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ELEMENTS OF MECHANICAL ENGINEERING

H.G. Patil • B.Y. Patil

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Elements of
Mechanical Engineering

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Foreword

It gives an immense pleasure to pen the foreward to "Elements of Mechanical Engineering" by Prof. H.G. Patil and Prof. B.Y. Patil. This book by the team of experienced teachers introduces the fundamentals of mechanical engineering to the first year students of all branches of engineering. It is an outcome of a long association in teaching by both the authors. Prof. H.G. Patil has been in the field of engineering education for the past 45 years. Prof. B.Y. Patil has 27 years of teaching behind him.

The book contains nine chapters. Chapter I, II, III, IV and IX introduce the thermal engineering fundamental concepts and applications. Chapter V and VIII encompass the principles of manufacturing engineering. Chapter VI and VII cover automation and material science. The concepts are introduced in lucid terms with numerical examples. The line diagrams help in visualisation.

The book is a good addition to the literature in Basic Mechanical Engineering. I salute Prof. H.G. Patil, my teacher during graduation for his endeavour and congratulate Prof. B.Y. Patil a colleague of mine over 24 years.

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Preface

Elements of Mechanical Engineering is intended to introduce the fundamentals of mechanical engineering to the first year students of all branches of engineering. This book is designed to cover the syllabus of Elements of Mechanical Engineering prescribed by the Visvesvaraya Technological University. It covers the topics in the area of thermal engineering, manufacturing engineering, automation and material science.

The book contains nine chapters. Chapter I covers various energy sources. Chapter II encompasses steam generation and its properties. Chapter III and IV explain the prime movers for energy conversion. The application of thermodynamics to refrigeration and air conditioning are dealt with in chapter IX. Principles of manufacturing engineering are introduced in Chapter V and VIII. Chapter V describes the constructional features and operations of machine tools. Chapter VIII explains the fabrication processes like welding, soldering, and brazing. Chapter VI introduces automation and robotics. The concepts in material science are coverd in chapter VII.

The fundamental principles are introduced in lucid terms. The line diagrams illustrate and help in visualisation. Solved examples illustrate the concepts numerically and help in better understanding. The questions at the end of the chapter serve to revise the subject matter covered in the chapter.

We gratefully acknowledge the active involvement of Dr. S. C. Pilli in preparation of manuscript of Chapter VI: Automation and Robotics.

We thank Prof. Ugran of KLE Society's Dr. M.S. Sheshgiri College of Engg. and Tech., Belgavi for his suggestions.

H. G. Patil
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Contents

CHAPTER 1

Energy Resources

Energy means capacity to do work. Energy is available in various forms in the nature. The body in motion possesses kinetic energy, a body in elevated position has potential energy, the chemical bonds between the molecules have chemical energy, which is released as heat during combustion (chemical reaction) and interatomic bonds have nuclear energy. Generally, forms of energy are mechanical, thermal, chemical, electrical, atomic and radiation. The basic source of energy is the sun. Solar radiations are absorbed by plants by the process of photosynthesis and stored as chemical energy. The living beings survive by utilizing this energy.

1.1 CLASSIFICATION OF ENERGY RESOURCES

Energy available in the nature is classified into two categories, namely:

(a) Non-renewable energy, and

(b) Renewable energy.

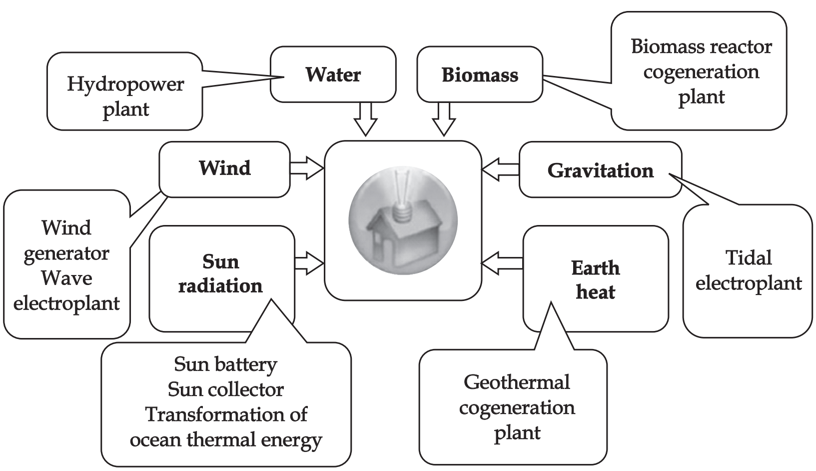


Fig. 1.1 Renewable energy resources.

Non–renewable energy is the chemical energy in fossil deposits deep in the earth, They are available in the form of oils, natural gas and coal. They are the result of the chemical degradation over a long period of time. These sources cannot be replenished. Similarly, nuclear energy released by fission or fusion cannot be restored. Hence, they are called non-renewable energy sources.

The sources of energy are continuously replenished by nature are sun energy, hydro energy, wind enegy, geothermal energy, tidal energy and biomass energy are called renewable energies.

1.2 COMPARISON OF THE NON-RENEWABLE AND RENEWABLE SOURCES

Table 1.1

Non-renewable sources	*Renewable sources*
1. These source cannot be regenerated	These sources can be renewed within a short period
2. The sources are exhaustible	These can be continuously replenished
3. High energy density	Low energy density
4. Continuous supply and highly reliable	Fluctuating and less reliable
5. They are not site specific	They are available in certain areas only
6. Generation can be matched to demand	Matching to demand is difficult to achieve
7. Initial and maintenance costs are high	High initial cost but low maintenance cost
8. Hazardous to environment	Non-pollutant to environment

These resources can also be classified as (a) conventional and (b) non-conventional resources.

Conventional sources are fossil fuels like coal, petroleum oils, natural gas, hydel power and nuclear power. Technologies for harvesting these resources are well established. The cost of production is comparatively low.

Non-conventional resources are solar energy, wind energy, tidal energy, ocean energy, bio–energy. They are available in abundance in nature and have been in use in small quantities for over a long period. They are inexhaustible, because they are renewable.

1.3 CONVENTIONAL RESOURCES

1.3.1 Fuels

Fuel is defined as a substance, which when burnt in the presence of air or oxygen, produces heat energy. Chemical energy of fuel is converted into heat energy, during combustion of fuel. For combustion, fuel contains combustible elements like Carbon C, Hydrogen H, and Sulphur S.

1.3.2 Classification of Fuels

Fuels are broadly classified

(i) According to the physical state in which they exist in nature—solid, liquid and gaseous.

(ii) According to mode of availability—natural fuels and manufactured fuels.

Table 1.2 Natural fuel and manufactured fuel

Type of fuels	*Natural fuels*	*Manufactured fuels*
1. Solid fuel	Wood, coal	Charcoal, coke, bagasse, briquettes.
2. Liquid fuel	Petroleum	Petrol, diesel, coal tar, vegetable oil, alcohols
3. Gaseous fuel	Natural gas	Producer gas, coal gas, blast furnace gas, hydrogen, acetylene sewage gas

1.3.3 Solid Fuels

1. **Wood:** It is a vegetable tissue of trees and plants. It consists of cellular tissues and lignin and small percentage of sugar, water, fat and tar. Composition of wood has the following elements.

   C = 50%, H = 6.00%, O = 43%, N = 0.35%, Ash = 0.65%.

2. **Coal:** Coal is solid fuel which is obtained naturally from coal mines. It is a vegetable origin, and is largely available in Madhya Pradesh, West Bengal and Bihar coal mines.

   Coal in refined form is used by railways, steel industry and thermal power plants.

   Coal is classified into three major types:

   1. Anthracite coal—semi-anthracite
   2. Bituminous coal—semi-bituminous, sub-bituminous
   3. Lignite coal

   Anthracite is the oldest coal from geological perspective and composed of mainly carbon with little volatile content and practically no moisture.

   Lignite is considered youngest coal from geological perspective and contains mainly volatile matter and moisture content with low fixed carbon.

3. **Manufactured solid fuels and their characteristics**

   (a) **Charcoal:** It is a product obtained by destructive distillation of wood, in the form of solid residue. Charcoal burns with a clear, bright flame, producing no smoke and the heat energy is 6050 cal/kg.

   (b) **Coke:** Coke is of two types:

   (i) **Soft coke** is obtained as solid residue from the destructive distillation of coal in the temperature range of 600–700°C. It contains 5-10% of volatile matter and burns without smoke. Used commonly for domestic applications.

(ii) **Hard coke** is also obtained by destructive distillation at 1200°C. This burns with smoke and is used for foundry castings.

(c) **Briquettes** are obtained by compressing the waste remains of coal, coke, lignite along with (5-8%) binders like asphalt, pitch, etc. They are obtained as solid cakes of different shapes after preheating and pressing. Hence, briquetting industry improves fuel economy.

(d) **Bagasse** is residue of sugarcane, which is fibrous and is mostly used in sugar industry. It has heating value/calorific value of 2200 cal/kg and is used as a quick burning fuel with good efficiency.

Advantages & disadvantages of solid fuels

Advantages

1. Easy to transport
2. Easy to handle, and store without any risk of spontaneous explosion.
3. Cost of production is low.
4. Solid fuels have moderate ignition temperature

Disadvantages

1. Ash content is very high
2. Heat energy liberated per unit mass is less.
3. It burns with clinker formation.
4. Cost of combustion and handling is high.

1.3.4 Liquid Fuels

They are classified into two groups:

(a) Natural or crude oil, i.e., petroleum

(b) Manufactured oil or derived oils, i.e., petrol, kerosene, diesel, etc.

Natural Fuels

Petroleum: [C = 80 to 85%, H = 12–15%, S = 0.1% to 3%, N = 0.3%, O = 0.3%]

It is naturally found in the earth's crust, deep in the oil wells. It is a dark greenish-brown, viscous oil. It is composed of many hydrocarbons, and classified into the following.

(i) Paraffins ($C_n H_{2n+2}$) eg. CH_4, saturated hydrocarbons

(ii) Olefins ($C_n H_{2n}$)

(iii) Naphthenes ($C_n H_{3n}$)

(iv) Aromatics ($C_n H_{4n-2}$)

Manufactured Liquid Fuels

These are commonly obtained by fractional distillation of crude petroleum (liquefaction of coal).

(i) **Petrol (Gasoline):** It is obtained by distillation of crude petroleum at 80°C to 120°C temperature. It contains unsaturated straight chain hydrocarbons and sulphur compounds. Tetraethyl lead is added to gasoline for better ignition properties. Sulphur compounds from gasoline are removed by treating with an alkaline (sodium plumbite) solution.

It is commonly used as aircraft fuel and also for spark ignition in internal combustion engines. It is used for dry–cleaning and also as a solvent.

(ii) **Diesel fuel:** It is obtained by fractional distillation of crude petroleum at temperature in the range of 250°C to 320°C. This oil contains 85% C and 12% H. Its heating or calorific value is 11,000 Kcal/kg.

Diesel oils have longer hydrocarbon, with straight chain and suitability is determined by Cetane number. They are commonly ignited by compression temperature and used in compression ignition engines.

(iii) **Kerosene oil:** During fractional distillation of crude petroleum, kerosene oil is obtained between 180°C and 250°C. It is commonly used for lighting lamps, stoves, etc. It is also used as fuel for jet engines, tractors. It burns with smokeless flame in excess of air.

(iv) **Heavy oil (wax, grease):** By fractional distillation of crude petroleum, at temperature range 320°C to 400°C, heavy oil is obtained. It is used for lubrication in engines, as petroleum jelly (Vaseline) in medicine.

Grease and paraffin wax are used as lubricant and in wax paper, candles, etc.

Properties of Liquid Fuels

(i) **Density or Specific Density:** It is defined as the ratio of the mass of liquid fuel to the volume of the fuel at standard temperature (NTP). Units of density are in kg/m^3.

(ii) **Specific Gravity:** It is defined as the ratio of specific density of the fuel to specific density of the standard liquid, i.e., water, specific density of water at NTP is 1000 kg/m^3 and specific gravity of water is 1.

(iii) **Viscosity:** Viscosity is an important property of liquid and it gives a measure of its internal resistance to flow. Viscosity of a liquid depends on temperature and it decreases with rise in temperature, and flows easily.

Dynamic viscosity is measured in Pascal seconds and kinematic viscocity is measured in stokes or centi stokes.

Say Bolt, Redwood and Engler viscometers are used for measuring viscosity of a given liquid at a particular temperature.

(iv) **Flash Point:** It is defined as the lowest temperature at which liquid fuel vapours give off fire momentarily when an open flame is passed over the surface of the liquid.

(v) **Fire Point:** It is defined as that temperature at which vapours of liquid fuel provide a continuous fire, when an open flame is passed over the surface of liquid.

