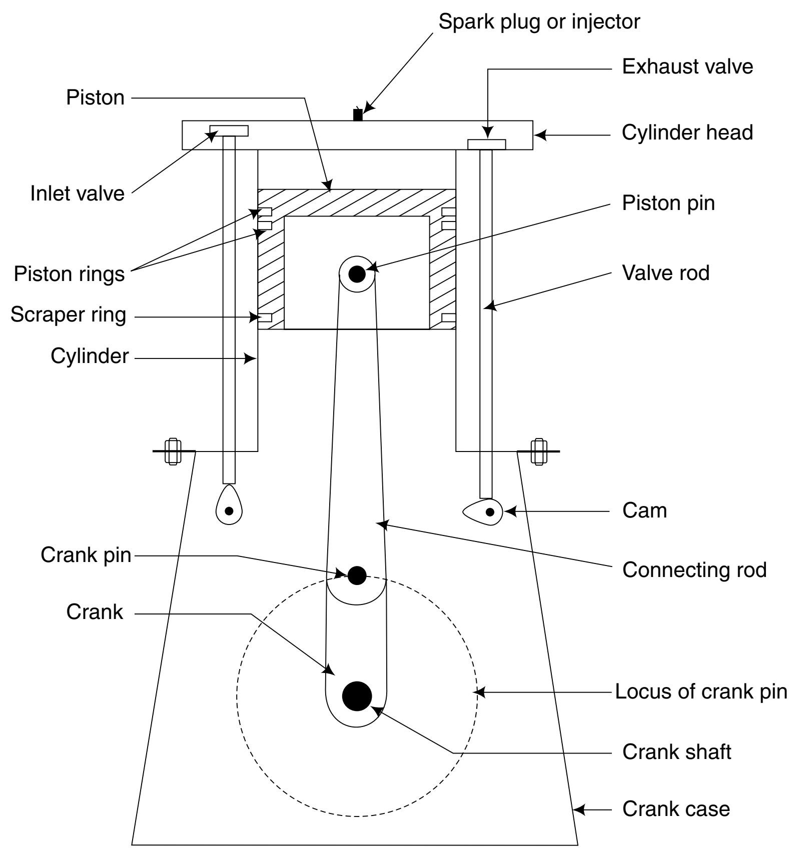



**Fig. 4.1(a)** *Four-stroke engine*

***1. Cylinder*** The cylinder allows the piston to move to and fro. The cylinder is made of cast iron or steel or an aluminium alloy. Sometimes, a liner made of alloy cast iron is inserted into the cylinder which can be replaced when worn out.

***2. Cylinder Head*** It is fitted on the top of the cylinder. A gasket is provided between the cylinder and the cylinder head to prevent the leakage of hot gases. The cylinder head also accommodates the inlet valve, the exhaust valve, and the spark plug or injector.

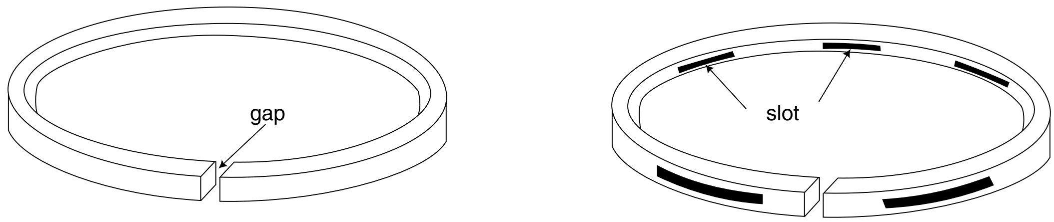



**Fig. 4.1(b)** *Piston rings*

***3. Piston*** It transmits the force exerted by the burning gases to the connecting rod and finally to the crank shaft. The piston is usually made of cast iron or steel or an aluminium alloy. There is an interesting and complex science behind the design and manufacture of a piston of an IC engine. The diameter of a piston in a large marine engine is about 1 m.

***4. Piston Rings*** Two different types of piston rings are housed in the circumferential grooves provided on the outer surface of the piston. The function of upper rings known as compression rings is to provide gas-tight sealing to maintain the compression pressure inside the cylinder and to prevent the leakage of burnt gases into the crank case. The function of the lower rings is to scrap the used lubricating oil into the crank case. These rings are called scraper rings.

***5. Connecting Rod*** This transmits the force from the piston to the crank shaft. It also helps in converting the reciprocating motion of the piston into the rotary motion of the crank shaft. For the lubrication of the piston pin in the connecting rod, a small hole is provided from the big end to the small end. The small end of the connecting rod is attached to the piston by a gudgeon pin or piston pin.

***6. Crank Shaft*** Great care should be taken in the proper design of the crank shaft. Alloy steels are used for the crank shaft to withstand the high stress and strain. The crank shaft is provided with suitable holes to help in the lubrication system. The crank case serves as a sump for the lubricating oil.

***7. Flywheel*** It is mounted on the crank shaft. The flywheel stores the excess energy during the power stroke of the engine and helps the movement of the piston during the remaining idle strokes.

***8. Cams*** Properly designed cams control the opening and closing of the inlet and exhaust valves in the case of four-stroke engines. Cams are rotated by a cam shaft driven by the crank shaft through gears.

## 4.3.1. Compression Ratio

The compression ratio is defined as $\frac{V_S + V_C}{V_C}$ where

$V_s$ is the stroke volume, and

$V_c$ is the clearance volume.

This is further explained by the following example:

*A motorcycle has a cylinder diameter of 4.6 cm and a stroke of 4.2 cm. If the clearance volume is 12.2 cc, determine the compression ratio r.*

$$\text{Stroke volume} = \frac{\pi d^2}{4} \times l$$

$$= \frac{\pi (4.6)^2}{4} \times 4.2 = 67.8 \text{ cc}$$

The compression ratio

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

$$= \frac{67.8 + 12.2}{12.2} = 6.7$$

## 4.4 WORKING OF A FOUR-STROKE PETROL ENGINE

Figure 4.2 depicts the working of a typical four-stroke petrol engine. The different strokes are described in this section.

***1. Suction Stroke*** During this stroke, the inlet valve is kept opened and the exhaust valve is closed. The piston comes down to the bottom dead centre (BDC) from the top dead centre (TDC). Pressure in the cylinder will be slightly less than the atmospheric pressure. Petrol–air

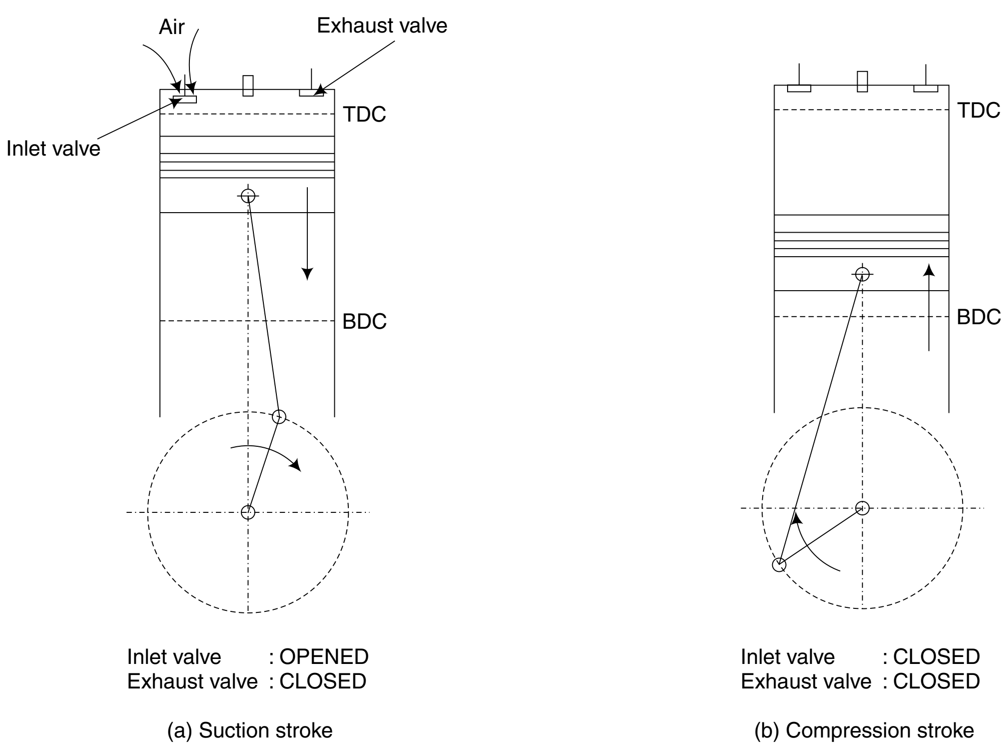



**Fig. 4.2** (contd.)

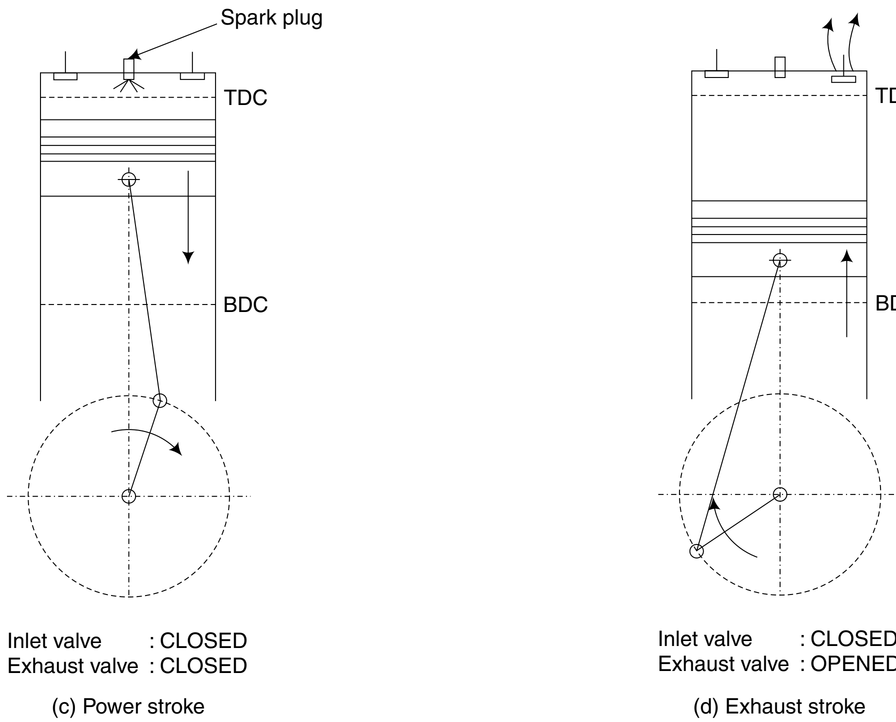



**Fig. 4.2** *4-stroke cycle petrol engine*

mixture in the correct proportion from the carburetter is drawn inside the engine cylinder through the inlet valve.

***2. Compression Stroke*** In this stroke, both the inlet and exhaust valves are kept closed. The mixture of petrol–air is compressed when the piston moves up to TDC. The compression ratio varies from 7–10 for petrol engines. The ratio between the cylinder volume before compression to the volume after compression is known as the compression ratio. At the end of the compression stroke, a spark is produced at the spark plug due to which combustion starts resulting in high pressure and temperature which are comparatively less than that of a diesel engine.

***3. Working or Power Stroke*** During this stroke, both valves are kept closed. The piston is pushed down from TDC to BDC. The force above the piston is transmitted to the crank shaft through the connecting rod and crank mechanism. Excess energy due to the combustion is stored in the flywheel which helps for the operation of three idle strokes.

***4. Exhaust Stroke*** During the stroke, the exhaust valve is kept opened and the inlet valve is kept closed. The piston moves up from BDC to TDC. The waste gases are sent out through the exhaust valve and the cycle is repeated.

During these four strokes, the crank shaft will make two revolutions. The thermal efficiency of a four-stroke engine is higher compared to a two-stroke cycle engine. Most of the cars operate on a 4-stroke cycle.

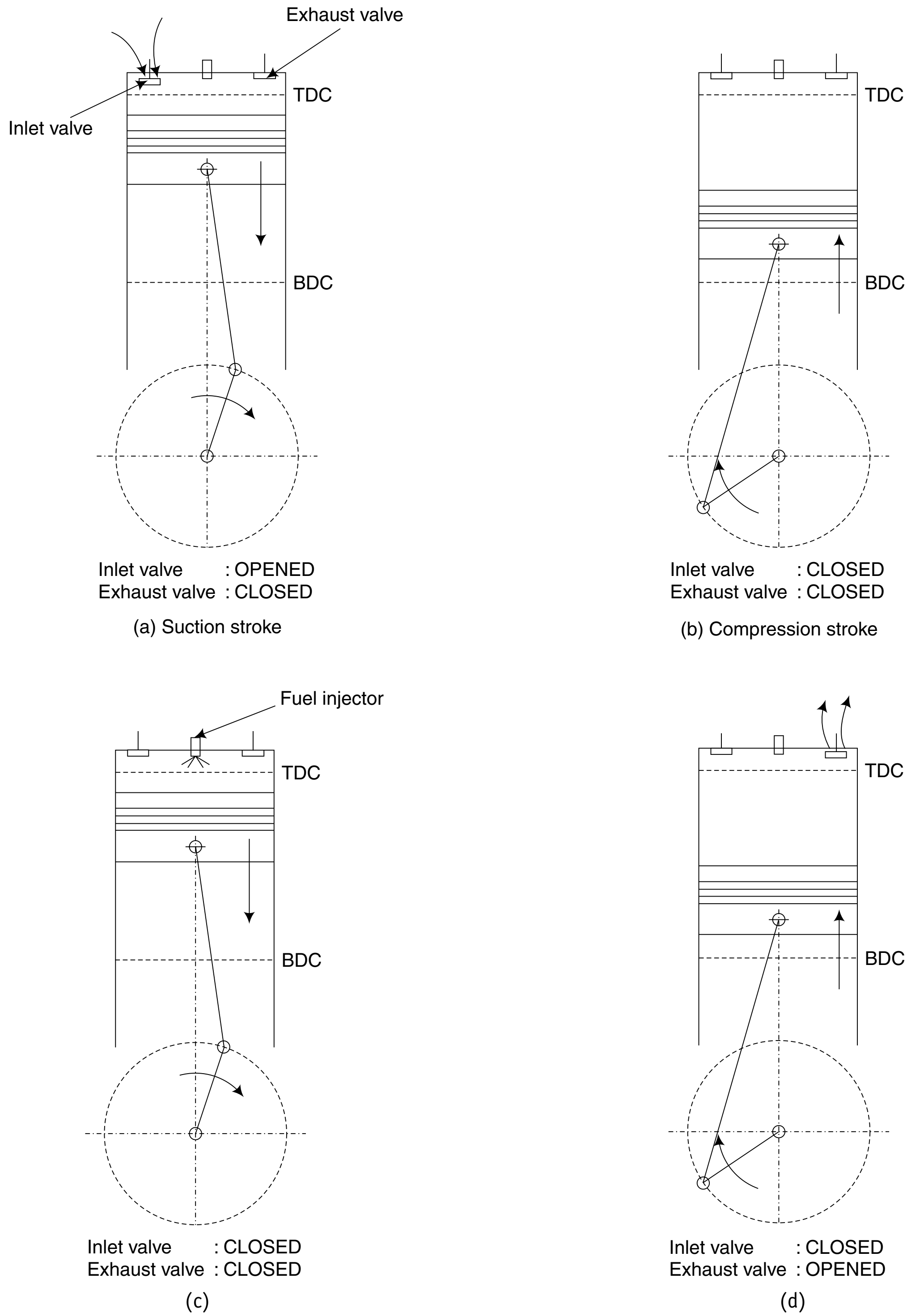



**Fig. 4.3** *4-stroke cycle diesel engine*

## 4.5 WORKING OF A FOUR-STROKE DIESEL ENGINE

This is similar to the operation of a 4-stroke petrol engine. Instead of petrol-air mixture, only air is sucked from the atmosphere during the suction stroke. In a diesel engine, there is no need for a spark plug. Diesel engines are also called compression ignition engines. Dr Rudolf Diesel who invented the compression ignition engine was born in 1858.

***1. Suction Stroke*** During this stroke, the inlet valve is kept opened and the exhaust valve is closed. The piston comes down to the bottom dead centre (BDC) from the top dead centre (TDC). Pressure in the cylinder will be slightly less than the atmospheric pressure. Air is drawn inside the engine cylinder through the inlet value.

***2. Compression Stroke*** In this stroke, both the inlet and exhaust valves are kept closed. The air is compressed when the piston moves up to TDC. The compression ratio varies from 15 – 20 for diesel engines. Due to high compression, higher temperature is obtained in the range of 550°C. At this juncture, diesel oil at a high pressure is injected inside the hot compressed air in an atomised form. Due to the special shape of the combustion chamber, the mixing of fuel and air takes place very rapidly and the mixture is ignited due to the high compression temperature, without the help of a spark plug. Therefore, the diesel engine is also called compression ignition engine. Due to combustion, very high pressure is produced.

***3. Working or Power Stroke*** During this stroke, both valves are kept closed. The piston is pushed down from TDC to BDC. The force above the piston is transmitted to the crank shaft through the connecting rod and crank mechanism. Excess energy due to the combustion is stored in the flywheel which helps the operation of three idle strokes.

***4. Exhaust Stroke*** During this stroke, the exhaust valve is kept opened and the inlet valve is kept closed. The piston moves up from BDC to TDC. The waste gases are sent through the exhaust valve and the cycle is repeated.

During these four strokes, the crank shaft will make two revolutions. The thermal efficiency of a 4-stroke engine is higher compared to a 2-stroke cycle engine. Most cars operate on a 4-stroke cycle.

## 4.6 DIFFERENCES BETWEEN PETROL ENGINES AND DIESEL ENGINES

**Table 4.1**

| | Petrol engines | Diesel engines |
|---|---|---|
| 1. | Compression ratio is 7–10. | Compression ratio is 15–20. |
| 2. | Petrol–air mixture is compressed. | Only air is compressed. |
| 3. | Compression pressure is 15–20 bar. | Compression pressure is 30–40 bar. |
| 4. | Compression temperature is about 400°C. | Compression temperature is above 550°C. |
| 5. | Peak pressure is in the range of 50–70 bar. | Peak pressure is high in the range of 80–100 bar. |
| 6. | Thermal efficiency is low in range of 20–25% due to low compression ratio. | Thermal efficiency is high in the range of 25–30% due to high compression ratio. |

| | | |
|---|---|---|
| 7. | Spark plug is necessary to ignite the fuel-air mixture | No need for spark plug as compression temperature is enough to ignite. |
| 8. | Due to low peak pressure, thickness of parts is less. | Due to high pressure, thickness of parts is more. |
| 9. | Weight of the engine is less. | Weight of the engine is more. |
| 10. | Cost of the engine is less. | Cost of the engine is more. |
| 11. | Operating cost per km is high due to high cost of petrol and low thermal efficiency. | Operating cost per km is considerably low due to low cost of diesel and higher thermal efficiency. |
| 12. | Due to better mixing of air and petrol, air–fuel ratio is less. For normal operation, it is in the range of 17–18. | Due to poor mixing of air and fuel, air–fuel ratio is very high (25–40). Mixing becomes poor due to lack of time. |

## 4.7 WORKING OF A TWO-STROKE PETROL ENGINE

In a two-stroke petrol engine, the cylinder is provided with the inlet port, the transfer port and the exhaust port.

These ports are opened and closed by the movement of the piston itself. The exhaust port as shown in Fig. 4.4 (a), is located slightly above the transfer port.

Let us study the condition when the piston is at TDC. In this position, only the inlet port is kept opened and the other two ports are closed. The mixture of air and petrol is drawn into the

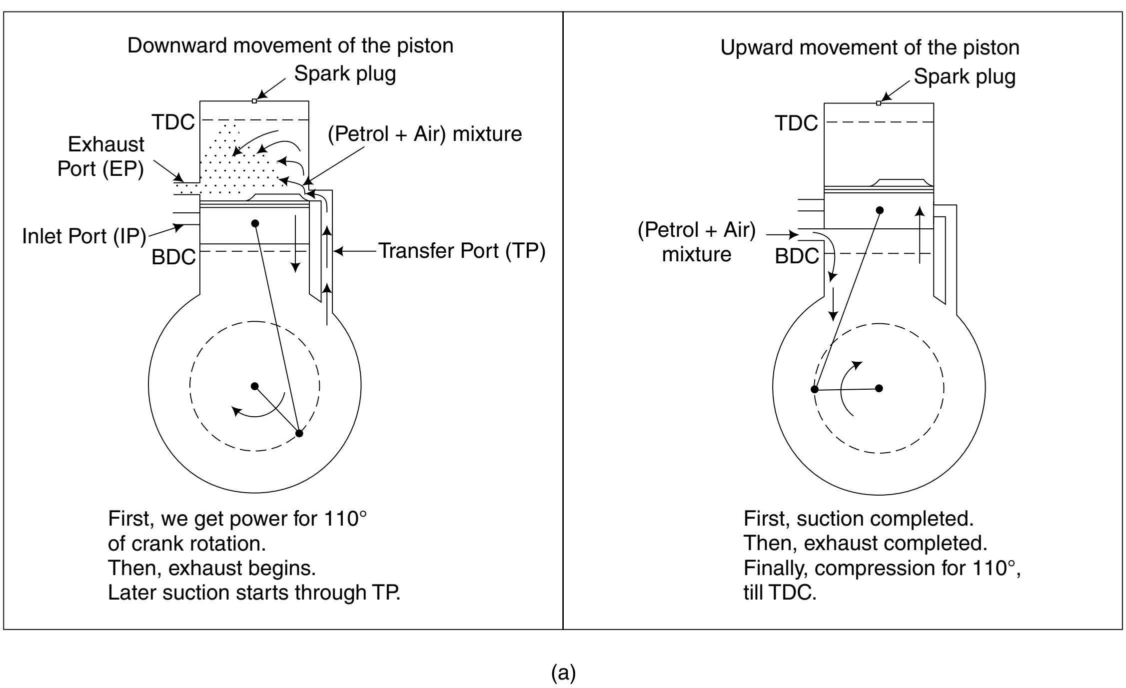



**Fig. 4.4(a)** *2-stroke cycle petrol engine*

crank case due to the vacuum produced by the upward movement of the piston. Also, the mixture above the piston is compressed. The compression ratio for a petrol engine varies from 7–10.

When the spark occurs, the combustion starts and the piston is pushed down due to the pressure created. During its downward motion, the inlet port also is closed due to which the mixture will get compressed inside the crank case. At about 70° from BDC the exhaust port is opened and the gases are sent to the atmosphere. At about 60° from BDC, the transfer port is opened due to which the mixture from the crank case enters the cylinder. Refer to the port timing diagram in Fig. 4.4(c).

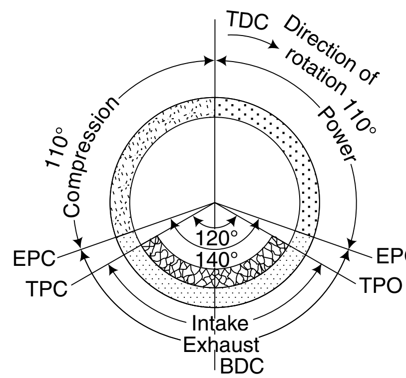



**Fig. 4.4(c)** *Port-timing diagram*

Because of the special shape of the piston crown, the mixture is deflected up and is prevented from going out directly through the exhaust port. Also, the deflected mixture helps in pushing the exhaust gases out. Thus, during the downward motion of the piston, we get the operation of power, exhaust and suction or intake.

When the piston is pushed up by the flywheel, the following sequence of operations take place:

1. Closing of transfer port
2. Closing of exhaust port
3. Opening of inlet port

After closing the exhaust port, the mixture gets compressed and the cycle is repeated.

## 4.8 WORKING OF A TWO-STROKE DIESEL ENGINE

It is very similar to the operation of a 2-stroke petrol engine. In a 2-stroke diesel engine, the cylinder is provided with the inlet port, the transfer port and the exhaust port.

The ports are opened and closed by the movement of the piston itself. The exhaust port is slightly above the transfer port.

Let us study the condition when the piston is at TDC. In this position, only the inlet port is kept open and other two ports are closed. The air from the atmosphere is drawn into the crank case due to the vacuum produced by the upward movement of the piston. The air above the piston is compressed to a high temperature. The compression ratio for a diesel engine varies from 15 – 20. Diesel oil at a high pressure is injected in an atomised form into the hot compressed air.

Combustion starts and the piston is pushed down due to the pressure created. During this downward motion, the inlet port is also closed due to which the air will get compressed inside the crank case. At about 70° from BDC the exhaust port is opened and the gases are sent to the atmosphere. At about 60° from BDC, the transfer port is opened due to which the air from the crank case enters the cylinder.

Because of the special shape of the piston crown, the air is deflected and is prevented from going out directly through the exhaust port. Also, the deflected air helps in pushing the exhaust gases out. Thus, during the downward motion of the piston, the operations of power, exhaust and suction are obtained.

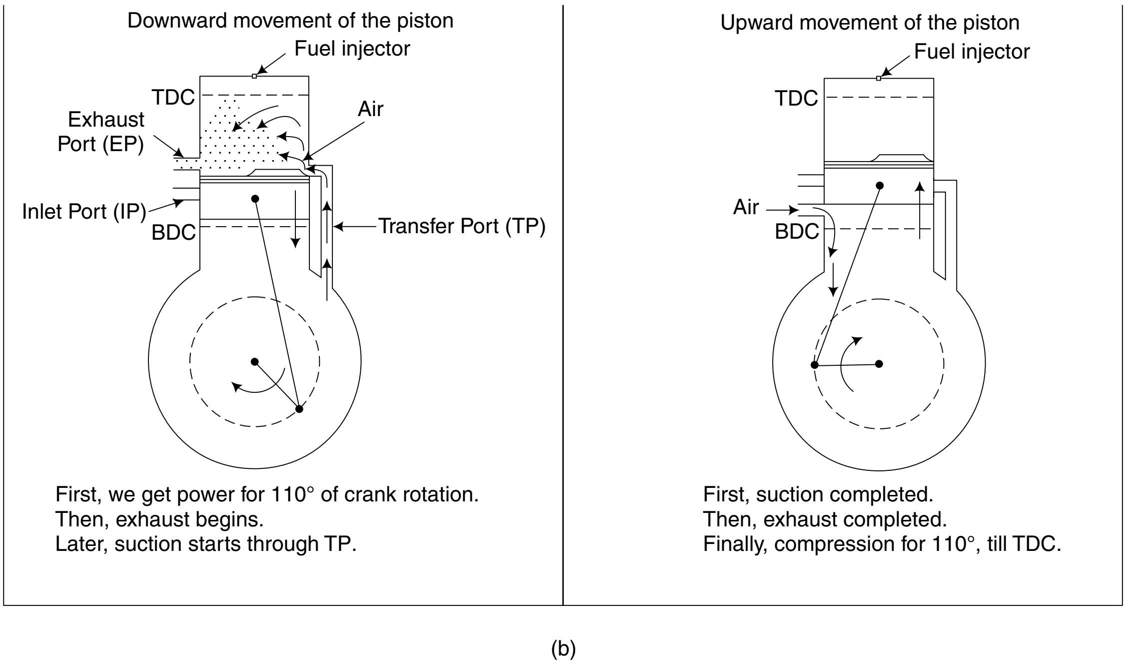



**Fig. 4.4(b)** *2-stroke cycle diesel engine*

When the piston is pushed up by the flywheel, the following sequence of operations take place.

1. Closing of transfer port
2. Closing of exhaust port
3. Opening of inlet port

After closing of the exhaust port, the air gets compressed and the cycle is repeated.

## 4.9 DIFFERENCES BETWEEN A 4-STROKE AND A 2-STROKE ENGINE

**Table 4.2**

| | 4-stroke engine | 2-stroke engine |
|---|---|---|
| 1. | One working stroke for every 4 strokes or 2 revolutions. | One working stroke for every 2 strokes or one revolution. |
| 2. | As the number of cycles is less, power output is less for the same cylinder size. | Power is more for the same cylinder size. More suitable for a diesel power plant. |
| 3. | The weight of the engine is more for the same output power. | The weight of the engine is considerably less. So, it is more suitable for a marine engine. |
| 4. | Operating temperature is less. So, less consumption of lubricating oil. | Operating temperature is more. So, more consumption of lubricating oil. Special piston cooling is necessary in large engines. |
| 5. | Variation of torque is more. So, heavier flywheel is necessary. | Smaller flywheel is enough as the torque is more uniform. |

| | | |
|---|---|---|
| 6. | Noise is less. | Noise is more due to frequent exhaust. |
| 7. | Higher thermal efficiency. | Thermal efficiency is less due to possible wastage of fuel–air mixture through the exhaust port. |
| 8. | Due to the valve mechanism, the design and manufacture of the engine is difficult and cost is more. | Easier in design and the manufacturing cost is less. |
| 9. | Straight piston is used. | Deflector piston is used. |

## 4.10 FUEL SYSTEM IN A PETROL ENGINE

The fuel system in a petrol engine consists of the following: a fuel tank, fuel gauge, a fuel filter, a fuel pump and a carburetter.

For cars, the capacity of the fuel tank is about 50 litres. To indicate the amount of fuel in the tank, a fuel gauge is provided which operates by means of a float mechanism. As the fuel has to pass through a fine hole in the carburetter, the petrol should be filtered first. As the petrol tank is at a lower level than the carburetter, the petrol is pumped by a small -capacity diaphragm pump by a cam mechanism driven by the crankshaft.

### 4.10.1 Carburetter

This can be considered as the heart of a petrol engine. Extensive development work has been carried out throughout the world in improving the working of the carburetter.

***Functions of the Carburetter***

1. To evaporate the liquid petrol and mix with the correct amount of air and supply the petrol–air mixture in the desired ratio at all speeds and loads. For normal speed, the desirable air – fuel ratio is in the range of 17 – 18. At higher speeds, we need a richer mixture and for starting, we need extra rich mixture with air – fuel ratio in the range of 10 – 12.
2. Provision to vary the speed of the engine by regulating the amount of fuel – air mixture entering the cylinder (throttle).
3. Provision for easy starting (choke).
4. In modern carburetters, provision has been made for altitude correction, climatic correction, quick acceleration, etc., by providing multijets and various other means.

Dealing with modern carburetters is beyond the scope of this textbook. Only the working of a single-jet carburetter is dealt with, giving the basic principle of working.

***Working of a Simple or Single–Jet Carburetter***

A simple carburetter consists of the following parts:

1. A float chamber
2. A venturi tube
3. Single petrol jet
4. Choke
5. Throttle

The float chamber as shown in Fig. 4.5 maintains a constant level of petrol. The tip of the petrol jet is slightly above the level of petrol and it is located in the reduced area of the venturi tube.

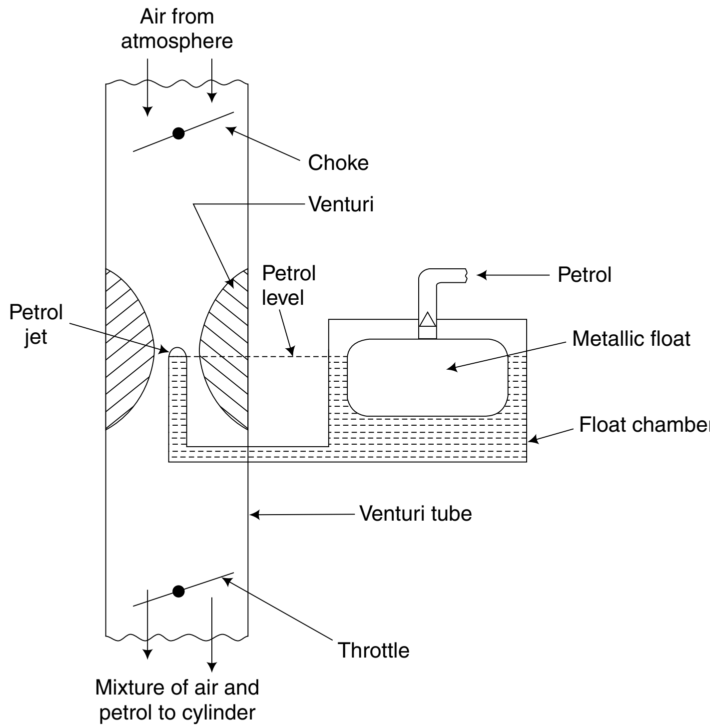



**Fig. 4.5** *Single-jet carburetter*

During the suction stroke of the engine, vacuum is produced in the cylinder due to which air rushes through the *venturi tube*. When the air passes through the centre of the venturi tube, the velocity of air increases and the pressure decreases due to the reduction in area. Due to the vacuum produced, the petrol is automatically sucked through the *petrol jet*. It is sprayed through the fine hole at the end of the jet. The vapourised petrol mixes with air and the mixture goes to the engine cylinder through the throttle.

The speed of the engine can be changed by controlling the amount of mixture, by means of the throttle, connected to the accelerator. For starting, an extra rich mixture is required and this can be obtained by partly closing the choke, thereby reducing the amount of air.

### *Defects of a Single-Jet Carburetter*

1. It tends to supply richer mixture at high speed and weaker mixture at slow speed.
2. Starting is comparatively difficult.
3. There is no correction for altitude.
4. There is no correction for climatic variation.

## 4.11 BATTERY OR COIL-IGNITION SYSTEM

Figure 4.6(a) shows the coil-ignition circuit for a four-cylinder petrol engine. The battery provides 12 V supply to the primary circuit. It is kept charged by a dynamo driven by the engine. The ignition switch is in the form of a key, operated by the driver.

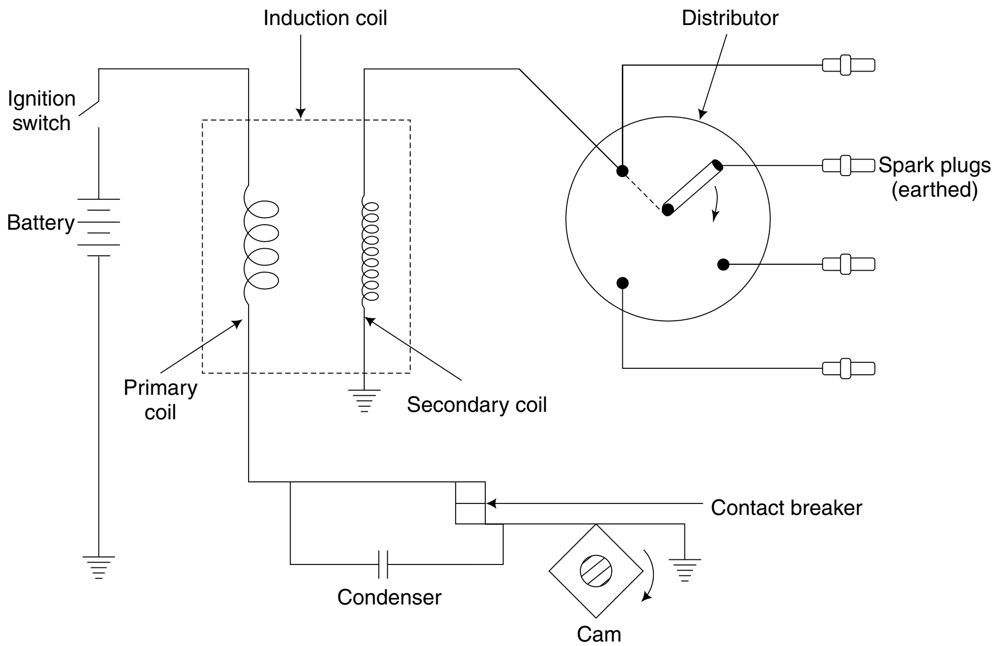



**Fig. 4.6(a)** *Ignition system*

The induction coil consists of two coils, one primary and the other secondary. The primary coil consists of 200–300 turns of thick enamelled copper wire and the secondary coil consists of 15000–20000 turns of thin enamelled copper wire. The contact breaker is a mechanical device for breaking and making the primary circuit. It is operated by a cam, as shown in the sketch. An electrical condenser is provided to avoid sparking at contact- breaker points.

When the contact breaker is closed, the current flowing in the primary circuit produces a magnetic field in the induction coil. When this magnetic field is made to collapse suddenly by the contact breaker, a high voltage is induced in the secondary coil. The high voltage is supplied to the correct spark plugs at the correct time by means of the distributor and produces the spark.

### 4.11.1 Spark Plug

In a petrol engine, as the temperature at the end of compression is not enough to ignite the petrol–air mixture, a spark is provided at the right time by means of a spark plug. A simple sketch of the spark plug is given in Fig. 4.6(b).

The spark plug is screwed into the cylinder head. It consists of a central electrode surrounded by an insulator. When a high voltage is applied to the central electrode, a spark is produced in the spark gap when the high voltage tries to jump across the gap. The spark gap varies from 0.6–1 mm. The gap should be maintained correctly and it should be free from carbon dust or oil. Periodically, the tip should be cleaned.

### 4.11.2 Magneto-Ignition system

Figure 4.6(c) shows the sketch of a magneto-ignition system. This is similar to the coil-ignition system, except that the battery is replaced by a magneto. The magneto consists of a rotating

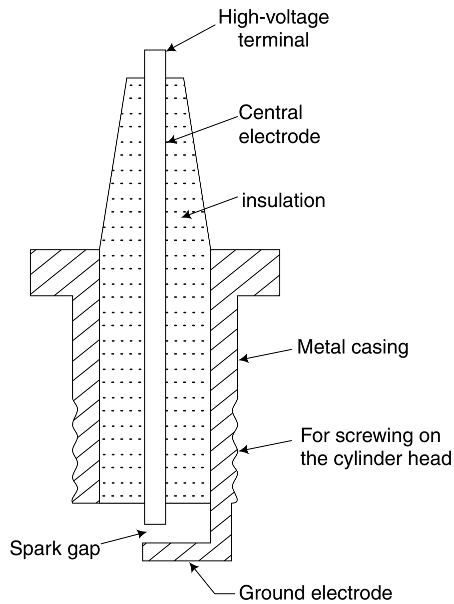



**Fig. 4.6 (b)** *Spark plug*

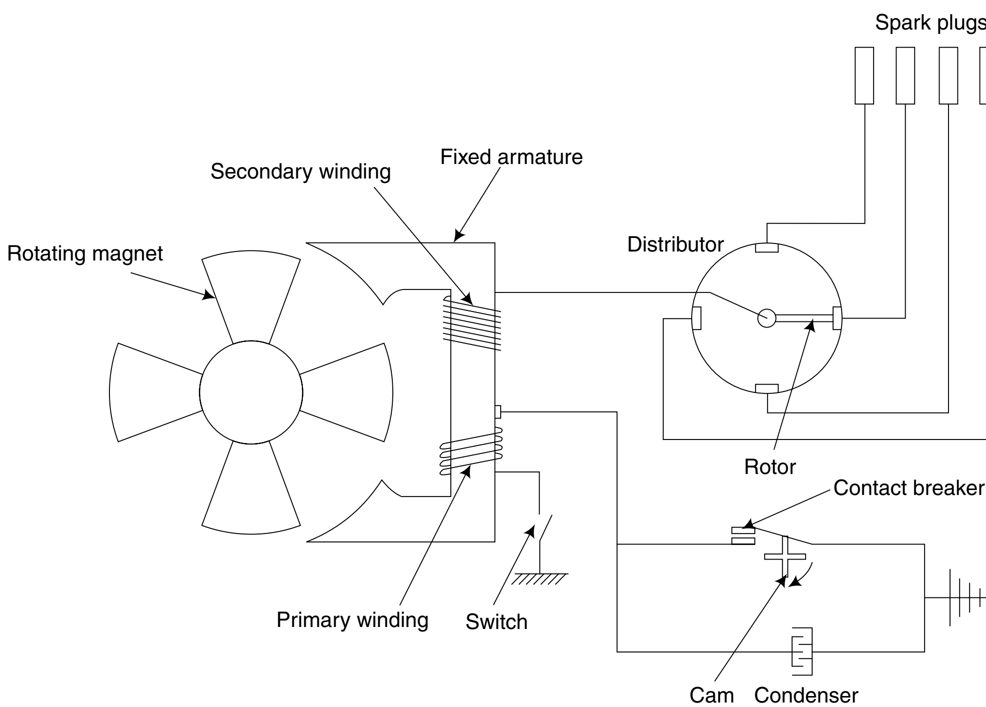



**Fig. 4.6 (c)** *Magneto-ignition system*

magnet and a fixed armature. It is like an electric generator. The armature consists of primary and secondary windings. The magneto is located on the outer rim of the flywheel and revolves around the stationary coil.

The primary winding, ignition switch, condenser and the contact breaker form the primary circuit and the secondary winding, distributor and spark plugs form the secondary circuit.

When the contact breaker is closed by the rotating cam, current flows in the primary circuit. This will produce magnetic field in the primary circuit. When the contact breaker is opened by the rotating cam, very high voltage is produced in the secondary coil due to sudden collapse of magnetic field. The high voltage is distributed to the spark plugs through the distributor.