(vi) **Pour Point:** The pour point of a liquid fuel is defined as the lowest temperature at which it will easily flow or pour. This also gives indication of the lowest temperature at which the liquid can be pumped.

(vii) **Specific Heat:** It is defined as the amount of heat energy needed to raise the temperature of 1 kg of liquid by 1°C. The units of specific heat is kJ/kg°C.

Advantages and disadvantages of liquid fuels over solid fuels

Advantages

1. Liquid fuels have higher calorific value.
2. They burn without ash, dust or clinkers.
3. Easy to start, stop and control combustion of fuel.
4. Easy to store, transport in pipes without any loss.
5. Maintenance required is less, no wear and tear of grate.
6. Air required is less for complete combustion.
7. Less furnace space required for combustion.

Disadvantages

1. Cost of liquid fuel is relatively higher than the solid fuels.
2. Storage tanks increase the cost of storage.
3. There may be risk of fire hazards, because they are highly inflammable and volatile.
4. Some liquid fuels have bad odour.
5. Specially designed burners and spraying apparatus are required for complete and efficient burning.

1.3.5 Gaseous Fuel

This fuel is commonly used in highly dense populated area, continuously used in large scale industries, individual gas containers where distribution is through pipeline network and it is maintenance-free burner system.

Types of Gaseous Fuels

1. Natural gases found in nature.
   (i) Natural gas from oil wells.
   (ii) Methane from coal mines.
2. Manufactured gases.
   (i) Blast furnace gas
   (ii) Gases from waste and biomass.
   (iii) Liquefied petroleum gas (LPG)
   (iv) Refinery gases.
   (v) Fermentation gases.
   (vi) Producer gas, coke oven gas

Commonly Used Gaseous Fuels

1. **Natural gas:** It is available in nature and its major composition is 95% methane (CH_4) by volume and ethane, propane, butane, nitrogen, carbon dioxide and traces of other gases. Natural gas generally has same properties of methane, as it is 95%. It has high calorific value (12000 kJ/m^3), mixes with air easily, lighter than air and requires no storage facility. It disperses into air easily in case of leakage. Commonly used for domestic heating.
2. **Liquefied petroleum gas (LPG):** Main composition of LPG is mixture of propane and butane with small percentages of propylene and butylene, LPG includes propane (C_3H_8), propylene (C_3H_6), iso-butane C_4H_{10} and butylene (C_4H_8).

   LPG is also defined as a gaseous mixture of hydrocarbons at NTP, but is condensed to a liquid state at normal temperature, by increasing pressure. LPG is stored and transported as liquid under pressure, for easy transportation and handling. When LPG evaporates, it produces 250 times the volume of gas.

   LPG vapours are denser than air (nearly twice). Small quantity of LPG leakage will form large volume of vapours. Hence, LPG should be stored with good ventilation where air can easily flow.
3. **Coal gas:** Coal gas is obtained by burning or carbonizing coal in the absence of air at 1300°C.

   $$C + \frac{1}{2} O_2 \rightarrow CO + 29.5 \text{ kJ}$$

   Coal gas is a colourless gas, with typical odour. It is lighter than air, burns with long smoky flame. Composition of coal gas is CH_4 = 32%, H_2 = 47% CO = 7% and C_2H_4, C_2H_2, N_2, CO_2, etc.

   Calorific value is 4900 kJ/m^3. It is used as a fuel and for metallurgical operations in foundry.
4. **Blast furnace gas:** (25% CO, others CO_2 N_2)

   This gas is produced during reduction of iron ore by coke in the blast furnance. It has calorifc value of 1000 kJ/m^3. It is used for preheating of air and also preheating of furnace.
5. **Water gas:** Composition H_2 = 51%, CO = 41%, N_2 = 4%. Its calorific value is around 2800 kJ/m^3.

   Water gas is a mixture of combustible gases CO, carbon monoxide and hydrogen. It is obtained by passing steam and air alternatively through a bed of red hot coke at 1000°C in a steel vessel reactor.

   The reactions are

   $$C + H_2O_{(steam)} \rightarrow CO + H_2 - 29 \text{ kJ}$$
   $$C + O_{2(air)} \rightarrow CO_2 + 97 \text{ kJ}$$

   It is used as an illuminating gas and also as a fuel gas.

6. **Producer gas:** (Composition CO = 22.3%, N_2 = 52%, CO_2 = 3%, H_2 = 8%). It is a mixture of combustible gases CO and H_2. It is obtained by passing air mixed with steam over red hot coal or coke at 1100°C in a reactor, steel vessel lined with fire bricks.

   The reactions in the reactor are:

$$CO_2 + C \rightarrow 2CO - 94 \text{ kJ}$$
$$C + H_2O \rightarrow CO + H_2 + 29 \text{ kJ}$$
$$C + 2H_2O \rightarrow CO_2 + 2H_2 - 19 \text{ kJ}$$

Producer gas is cheap and economical and is used as fuel in:

(i) Open hearth furnace (steel industry, glass manufacture)

(ii) Muffle furnace (coal gas manufacture)

(iii) As a reducing agent in metallurgical operations.

Advantages and disadvantages of gaseous fuels

Advantages

1. Easy transportation through pipe network.
2. Easy to start, stop and control the combustion rate, by oxidizing or reducing atmosphere, length of flame.
3. They are clean and require no special burners.
4. There is no smoke or soot and ash.

Disadvantages

1. Large storage tanks required.
2. In case of leakage, risk of fire hazards.

1.3.6 Fuel Combustion

Fuels consists of both combustible elements carbon, sulphur, hydrogen (C, S, H), and incombustible elements such as nitrogen (N_2), oxygen (O_2) and ash.

Combustion: It is defined as a chemical reaction between combustible elements of fuel and an oxidizing agent, air. Atmospheric air contains 21% and 79% by volume.

When complete combustion of fuel takes place, following reactions take place:

$$C + O_2 + N_2 \rightarrow CO_2 + N_2$$
$$S + O_2 + N_2 \rightarrow SO_2 + N_2$$
$$2H_2 + O_2 + N_2 \rightarrow 2H_2O + N_2$$
$$\text{Fuel} + (O_2 + N_2) \text{ Air} \rightarrow \text{Products of combustion.}$$

When fuel combustion is not complete, combustion products contain unburnt carbon with carbon monoxide CO along with other reactants.

When air supplied for combustion is insufficient, then some of the carbon will form CO instead of CO_2 and this reaction reduces the amount of heat produced during combustion and increases pollution.

Air–Fuel Ratio

It is defined as the ratio of amount of air supplied per kg of fuel for combustion

$$A : F \text{ Ratio} = \frac{\text{Mass of air supplied}}{\text{Unit mass of fuel}}, \frac{\text{kg of air}}{\text{kg of fuel}}$$

Stoichiometric Air–Fuel Ratio

It is defined as the ratio of mass of air supplied for complete combustion of 1 kg of fuel in standard conditions.

The stoichiometric amount of air is defined as the theoretical amount of air required for complete combustion of fuel, which is obtained by balanced chemical equation.

Complete combustion takes place when the amount of air supplied is equal or slightly higher than stoichiometric air. When excess air is supplied, products of combustion contain O_2 in addition to CO_2, H_2O, N_2, and SO_2.

When air supplied is less than stoichiometric air, it leads to incomplete combustion and formation of carbon monoxide, CO.

Importance of Air–Fuel Ratio

Let M_f = Mass of fuel

M_a = Mass of air supplied

M_g = Mass of burnt gas or combustion products.

Then $\boldsymbol{M_f + M_a = M_g}$

$$1 + \frac{M_a}{M_f} = \frac{M_g}{M_f}$$

Let λ be Air – Fuel ratio, $\lambda = \dfrac{M_a}{M_f} = \dfrac{\text{Mass of air}}{\text{Mass of fuel}}$

Stoichiometric air-fuel ratio, $\lambda_{st} = \dfrac{(Ma)_{st}}{M_f}$

and M_f = mass of fuel = λ_{st}

$(M_a)_{st}$ = stoichiometric air

If $K = \dfrac{\lambda}{\lambda_{st}} = \dfrac{M_a}{(M_a)_{st}}$, then

$$\frac{M_g}{M_f} = 1 + \frac{M_a}{M_f} = 1 + \frac{M_a}{\frac{(M_a)_{st}}{\lambda_{st}}}$$

$$\frac{M_g}{M_f} = 1 + \lambda_{st} K$$

(i) If $K < 1$, i.e., $\lambda < \lambda_{st}$ leads to incomplete combustion and products of combustion contain CO, CO_2, N_2, H_2O.

(ii) If $K = 1$, i.e., $\lambda = \lambda_{st}$, $Ma = (M_{st})$, leads to complete combustion.

(iii) If $K > 1$, i.e., $\lambda > \lambda_{st}$ products of combustion contain CO_2, H_2O, SO_2, N_2 and no CO.

Combustion efficiency

Combustion efficiency of any fuel is defined as the ratio of heat energy obtained by combustion to chemical energy of fuel.

$$\text{Combustion efficiency} = \frac{\text{Heat energy}}{\text{Chemical energy}} \times 100$$

Ideally, 100% efficiency means heat energy obtained is equal to chemical energy of fuel.

Incomplete combustion leads to reduced efficiency and also loss of fuel, pollution and increases the cost of process.

Calorific value

The calorific value of a fuel is defined as the heat energy obtained by the complete combustion of unit mass of fuel, in solid or liquid state, (kJ/kg).

The calorific value of gaseous fuel is defined as heat energy obtained by the complete combustion of unit volume of gaseous fuel at NTP (kJ/m^3).

Higher Calorific Value: All the fuels contain hydrogen, which converts to form water vapour during combustion.

When combustion products including water vapour are cooled to initial or room temperature, then all the water vapour condense evolving its latent heat producing maximum amount of heat energy per kg of fuel. This heat energy is known as higher colorific value of fuel.

Lower Calorific Value: In most of practical cases, combustible products cannot be cooled to room temperature, so heat of water vapour is lost to atmosphere. The heat energy obtained by fuel combustion excluding heat energy of water vapour is known as lower calorific value of fuel.

$$\text{LCV} = \text{HCV} - \text{Heat carried by water vapour per kg of fuel.}$$

$$\text{LCV} = \text{HCV} - M_\omega \times 2460 \text{ kJ/kg}$$

where M_ω = Mass of water vapour/kg of fuel and 2460 kJ/kg is latent heat of water vapour at NTP.

1.3.7 Thermal Power Plant

A thermal power plant consists of a boiler, steam turbine coupled to a generator, condenser, pump and cooling tower. Coal is burnt in the boiler to produce steam at high pressure and high temperature. Steam is used in the turbines to create high speed rotary motion to drive the generator. The electricity generated is distributed to the various places of use. The used steam from the turbine is condensed in the cooling tower. The condensed water is treated to remove the corrosive materials and is pumped to the boiler for steam generation.

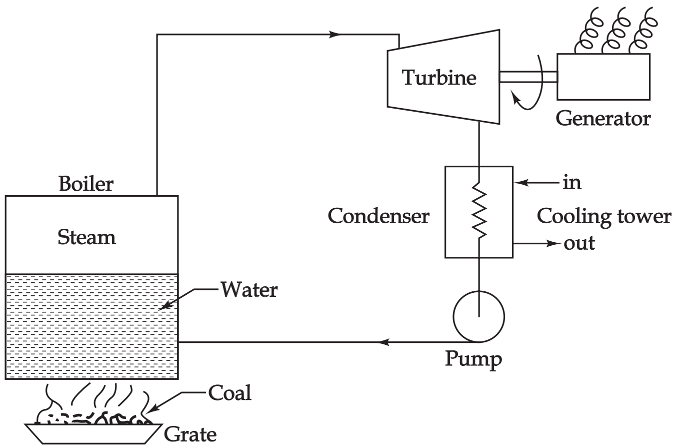


Fig. 1.2 Schematic diagram of a thermal power plant.

Advantages

1. These plants can be established in all climatic zones.
2. A wide variety of fuels can be used.
3. They are more reliable.
4. Power generation can be controlled closely.
5. Demand and supply of power can be matched.

Disadvantages

1. Products of combustion cause environmental pollution.
2. Coal fired boilers produce a large amount of solid waste in the form of ash and clinkers.
3. Large area is required for storage of fuel and ash.
4. High capital cost.
5. High maintenance cost.

1.3.8 Hydropower Plant

A hydropower plant consists of a dam (reservoir of water), conduit pipe (penstock) and water turbine coupled to a generator. The water in the reservoir is made to flow through the penstock and the nozzle, impinges on the blades of the turbine, causing the rotor of the connected generator to rotate at high speed. This generates electricity. Thus, the potential energy in water is converted to kinetic energy in the turbine, and this kinetic energy is further converted to electric energy in the generator.

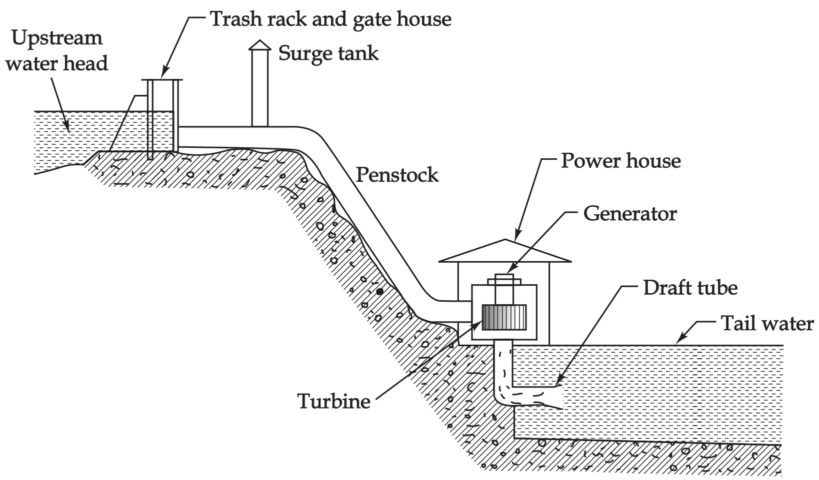


Fig. 1.3 (a) Hydroelectric power plant.

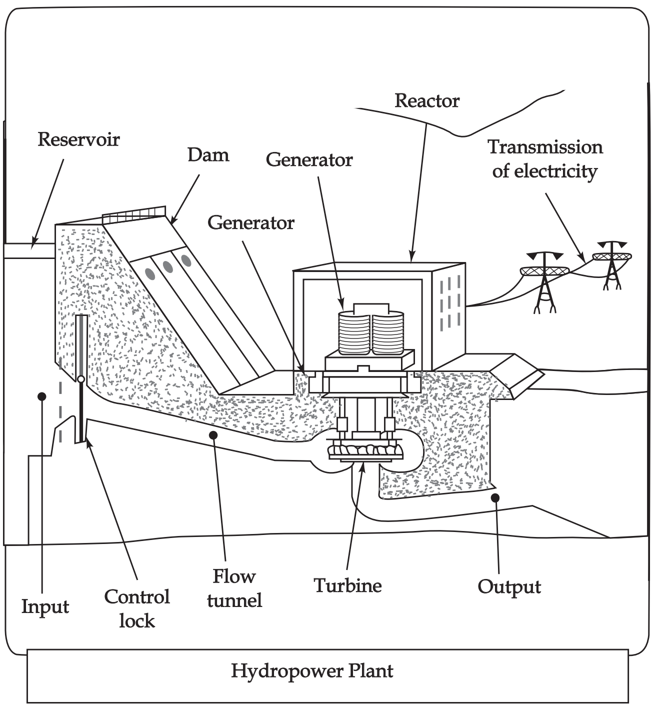


Fig. 1.3 (b) Hydroelectric power plant.

Advantages

1. Water power does not create any pollution to the environment.
2. Water from the turbine can be reused for irrigation.
3. Periodic rain replenishes water storage in the dam and hence it is inexhaustible.
4. It is more reliable.
5. A dam can serve as a flood control device.
6. A dam can be the source of water supply to domestic and industrial use.
7. Maintenance cost (running cost) of the hydel plant is very low.

Disadvantages

1. Dams distrupt the natural flow of water in the river basin and disturb the ecosystems upstream and downstream.
2. Dams are very expensive to construct.
3. Inflow of water into the dam and hence power supply are affected by the vagaries of nature.

1.3.9 Nuclear Power Plant

The isotope 235 of Uranium is a fissionable material. This atom is split into two lighter atoms, when hit by a neutron projectile. The combined mass of the resulting atoms is less than the original combined mass of the atom and the projectile neutron, the balance mass is converted into heat energy. This phenomena is called fission reaction. If the released neutrons are captured by the fissionable nuclei, more fission reactions occur and more energy is released. When the reaction becomes self-sustaining it is called chain reaction. There is continuous release of energy. If the chain reaction is not controlled there is sudden burst of energy, leading to explosion. If the reaction is properly controlled, steady output of energy can be obtained. This principle is used in the nuclear power plants.

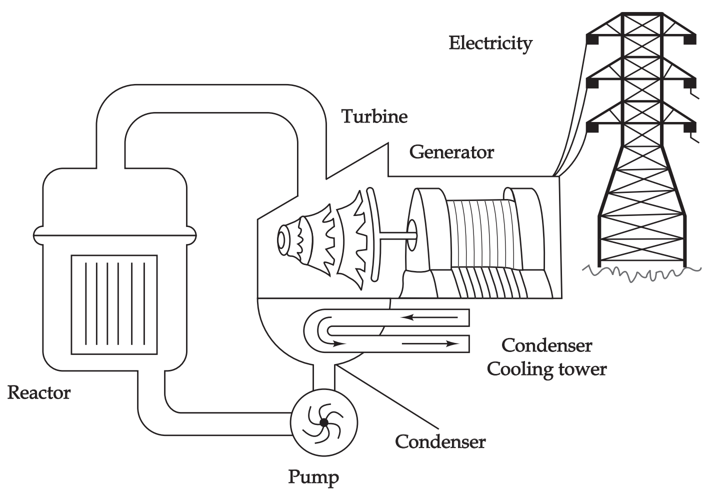


Fig. 1.4 (a) Nuclear power plant.

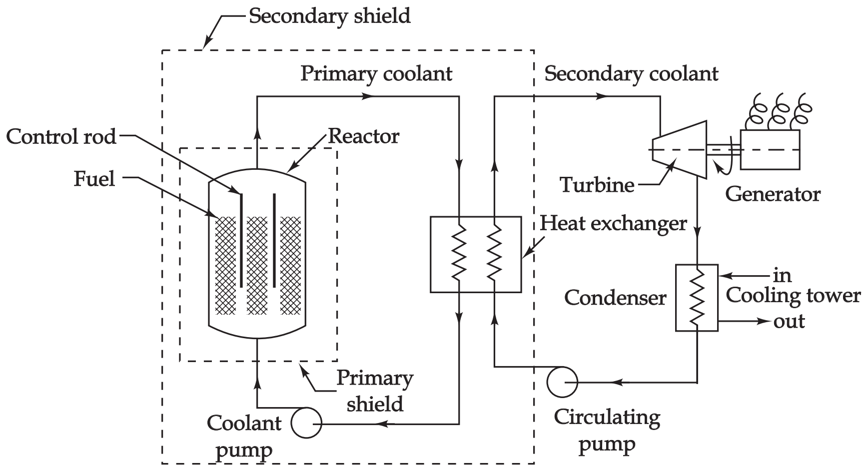


Fig. 1.4 (b) Nuclear power plant.

A nuclear power plant consists of (a) nuclear reactor, (b) heat exchanger, (c) steam turbine coupled with a generator, (d) condenser and cooling tower and (e) pump.

A reactor is a strong walled container, usually an RCC dome structure. It houses the reactor core, moderator, reflectors, control rods, thermal shield, and flow passage for the coolant.

The heat exchanger placed within the dome transfers heat from the primary coolant to the secondary coolant. The primary coolant is heavy water. It absorbs the heat released in the reactor. The secondary coolant is ordinary water. It receives heat from heavy water in heat-exchanger and gets converted into high pressure steam. This steam is fed to the steam turbine for power generation. The low pressure steam from the turbine is condensed to water in the cooling tower. The condensed water is pumped to the heat exchanger.

Advantages

1. The fuel is uranium in the form of rods, and a small quantity is consumed.
2. Storage space required is comparatively small.
3. Power generation can be closely monitored.
4. It is highly reliable.
5. The operation is not affected by the vagaries of nature.
6. Very large quantities of power can be generated.

Disadvantages

1. Capital cost is very high.
2. Maintenance cost is also high.
3. Trained personnel are required for the operation of the plant.

4. The inhabitants in the surroundings have to be protected against the radioactive leakages.
5. Disposal of the radioactive waste is a big problem.

1.4 NON-CONVENTIONAL RESOURCES

1.4.1 Solar Energy

Introduction: Solar energy is radiated by the sun in the form of electromagnetic waves of wavelength range of 0.2 to 0.4 μm. The solar energy reaching the earth's atmosphere consists of 8% utraviolet radiation (short wavelength < 0.39 m); 46% visible light (0.3 to 0.78 μm) and 46% infrared radiation (long wavelength > 0.78 μm).

Solar Constant: The sun is a very large sphere of hot gases, due to the various fission reactions. Its diameter is 1.39×10^6 km, while earth's diameter is 1.27×10^4 km. The mean distance between the sun and the earth is 1.5×10^8 km. The sun subtends at an angle of only 32 minutes at the earth's surface, because of the large distance between them. As a result the radiation received is almost parallel. The rate at which solar energy arrives at the top of the atmosphere is called solar constant.

It is also referred to as the amount of energy received in unit time on unit area perpendicular to the sun's direction at the mean distance of the earth from the sun. NASA's standard value is 1.353 kg/m^3.

The sun is the primary source of energy for the earth. The earth receives 1.6×10^{18} units of energy from the sun annually, which is 20,000 times the requirement of mankind on the earth. Some of the solar energy causes evaporation of water, leading to rains and creation of rivers, etc. Some of it is utilized in photosynthesis which is essential for sustenance of life on the earth. Man has tried, from time immemorial, to harness this infinite source of energy, but has been able to tap only a negligibly small fraction of this energy till today.

Three broad categories of possible large-scale applications of solar power are:

(i) Heating and cooling of residential and commercial buildings.

(ii) Chemical and biological conversion of organic material to liquid, solid and gaseous fuels.

(iii) Conversion of solar energy to electricity.

Use of solar energy for generation of electricity is costly as compared to conventional methods. However, due to scarcity of fuel, solar energy will certainly find a place in planning the national energy resources.

(i) **Residential cooling and heating:** A major component of our electricity bill is due to heating and cooling of buildings. This bill can be reduced by using solar energy. A typical solar energy scheme is shown in Fig. 1.5. A flat plate collector is located on the roof of a house, which collects the solar energy. The water is pumped through the tubes of the solar collector. The heat is transferred from the collector to the water and the hot water is stored in a storage tank which may be located at the ground level or in the basement of the house. Hot water is then utilized to heat or cool the house by adjusting the automatic valve. A separate circuit is there to supply hot water. Thus, all the three requirements i.e., space cooling, heating and water heating are met.

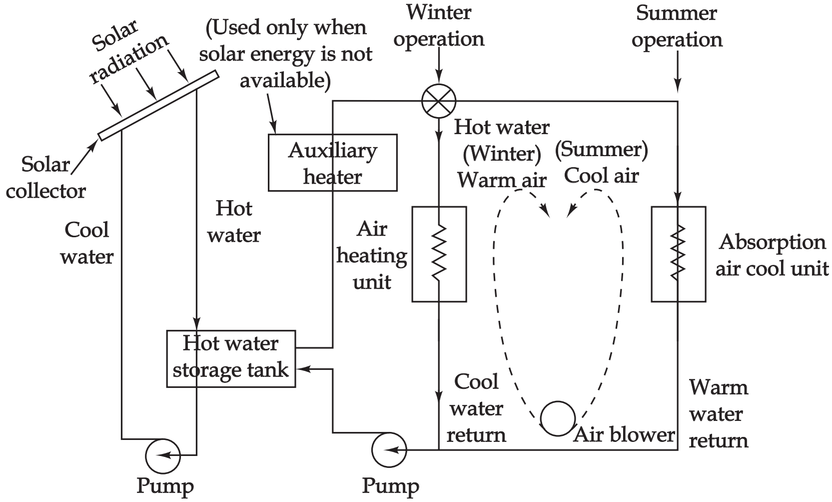


Fig. 1.5 Schematic diagram of residential cooling and heating with solar energy.

(ii) **Photosynthesis Production of Energy Sources:** Solar energy can be transformed into chemical energy in the form of plants and trees, through the process of photosynthesis, which is the basis of the world's fossil fuels and biofeuls. It is now possible to produce organic matter with high heat content, by using suitable chemical processes.