## 4.12 COOLING SYSTEMS IN IC ENGINES

Due to the combustion of fuel inside the cylinder, very high temperature is produced. Any metal tends to become weak at high temperature. If the engine is not cooled, parts such as the cylinder, the cylinder head, the piston, the piston rings, and the valves will get overheated resulting in the reduction of strength and possibility of distortion of components. Overheating may even cause seizure of the piston. Properties of the lubricating oil will change at high temperature and it may decompose resulting in carbon deposit in the cylinder and piston. So, cooling becomes essential in IC engines. At the same time, overcooling should be avoided. At full load, about 30% of the heat liberated by the fuel is lost in cooling. Two types of cooling are usually adopted.

***1. Air Cooling*** This system is adopted for motorcycles, scooters, aero engines and also in some cars. Cooling fins are provided in the cylinder and cylinder head as shown in Fig. 4.7. In large-sized engines, arrangement is made to circulate the air around the cooling fins. The amount of heat dissipated depends on the area of cooling fins, the amount of air circulated, the velocity of air and the temperature difference with the surroundings.

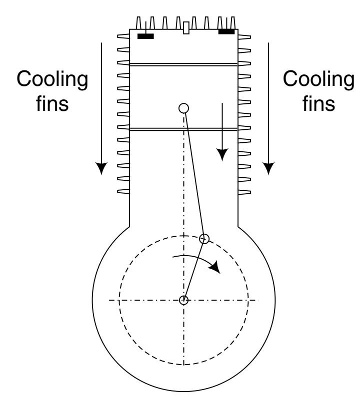


**Fig. 4.7** *Air cooling*

***2. Water Cooling*** This system is commonly used in cars, buses and lorries. Water passages between the double walls of the cylinder and the cylinder heads are called the *water jackets*. Water is circulated through jackets by a pump driven by the crank shaft. When the circulating water becomes hot, it is cooled in a radiator as shown in Fig. 4.8(a). Water used in the radiator should be free from salt and other impurities. Otherwise, the deposit will block the water tubes. It is desirable to add some anticorrosion solution in the water. The radiator should be periodically cleaned. In cold places, antifreeze solution should also be added in the water.

It is desirable to fit a thermostat in the upper hose connection in the radiator. During the warm-up period of the engine, the thermostat valve is closed. When the normal operating temperature of about 60°C is reached in the water, the thermostat valve opens due to the evaporation of ether in the bellows and permits the water to circulate through the radiator. The sketch of a thermostat is given Fig. 4.8(b).

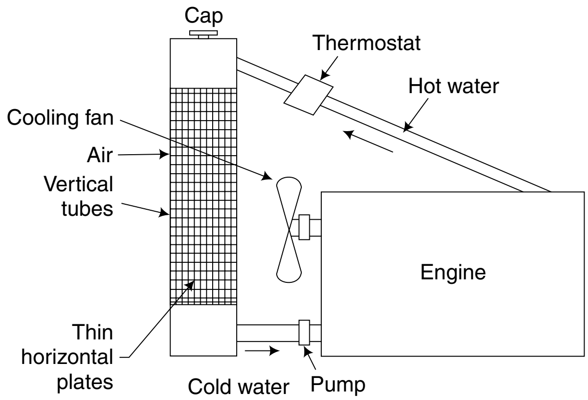



**Fig. 4.8(a)** *Radiator cooling system*

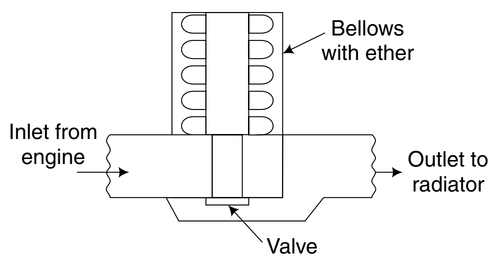



**Fig. 4.8(b)** *Thermostat*

### 4.12.1 Difference between Air Cooling and Water Cooling

**Table 4.3**

| | Air cooling | Water cooling |
|---|---|---|
| 1. | Design is simple | Design is comparatively complex |
| 2. | Weight of the engine is less | Weight is more due to water in the radiator |
| 3. | Cost of engine is less | Cost is more |
| 4. | No problem of leakage or freezing of water | Both the problems exist |
| 5. | More noise | Less noise as water dampens the vibration |
| 6. | Maintenance is very easy | Maintenance is comparatively difficult due to the possibility of leakage of water, blockage of tubes in the radiator, pump failure etc |
| 7. | Control of the temperature is difficult | It can be easily controlled by fitting a thermostat |

## 4.13 LUBRICATION SYSTEM

The following are the main functions of a lubrication system:

1. To reduce the friction between the rubbing parts and reduce the wear and tear.
2. To reduce the temperature of the working parts.
3. To reduce the noise.
4. To keep the rubbing parts clean by removing worn-out materials and carbon dust.
5. To act as a sealing between the cylinder and piston and to prevent the leakage of gases.

***Parts to* be *Lubricated***

1. Reciprocating parts like piston.
2. Rotating parts like crank shaft.
3. Oscillating parts like connecting rod.

***Types of Lubricants***

1. Liquids like mineral oil, vegetable oil, etc.
2. Semiliquids like grease.
3. Solid lubricants like graphite powder, either alone or mixed with oil or grease.

### 4.13.1 Requirements of a Good Lubricating Oil

1. High viscosity index (if the change of viscosity with temperature is less, the oil is rated to have a high viscosity index).
2. High flash point and low pour-point temperatures.
3. Non-corrosive.
4. Good detergent quality to keep the rubbing surfaces clean.
5. High film strength (ability to maintain a thin film of oil even at high load).
6. The quality of lubricating oil is improved by adding different types of additives such as the viscosity index improvers, the corrosion inhibitors, the detergent additives, and the film strength additives.

Lubricating oils are graded in SAE number according to the viscosity. For example, the viscosity of oil SAE 40 is higher than that of oil SAE 30. For different engines or machines, we should use the oil of correct grade as specified by the manufacturer. In IC engines, oil should be filled in the crank case to the specified level, as indicated by the dip stick.

### 4.13.2 Types of Lubrication

The different types of lubrication are the following:

1. Splash lubrication
2. Pressure lubrication
3. Petroil method

The *splash lubrication* system as in Fig. 4.9(a) is suitable only for small capacity engines. During the working of the engine, the scoop dips into the lubricating oil in the crank case and throws the oil to the piston, cylinder and other parts.

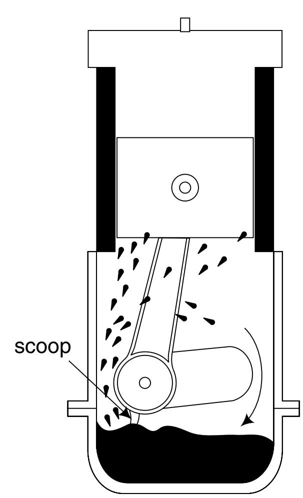



**Fig. 4.9(a)** *Splash lubrication*

In the *pressure lubricating system*, the oil in the crank case is filtered by an oil filter. The filtered oil enters the oil pump and its pressure is

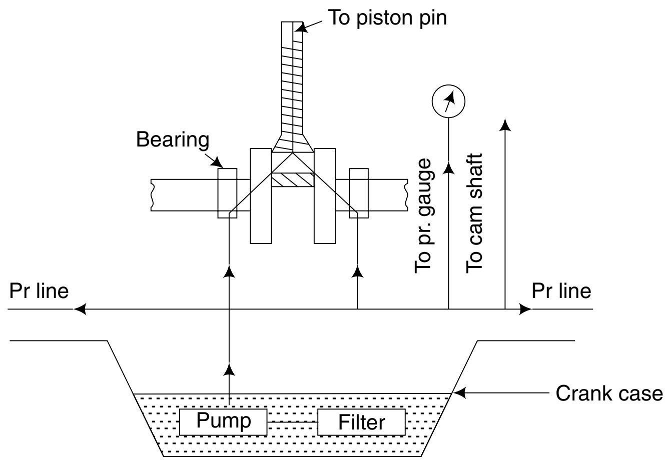



**Fig. 4.9(b)** *Pressure lubrication*

raised to the desired value and distributed to the different parts, as shown in Fig. 4.9(b). For the lubrication of the crank pin and the piston pin, small holes are provided in the crank shaft, and connecting rod crank pin. through which oil flows.

For lubrication of light spark ignition engines, lubricating oil is directly mixed with petrol and this is known as the *petroil method*.

## 4.14 FUEL SYSTEM FOR DIESEL ENGINES

The system consists of the following:

1. Fuel tank with a float mechanism connected to the fuel gauge
2. Fuel filter
3. Fuel pump
4. Fuel injector or atomiser

***Function of the Fuel System***

1. It should deliver the required amount of fuel at the correct time for different loads and speeds.
2. Injection of fuel should be at the desired rate to control the pressure rise during combustion.
3. Atomisation of the fuel should be to the desired degree. If the atomisation is too high, the penetration of fuel becomes poor.
4. It should help in the rapid mixing of fuel and air.
5. Opening and closing of injection should be sharp.

### 4.14.1 Fuel Pump

The pump produces the high pressure necessary for injection, in the order of 100 – 400 bar, depending upon the engine size and the type of combustion chamber used. It also controls the amount of fuel pumped for different loads and speeds.

It consists of a plunger working in a barrel. The plunger is moved up against the action of a spring by means of a cam. Fuel comes to the barrel through the inlet line. During the upward movement of the plunger, when the inlet and spill ports are closed, pressure is developed in the fuel and is sent to the injector through a delivery valve under the action of a spring (not shown in the sketch).

By the action of a cam, the plunger has a constant stroke. But, the effective stroke of the plunger can be varied and thereby the quantity of fuel can be changed by slightly rotating the plunger through an angle by means of a control rod, connected to the accelerator. This is made possible by a vertical hole or slot in the plunger and also by a special helical cut in the plunger as shown in Fig. 4.10.

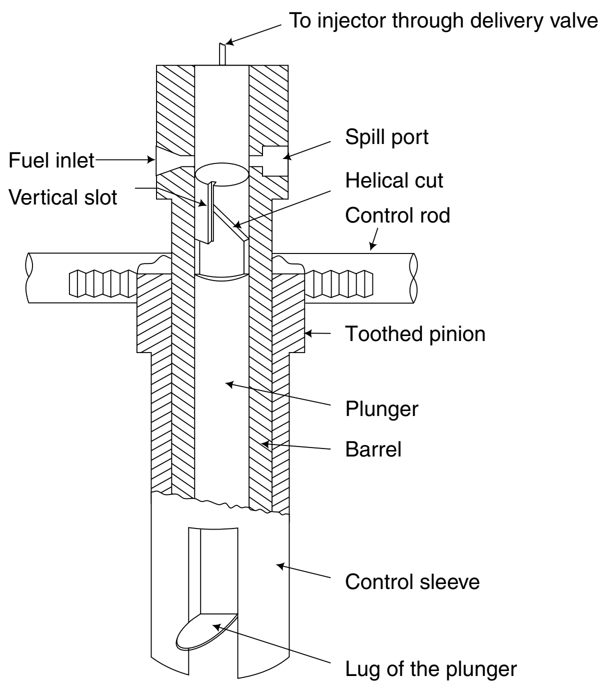



**Fig. 4.10** *Fuel pump for a diesel engine*

## 4.14.2 Fuel Injector

The lower portion of the fuel injector is described in Fig. 4.11. The needle valve is kept in the seat by a helical spring. The tension of the spring can be adjusted manually by a nut on the top of the injector (not shown in the sketch) to vary the pressure of injection. Fuel under pressure from the fuel pump enters the pressure chamber through the fuel duct. Because of high pressure, the needle valve is lifted up against the spring tension. When the valve is lifted, the fuel rushes out through the fine hole (single hole or multiholes) in an atomised form and rapidly mixes with the compressed air which will be turbulent inside the combustion chamber.

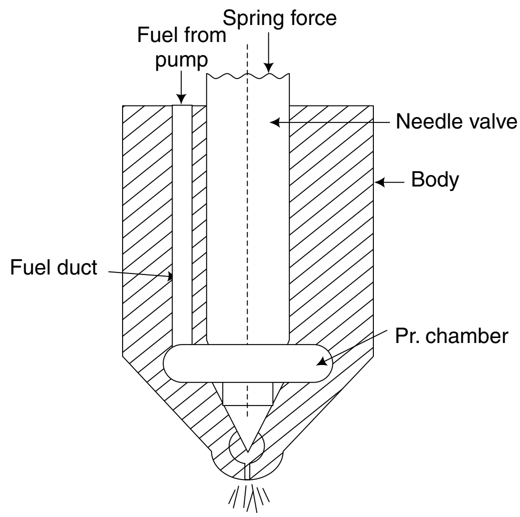



**Fig. 4.11** *Single-hole injector*

## 4.15 PETROL INJECTION

As modern carburetters used in petrol engines have certain drawbacks, there is a shift towards petrol injection systems. In petrol injection, timing is by no means critical and the fuel may be injected during the suction stroke in the inlet mainfold at low pressures. The petrol-injection systems are mainly grouped into the following two groups:

***1. Continuous Injection System*** In this system, fuel is sprayed at a low pressure continuously into the air supply. The air-throttle opening governs the amount of fuel injected into the cylinder. The advantages of this system are listed below:

1. Atomisation of fuel is very efficient.
2. Supplies uniform mixture to all the cylinders.
3. Volumetric efficiency increases due to the cooling of compressed charge by the evaporative effect of the fuel.
4. One injector and one fuel injection pump are enough for this system.

***2. Timed Injection System*** The timed injection system is similar to the system used in high-speed diesel engines. The timed injection system is further grouped into the following two groups.

**(i) Multiple-Plunger Jerk Pump System** A pump having a separate plunger for each cylinder is employed in this system. At a definite time and over a definite period of the induction stroke, the fuel is delivered into each cylinder. The injection pressure usually ranges from 100 bar to 300 bar.

**(ii) Low-Pressure Single-Pump and Distributor System** In this system, a single plunger pump delivers fuel at low pressure to the rotating distributor which supplies the fuel to each cylinder. The injection pressure usually ranges from 3.5 bar to 7 bar.

***Disadvantages of Petrol Injection***

1. Due to high precision and complex component assemblies, initial cost of the petrol- injection system is much higher than conventional carburetion system.
2. As there are many moving parts, there are increased service problems. The noise level is also more.
3. Weight and size of this system will be more than that of a carburetter.

Due to the above disadvantages, it is not popular in cars and motorcycles today. However, it is being used in some racing cars and aero engines.

## 4.16 DIFFERENCE BETWEEN DIESEL INJECTION AND PETROL INJECTION

**Table 4.4**

| | Diesel injection | Petrol injection |
|---|---|---|
| 1. | Fuel is directly injected into the cylinder. | Fuel is injected in the inlet manifold. |
| 2. | Injecting pressure is high. | Injecting pressure is low. |
| 3. | The moment at which fuel injection commences has a very important influence. | Timing is by no means critical and the fuel may be injected during the suction stroke. |
| 4. | Fuel is injected at the end of the compression stroke. | Fuel is injected during the induction stroke. |

## Short-Answer Questions

1. *Answer the following questions:*
   (a) What is the function of scraper rings provided on the piston?
   (b) What is the function of flywheel?
   (c) List the strokes that constitute a four-stroke engine.
   (d) Define scavenging in a 2-stroke engine.
   (e) List the ports used in a 2-stroke engine.
   (f) Briefly list the important functions of the carburetter.
   (g) What is the function of a spark plug?
   (h) What is the function of a fuel injector in diesel engines?
   (i) Why is cooling necessary in an IC engine?
   (j) What are the different types of cooling in IC engine?
   (k) What is the use of thermostat valve in the case of a radiator cooling system?
   (l) Why should the IC engines be lubricated?
   (m) What are the different methods of lubrication?
   (n) Explain what is meant by viscosity index of lubricating oil.
   (o) What is the Petroil method of lubrication?
   (p) Explain the specific function of fuel pump and injector in a diesel engine.
   (q) List the requirements of a good lubricating oil.

(r) What operations take place when the piston is pushed up by the fly-wheel in a 2-stroke IC engine?

(s) State the differences between petrol injection and diesel injection.

2. *Fill up the blanks with suitable word/words:*

(a) A gasket is provided between the cylinder and the cylinder head to __________ .

(b) Common gasket materials are __________ and __________ in IC engine.

(c) A connecting rod converts __________ motion of the piston into the __________ of the crankshaft.

(d) In the suction stroke, the pressure in the cylinder will be __________ than the atmospheric pressure.

(e) The thermal efficiency of the four-stroke engine is more compared to a two -stroke engine because __________ .

3. *Choose the correct answer from the following:*

(a) In a four-stroke cycle engine, the operations are in sequence.

(i) suction, expansion, compression and exhaust

(ii) suction, exhaust, compression and expansion

(iii) suction, compression, exhaust and expansion

(iv) none of the above

(b) In a four-stroke cycle engine, the number of revolutions of the crankshaft for completion of working cycle is

(i) one (ii) two

(iii) three (iv) four

(c) In a two-stroke cycle engine, the number of revolutions of the crakshaft for completion of working cycle is

(i) one (ii) two

(iii) three (iv) four

(d) At the same speed, the number of power strokes given by a two-stroke cycle engine as compared to a four-stroke cycle engine is

(i) half (ii) same

(iii) double (iv) four times

(e) The petrol engine works on

(i) Otto cycle (ii) Joule cycle

(iii) Diesel cycle (iv) Carnot cycle.

(f) The suction in a petrol engine contains

(i) fuel only (ii) mixture of air and fuel

(iii) air only (iv) none of the above.

(g) The term ‘scavenging’ is generally related with

(i) two-stroke engines (ii) four-stroke engines

(iii) steam engines (iv) air-cooled engine

(h) The function of the distributor in a coil ignition system of an IC engine is to

(i) distribute spark (ii) distribute current

(iii) distribute power (iv) time the spark

(i) The function of the carburetter is to supply
  (i) air and petrol (ii) air and diesel
  (iii) only petrol (iv) only diesel

(j) In a petrol engine, air–fuel ratio is controlled by the
  (i) distributor (ii) carburetter
  (iii) governor (iv) injector

(k) A fuel injector is used for a
  (i) 5:1 engine (ii) CI engine
  (iii) steam engine (iv) steam turbine

(l) In a diesel engine, fuel is injected
  (i) at the beginning of the suction stroke
  (ii) at the beginning of the compression stroke
  (iii) nearly at the end of the compression stroke
  (iv) none of the above

(m) The number of valves in a 2-stroke motorcycle engine is
  (i) two (ii) three
  (iii) four (iv) none of the above

4. *State whether the following statements are true or false:*

(a) The function of the upper rings in IC engine is to provide gas-tight sealing and to prevent the leakage of burnt gases.
(b) Cams control the opening and closing of valves in four-stroke engines.
(c) During the four strokes, the crankshaft makes two-revolutions.
(d) One complete revolution of the crankshaft produces one power stroke in two -stroke engines.
(e) Thermal efficiency of a diesel engine is higher than the petrol engine due to high compression ratio.
(f) The speed of the engine is controlled by the throttle valve.
(g) Air cooling is used in buses and lorries.
(h) The voltage supplied to the battery ignition system is 12 V.
(i) Petrol lubrication is used in heavy-duty spark ignition engines.

## Long-Answer Questions

1. Describe the classification of IC engines.
2. Explain the working of a 4-stroke diesel engine.
3. Explain the differences between a petrol and a diesel engine.
4. Describe the working of a single-jet carburetter.
5. Describe water cooling and its differences with air cooling.
6. What are the requirements of a good lubricating oil.
7. Explain the timed injection system.
8. Describe a fuel pump with a neat sketch.
9. What is petrol injection and why is it not favoured

# Chapter 5
# TRANSMISSION OF POWER

## 5.1 BELT AND ROPE DRIVES

Belts and ropes are used to transmit power or rotary motion from one shaft to another. These are useful when power is to be transmitted between shafts whose center distance is large. Belts and ropes transmit power due to friction between them and the pulleys.

An open belt drive is shown in Fig. 5.1. Here, Pulleys A and B are mounted on two shafts. Pulley A is keyed to the rotating shaft (driver) and Pulley B is keyed to the shaft which is to be rotated (follower).

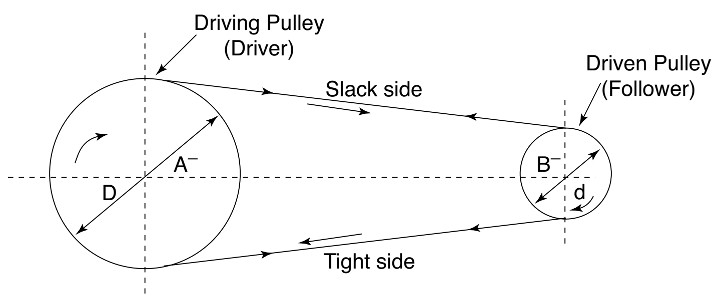



**Fig. 5.1** *Open belt drive*

When Pulley A rotates, the belt is carried by this pulley due to the grip between its surface and the belt. Now, the belt carries the driven pulley B which starts rotating. The grip between the pulley and the belt is obtained by friction which arises from the pressure between the belt and the pulleys. The speed of the driven shaft can be varied by the varying the diameters of the two pulleys.

## 5.2 TYPES OF BELTS

A belt may be of rectangular section known as a **flat belt** or of trapezoidal section known as a **V-belt** or of circular section known as a **rope**, as shown in Figs. 5.2(a), (b) and (c) respectively.

Flat belts are used to transmit a moderate amount of power from one shaft to another, when the distance between the two pulleys is not more than 15 m. V-belts are used to transmit a large amount of power from one shaft to another when the two pulleys are very close to each other. Ropes are used to transmit a great amount of power when the distance between the shafts is large (more than 10 m).

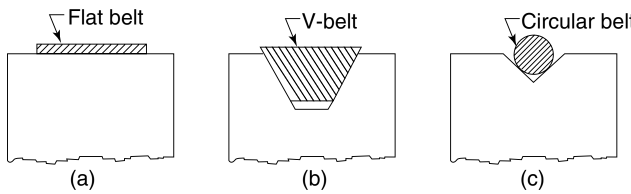



Fig. 5.2 *Types of belts*

## 5.3 MATERIALS

The material used for belts and ropes should be strong, flexible and durable. It must have a high coefficient of friction. Belt materials generally used are leather, cotton and rubber.

## 5.4 TYPES OF FLAT BELT DRIVES

The following types of belt drives are available to transmit power from one shaft to another.

***1. Open Belt Drive*** An open belt drive is used when driven pulley (follower) is intended to be rotated in the same direction as the driving pulley (driver) as shown in Fig. 5.1.

In this case, shafts are arranged parallel and driver A pulls the belt from one side (lower side) and delivers it to the other side (upper side). Thus, the tension is more in the lower side of the belt than that in the upper side. The lower side belt is known as tight side (because of more tension) and the upper side belt is known as slack side (because of less tension) as shown in Fig. 5.1.

***2. Crossed Belt Drive*** A cross belt drive is used when the driven pulley (B) is to be rotated in the opposite direction of the driving pulley (A) as shown in Fig. 5.3.

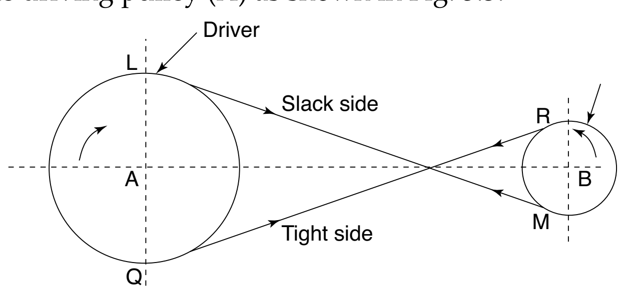



Fig. 5.3 *Crossed belt drive*

***3. Stepped or Cone Pulley Drive*** In this case, the driving shaft rotates at a constant speed. The speed of the driven shaft can be changed by shifting the belt from one step to another.

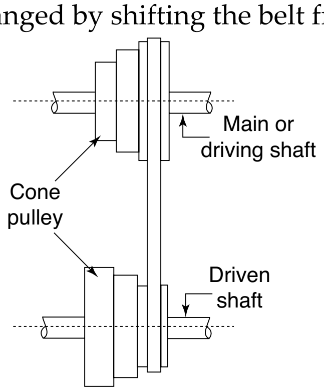



Fig. 5.4 *Stepped or cone pulley drive*

## 5.5 VELOCITY RATIO OR SPEED RATIO

It is the ratio between the speed of the driven pulley (follower) and the speed of the driving pulley (driver). Velocity ratio may be expressed, mathematically as given below.

$$\frac{\text{Speed of the follower } (N_2)}{\text{Speed of the driver } (N_1)} = \frac{\text{Diameter of driver (D)}}{\text{Diameter of follower (d)}}$$

## 5.6 ROPE DRIVES

The rope drives are widely used to transmit large amount of power from one pulley to another, over a long distance. Ropes are made of cotton, hemp, manila or steel wire. The frictional grip in the case of rope drive is more than the belt drive. One of the main advantages of rope drive is that a number of drives can be taken from one driving pulley. For example, in many spinning mills, the line shaft on each floor is driven by ropes passing directly from the main engine pulley on the ground floor. For a rope drive, the groove angle of the pulley is normally 45°, as shown in Fig. 5 .2.(c)

### 5.6.1 Steel wire rope

This is used to transmit larger power over longer distances, compared to cotton rope or hemp rope. Wire ropes are used for cranes, elevators etc., unlike fiber ropes which are wedged between the sides of the grooves, steel ropes rest at the bottom of the grooves in the pulley.

Following are the advantages of wire ropes :

1. It can withstand heavy load and shock load
2. It can also withstand fatigue
3. It is more durable
4. It is highly reliable.

## 5.7 DIFFERENCES BETWEEN ROPE DRIVE AND BELT DRIVE

**Table 5.1**

| | Rope drive | Belt drive |
|---|---|---|
| 1. | More suitable for long center distances between the shafts (more than 15m) | Suitable for shorter center distances (not more than 15 m) |
| 2. | Frictional grip is more | Frictional grip is less |
| 3. | Occurrence of slip is not possible | Occurrence of slip is possible |
| 4. | More power is transmitted | Moderate power is transmitted |
| 5. | Number of separate drives may be taken from one driving pulley | It is not possible to take number of separate drives from one driving pulley |
| 6. | Operating speed is less than 3 m/sec | Operating speed is up to 24 m/sec |

## 5.8 DIFFERENCES BETWEEN V-BELT AND FLAT BELT

**Table 5.2**

| | V-belt | Flat belt |
|---|---|---|
| 1. | Suitable for shorter center distances between the shafts | Suitable for comparatively longer center distances |
| 2. | Trapezoidal section | Rectangular section |
| 3. | Frictional grip is more | Frictional grip is less |
| 4. | Since more than one belt can be used, power transmitted will be more | Since single belt can be used power transmitted is less |
| 5. | Velocity ratio is high | Velocity ratio is low |
| 6. | Occurrence of slip is seldom possible | Slip occurs easily |

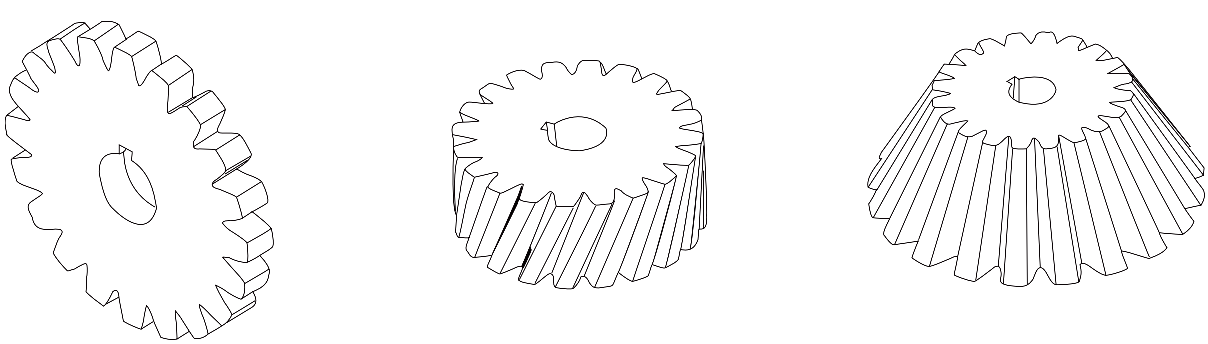
## 5.9. GEARS

A gear is a toothed wheel attached to a rotating shaft. There are many types of gears like spur gear, helical gear, bevel gear etc., as given in Fig. 5.5

***Spur Gears*** This is the simplest types of gear. It has teeth parallel to the axis of rotation and is used to transmit rotation from one shaft to another parallel shaft.

***Helical Gear*** This gear has its teeth inclined to the axis of rotation. Helical gears are also used for the some application as spur gears. One major advantage of helical gears is its silent operation. The noise level is much less. In addition, helical gears have the ability to transmit heavy loads at high speeds.

***Bevel Gears*** These gears have their teeth formed on conical surfaces and are used for transmitting motion between two shafts at 90°.



(a) Spur gear (b) Helical gear (c) Bevel gear

**Fig. 5.5** *Types of gears.*

***Application of gears***

1. To increase or decrease the speed of rotation.
2. To reverse the direction of rotation
3. To change the axis of rotation

## 5.10 GEAR TRAINS

Gears constitute one of the modes of transmission of power from one shaft to another. However, these are used when the distance between the driving and driven shafts is relatively small. A gear train can be defined as a mechanism which transmits power or motion from one shaft to another, with the help of gear wheels.

### 5.10.1 Types of Gear Trains

Here the following two gear trains are discussed. Other types of gear trains are beyond the scope of this text.

***1. Simple Gear Train*** In a simple gear train, each shaft between the driver and the follower carries only one gear as shown in Fig. 5.5.

In Fig. 5.5(a), gear 1 drives gear 2. Gear 1 is called driver and gear 2 is called driven or follower. It may be noted that the motion of the driven gear is in opposite direction to the motion of the driving gear. It may also be noted that when one more intermediate gear is added, the rotation of the driver and the follower will be in the same direction as shown in Fig. 5.5(b).

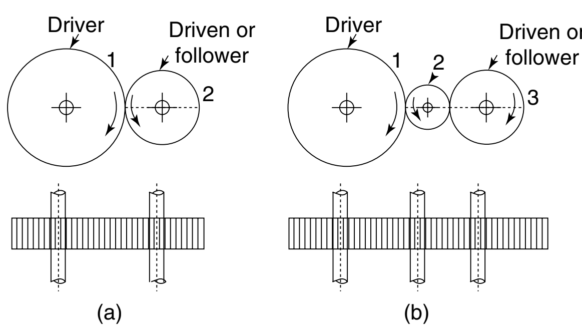



**Fig. 5.5** *Simple gear train*

***Speed ratio of a gear train*** It is the ratio between the speed of the driver and the speed of the follower. Speed ratio may be expressed mathematically as given below.

$$\frac{\text{Speed of driver } (N_1)}{\text{Speed of follower } (N_2)} = \frac{\text{Number of teeth on driver } (T_1)}{\text{Number of teeth on follower } (T_2)}$$

In a simple gear train, the speed ratio is independent of the intermediate wheels. These intermediate wheels are also called idle wheels, as they do not effect speed ratio of the system.

***2. Compound Gear Train*** In a compound gear train, each intermediate gear shaft carries two gears which are fastened together rigidly. Such gears are termed as compound gears. Figure 5.6 represents a compound gear train comprising gears 1, 2, 3, 4, 5 and 6.

In Fig 5.6 gear 1 is the driving gear mounted on shaft A, gears 2, 3, 4 and 5 are compound gears which are mounted on the shaft B and C and gear 6 is the driven gear (follower) mounted on shaft D. Compared to simple gear trains, the main advantage of compound gear train is that it can provide a larger velocity ratio in a limited space.

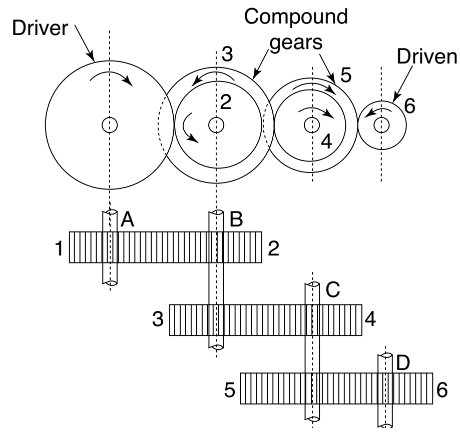


**Fig. 5.6** *Compound gear train*

***Speed ratio of a compound gear train*** It is expressed mathematically as given below.

$$\frac{\text{Speed of the first driver}(N_1)}{\text{Speed of the last follower}} = \frac{\text{Product of the number of teeth on the followers}}{\text{Product of the number of teeth on the drivers}}$$

$$\frac{N_1}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}$$

## Short-Answer Questions

1. What is the use of belt and rope drives?
2. What are the various types of belts used for the transmission of power?
3. Name the materials used for a belt?
4. Define speed ratio.
5. Differentiate between belt drive and rope drive.
6. What are the differences between V-belt and flat belt?
7. What are the advantages of rope drive as compared to belt drive.
8. What do you understand by a gear train?

## Long-Answer Questions

1. What are the different types of flat belt drives?
2. Describe the different types of gear trains?
3. Describe the different types of gears with sketches.

# Chapter 6
# REFRIGERATION AND AIR CONDITIONING

## REFRIGERATION

### 6.1 INTRODUCTION

Refrigeration is defined as 'the science of providing and maintaining the temperature below that of the surrounding atmosphere.' For this to be achieved, heat has to be removed from the source at a lower temperature and rejected to the atmosphere at a higher temperature. It is well known that heat can spontaneously flow from higher temperature to a lower temperature. However, for heat to flow in the reverse direction, the second law of thermodynamics stipulates that external work should be supplied. Therefore, a refrigerator is a heat pump, using power.

### 6.2 UNIT OF REFRIGERATION

The unit of refrigeration is called 'Ton of Refrigeration' (TR) which is defined as the quantity of heat to be removed to produce one ton of ice at 0°C, within 24 hours when the initial condition of water is also at 0°C. In the SI units, 1 TR is equivalent to 210 kJ/min or 3.5 kW. Air conditioners are also specified by the same unit TR.

### 6.3 PERFORMANCE OF A REFRIGERATOR

When a refrigerator is removing $Q$ amount of heat consuming $W$ amount of work, then the performance of the refrigerator is determined by the ratio $Q/W$, which is called the coefficient of performance (COP).

$$\text{COP} = Q/W \text{ when } Q \text{ and } W \text{ are in the same units.}$$

One should not confuse it with the term 'efficiency' which is always less than 1. For example, in a heat engine, heat is converted into mechanical or electrical work. During the conversion, some heat energy is lost due to which the efficiency will be always less than 1. But, in the case of a refrigerator, the input energy (W) helps only in transfer of heat. Here, COP is always more than 1. Higher the value of COP, performance of the refrigerator can also be treated as higher or better.

### 6.4 APPLICATIONS OF REFRIGERATION

1. In water coolers, to supply cold water for drinking.
2. To manufacture ice.

3. For preservation of food, vegetables, milk, ice cream, etc., in houses, hotels, ships, etc.
4. For preservation of perishables like fish, mutton, chicken, etc.
5. Preservation of medicines, blood, tissues, etc., in hospitals.
6. Preservation of dead bodies in mortuaries in hospitals.
7. Different types of industrial applications.
8. For air conditioning in houses, offices, theatres, hospitals, computer centres, etc.

## 6.5 REFRIGERANTS

A refrigerant is the working fluid in a refrigerator. It is capable of absorbing heat at a lower temperature and rejecting the heat at a higher temperature, in the form of sensible heat or latent heat or both.

### 6.5.1 Desirable Properties of Refrigerants

1. Low boiling point, low freezing point, high latent heat of evaporation.
2. Low specific heat and low viscosity.
3. It should be easy to liquefy.
4. Odourless and no hazardous effect on leakage.
5. Chemical stability.
6. Nonflammable.
7. Low cost.

## 6.6 TYPES OF REFRIGERANTS

1. ***Freon-12*** This is most commonly used in domestic refrigerators, water coolers and freezers. It is dichloro difluoro methane ($CCl_2F_2$). It has a boiling point of –29°C.
2. ***Freon-22*** It is monochloro difluoro methane ($CHClF_2$) and it has a boiling point of –41°C. It is mostly used in air conditioners.
3. ***Ammonia*** It is mostly used in absorption system. It has a boiling point of –33.3°C.
4. Other refrigerants include carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$) and methyl chloride ($CH_3Cl$). Carbon dioxide is mainly used in marine refrigerators.

## 6.7 AIR REFRIGERATION

### INTRODUCTION

Due to the availability of air free of cost from the atmosphere, air was used as a refrigerant even in commercial application. But, its low heat carrying capacity and its low co-efficient of performance (COP) prevented its use in modern systems. However, it is now used for aircraft refrigeration where safety is the primary concern. In the meantime, possibility of its use in other applications are being explored.

### 6.7.1 Closed Air Refrigeration Cycle

In this cycle, air is passed through pipes.The schematic diagram of the equipment is shown in fig 6.1 Air is compressed in the compressor where the pressure and temperature are increased. The warm air from the compressor is cooled in a cooler with water. The cold air from the cooler expands in the expander causing a big drop in pressure and temperature. Cold air from the expender is passed on to the refrigerator where it absorbs the heat and makes it cold. Then, the air returns to the compressor and the cycle is repeated.

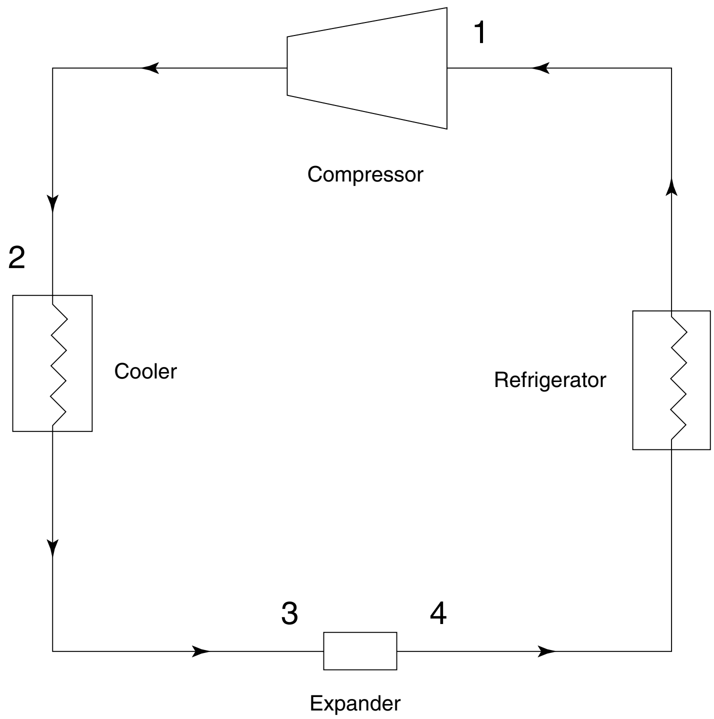



**Fig. 6.1** *Air refrigeration cycle*

### 6.7.2 Advantages of air refrigeration

1. Air is easily available, free of cost.
2. Leakage of air will not create any problem.
3. Air is very safe, as it is non-toxic and non-flammable.
4. The air system is light in weight
5. Maintenance cost is very low
6. Charging of the refrigerant is very easy.

### 6.7.3 Disadvantage

1. COP. is very low
2. Low heat carrying capacity.

## 6.8 METHODS OF REFRIGERATION

In this section, the following two methods to produce refrigeration effect are described:

1. Vapour-compression refrigeration
2. Vapour-absorption refrigeration

### 6.8.1 Vapour-Compression Refrigeration Systems

The vapour-compression refrigeration system is widely used in refrigeration applications like refrigerator, water cooler, air conditioner and cold storage. The schematic diagram of this system is shown in Fig. 6.1. The refrigeration effect is produced at the evaporator. The refrigerant enters the evaporator as wet vapour at a lower pressure and lower temperature. Here, it absorbs its latent heat of vaporisation from the substances kept around the evaporator, thus cooling them. The refrigerant usually comes out of the evaporator with its phase changed to dry saturated or slightly superheated state. Now it enters the compressor which is the heart of the system. The refrigerant vapour is compressed to a higher pressure and higher temperature as superheated vapour in the compressor. For this activity, power is supplied to the motor connected to the compressor and it constitutes the major running cost of the system. The compressed refrigerant vapour is led into the condenser. Generally, atmospheric air is blown over the condenser using a fan and it carries away the latent heat from the refrigerant vapour. Therefore, the refrigerant vapour is condensed into high pressure liquid. The liquid refrigerant enters the expansion device which can be a long spirally wound capillary tube in small refrigerators. Here, the refrigerant is throttled to low pressure, low temperature wet vapour, thus completing the cycle.