(iii) **Direct Conversion to Electricity—The Solar Cells:** The solar cells operate on the principle of photoelectricity, i.e., electrons are liberated from the surface of a body when light is incident on it. Backed by semiconductor technology, it is now possible to utilize the phenomenon of photoelectricity. It is known that if an *n*-type semiconductor is brought in contact with a *p*-type material, a contact potential difference is set up at the junction (Schottky effect), due to diffusion of electrons. When the *p*-type material is exposed to light, its electrons get excited, by the photons of light, and pass into the *n*-type semiconductor. Thus, an electric current is generated in a closed circuit. The *p*-*n* junction silicon solar cells have emerged as the most important source of long duration power supply necessary for space vehicles. These cells are actuated by both, direct sun rays and diffuse light. The efficiency of silicon solar cells increases with decreasing temperature. In cold weather the decreased luminous flux is compensated for, by higher efficiency. The efficiency of these solar cells varies from 15 to 20%.

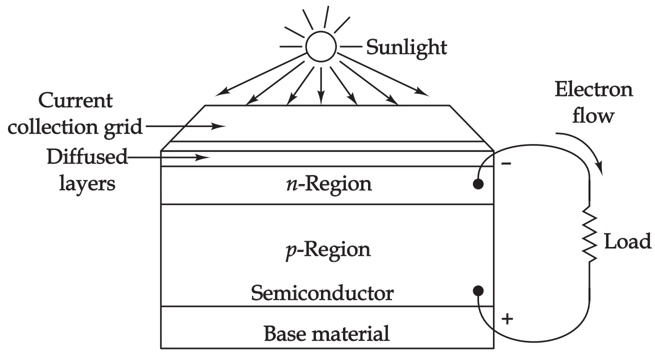


Fig. 1.6 Solar cells.

Solar collectors: Although energy from the sun is available free of cost, the cost of fabrication and installation of systems, for utilization of solar energy, is often too high to be economically viable. In order to make solar installations economically attractive, plastic materials are being increasingly used for the fabrication of various components of the system.

The efficiency of solar heating/cooling installations depends on the efficiency of collection of solar energy and its transfer to the working fluid (e.g., water, air, etc.). There are two main classes of collectors: (a) Flat plate collectors (b) Concentrating collectors. The flat plate collector is best suited for low and intermediate temperature applications (40°C–60°C, 80°C–120°C) which include water heating for buildings, air heating and small industrial applications like agricultural drying, etc. Concentrating collectors are usually employed for power generation and industrial process heating.

Flat plate collector: The schematics of a flat plate collector are shown in Fig. 1.7. It usually consists of five main components, namely,

(i) An absorber plate (metallic or plastic)

(ii) Tubes or pipes for conducting or directing the heat transfer fluid, one or more covers.

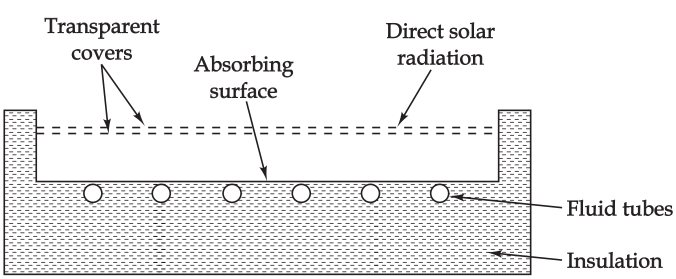


Fig. 1.7 Schematics of a flat plate solar collector.

(iii) Insulation to minimise the downward heat loss from the absorbing plate.

(iv) Casing which encloses the foregoing components keeps them free of dust and moisture and also reduces the thermal losses.

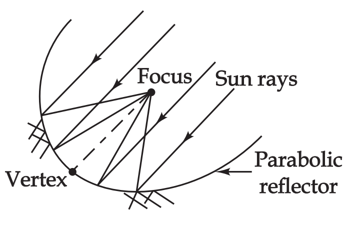
Generally, flat plate collectors are framed sandwich structures, mounted on roofs or sloping walls. In most of these collectors, the absorber element is made of a metal such as galvanised iron, aluminium, copper, etc., and the cover is usually of glass of 4 mm thickness. The back of the absorber is insulated with glass wool, asbestos wool or some other insulating material. The casing, enclosing all the components of the collector is either made of wood or some light metal like aluminium. The cost, with such meterials, is rather too high to be acceptable for common use. As the temperatures needed for space heating are rather low, plastics are being considered as potential material for fabrication of various components of the flat, plate collector. This would make solar energy systems comparable with other energy systems.

Solar concentrators: Solar concentrators are the collection devices which increase the flux on the absorber surface as compared to the flux impinging on the concentrator surface. Optical concentration is achieved by the use of reflecting/refracting elements, positioned to concentrate the incident flux onto a suitable absorber. Due to the apparent motion of the sun, the concentrating surface, whether reflecting or refracting, will not be in a position to redirect the sun rays onto the absorber, throughout the day if both the concentrator surface, and absorber are stationary. Ideally, the total system consisting of mirrors or lenses and the absorber should follow the sun's apparent motion so that the sun rays are always captured by the absorber. In general, a solar concentrator consists of the following:

(i) a focussing device;

(ii) a blackened metallic absorber provided with a transparent cover; and

(iii) a tracking device for continuously following the sun.



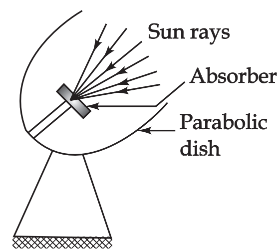


Fig. 1.8 Line focussing collector. **Fig. 1.9** Point focussing collector.

Temperatures as high as 3000°C can be achieved with such devices and they find applications in both photothermal and photovoltaic conversion of solar energy.

The use of solar concentrators has the following advantages:

(i) Increased energy delivery temperature, facilitating their dynamic match between temperature level and the task.

(ii) Improved thermal efficiency due to reduced heat loss area.

(iii) Reduced cost due to replacement of large quantities of expensive hardware material for constructing flat plate solar collector systems, by less expensive reflecting and/or refracting element and a smaller absorber tube.

(iv) Increased number of thermal storage options at elevated temperatures, thereby reducing the storage cost.

A solar concentrator consists of the following components:

(i) A reflecting or refracting surface,

(ii) An absorbing surface, i.e., an absorber,

(iii) A fluid flow system to carry away the heat,

(iv) A cover around the absorber,

(v) Insulation for the unirradiated portion of the absorber, and

(vi) A self-supporting structural capability and well adjusted tracking mechanism.

Solar Pond: A solar pond is a natural or artifitial body of water used for collecting and absorbing solar rdiation energy and storing it as heat energy.

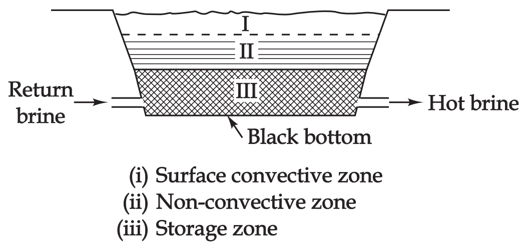


Fig. 1.10 Solar pond.

A simple solar pond is very shallow with depth ranging from 1 metre to 5 metres. The bottom is lined with black plastic to absorb the solar radiations. A bed of insulating materials under the tank minimizes the heat loss to the ground. As the solar radiations enter the water in the tank, it is partially absorbed by the water and fully by the black bottom. If the water is fresh, hot water at the bottom rises to the top surface, loses to the atmosphere and the cold water at the top goes to the bottom. Thus, a convective circulation sets in and most of the heat collected is lost. To prevent this phenomenon, brine water is fed at the bottom of the tank. Then three zones are created. (i) surface convective zone of fresh water; (ii) non-convective zone and (iii) storage zone of brine water.

The convective zone extends to a depth of 0.3 to 0.5 m and has very low salinity of less than 5%.

The non-convective zone extends from 1.0 m to 1.5 m and the salinity is more than 5%.

The storage zone extends below the depth of 1.5 m and the salinity increases to about 20%.

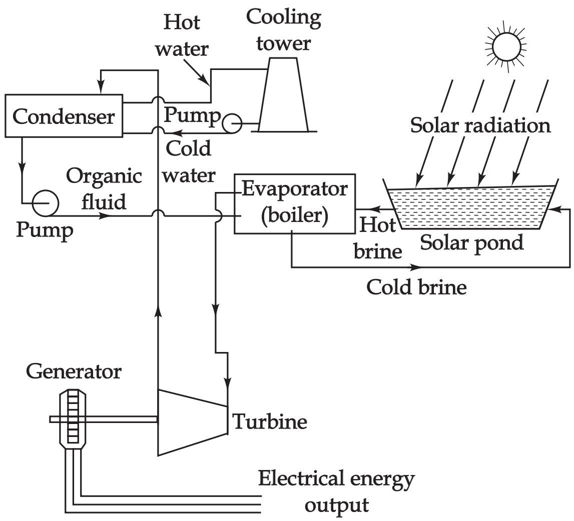


Fig. 1.11 Solar power plant.

The schcematic diagram of a solar power plant is shown in Fig. 1.11. The hot brine at the bottom of the tank is extracted by a pump without affecting the salinity gradient in the tank and circulated though the evaporator (heat exchanger). The organic working fluid receives heat from the hot brine and gets evaporated. The high pressure vapour enters the turbine and expands to low pressure causing the turbine to rotate at high speed. The rotation of the coupled generator-rotor, generates electricity.

Advantages of solar energy

1. Solar energy is freely available.
2. Solar energy does not cause pollution.
3. Solar energy can be used in remote areas where it is too expensive to extend the electricity power grid.
4. Many everyday items such as calculators and other low power consuming devices can be powered by solar energy effectively.
5. Solar energy is a clean and renewable energy source.
6. Solar energy will last forever whereas it is estimated that the world's oil reserves will last for 30 to 40 years.
7. Solar cells make absolutely no noise at all. On the other hand, the giant machines utilized for pumping oil are extremely noisy and therefore very impractical.
8. Very little maintenance is needed to keep solar cells running. There are no moving parts in a solar cell which makes it impossible to really damage them.
9. In the long term, there can be a high return on investment due to the amount of free energy a solar panel can produce, it is estimated that the average household will see 50% of their energy coming in from solar panels.

Disadvantages of solar energy

1. Solar energy can only be harnessed when it is daytime and sunny.
2. Solar collectors, panels and cells are relatively expensive to manufacture although prices are falling rapidly.
3. Solar power stations can be built but they do not match the power output of similar sized conventional power stations. They are also very expensive.
4. In countries such as UK, the unreliable climate means that solar energy is also unreliable as a source of energy. Cloudy skies reduce its effectiveness.
5. Large areas of land are required to capture the sun energy. Collectors are usually arranged together especially when electricity is to be produced and used in the same location.
6. Solar power is used to charge batteries so that solar powered devices can be used at night. However, the batteries are large and heavy and need storage space. They also need replacing from time to time.

1.4.2 Wind Energy

Wind is a form of **solar energy**. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern **wind turbines**, can be used to generate electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

Wind Turbines: Wind turbines, like aircraft propeller blades, turn in the moving air and power an **electric generator** that supplies an electric current. Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which is connected to a generator for electricity generation.

Wind Turbine Types

Modern wind turbines fall into two basic groups: the horizontal-axis variety, like the traditional farm windmills used for pumping water, and the vertical-axis design, like the eggbeater-style. Darrieus model is named after its French inventor. Most large modern wind turbines are horizontal-axis turbines.

Horizontal turbine components include:

- **blade** or **rotor,** which converts the energy in the wind to rotational shaft energy;
- a **drive train**, usually including a gearbox and a generator;
- a **tower** that supports the rotor and drive train; and
- other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.

Turbine configurations

Wind turbines are often grouped together into a single wind power plant, also known as a **wind farm**, and generate bulk electrical power. Electricity from these turbines is fed into a utility grid and distributed to customers, just as with conventional power plants.

Principles of wind energy conversion: There are two primary physical principles by which energy can be extracted from the wind through the creation of either lift or drag force, i.e., or through a combination of the two.

Drag forces provide the most obvious means of propulsion, these being the forces felt by a person (or object) exposed to the wind. This principle is used in vertical-axis turbines.

Lift forces are the most efficient means of propulsion, this principle is used in horizontal-axis turbines.

The basic features that characterise lift and drag are:

- drag is in the direction of air flow
- lift is perpendicular to the direction of air flow
- generation of lift always causes a certain amount of drag to be developed
- with a good aerofoil, the lift produced can be more than thirty times greater than the drag
- lift devices are generally more efficient than drag devices

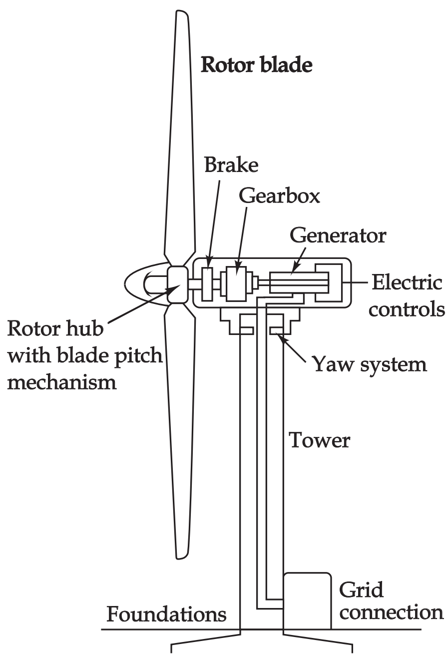


Fig. 1.12 Wind power plant.

Advantages of wind power

1. The wind is free and with modern technology it can be captured efficiently.
2. Once the wind turbine is built the energy it produces does not cause greenhouse gases or other pollutants.
3. Although wind turbines can be very tall, each takes up only a small plot of land. This means that the land below can still be used. This is especially the case in agricultural areas as farming can still continue.
4. Many people find wind farms an interesting feature of the landscape.
5. Remote areas that are not connected to the electricity power grid can use wind turbines to produce their own supply.
6. Wind turbines have a role to play in both the developed and the third world.
7. Wind turbines are available in a range of sizes which means a vast range of people and businesses can use them. Single households to small towns and villages can make good use of range of wind turbines available today.

Disadvantages of wind power

1. The strength of the wind is not constant and it varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all.
2. Many people feel that the countryside should be left untouched, without these large structures being built. The landscape should be left in its natural form for everyone to enjoy.
3. Wind turbines are noisy. Each one can generate the same level of noise as a family car travelling at 110 kmph.
4. When wind turbines are being manufactured some pollution is produced. Therefore wind power does produce some pollution.
5. Large wind farms are needed to provide entire communities with enough electricity. For example, the largest single turbine available today can only provide enough electricity for 475 homes, when running at full capacity.

1.4.3 Biofeuls

Biofuels are drawing increasing attention worldwide as substitutes for petroleum-derived transportation fuels to help address energy cost, energy security and global warming concerns associated with liquid fossil fuels.

Definition Any hydrocarbon fuel that is produced from biomass or organic matter (living or once living material) in a short period of time (days, weeks, or even months) is considered a biofuel. This contrasts with fossil fuels, which take millions of years to form and with other types of fuels which are not based on hydrocarbons (nuclear fission, for instance).

Biomass: Biomass is simply organic matter. In others words, it is dead material that was once living. Kernels of corn, mats of algae, and stalks of sugarcane are all biomass.

Biomass fuel is liquid, solid, or gaseous fuel produced by conversion of biomass. They are actually organic materials produced by plants, animals, or microorganisms. Those plants, animals or microorganisms can be burnt directly as a heat source or they can be converted into a gaseous or liquid fuel. Scientists are looking to biomass for sources of alternative fuels. Biomass can be directly converted to energy or converted to liquid or gaseous fuels such as ethanol, methanol, methane, and hydrogen.

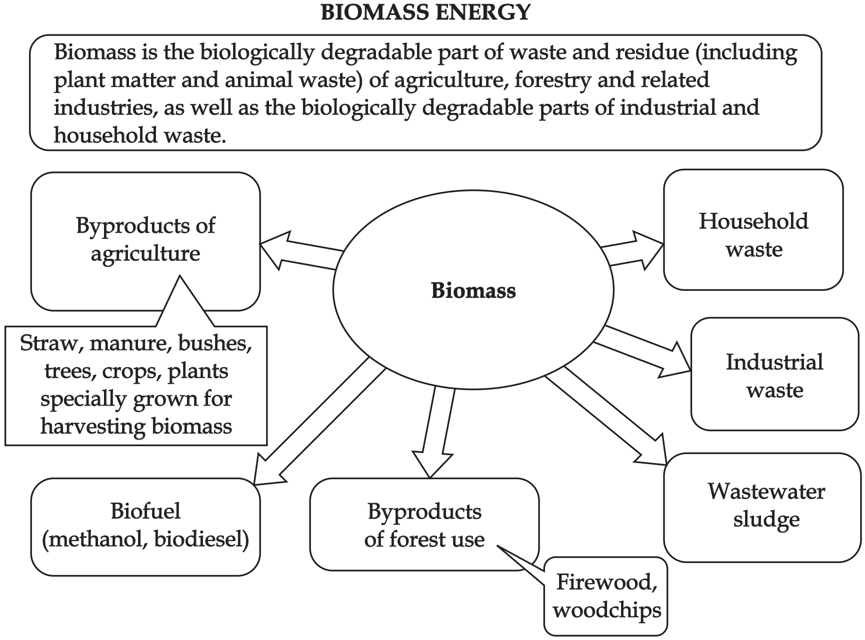


Fig. 1.13 Sources of biomass.

Types of biofuels: Biofuels can include relatively familiar ones, such as ethanol made from sugar cane or diesel-like fuel made from soybean oil, to less familiar fuels such as dimethyl ether (DME) or Fischer-Tropsch liquids (FTL) made from lignocellulosic biomass. Table 1.3 compares various biofuels with their fossil fuel counterparts.

A relatively recently popularized classification of liquid biofuels includes "first-generation" and "second-generation" fuels. There are no strict technical definitions for these terms. The main distinction between them is the feedstock used.

First-generation fuel is generally one made from sugars, grains, or seeds, i.e., one that uses only a specific (often edible) portion of the above-ground biomass produced by a plant, and relatively simple processing is required to produce a finished fuel. First-generation fuels are already being produced commercial in significant quantities in a number of countries. First-generation biofeuls are ethanol, biodiesel, green diesel, biofeul gasoline, bioalcohols, vegetable oils, bioethers, biogas, syngas and solid biofeuls.

Table 1.3 Comparison between biofuels and petroleum fuels

Biofuel	*Fossil Fuel*	*Differences*
Ethanol	Gasoline/Ethane	Ethanol has about half the energy per mass of gasoline, which means it takes twice as much ethanol to get the same energy. Ethanol burns cleaner than gasoline, however, producing less carbon monoxide. However, ethanol produces more ozone than gasoline and contributes substantially to smog. Engines must be modified to run on ethanol.
Biodiesel	Diesel	Has only slightly less energy than regular diesel. It is more corrosive to engine parts than standard diesel, which means engines have to be redesigned to take biodiesel. It burns cleaner than diesel, producing less particulate and fewer sulfur compounds.
Methanol	Methane	Methanol has about one-third to one half as much energy as methane. Methanol is a liquid and easy to transport whereas methane is a gas that must be compressed for transportation.
Biobutanol	Gasoline/Butane	Biobutanol has slightly less energy than gasoline, but can run in any car that uses gasoline without the need for modification to engine components.

Biofuels can be substituted for petroleum fuels. Figure 1.14 shows the substitutability chart.

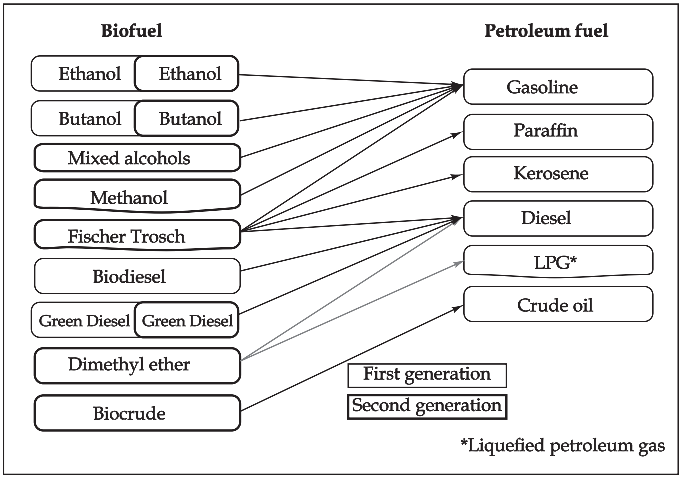


Fig. 1.14 Substitutability of biofuels with common petroleum–derived fuels.

Second-generation fuels are generally those made from non-edible lignocellulosic biomass, either non-edible residues of food crop production (e.g., corn stalks or rice husks) or non-edible wholeplant biomass (e.g., grasses or trees grown specifically for energy). Second-generation fuels are not yet being produced commercially in any country.

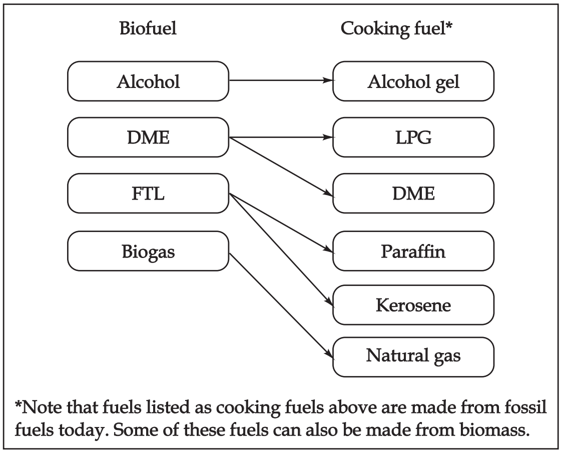


Fig. 1.15 Substitutability of biofuels for clean fossil fuels used for cooking.

Table 1.4 Biofuel classification

First-generation biofuels (from seeds, grains or sugars)	*Second-generation biofuels (from lignocellulosic biomass, such as crop residues, woody crops or energy grasses)*
• Petroleum-gasoline substitutes – Ethanol or butanol by fermentation of starches (corn, wheat, potato) or sugars (sugar beets, sugar cane)	• Biochemically produced petroleum-gasoline substitutes – Ethanol or butanol by enzymatic hydrolysis
• Petroleum diesel substitutes – Biodiesel by transesterification of plant oils, also called fatty acid methyl ester (FAME) and fatty acid ethyl ester (FAEE) • From rapeseed (RME), soybeans (SME), sunflowers, coconut, palm, jatropha, recycled cooking oil and animal fats – Pure plant oils (straight vegetable oil)	• Thermochemically produced petroleumgasoline substitutes – Methanol – Fischer-Tropsch gasoline – Mixed alcohols • Thermochemically produced petroleum-diesel substitutes – Fischer-Tropsch diesel – Dimethyl ether (also a propane substitute) – Green diesel

Advantages and disadvantages of biofeuls

Advantages

1. **Cost:** Biofuels have the potential to be significantly less expensive than gasoline and other fossil fuels. This is particularly true as worldwide demand for oil increases, oil supplies dwindle, and more sources of biofuels become apparent.
2. **Source material:** Whereas oil is a limited resource that comes from specific materials, biofuels can be manufactured from a wide range of materials including

crop waste, manure, and other byproducts. This makes it an efficient step in recycling.

3. **Renewability:** It takes a very long time for fossil fuels to be produced, but biofuels are much more easily renewable as new crops are grown and waste material is collected.
4. **Security:** Biofuels can be produced locally, which *decreases the nation's dependence upon foreign energy*. By reducing dependence on foreign fuel sources, countries can protect the integrity of their energy resources and make them safe from outside influences.
5. **Economic stimulation:** Because biofuels are produced locally, biofuel manufacturing plants can *employ hundreds or thousands* of workers, creating new jobs in rural areas. Biofuel production will also increase the demand for suitable biofuel crops, providing economic stimulation to the agriculture industry.
6. **Lower carbon emissions:** When biofuels are burnt, they produce significantly less carbon output and fewer toxins, making them a safer alternative to preserve atmospheric quality and lower air pollution.

Disadvantages

Despite many positive characteristics of biofuels, there are also many disadvantages to these energy sources.

1. **Energy output:** Biofuels have a lower energy output than traditional fuels and therefore require greater quantities to be consumed in order to produce the same energy level. This has led some noted energy analysts to believe that biofuels are not worth the work.
2. **Production carbon emissions:** Several studies have been conducted to analyze the carbon footprint of biofuels, and while they may be cleaner to burn, there are strong indications that the process to produce the fuel—including the machinery necessary to cultivate the crops and the plants to produce the fuel—create huge carbon emissions.
3. **High cost:** To refine biofuels to more efficient energy outputs, and to build the necessary manufacturing plants to increase biofuel quantities, a high initial investment is often required.
4. **Food prices:** As demand for food crops such as corn grows for biofuel production, it could also raise prices for necessary staple food crops.
5. **Food shortages:** There is concern that using valuable cropland to grow fuel crops could have an impact on the cost of food and could possibly lead to food shortages.
6. **Water use:** Massive quantities of water are required for proper irrigation of biofuel crops as well as to manufacture the fuel, which could strain local and regional water resources.