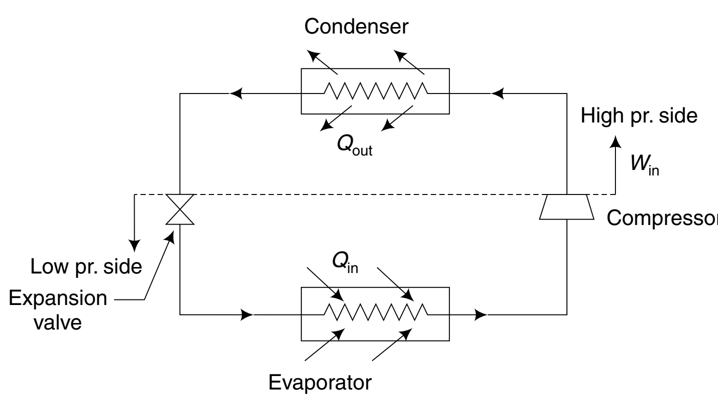



**Fig. 6.1** *Vapour-compression refrigeration*

### 6.8.2 Domestic Refrigeration System

The layout of a domestic refrigerator is given in Fig. 6.2. It belongs to the vapour compression type. The evaporator which is the coldest part is located in the freezer compartment. A separate door is provided for the freezer where we can store ice, ice-cream and perishable items like mutton, chicken, fish etc. Just below the freezer, usually a chiller tray is provided. Further below and behind the main door, there are several compartments with progressive higher temperatures. The bottom-most compartment is for vegetables where a very low temperature is not necessary.

The condenser tubes are kept on the back of the refrigerator cabinet. The refrigerant vapour is condensed with the help of surrounding air which rises above by natural convection. In the no-frost refrigerator, the evaporator is located outside the freezer compartment. The cold air is made to flow into the freezer compartment by a fan.

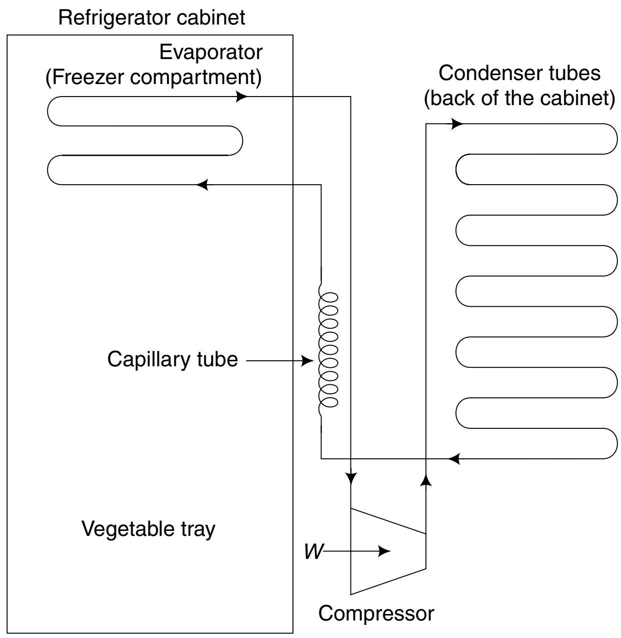



**Fig. 6.2** *Domestic refrigerator layout*

### 6.8.3 Vapour-Absorption Refrigeration System

The vapour-absorption refrigeration system is similar to the vapour-compression refrigeration system except for the manner in which the low-pressure vapour coming out of the evaporator is compressed. This system eliminates the compressor, yet produces the compressor effect by the combined effects provided by an absorber, a pump and a generator. The pump

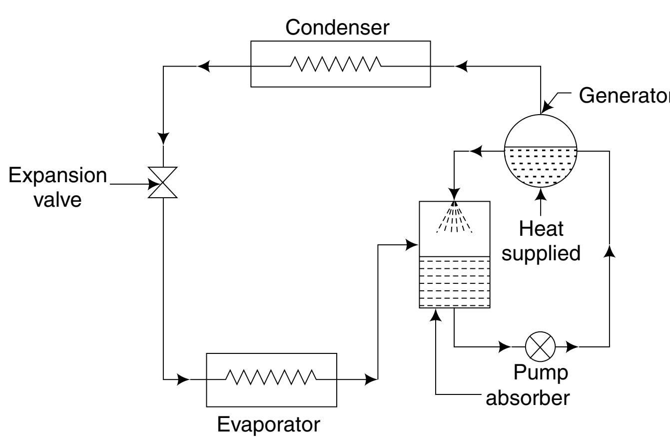



**Fig. 6.3** *Vapour-absorption refrigerator*

consumes comparatively a lesser amount of electric power and the generator can be operated by heat energy obtained from the burning of any low-cost fuel or any heat source including solar energy.

The schematic diagram of a simple vapour absorption system is shown in Fig. 6.3. The refrigerant used is ammonia and the absorber is water. Ammonia vapour coming out from the evaporator at low pressure is absorbed by water available in the absorber tank resulting in a strong ammonia solution. The pump pumps the solution, thereby increasing its pressure and sends the high-pressure solution into the generator. In the generator, the solution is healed by external heat supply. Now, high-pressure ammonia gas is generated which enters the condenser. The weak ammonia solution available in the generator contains more amount of water. It goes back to the absorber tank where it absorbs the incoming ammonia vapour and becomes a strong solution once again. The processes taking place in the condenser, expansion device and the evaporator are similar to those discussed under Section 6.8.1.

The absorber used in the vapour-absorption refrigeration system should have high affinity for the refrigerant, remain in the liquid phase under the operating conditions and should possess high boiling point, low specific heat and good chemical stability.

## 6.9 COMPARISION BETWEEN VAPOUR-COMPRESSION AND VAPOUR-ABSORPTION SYSTEM

**Table 6.1**

| | Vapour Compression | Vapour Absorption |
|---|---|---|
| 1. | Smaller in size | Very large in size for the same capacity |
| 2. | Refrigerant is Freon-12 | Ammonia |
| 3. | Electric power is needed to run the compression | Heat input can be supplied by a heater, or by exhaust steam or even by solar energy |
| 4. | COP is higher | Lower |
| 5. | Wear and tear will be more | Less |
| 6. | System produces noise | Silent in operation |
| 7. | Maintenance cost is high | Low |

## 6.10 SOLAR REFRIGERATOR/AIR-CONDITIONING SYSTEM

This system belongs to vapour-absorption type. Instead of heating the solution in the generator by an electric heater or by supplying the heat by burning any fuel, the solution can be directly heated in a solar collector.

It is rather ironical to note that solar heat can be used to produce cooling effect in the refrigerator or to cool a room by a solar air conditioner. The author has made use of a Japanese solar air conditioner in the laboratory at Bahrain University during 1980 – 1984. As the crude oil in the Gulf countries is expected to be exhausted in about 75 years, solar refrigeration/air conditioning system will become popular in the future.

# AIR CONDITIONING

## 6.11 INTRODUCTION

Air conditioning involves controlling and maintaining the desired temperature, humidity and direction of flow of air in a closed space. Also, filtering and cleaning of air is carried out by the air-conditioning system.

Air-conditioning does not always mean cooling the air. During winter, in many places across the world, the temperature becomes extremely low. Hence, in such areas, air conditioning means heating and humidification. The author has experienced up to –27°C in USA during the period of his stay from 1956 – 58 at Purdue University. Similarly, when we are flying at an altitude of about 10,000 metres, the temperature surrounding the aircraft will be several degrees below 0°C, due to which the passengers' area should be warmed up.

## 6.12 APPLICATIONS OF AIR CONDITIONING

1. Air conditioning of houses, hotels, theatres, etc.
2. Hospitals, operation theatres and intensive care units are air conditioned.
3. For comfort of passengers in cars, buses, trains, ships and aeroplanes.
4. Air conditioning becomes very essential in many industries like textiles, food, printing, machine tools, etc.

## 6.13 IMPORTANT TERMINOLOGY IN AIR CONDITIONING

| | |
|---|---|
| *Dry air* | Air without water vapour or moisture. |
| *Moist air* | It is a mixture of dry air and moisture. |
| *Dry-bulb temperature* | Actual temperature, measured by a standard mercury thermometer |
| *Wet bulb temperature* | The temperature measured by a mercury thermometer, when the bulb is covered by a moistened cloth |
| *Saturated air* | A mixture of dry air along with the maximum possible water vapour, at dry-bulb temperature |
| *Relative humidity* | The ratio of the mass of water vapour in a given volume of air at the given temperature to the mass of water vapour present in the same volume under the same temperature of air when it is fully saturated |

## 6.14 REQUIREMENTS OF COMFORT AIR CONDITIONING

Due to the natural phenomenon of body heat disposal by evaporation of moisture from the human body and inflow of moisture from other sources, the humidity inside a room increases. The increased humidity causes difficulty in disposing of body heat. Also, the room temperature rises due to the heat dissipated from the human body and heat from light source and any other equipments. When the room temperature is high, it causes human discomfort.

It has been found that for human comfort, we need a dry-bulb temperature of 20°C and relative humidity of 60 per cent in the room. Any air-conditioning system should primarily be able to achieve the above said conditions inside the room.

Under normal living conditions, a person inhales about 0.65 $m^3$ of oxygen and exhales about 0.2 $m^3$ of carbon dioxide in an hour. If the $CO_2$ level in the room increases above two per cent, it will cause human discomfort. Hence, the air conditioner should supply enough quantity of fresh air called ventilation air to meet the oxygen requirements and maintain the $CO_2$ level within limits. Also, the conditioned air should have a velocity in the range of 8 m/min to 14 m/min and be properly distributed inside the room for a feeling of comfort. Further requirements of comfort air conditioning demand that the conditioned air be free from dust, bacteria, odour and toxic gases.

## 6.15 WINDOW AIR CONDITIONER

A simple air-conditioning system without ducts, assembled inside a casing suitable for installation on windows or wall openings is called a window air conditioner. The unit consists of a vapour-compression refrigeration system, a double shaft motor, a blower, a fan, air filter, supply air grill, return air grill, fresh air damper, drain tray and a control panel as shown in Fig. 6.4. (a) & (b)

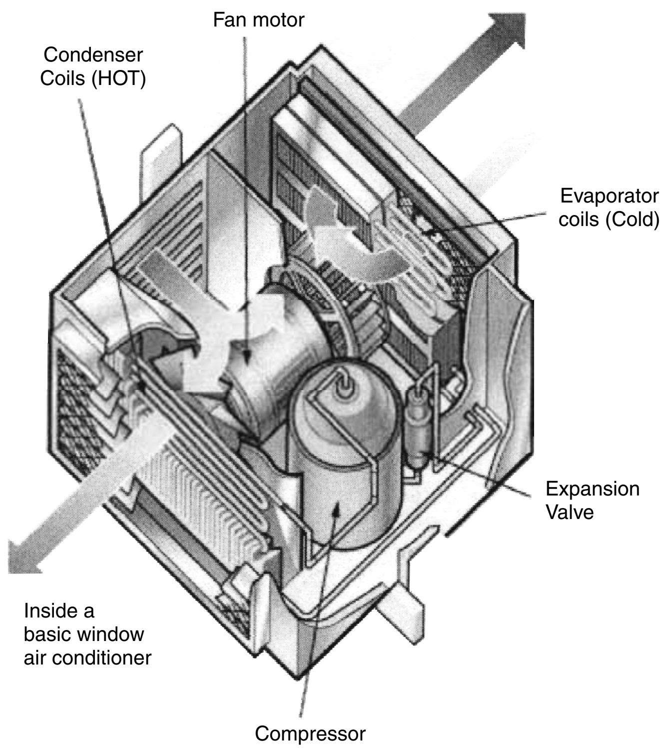



**Fig. 6.4(a)** *Pictorial view of a window AC*

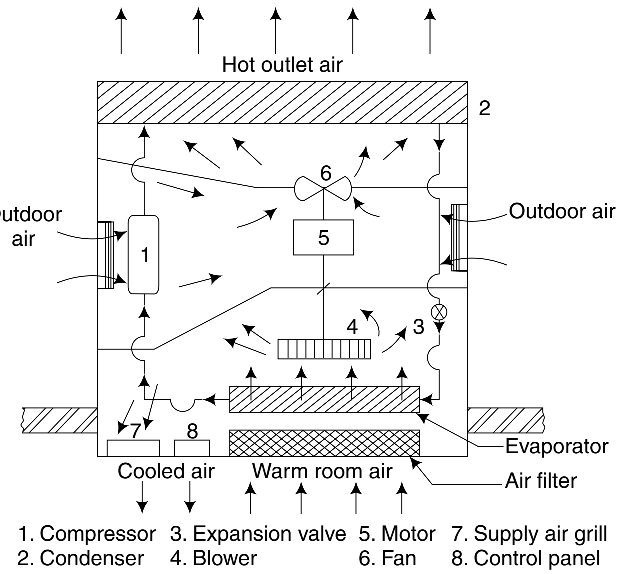



**Fig. 6.4(b)** *Layout of a window AC*

The blower sucks the warm air from the room through the air filter and the evaporator or cooling coil of the refrigeration system. Then, it delivers the cooled and dehumidified air back into the room through the supply air grill. The moisture condensing out when the inlet air is passed over the evaporator coil is drained out. The operation of the refrigeration system is the same as discussed in Section 6.8.1. The supply air grill has adjustable louvers or deflectors for changing the direction of air upwards, downwards or horizontally. Mechanised louvers are available in some window air conditioners which continuously change the direction of air flow to ensure uniform distribution of conditioned air inside the room. The conditioned air sent into the room mixes with the room air and decreases the temperature and humidity levels in the room and thereby maintains human comfort inside the room. Fresh air is admitted through the adjustable damper for the purpose of ventilation.

Window air conditioners usually operate on 230 V, single phase A.C. supply and are available in cooling capacities ranging from 0.5 TR to 3 TR. Their installation is simple and does not require any plumbing work. However, they are not suitable for large halls and applications where the heat and moisture loads are very high. In such cases, central air-conditioning systems are preferred. Pictorial view of a window air conditioner is given in Fig. 6.4(a).

## 6.16 SPLIT AIR-CONDITIONER

An air conditioner has four major components, namely, the compressor, condenser throttling device and evaporator. In a window air conditioner, all these four major components are placed inside a single cabinet, with a small partition. In the case of a spilt air conditioner, the components are placed in two cabinets, namely, the indoor unit and outdoor unit as in Fig. 6.5. As the name implies, the indoor unit is to be placed inside the conditioned room while the outdoor unit is to be fixed outside the room. The indoor and the outdoor units are fixed with the help of suitable fixtures or hooks and they are connected with the help of tubes in which high pressure liquid and low pressure vapour would pass through a hole in the wall.

The main components of the indoor unit are the blower (B), evaporator (E), throttling valve (Th.V.) and drainage (D) system. The high-pressure liquid refrigerant from the outdoor unit is allowed to flow through the throttling valve to obtain low-pressure vapour refrigerant. The low-pressure wet vapour refrigerant is then allowed to pass through the evaporator. As the blower blows air over the evaporator, low pressure refrigerant obtained from the throttling valve is evaporated to produce chillness in the surrounding of the evaporator. Air inlet and outlet louvers are placed at suitable locations to enable free cold-air flow.

The main components of the outdoor unit are the fan (F), condenser (Cond.) and compressor (Comp.). The low-pressure vapour refrigerant from the evaporator of the indoor unit is allowed to flow through the compressor to obtain high pressure and high-temperature refrigerant. The high pressure and temperature vapour is then allowed to pass through the condenser. As the fan blows air over the condenser, high-pressure vapour condenses to form high-pressure liquid refrigerant. Air inlet and outlet louvers are placed at suitable locations to enable free air flow. Rubber pads are used to mount the outdoor unit, as the working of compressor will produce vibration.

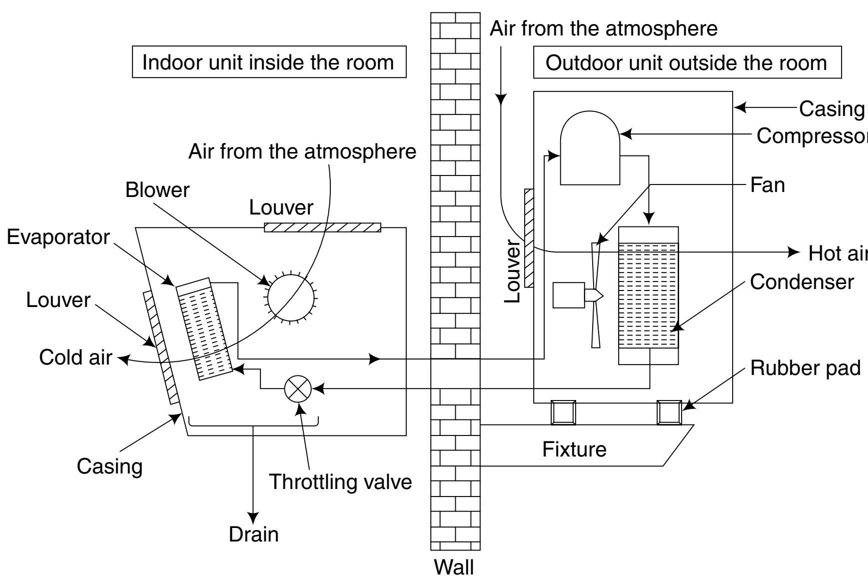



**Fig. 6.5** *Split air conditioner*

## 6.17 CENTRAL AIR CONDITIONING

The central air-conditioning system is adopted for large buildings, star hotels, hospitals, cinema theatres, etc. This system is used only for heavy loads of about 20 tons or more. Various components of the central air-conditioning system are not assembled at the factory. Instead, they are all assembled at the site in a control room from where conditioned air is distributed to the required places through duct work. The duct work should be carefully designed, fabricated and erected.

## 6.18 COMPARISON OF UNITARY AND CENTRAL AIR-CONDITIONING SYSTEM

**Table 6.2**

| | Unitary Type | Central |
|---|---|---|
| 1. | The capital cost is high, per ton of refrigeration | Cost is low |
| 2. | Factory assembled | Assembled at site |
| 3. | Located in the space to be conditioned | Located away from the conditioned space |
| 4. | Smaller capacity units | Large capacity unit of 20 tons or more |
| 5. | No need for duct work | Extensive duct work is essential |
| 6. | Failure in the system will affect one room only | Will affect all the rooms |
| 7. | Installation charges are less | Much higher |

## 6.19 THERMOELECTRIC COOLING

The difference between the conventional and thermoelectric cooling methods is that a thermoelectric cooling system refrigerates without the use of mechanical devices and refrigerant. Its working is based on the *Peltier Effect.* Two dissimilar conductors replace both the liquid and vapour phases of a conventional system in a thermo electric cooling refrigeration system. The compressor is replaced by a D.C. power source which pumps electrons from one semiconductor to another.

The schematic diagram of a pair of semiconductors with different characteristics, which form a thermoelectric cooling module, is shown in Fig. 6.6. They are connected electrically in series and thermally in parallel so that two junctions are created.

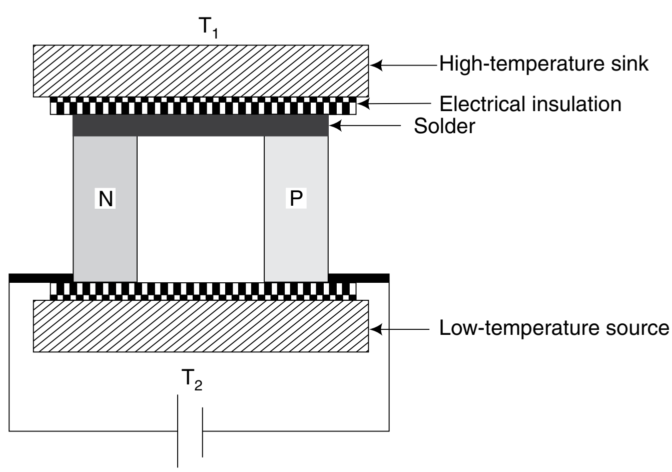



**Fig. 6.6** *Schematic diagram of thermoelectric cooling module*

Semiconductor materials are of *N* and *P* type. They are named so because either they have more electrons than necessary to complete a perfect molecular lattice structure (*N*-type) or do not have enough electrons to complete a lattice structure (*P*-type). The extra electrons in the *N*-type material and holes left in the *P*-type material are called *carriers* and they are agents that move the heat energy from the cold to the hot junction, leading to refrigerating effect. These coolers can operate in the range of + 60°C to – 40°C. Good thermoelectric semiconductor materials such as bismuth telluride are widely used in these cooling devices.

### 6.19.1 Advantages of Thermoelectric Cooling

1. As there are no moving components, there is no problem of wearouts.
2. As conventional refrigerants like freon (CFC), corrosive liquids and gases are not used, they are environmentally safe.
3. Silent and maintenance-free operation.
4. Compact designs.
5. A unit may be converted from cooling to heating mode by reversal of polarity of the input power.
6. Light in weight.

### 6.19.2 Disadvantages of Thermoelectric Cooling

1. Separate D.C. power source is required (low voltage-up to 12 V dc and low current-up to 5 A D.C.).
2. Suitable only for small units.
3. Poor performance and so not suitable for large installations.

### 6.19.3 Applications of Thermoelectric Cooling

The use of thermo electric cooling may be widely found in the electronics industry and in many computer centres. The main aim is to provide local cooling for the electronics components for better performance. Industrial equipment like computer aided manufacturing machines makes use of these cooling devices for the control systems.

## Short-Answer Questions

1. Define ton of refrigeration.
2. State the desirable properties of refrigerants.
3. State the requirements of conditioned air.
4. What are the limitations of a window air conditioner?
5. What are the normal capacities of window air conditioners?
6. List the applications of a refrigerator.
7. What are the commonly used types of refrigerators?
8. Compare unitary and central air-conditioning systems.
9. What is Peltier effect?
10. What is meant by dry bulb temperature?
11. What is relative humidity?

## Long-Answer Questions

1. Explain the working of an Air refrigerator with the help of a layout sketch.
2. How is a refrigerator's performance measured?
3. Compare and contrast the working of vapour compression and vapour absorption refrigeration systems?
4. Explain the working of a split air conditioner?
5. What are the advantages and disadvantages of thermoelectric cooling?

# CHAPTER 7
# METAL CASTING PROCESS

## 7.1 INTRODUCTION

Metal casting is one of the most versatile forms of production processes. There is no limit to the size and shape of the articles that can be produced by casting. The production cost is considerably low. Although all metals can be cast, iron is mostly used because of its fluidity, small shrinkage and ease with which its properties are controlled.

Casting process involves the pouring of molten metal into a cavity or mould of the desired shape and size, and allowing it to solidify. When it is removed from the mould, the casting is of the same shape but slightly smaller due to the contraction of metals. The process requires moulding sand which can withstand high temperatures. By using a replica of the required cast which is called a pattern, a cavity of the desired shape and size is made in the moulding sand. The metal is melted in a furnace and poured in the cavity. After the solidification is completed, the casting is removed and cleaned.

## 7.2 ADVANTAGES OF THE CASTING PROCESS

1. The cost involved in the casting process is very low compared to the other manufacturing processes.
2. Very heavy and bulky parts which are difficult to fabricate can be manufactured by the casting process.
3. Casting can be employed for the mass production as well as for batch production.
4. A product can be cast as a single piece and hence the metal joining process is eliminated.

## 7.3 PATTERNS

A pattern is a model or a replica of the object to be manufactured around which moulding sand is packed to get a mould of desired shape and size.

The quality of casting in terms of dimensional accuracy, surface finish, and mechanical properties depends largely on the material used for the patterns, type of pattern, design and construction of patterns. Hence, a lot of preparation is necessary before starting the production of patterns. The preparation includes making decision about,

1. The type of materials to be used;
2. The type of pattern to be adopted;
3. The tolerance and allowances to be provided;

4. The constructional details, including the provision of loose pieces, core boxes and
5. The method of gating and feeding to be adopted.

### 7.3.1 Pattern Materials

In a metal casting process, the quality of castings is also influenced by the pattern materials. It is necessary to select the right material that can give the desired quality at the minimum cost. The selection of pattern materials depends on the following:

1. The number of casting to be manufactured.
2. The desired level of dimensional accuracy and surface finish required.
3. The shape and size of the casting.
4. The design and fine details of the casting.
5. The type of moulding processes.
6. The method of moulding, i.e sand moulding or machine moulding. Patterns may be made by using materials such as wood, metals, plastics, plaster and wax.

***Wood*** Wood is the material most commonly used for making patterns for sand moulding, Wood can be easily shaped or worked with to get patterns of desired shape and size. It is light in weight, abundantly available, cheap and can be handled easily.

However, wood is easily affected by moisture, and it possesses less strength. Hence, it is not suitable for mass production. The most common types of wood used are mahogany, teak and pine.

***Metals and Alloys*** Metal patterns are mostly cast from wooden patterns or machined to desired shape. Metal patterns are stronger, accurate and durable. The other advantages are its ability to withstand rough handling, high resistance to warp, wear and abrasion.

However, metal patterns are expensive and not easily repaired. Ferrous metals get rusted. Metals are heavier and difficult to handle. Metals cannot be machined easily. Metal patterns are used when the number of castings to be manufactured is large. Aluminium and its alloys, steel, cast iron, brass and white metal are the different metals used for making patterns.

***Plastics*** Plastic patterns are prepared with the help of wooden patterns. Plastics are light. These are moisture resistant and provide a smooth surface. These are also wear and corrosion resistant. Plastic patterns are durable and do not involve any appreciable change in size or shape.

However, plastic patterns are weak and need metal reinforcement for light sections. Plastic patterns are also not suited for machine moulding.

Both the thermosetting and the thermoplastic materials are used for making patterns. Common plastic materials used for making patterns are epoxy resin, polyester resins and polystyrene.

***Plaster*** Plaster pattern is also made with the help of wooden patterns. Plaster pattern can be easily worked by using wood working tools. Intricate shapes can be made easily. Plaster has a high compressive strength. Hence, the plaster pattern is used for making small and intricate castings and core boxes. Materials such as plaster of Paris or gypsum cement are commonly used for plaster patterns.

***Wax*** The wax pattern is made in a water cooled metal mould or a die. The wax pattern provides a very good surface finish and high accuracy. For removing the wax pattern, the mould with the pattern is inverted and heated to make the wax melt away. The wax pattern is used in investment casting or lost wax process.

## 7.3.2 Pattern Allowances

In the metal casting process, the pattern is used to manufacture a casting of the desired dimensions, but the pattern is not made dimensionally identical with the casting. The various reasons are the following:

1. All metals shrink in size when there is a change from the liquid to the solid state.
2. Castings require surface finishings.
3. The pattern should be removed from the mould cavity without tearing the mould cavity surface.
4. Casting tends to warp or distort during the cooling stage.

Therefore, the patterns are made with certain allowances on size. The various patterns allowances include the following:

1. Shrinkage allowance.
2. Finishing allowance or machining allowance.
3. Draft allowance or taper allowance.
4. Distortion allowance or camber allowance.
5. Shaking allowance or rapping allowance.

For quality castings, there should be a balance between all these allowances.

***Shrinkage Allowance*** Shrinkage allowance is the allowance given on the pattern size for avoiding any change in the dimensions of the casting because of the shrinkage of the metal during solidification.

Different metals shrink differently and have different shrinkage allowances. Shrinkage allowances for important casting metals are given below:

| | |
|---|---|
| Grey cast iron | 7-10.5 mm/m |
| Steel | 20 mm/m |
| Aluminium | 18 mm/m |

Shrinkage allowances are given by using a shrink rule which includes the proportionate allowances on every measurement. Shrink rules are available for every casting metal. The shrinkage allowance to be given depends on the following major factors:

1. The type of metal being used
2. The size and shape of the casting and
3. The moulding medium.

***Finishing Allowance or Machining Allowance*** The finishing or machining allowance is the allowance given on size of the pattern for finishing or machining the rough surface of the casting. The standard finishing allowance for ferrous metal is 3 mm and that for nonferrous metals is 1.5 mm. The finishing or machining allowance to be given depends on the following major factors:

1. The type of metal being used.
2. The casting design.
3. The method of casting.
4. The method of cleaning and
5. The degree of finish required for the casting.

***Draft Allowance or Taper Allowance*** Draft allowance is the taper allowed on vertical faces of a pattern for easy removal of the pattern without damaging the mould cavity surface as given in Figs. 7.1(a) and 7.1(b). A draft of 3-6 mm per metre is generally adopted. For patterns used in machine moulding, normally one degree taper is given. This allowance depends on the following factors:

(1) The size and shape of the casting.
(2) The length of the vertical face of the casting.
(3) The method of moulding and
(4) The intricacy or fine details of the casting.

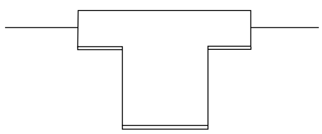


**Fig. 7.1(a)** *Pattern having no Draft Allowance*

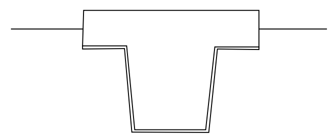


**Fig. 7.1(b)** *Pattern having Draft Allowance*

***Distortion or Camber Allowance*** Due to the internal stresses developed during cooling, the casting may be distorted. For example, if the casting has a U-shape, it will tend to cool faster at the ends, giving rise to internal stresses in the bent portion. As a result, on cooling, the legs of the casting would deflect outwards as shown below in Figs. 7.2(a) and 7.2(b). Distortion allowance is given to avoid this by intentionally deflecting the leg inwards. This allowance depends on the following factors:

1. The type of metal being used;
2. The design of the casting; and
3. The length of thin section in casting.

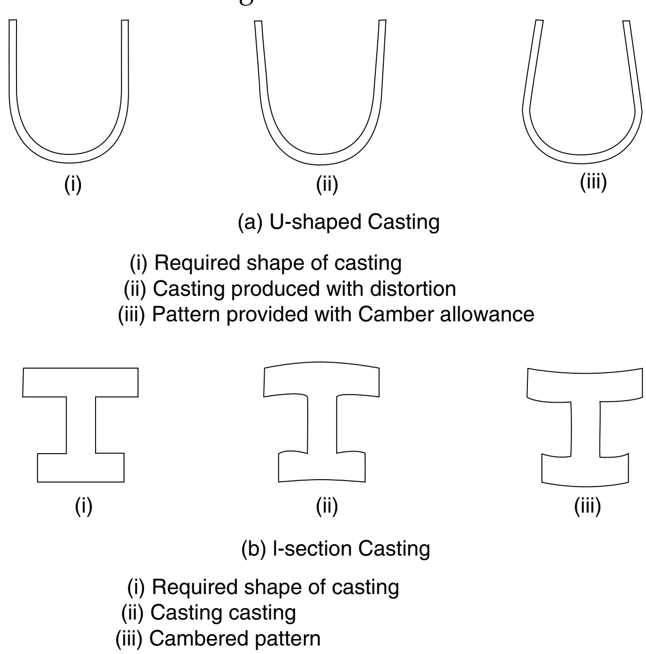



**Fig. 7.2** *Distortion or Camber Allowance*

Distortion allowance is given based on previous experience or the distortion produced in a casting made with a pattern without any distortion allowance is measured and then the allowance is provided on the pattern.

***Shake Allowance or Rapping Allowance*** For the easy withdrawal of the pattern from the moulding sand, the pattern is slightly rapped or shaked around the vertical faces which leads to a slight enlargement in the mould cavity. So, the final casting will be slightly over sized. The shake allowance is given to overcome this problem, by making the pattern slightly smaller in size.

### 7.3.3 Types of Patterns

In the metal casting process, various types of patterns can be used; but it is necessary to select a particular type of pattern for our application. The various factors to be considered to the selection of a pattern type are the following:

1. Shape and size of the casting
2. Number of casting
3. Method of moulding adopted
4. Complexity and intricacy of the casting
5. Accuracy required; and
6. Problems associated with the moulding operation such as the removal of patterns from the mould.

The various types of patterns commonly used are explained in the following sections;

***Solid Pattern or Single Piece Pattern*** The simplest form of pattern made without any joints, partings or loose pieces in its construction is called a solid or single piece pattern as shown in Fig. 7.3(a). It is inexpensive and generally used for large castings of simple shape.

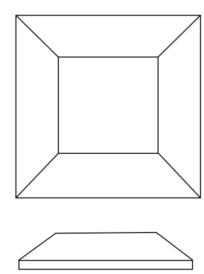


**Fig. 7.3(a)** *Single Piece Pattern*

***Split Pattern*** All patterns cannot be made in a single piece because of the difficulties faced in removing them from the mould. To overcome this problem, some patterns are made in two parts so that half of the pattern will rest in the lower part of the mould and the other half in the upper part. The two parts are aligned by means of dowel pins as shown in Fig. 7.3(b). Some complicated casting requires three or more parts to be constructed and such a pattern is called a multi-piece pattern.

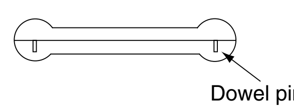



**Fig. 7.3(b)** *Split Pattern*

***Match Plate Pattern*** In match plate patterns, each half of the patterns are mounted on opposite sides of a plate called a match plate. This is widely used in machine moulding. The gates and runners are also attached to the plate. The match plate pattern is aligned by means of locator holes in the match plate and locating pins on the moulding box as shown in Fig. 7.3(c).

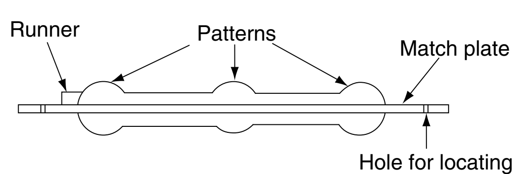



**Fig. 7.3(c)** *Match plate pattern*

***Loose Piece Pattern*** It is a pattern with loose pieces which are necessary to facilitate the withdrawal of the pattern from the mould as in Fig. 7.3(d). Loose pieces are removed separately by turning or moving through the cavity formed after the main pattern has been removed. These loose pieces are fastened loosely to the main part by means of wooden dowel pins.

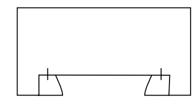


**Fig. 7.3(d)** *Loose Piece pattern*

***Skeleton Pattern*** Skeleton pattern is used for making a few large castings. The skeleton pattern has a wooden framework filled with loam sand. This is to save the amount of pattern materials used. The final shape is given with a strickle. It is shown schematically Fig. 7.3(e).

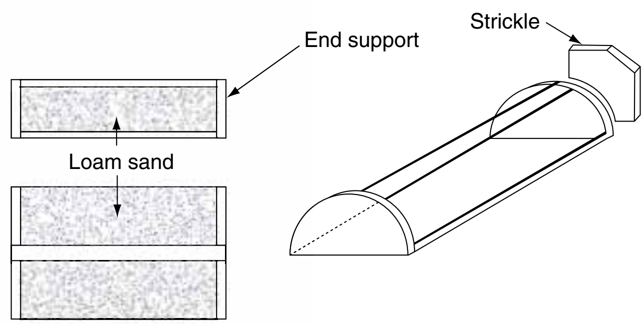



**Fig. 7.3(e)** *Skeleton Pattern*

***Follow Board Pattern*** Follow board pattern is used for casting which has some structurally weak portions which need some support for avoiding breakage during the moulding process. Hence, these weak portions are supported by means of a board that will closely fit the contour of the weak pattern. This arrangement is shown in Fig- 7.3.(f).

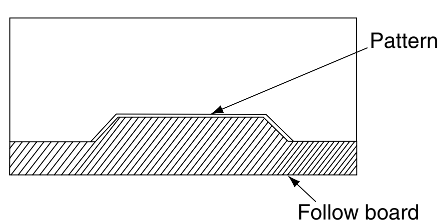



**Fig. 7.3(f)** *Follow board pattem*

***Sweep Pattern*** Sweep patterns are used to manufacture large casting of symmetrical shape and with a circular cross-section. A sweep pattern consists of a wooden board with outer contour similar to the casting's form. This board is fixed to a metal rod and rotated about the metal rod as the axis of rotation, for getting a complete mould cavity. This arrangement is shown in Fig. 7.3(g). This pattern is economical, since only a wooden board is used instead of large-size expensive solid pattern.

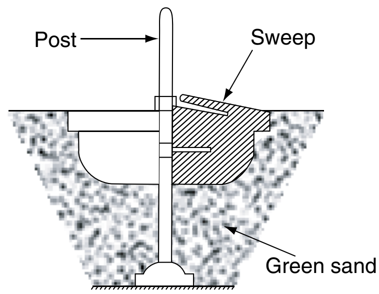



**Fig. 7.3 (g)** *Sweep pattern*

***Gated Pattern*** When large number of small castings are required, gated patterns are used. Such patterns are usually made of metal to give them strength. The gates and runners for the molten metal are formed by the connecting parts between individual patterns as shown in Fig. 7.3(h).

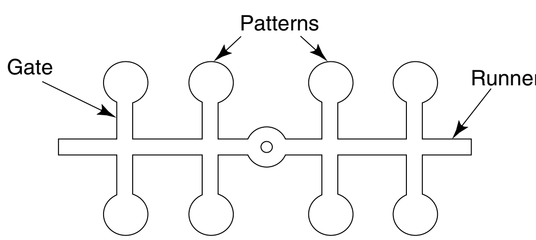



**Fig. 7.3 (h)** *Gated pattern*

***Shell Pattern*** Shell patterns are widely used for large symmetrical casting such as drainage fittings and pipes. The shell pattern consists of a hollow construction. The outside contour is used as a pattern to form the mould. The shell pattern is made of two halves, which are correctly aligned together by means of dowel pins. The shell pattern is usually made of metals and shown in Fig. 7.3(i).

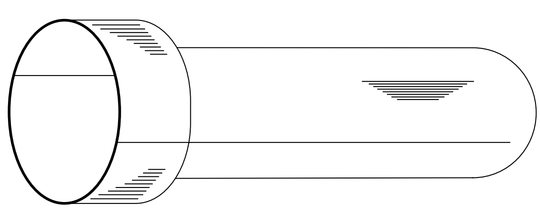


**Fig. 7.3 (i)** *Shell pattern*

***Cope and Drag Pattern*** The cope and drag pattern is used for very large castings, in case the complete mould is too heavy and difficult to handle by a single operator. The cope and drag pattern is made in two halves. Both are moulded separately and are then assembled to make the complete mould.

### 7.3.4 Pattern Making

Considering the importance of the pattern in the metal casting process, it is necessary to select proper equipment, machines, tools and instruments for pattern making. These requirements depend on the pattern materials used and the method of making.

Wooden pattern may be hand worked or machine worked. For making wooden patterns, utensils such as work benches, carpenter's vice, circular saw, band saw, wood planer, disc sander, pattern maker's lathe, pattern milling machine, and wood boring machine are required. For machining a metal pattern, traditional machines such as the lathe, milling machine, drilling machine, shaper, planner, and grinding machine are used.

## 7.4 MOULDING

Once the pattern of correct shape and size of the casting is prepared, it is necessary to make a cavity with the help of a medium. The process of making this cavity of the desired shape and size on a medium is called moulding. The medium may be ordinary moulding sand or resin-bonded sand. In case of diecasting, metal moulds are used.

### 7.4.1 Moulding Sand

Moulding sand is the medium in which the cavity is made for the casting. It consists of a mixture of basic ingredients such as the refractory sand, grains, binders, water and some additives details of which are dealt in Section 7.4.3.

### 7.4.2 Properties of Moulding Sand

The principal properties of the moulding sand are the following:

***Refractoriness*** It is the ability of the moulding sand to withstand the high temperature of the molten metal so that it does not cause fusion.

***Strength*** The moulding sand should have sufficient strength (green strength, dry strength and hot strength) to retain the mould shape under green (5 to 8% water content), dry and hot conditions respectively.

***Flowability*** Flowability is the ability of the moulding sand to get compacted to take up the required shape. Flowability increases as clay and water contents increase.

***Porosity or Permeability*** The moulding sand should be porous enough to allow the gases picked up by the molten metal while transferring or gases generated in the mould to escape from the mould. This capability of the moulding sand is known as permeability.

***Strength or Cohesiveness*** It is the ability of the moulding sand grains to adhere to each other. It is necessary for a uniform packing of the moulding sand while preparing a mould.

***Adhesiveness*** Adhesiveness is the property of moulding sand to adhere to the walls of moulding boxes. It is necessary to enable the safe handling of the mould from one place to another.

***Collapsibility*** Collapsibility is the readiness of the moulding sand to get collapsed, after the solidification of the casting.

***Durability*** It is the ability of the moulding sand to withstand the heating and cooling during repeated usage.

***Chemical Resistivity*** It is the ability of the moulding sand to resist any chemical reaction with the molten metal.

### 7.4.3 Ingredients of Moulding Sand

The principal ingredients of moulding sand are the following:

***Refractory Sand Grains*** This is a mixture of silica sand $SiO_2$(80-90%), alumina and magnesium oxide. Refractory sand grains give the refractoriness, chemical resistivity and permeability of the moulding sand.

***Binders*** Binder provides the necessary bonding strength to the moulding sand and it holds the sand together. Clay is most commonly used binder along with the moulding sand. Kaolinite or fire clay and bentonite are the most commonly used binders.

***Water*** Water is added to activate the clay in the moulding sand. The addition of water develops the necessary plasticity. The amount of water should be kept within certain range as excess water decreases the strength and the formability of the moulding sand. Normally, the water content is in the range of 2-8 per cent.

***Additives*** In addition to these basic ingredients, any other materials added to get some specific properties in the moulding sand are called additives. These are mixed with the moulding sand during sand preparation. Some common additives and their purposes are given below:

Coal dust—for protecting the mould surface against the action of molten metal and to get a good surface finish.

Dextrin—for increasing the toughness and collapsibility.

Iron oxide powder—for getting high temperature plasticity, hot strength and anti-metal penetration properties for the moulding sand.