Table 1.5 Calorific values of solid, liquid and gaseous fuels

Solid and liquid fuels	*Gross calorific value/MJ kg^{-1}*
Alcohols	
Ethanol	30
Methanol	23
Coal and coal products	
Anthracite (4% water)	36
Peat	
Peat (0% water)	16
Petroleum and petroleum products	
Diesel fuel	46
Gas oil	46
Heavy fuel oil	43
Kerosene	47
Petrol	44.8 – 46.9
Wood	
Wood (15% water)	16
Gaseous fuels at* 15°C, 101.325 kPa, *dry	***Gross calorific value*/MJ m^{-3}**
Coal gas coke oven (debenzolized)	20
Commercial butane	118
Commercial propane	94
Producer gas coal	6
Water gas carburetted	19

EXERCISES

1. Explain the conventional and non-conventional energy sources.
2. Compare the renewable and non-renewable energy sources.
3. Define fuel and give classification of fuel.
4. List the various fuels, with suitable examples.
5. Differentiate between natural fuels and derived fuels.
6. List properties of liquid fuel.
7. Explain advantages of liquid fuels over solid fuels.
8. Explain advantages of gaseous fuels.
9. List the important gaseous fuels and their applications.
10. Explain terms
    (i) Combustion
    (ii) Air–fuel ratio

(iii) Calorific value

(iv) Stoichiometric air-fuel ratio.

11. Differentiate between solid, liquid and gaseous fuels.
12. Explain the working of a thermal power plant with sketch.
13. Describe the working of a hydel power plant.
14. What are the merits and demerits of a nuclear power plant?
15. Explain the solar constant.
16. Name and describe the solar collectors.
17. What are the methods of harnessing solar energy?
18. Explain the working of solar cells.
19. List the advantages and disadvantages of the solar energy.
20. Explain the principle of working of the wind mills.
21. Define biofuel and list the types of biofuels.
22. List the biofuels which can be substituted for the petroleum products for transportation purposes.
23. How are the biofuels classified?
24. What are the sources for producing biofuels?
25. Compare the calorific values of biofuels with other fuels.

CHAPTER **2**

Steam Formation and Steam Boilers

2.1 STEAM AND PROPERTIES OF STEAM

Steam: Steam is the vapour form of water. Water is one of the pure substances which can exist in three phases with same chemical composition.

Solid phase – ice
Liquid phase – water
Gaseous phase – steam

Steam is used as a working medium in steam turbines and steam engines. It is also used as process steam in chemical industries and textile industry. It also serves as a vehicle to transport heat energy.

2.1.1 Formation of Steam at Constant Pressure

One kg of water at 0°C (273°K) is taken in a cylinder and piston with a certain weight is placed on it. The piston cylinder interface is tight and leak proof. The water is heated by a burner.

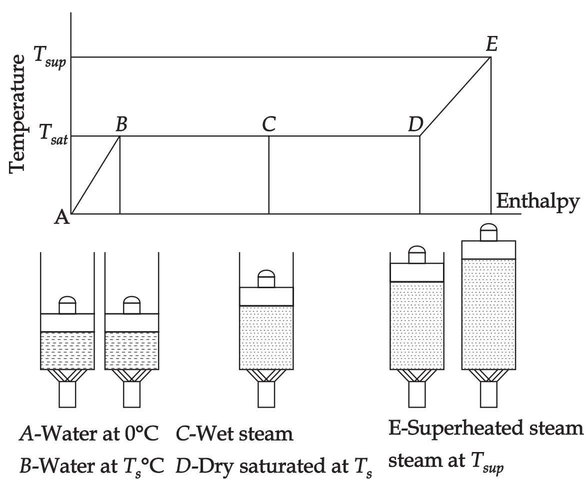


Fig. 2.1 Temperature enthalpy diagram.

As heat is added at constant pressure water temperature increases as shown by the line AB on T-H chart in Fig. 2.1. There is a very small increase in volume. On reaching temperature $T°_s$ K (point B), water starts boiling and vaporization takes place. This temperature is called saturation temperature. The temperature remains constant until all the water is evaporated into dry steam. The line *BCD* represents the heat addition during the evaporation.

2.1.2 Properties of Steam

Steam in the partially vaporized state is called wet-steam and is represented by the dryness fraction defined as follows:

Dryness fraction

$$X = \frac{\text{mass of dry steam}}{\text{mass of total steam}}$$

$$= \frac{\text{mass of dry steam}}{\text{mass of dry steam + mass of water droplets}}$$

$$X = \frac{m_g}{m_g + m_w}$$

When all the water is evaporated

$$X = 1$$

This condition is called dry saturated steam. Heat added during evaporation is called latent heat. The total heat added upto '*D*' is called heat of saturation (h_g). The specific volume increases from V_f to V_g during the evaporation process.

Addition of heat to the dry saturated steam results in increase in the temperature to T_{sup} and is represented by the line *DE* on *T-H* chart and there is appreciable increase in volume also. This process is called superheating. The heat added is called super-heat. The steam at this condition is called *superheated steam*. This steam behaves as a perfect gas.

2.1.3 Dryness Fraction 'x' or 'q' = $\frac{\mathbf{m_g}}{\mathbf{m_g + m_f}}$

where m_g = Mass of dry steam

$m_w = m_f$ = Mass of water droplets

2.1.4 Quality of Steam

It is a term used for expressing dryness fraction in percentage, e.g., if steam is 75% dry, then quality of steam is x = 75%. Dry and dryness fraction x = 0.75.

2.1.5 Wetness Fraction

It is defined as ratio of mass of wet steam to total mass of dry steam and mass of water droplets.

Wetness fraction $= 1 - x = \dfrac{m_f}{m_g + m_f}$

2.1.6 Enthalpy of Steam

1. Sensible heat
2. Enthalpy of wet steam, 'x' = dryness fraction
3. Enthalpy of superheated steam
4. Degree of superheat.

The total heat added to water or steam at constant pressure is called enthalpy.

Enthalpy of water is the heat added to increase the temperature of water. The heat added to increase from 273°K (0°C) to saturation temperature T_s° K is called the sensible heat of water and is given by,

$$h_f = c_{pw}(T_s - T_0) \text{ kJ/kg.}$$

where C_{pw} = specific heat of water in kJ/kg.°K

T_0 = 273°K, T_s saturation temperature of water

Heat added during the evaporation is called the **latent heat** – represented by h_{fg}. The enthalpy of the dry saturated steam is given by,

$$h_g = h_f + h_{fg} \quad \text{(i)}$$

Enthalpy of wet steam is given by,

$$h_w = h_f + x\, h_{fg} \quad \text{(ii)}$$

where x = dryness fraction of steam

Enthalpy of superheated steam is given by,

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_s) \quad \text{(iii)}$$

where C_{ps} is the specific heat of superheated steam at constant pressure.

C_{ps} = 1.45 to 2.29 kJ/kg. K. and

T_{sup} = Temperature of the superheated steam.

The enthalpy of superheat is the difference between the enthalpy of superheated steam and enthalpy dry saturated steam and is given by,

$$h = h_{sup} - h_g$$
$$= C_{ps}(T_{sup} - T_s) \text{ kJ/kg. K}$$

Degree of superheat is the difference in temperature of superheated steam and the saturation temperature.

Degree of superheat $= \theta = (T_{sup} - T_s)$

2.1.7 Specific Volume

Specific volume of saturated water: It is the volume in m^3 occupied by one kg of water at saturation–temperatue at a given pressure and is represented by V_f.

Specific volume of dry saturated steam: It is the volume represented by V_g. It is dependent on pressure.

Specific volume of wet steam: It is the volume in m^3 occupied by one kg of wet steam at a given pressure and is represented by V_w. It is given by $V_w = V_f + x\,(V_g - V_f)$.

Specific volume of superheated steam: It is the volume in m^3 occupied by 1 kg of superheated steam at a given temperature and pressure and is denoted by V_{sup}. The superheated steam behaves like a perfect gas.

By applying the Charles Law. We can write for V_{sup} as,

$$V_{sup} = V_g\left(\frac{T_{sup}}{V_s}\right)$$

2.1.8 External Work of Evaporation

During the liquid phase (AB) there is a very small change in the volume of water. Hence, the work done against the surroundings is neglected. The heat added is used solely in increasing the temperature.

During the evaporation phase, (*BCD*) there is a large increase in volume from V_f to V_g and the work done against the surroundings is.

$$W_s = p(V_g - V_f) \text{ J/kg} = \frac{pV_g}{1000} \text{kJ/kg}, \qquad (\therefore\ V_f \text{ is very small})$$

where pressure p is in pascal (N/m^2), V_g is in m^3

For customary units, p in bar (= 10^5 N/m^2)

The work done $W_s = 100$ p V_g. kJ/kg.

For wet steam the work done is given by

$$W_x = p\ .\ x\ .\ V_g.\ \text{J/kg}, = \frac{x.pV_g}{1000}\text{kJ/kg}$$

For p expressed in bars

$$\text{Wx} = 100\ .\ \text{x}\ p\ \text{Vg. kJ/kg.}$$

During the superheating process, there is large increase in volume. The work done against the surroundings is given by

$$\Delta W_{sup} = p\ (V_{sup} - V_g)\ \frac{J}{\text{kg}} = \frac{P(V_{sup} - V_g)}{1000}\ \text{kJ/kg}$$

The total external work done by the superheated steam,

$$W_{sup} = W_s + p(V_{sup} - V_g)$$

$$W_{sup} = p\ .\ V_g + p(V_{sup} - V_g)\ \text{J/kg} = \frac{\text{p.V}_{\text{sup}}}{1000}\text{kJ/kg}$$

When p is expressed in bars.

$$W_{sup} = 100\ p\ .\ V_{sup}\ \text{kJ/kg.}$$

2.1.9 Internal Energy (U)

A part of the heat added is spent in doing external work due to expansion in volume and the remaining heat is stored as external energy (U),

$$h = u + PV$$

$$u = h - PV$$

For water- $U_f = h_f$

For **wet steam** $U_x = \left(h_w - \frac{p.V_w}{1000}\right)$ kJ/kg

$$= (h_w - 100\ p\ .\ x\ .\ V_g)\text{kJ/kg (for } p \text{ in bars)}$$

For **dry saturated steam:**

$$U_g = \left(h_g - \frac{pV_g}{1000}\right)\text{kJ/kg}$$

$$= (h_g - 100\ p\ V_g)\ \text{kJ/kg} \quad (\text{for } p \text{ in bars})$$

For **superheated steam**:

$$U_{sup} = \left(h_{sup} - \frac{pV_{sup}}{1000}\right)\text{kJ/kg}$$

$$= (h_{\text{sup}} - 100\ pV_{\text{sup}})\ \text{kJ/kg} \quad (\text{for } p \text{ in bars})$$

2.1.10 Advantages of Superheated Steam

1. Heat energy of superheated steam is much higher and this increases the capacity of steam to do work.
2. Superheated steam increases thermal efficiency of boilers, and steam turbines.
3. It does not have moisture, hence corrosion of blades is minimized.

2.1.11 Steam Tables

The steam table gives various properties of the steam, such as speafic volume, sensible heat, enthalpy, saturation temperature, etc. for 1 kg of steam. The table gives compilation of experimental results, at different pressures and temperatures. Commonly the properties are referred with respect to given pressure of steam.

EXAMPLE 2.1

Determine the enthalpy of 1 kg of steam at 12 bar, when steam is (i) dry saturated (ii) 80% dry (iii) superheated to 300°C. Assume specific heat of the superheated steam as 2.25 kJ/kg K.

Given:

Mass = 1 kg, $x = q = 0.80$

$t_{sup} = 300 + 273 = 573k$

From steam table at pressure of 12 bar

$T_s = 460.9°\ \text{K} = 187.9°\text{C}$

$$h_f = 798.1 \text{ kJ/kg}$$
$$h_{fg} = 1984.5 \text{ kJ/kg}$$
$$h_g = 2782.6 \text{ kJ/kg}$$

(i) Enthalpy of dry saturated steam (1 kg) = $h_g = 2782.6 \dfrac{\text{kJ}}{\text{kg}}$

(ii) Enthalpy of wet steam, 80% dryness fraction,
$h_{wet} = h_f + x\, h_{fg} = 798.1 + 0.8 \times 1948.5 = 2385.7$ kJ/kg

(iii) Enthalpy of superheated steam.
$h_{sup} = h_g + C_{ps}\ (T_{sup} - T_s) = 2782.6 + 2.25\ (573 - 460.9) = 3034.825$ kJ/kg

EXAMPLE 2.2

Determine enthalpy of 3 kg of steam at the following conditions:

(i) 90% dry at 10 bar

(ii) Superheated to 360°C, $C_{ps} = 2.25 \dfrac{\text{kJ}}{\text{kg K}}$ and pressure 10 bar.

Find also degree of superheat for superheated steam

GIVEN:

Mass of steam = 3 kg

At pressure of 10 bar, from steam table

$$T_s = 452.8 \text{ K}$$
$$h_f = 762.2 \text{ kJ/kg}$$
$$T_{sup} = 360 + 273 = 633°\text{K}$$
$$C_{ps} = 2.25 \text{ kJ/kgK}$$
$$h_{fg} = 2013.8 \text{ kJ/kg}$$
$$h_g = 2776.1 \text{ kJ/kg}$$

Enthalpy of 1 kg, wet steam (0.9 dry)

$$h_{wet} = h_f + xh_{fg} = 762.2 + 0.90\ (2013.8) = 2574.62 \text{ kJ/kg of steam}$$

Total enthalpy of 3 kg, wet steam

$$h_{wet} = 3 \text{ kg} \times 2574.62 = 7723.86 \text{ kJ}$$

Enthalpy of 1 kg of superheated steam, 360°C

$$h_{sup} = h_g + C_{ps}\ (T_{sup} - T_s) = 2776.1 + 2.25\ (633 - 452.8) = 3181.55 \text{ kJ/kg}$$

Enthalpy of 3 kg, superheated steam = 3181.55 × 3 = 9544.65 kJ

Degree of superheat = $T_{sup} - T_s = 633 - 452.8 = 180.2°$K

EXAMPLE 2.3

Nine kg of wet steam contains 2.1 kg of water droplets in suspension. Determine the dryness fraction of the steam.

Given:

Mass of wet steam = M = 9 kg = $M_f + M_g$

Mass of water droplets = M_f = 2.1 kg

Mass of dry steam = $M_g = M - M_f$

M_g = 9 – 2.1 = 6.9 kg of vapour

Dryness fraction of steam = $x = \dfrac{M_g}{M_f + M_g} = 0.766$

∴ Quality of steam = 76.6% dry

EXAMPLE 2.4

Enthalpy of wet steam at temperature 190˚C is 2400 kJ/kg. Determine the quality of steam and its wetness fraction. If 750 kJ of heat is added at constant pressure, find the final state of steam.

Given:

At saturation temp T_s = 190°C, from steam table

$$h_f = 807.5 \text{ kJ/kg}$$
$$h_{fg} = 1976.8 \text{ kJ/kg}$$
$$h_g = 2784.3 \text{ kJ/kg}$$
$$p = 12.55 \text{ Bar}$$
$$x = \text{Dryness fraction}$$

Enthalpy of wet steam = $h_{wet} = h_f + x.h_{fg}$

$$2400 = 807.5 + x(1976.8)$$

Dryness fraction x = 0.524

$$q = \text{Quality of steam} = 52.4\% \text{ dry}$$

Wetness fraction = 1 – x = 47.6% wet

Enthalpy of steam increases when heat energy of 750 kJ is added at constant pressure.

Enthalpy of steam = 2400 + 750 = 3150 kJ/kg

Hence, steam is superheated steam, since 3150 > h_g (2784.3)

$$\therefore \quad h_{sup} = 3150 = h_g + C_{ps}(T_{sup} - T_s)$$
$$3150 = 2784.3 + 2.25(T_{sup} - 190)$$
$$\therefore \quad T_{sup} = 162.53 + 190 = 352.53°\text{C} = 625.53°\text{K}$$

EXAMPLE 2.5

One kg of steam initially at 9 bar, has dryness fraction of 0.98. Find the quality of steam and its temperature at the following conditions:

(i) When steam loses 50 kJ/kg at constant pressure.
(ii) When steam receives 150 kJ/kg at constant pressure.

GIVEN:

At pressure 9 bar, $X = 0.98$ = dryness fraction.

$$T_{sat} = 175.4°C, \; h_f = 742.6 \text{ kJ/kg}$$
$$h_{fg} = 2029.5 \text{ kJ/kg}$$
$$h_g = 2772.1 \text{ kJ/kg}$$

Given steam is wet, with $x = 0.98$

Enthalpy of given wet steam $h = h_f + xh_{fg}$

$$h_{wet} = 742.6 + 0.98 \times 2029.5$$
$$h_{wet} = 2731.51 \text{ kJ/kg}$$

(i) When 50 kJ/kg of heat energy is lost, the enthalpy of steam = h_i = 2731.51 – 50 = 2681.51 kJ/kg.

Hence, steam is wet. Let dryness fraction be x_1

$\therefore \quad h_i = h_f + x_1 h_{fg}$

$2681.51 = 742.6 + x_1 (2029.5)$

$2681.51 = 742.6 + x_1 (2029.5)$

$x_1 = 0.955$ or 95.5% Dry

Dryness fraction of steam after heat loss is 0.955.

(ii) When heat energy of 150 kJ/kg is added

Enthalpy = $h_2 = h_{wet} + 150 = 2731.51 + 150$

$h_2 = 2881.51$ kJ/kg

$\therefore$ Enthalpy of steam is greater than saturated steam enthalpy at the same pressure, ie. 2881.51 > h_g (2772.1). Hence, steam will be in superheated condition. If C_{ps} = 2.25 kJ/kg K, then temperature of superheated steam.

$h_2 = h_{sup} = h_g + C_{ps} (T_{sup} - T_s)$

$2881.51 = 2772.1 + 2.25 (T_{sup} - 175.4)$

$T_{sup} = 224.02°C = 497.02°K$

Degree of superheat = $T_{sup} - T_s = 224.02 - 175.4 = 48.42°C$

EXAMPLE 2.6

Determine the internal energy, specific valume, mass density of 2.5 kg of steam at 20 bar, when

(i) With dryness fraction of 0.90

(ii) Superheated steam at 350°C and C_{ps} = 2.3 kJ/kg K

GIVEN:

Mass of steam = M = 2.5 kg

At pressure P = 20 bar, properties of steam, are (from steam table)

$$t_{sat} = 212.4°C$$
$$h_f = 908.5 \text{ kJ/kg}$$

h_{fg} = 1888.7 kJ/kg
h_g = 2797.2 kJ/kg
V_g = 0.09955 m^3/kg

(i) x = 0.90, dryness fraction.
Enthalpy of wet steam $h_{wet} = h_f + x\, h_{fg}$ = 908.5 + (0.9 × 1888.7) = 2608.33 kJ/kg
Internal energy of wet steam = $U_\omega = [h_w - 100\, p \times V_g]$ kJ/kg = 2608.33 – 100 × 20 × 0.9 × 0.09955 = 2429.14 kJ/kg of steam
U_ω = Internal energy of 2.5 kg of steam = 2429.14 × 2.5 = 6072.85 kJ
Specific volume of wet steam $V_{wet} = x\, V_g$ = 0.9 × 0.09955 = 0.089595 m^3/kg

Specific density (mass density) of steam $\rho_{wet} = \dfrac{1}{V_{wet}} = \dfrac{1}{0089595} = 11.16\dfrac{\text{kg}}{M^3}$

(ii) Internal energy of superheated steam
Enthalpy $h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$ = 2797.2 + 2.3(350 – 212.4)
h_{sup} = 3113.68 kJ/kg

Specific volume of superheated steam, $V_{sup} = V_g \dfrac{T_{sup}}{T_s}$

$$\therefore \quad V_{sup} = \frac{(350+273)}{(212.4+273)} \times 0.0995 = 0.1277 \text{ m}^3/\text{kg}$$

Internal energy of superheated steam = $U_{sup} = h_{sup} - 100\text{ P } V_{sup}$

$\therefore \quad U_{sup}$ = 3113.68 – 100 × 20 × 0.1277 = 2858.28 kJ/kg
Internal energy of 2.5 kg of superheated steam = 2858.28 × 2.5 = 7145.7 kJ

Mass density of superheated steam, $\rho_{sup} = \dfrac{1}{V_{sup}} = \dfrac{1}{0.1277}$ = 7.8308 kg/m^3

EXAMPLE 2.7

Calculate the enthalpy, specific volume and internal energy for steam at 30 bar (a) when it is 0.75 dry (b) when it is super heated to 400˚C

For p = 30 bar, t_s = 233.84°C
V_f = 0.0012163 m^3/kg; V_g = 0.06663 m^3/kg.
h_f = 1008.4 kJ/kg, h_g = 2802.3 kJ/kg

(a) For wet steam, x = 0.75
Enthalpy $h = h_f + x.h_{fg}$ = 1008.4 + 0.75 (2802.3 – 1008.4) = 2353.825 kJ/kg.
Specific volume – V_x.
$V_w = x.V_g$ = 0.75 × 0.0663 = 0.0499725 m^3/kg;

Internal energy $U_x = h - \dfrac{pV_x}{1000} = 2353.825 - \dfrac{30 \times 10^5 \times 0.0499}{1000} = 2203.9$ kJ/kg

(b) For superheated steam [C_p = 2.3 kJ/kg]

Enthaply $h_{sup} = h_g + C_p\,(T_{sup} - T_s) = 2802.3 + 2.3\,[400 - 233.84] = 3184.468$ kJ/kg

Specific volume $V_{sup} = V_s \dfrac{T_{sup}}{T_s} = \dfrac{0.06663(400+273)}{(233.84+273)} = 0.08847$ m^3/kg;

Internal energy $U_{sup} = h_{sup} - \dfrac{p.V_{sup}}{1000} = 3184.468 - 100 \times 0.08847 \times 30 = 2919.05$ kJ/kg

EXERCISES

1. Define the following terms:
   (a) Sensible heat
   (b) Latent heat
   (c) Enthaply of superheated steam
2. Explain the following,
   (a) Wet steam
   (b) Dry saturated steam
   (c) Dryness fraction
   (d) Superheated steam
3. Determine the enthalpy & specific volume for the following conditions of steam:
   (a) At pressure of 100 bar and 0.92 dry.
   (b) At a pressure of 0.24 Mpa and dry statured,
   (c) At a pressure of 20 bar and at a temperature of 400˚C,
   [**Ans.** (a) h = 2615.11 kJ/kg, V = 0.178 m^3/kg
   (b) h = 2706.3 kJ/kg, V = 0.885 m^3/kg
   (c) h = 3228.68 kJ/kg, V = 0.138 m^3/kg]
4. The steam of mass 1 kg is at pressure of 20 bar and has a specific volume of 0.125 m^3/kg. Determine the enthaply and internal energy of the steam. The specific heat of superheated steam = 2.3 kJ/kg.
   [**Ans:** h = 3081.9 kJ/kg, U = 2831.94 kJ/kg]
5. Find the following by using the steam tables:
   (a) Enthalpy and specific volume of steam of 0.85 dryness fraction at pressure of 18.3 bar.
   (b) Enthalpy and specific volume of steam at a pressure of 16 bar at 230°C the specific heat of steam C_p = 2.09 kJ/kg/K.
   (c) Dryness fraction of steam having enthalpy of 2550 kJ/kg at pressure of 4.5 bar.

[**Ans.** (a) h = 246275 kJ/kg; V = 0.136 m^3/kg
(b) 2851.47 kJ/kg; V = 0.131 m^3/kg
(c) x = 0.91]

2.2 BOILERS

A steam boiler or generator is a closed vessel in which water is heated to produce steam at a predetermined pressure and temperature. The source of heat is the combustion of fossil fuels in the combustion chamber. The heat is transferred from the combustion gases to the water through the tube walls. The wet steam generated by the primary heating is passed through the superheater coils to produce dry saturated or super heated steam. The supply pressure, quality and quantity of steam can be maintained at the desired level by controlling the water feed rate and the fuel combustion rate. The quality required depends upon the use of steam. The high pressure, superheated steam is required for power generation. The process industries require wet steam.

Classification of boilers: Boilers are classified on the basis of various criteria listed as follows:

(a) **According to the flow paths of water and gases**

1. **Fire tube or smoke tube boiler:** Combustion gases from the combustion chamber flow through the tubes immersed in stationary water contained in the boiler drum. The steam formed is stored in the space above the water in the drum.
2. **Water tube boilers:** Water from the boiler drum is circulated through tubes placed in the path of the combustion gases flowing from the furnace to the chimney. When the hot water enters the drum, the steam formed is released into the space above the water.

(b) **According to the location of furnace**

1. **Externally fired boiler :** The furnace is provided outside the boiler drum. Water tube boilers are generally externally fired boilers.
2. **Internally fired boilers :** The furnace is provided inside the boiler shell. The fire tube boilers are generally internally fired boilers.

(c) **According to the axis of the shell**

1. Vertical boilers: The axis of the drum is vertical.
2. Horizontal boiler: Axis is horizontal.

(d) **According to the number of tubes**

1. Single tube boiler: Contains only one fire tube or water tube.
2. Multiple tube boiler: Contains two or more fire tubes or water tubes.