Molasses—for higher dry strength and collapsibility.

### 7.4.4 Preparation of Moulding Sand

Sand preparation means mixing the moulding sand ingredients such as sand, binder, water and other additives. Mixing may be carried out manually or by mechanical means. For the mechanical mixing, the sand muller is used.

A moulding sand muller basically consists of a cylindrical bowl or a pan. Inside the bowl, there are two heavy rollers which roll in a circular path about a vertical rotating shaft. In addition to this, there are two plough blades which force the moulding sand towards the rollers for homogeneous mixing. The schematic diagram is shown in Fig. 7.4.

For mechanised casting, high speed sand muller with two or more high speed wheels rotating in a horizontal plane are used.

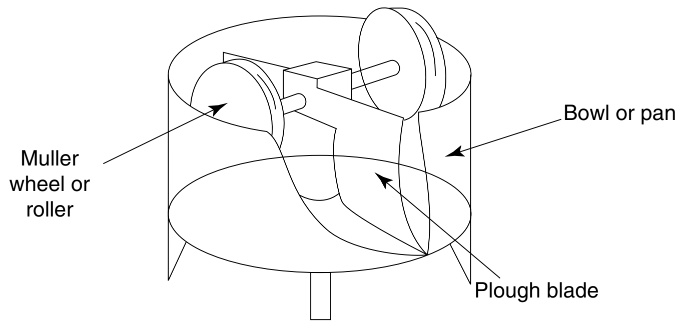



**Fig. 7.4** *Sand Muller*

### 7.4.5 Types of Sand Moulding

Sand moulding is classified according to the type of moulding sand used as given below:

***Green Sand Moulding*** In green sand moulding, the molten metal is poured when the mould is in moist condition. Green sand moulding is the most widely used type of sand moulding. The permeability of the green sand mould should be properly controlled for avoiding casting defects such as blow holes and air inclusions.

***Dry Sand Moulding*** In dry sand moulding, the mould is prepared with the moulding sand having high dry strength and is then dried in an oven. Dry sand moulding is used for large castings and for the mould requiring greater strength.

***Skin Dried Moulding*** In skin dried moulding, the moisture from the surface layer of the mould side only is dried to a depth of 25 mm or more by using gas torches or heaters.

***Loam Sand Moulding*** In loam sand moulding, loam sand mortar which is a mixture of equal amount of sand grains and clay wetted to the consistency of mud is used. The loam is constructed of porous bricks joined with loam sand mortar. Skeleton patterns are used with loam moulding.

***Oil Sand Moulding*** In oil sand moulding, moulding sand with an organic binder (linseed oil, vegetable oils, mineral oils, animal oils or natural resins) along with dextrin and bentonite are used. This is commonly used for core making.

### 7.4.6 Preparation of Green Sand Moulding

The procedure for preparing a green sand mould is as follows:

A bottom board or moulding board is placed on the moulding platform or on the floor. The drag portion of the moulding box is kept upside down on the bottom board. The drag portion of the pattern is placed at the centre of the moulding box on the moulding board with sufficient clearance between the pattern and the moulding box walls as shown in Fig. 7.5 (a). Dry facing sand is sprinkled all around the patterns to avoid the sticking of pattern with the moulding sand. Then, sufficient amount of moulding sand is put into the moulding box and on the drag pattern so as to fill the box completely. The moulding sand is added if necessary. The excess sand is subsequently removed by striking off with a bar and the moulding sand in the box is levelled. Parting sand is then sprinkled over the top of the moulding box. Vent holes are made in the drag portion for the removal of gases during solidification of the casting. This is done by using a vent wire. Now the moulding box is turned over and is kept in an upright position. This is explained in Fig. 7.5(b).

The edges of sand around the drag pattern is improved. Cope portion of the pattern is placed over the drag portion and properly aligned with the help of dowel pins. The cope box is then placed over the drag box and properly aligned. A sprue pin is placed at some distance from the pattern for making the sprue hole. The sprue hole is the passage through which the molten metal from the funnel shaped cavity at the top of the mould reaches the mould cavity. Then a riser pin is kept at an appropriate place for making the riser. The riser is a reservoir of molten metal provided in the mould and it is also used as a vent. These arrangements are shown in Fig. 7.5(c). Then a sufficient amount of moulding sand is added and the entire procedure adopted for preparing the drag half of the mould is repeated. Then the sprue pin and the riser pin are carefully withdrawn. A funnel-shaped cavity is formed near the top of the sprue hole. This is called the pouring basin.

The cope is separated from the drag and the loose sands on cope and drag interface are removed. Then, the pattern halves are withdrawn carefully by using drawspikes and by rapping the pattern. The runners and the gates are cut in the mould cavity carefully without spoiling the mould cavity using the gate cutters. The loose sands are removed by blowing away with bellows. Now, the facing sand in the form of a paste is applied all over the mould cavity which is called the mould wash.

The cope is placed over the drag again after properly aligning by means of pins. The mould is now ready for pouring which can be seen in Fig. 7.5(d).

Various hand tools used for moulding are shown in Figs. 7.5(e)-(j).

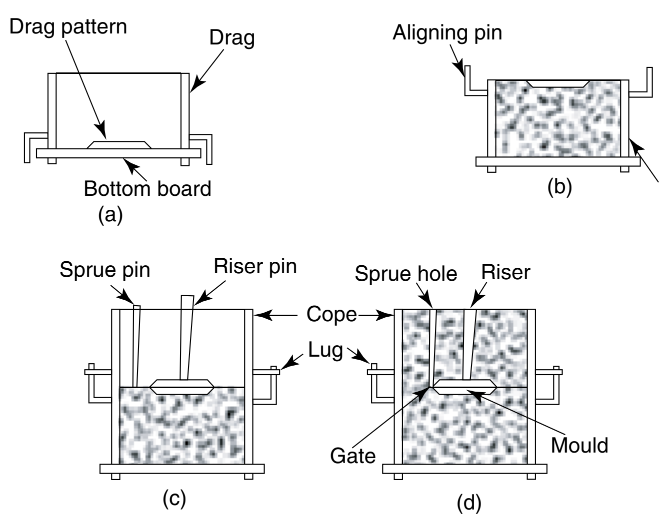



**Fig. 7.5** *Green sand moulding stages and tools*

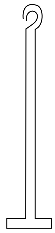


Fig. 7.5 (e) *Rammer*

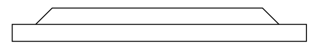


Fig. 7.5(f) *Strike offbar*

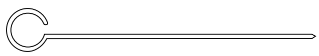


Fig. 7.5 (g) *Vent wire*

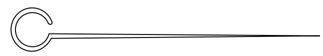


Fig. 7.5 (h) *Draw spike*

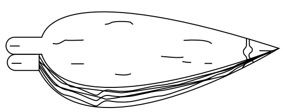


Fig. 7.5(i) *Bellows*

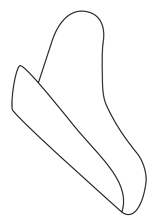


Fig. 7.5(j) *Gate cutter*

### 7.4.7 Cores

Cores may be defined as any projections into the mould for making cavities and hollow shapes which cannot be produced by the pattern alone. In general, cores are surrounded on all sides by the molten metal. Cores are made separately, baked and suitably placed or positioned in the mould cavity.

### 7.4.8 Moulding Machines

The green sand moulding done by compacting the moulding sand around the pattern by ramming the sand using the hand tools as explained in the previous section is limited to the production of very few moulds. The huge or mass production of castings is done by using machine moulding which uses techniques like squeezing, jolting, vibrating, slinging, blowing or any combined methods for compacting the moulding sand around the pattern. Various machines used to prepare the moulds are namely.

1. Squeezers
2. Jolt Machines
3. Jolt and Squeeze Machines
4. Slingers

The principles of operation of each moulding machine are explained below:

***Squeezers*** Squeeze moulding machines utilize pressure for compacting the moulding sand. The pressure may be applied through a squeezer head. This type of moulding machine is available with tight moulding chambers. These machines normally utilize gravity to fill the moulding chamber. Then the squeeze pressure is applied by air cylinders as shown in Fig. 7.6.

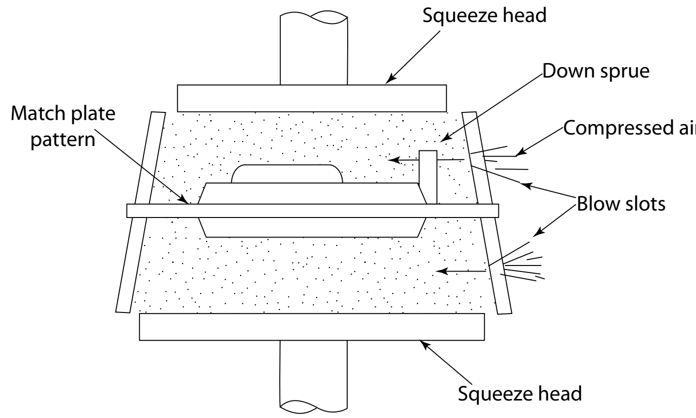



**Fig. 7.6** *Squeeze moulding machine*

***Jolt Machines*** The jolt type machines operate with the pattern mounted on a pattern plate, which in turn is fastened to the machine table. A flask is placed on the pattern and positively located by pins relative to the pattern. The flask is filled with sand and the machine starts the jolt operation. This is accomplished by alternately applying and releasing air pressure to the jolt piston which causes the flask, sand and pattern to lift for few centimeters and then fall to a stop, producing a sharp jolt. This process is repeated for a predetermined number of times and due to the kinetic energy of the sand, the moulding sand will be compacted. When the process is completed, the push off pins at the bottom edge of the flask lift the flask. The operation of the jolt machine is shown in Fig. 7.7.

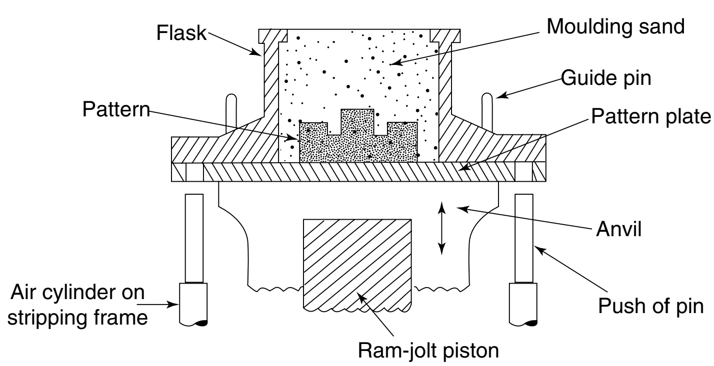



**Fig 7.7** *Jolt type moulding machine*

***Jolt and Squeeze Machines*** The jolt and squeeze machines operate in the same manner as jolt machines. In the mould prepared by the jolt machines, the top portion is having less density compared with the bottom portion. So, a supplemental compaction is done by a squeeze head which compacts the loose sand at the top. The required pressure for squeeze operation can be supplied by pneumatic cylinders. The operation of the jolt and squeeze machine is shown in Fig. 7.8 which can use either a solid squeeze head or a compensating squeeze head for the required squeezing action.

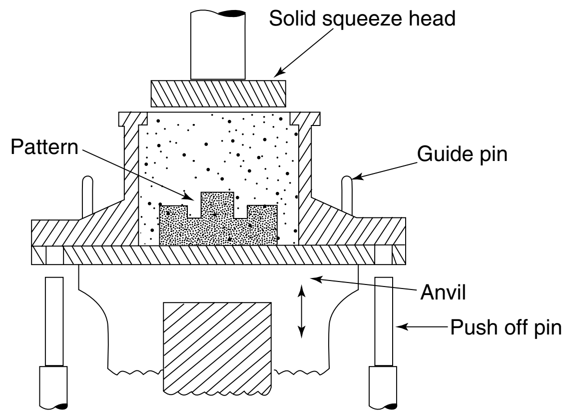



**Fig. 7.8** *Jolt and Squeeze Type Machine*

***Sand Slingers*** Sand slinging machines deliver the sand into the mould at high velocity from a rotating impeller. Moulds made by this method will have very high strength because a very dense mould can be made. Density is a function of sand velocity and the thickness through which the high velocity sand must compact the previously placed sand. Sand slingers are used to produce larger moulds.

## 7.5 MELTING OF CAST IRON

In metal casting, melting is considered to be important; because it controls the quality of the casting. A wide range of furnaces such as the pit furnace, open hearth furnace, rotary furnace, cupola furnace, and electric arc furnace are available for melting. The choice of the furnace is made based upon the amount and type of metals or alloys to be melted. A cupola furnace is most commonly used for melting cast iron.

## 7.6 CUPOLA FURNACE

A cupola furnace basically consists of a cylindrical steel shell with both its top and bottom open. The inner walls of the shell are lined with heat resisting materials such as the fire brick. The bottom opening is closed by a cast iron drop bottom door supported by a metal prop. This door swings out after the melting when the metal prop support is removed. This arrangement is shown in Fig. 7.9. After closing the bottom door, a sloping sand bed is prepared for giving the necessary heat resistant bottom for the molten metal and the fuel. Just above the sand bed is the metal tapping hole through which the molten metal is taken out to pour into the mould or the ladle. A spout called the tapping spout is provided for guiding the molten metal out. Above the tapping hole and opposite to it is a hole with a spout for removing the slag generated during the melting. It is called the slag hole.

Above the slag hole is the wind box which surrounds the cupola shell and supplies air at a given pressure and quantity. Air comes to the wind box through an air blast pipe from an air blower (not shown in the figure). Air enters into the cupola furnace through tuyers which extend through the steel shell and the refractory lining. The number of tuyers and their spacing along circumference of the shell varies with the size of the cupola furnace.

A cupola furnace is also provided with a charging platform or floor and a charging door for feeding the charges. The charge consists of pig iron, scrap iron, coke and fluxes. At its top, the cupola furnace has a metal shield or a spark arrester. It arrests the spark or burning particles from going outside while allowing the hot gases to escape out. The schematic diagram is shown in Fig. 7.9.

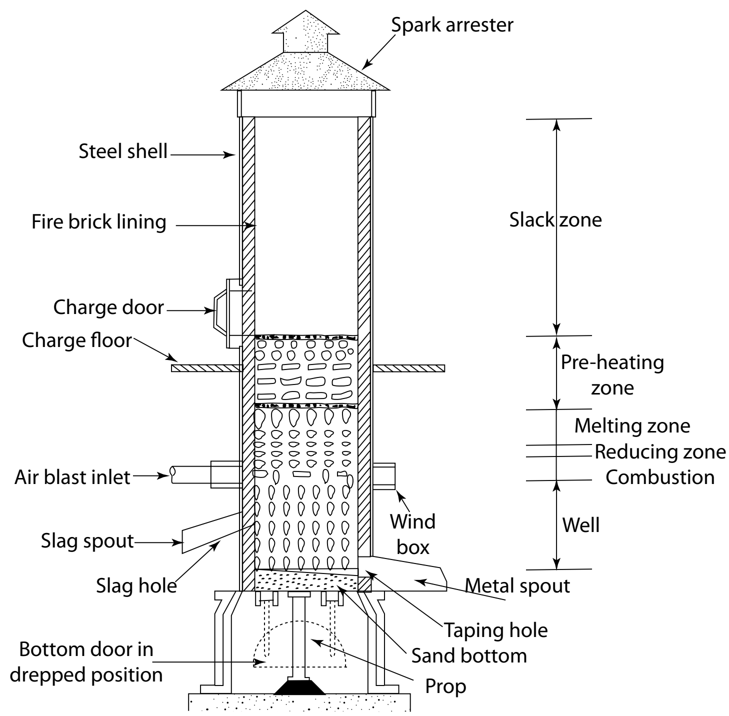



**Fig. 7.9** *Cupola furnace*

### 7.6.1 Operation of Cupola Furnace

The various steps in the operation of a cupola furnace are the following:

***Preparation of Cupola*** The preparation of a cupola furnace begins after dropping the bottom at the completion of the previous melting. In this step, the remaining materials (coke, slag, and metal) in the cupola in the previous melting are removed. Slag, coke and the metal pieces adhering to the side linings are chipped off. Heat resistant linings are repaired with new fire bricks and clay. Then the bottom door is closed and duly supported with the metal prop. A sloping sand bed is prepared with tempered sand over the bottom door. The slope gives a better metal flow. The sand bed is prepared by uniform ramming to avoid any leakage of molten metal.

***Starting of Ignition*** For starting the cupola, soft and dry pieces of woods are spread over the sand bed. A coke bed is prepared over the wooden pieces. The wooden pieces are ignited either through the tap hole or through some other opening. The height of coke bed is maintained in the order of about 75 cm above the tuyers by adding an additional amount of coke as the initial coke bed burns well. The ignition is started about three hours before the molten metal is needed for pouring into the moulds.

***Charging*** After the coke bed is properly ignited, the charging is done. The charging of cupola is adding alternate layers of lime stone (flux), iron and coke upto the level of the charging floor. The flux is a substance added for slag formation and for easy removal of impurities. It also reduces the oxidation of iron and lowers the melting point of slag. It increases the fluidity of slag. lime stone ($CaCO_3$) is mostly used as flux. Coke is the fuel commonly used in cupola. The metal charge consists of pig iron (30%), new scrap iron (30%) and returns (sprue, gates, risers, and defective castings).

***Melting*** After the cupola furnace has been fully charged, the charge is allowed to get heated slowly for about 45 minutes without allowing the air blast. This is called the soaking of iron.

At the end of soaking period, the air blast is opened. The tapping hole is closed by means of a bolt or a plug till sufficient amount of molten metal gets accumulated inside the furnace. As the melting continues, additional charges are added and the charge level is kept upto the charging door during the entire operation of the cupola.

***Slagging and Tapping*** After sufficient amount of molten metal gets accumulated inside the cupola, the slag hole is opened and the slag is removed through the spout. This process is called slagging.

The plug closing the tap hole is then removed and the molten metal is taken out through tapping spout for pouring into the mould. This process is called tapping.

***Dropping Down the Bottom*** Once sufficient amount of molten metal is taken out from the cupola, the charging is stopped. Then all the contents of the cupola are allowed to melt by keeping the air blast closed. The metal prop is knocked down making the drop bottom door to swing out. Hence the remaining material in the cupola drops down on to the floor or into some vessels.

### 7.6.2 Zones of a Cupola Furnace

The various zones of cupola furnace (refer to Fig. 7.9) are the following:

***Well*** This extends up to the bottom of tuyers from the sand bed. It is a sort of a well of molten iron. Molten iron collects in this zone before tapping.

***Superheating Zone, Combustion Zone or Oxidizing Zone*** The zone starts from the tuyers and extends upto 15-30 cm above the top of tuyers. Combustion takes place in this zone with the aid of oxygen from the air blast. Some exothermic reactions which occur in this zone are: (7.1)

$$C + O_2 \rightarrow CO_2 + \text{Heat} \tag{7.1}$$

$$Mn + O_2 \rightarrow MnO_2 + \text{Heat} \tag{7.2}$$

$$Si + O_2 \rightarrow SiO_2 + \text{Heat} \tag{7.3}$$

The temperature of this zone varies from 1550-1850°C.

***Reducing Zone*** The reducing zone starts from the top of combustion zone and extends upto the bottom of the first metal charge. In this zone, the endothermic reaction of reducing $CO_2$ to CO is taking place

$$CO_2 + C(coke) \rightarrow 2CO - Heat$$

This reduces the heat in the zone and the tempetature in the zone is around 1200°C only.

***Melting Zone*** Melting Zone starts with the first layer of the metal charge and extends upto 90 cm or less. The metal charge melts in this zone and moves down to the well. The temperature of this zone is around 1600°C and the following reaction which adds up the carbon content of molten metal takes place.

$$3Fe + 2CO \rightarrow Fe_3C + CO_2$$

***Preheating Zone*** Preheating zone starts from the top of the melting zone and extends upto the charging door. The charge in this zone is preheated by the hot gases such as $CO_2$, CO and $N_2$ moving upwards from the combustion and reducing zones.

***Stack Zone*** Stack zone extends from the end of preheating zone to the end of cupola shell and includes the spark arrester. Hot gases from the cupola pass through the stack zone and escape to the atmosphere through the spark arrester.

## 7.7 CRUCIBLE FURNACE

The Crucible Furnace is used to melt non-ferrous metals like Brass, Bronze, Aluminium, etc. The crucible process is the oldest process for melting metals. Crucibles are usually made of a mixture of graphite and clay. They possess greater strength when they are heated. The material to be melted is placed inside the crucible and they are heated with coke or oil as fuel. The molten metal can be transferred to a ladle. The two types of crucible furnace are explained below.

### 7.7.1. NON-TILTING CRUCIBLE FURNACE

This is also called as stationary type crucible furnace. The non-tilting type furnace is used for melting a small amount of metal. The schematic diagram of non-tilting type furnace is shown in Fig 7.10.

The advantage of non-tilting type crucible furnace is that no preheated ladle is necessary. A blower is used in the crucible furnace which supplies me primary air for combustion.

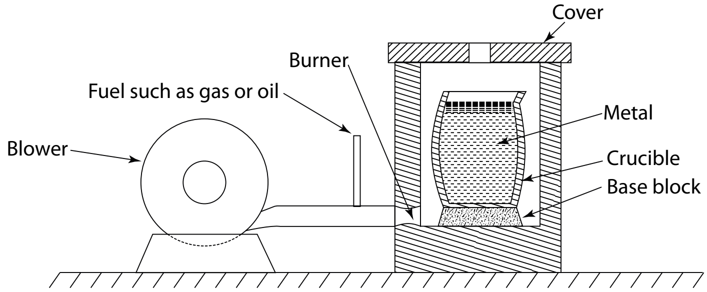



**Fig 7.10** *Non-tilting type crucible furnace*

## 7.72. TILTING TYPE CRUCIBLE FURNACE

The tilting type crucible furnace is used to melt larger amounts of metal. When the molten metal is ready to be poured, the furnace is tilted and transferred to a preheated ladle. A preheated ladle is used to reduce the undesirable drop of metal temperature. The schematic representation of a tilting type crucible furnace is shown in Fig. 7.11.

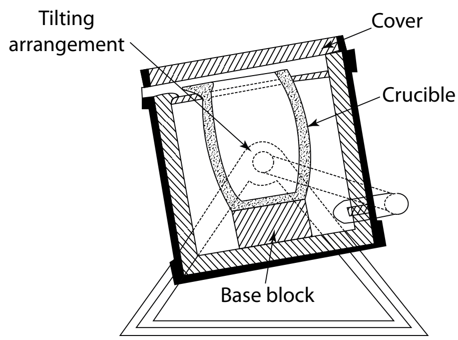



**Fig. 7.11** *Tilting type crucible furnace*

## 7.8 FETTLING

Fettling is the process of cleaning and finishing a casting. This includes the removal of cores, sand and oxide scale from the surface of a casting, gates risers, runners and other unwanted projections from the casting.

## 7.9 CASTING DEFECTS

The most common type of defects in casting are as follows:

***Blow Holes*** Blow holes are cavities present inside the casting or on the surface of the casting. They are caused by the entrapped gases or steam in the casting. Because of molten metal, gases are generated and the moisture present in the moulding sand accounts for the steam. For avoiding blow holes, proper venting should be provided. Also the presence of gas producing ingredients in moulding sand should be avoided and the permeability of the moulding sand should be high. Due to low moisture content, blow holes will be considerably less in dry sand and skin dried moulding, compared to green sand moulding. The blow holes occurring on the surface are called open blows.

***Pin Holes*** Pin holes are large number of small holes occurring on the surface of the casting. This is caused by hydrogen or carbon monoxide picked up by the molten metal in the furnace or while transferring it for pouring. When the metal gets solidified, the solubility of these gases decreases. Hence, these gases are expelled out of the casting and during this process, these leave a number of small holes.

***Swell*** *A* swell is an enlargement of the mould cavity because of the pressure exerted by the molten metal. This causes some error in the dimensions of the casting. This can be avoided by a proper ramming of the moulding sand.

***Shrinkage Cavity*** Shrinkage cavity is a void or depression caused by shrinkage of the metal. This may be avoided by adequate risers and by proper mould design.

***Shift*** A shift is caused when there is mismatch of the sections of a casting usually at parting line. This can be avoided by proper alignment of the pattern, moulding boxes, etc.

***Drops*** Drop is caused by the falling of some loose moulding sand from the cope surface of the mould into the mould cavity. This leads to unwanted projections or cavities in the castings. This can be avoided by proper ramming and by using moulding sand having high green strength.

***Misruns*** Misruns are caused by the incomplete filling of the mould cavity by the molten metal. This leads to unfilled cavities in the casting. This defect can be avoided by having an increased fluidity of the metal and by avoiding the small thickness of the casting.

***Cold Shuts*** A cold shut is caused by incomplete fusion of the molten metal stream while meeting in the mould cavity. This leads to a discontinuity or a weak spot in the casting. This can be avoided by having increased fluidity of the metal and by avoiding too small thickness of the casting.

***Runout*** A runout is caused by the leakage of the molten metal out of the mould cavity. This leads to unwanted projections in the casting. This can be avoided by proper ramming while making the mould.

***Metal Penetration*** A metal penetration is caused by the entering of molten metal into the space between the grains of the moulding sand. This can be avoided by using moulding sands having lower permeability and smaller grains.

## Short-Answer Questions

*(A) Answer the following briefly:*

1. List the commonly available foundry processes.
2. What are the advantages of metal casting process?
3. What is a pattern?
4. What are the pattern materials normally used in metal casting process?
5. What are the factors to be considered while selecting a pattern material?
6. What is meant by pattern allowances?
7. What are the purposes of providing pattern allowances?
8. List out various types of patterns
9. Distinguish between solid pattern and split pattern.
10. What is moulding?
11. What are the basic ingredients of moulding sand?
12. List out the principal properties of moulding sand.
13. Define the following properties with respect to moulding sand.
    (a) Refractiveness (b) Collapsibility
    (c) Strength (d) Permeability
    (e) Flowability (f) Chemical resistivity

15. Compare cohesiveness and adhesiveness of the moulding sand.
16. What are the various types of sand moulding methods?
17. What are the various tools used for hand moulding?
18. What are the various types of furnaces available to melt metals and alloys?
19. What are tuyers? Explain their importance in a cupola furnace.
20. What is slag? How is it formed during the melting of cast iron in cupola furnace?
21. What are the various steps in the operation of cupola furnace?
22. What is meant by charging in a cupola furnace?
23. Distinguish between slag hole and tapping hole.
24. Mention the importance of spark arrester in a cupola furnace.
25. Enumerate the various zones in a cupola furnace.
26. Briefly explain the following in a cupola furnace.
    (a) Well (b) Superheating zone
    (c) Preheating zone (d) Melting zone
27. Briefly explain the following casting defects with cause and remedial methods.
    (a) Blow holes (b) Pin holes
    (c) sand drop (d) Swell
    (e) shrinkage.
28. Compare the following defects
    (a) Misrun and Cold shut
    (b) Runout and Metal Penetration
29. What is fettling?
30. What does the preparation process before the production of patterns involve?
31. What are the various factors to be considered before the selection of pattern type?

*(B) Fill up the blanks by choosing the correct answer:*

1. (a) The surface finish of casting are decided by sand ____________ (additives/grains)
   (b) Cushioning material added to the moulding sand for steel castings is ____________ (coal dust/Iron Oxide).
2. (a) The economical method to produce cast iron is by ____________ (induction/cupola) furnace.
   (b) Flux used in cupola furnace is ____________ (coke/Limestone).

*(C) Choose the correct answer:*

(1) Pure metals can be melted using
    (a) Cupola furnace (b) Rotary furnace
    (c) Induction furnace (d) Crucible furnace.
(2) Steel castings can be melted in coke fired furnaces. (True/False).

## Long-Answer Questions

1. Describe the metal casting process.
2. What does the preparation process before moulding involve?
3. Explain the preparation process of green sand moulding.
4. Describe the various moulding machines.
5. Explain the various pattern materials in detail.
6. Explain the five types of pattern allowances with appropriate diagrams.
7. Compare skeleton pattern and split pattern.
8. What are tuyers? Explain their importance in a cupola furnace.
9. What are the various steps in the operation of a cupola furnace.
10. Distinguish between
    a) Green sand moulding and dry sand moulding
    b) Dry sand and skin dried sand moulding
    c) Loam sand and oil sand moulding.

# Chapter 8
# METAL FORMING PROCESSES

## 8.1 INTRODUCTION

The metal forming process is a deformation process which makes use of the remarkable property of some materials (usually metals), i.e. their ability to flow plastically in the solid state without any reasonable change in their properties. This can be achieved by applying a large amount of mechanical forces or by heating the metal and then applying a relatively smaller amount of force.

Metals have crystals or grains separated from each other by grain boundaries. This can be seen in their microstructure, magnified more than 1000 times when viewed through a microscope. When a metal is heated and some mechanical forces applied, a new fine grain start forming. This process is called recrystallization. The minimum temperature at which the recrystallisation is completed is called the recrystallization temperature of a metal. The recrystallization temperatures for metals are usually around 0.3-0.6 times their melting point.

Metal forming process can be classified as hot working and cold working based on the material being formed and the temperature of forming. Hot working is defined as the forming of metals above their recrystallisation temperature, while cold working is the forming of metal below their recrystallisation temperature.

The various metal torming processes are: forging, rolling, extrusion and drawing. Each of these processes are described in this chapter.

## 8.2 FORGING

Forging is a metal forming process in which the product of desired shape and size is achieved by pressing or hammering. Forging is generally a hot working process, though cold forging is also used for some applications. Forging is a step by step forming process to change the shape of the raw material to the finished form. Different operations or works that can be done by the forging process are detailed below and can be seen in Figs. 8.1(a)-(e).

***Drawing*** It is the operation in which the cross-section area or the thickness of the work piece is reduced with an increase in the length. This is done by striking the metal piece with flat dies.

***Fullering*** It is similar to drawing, but this operation is carried out with a set of two fullers. Fullering results in an irregular surface which should be smoothened by means of flatters.

***Edging*** It is a forging operation in which the edge of the raw material is changed to desired shape by pressing it between two dies.

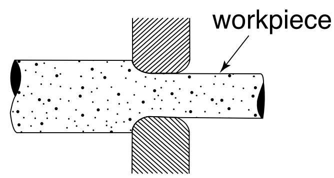



**Fig. 8.1(a)** *Drawing*

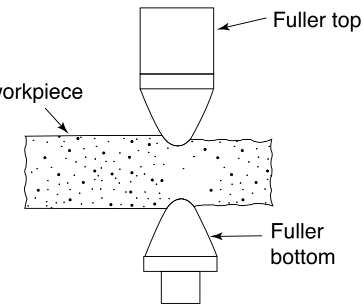



**Fig. 8.1(b)** *Fullering*

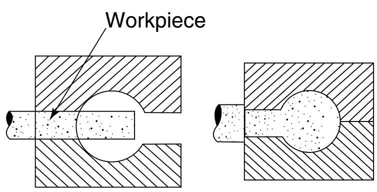



**Fig. 8.1(c)** *Edging*

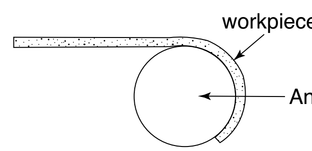



**Fig. 8.1(d)** *Bending*

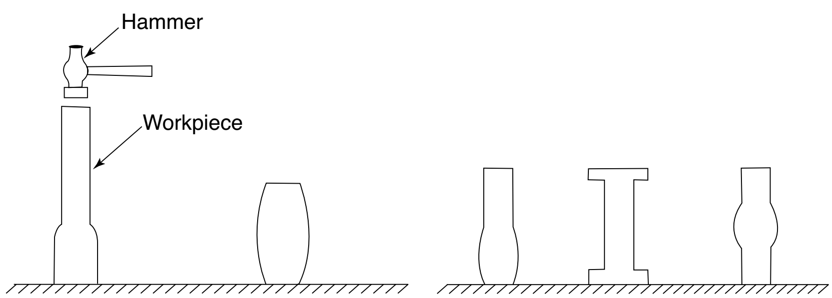



**Fig. 8.1(e)** *Upsetting*

***Bending*** It is an operation to bend the workpiece as desired by using the front portion of the anvil suitably.

***Upsetting*** It is forging operation in which the cross-sectional area or the thickness of the work piece is increased by hammering or pressing. The length of the work piece is decreased.

***Forge Welding*** It is a process of joining two metal pieces by pressing or hammering the hot metal pieces.

***Types of Forging*** The various types of forging are as follows:

### 8.2.1 Hand Forging

In this type of forging, the required shape of the work piece is obtained manually. The accuracy of hand-forged products is less. Hence, it is mostly used for repair work and for producing small tools. A wide range of tools are used for hand forging. The following are the various hand forging tools and these are shown in Figs. 8.2(a)-(l).

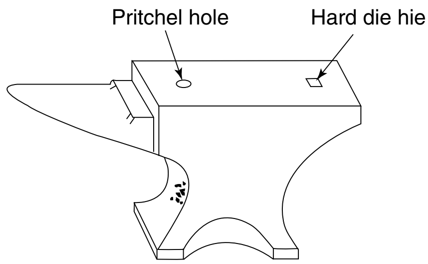



**Fig. 8.2(a)** *Anvil*

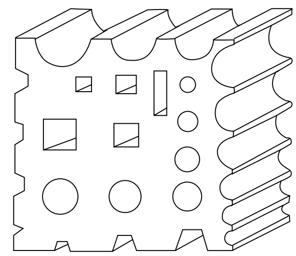


**Fig. 8.2 (b)** *Swage block*

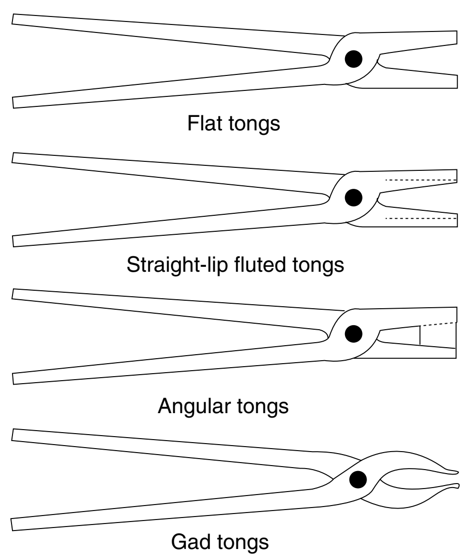



**Fig. 8.2(c)** *Tongs*

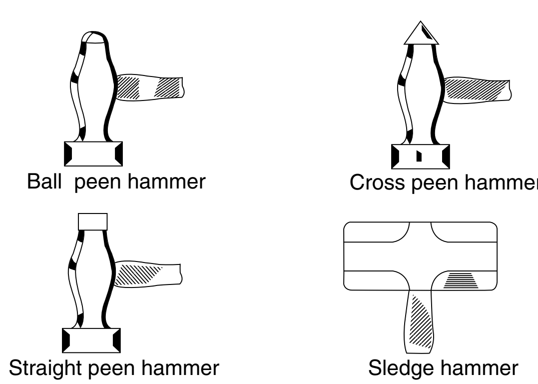



**Fig. 8.2(d)** *Hammers*

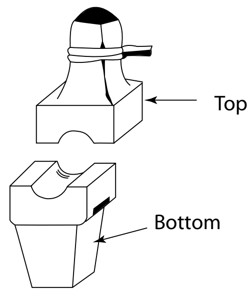



Fig. 8.2 (e) *Swage*

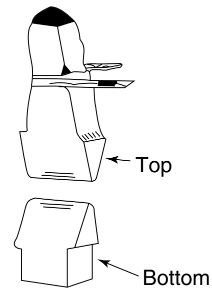



Fig. 8.2 (f) *Fuller*

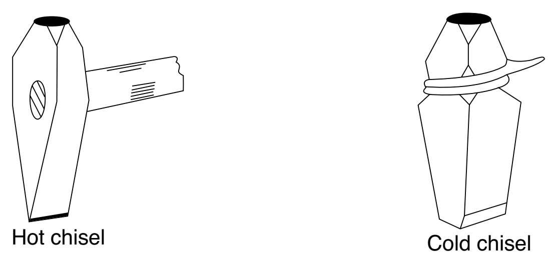



Fig. 8.2 (g) *Chisels*

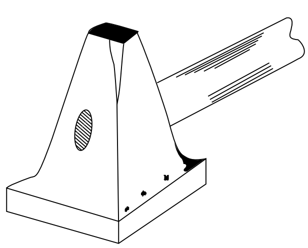


Fig. 8.2 (h) *Flatter*

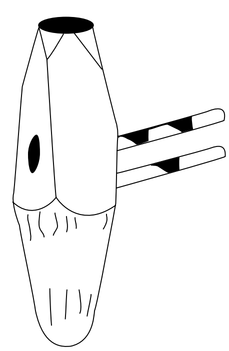


Fig. 8.2 (i) *Punch*

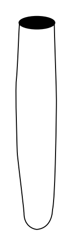


Fig. 8.2 (j) *Drift*

***Anvil*** It is used for supporting the work piece for hand forging operations.

***Swage Block*** It is for holding the work piece and for shaping into various sizes and shapes.

***Tongs*** Tongs are used for holding the work piece during the forging operations. Various types of tongs are available.

***Hammers*** A hammer is used for applying forces required for shaping the work pieces. Various types of hammers are used in forging.

***Swage*** Swage is used to lengthen round rods and finish their surfaces.

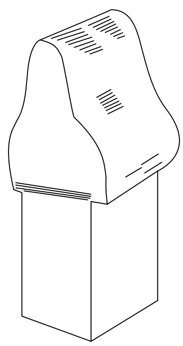


**Fig. 8.2(k)** *Harddie*

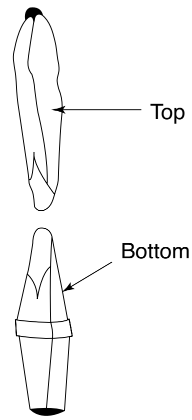



**Fig. 8.2(l)** *Gouges*

***Fuller*** Fuller is used to increase the length, to make the recess and to finish the work piece.

***Chisels*** Chisels are used for cutting work pieces.

***Flatter*** It is used to make the surfaces flat or smooth.

***Punch*** A punch is used to make a dot or a mark in the work piece.

***Drift*** A drift is used for finishing and enlarging punched marks.

***Harddie*** It is a type of chisel with a tapered head which can be fixed into the harddie of the anvil.

***Gouge*** Gouge is a type of chisel used for cutting in a curved form.

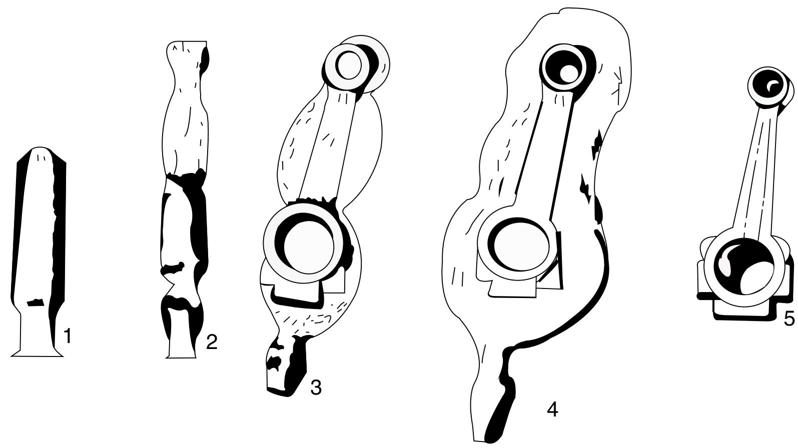
### 8.2.2 Power Forging

Power forging is done with power hammers and tools which are larger in size compared to the hand forging tools. Power is supplied either by hydraulic press, compressed air or by steam. In both the operations of hand forging or power forging, the accuracy and uniformity of the work depends on the skill of the operator.

### 8.2.3 Drop Forging

Drop forging is an operation in which the product of desired shape and size is formed by giving repeated blows to the metal bar heated to the forging temperature and placed between a pair of dies having the impression of the final shape required. The metal bar before heating in a furnace is cut to proper length based on the amount of metal required for the product. For giving the repeated blows, drop hammers are used. Various stages in drop forging are shown in Fig. 8.3.

A drop hammer may be a gravity drop hammer or steam drop hammer. In case of a gravity drop hammer, rollers which engage the board are used to lift the hammer to a certain height. When the hammer is released from that height, it will develop the impact pressure for forming




1. Reducing to proper size
2. Basic forging operations like edging, drawing, etc.
3. Blocking
4. Finishing
5. Trimming

**Fig. 8.3** *Stages in drop forging*

as it strikes the lower fixed die. The force developed is directly proportional to the weight of the hammer as in Fig. 8.4.

In case of steam drop hammer, the lifting of hammer and the blows are controlled by steam as in Fig. 8.5.

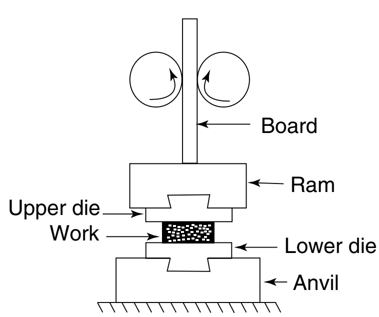



**Fig. 8.4** *Board hammer or gravity hammer*

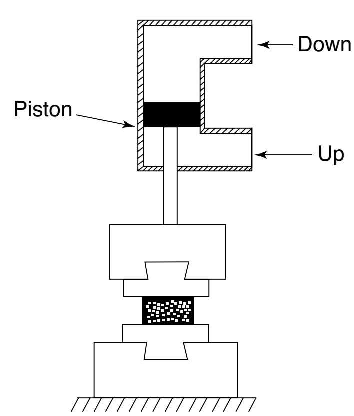



**Fig. 8.5** *Steam hammer*

### 8.2.4 Press Forging

The press forging makes use of similar dies as in the case of the drop forging, but hydraulic presses are used here. Hence, the metal is subjected to a continuous squeezing action. In case of drop forging, greater amount of energy is absorbed by the machine and the foundations. But in press forging, it is fully transmitted to the metal stock. The press-forged products are more accurate, compared to the drop forged products.

## 8.3 ROLLING

Rolling is a metal forming process which is achieved by passing the metal between rotating rolls. Rolling is the most widely used manufacturing process because of its high productivity and low cost. Many shapes such as I, T, L and other complex sections are possible to be formed by the rolling process.

In rolling, high compressive forces are applied on the metal by means of the rotating rolls. As a result, the cross-sectional area or the thickness of the metal is reduced with an increase in the length. The schematic view of the rolling process is given in Fig. 8.6

A metal block with an initial thickness $T_i$ enters the rolls with a velocity of $V_i$. It is fed into the rolls by friction. It passes through the roll gap and leaves the roll with a velocity of $V_f$ and the thickness is being reduced to $T_f$. The rolls rotate in opposite directions.

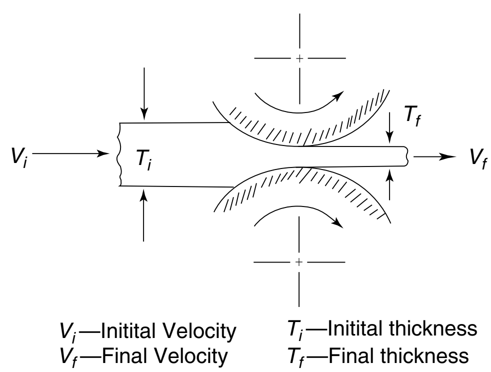



**Fig. 8.6** *Schematic view of rolling process*

The rolling process can be hot or cold rolling based on their operating temperatures. The feeding of the metal between the rolls once is called a rolling pass. The rolling process requires a number of passes to get the final shape and size of the product. A number of rolling mills or rolling stands can be used for achieving this. A rolling mill or rolling stand consists of rolls, bearings, a housing for containing these parts and a drive for applying power to the rolls.

### 8.3.1 Classification of Rolling Mills

Rolling mills can be classified into various types based on the number of rolls and their arrangement as explained below and schematically shown in Fig.8.7(a)-(e).

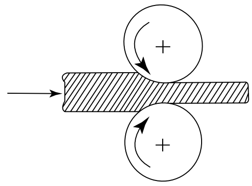


**Fig. 8.7a(i)** *Two-high, Non-reversing*

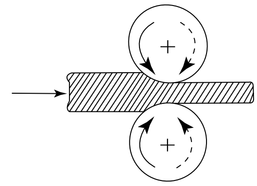


**Fig. 8.7a(ii)** *Two-high, reversing*

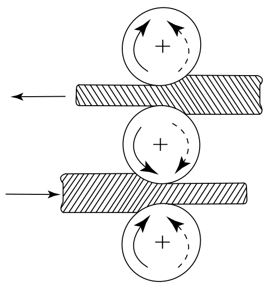


**Fig. 8.7(b)** *Three-high*

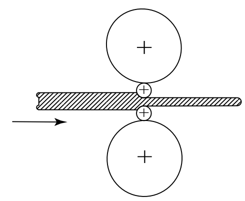


**Fig. 8.7(c)** *Four-high*

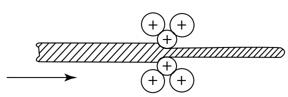


**Fig. 8.7(d)** *Cluster*

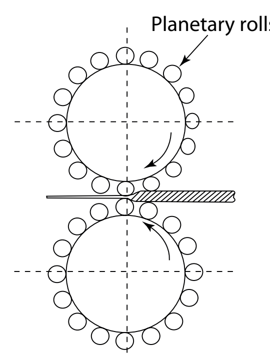



**Fig. 8.7(e)** *Planetary mill*

***Two-high Rolling Mills*** It is the simplest and most common type of rolling mill. It has two rolls rotating in opposite directions. It may be two high non-reversing rolling mill where the rolls always rotate in only one direction while in two high reversing rolling mill, the direction of rotation of rolls can be reversed. Here, the metal work can be passed back and forth through the rolls by reversing the direction of the rotation of rolls.

***Three-High Rolling Mill*** It consists of three rolls placed one over the other. The gap between the lower roll and the middle roll is usually greater than the gap between the upper roll and the middle roll. The upper and lower rolls are driven and the middle roll rotates by friction. These are used for rolling of two continuous passes without reversing the direction of rotation.

***Four-High Rolling Mill*** A four high rolling mill consists of two small-sized working rolls and two large-sized back-up rolls. The back-up rolls provide the strength and the necessary rigidity to the small rolls. A very thin sheet can be rolled by small diameter rolls to very close tolerances.

***Cluster Rolling Mill*** In a cluster rolling mill, each working roll is backed up by two large back-up rolls giving more support and rigidity to the working rolls.

***Planetary Rolling Mill*** It consists of a set of large back-up rolls surrounded by a number of smaller sized working rolls. This gives a large reduction in a single pass.

## 8.4 EXTRUSION

Extrusion is a metal forming process in which a block of metal is reduced to the desired shape and size by confining it in a closed container and then forcing it to flow only through a die orifice under high pressure. Extrusion may be hot extrusion or cold extrusion based on the operating temperature. The two basic types of extrusion are direct or forward extrusion and indirect or backward extrusion.

### 8.4.1 Direct or Forward Extrusion

In the direct extrusion, a block of metal is placed in a closed container. A die with a proper die holder is placed at one end of the container and a ram at the other end of the container as shown in Fig.8.8. A dummy block or pressure plate is placed at the end of the ram. This is to avoid direct contact of the hot metal and the ram. Extrusion is done when the metal is forced through the die by the ram. The extruded product will have the same size and shape as that of the die orifice.

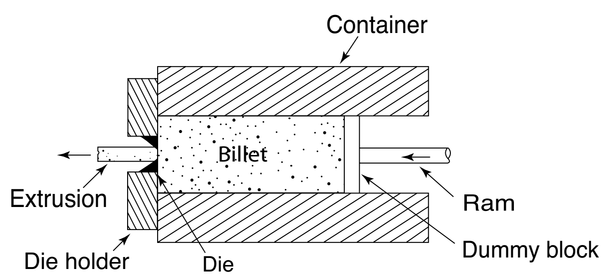



**Fig. 8.8** *Direct extrusion*

In direct extrusion, the direction of flow of the extruded metal is along the same direction of the ram movement.

### 8.4.2 Indirect or Backward Extrusion

In indirect extrusion, a block of metal is placed in a closed container. One end of the container is fully closed by a closure plate. A hollow ram with a die is placed on the other end of the container as shown in Fig.8.9. Extrusion is carried out by forcing the metal through the die orifice by driving the hollow ram. The extruded metal flows through the hollow ram.

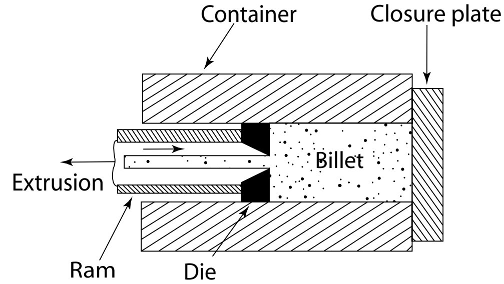



**Fig. 8.9** *Indirect extrusion*

In indirect extrusion, the direction of flow of the extruded metal is in the opposite direction of the ram movement. Hence, the name is given as indirect or backward extrusion.

### 8.4.3 Tube Extrusion

Tubes can be manufactured by the extrusion process. The tube extrusion process is a direct extrusion with an additional attachment for making tubular shape. In tube extrusion process, a mandrel is placed at the face of the container opening as shown in Fig. 8.10.

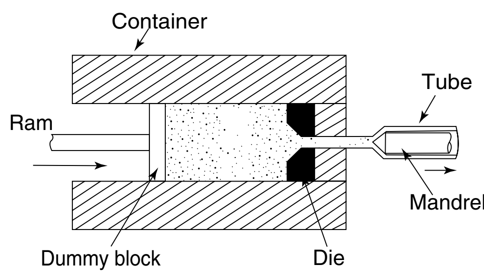



**Fig. 8.10** *Tube extrusion*

When the ram is moved, the metal is forced through the die orifice. This extruded metal flows around the mandrel producing a tubular shape. The clearance between the mandrel and the die wall determines the wall thickness of the extruded tube.

## 8.5 DRAWING

Drawing is a metal forming process which involves pulling the metal through a die by applying some mechanical forces. For drawing, a high tensile force is applied to the exit side of the die. Depending on the diameter of the final product, drawing operations can be rod or wire drawing. Drawing is usually a cold working process.

***Rod and Wire Drawing*** The basic principles of rod and wire drawing are the same but the equipments used are different for different types of products. See Fig.8.11 for drawing of rod.

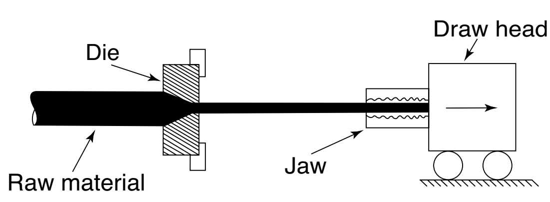



**Fig. 8.11** *Drawing of rod*

The end of the raw material in the form of a rod is shaped to have a pointed circular edge and inserted through the opening. This end is clamped to the jaws of the draw head. The draw head is then moved by some drive mechanism. During the drawing operation, because of the high compression force at the die and metal interface, a suitable lubricant is used. Drawing dies are mostly made of cemented carbide or industrial diamond.

When the metal is drawn out into (wire shapes)/wires, the process is called wire drawing. Wires are smaller diameter products, usually under 5 mm in diameter. The raw material for wire drawing is a hot-rolled rod or coil. The rod is first cleaned by picking to remove any scale and rust present on the surface. These may affect the die when the rod is not properly cleaned.

After proper cleaning, the rod is coated with one of the following chemicals such as ferrous hydroxide, manganese, zinc and iron phosphate, and lime. This coating serves as a vehicle for lubricant coating. Then, a coating of proper lubricant is given. The lubricant normally used is soap solution. The end of the rod is prepared as in the drawing process and is pulled through the die by grippers. The end of the drawn wire is then fitted to the jaw on a power reel which can be driven for further wire drawing as shown in Fig. 8.12.

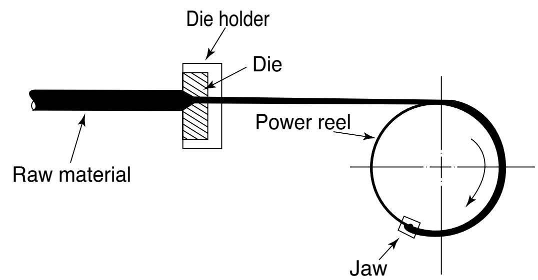



**Fig. 8.12** *Wire drawing*

## Short-Answer Questions

*(A) Answer the following briefly:*

1. List the various metal forming processes.
2. Explain briefly the hot working and cold working of metals.
3. With a simple diagram explain the rolling process.
4. What are the two types of drop hammers used in drop forging?
5. Explain the following Rolling stand arrangements.
   (a) Two high (b) Two high reversible
   (c) Three high (d) Four high
   (e) Cluster (f) Planetary Rolling mill.
6. With simple sketches explain the sequence of passes to get a round rod from a billet.
7. What is the difference between "Drawing out" and "Upsetting" forging operations?
8. Define the wire Drawing process.
9. Define the process of Extrusion.
10. Explain the difference between forward and Backward extrusion.
11. Give few examples for Extruded products.

*(B) State whether the following statements are true or false:*

1. Diameters of round bars can be reduced by rotary swaging process. (TRUE/FALSE)
2. Fastners can be manufactured by cold heading process. (TRUE/FALSE)

(C) *Fill up the blanks with correct answer:*

1. For mass production of threads, ____________________ process is used.
2. ____________________ are manufactured by piercing method.
3. Upsetting ____________________ operation in which the metal cross section is ____________________ with a ____________________ in length.
4. Hollow object can be obtained by ____________________ extrusion.

## Long-Answer Questions

1. Define forging and explain the types of forging.
2. List the various machines used for forging.
3. Describe the different operations in the forging process.
4. Explain the different types of extrusion.
5. Explain the drawing process with a schematic diagram.

# Chapter 9
# METAL JOINING PROCESSES

## 9.1 INTRODUCTION

Metal joining processes are manufacturing processes in which metal pieces are joined by the application of heat by some means. The various metal joining processes are welding, brazing and soldering.

These processes differ from each other in the temperature at which the joining is done. Welding involves heating the metals over a higher range of temperature up to fusion and then allowing it to cool. In case of brazing and soldering, the metals being joined are heated below their melting point.

## 9.2 WELDING

Welding is a metal joining process in which the joining of metals is done by the application of heat with or without the application of pressure. During welding, the edges of the metal pieces are heated over a higher range of temperature, i.e, these are either melted or brought to a plastic condition and then allowed to cool. Welding processes may be classified into many types based on the method in which the heat is applied. In arc welding, heat is applied by producing an electric arc between two conductors whereas in gas welding heat is applied by the combustion of a fuel gas with oxygen.

### 9.2.1 Types of Welded Joints

Welding may be done with or without the preparation of edges of the metal pieces. The following types of joints are used widely in welding processes:

1. Lap joints
   (a) Single or double fillet weld
   (b) Single or double joggled weld
2. Butt joints
   (a) Single vee
   (b) Double vee
   (c) U-shaped
   (d) Single strap
   (e) Double strap

3. Edge joints
   (a) Straight joint
   (b) Right angled joint
4. Corner joints
5. Plug joint
6. Tee joint

The above mentioned joints are shown in Fig. 9.1.

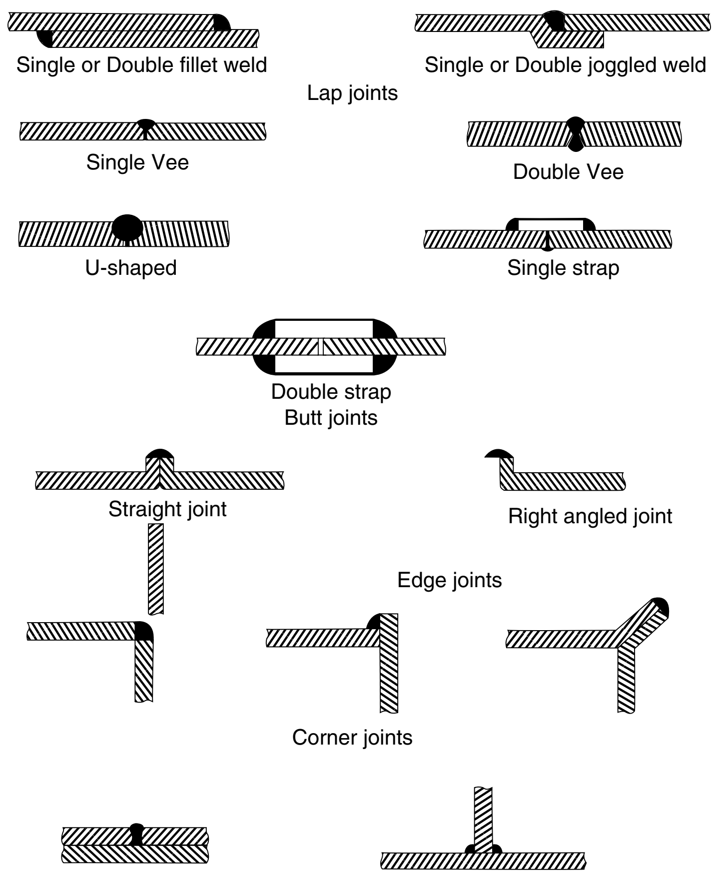



**Fig. 9.1** *Types of welding joints*

### 9.2.2 Basic Welding Terms

One should be familiar with the several technical terms used in welding technology.

***Base Metal or Parent Metal*** In welding, the metal to be joined is known as parent metal or base metal.

***Filler Metal*** It is a metal or alloy used for filling the weld cavity. Filler metals usually have the same composition as that of the base metal. Sometimes, it may have some additional alloying element to strengthen the joint.

***Weld Metal*** It is the metal that is solidified in the weld cavity. It may be only metal or a mixture of base metal and filler metal.

***Edge Preparation*** It is the preparation of the edges of metal pieces to be joined into some forms depending on the thickness of the metal and types of welded joints.

***Root*** It is the narrow region at the bottom of the welded joint, shown in Fig. 9.2. The gap between the metal pieces at the root region is called root opening.

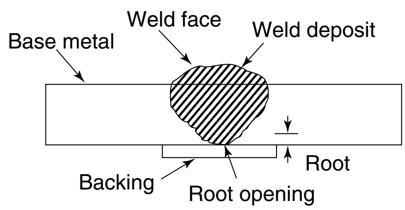



**Fig. 9.2** *Basic welding terms*

***Weld Pass*** A single movement of the welding torch or electrode along the length of the joint is called as a weld pass. Based on the thickness of the metal piece, welding can be completed in a singe or multi-pass. The weld pass in the root region is called as a root pass and subsequent passes for filling the joint are called as filler passes.

***Penetration*** The depth up to which the weld metal combines with parent metal is called metal penetration. It is measured from the top surface of the joint.

***Deposition Rate*** It is the rate at which the weld metal deposits in the joint per unit time.

***Tack Welds*** These are two small welds made at the end of the joint for temporarily holding the metal pieces.

***Backing*** It is the metal support given below the root portion to control the penetration.

***Weld Face*** It is the convex shape of the weld deposit.

## 9.3 ARC WELDING

Arc welding is the process of joining two metal pieces by melting their edges with an electric arc. An arc is an electric discharge through the ionised gas column between two conductors of electricity namely the cathode and the anode. When two conductors are touched and then separated by a small distance, electrons are liberated from the cathode and move towards the anode. Also, the positively charged ions move from the anode towards the cathode. The impact of these electrons and positive ions at high velocity onto the conductors liberates heat. The temperature of the arc is about 3870°C.

An arc useful for generating heat can be obtained between an electrode and the work piece, between two electrodes and also between two metal pieces to be welded.

Figure 9.3 shows a schematic arrangement of an arc welding equipment. An alternating current or a direct current source can be used for arc welding process. In direct current arc welding, two types are possible. When the electrode is connected to the negative terminal of the power source and work piece to the positive terminal, it is called direct Current Straight Polarity (DCSP) arc welding. If the electrode is connected to the positive terminal of the power source and the work piece to the negative terminal, it is called as Direct Current Reverse Polarity (DCRP) welding. Direct current arc welding power sources are usually d.c. generators, whereas in the case of alternate current arc welding, the power sources are transformers.

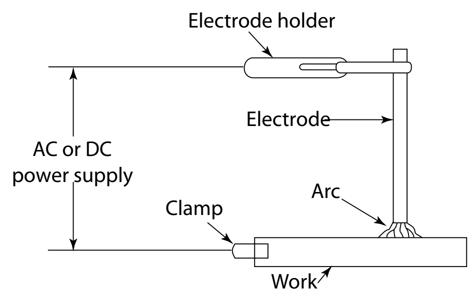



**Fig. 9.3** *Arc welding circuit*

The electrode is held by means of an electrode holder and the work pieces are kept on a metal work table. The electrode holder and the metal work table are connected to different terminals of the welding power source by means of long insulated cables. Initially, the metal work piece is touched with the electrode and then separated leaving a small gap between the electrode tip and the work piece. In arc welding, the gap between the electrode and the work piece is important for the arc to exist continuously and it is known as the arc length. This has to be maintained within a specified range for good quality welding. Once the arc has been initiated, the electrode is moved along the length for completing the welding process, as shown in Fig. 9.4.

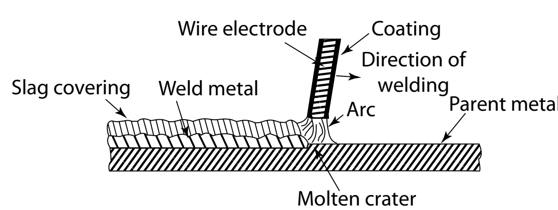



**Fig. 9.4** *Arc welding*

## 9.3.1 Electrodes

Electrodes used in arc welding may be a consumable or a non-consumable electrode. A consumable electrode is used to produce an arc and is also melted to fill the weld cavity, i.e. it also serves as a filler metal. A non-consumable electrode is used only for producing an electric arc.

Electrodes may be bare, flux coated or heavy coated. Bare electrodes are without any coatings on their surface and are widely used in automatic and semi-automatic welding.

Flux coated electrodes are coated with a thin layer of some chemical components, generally called as flux. This coating usually consists of lime mixed with soluble glass which serves as a binder.

Heavy coated electrodes are provided with thick flux coatings. Many chemicals are added in flux coating for getting some specific advantages. Common flux materials with their functions are given below:

Starch and wood pulp form a gas shield around the weld zone preventing it from atmospheric oxygen. China clay, felspar, manganese and titanium ores form a slag deposit over the molten weld metal, preventing contaminations due to atmospheric air and also ensures a uniform rate of cooling of the weld metal. Ferro-silicon, ferro-titanium and ferro-manganese reduce the oxides which are likely to be formed in the weld metal. Sodium silicate, potassium silicate and asbestos serve as binding materials. The alloying components: aluminium, zirconium, nickel, chromium and molybdenum improve the strength of the joint. Other advantages of the coating materials are stabilised arc, increased deposition, improved arc penetration, facilitated over head welding and reduced spatter of weld metal.

## 9.4 GAS WELDING

Gas welding is the process of joining two metal pieces by melting their edges by a flame resulting from the burning of a gas fuel and oxygen. Oxygen acetylene combination is the most widely used in this process. The process using the above combination is called as oxy-acetylene welding. In gas welding, the flame is produced at the tip of a welding torch. It is used for heating the metal. A filler metal, in the form of a rod is added separately for filling the weld cavity. Gas welding is widely used for welding all ferrous and non-ferrous metals.

***Oxy-acetylene Welding*** In oxy-acetylene welding, the flame is produced by burning a mixture of oxygen and acetylene. This mixture burns to produce the high flame temperature upto 3480°C in a two stage reaction.

In the first stage, oxygen and acetylene react to form carbon monoxide and hydrogen.

$$C_2H_2 + O_2 \rightarrow H_2 + 2CO \tag{9.1}$$

This reaction occurs near the end of the torch tip.

In the second stage, carbon monoxide and hydrogen react with oxygen forming carbon dioxide and water vapour respectively.

$$2CO + O_2 \rightarrow 2CO_2 \tag{9.2}$$

$$2H_2 + O_2 \rightarrow 2H_2O \tag{9.3}$$

These reactions occur just after the first combustion zone. The oxygen for above two reactions is obtained from the atmosphere.

Based on the ratio of oxygen and acetylene in the mixture, the flame may be neutral, oxidizing or carburising flame. They are shown in Fig. 9.5 (a)-(c). A neutral flame is obtained by supplying equal volumes of oxygen and acetylene. The neutral flame has two sharply defined zones, one inner white cone flame and an outer blue flame envelope. Neutral flame is used for welding steel, stainless steel, cast iron and copper.

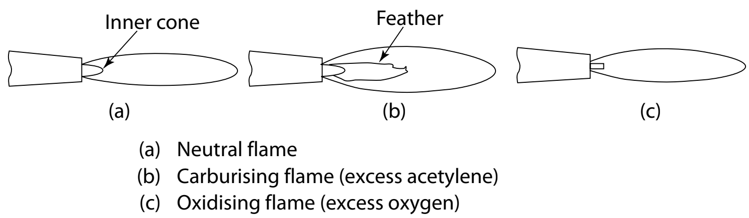



**Fig. 9.5** *Types of gas flames*

A carburising flame is obtained by supplying more volume of acetylene than oxygen. A carburising flame has the two sharply defined zones as in case of a neutral flame with the addition of a third zone, whitish in colour known as intermediate flame feather. The carburising flame is used for welding monel, low-carbon steels and some alloy steels.

An oxidising flame is obtained by supplying more volume of oxygen than acetylene. The oxidising flame is similar to neutral flame with two distinct zones. But, the inner white zone is much smaller than that of a neutral flame. Oxidising flame is used for welding copper and copper alloys.

Figure 9.6 shows a schematic view of the equipment used for oxyacetylene welding. In this, oxygen and acetylene are to be supplied at a specified pressure range only. Hence, the gas cylinders are provided with pressure gauges and pressure regulators. Oxygen and acetylene flow to the welding torch through separate rubber hoses.

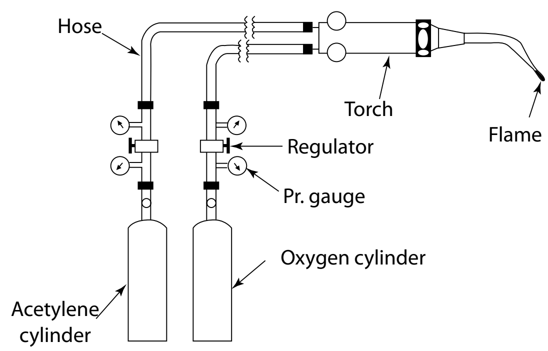



**Fig. 9.6** *Oxy-acetylene welding circuit*

Figure 9.7 shows cross section of a welding torch. The welding torch mixes oxygen and acetylene in the desired proportions and burns the mixture at the tip. This can be achieved by means of control valve for oxygen and acetylene and a well designed mixer.

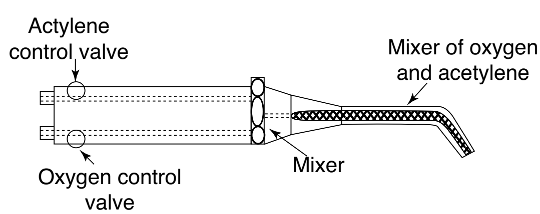



**Fig. 9.7** *Welding torch*

Initially, the acetylene is supplied and it is ignited with a friction spark lighter. After this, oxygen is supplied with the help of a separate valve and the nature of the flame is adjusted. A filler metal in the form of a rod is held in the flame and is melted to fill the weld cavity as shown in Fig, 9.8.

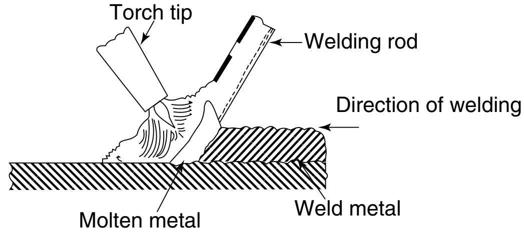



**Fig. 9.8** *Oxy-acetylene welding*

## 9.5 RESISTANCE WELDING

In this process, the heat required for welding is produced by high current from a step down transformer, passing through the resistance between the two plates to be welded. When the area or spot to be welded is heated to plastic stage, high pressure is applied to effect fusion.

***Heat produced in this welding can be given by***

$$H = I^2 R \text{ where}$$

H = Heat produced in Joules

I = Current in Amperes and

R = Resistance in ohms.

***Procedure***

Two pieces of metals to be welded are overlapped and held between water cooled electrodes, as in Fig. 9.9. Bottom electrode is fixed and the top electrode is movable. When the step down transformer is switched on and kept for some time, known as weld time, the area or contact point of the metal will reach the plastic stage. High pressure is extended on the metal pieces to be welded, using hydraulic or pneumatic system, actuated by the foot lever. At the end of weld time, the current is switched off. But, the pressure is maintained for some more time for the metals to cool and produce a solid joint.

***Advantages of Resistance Welding***

1. The welding process is quite quick
2. Operations are easily automated
3. Dissimilar metals can be easily welded
4. Skilled operator is not required
5. No need for filler material or flux.

***Limitations***

1. High initial cost
2. High maintenance cost

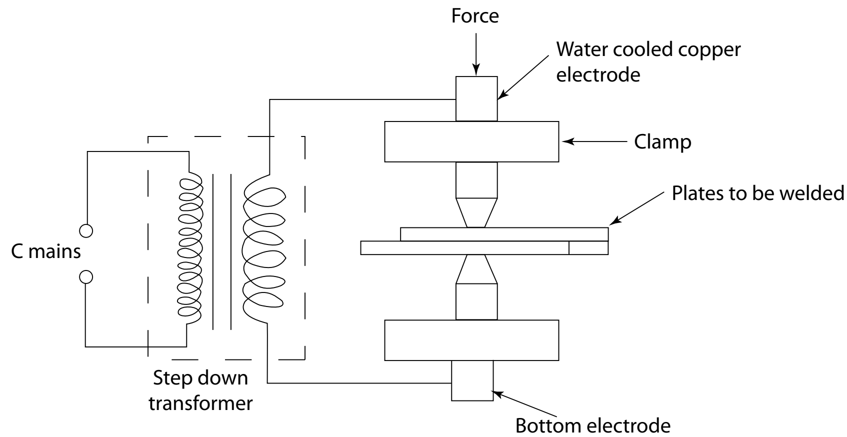



**Fig. 9.9** *Resistance welding*

## 9.6 THERMIT WELDING

This is a special type of welding used for joining heavy sections like rails or pipes at site. In this method, a mould is built around the two ends to be joined, using sand or ceramic.

Thermit is a mixture of finely divided aluminium and magnetic iron oxide. The mixture is ignited in a refractory lined crucible. Within a minute, high temperature of about 2500°C is obtained and superheated molten iron results. The molten metal is poured into the mould which fuses with the parts to be welded, as shown in fig. 9.10.

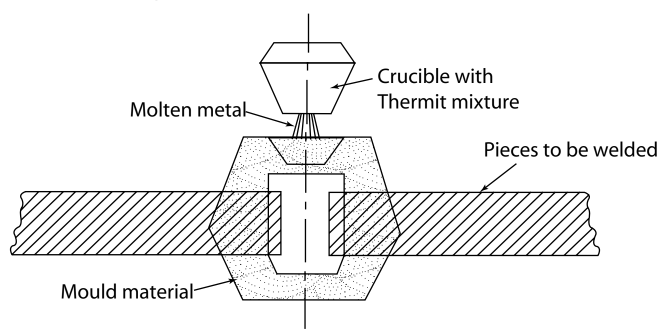



**Fig. 9.10** *Thermit welding*

## 9.7 GAS CUTTING

Gas cutting is a process to cut ferrous metals and steels. The equipments used for this process is similar to that of oxy-acetylene welding except for the torch. The cutting torch differs from the welding torch in that it has several small holes for the oxygen-acetylene mixture, surrounding a central hole for pure oxygen. The sectional view can be seen in Fig. 9.11. This oxygen-acetylene mixture through the small holes is used for preheating the metal to be cut. For ferrous metals, the cutting process is the rapid oxidation at high temperature.

$$3Fe + 2O_2 \rightarrow Fe_3O_4 + \text{Heat} \tag{9.4}$$

But, this reaction occurs at high temperature approximately at about 870°C. Hence, the preheating flame is first used to raise the temperature. Then a stream of pure oxygen is added to the torch which oxidises the iron and also expels the liquid iron oxide from the joint. This process gives economic and accurate cuts.

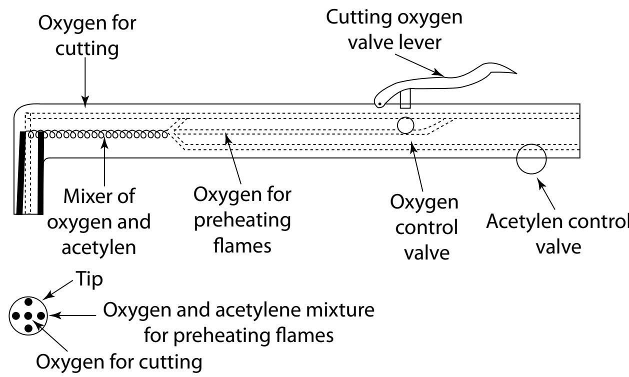



**Fig. 9.11** *Oxy-acetylene cutting torch*

## 9.8 BRAZING

Brazing is a metal joining process which is done by the use of heat and a filler metal whose melting temperature is above 450°C but below the melting point of the metals being joined.

Brazing differs from welding in the following ways:

1. The composition of the filler metal or alloy (brazing metal) is different from the base metal.
2. The strength of the brazing alloy is lower than that of the base metal.
3. The melting point of the brazing alloy is lower than that of the base metal. So, the base metal is not melted during brazing.
4. Bonding requires the capillary action in brazing.

Brazing requires a clean surface, proper clearance between metals, good wetting of the joint and good fluidity for the brazing alloy in the joint.

### 9.8.1 Brazing Metals

The most commonly used brazing metals are copper and copper alloys, silver and silver alloys and aluminium alloys.

### 9.8.2 Purpose of Fluxes

Fluxes are some chemical compounds which are added into the brazing joints for the purpose of:

1. Dissolving oxides present on the surface of base metals.
2. Preventing the formation of oxides during heating.
3. Lowering the surface tension of the molten brazing metal and thus promoting its flow into the joint.

Most commonly used brazing flux is borax. However, metallic halide salts such as sodium and potassium chlorides are used to braze aluminium.

### 9.8.3 Brazing Methods

A general brazing method involves the following:

1. Cleaning of the joint and setting proper clearance between the metals.
2. Applying flux to the joint.
3. Heating the joint to bring it to the liquidous temperature of the brazing alloy.
4. Applying the brazing metals so that it flows into the joint by capillary action. The brazing metal may also be pre-placed in the joint.

The brazing metal on solidification gives the necessary joint strength. Based on the method adopted for heating, brazing can be classified into various types. The following methods are commonly used.

***1. Torch Brazing*** In torch brazing, the source of heat for brazing is a gas flame torch. It may be oxy-hydrogen or other gas flames.

***2. Dip Brazing*** In dip brazing, the pre-assembled metal joints are dipped in a bath of molten brazing metal. The molten brazing metal bath provides both the required heat and the brazing metal for the joint. It is usually adopted for a small part.

***3. Salt Brazing*** In salt brazing, the assembled parts are dipped in a bath of molten salt kept at a temperature slightly above the melting point of the brazing metal. The brazing metals are preplaced in the joint and the molten salt bath provides the heat to melt them.

***4. Furnace Brazing*** In furnace brazing, the assembled metal joints with preplaced brazing metals are kept in controlled atmosphere or vacuum furnaces. Because of the easy control of brazing temperature and as no skilled labour is required, furnace brazing is used for mass production.

***5. Induction Brazing*** In induction brazing, high frequency induction current is used for heating the joints. Induction brazing requires simple heating coil which should fit around the joint to provide the heating at the required area. The brazing metal is preplaced in the metal joint.

***6. Resistance Brazing*** In resistance brazing, the metals to be joined are held under pressure between two electrodes. The heating is due to the electric resistance between the electrodes when electric current is passed through them.

### 9.8.4 Braze Welding

Braze welding differs from the general brazing process in that the capillary action is not used to fill the joints by the filler metal. Here, the filler metal fills the metal joint by gravity as in some welding processes. Mostly, braze welding is done with an oxy-acetylene torch.

## 9.9 SOLDERING

Soldering is a metal joining process in which the joining of metal is done by the use of heat and a filler metal whose melting temperature is below 450°C.

Joint strength is relatively low in case of soldering and the joining is due to adhesion between the filler metal called the solder and the parent metal.

**Differences between Brazing and soldering**

| S.No. | Brazing | Soldering |
|---|---|---|
| 1. | Used for joining dissimilar metals, pipes, copper tubes etc. | To make electrical connections, to make printed circuit boards, joining light sheet metals etc. |
| 2. | Melting temperature of the filler material is above 450°C | Below 450°C |
| 3. | Filler materials are copper based alloys and silver based alloys | Alloy of lead and tin |
| 4. | Fluxes are borax, flurides and chlorides | Zinc Chloride |
| 5. | Joint has a better strength | Strength is comparatively less. |

### 9.9.1 Solder Metals

Most solders are alloys of lead and tin with a little amount of antimony (less than 0.5%). However, tin-antimony alloys are used in electrical applications. Tin-Zinc, cadmium-zinc or aluminium-zinc or cadmium silver alloys are used for high temperature service.

### 9.9.2 Soldering Fluxes

Soldering fluxes are classified as corrosive and non-corrosive fluxes. The most commonly used corrosive fluxes are muriatic acid and a mixture of zinc and ammonium chlorides. A common non-corrosive flux is rosin in alcohol.

### 9.9.3 Soldering Methods

It is similar to that of brazing. Here the flux used is not intended to remove any appreciable amount of contamination. Hence, the surface has to be cleaned to remove all dirt, oil and grease before the flux is applied.

As in brazing, soldering may also be classified into various types based on the methods adopted for heating the joints. Dip soldering is used extensively for soldering electronic appliances. Induction soldering is used for large number of identical parts. In iron soldering, electric soldering iron is the commonly used heat source. In case of low melting point solders, infra-red heat source can be used which is called as infra red soldering.

### 9.9.4 Flux Removal in Brazing and Soldering

Some fluxes used in brazing and soldering are corrosive. So, the flux residues must be completely removed for preventing corrosion in joints. Water soluble fluxes are removed with hot water. Alcohol or grease can also be used as solvents for flux removal.

## Short-Answer Questions

*(A) Answer the following briefly:*

1. Name the different metal joining processes?
2. What is meant by edge preparation?
3. Define weld pass and its types.

4. What are the different flames obtained in Oxy-acetylene welding?
5. Briefly explain the leftward and Rightward Techniques of welding.
6. List out various safety equipments used in welding.
7. What are the different reactions that take place in oxy-acetylene welding?
8. What are the most commonly used brazing metals?
9. How does braze welding differ from the general brazing process?
10. What is the basic principle of Gas cutting?
11. How is the acetylene produced in acetylene cylinder?
12. What is the principle of soldering?
13. What are the types of solders used in soldering?
14. Differentiate between active flux and inactive flux in soldering.
15. How is flux removed in brazing and welding?
16. What are the differences between Brazing and soldering?
17. Briefly explain about
    (a) Torch brazing
    (b) Resistance brazing
    (c) Induction brazing.

*(B) State whether the following statements are True or False:*

1. Filler rods used in the welding are made of the same base metal composition. (True/False)
2. Cast iron cannot be welded without flux (True/False)
3. Aluminium can be easily welded (True/False)

*(C) Choose the correct Answer:*

Gas welding is a ___________ process.

(a) Forge welding (b) Fusion welding

(c) None of the above

*(D) Fill up the blanks with correct answers:*

1. ___________ is used as flux in welding stainless steel.
2. For soldering electrical parts ___________ flux is used.

## Long-Answer Questions

1. Describe the different types of welded joints with diagrams.
2. Describe the working of arc welding.
3. What are the different types of electrodes used in arc welding.

# Chapter 10
# METAL REMOVAL OR MACHINING PROCESSES

## 10.1 INTRODUCTION

Metal removal or machining process is a manufacturing process in which products of desired shape and size is got by removing excess material from the work piece by means of some machine tools. A machine tool is a device which securely holds the work piece and cutting tool for performing various machining processes. Machining is a process of forcing a cutting tool with one or more cutting edges through the excess material of the work piece.

***Types of machines***

1. Lathe
2. Drilling Machine
3. Shaping Machine
4. Milling Machine
5. Planing Machine

## 10.2 LATHE

The lathe is one of the oldest and most important machine tools. The lathe has become a general purpose machine tool which is used widely in production works. The lathe removes the excess material from the work piece by rotating it against a cutting tool. The tools can be fed deep through the excess material on the work piece. The job is held between rigid supports. Figure 10.1 shows the working principle of a lathe.

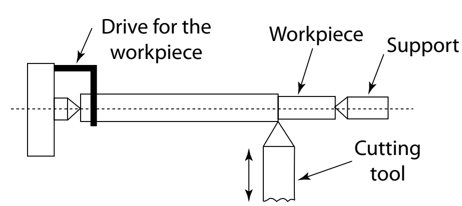



**Fig. 10.1** *Working principle of a lathe*

### 10.2.1 Types of Lathes

Lathes can be classified into various types: speed lathe, engine lathe, bench lathe, tool room lathe, turret and capstan lathes.

***1. Speed Lathe*** It is the simplest form of a lathe and it consists of all the main components of a lathe. Its head stock spindle can rotate at a very high speed, usually driven by a variable speed motor built inside the headstock. The work piece is held between centres or attached to some other work holding devices and the tools are hand operated. Wood working, metal spinning and polishing operations etc are widely done with speed lathes.

***2. Centre Lathe or Engine Lathe*** It is the most commonly used lathe and is normally used in all types of machine shops. In its earlier version, steam engines were used to supply the power required for the machine. Hence, it is named as engine lathe. It has additional features for varying the speed of the lathe spindle compared to the speed lathes. A wide range of attachments can be fitted on this lathe to increase its utility.

***3. Bench Lathe*** It is a small lathe which can be mounted on a bench. It may have the same features as a speed lathe or an engine lathe but, differs from them in size and mountings. Hence, it finds wider applications in small and light works.

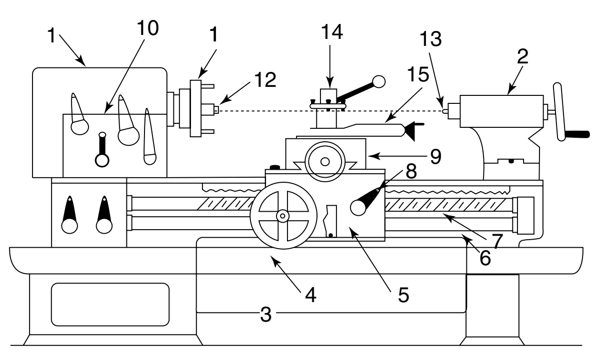
***4. Tool Room Lathe*** As the name indicates, it is used mainly for accurate tool room works. It is the most modern engine lathe employed for making small tools, test gauges, dies and other precision parts.

***5. Special Purpose Lathe*** In addition to the above types, some lathes have been specially designed and manufactured for doing some specific set of operations for making a particular product. Such lathes are called special purpose lathes. Special purpose lathes are available for making crank shaft, car wheels, etc.

***6. Turret and Capstan Lathes*** These are production lathes having provisions for holding several tools for performing a wider range of operations on a job within a minimum time. The cost of these lathes is quite high.

## 10.2.2 Main Parts of a Lathe

The main parts of a central lathe are given in Fig. 10.2.




1. Head stock
2. Tail stock
3. Leg/Bed
4. Tray
5. Carriage
6. Feed shaft
7. Lead screw
8. Half-nut lever
9. Cross-slide
10. Gear box
11. Driving plate
12. Live centre
13. Dead centre
14. Tool post
15. Compound rest

**Fig. 10.2** *Centre lathe*

***1. Bed*** The bed is the basic structure of the lathe and constitutes 70-90 percent of the total weight of the lathe. All other parts are fitted on to this bed. Two sets of parallel, longitudinal guideways are contained on the bed's upper surface. These guideways are precision machined to ensure accurate alignments of other parts fitted on the bed. It is made strong enough to resist the deflections and vibrations due to cutting forces. The bed is usually made of cast iron or nickel cast iron alloy.

***2. Head Stock*** The head stock is mounted at the left end of the bed. It provides the power required for rotating the work at various speeds and for the tool movement as well. The head stock receives the drive from an electrical motor and it makes use of the cone pulleys and gears for getting various spindle speeds. There are speed change levers on the head stock for this purpose. The head stock also contains work holding devices such as chucks, face plates and dog plates on it. The head stock mounts the live centre.

***3. Tail Stock*** The tail stock is mounted at the right end of the bed. It mounts the dead centre. It can be moved along the lathe bed for accommodating work pieces of different sizes. It is mainly used for the following purposes:

(a) to support one end of a long work piece.

(b) to hold a tool for the operations like drilling, reaming, tapping etc.

***4. Carriage*** The carriage provides the means for mounting and moving the cutting tools. The carriage has the following parts:

(a) *The saddle:* It is H-shaped casting fitted onto the bed and moves along the outer set of guideways on the bed surface.

(b) *The cross slide:* It is mounted on a transverse bar on the saddle and can be moved by means of the feed screw that is controlled by a small hand wheel. The cross slide is used to move the cutting tool along a perpendicular direction to the axis of rotation of the work piece.

(c) *The compound rest:* It consists of a base, which is mounted on the cross slide and an upper casting. The base is graduated in angle for swivel of the compound rest through any angle. The upper casting is mounted on guide ways on the base. It can be moved along the guide ways by a hand wheel.

(d) *The tool post:* It is mounted on the compound rest. The cutting tool is clamped in the tool post.

(e) *The Apron:* It is attached to the front of the carriage. It contains the mechanism for the manual and automatic motion of the carriage and the cross slide. For the manual movement of the carriage along the bed, there is a hand wheel on the front of the apron. The hand wheel shaft has a pinion at its other end which engages with a rack attached to the bed.

***5. Feed Mechanism*** The power is transmitted to the apron through the feed mechanism. It is located at the left of the bed. Power is transmitted to the apron by a rotating feed rod through the gearing and clutch arrangement in the apron.

For cutting threads, the drive is given by a lead screw by a direct connection between the apron and the lead screw by means of a split nut.

### 10.2.3 Operations Done on a Lathe

The various operations carried out on a lathe are given below:

***1. Turning*** Turning is a lathe operation in which the diameter of cylindrical jobs is reduced to the desired dimensions. In turning, the work piece is held between the lathe centres or in a chuck. The tool is clamped in the tool post.

The work piece is rotated and tool is fed parallel to the axis of rotation, as shown in Fig. 10.3. Turning operation resulting in the same diameter over the full length of the work piece is called straight turning and when different diameters are obtained, it is called step-turning or shoulder turning.

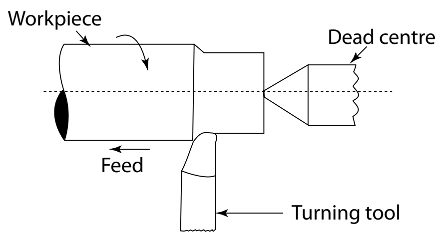



**Fig. 10.3** *Turning*

***2. Facing*** In facing, the ends of the work pieces are made flat. The work piece is held in the chuck and is rotated. The tool in the tool post is fed perpendicular to the axis of rotation. The tool is slightly inclined to the work piece. The arrangement can be seen in Fig. 10.4.

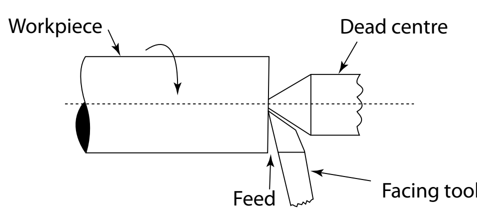



**Fig. 10.4** *Facing*

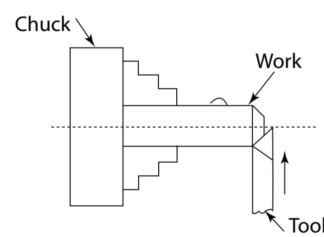



**Fig. 10.5** *Chamfering*

***3. Chamfering*** In chamfering, a bevel or small tapered shape is formed at the ends of the work piece. The work piece is rotated and the tool is fed perpendicular to the axis of rotation. Chamfering is the process of removing burrs after the operations such as knurling, turning or thread cutting. The arrangement can be seen in Fig. 10.5.

***4. Knurling*** In knurling, the surface of the work piece is made rough for easy gripping as shown in Fig,. 10.6 The knurling tool consists of two or more hardened steel rollers which have diamond patterns on their surface. These patterns are formed on the surface of the work piece by pressing the knurling tool against the rotating work piece.

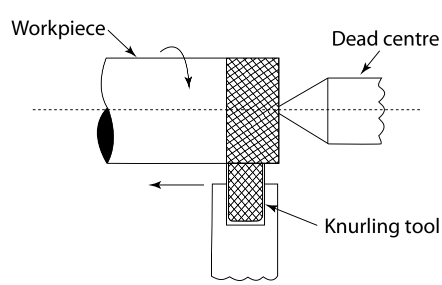



**Fig. 10.6** *Knurling*

***5. Forming*** The required profile is obtained by pressing a form tool against the surface of the rotating work piece. Forming can produce concave, convex or any irregular shape as shown in Fig. 10.7.

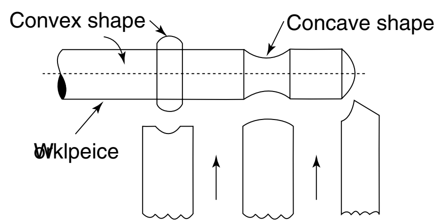



**Fig. 10.7** *Form turning*

***6. Grooving and Parting Off*** Grooving is the operation by which some grooves or neckings are produced on the work piece as shown in Fig. 10.8. Parting off is the operation by which one section of a work piece is cut or parted off from the remainder by means of a parting off tool. The tools used for this are thin as shown in the Fig. 10.8. Both the above operations are done by feeding the tool into the work piece at a proper and uniform rate.

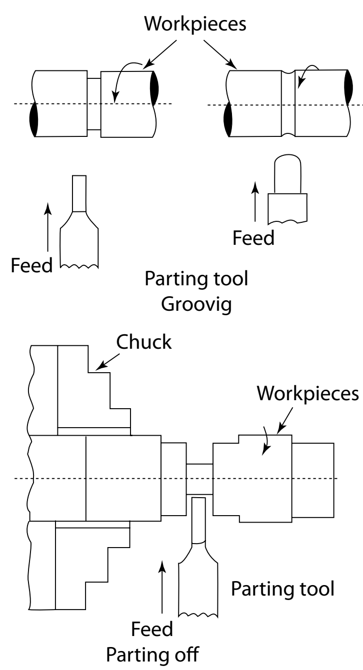



**Fig. 10.8** *Grooving and parting-off*

***7. Drilling*** Drilling is the operation by which a hole is produced in the work piece. For drilling, the work piece is rotated by holding in a chuck while the drilling tool is held in the tail stock and fed into the work piece. This can be seen in Fig. 10.9.

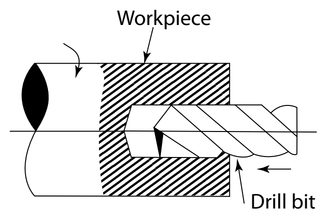



**Fig. 10.9** *Drilling*

***8. Reaming*** Reaming is the operation by which the dimension of a drilled hole is corrected. This is similar to drilling, but the reaming is more accurate and involves very little metal removal. The reaming operation is shown below in Fig. 10.10.

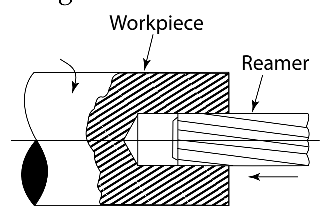



**Fig 10.10** *Reaming*

***9. Boring*** Boring is the operation by which a drilled hole is enlarged. For boring, the work piece is rotated by holding in a chuck and the boring tool fitted on the tool post is fed into the work piece for enlarging the holes drilled which can be seen in Fig. 10.11. If the enlarging is done only through some length of the work piece, it is called counter boring as given in Fig. 10.12.

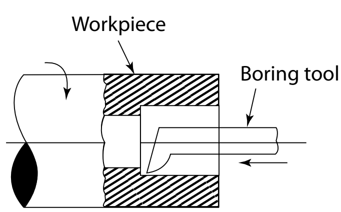



**Fig. 10.11** *Boring*

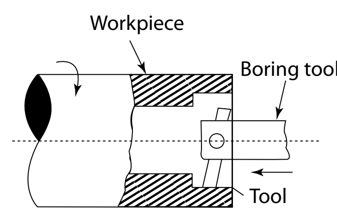



**Fig. 10.12** *Counter boring*

***10. Taper Turning*** Taper turning is the operation by which the tapered surface is produced on the work piece.

For taper tuning, any one of the following methods can be adopted:

(a) By using a form tool as in Fig. 10.13.

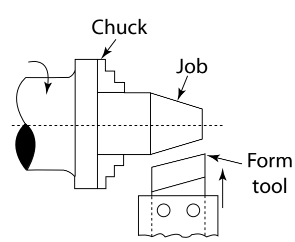



**Fig. 10.13** *Taper turning by a form tool*

(b) By tail stock set over method as in Fig. 10.14.

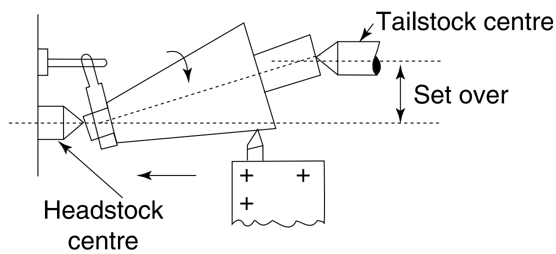



**Fig. 10.14** *Taper turning by tail stock set over*

(c) By swivelling the compound rest to the required angle as shown in Fig. 10.15.

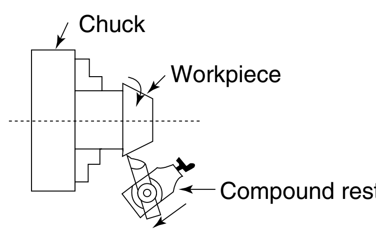



**Fig. 10.15** *Taper turning by compound rest*

Taper turning calculations for swivelling the compound rest: By rest swivel method, the half angle of taper θ can be calculated as:

$$\theta = \tan^{-1}\frac{(D-d)}{2L} \tag{10.1}$$

D is the large diameter of taper

*d* is the small diameter of taper and

*L* is the length of the taper

The compound rest is swivelled through this angle and the cutting tool is fed by compound rest hand wheel.

***11. Thread Cutting*** Thread cutting is the operation by which threads are formed on the surface of the work piece.

Thread cutting on a lathe is done by making use of a special arrangement in the carriage and the lead screw. The special arrangement is the half nut which can be engaged with the lead screw as shown in Fig. 10.16. This engagement makes the cutting tool to move through distance equal to one pitch of the thread for one revolution of the work piece. For obtaining different pitches on the work, the speed of the lead screw is changed by engaging proper change gears between the head stock spindle and the lead screw.

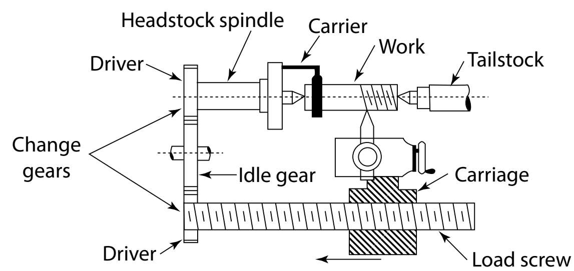



**Fig. 10.16** *Thread cutting*

The change gear may be selected by the following calculation:

$$\frac{\text{Number of teeth on the spindle gear}}{\text{Number of teeth on the lead screw}} = \frac{\text{Pitch of the thread to be cut}}{\text{Pitch of the lead screw tureads}}$$

## 10.2.4 Lathe Tools

Most of the lathe operations are done with simple and single point cutting tools. These tools slightly vary in their shapes according to the operations for which these are used. In case of turning tools and facing tools, the cutting takes place on the side of the tool. But, in the case of parting-off tools, finishing tools and thread cutting tools, cutting takes place on or near the end of the tool. Various shapes of common single point lathe tools are shown in the Fig. 10.17 along with their uses.

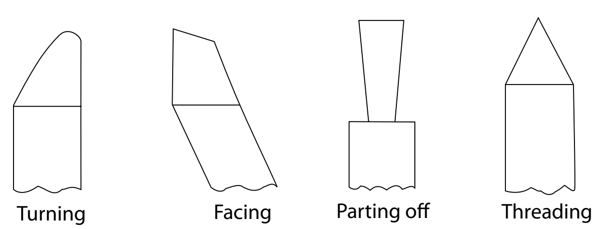



**Fig. 10.17** *Lathe tools*

## 10.2.5 Specification of a Lathe

A lathe can be specified by giving the various data regarding the maximum diameter of the work piece that can be rotated on a lathe (swing diameter), distance between the centres, height of the centre, hole through the spindle, number of spindle speeds and their range, feed ranges, motor power rating, net weight etc. The specification differs based on the type of lathe. A typical technical specification of an engine lathe is given below:

| | | |
|---|---|---|
| Height of the centre | : | 165 mm |
| Swing diameter over bed | : | 315 mm |
| Distance between centres | : | 700 mm |
| Hole through spindle | : | 35 mm |

| | | |
|---|---|---|
| Number of spindle speeds | : | 16 |
| Motor power | : | 0.75 kW |
| NET weight | : | 475 kg |

### 10.2.6 Cutting Parameters

For all metal cutting processes, it is necessary to have a clear idea about the cutting parameters. The various cutting parameters for a lathe are given below:

***1. Cutting Speed*** The cutting speed is the primary cutting motion and it represents the speed at which the material is removed from the work piece. In lathes, the cutting speed is got by the rotary motion given to the work piece. It can be calculated from the following equation:

$$V = (\pi DN)/1000$$

where V is the cutting speed in m/min.

D is the diameter of the work piece in mm

N is the number of revolutions of the work piece in r.p.m.

***2. Feed*** Feed determines the amount of material removed per revolution. In lathe, it is the distance moved by the tool for one revolution of the work piece, in a direction which depends on the operation performed. It is expressed in mm/rev.

***3. Depth of Cut*** In lathe, the depth of cut is the perpendicular distance between the machined and unmachined surface. The depth of cut is the tool movement in a direction perpendicular to the work piece surface given before each cut. It is expressed in mm and can be obtained from the equation,

$$d = (D_1 - D_2)/2 \text{ mm}$$

where $D_1$ is the original diameter of the work piece

$D_2$ is the diameter of the work piece after a cut

### 10.2.7 Application of Lathe

Lathes are designed in a variety of versions to suit different applications. Lathe is the most versatile conventional machine tool used for performing a large number operations explained in earlier sections. Lathes are used in the production of plain and stepped shafts, bolts, small tools, dies, gauges, fixtures, instrumental parts, pipes used in petroleum industries, wheels, crank shafts, screws etc. With special attachments, lathe can be used for polygonal turning, slot milling, grinding etc. The lathes can also be used for doing drilling and other allied operations using the tail stock arrangement.

### 10.2.8 Capstan and turret Lathes

These lathes are used for mass production. To make the operations faster, tail stock is replaced by a hexagonal turret where many tools can be fixed. Lot of operations can be done on a work piece, without any resetting of work or tools.

***Difference between Capstan and Turret Lathe***

Following are the differences in construction, operation and Use :-

1. The hexagonal turret of a Capstan lathe is mounted on a short slide or ram which slides on a saddle. The saddle is clamped on bedways, after adjusting the length of the work piece.

Thus, in a capstan lathe, the travel of the turret depends on the length of travel of the ram. This limits the maximum length of the work to be machined in one setting.

2. The hexagonal turret of a turret lathe in mounted on a saddle which slides directly on the bed. This enables the turret to be moved on the entire length of the bed and can machine longer work.
3. In the Capstan lathe, the hexagonal turret can be moved back and forth rapidly, without having to move the entire saddle unit. Thus, the capstan lathes are handy for small works which require light and fast cuts.

Principal parts of capstan and turret lathes are given in Fig. 10.18 and 10.19

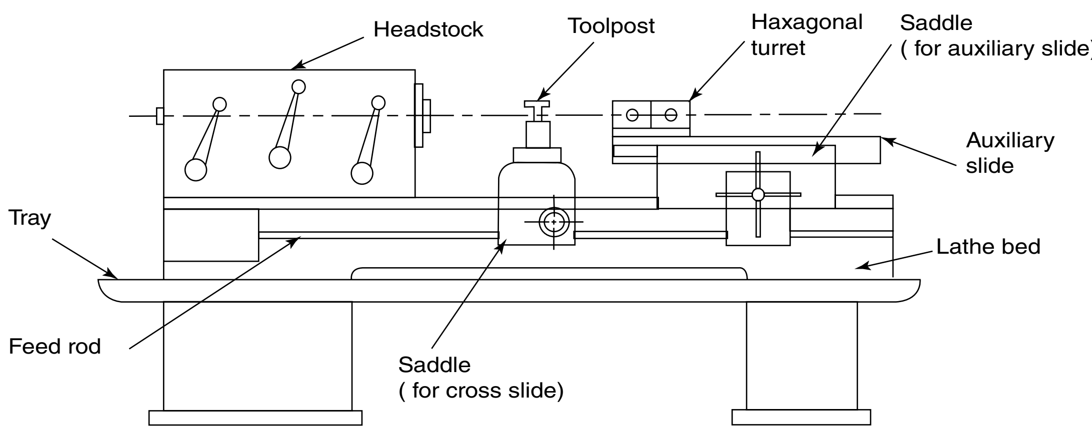



**Fig. 10.18** *Capstan Lathe*

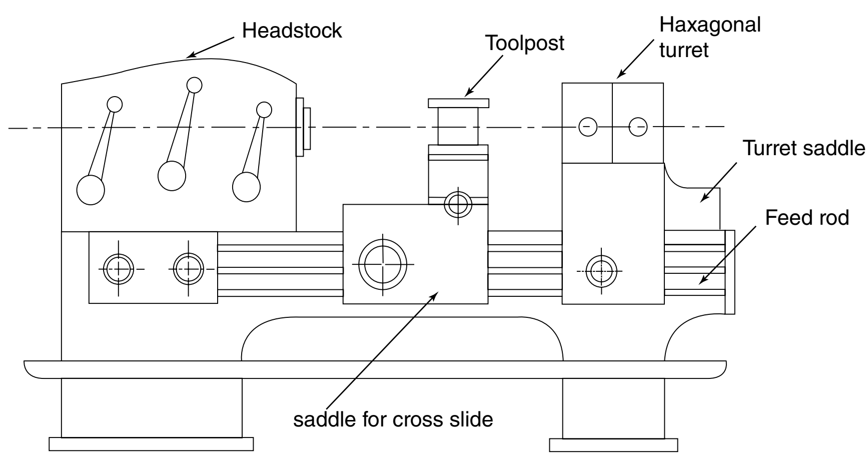



**Fig. 10.19** *Turret Lathe*

## 10.3 DRILLING MACHINES

In a drilling machine, holes are drilled by rotating a cutting tool called a drill. Drilling machines can also be used for other operations like boring, reaming, taping, spot facing, etc.

### 10.3.1 Types of Drilling Machines

In this section, the different types of drilling machines are described:

***1. Portable Drilling Machine*** Portable drilling machines are small compact machines which can be easily carried around. It has an in-built electric motor which rotates the drill at high speeds. It is specified by the maximum diameter of the hole that can be drilled. It is used for the jobs which cannot be taken to the drilling machines. It is also used for drilling small holes on large job at any desired angles.

***2. Sensitive Drilling Machine*** It has a base on which a cylindrical post is mounted vertically. The cylindrical post is called the column of the drilling machine. A table is attached to the column by means of a table clamp. The table supports the work piece and work holding devices. It can be moved along the column for proper positioning of the work piece.

A spindle head and a drive mechanism are mounted at the top of the column. It has an electric motor which drives the spindle by means of a belt and cone pulley arrangement as shown in Fig. 10.20. Spindle speeds can be changed by shifting the belt from one pulley to another.

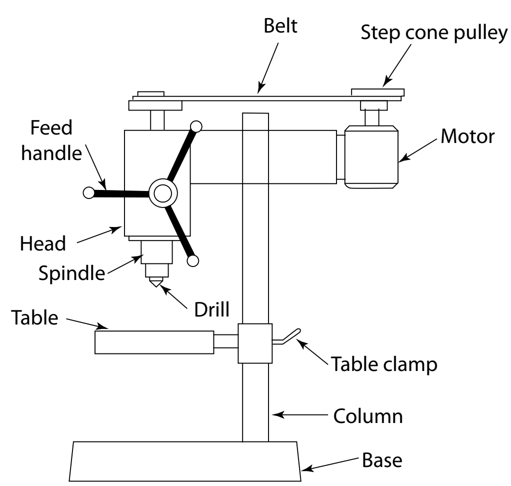



**Fig. 10.20** *Sensitive drilling machine*

The drill is held by a proper holding device such as a drilling chuck attached to the spindle. The drill is fed into the work piece placed on the table by manually rotating the drill feed handle. This can be used to drill holes from 1-25 mm.

***3. Pillar Drilling Machine or Upright Drilling Machine*** Upright drilling machines are similar to sensitive drilling machines except that these are used for heavier work and have provisions for the power feed mechanism.

It has a base, a column, a table and a spindle head. The column may be round or box type. On the column, a table is mounted on vertical guide ways and can be raised using an elevating screw.

The spindle head is mounted on the top of the column. It has a power feed mechanism with a wide range of spindle speeds. Upright drilling machine can drill holes up to 25 mm in diameter. Figure 10.21 shows a schematic view of a pillar drilling machine.

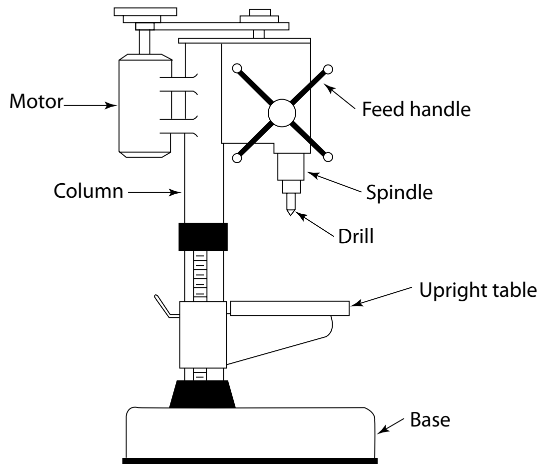



**Fig. 10.21** *Pillar drilling machine*

***4. Radial Drilling Machine*** When holes are to be drilled at different locations on large work pieces which cannot be readily moved and clamped on a drilling machine, radial drilling machines are used.

Radial drilling machines have a large, heavy, round and vertical column supported on a large base. The column supports a radial arm that can be raised or lowered by an elevating screw and also be swivelled over the base. The Spindle head and the driving mechanism are mounted on the radial arm. It can be moved horizontally along the guideways in the radial arm so that the spindle can be properly positioned at any desired location on a large work piece. The schematic diagram is shown in Fig. 10.22.

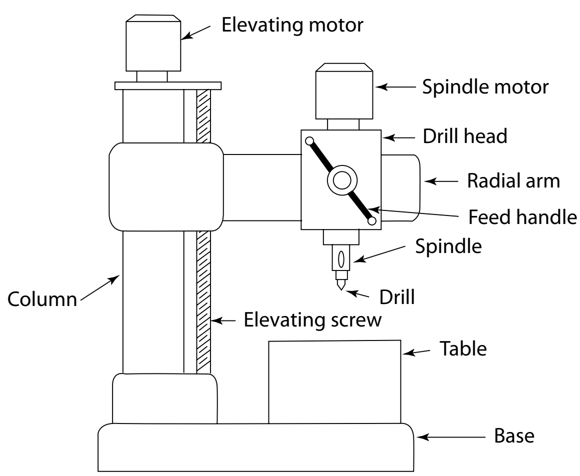



**Fig. 10.22** *Radial drilling machine*

***5. Gang Drilling Machine*** For a work piece which requires several related operations, such as drilling holes of different sizes, reaming, and boring a gang drilling machine can be used. A gang drilling machine has a number of independent columns and spindle heads mounted on a common base having a single common table. The spindles can be operated simultaneously and independently for different operations. Gang drilling machines are available with or without a power feed mechanism.

***6. Multi Spindle Drilling Machine*** For a work piece which requires a number of parallel holes to be drilled, a multi-spindle machine can be used. Multi-spindle drilling machine has a number of spindles driven by a single spindle head. Here, all the spindles are operated simultaneously and are used for drilling a number of holes on a work piece such as pipe flanges and pump housings.

## 10.3.2 Important Drilling Machine operations

1. Drilling
2. Reaming
3. Boring
4. Counter sinking
5. Spot Facing.

***1. Drilling***

By drilling operation, we make a round hole of the desired size. Before drilling, the centre of the hole should be marked on the object. The drill is pressed at the marked point and fed into the object as in fig. 10.23(a). In this process, the quality of finish will not be good. It can be improved by reaming.

***2. Reaming***

The tool used for reaming is called a Reamer. It is a cylindrical tool with many cutting edges as in Fig. 10.23(b). A reamer cannot make a new hole. It can only follow the path of the already drilled hole and finish it to the correct size.

***3. Boring***

Boring is the operation of enlarging a hole already drilled as in Fig. 10.23(c)

***4. Counter Sinking***

Counter sinking is an operation of machining a beveling at the end of a drilled hole. Counter sinking is done to provide a recess for the head of a counter sink screw so that the screw head can be seated firmly, as shown in Fig. 10.23(d).

***5. Spot facing***

It is an operation to make the surface flat around a hole so that a washer and a nut can be seated, as in Fig. 10.23(e).

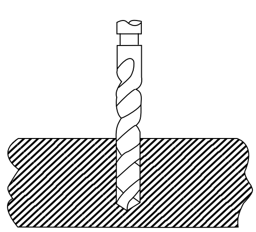


**Fig. 10.23 (a)** *Drilling*

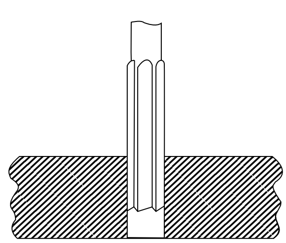


**Fig.10.23 (b)** *Reaming*

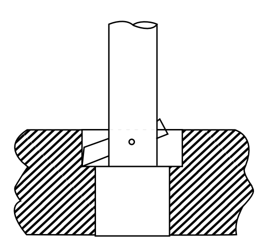


**Fig.10.23 (c)** *Boring*

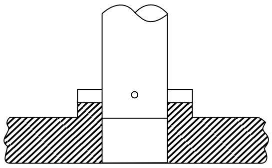


**Fig.10.23 (d)** *Countersinking*

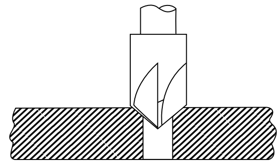


**Fig. 10.23 (e)** *Spot facing*

### 10.3.3 Drilling Tools

The drilling machines can be made use for drilling and allied operations. The tools used for various operations differ significantly. A drilling tool with the main parts and some of the common tools used for the other allied operations are shown in Fig. 10.24.

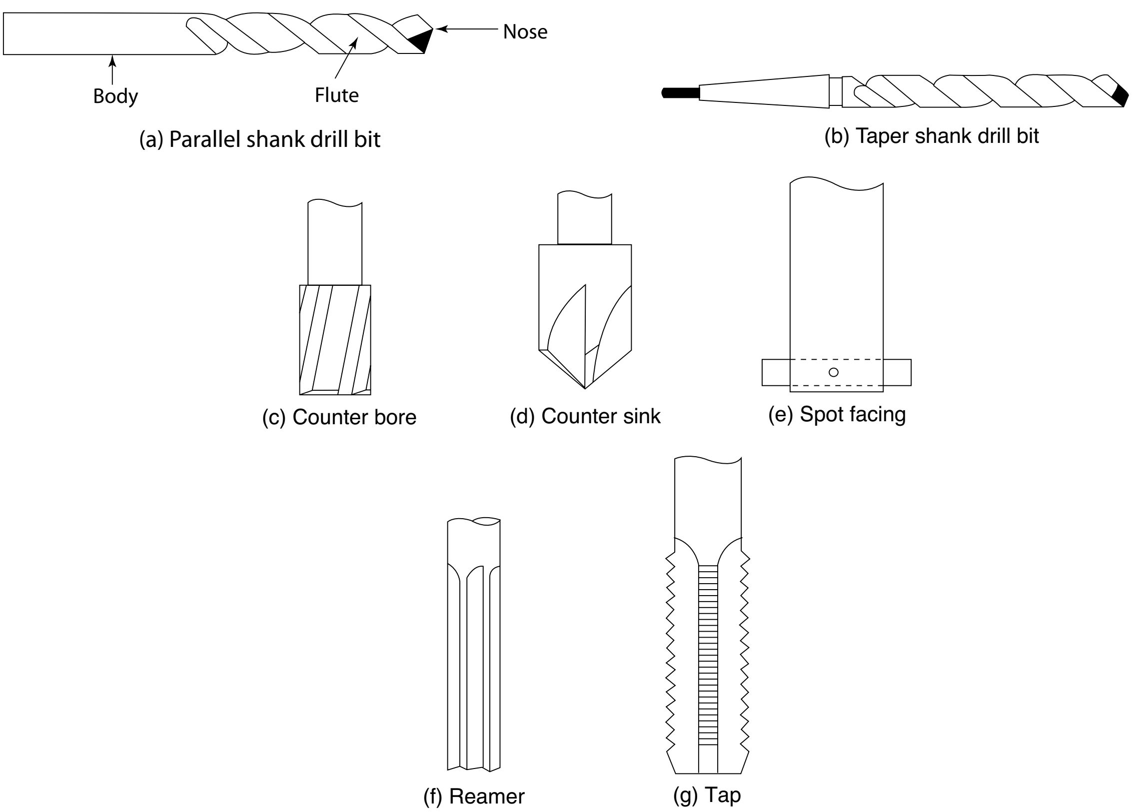



**Fig. 10.24** *Drilling and other allied tools*

### 10.3.4 Specification of a Drilling Machine

The specification of a drilling machine varies based on the type of the drilling machine. The specification normally includes the data regarding the drilling capacity or maximum diameter of the hole drilled, taper in the spindle, spindle traverse, pillar or column diameter, radial arm reach dimensions in radial drilling machines, number of spindle speeds, the net weight of the machine, working space etc. A typical technical specification of a high speed sensitive drilling machine is given below:

| | | |
|---|---|---|
| Drilling capacity in steel | : | 12 mm |
| Taper in spindle (external) | : | MT 2 |
| Spindle traverse | : | 76 mm |
| Pillar diameter | : | 101.6 mm |
| Working base surface | : | 255 × 305 mm |
| Spindle speed | : | 580 to 14000 rpm |
| Number of speeds | : | 8 |
| Motor power | : | 0.75 kW, 2880 rpm |

### 10.3.5 Cutting Parameters

Based on the main cutting motion and other motion, the cutting parameters in a drilling machine slightly differs from that of a lathe.

***1. Cutting Speed*** In a drilling machine, the cutting speed is the speed at which the material is removed from the work piece due to the rotary motion given to the drill. In particular, this refers to the peripheral speed of a point on the surface of the drill in contact with the work. It is expressed in metre per minute and can be calculated by using the following equation:

$$V = (\pi D_t .N)/1000 \text{ m/min}$$

where $V$ is the cutting speed in m/min
$D_t$ is the diameter of the drill in mm, and
$N$ is the speed of revolution in r.p.m.

***2. Feed*** The feed in a drilling machine refers to the distance moved by the drill in one revolution. It is expressed in mm/rev. It may also be expressed as feet/min.

***3. Depth of Cut*** The depth of cut in drilling refers to the radius of the drill being used and is selected on the basis of hole diameter desired or required. It is expressed in mm and can be calculated from the following equation:

$$d = D_t/2 \text{ in mm}$$

where d is the depth of cut in mm, and
$D_t$ is the diameter of the drill in mm.

## 10.4 SHAPING MACHINE

### 10.4.1 Introduction

Shaping is a machining process used for removing the metal from surface in horizontal, vertical and angular planes by the use of a single point tool. The process involves the reciprocation of the tool in a linear direction across the work piece. Figure 10.25 shows the basic principle of the shaping process. The basic shapes machined on a shaping machine are given in Fig. 10.26.

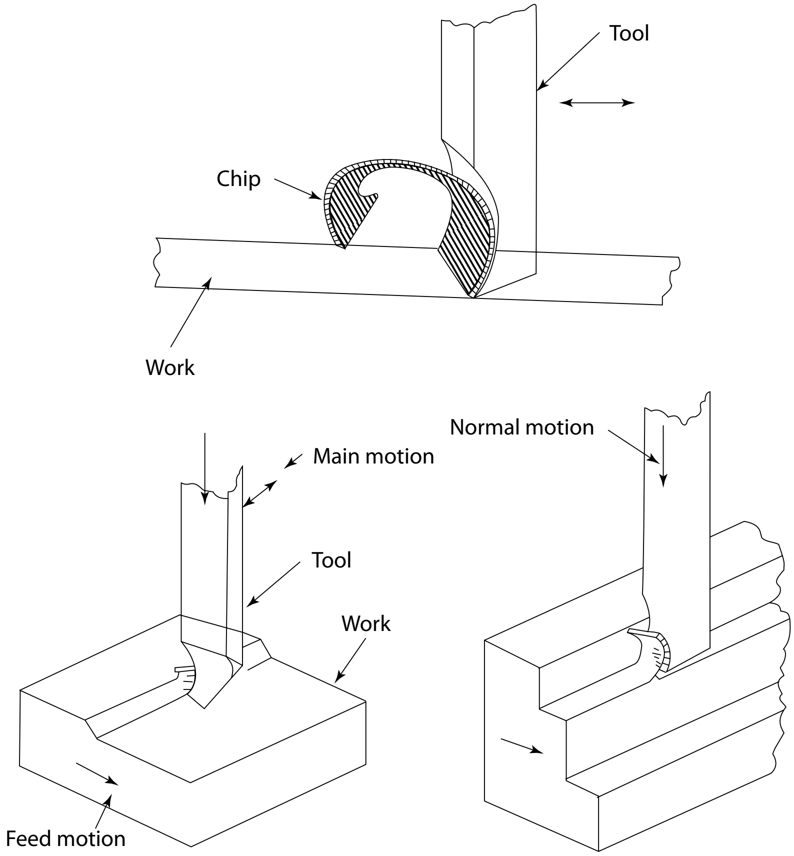



**Fig. 10.25** *Shaping process*

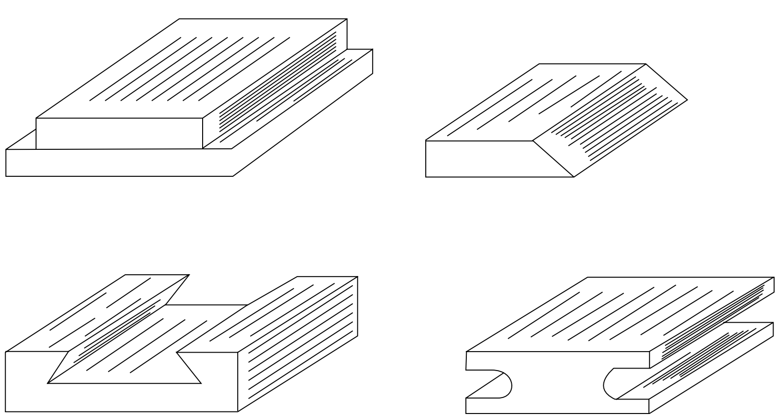


**Fig. 10.26** *Basic shapes*

The machine tool used for shaping process is called a shaping machine or a shaper. The shaping machine is provided with all the necessary arrangement for performing the shaping process. The main or cutting motion is the reciprocating motion of the tool in a linear direction which is given by a ram. The feed motion is the crosswise movement of the work piece or the tool. This motion produces the chip thickness. The normal motion is the movement of the tool perpendicular to the work piece given just before the beginning of a cut which produces the depth of cut.

## 10.4.2 Principal Parts

The principal parts of a shaping machine are shown in Fig. 10.27. and Fig. 10.28.

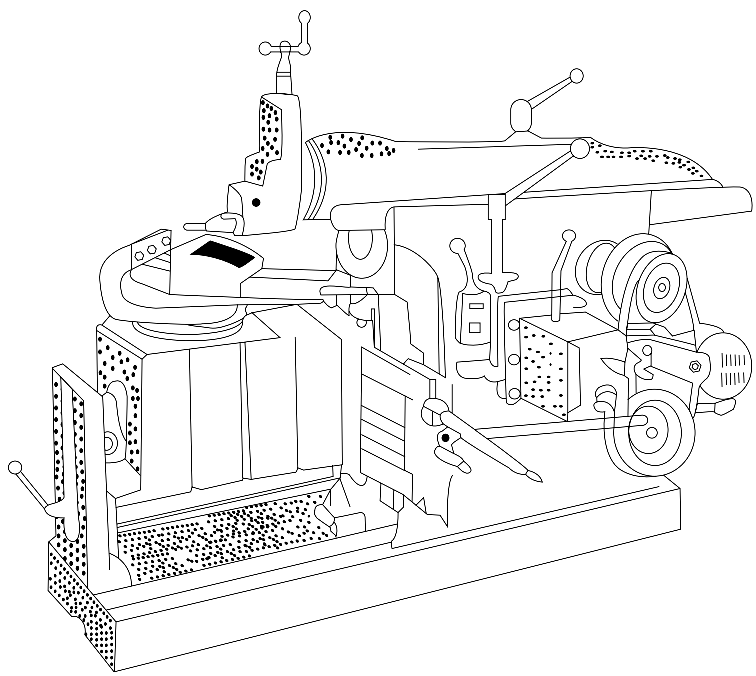


**Fig. 10.27** *Pictorial view of Shaping Machine.*

***1. The Base*** The base supports the whole machine and it is rigidly bolted to the floor with the help of foundation bolts for avoiding the possible vibration during cutting. Much care is taken to place the base flat and at suitable height for the convenient operation of the machine.

***2. The Column*** The column is the basic structure of shaping machine onto which all the other parts are attached. It is a hollow casting having two vertical walls firmly supported on the base. The top of the column walls have the guide ways for tool reciprocation. The front side of the column has the crossrail which carries the table for the work mounting. The column also houses the drive mechanism of the shaping machine in the hollow space between the walls. The column is provided with holes in the two walls for the inspection of the drive mechanism.

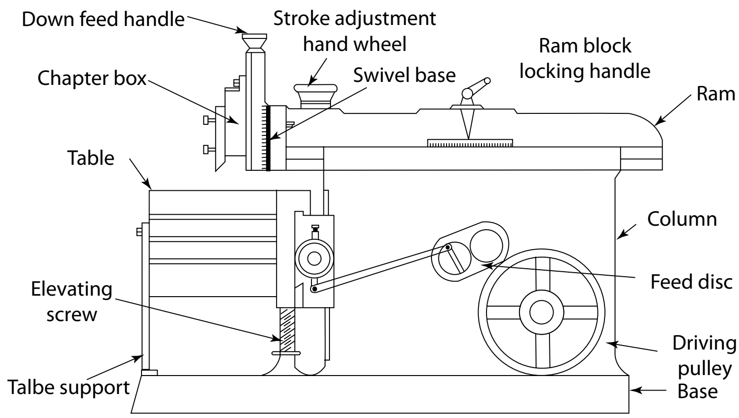



**Fig. 10.28** *Layout of a Shaping machine*

***3. The Crossrail*** The crossrail is the box like structure over which a saddle slides horizontally and it is supported on the front vertical guide ways of the column. It is provided with a cross feed screw for the table and the crossrail vertical feed screw is located inside.

***4. The Table*** The table is bolted onto the saddle and hence the table can be moved in the horizontal and vertical directions with the help of cross feed screw and the vertical feed screw respectively.

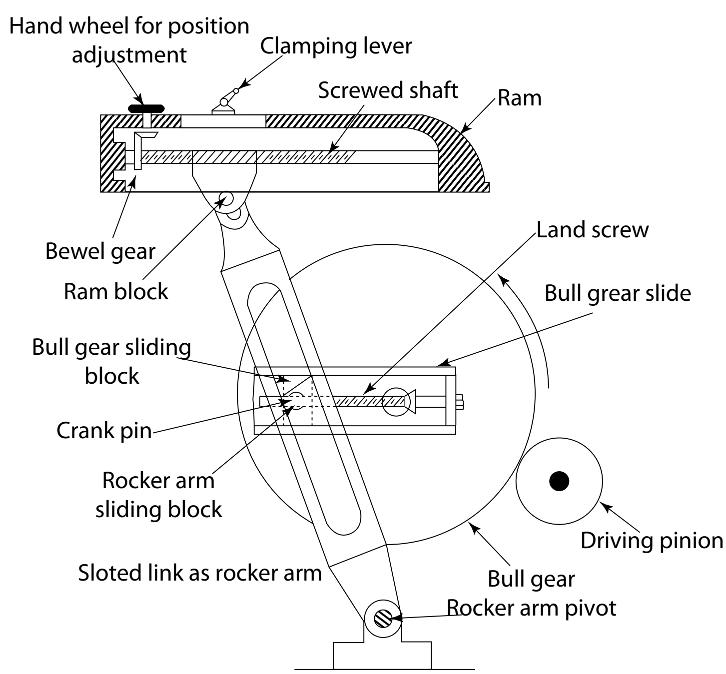



**Fig. 10.29** *Crank and slotted link quick return mechanism*

The table is used for clamping the work piece and is provided with T-slots for clamping vice or any work holding fixtures which are used for supporting the work piece

***5. The Ram*** The ram is the reciprocating part of the shaping machine. It is seated in the top guide ways of the column walls and performs the main cutting motion. It carries the arrangement for the tool holding called the shaper head on its front end. The ram is driven by a quick return mechanism which ensures a slower motion in the direction of cutting and comparatively faster motion in the return. Its position related to the work piece can be adjusted by a ram position control arrangement. It also has a ram locking arrangement which is supported on a screwed shaft for setting its position. The basic arrangement is shown in Fig. 10.29.

***6. The Shaper Head*** The shaper head is the tool head of the shaping machine fixed securely to the front end of the ram. It consists of vertical tool slide, clapper box and the tool post. The tool post is fitted to a clapper block which in turn is hinged to the clapper box. The hinge type arrangement allows the tool to swing up and slide freely along the work piece during the return stroke. This prevents any damage to the machined surface. This is shown in Fig. 10.29. The clapper box is provided with a slotted arc which permits it to be swivelled and fixed away from the work surface for facilitating vertical and angular cuts. The clapper box is fixed onto the vertical tool slide. The vertical tool slide is provided with vertical tool feed screw, vertical feed slide way, a hand wheel for giving the vertical feed and a micrometer dial for measuring the tool slide movement. The whole shaper head can be swivelled to any desirable angle for taking angular cuts. This is effected by loosening the swivel clamp on the ram.

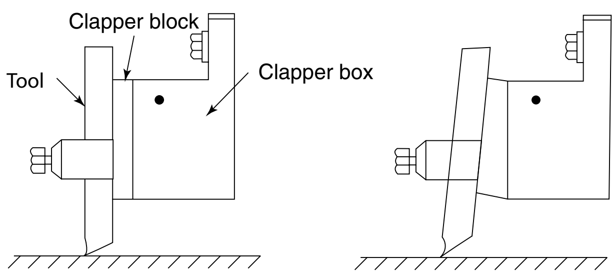



**Fig. 10.30** *Clapper box assembly*

***7. Drive Mechanism*** An electric motor gives a uniform rotary motion over a gear drive to the drive mechanism of the shaping machine which converts it to a reciprocating motion for the ram by suitable arrangement.

The most commonly used shaper mechanisms are the crank and slotted link mechanism, Whitworth Quick return mechanism and the hydraulic shaper mechanism.

The crank and slotted link quick return mechanism is shown in Fig. 10.28. The drive from the electric motor is received by a driving pinion through a driver transfer arrangement which may be a gear train or belt and a step cone pulley arrangement. Hence, the speed of the driving pinion can be changed by different combination of gearing by simply shifting the belt on the cone pulley. The driving pinion transmits the power to a large gear called bull gear or wheel which is mounted within the column. A radial slide is bolted centrally to the bull gear which carries a sliding block. It is also provided with a lead screw and a set of bevel gears for adjusting the position of the sliding block with respect to the center of the bull gear. A crank pin is fitted into the sliding block and a rocker arm sliding block is also fastened to it. The rocker arm sliding block is fitted within a slotted link called rocker arm. The rocker arm is pivoted at its bottom end is attached to the frame of the column. The upper end of the rocker arm is connected to the arm block of the ram locking arrangement.

When the bull gear is rotated, the crank pin will rotate on the crank pin circle. The rocker arm sliding block fastened to the crank pin will also rotate on the crank pin circle as shown in the Fig. 10.29 and at the same time it will also slide up and down along the slot in the rocker arm. This motion is transmitted to the ram through the rocker arm resulting in the final reciprocating motion. The shaping machine removes metal in the forward motion of the ram and the backward motion without the metal removal will be fast enough to save time in machining.

The principle of achieving the quick return of the ram is explained below. Figure 10.31 shows the principle of quick return mechanism.

When the rocker arm is at its extreme position PR, the ram will be at the extreme backward position of its stroke. The ram will be at the extreme forward position of its stroke when the rocker arm is at its extreme position PL. PR and PL are line drawn tangential to the crank pin circle. In the forward cutting stroke, the crank rotates through an angle α and the return non cutting stroke corresponds to the crank rotation through the angle β.

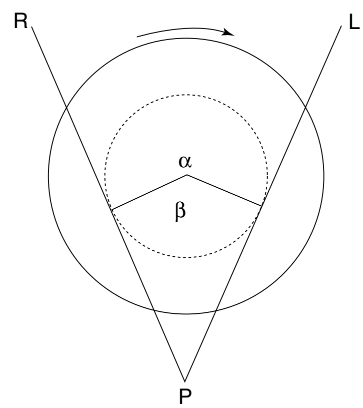



**Fig. 10.31** *Principle of the quick return mechanism*

The angular velocity of the crank is constant. It can be seen from Fig. 10.31 that the angle made by the forward cutting stroke is greater than the angle made by the return on cutting stroke. Hence, the return stroke requires only a shorter time ensuring a quick return. The length of the stroke can be adjusted by making use of the lead screw and bevel gears arrangement of the rocker slide. The distance between the crank pin and the center of the bull gear decides the stroke length. A smaller distance will give smaller stroke length and a larger distance will give larger stroke length.

The position of the ram stroke can be adjusted by making use of the ram position control and ram locking arrangement. The position of the ram stroke depends upon the ram block along the screwed shaft in the ram.

### 10.4.3 Types of Shaping Machines

The shaping machines are classified into various type based on the basic design features or application.

1. Based on the type of mechanism used in the drive mechanism, the shaping machines are classified into:
   (a) *Crank type,* a more common one which makes use of the crank and slotted link mechanism.

(b) *Gear type,* which makes use of a rack and a pinion arrangement for getting the desired reciprocating motion. This is not widely used.

(c) *Hydraulic shaper,* which makes use of hydraulic powered arrangement for getting the desired reciprocating motion.

2. Based on the orientation and travel of the ram,

   (a) *Horizontal type,* which has the ram reciprocating in a horizontal axis and is widely used.

   (b) *Vertical type,* which has the ram reciprocating in a vertical axis.

   (c) *Traveling head type,* which is similar to the horizontal type but it is used for heavy work pieces. The work pieces are held static on the base of the machine. The shaper head moves crosswise to give the required feed in addition to the normal reciprocating motion.

3. Based upon the table design,

   (a) *Standard or plain type,* which is provided with two table movements, namely, the vertical and horizontal crosswise movement.

   (b) *Universal type,* which is provided with tables having swivel facility about an axis parallel to the ram and tilting provision for the top portion of the table about the axis perpendicular to the ram.

4. Based on the cutting stroke,

   (a) *Push cut type,* which is the most general type of shaper in which the metal removal takes place when the ram moves away from the column.

   (b) *Draw or pull cut type,* in which the metal removal takes place when the ram move towards the column.

### 10.4.4 Cutting Tools

The various cutting tools used in the shaping machines are similar to the lathe tools. But, the tools used here are more rigid and heavier to withstand the shock experienced during the intermittent cutting in shaping machine. The various shapes of tools used in shaping machine are given in Fig. 10.32.

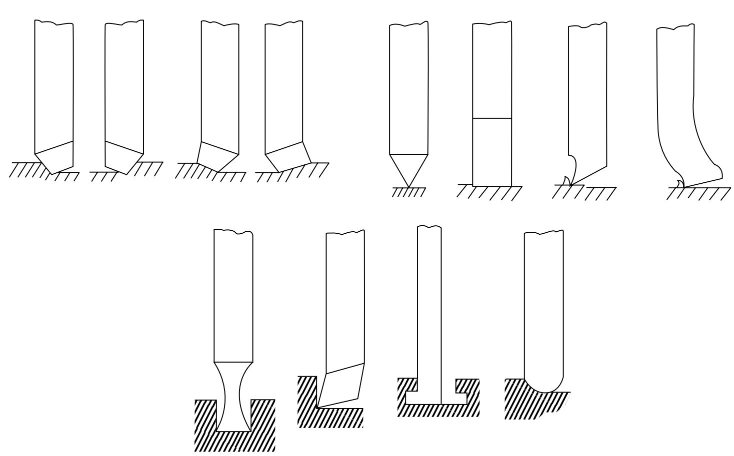


**Fig. 10.32** *Shaping tools*

### 10.4.5 Specification of a Shaping Machine

The shaping machines are specified by giving the data regarding the stroke length, working space of the table, table travel distances and angular movements, tool slide vertical movement and swivel angle, range of speeds etc.

The specification of a typical shaping machine is given as follows:

| | | |
|---|---|---|
| Stroke length | : | 356 mm |
| Length of the ram | : | 813 mm |
| Length of the cross slide | : | 610 mm |
| Working space in the table | : | 254 x 254 mm |
| Number of ram speeds | : | 3 |
| Number of ram stroke per minute | : | 12 to 60 |
| Vertical travel of table | : | 127 mm |
| Cross travel of table | : | 178 mm |
| Power of the motor | : | 0.75 kW |
| Approximate weight | : | 800 kg |

### 10.4.6 Cutting Parameters

The various cutting parameters involved in the shaping machine are given below:

***1. Cutting Speed*** In a shaping machine, the cutting speed is the rate at which the metal is removed and is given by the ratio between the length of the cutting stroke and the time taken by the cutting stroke. It can be calculated by the equation

$$V = n\,L(1 + m)/1000$$

where $V$ represents the cutting speed expressed in m/min,
$n$ represents the number of double strokes or rev/min of the bull gear,
$L$ represents the length of the cutting stroke in mm, and
$m$ represents the ratio between the return stroke time to the cutting stroke time.

The cutting speed so calculated is the average cutting speed and it is assumed that the cutting stroke is completed at a uniform speed.

***2. Feed*** Feed in shaping machine represents the relative movement of the tool or work in a direction perpendicular to the ram motion per double stroke and is expressed in mm/double stroke. The feed is normally given at the end of a return stroke before the starting of the cut.

***3. Depth of Cut*** In a shaping machine, the depth of cut represents the perpendicular movement of the tool towards the work piece surface. This determines the thickness of the metal that is removed in one cut.

### 10.4.7 Applications of Shaping Machine

The shaping machines are basically used in machining flat surfaces which may be horizontal or vertical or angular. These are also used full in machining slots, grooves and key ways. Even irregular surface can be machined with a shaping machine. By means of special tools, attachments and work holding devices, the shaping machine can be used for cutting external and internal key ways, spiral grooves, T-slots and other miscellaneous shapes, as given in Fig. 10.33(a to d).

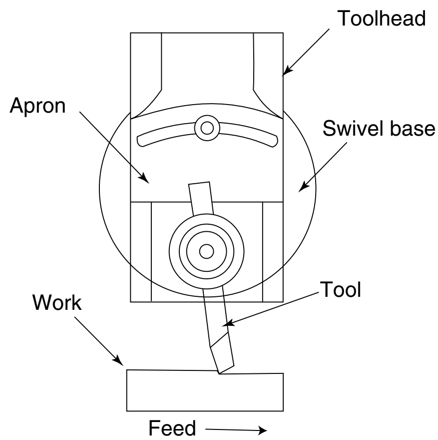



**Fig 10.31(a)** *Shaping horizontal surface*

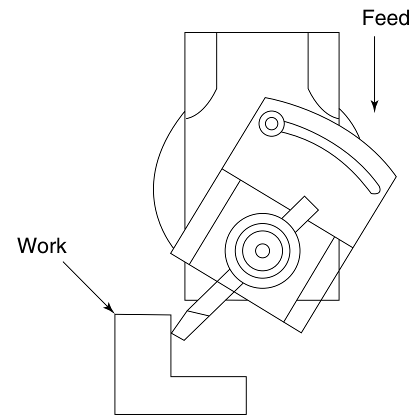



**Fig 10.31(b)** *Shaping vertical surface*

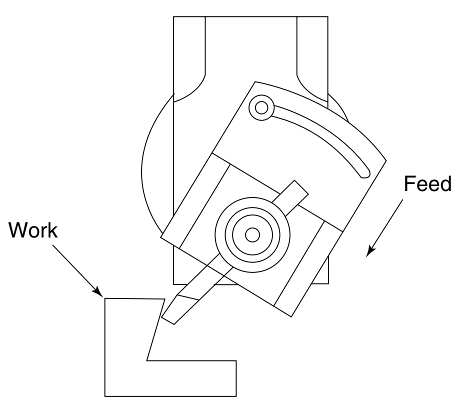



**Fig 10.31(c)** *Shaping angular surface*

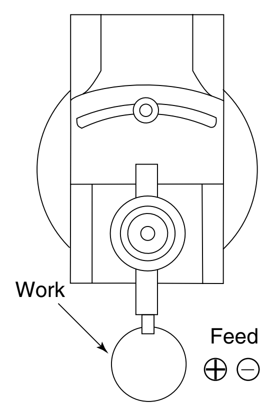



**Fig 10.31(d)** *Shaping external keyway*

## 10.5 MILLING MACHINE

### 10.5.1 Introduction

Milling is the process of removing the metal from a work piece by feeding it past a rotating cutting tool called a milling cutter. The cutters used here are provided with multiple tooth and produce a number of chips in one revolution. The basic milling process is shown in Fig. 10.34. Here, the cutting edges are also arranged in circular way. The milling process is widely used in machining a variety of shapes on work pieces of all materials including cast iron, steel, non ferrous metals, non metallic materials etc. The process of milling produces good surface finish and dimensional accuracy compared to other machining processes. The milling machines are provided with all the necessary arrangement for given rotary motion for the milling cutter, work piece clamping, positioning and feeding past the milling cutter.

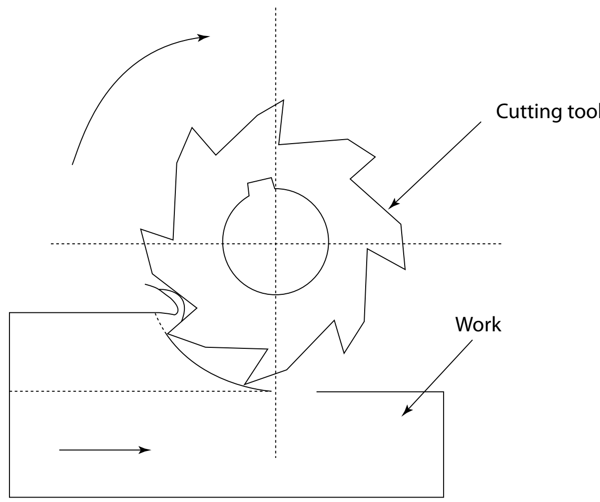



**Fig. 10.34** *Principle of milling process*

### 10.5.2 Principal Parts

The principal parts of the most commonly used column and knee type milling machine is explained below in detail and is shown in Fig. 10.35 and Fig. 10.36.

***1. The Base*** The base is the foundation of the milling machine and hence supports all other parts. It is a rigid casting bolted to the floor. Much care is taken to make the top and bottom surface of the base extremely smooth and accurate for machining. The base of certain milling machines are hollow and are used as a reservoir for the cutting fluid.

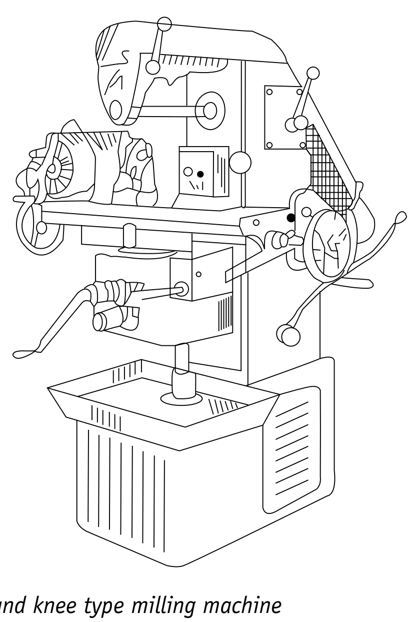


**Fig. 10.35** *Pictorial view of a Column and knee type milling machine*

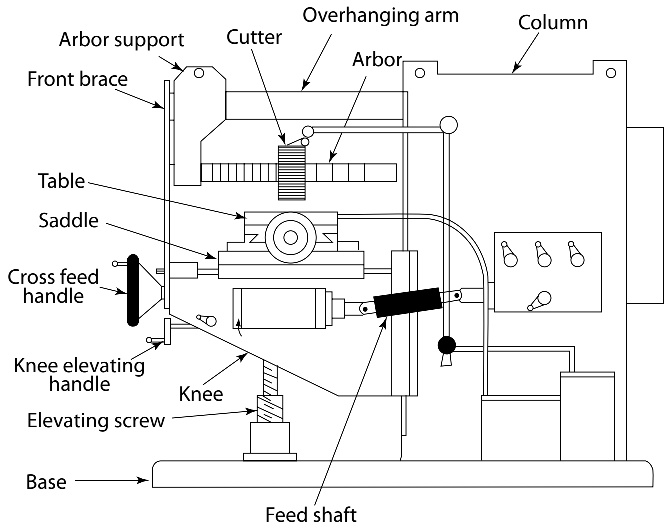



**Fig. 10.36** *Layout of a Column and knee type milling machine*

***2. The Column*** The column is the main structure of a milling machine and has all other parts attached to it. It is a box shaped structure which houses the motor drive and all the mechanisms of the milling machine. For adding rigidity to the structure, the column is provided with heavy ribbed supports inside. The front side of the column has accurately machined smooth surface and is called as column face. The column face is provided with guide ways for any vertical movement along with it. The top of the column is also machined accurately and is used to hold and guide an over arm.

***3. The Knee*** The knee is an overhanging part which projects from the column of the milling machine. The knee slides along the guide ways of the column face either up or down. The knee is firmly supported by an elevating screw which is mounted on the base. The elevating screw serves to raise or lower the knee for positioning the workpiece with respect to the milling cutter. The knee of a milling machine houses the feed mechanisms and controls for the table used to hold the workpiece. The knee is also provided with guide ways on its top surface.

***4. The Saddle*** The saddle in a milling machine is fixed on the knee and slides transversely along the guide ways in the top surface of the knee. It is provided with graduations for exact movement and can be operated manually or by power.

***5. The Table*** The table rests on the saddle and slides longitudinally along the saddle guide ways. The table can be moved transversely by moving the saddle for giving any cross feed. The table has accurately finished top surface and is provided with T-slots for clamping the workpiece and any work holding fixtures. The longitudinal movement of the table may be limited with the help of trip dogs fixed on the side of the table. Based on the machine type, the table can also have provisions like swivelling and tilting.

***6. The Spindle and the Arbor*** The spindle is the main driving element which receives power from the motor through an arrangement with belt, gears and clutches. The spindle in turn transmits power to an arbor or stub arbor. The cutter may also be directly mounted in the spindle nose. The arbor is an accurately machined shaft attached to the spindle by fitting its one end to the spindle nose. The arbor is used in mounting and rotating the arbor type milling cutters. The position of the milling cutter along the arbor may be adjusted using suitable spacing collars. The arbor is supported by a front brace.

***7. The Over Arm and the Front Brace*** The over arm is the overhanging arm mounted on the top of the column and can be moved in and out manually to a suitable position. The over arm provides support for the arbor through a front brace which is an extra support that is fitted between the knee and the arbor. The front brace has the provision (a slot) for adjusting the height of the knee with respect to the over arm.

In addition to the principal parts, a milling machine can have other accessories like a suitable vice, dividing head or indexing head, work holding fixtures, cutting fluid supply etc. A number of milling machine attachments are available for improving the versatility of the machine. The common milling machine attachments include vertical milling attachment, high speed attachment, universal spiral attachment, rack milling attachment, slotting attachment, gear cutting attachment, rotary table attachment, etc.

The drive mechanism used in milling machines are quite complicated and the details of which are beyond the scope of this book.

### 10.5.3 Types of Milling Machines

Based on their capabilities to do a variety of cutting operations, the milling machines are the most versatile and useful machine tools.

A number of different types of machines are available depending on the design feature of the machine tool. The milling machines can be broadly classified into four groups, namely, the column and knee type machines, the bed type machines, the planer type machines and the special type machines.

- The column and knee type machines are most common and general purpose milling machines. Based upon the number of movements available for the table and the orientation of the spindle, these machines can be further classified into ph in, universal, omniversal, vertical milling machines etc.
- The bed type machines are milling machines with their work table mounted directly on the bed without any knee arrangement. Hence, this type of machines are not as versatile as others, but have high stiffness and are used for high production. Based on the number of spindle heads available, these machines can be classified into simplex, duplex and triplex milling machines with one, two and three spindle heads respectively. These spindle heads can be used for simultaneous machining of two or three work piece surfaces.
- The planer type machines are massive milling machines used for heavy cutting and are similar to a planing machine in their constructional features. These are equipped with several heads and cutters to mill various surfaces. These are more efficient than planing machines.
- The special type machines are available for specific applications and with special features. Some of the special type milling machines are rotary table machines, duplicating or copy milling machines, CNC milling machines, profile milling machines etc.

- The details of individual machines mentioned above can be read from advanced books on Machine Tools or Production Technology.

### 10.5.4 Milling-Cutting Tools

The milling process is widely used for machining various shapes. The cutters used for this also have different shapes and sizes. The cutters also depend on the type of milling operations. Some of the common milling cutters used and their names are given in Fig. 10.37.

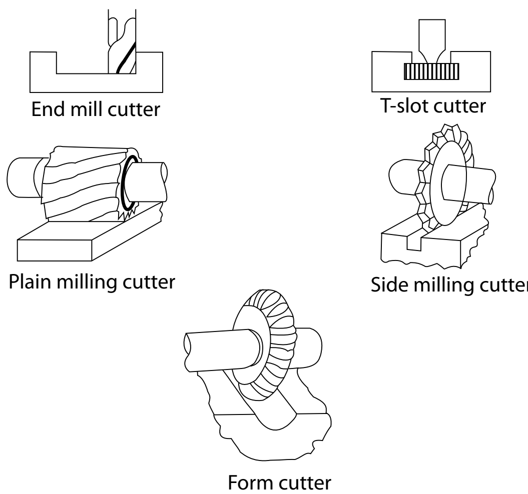



**Fig. 10.37** *Milling cutters*

### 10.5.5 Specification of a Milling Machine

The milling machines are specified by specifying the data regarding the dimensions of the working surface of the table, the longitudinal, cross and vertical travel distances, number of spindles, number of speeds, spindle nose number, power ratings, net weight, the floor space requirements etc. A typical technical specification of a column and knee milling machine is given below:

| **Model** | **:** | **Horizontal** |
|---|---|---|
| Working surface | : | 1120 × 280 mm |
| Longitudinal traverse | : | 558 mm |
| Cross traverse | : | 228 mm |
| Vertical traverse | : | 406 mm |
| Diameter of spindle nose | : | 79 mm |
| Length of arbor | : | 635 mm |
| Maximum swing of the tool dia. | : | 279 mm |
| Spindle motor | : | 1.5 kW |
| Weight approximately | : | 2000 kg |

### *10.5.6 Cutting Parameters*

***1. Cutting speed*** In a milling machine, the cutting speed is the circumferential speed of the milling cutter expressed in m/min. It is the linear distance which a point on the outer cutting edge of a milling cutter tooth travels in one minute. It can be calculated from the following equation:

$$V = (\pi D_t N)/1000$$

where V is the cutting speed in m/min,

$D_t$ is the diameter of the milling cutter in mm,

$N$ is the number of revolution of the milling cutter in rpm.

***2. Feed*** The feed in milling machine is the rate at which the work is moved past the rotating cutter. It is the most important factor in determining the rate of metal removal and overall machining efficiency. The feed in milling machine is expressed by three different methods, namely;

(a) Feed per tooth ($f_z$ ) refers to the distance moved by the work piece in the time between engagement of the two successive teeth.

(b) Feed per cutter revolution ($f_z$) refers to the distance moved by the work piece for one complete revolution of the cutter.

(c) Feed per minute ($f_{rev}$) refers to the distance moved by the work piece in one minute.

The following equation gives the relationship between these three feeds,

$$f_m = N f_{rev} = f_z \cdot Z \cdot N$$

where Z is the number of teeth in the milling cutter.

***3. Depth of cut*** The depth of cut in the milling process is the perpendicular distance between the machined and unmachined surface expressed in mm. It is given before each cut by the movement of the work piece towards the cutter.

### 10.5.7 Applications of Milling Machines

The milling machines are versatile machines used in machining various shapes like flat surface, contoured surfaces, surfaces of revolution, external and internal threads and helical surfaces of various cross sections. The milling machines are used in milling or sinking dies and mould cavities. Milling is used in machining key ways, the wide bottom portion of T-slots, the tooth space of roller chain sprockets etc. The milling machines are also used in the manufacturing of various types of gears like worm gear, bevel gear, spur and helical gear.

## 10.6 PLANING MACHINE

The planing machine is used for machining very large work pieces which cannot be machined in a shaping machine. In a shaping machine, single point cutting tool reciprocates against the stationary work piece. But, in a planing machine, work piece moves to and fro against the stationary single point cutting tool.

### 10.6.1. Types of Planing Machine

Through there are many different types with minor differences, the most commonly used one is known as standard or double housing planner which is described here in Fig. 10.37.

***Following are its main parts***

1. Bed
2. Table
3. Housing or Column
4. Cross Rail
5. Tool Head

***Bed***

The Bed is a very large and heavy casting which supports the column and all other moving parts of the machine. The Table slides over the bed through precision ways. The driving mechanism for the table is provided in hollow space of bed.

***Table***

The Table is provided with T-slots to hold the work and work holding devices and reciprocates along the ways of the bed. A hollow space is left at each end of table for collecting chips. Also, a groove is cut on the side of the table for clamping dogs.

***Housing***

The housing is the vertical structures placed on each side of the bed. The cross rail slides up and down on the housing. The tool head is placed on the cross rail.

***Cross rail***

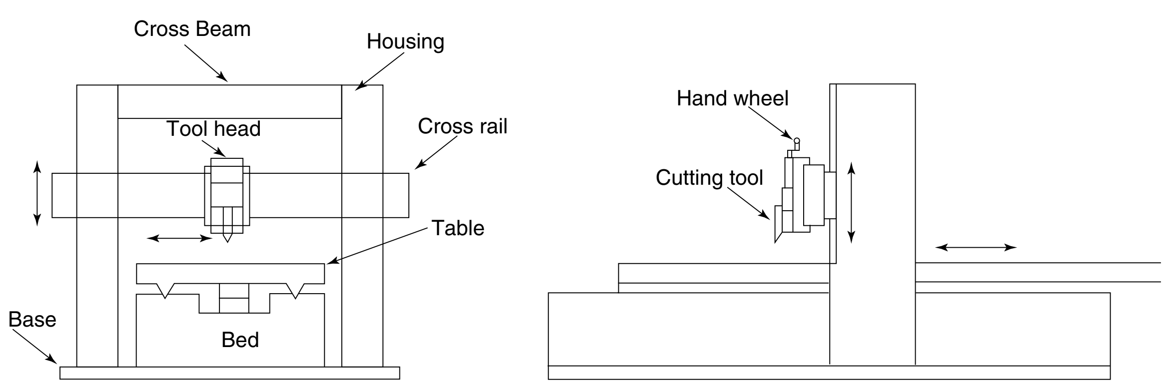



**Fig. 10 38** *Double Housing Machine*

The Cross rail is a rigid casting connecting the two housings. It is moved up and on the housing by manual, hydraulic or electrical clamping devices. Tool head is ded at the front face of the cross rail.

***Tool Head***

The Tool head is mounted on the cross rail by a saddle. Saddle is used to give cross feed. The swivel base is swiveled for machining angular surface. During the return stroke, tool head is lifted upwards to prevent the dragging of tool on the work.

**Differences between a Planing Machine and Shaping Machine.**

| Shaping Machine | Planing Machine |
|---|---|
| The tool moves and the work is stationary | The work moves and the tool is stationary. |
| Suitable only for small size machining | Suitable for large size. |
| Tools used are lighter and smaller | Larger, heavier and stronger |
| Only one cutting tool can be used | More tools can be used.av So, machining is faster |
| Cost of the machine is low | Cost is very high |

## Short-Answer Questions

1. Define metal removal processes.
2. List all the principal parts of a central lathe.
3. Why are planing machines used?
4. Briefly explain the main features of the head stock of a central lathe.
5. What are the main functions of the tail stock of a central lathe?
6. Give the important features of a lathe bed.
7. List down the various types of tool posts of a central lathe.
8. List down the various work holding devices used on a central lathe.
9. Define the following machining parameters with respect to a central lathe.
   (a) Cutting speed (b) Feed and
   (c) Depth of cut.
10. Give any five applications that can be done on a central lathe.
11. Define the following machining operations.
    (a) Turning, step turning (b) Taper turning
    (c) Drilling, boring (d) Counter boring
    (e) Facing, chamfering (f) Knurling, thread cutting
12. Name the various single point cutting tools used on a central lathe.
13. Briefly compare the multispindle drilling machine and gang drilling machine.
14. Give the principal parts of a standard drilling machine.
15. Define the following machining parameters with respect to a drilling machine.
    (a) Cutting speed (b) Feed and
    (c) Depth of cut.
16. What are the applications of a drilling machine?
17. Define the following machining operations.
    (a) Reaming (b) Counter sinking
    (c) Spot facing

18. Distinguish between the following
    (a) Drilling and reaming
    (b) Boring and counter boring
    (c) Counter sinking and spot facing
19. What is the main purpose for having flutes on a drill?
20. How to specify the following?
    (a) Central lathe (b) Drilling machines.
21. Define shaping.
22. Draw a simple sketch of a shaper head.
23. What are the common arrangements used for obtaining quick return in a shaper?
24. Name the various work holding methods in a shaping machine.
25. How do you specify a shaping machine?
26. Define the following in relation to a shaping machine
    (a) Cutting speed (b) Feed and
    (c) Depth of cut
27. Give some typical applications of a shaping machine.
28. With help of simple sketches give common tools used on shapers.
29. Define the process of milling.
30. Write short notes on specification of a milling machine.
31. Define
    (a) Cutting speed (b) Feed and
    (c) Depth of cut in relation to a milling machine
32. What are the main applications of milling machines?
33. What are the common attachments used on milling machines?

## Long-Answer Questions

1. Briefly explain the principle of operation of a lathe.
2. Give the various types of lathes.
3. Name the various components of a lathe carriage.
4. Explain the various methods used for taper turning on a central lathe.
5. Describe the various types of drilling machines.
6. Give the principal parts of a shaping machine.
7. What are the various types of shaping machines?
8. What are the general types of milling machines?
9. Give the principal parts of a column and knee type milling machine.
10. Describe the main parts of a planing machine.

# Chapter 11
# ENGINEERING MATERIALS

## 11.1 INTRODUCTION

The Period when the primitive man used stone and wood for his survival is known as the stone Age. The story of civilization is nothing but the development of newer materials and advances in the field of Material Science and Metallurgy. Materials have become the backbone of modern Civilization and industrial development.

### 11.1.1. Classification Of Engineering Materials

Engineering materials are normally classified into three main categories :-

1. Ferrous and Non-Ferrous metals and alloys.
2. Polymer Materials.
3. Glasses and Ceramics.

Metals are pure elements bonded by metallic bonding. Pure metals have very limited applications, due to their specific properties. Desirable and wide range of properties can be obtained by the addition of one or more elements to a pure metal. This process called alloying can be carried out by melting the pure metal and other element or elements together. The final product, known as alloy has properties quite different from those of the constitutional elements.

Natural and synthetic rubbers, leathers, plastics are some examples of Polymer materials. Polymer Technology has become separate field of study, in the U.G. and P.G. level.

Silica is the main constituent of glasses. Basic oxides like sodium oxide, Pottasium oxide, or Calcium oxide are added to silica to form glasses. Bricks, rocks, refractories, minerals and abrasives are some examples of ceramics. In this text book, further study is restricted to metals and alloys.

### 11.1.2 Properties

***Physical Properties***

1. Density (Mass per unit volume)
2. Melting point (Temperature at which it melts)
3. Specific Heat (Heat required for unit mass, to raise 1 degree)
4. Thermal conductivity (ability to conduct heat)
5. Thermal Expansion (expansion due to temperature raise)
6. Electrical conductivity (ability to conduct electricity)

***Mechanical Properties***

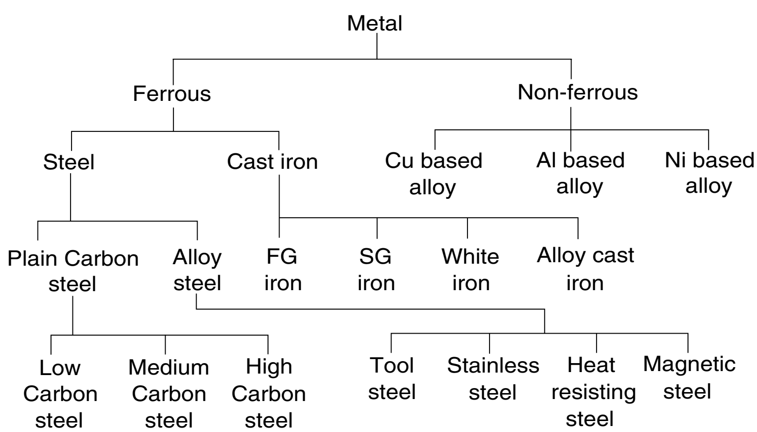
1. Tensile strength (Strength to withstand tensile force)
2. Compressive strength (Strength to withstand compressive force)
3. Torsional strength (Strength to withstand Twisting Force)
4. Hardness (Ability to withstand penetration by another body)
5. Brittleness (easily breakable quality)
6. Machineability (Easy removal of metal, in any machine tool)
7. Fatigue strength (Failure due to repeated action for a long period)

***Chemical Property***

1. Corrossion Resistances.

### 11.1.3 Classification Of Metals And Alloys :

Metals and alloys are having immense applications in construction works, electric Power generation and transmission, transportation, Vehicles, Agricultural Machines, Earth moving equipments, Machine tools etc. Metals are broadly classified as follows :




## 11.2 FERROUS METALS AND ALLOYS

Ferrous materials and their alloys provide a very wide spectrum of mechanical properties and they contain iron as a base constituent. This group starts from pig iron and ends with alloy steels.

### 11.2.1 Pig Iron

Today, the iron and steel industry is a heavy industry and pig iron forms the raw material that is obtained after a chemical reduction of iron ore in a blast furnace. This process is known as smelting, which uses iron ore, coke, limestone, air etc. as raw materials to produce pig iron.

Iron ores are basically carbonates, oxides and hydrates. Various metals along with a lot of ash are available in Bihar, Orissa, Madhya Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu and Goa.

The appropriate composition of the pig iron is 3.0-4.2% C, 0.5-1.0% Si, 0.1-0.5% Mn, 0.02-0.075% S and 0.20-0.30% P; balance Fe.

### 11.2.2 Cast Iron

Pig iron being weak and brittle cannot be used as such for any structural purpose. Cast iron is obtained by re-melting the pig iron with a definite amount of limestone, steel scrap and cast iron scrap in a cupola furnace. Cast iron is used in the industries because of its low cost, good casting characteristics, high compressive strength, wear resistance and good damping qualities. The principal types of cast iron are

1. F.G. iron (or) grey iron
2. S.G. iron (or) nodular iron (or) ductile iron
3. White iron
4. Alloy cast iron

***1. F.G. Iron*** The graphites are distributed like flakes and after fracture, the exposed graphite gives a dark grey appearance, hence called as flake graphite (F.G. iron) or grey iron respectively. In most of the castings, up to 0.8% C stays in the form of iron carbide ($Fe_3C$) and the remaining carbon exists in a the form of free carbon (graphite), which can be seen if filed on the surface.

It is brittle and it has higher compressive strength (600-750 N/mm$^2$); tensile strength (120-200 N/mm$^2$); hardness (150-250 BHN); melting temperature (1150°C-1200°C). It is used for manufacturing low grade automobile cylinders, machine castings and machine beds etc. Since, it has 2.50-3.75% C and graphite flakes scattered throughout the metal, it is more easily machinable than other types of cast irons. Because of the tiny flaky particles of graphite, cast iron needs little lubrication when being machined.

Grey cast iron can be welded with an oxy-acetylene torch or with an electric arc. Preheating is done to make expansion and contraction more uniform, in the case of oxy-acetylene welding. In the electric arc welding, short welds are preferable in order to keep the temperature low. Slow cooling is essential to permit the carbon to separate out in the form of graphite flakes. Welding of grey cast iron is limited to repair work rather than fabrication. However, brazing with Ni-Cu or bronze can be used for fabrication as well. Grey cast iron is conventionally not considered for forming or forging operations because of low ductility value (1%).

***2. S.G. iron*** Magnesium causes the flake graphite iron to take on a spherical or nodular shape, well dispersed which ultimately reduces the discontinuities in the surrounding structure. This process gives more strength and ductility. It has high strength (330 N/mm2), ductility (up to 14%), toughness and wear resistance of cast materials. It is used in the manufacture of machine castings undergoing bending and vibrations.

Products like hydraulic cylinders, valves, cylinder heads for compressors and diesel engines, rolls of rolling mills, light duty crank shafts etc. can be manufactured. Ductile iron has a high carbon content (3.2-4.2% C). Special care is needed for welding as in the case of grey cast iron. Castings of a thin section upto 1.5 mm and complicated shapes can be obtained.

***3. White iron*** It is often referred to as chilled cast iron. It has high tensile strength (400 N/mm$^2$). Compressive strength (690 N/mm$^2$) and hardness (400 BHN). It is brittle and used in manufacturing of plough spares, chilled rolls, dies, wearing plates, stamping shoes, balls, crusher Jaws, etc.

***4. Alloy Cast Iron*** Many foundries produce alloy cast iron in electric furnace where precise control of composition is possible and the alloying elements can be mixed uniformly. This is not possible in a cupola furnace. Cast iron is alloyed to increase its strength and to improve its corrosion resistance.

Ni up to five per cent is added to increase the hardness and strength without decreasing the machinability. It also promotes corrosion resistance and uniformity in properties throughout the casting thickness.

Cr up to three per cent has the opposite effect of Si and Ni. It promotes the formation of carbides and increases the corrosion resistance. So, a higher percentage of chromium hardens the iron by increasing the percentage of combined carbon ($Cr_2C$).

Mo up to 1.5 per cent is the most effective element to improve strength and wear resistance with a decrease in machinability.

V up to 0.5 per cent is a very powerful carbide former which increases hardness and strength considerably.

Ni-alloyed cast iron is used to manufacture cylinders, cylinder liners, pipes and parts of steam, hydraulic machinery, compressors and IC Engine.

### 11.2.3 Steel

In steel, apart from carbon, many other elements are present either as impurities or as alloying elements. According to IS-7598-1974, steel shall be classified into plain carbon steel and alloy steel.

### 11.2.4 Plain Carbon Steel

Carbon is the main constituent affecting the properties of plain carbon steels. The content of carbon decides the strength and hardness of steel. However, the increases in carbon content decreases the ductility, formability, machinability, weldability, thermal and electrical conductivity, and corrosion resistance. Plain carbon steels are classified according to carbon content as below:

| | | |
|---|---|---|
| 1. | Low carbon (or) Mild steel | 0.05 to 0.30% C |
| 2. | Medium carbon steel | 0.30 to 0.6% C |
| 3. | High carbon steel | 0.60 to 1.5% C |

The applications and their mechanical properties have been discussed here in brief.

***1. Mild Steel*** It is having 0.05-0.30 % C. Tensile strength varies from 400 to 550 MPa, ductility from 20 to 35 per cent, hardness from 120 to 150 BHN and it is a good machinable material. These are universally used as structural steels because of very good ductility and weldability. However, some steels having a uniform distribution of carbon can be used to manufacture gears, shafts, spindles, etc. by forging.

***2. Medium Carbon Steel*** It is having 0.30-0.60 % C, tensile strength 700-750 MPa, ductility about 20 per cent, hardness 150-350 BHN and it is machinable. These are used to manufacture connecting rods, shafts, axles, crank shafts, gears, die blocks, wheel drums, etc. and can be heat treated to suit the working conditions.

***3. High Carbon Steel*** It is having 0.60-1.5 per cent C. With a variation of carbon percentage, there is a tremendous change in mechanical properties and applications. It has tensile strength 1200-1400 MPa, hardness 350-500 BHN and ductility 10-12 per cent. As regards applications, steels having 0.6-0.8 per cent C are extensively used to manufacture loco wheels, rails, wire ropes, drop hammer, dies, screw drivers, saws, band saws, hammer, wrenches, laminated springs, etc.

Steels having 0.8-0.9 per cent C are used to manufacture cold chisels, shear blades, punches, rock drills, while 1.0-1.5 per cent C steel is useful for wire drawing dies, punches, pins, balls, etc.

### 11.2.5 Effect of Alloying Elements on Steels

Common alloying elements used in steels are Ni, Cr, Mo, V, W, Mn, Al, Cu, etc.

***Nickel (Ni)*** It increases the toughness, resistance to impact and corrosion, distortion and lowers distorition in quenching. Ni can impart the desired strength with a considerable low carbon content.

***Chromium (Cr)*** The addition of 'Cr' forms chromium carbide after combining with carbon and increases the resistance to abrasion, wear and corrosion. It also improves the hardenability. These steels are stable even at high temperatures.

***Molybdenum (Mo)*** It combines with carbon and increases the hardenability. 'Mo' alloy steels are used to manufacture high speed cutting tools, forged gears for heavy duty items, heavy duty crank shafts, turbine rotor, high pressure boiler, high quality tubing, etc.

***Vanadium (V)*** The addition of 'V provides a fine-grained structure over a wide range of temperatures. So, this steel is suitable to make gears, high temperature boiler plates, forged axles, shafts, etc. and items requiring high impact and fatigue resistance.

***Tungsten (W)*** Its addition increases hardness and heat resistance, and provides fine grained structure. At high temperatures, it forms tungsten carbides which are very hard and stable.

***Manganese (Mn)*** About 13% Mn hardens the steel. Such steels have long life (wear resistant). So, products like shovel teeth, crushing machinery parts, forged parts, etc. are made.

***Aluminum (Al)*** It is used as an deoxidiser having affinity for oxygen. It helps to refine grains.

***Copper (Cu)*** It is added in the range of 0.2-0.5 per cent as a strengthening agent. It improves the resistance to atmospheric corrosion.

### 11.2.6 Alloy Steels

An alloy steel is defined as one whose characteristic properties are due to some element other than carbon. Alloying elements are added to steels for many purposes as detailed below:

1. Increase hardenability
2. Improve strength at ordinary temperatures
3. Improve mechanical properties at either high or low temperatures
4. Improve toughness at any minimum hardness or strength
5. Increase wear resistance
6. Increase corrosion resistance
7. Improve magnetic properties

### 11.2.7 Tool Steels

Low alloy tool steels can retain hardness up to 600°C. These steels include cold worked tool steels, hot worked tool steels, etc. Low alloy tool steels contain Cr, Si, Mn, W as alloying elements and are able to retain hardness, wear resistance, etc.

High alloyed steels contain considerable quantities of W, V, Cr, (all carbide forming elements) and the presence of their carbides increases the ability of the steels to retain the hardness and cutting properties at elevated temperatures. High speed steel (HSS) is the biggest achievement in the field of tool steels. Some of the important compositions of HSS are:

***1. 18-4-1 HSS*** It is known as an all purpose tool steel containing 18% W, 4% Cr and 1% V with 0.8% C. It is extensively used in industries as a cutting tool material on lathe, shaper, drilling and milling machines.

***2. 'Mo' HSS*** It contains 6% Mo, 6% W, 4% Cr and 2% V. It has excellent toughness and cutting properties at higher temperatures.

### 11.2.8 Stainless Steel

These have high resistance to corrosion even in the abrasive media (air, water, vapour, sea water, solutions of acids and salts, etc.). 18-8 stainless steel (18% Cr, 8% Ni) is very common and is extensively used for storage of liquid helium, hydrogen, nitrogen and for cryogenic temperatures.

Commercially, these steels are classified into three broad categories.

1. Martensitic stainless steel
2. Ferritic stainless steel
3. Austenitic stainless steel

***1. Martensitic Stainless Steel*** Martensitic stainless steels are non-magnetic at room conditions. These steels are hardenable by heat treatment. Typical uses are pumpsets, valves, springs, cutlery, screws, nuts, bolts, etc.

***2. Ferritic Stainless Steel*** These steels are tough, magnetic and have good resistance to corrosion. They have good strength at elevated temperatures. Typical uses include the manufacture of dairy equipments, chemical industries, food processing and brewery industries, boiler tubing, heat exchanger, all types of surgical cutlery, household utensils, components of nuclear power production, etc.

***3. Austenitic Stainless Steel*** Owing to ductility, these steels are used for fabrication work. These steels are weldable, non-magnetic and good corrosion resistant. These steels cannot be hardened by heat treatment. These steels are used in aircraft, household items, pharmaceuticals, dairy, food processing and chemical industries.

### 11.2.9 Heat Resistant Steel

These steels retain their mechanical properties at high temperatures for long periods without the formation of a layer of scale on their surface, For example, heating elements for furnaces. Such characteristics are obtained through a proper selection of chemical composition and appropriate heat treatment. Such steels generally have Cr, Al, Si which increase the resistance of steel against oxidising gases at high temperatures.

Nichrome (23-27% Cr, 18-21% Ni, 2-3% Si) are used for the parts subjected to high temperatures and pressures. A complex grade of steel that is used to make steam and gas turbine valves has a composition of 13-15% Cr, 13-15% Ni, 2.0-2.5% W, 0.2-0.4% Mo and 0.4-0.5% C.

### 11.2.10 Magnetic Alloy Steel

These are classified into soft magnetic and permanent magnetic steels. Soft magnetic steels are used to produce pole cores, transformers, generators, motors, electromagnets, etc. These steels have a high magnetic permeability, so that high magnetic induction is produced in the core of an electromagnet by passing a weak current through the winding. The coersive force must be low. Most of the common alloys used in the form of thick sheets are low carbon steels and increased silicon content (3.5-4.5% Si) for transformers and 0.8-2.5 per cent Si for dynamos.

Permanent magnet steels are complex steels with Co, W, Ni, Cr, Cu, Al, etc. and are used to make permanent magnets which are used in many measuring instruments like ammeter, voltmeter, magnetos, etc. These steels must possess a high coersive force and a high residual induction. These steels are hardened at 1300°C and are slowly cooled in a strong magnetic field. This is followed by tempering operation at about 600°C.

## 11.3 NON FERROUS METALS AND ALLOYS

Non ferrous metals include those metals which do not contain iron as base. Though most of these metals possess a low strength at high temperatures, owing to the following desirable properties, these metals have got significant applications in industries.

1. Soft and ductile
2. Good formability
3. Good resistance to corrosion and
4. Easy to cast, weld, machine, etc.

The scope of this text is only to give a brief introduction about copper and its alloys.

### 11.3.1 Copper and its Alloys

Copper is extracted from its ore available in Bihar. It is a valuable metal and has wide applications in the field of engineering owing to its exceptionally high electrical and thermal conductivity, low oxidisability and good ductility. Copper is available in the purest form and can be casted, welded, rolled, drawn into wires and tubes, etc. Pure copper is used to make electrical wires, cables, bus bars, tubings, etc. An important use of copper is to produce various types of brass and bronze alloys.

***1. Brass*** These are principally alloys of copper and zinc. However, small amount of lead, tin or aluminium are added to obtain the desired colour, strength, ductility, machinability and corrosion resistance.

***2. Muntz-metal*** It contains 60% Cu, 40% Zn and a very small percentage of lead. It can be mechanically worked at about 700-750°C, but not at room temperature. It is used to make small components of a machine, electrical equipment, fuses, marine fittings, etc.

***3. Admiralty Brass*** It contains 70% Cu, 29% Zn and 1% Sn. It has high strength of 350-650 Mpa and high corrosion resistance. It is used to make condenser tubes exposed to salt water.

***4. Cartridge Brass*** It contains 70% Cu, 30% Zn. It is a general purpose brass and having high strength values. It is used to make cartridge cases, condenser tubes, fabrication sheet, etc.

***5. Bronzes*** These are alloys of copper, containing a number of elements, e.g.tin, aluminium, silicon, manganese, etc.

***6. Silicon Bronze*** It contains upto 4% Si and 1% Zn or Mn. It has strength as much as mild steel; good corrosion resistance to brine and other non oxidising inorganic acids. Wherever good corrosion resistance and high strength are required, the parts can be made out of bronze. It can be cast, rolled, forged, welded, used to make boiler parts, tanks, etc.

***7. Gun Metal*** It contains 88% Cu, 10% Sn and 2% Zn. It is a good casting alloy with enhanced properties of corrosion resistance. It is widely used for marine, chemical and steam fittings such as bushes, bearings, glands, etc.

***8. Bell Metal*** It contains 80% Cu and 20% Sn. It is suitable to the parts subjected to surface wear since it has high resistance to the surface wear. It is to make bells, utensils, etc.

## Short-Answer Questions

1. State the main reasons why pig iron cannot be used for industrial applications.
2. How can cast iron be further classified?
3. What is the percentage of carbon in mild steel?
4. What are the main reasons for extensive use of mild steel in industrial applications?
5. What is the percentage of carbon in high carbon steel?
6. What are the most common alloying elements in steel?
7. What are the main classifications of stainless steels?
8. List out some of the main parts made out of copper.
9. What are the percentage of Copper and Silicon in Pig Iron?
10. Why does cast iron need to be lubricated while being machined?
11. Why is alloyed cast iron not produced in a cupola furnace?
12. List the applications of Ni – alloyed cast iron and white iron.
13. Which of the plain carbon steels has greatest ductility and which has the greatest hardness?
14. What is the effect of adding chromium to steel?
15. Which element when added to steel makes it a deoxidizer?
16. Which type of steel is magnetic at room temperature and why?
17. Fill up the blanks with suitable words.
    (a) Tools are made from ____________ steel.
    (b) Pig iron is made in _______________ furnace.
    (c) The most desirable properties of copper are ____________and_______________.

## Long-Answer Questions

1. What are the applications of mild steel, medium carbon steel and high carbon steel.
2. Describe the two types of magnetic alloy steel.
3. Describe the major constituents of the different types of copper alloys.

# Chapter 12
# HEAT TREATMENT OF STEEL

## 12.1 INTRODUCTION

Most of the engineering properties of metals and alloys are related to their structure. In practice, change in mechanical properties can be achieved by a process known as heat treatment. Heat treatment is defined as the heating and cooling operation applied to metals and alloys in solid state in order to obtain the desired properties.

Heat treatment of metals is an important operation in the final fabrication process of many engineering components. The object of this process is to make the metal better suited, structurally and physically, for some specific application. Heat treatment is undertaken for the following purposes:

1. Improvement in ductility
2. Relieving internal stresses
3. Refinement of grain size
4. Increasing hardness or strength and achieving changes in chemical compositon of the metal surface. Other beneficial effects of heat treatment include improvement in machinability, alteration in magnetic properties, modification of electrical conductivity etc.

## 12.2 HEAT TREATMENT FURNACE

The success of heat treatment depends on proper choice of heat treating furnace. Heat treatment cycles are effective and result in reproducible properties only when other factors like rate of heating or cooling and uniformity of temperature are ensured according to the requirements. This makes the choice of furnace an important aspect in heat treatment practice. The following furnaces are normally used:

1. Muffle furnace
2. Conveyer furnace
3. Bath furnace using (a) salt bath (or) (b) lead bath
4. Induction heating furnace

***1. Muffle Furnace*** Muffle furnaces are charged and discharged through a front door opening and the bottom is exposed to hearth. The most important part of the muffle furnace is the muffle which is a hollow cuboid made of special refractory material. Electrically heated muffle furnaces are more popular and are extensively used for the heat treatment of small parts. Here, the muffle is surrounded by heating element such as nichrome and kanthal wire. Details are given in Fig. 12.1.

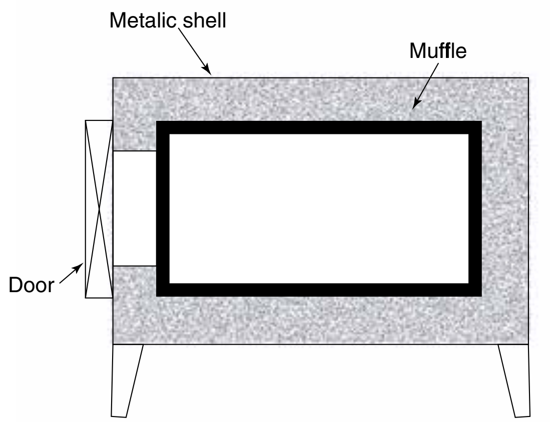



**Fig. 12.1** *Muffle furnace*

These furnaces are simple in construction and operation cost is low and has good thermal efficiency. It needs a low maintenance and is adaptable to a wide range of works.

***2. Conveyor Furnace*** As in Fig. 12.2, this furnace is provided with a conveyor mechanism to carry the parts automatically through the furnace.

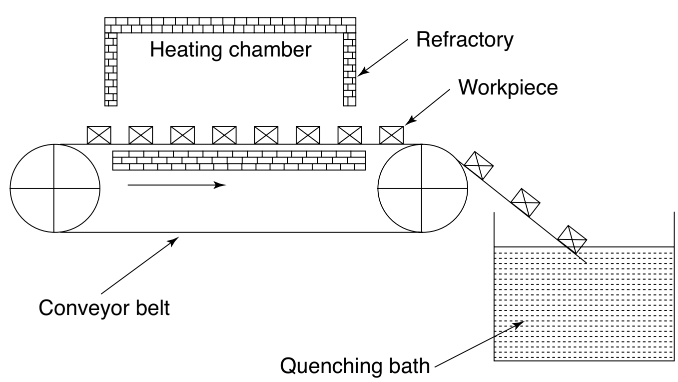



**Fig.12.2** *Conveyor furnace*

The speed of the conveying mechanism and closely controlled temperature zones of the furnace make possible any temperature timecycle. Such furnaces are suitable for on-line production, provide a greater uniformity and are adaptable to a wide range of products.

The conveyor furnace consists of an endless conveyor belt which moves at a very slow rate. The components to be heat treated are placed on the belt. The component on the belt enters the furnace from one end and comes out from the other. During this movement, the heating cycle is completed. Since the belt is moving continuously, components are either collected in a box or dropped into the quenching tank. These furnaces are generally used for hardening and tempering treatment.

***3. Salt Bath Furnaces*** As in Fig.12.3, salt bath furnaces consist of a container made of ceramic or metal. This container holds molten salt in which work pieces are immersed. This can be used for a wide range of temperatures (150-1300°C). The commonly used salts are nitrates, chlorides, carbonates, cyanides and caustic sada. As the molten baths possess high heat capacity and heat is transferred by convection, the workpiece is heated up very quickly as compared to conventional furnaces. Electrically heated salt bath furnaces are in common use. Salt bath furnaces are used for various heat treatment operations such as cyaniding, nitriding, hardening and tempering.

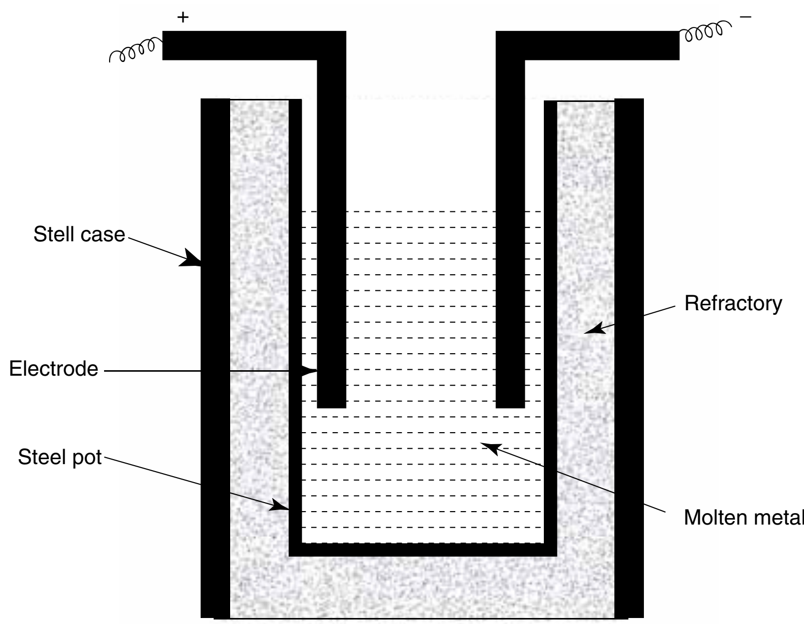



**Fig. 12.3** *Salt bath furnace*

***4. Induction Heating Furnace*** In an induction heating furnace, the metal is placed in the strong heating zone generated by an electromagnetic field. Low and high frequencies (60-10,000 cycles) are used for heating parts. The heat generated is entirely due to a magnetic flux created by an induction coil. The induction process can handle small lots of large scale repetitive production with good results.

## 12.3 HEAT TREATMENT PROCESSES

### 12.3.1 Classification

Heat treatment processes can be classified as

1. Annealing
   (a) Full annealing
   (b) Stress relief annealing
   (c) Process annealing
   (d) Spheroidise annealing

2. Normalising
3. Hardening
4. Tempering

### 12.3.2 Stages of Heat Treatment

(i) Heating a metal/alloy to definite temperature
(ii) Holding at that temperature for the required period to allow necessary changes in the structure,
(iii) Cooling at a rate necessary to obtain the desired properties.

***1. Annealing*** The term annealing, until and unless specified means full annealing. The heating temperature varies from 750-950°C, holding at this temperature followed by slow cooling. This process does not produce any new structure by phase transformation, but, produces new fine grains of the same structure. The various purposes of this treatment are to

(i) relieve internal stresses developed during solidification, machining, forging, rolling or welding
(ii) improve or restore ductility and toughness
(iii) enhance machinability
(iv) eliminate chemical non-uniformity
(v) refine grain size
(vi) reduce the gaseous contents in steel

***2. Normalising*** The objective of normalising is to secure grain refinement and obtain uniform conditions in materials mechanically treated in various ways as a result of which the grains might have become distorted. It will also relieve the internal stresses. Thus, the mechanical properties like machinability, weldability would be improved. This consists of

(i) heating temperature varying from 750-975°C
(ii) holding the workpiece for a short period and allowing it to air cool

Normalised steel has a higher yield point, tensile strength and impact strength than if they are annealed. But, ductility and machinability imparted by normalising will be slightly lower.

***3. Hardening*** The hardening process is applied to almost all the tools and important machine parts of various types of steel. It aims to develop high hardness, increased tensile strength, high wear resistance, etc. The hardening process is accomplished by heating to a temperature between 750 and 950°C, holding it for considerable time, then cooling at a fast rate by quenching in water or oil. In steels, hardening capability increases with the carbon or alloy content.

***4. Tempering*** The hardening treatment of steels imparts a fine grain size, maximum hardness, minimum ductility and severe internal strains. Being in an unstable condition, it is unsafe to use. So, to avoid or minimise problems of cracking and distortion, tempering always follows hardening. The tempering treatment relieves the strain, decreases brittleness and restores ductility and improves toughness.

The conventional method of tempering consists of reheating the hardened steel to a range of temperature which extends from room temperature to 400°C and holding it for a considerable time and then subjecting it to slow cooling.

### 12.3.3 Differences Between annealing and normalising

| Sl. No. | Annealing | Normalising |
|---|---|---|
| 1. | Heating temperature varies form 750-950°C | Varie form 750°C to 975°C |
| 2. | Held at that temperature for a longer period- 2 to 4 horse | Held for a shorter period |
| 3. | Very slow cooling within the furnace | Fast cooling by air, outside the furnace |
| 4. | Material becomes soft, because of slow cooling | Because of fast cooling, material becomes harder and stronger |
| 5. | Good improvement in machine-ability due to increased softness | Some improvement in machineability. |

## 12.4 CASE HARDENING

Numerous industrial applications require a hard wear-resistant surface called the case. There are five principal methods of case hardening.

1. Carburising
2. Nitriding
3. Cyaniding
4. Flame hardening
5. Induction hardening

The first three methods change the chemical composition. Carburising is addition of carbon, nitriding is addition of nitrogen and cyaniding is addition of both carbon and nitrogen. The last two methods are shallow hardening methods. In flame and induction hardening, the steel must be capable of being hardened. Therefore, the carbon content must be more than 0.3%.

***1. Carburising*** A low carbon steel (0.20% C) is placed in a Carbon monoxide atmosphere. The Carburising temperature is 920°C. At this temperature, the following reaction takes place

$$Fe + 2CO \rightarrow Fe(C) + CO_2$$

where Fe(C) represents carbon dissolved in high temperature phase.

Carburising can be divided into three categories according to the carbonaceous material used, pack carburising, liquid carburising and gas carburising. A detailed study of these processes are beyond the scope of this book.

***2. Nitriding*** This is a process for case hardening of alloy steel in an atmosphere consisting of a mixture in a suitable proportions of ammonia gas and dissociated ammonia at 500-570°C. It is extensively used for aircraft engine parts such as cams, cylinder liners, valve stems, shafts and piston rods.

***3. Cyaniding*** Cases that contain both carbon and nitrogen produced in liquid salt baths at 760-870°C is called cyaniding. This process is less time consuming. Because of the high heat transfer coefficient in liquid bath and uniform bath temperature, distortion of pieces is less.

***4. Flame Hardening*** Selected areas of the surface of a steel are heated from 750 to 950°C and then quenched to form hard structure. This process consists of moving an oxy-acetylene flame over a part, followed by spray quenching. The rate at which the flame is moved over the part will determine the depth to which the part is being heated. It is also a function of carbon present in the steel. Overheating of the workpiece should be avoided, otherwise there is the danger of cracking after quenching. Tempering is done at about 200°C for flame hardened surfaces.

***5. Induction Hardening*** Heat is quickly developed by high frequency eddy currents and hysteresis currents on the localised surface of layers. The primary current is carried by a cooled water tube and the workpiece serves as a secondary circuit. The depth of penetration decreases as the frequency of current increases. Crankshaft of a truck needs a few seconds of heating and spray quenching. Due to very short cycle time, very little or no distortion is obtained. Typical parts that have been induction hardened are piston rods, pump shafts, spur gears and cams.

## Short-Answer Questions

1. Define heat treatment.
2. What are the main objectives of heat treatment?
3. List out the important furnaces used for heat treatment.
4. Name the important heat treatment processes.
5. Indicate the main aims of the following:
   (a) Annealing (b) Normalising
   (b) Hardening (d) Tempering
6. What is the main purpose of case hardening process?
7. List out the principal methods of case hardening.
8. What is the significance of the furnace in heat treatment?
9. Give a brief description of the induction heating furnace.
10. List the different stages of heat treatment.
11. Briefly describe the conventional method of tempering.
12. Which of the case hardening methods affects the chemical composition of steel?
13. Which of the hardening methods require the carbon content to be more than 0.3%?
14. What is the reaction that takes place in carburizing and at what temperature?
15. List the three types of carburizing?
16. What is cyaniding?
16. What is cyaniding?

## Long-Answer Questions

1. Describe the following with diagrams
   (a) Muffle furnace (b) Conveyor furnace
   (c) Salt bath furnace
2. Explain nitriding with its applications
3. What is flame hardening? Why is tempering done on a flame hardened surface?
4. Explain the method of hardening parts such as piston rods, pump shafts, spur gears and cams

# Chapter 13

# INTRODUCTION TO CAD, CAM, CIM, FMS AND MEMS

## 13.1 INTRODUCTION

Computers are electronic devices which are used to perform arithmetic and logic operations at a very high speed. The application of computers in different fields is successful and economically justified. The adoption of computer technology is extended to design, drafting, manufacturing, shop floor control, process planning, inspection, etc. The application of computers in design process is termed as Computer Aided Design (CAD). The implementation of computer technology in controlling the machine tools is termed as Computer Aided Manufacturing (CAM). An approach which uses computers in all the activities of an enterprise from design of a product until its delivery, including the business functions like sales, finance and accounting, is termed as Computer Integrated Manufacturing (CIM).

## 13.2 COMPUTER AIDED DESIGN

Through Computer Aided Design, the ideas of a designer can be represented as mathematical and graphical models in a computer. Further, it involves the use of a computer to develop, analyse or modify an engineering design. The design process is an iterative procedure which involves the following four steps.

1. Geometric modelling
2. Engineering analysis
3. Design review and evaluation
4. Automated drafting

***Geometric Modelling*** The mathematical description of the geometry of any object which is compatible to a computer is called Geometric Modelling.

The designer creates the geometrical image of the object on the screen of the computer by using an Interactive Computer Graphics System. The various methods of representing the 3D image of the object on the computer screen are wire frame modelling, surface modelling and solid modelling.

***Engineering Analysis*** Most of the engineering analysis problems are concerned with stress-strain calculations, heat transfer computations, analysis of mass properties, etc. All the analysis and calculations can be done from the graphical image created by geometric modelling through a technique called Finite Element Method. The result and output from the Finite Element Method can also be visualised on the monitor of the computer.

***Design Review and Evaluation*** On the computer terminal itself, we can check the accuracy of the design and a new design can be easily created with the proper modifications. Layering and interference checking are the two procedures used to review the design. Layering involves the overlaying of different graphic images and interference checking involves the assembly of various components to form a structure. By using these two procedures, the errors can be detected and the design of the components can be changed easily.

***Automated Drafting*** The hard copy of the engineering drawings can be drawn easily from the data which are available in the CAD database generated from the previous steps. By using the drafting packages, the time taken for the drawing can be reduced considerably compared to manual drafting.

## 13.3 ADVANTAGES OF CAD

1. New and better quality designs can be created faster.
2. New designs created on CAD systems are more economical.
3. Detail drafting, assembly drawing, etc. can be automatically generated by a program.

## 13.4 COMPUTER AIDED MANUFACTURING (CAM)

Through Computer Aided Manufacturing, machine tools like lathe, milling machine, drilling machine, etc. can be used to produce accurate components by controlling the cutting speed, depth of cut and feed through computer technology. The implementation of computers in manufacturing can be achieved through numerical control. Numerical control is a set of programmable automation which is controlled by a set of numbers, letters and symbols. Here, each number or letter represents a predefined set of instructions designed for a particular work or job. The third generation of numerical control is achieved by the built- in integrated chips which leads to the Computer Numerical Control (CNC). Following are the main components of CNC.

1. Program, which is a set of instructions
2. Controller unit
3. Machine tool

The program consists of detailed step by step directions which instruct the machine tool on what must be done. The instructions are represented by codes which consist of numbers, letters and symbols that, instead of which are given in a sequence.

The controller unit consists of electronics hardware which reads and interprets the program instructions and converts them into mechanical movements of various machine tools.

The machine tool performs the actual and useful work and produces the components with higher accuracy and speed and increases the productivity.

The various basic components of CNC machine tools are given in Fig. 13.4.

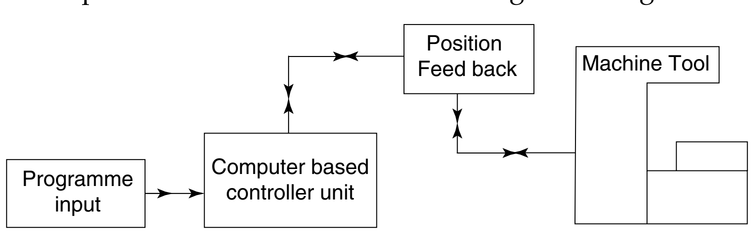



**Fig. 13.4** *Basic components of CNC*

### 13.4.1. Numerical Control (NC) Machine

Numerical control is the programmable automation where the operation in controlled by numbers, letters and symbals. Figure 13.5 shows the working principle of an NC machine.

The programmer studies the drawing of the component to be made. All the instructions necessary to machine the component is translated into a form acceptable to the control unit. Instructions are punched on a magnetic tape. The tape is fed into the control unit which will send suitable commands to the machine tool. In case, there is any error, the control unit can rectify, by the feedback system.

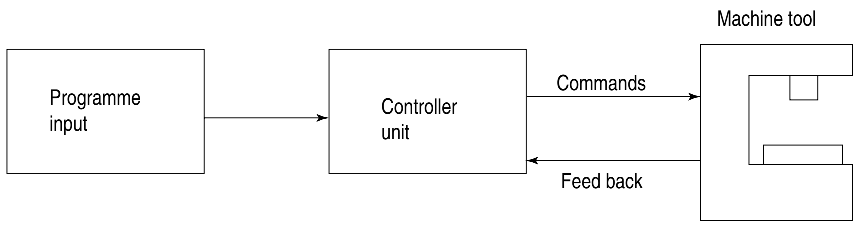



**Fig. 13.5** *Basic components of NC Machine*

### 13.4.2. Computer Numerical control (CNC) Machine.

An NC machine with one or more micro computers used to perform some or all the basic control functions is termed as a CNC machine. This can also be referred to as CAM.

### 13.4.3 Advantages of CNC Machines

1. Production is highly economical
2. Mass production is possible at reduced labour
3. As the control is by computer, measurements will be very accurate, in the finished products.
4. Modifying the original programme, revised control can be introduced in the computer easily and so there is more flexibility.
5. A CNC machine is highly reliable in every aspect.
6. Metric conversion is possible from inch, feet etc.

## 13.5 FUNCTIONS OF A ROBOT IN MANUFACTURING APPLICATIONS

A robot is an automatic mechanism made up of mechanical components, a control system and a computer. A robot can be programmed in different ways to perform different tasks. The ability of a robot is determined by the degree of freedom. A robot control system does a number of tasks at high speed. The control system can either be mechanical, hydraulic, pneumatic, electrical or electronic.

***Advantages Of Robots***

1. Robots can be made to work with more efficiency and accuracy than human beings.
2. They can do repetitive jobs better and faster.
3. They can perform better in difficult and hazardous situations like in the presence of extreme temperatures, radiations, chemicals, etc.
4. They do not suffer from human limitations like fatigue, need for rest, diversion of attention, absenteeism, etc.

*Note* However, they are not always the best choice. They cannot match the combination of mental and physical skills of human beings.

## 13.6 COMPUTER INTEGRATED MANUFACTURING (CIM)

The complete automation of all the processes and activities from the design of a product to its delivery under computer control is termed as Computer Integrated Manufacturing (CIM). CIM uses common database and communication technologies to integrate the design, manufacturing and business functions like marketing, finance, accounting, etc.

CIM incorporates many individual CAD/CAM systems which include the following.

1. Manufacturing equipments like CNC machine tools
2. CAD workstations
3. Work handling and tool handling devices
4. Shop floor data collection devices
5. Industrial robotics
6. Automated inspection system and many more.

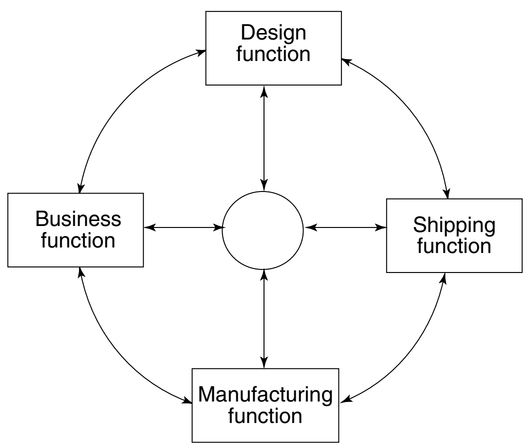



**Fig. 13.6** *Basic elements of CIM*

The major components of CIM are given in Fig. 13.6.

A detailed study of the various components of CIM is beyond the scope of this book.

## 13.7 FLEXIBLE MANUFACTURING SYSTEM (FMS)

### *Introduction*

The flexible manufacturing system consists of group of CNC Machines, interconnected by means of an automatic material handling and storage system and controlled by an integrated computer system, to produce variety of parts of high quality at reduced cost and time.

### *FMS requirements*

The FMS requirements are given below :

1. Manufacturing system or Machine Tools.
2. Tool handling and storage.
3. Material handling and storage.
4. Computer control
5. Human resources

***Manufacturing system***

The machining system consists of a set of CNC machines. FMS also includes assembly stations, Sheet metal presses, inspection stations etc., The machining system is capable of performing several of the operation on the work piece automatically.

***Tool Handling and storage***

In F.M.S, various cutting tools are loaded onto the machines at intervals. The cutting tools are stored in auxiliary tool storage from where the required tools can be transferred to the main tool magazine.

***Material handling and storage***

This system facilitates the timely supply of unmachined work pieces from the storage to the machining centres and transport of the machined parts to the desired locations.

***Computer control***

A computer is used to control the operation of FMS. The functions performed by the computer include the control of workstations, control of tools, production control, system performance and monitoring.

***Human Resources***

Functions typically performed by human labour included (i) loading raw work parts into the system. (2) Unloading finished parts (3) Changing and setting tools. (4) Performing equipment maintence and repair. (5) Reforming N.C. Part programming. (6) Programming and operation of the computer system.

***Benefits of FMS***

1. Better and quality finish for the final product.
2. Greater responsiveness to change of design, introduction of new parts etc
3. Opportunity for unattended production.
4. Higher labour productivity
5. Reduction in time for the manufacture
6. Higher machine utilisation.

## 13.8 MICRO ELECTRO MECHANICAL SYSTEMS (MEMS)

***INTRODUCTION***

We are already familiar with mechantronics which is an integration of mechanical Engineering with electronics, for the design and manufacture of products. Through it is relatively a new discipline, it has established itself. It primarily considers control solutions of macro scale machine systems. In India, mechantronics has been introduced as degree course in many Engineering Colleges.

MEMS are integrated devices which combine electrical, electronics and mechanical components, as shown in Fig. 13.7.

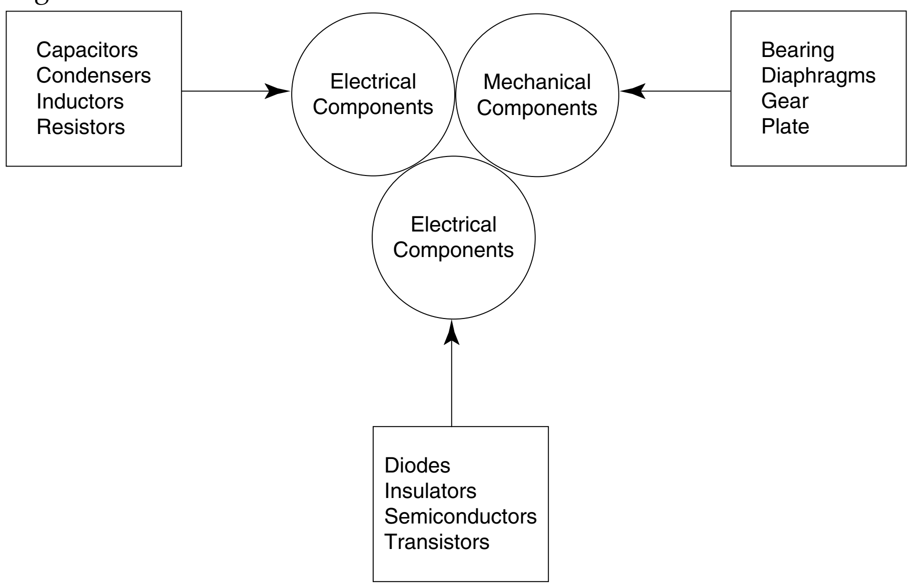



**Fig. 13.7** *COMPONENTS OF MEMS*

MEMS is a technology which is used for manufacturing microscopic transducers, probes, capacitors, inductors, actuators, switches, valves, gears etc. Ideally, MEMS combines Physics, microelectronics, micromechonics, material science and computer Aided Design (CAD) Technology. The Subject MEMS is slowly being introduced for the engineering students in the undergraduate and postgraduate levels, all over the world.

### *COMPARISON OF MEMS WITH INTEGRATED CIRCUIT (I.C.)*

MEMS design technology is an extended form of integrated circuit (I.C). Unlike the IC technology, MEMS technology can fabricate capacitors and Inductors as well as mechanical elements such as springs, gears and diaphragms. MEMS, therefore is an advanced technology, as for as micro manufacturing of Microsystems are concerned.

### *APPLICATION*

MEMS devices have already found significant applications is many sectors. They are used for controlling micromanipulator, micro handling equipments, micro grippers and micro robots. Many MEMS devices are found in clock, ink jet printer head, colour projection & display system and scanning problem equipments. MEMS technology also designs many types of sensors including pressure, temperature electrical and vibration sensors. Broadly, the application sectors are:

#### *Defense and space application*

1. Automobile & Air Craft industries
2. Clinical & Pharmaceutical industries
3. Automation industries
4. Manufacturing sector
5. Communication etc.

### *CLASSIFICATION OF MEMS*

1. Mechanical MEMS
2. Thermal MEMS
3. Magnetic MEMS
4. Micro fluidics and Bio MEMS.

### *MECHANICAL MEMS*

Mechanical MEMS deals with the following two types of devices :

1. Mechanical structure based device.
2. Piezoelectric material based device.

When the geometric structural configurations are exploited for sensing and actuating purpose, then MEMS design can be classified under the first category. As piezoelectricity concerns with mechanical properties like stress & Strain, piezoelectric material based MEMS are classified as mechanical MEMS.

### *FUTURE MEMS*

Mechatronics dealing with macro products, MEMS dealing with micro products and nanotechnology dealing with nano products can be expected to rule the entire world in the future and let us look forward for the same.

## Short-Answer Questions

1. Describe the CAD design process.
2. What are the various methods of representing the 3D image of an object on a computer?
3. What is the Finite Element Method?
4. What are the procedures to check the error in design?
5. What is layering?
6. What are the functions of a Robot?
7. What are the basic components of an NC machine?
8. Give a block diagrammatic representation of a CNC machine?
9. How are groups of CNC machines interconnected in a flexible manufacturing system?
10. List the benefits of FMS.
11. What are the advantages of a CNC machine?
12. Give a block diagrammatic representation of the components of MEMS?
13. How does MEMS compare against the Integrated Circuit (IC) ?

## Long-Answer Questions

1. Explain automated drafting?
2. What is CNC? Explain the main components of CNC with a block diagram.
3. Explain the FMS requirements.
4. Explain the applications and classifications of MEMS devices.

## Appendix
# GLIMPSE OF NANOTECHNOLOGY

## 1. INTRODUCTION TO NANO SCIENCE

Many are familiar with meter, centimeter and millimeter. But, everybody may not be familiar with nanometer which is one billionth of a meter ($10^{-9}$m). The nano particle is very small is size which can be observed using any type of electron microscope. An electron microscope contains an illumination source, a condenser lens to magnify the image and a projector lens to project the image.

## 2. NANOSCALE MANUFACTURING

The difficulty is the lack of suitable technologies for the mass manufacture of nanostructures and nanomaterials, at reduced cost. Research in manufacturing is focused in optical based system. Nano scientists are busy in research in the following areas :

1. Molecular motors and machines
2. Single molecular switch
3. Nano Lubrication
4. Improved solar cells with several thin layers.
5. Nano Fertilizer
6. Improvement in paint industry. Cars can be coated with a diamond strength layer that will guard against scratches.

## 3. APPLICATION OF NANOTECHNOLOGY IN OTHER FIELDS

The concept of effective use of nanotechnology in the treatment of disease was suggested as early as 1959 by the Nobel Laureate Richard Feynman. With the present day medicine, there are many undesirable "After effects" which will not be there with nano medicines. In Telesurgery, by using a nanorobot, a surgeon can perform the surgery on a patient, several Km away.

## 4. FUTURE PROSPECTS

During the next 100 years, we can expect a bright new future by harnessing all the good aspects of nanotechnology, for application in many useful areas like Medicine, Surgery, Agriculture, Textiles, and all fields of Engineering including Mechanical and Production.

# INDEX

**D**



**E**