(e) **Depending upon the circulation of water**

1. **Natural circulation boiler:** The natural thermo siphon action is the mode of circulation of water during the heating process.

2. **Forced circulation boiler:** A hot water pump is used to circulate water through the tubes.

(f) **According to the use**

1. **Stationary boilers:** Large boilers used in thermal power stations.
2. **Locomotive boilers:** The medium size boilers used in railways and road rollers.
3. **Marine boilers:** Large boilers used in ships. A few of the commonly used boilers are described below.

2.2.1 Lancashire Boiler

It is a horizontal, multiple tube, internally fired, fire tube, stationary boiler used in small and medium size power stations. It is now outdated and is replaced by modern compact packaged boilers.

Construction: The boiler consists of a long horizontal cylindrical steel shell with two steel fire tubes extending from the front end to the rear end. The tubes are placed in the lower half of the shell. The diameters of the tubes are large at the front end and smaller at the rare end. At the front portion of each tube, a grate is provided for placing and burning the fuel. At the end of grate, a fire bridge is provided to prevent

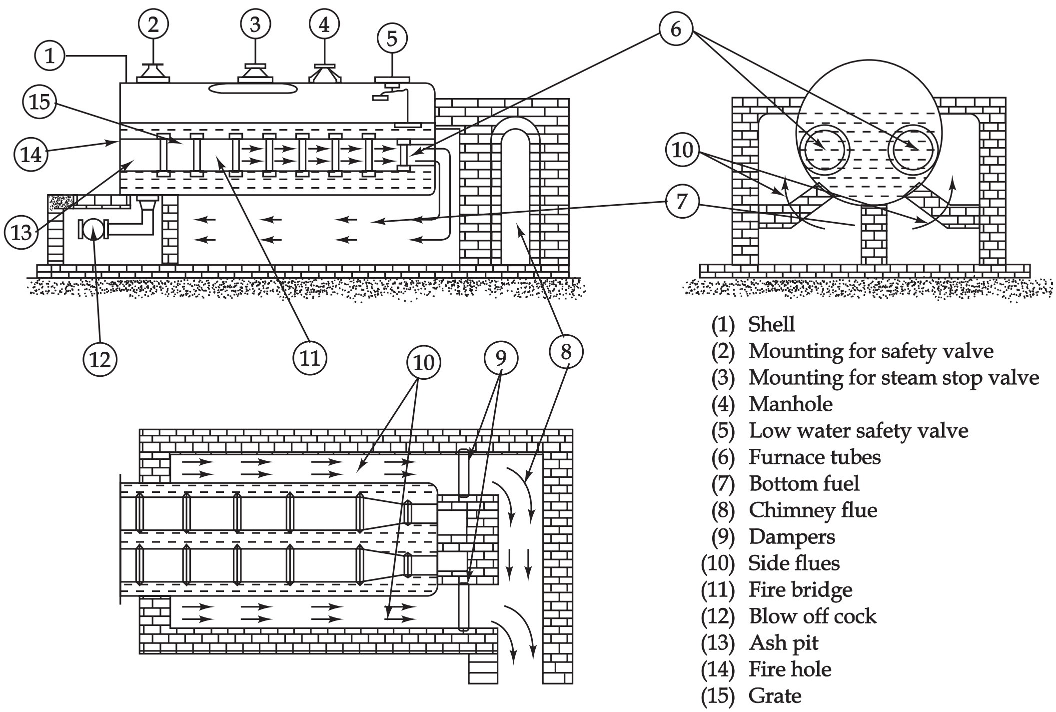


Fig. 2.2 Lancashire boiler.

the unburnt fuel and ash from entering into the fire tube. The portion of tube below the grate serves as ash pit. The shell is placed in a brick work so that only a small upper portion is open. The brick work is constructed such that three flues—one central flue, bottom flue and two side flues—are formed.

The chamber formed at the rear end of the drum connects the outlet of the two fire tubes to the bottom central flue. The central flue is bifurcated in the front and connected to the side flues. Thus, nearly three-quarters of the outer surface of the drum transfers heat from the combustion gases to the water. The two side flues are connected to a large flue leading to the chimney. The dampers are placed in the connecting passage to control the draught produced in the fire tubes and flues.

On the upper portion of the drum, steam-stop-valve, safety valves, etc., are mounted. A manhole at the top of the shell facilitates the repair and maintenance. A mud-hole with blow-off cock is provided at the bottom to remove the sediments.

The superheater coils are placed in the chamber formed at the rear end of the drum.

Working

The boiler-drum is filled with water so as to submerge the fire box and fire tubes completely. The minimum level of water to prevent the exposure of the fire tubes is maintained by means of a low water level safety valve. The coal is fed on to the grates and ignited. The combustion gases are deflected upwards into the fire tubes by the fire bridges. The flue gases travel to the rear of shell and are led into the bottom central fuel. The gases travel to the front heating the water from the bottom, then into the side flues heating the water from the sides. Then they are led to the chimney. Thus, the surfaces of fire box, fire tubes and the major part of the outer surfaces of the shell are utilized to transfer heat to water. The water evaporates and the steam formed is collected in the space above the water surface. The steam is drawn through the steam stop valve and passed through the superheater coils to superheat it.

Advantages

1. It is simple in design and operation.
2. Large quantities of steam can be produced.
3. The demand can be easily met.
4. It is easy to clean and maintain.

Disadvantages

1. Occupies large space.
2. The brickwork limits the working pressure and is costly to maintain.
3. The grate area is restricted.
4. The start up time is more.

2.2.2 Babcock and Willcox Boiler

It is a multiple tube, externally fired, stationary, water tube boiler. It produces steam at pressure of 11.5 bar to 20 bar at the rate of 20,000 to 40,000 kg/hr.

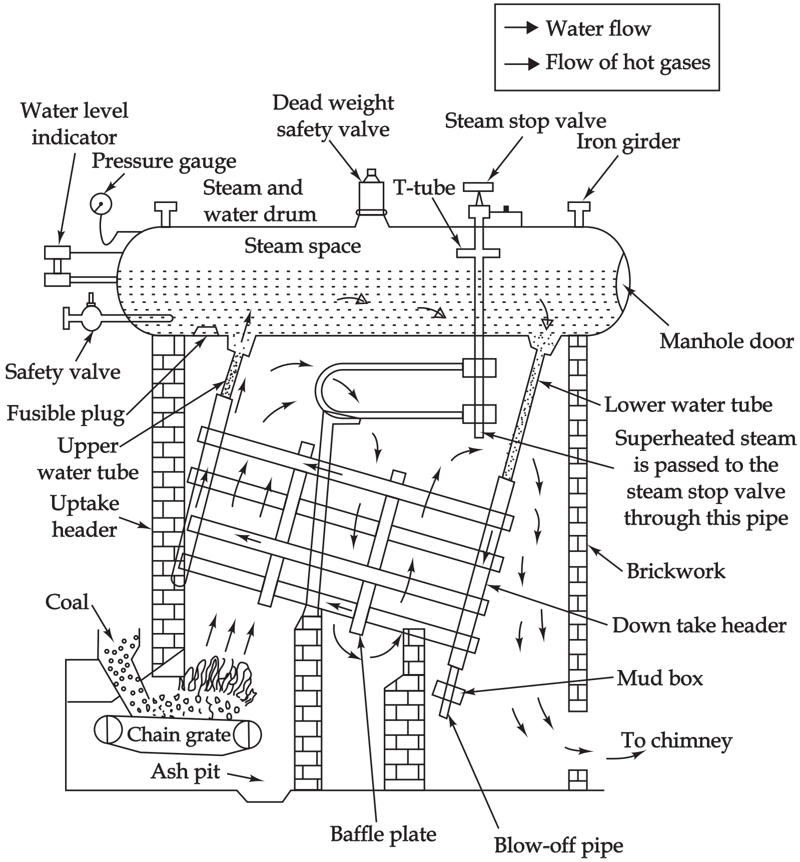


Fig. 2.3 Babcock and Wilcox water tube boiler.

Construction

The boiler consists of steel drum suspended horizontally from two girders and a bank of inclined water tubes between two headers placed below the drum. The down-take header at the rear end is at a lower level and is connected to the rear end of the drum and the uptake header in the front end is at upper level and is connected to the front bottom of the drum. The grate is provided below the uptake header. There is brick-work on all four sides up to the drum. There is an opening in the front for the grate and ash pit and another opening at the rear is connected to the chimney. There are doors at the side walls for cleaning and repair purpose. There are partition walls and baffles inside the brick chamber to guide the flue gases to flow over the water tubes many times. This ensures maximum heat transfer to the water flowing inside the tubes. The U tube superheater is placed below the drum, but above the water tubes. The inlet header of the superheater is connected to the priming pipe in the steam space. The outlet header is connected to steam stop valve. The safety valves and stop valve are mounted on the top of the drum. The pressure gauge and water level gauge are placed on the front cover of the drum.

Working: Water is supplied to the drum through a feed check valve by a feed pump working continuously to maintain the water level at half the height. The coal is fed on to the grate and burnt on it. Combustion gases are made to flow over the inclined water tubes two to three times before escaping to the chimney. The heated water in the tubes moves onto the steam drum through the uptake header. The cold water from the drum flows to the tubes through the downtake header. This thermosyphon circulation of water is maintained by continuous addition of heat from the combustion gases to the water in the inclined water tubes. As the temperature increases evaporation takes place and steam formed is stored above the water in the drum. The steam pressure is maintained by properly controlling the burning rate of fuel in the grate and water feed rate depending upon the demand for steam supply. The steam is passed through the superheater before supplying steam to the steam turbine or engine.

The flow of the flue gases is maintained by the natural draught provided by the chimney. This may also be assisted by an induced fan placed at the inlet to the chimney.

Advantages

1. Its overall efficiency is high.
2. Defective tubes can be replaced easily.
3. All the components are accessible for inspection even during the operation.
4. Draught loss is minimum.
5. Steam generation capacity is high.
6. Operating pressures are high.
7. Steam can be raised more quickly. Hence, it can be more easily used for variation of load.
8. The boiler rests over a steel structure independent of brickwork so that the boiler may expand or contract freely.

Disadvantages

1. It is less suitable for impure and sedimentary water. Water treatment is very much essential.
2. It involves high initial cost.
3. More time is required for installation.
4. Maintenance cost is high.
5. Failure in feed water supply even for a short period is liable to make the boiler overheated.
6. It is suitable for stationary applications only.

2.2.3 Locomotive Boiler

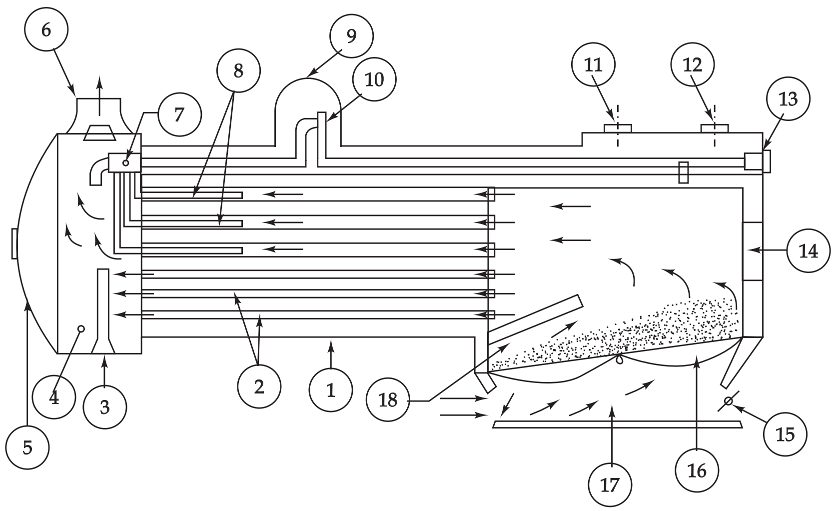
Locomotive boiler is a horizontal, multi-tube, artificial draught, internally fired fire tube boiler. The boiler is designed to meet the sudden and variable demand of steam. This type is widely used in railways.

Construction

The locomotive boiler consists of a large cylindrical steel drum. It is enlarged at the rear end to house a fire box. It has a smoke box in the front. There are a number of tubes connecting the fire box to the smoke box. The tubes are of two sizes. The upper set has large diameter tubes and houses superheater U tubes. The shell has a spherical dome to collect steam. A large pipe connects this space to the inlet header of the superheater, placed in the smoke box. A throttle valve is provided to control the flow of steam into the pipe. The valve is operated by a long rod from the driver's cabin at the rear of the boiler.

At the top of the smoke box a short chimney is provided to lead the flue gases into the atmosphere. A jet pipe connected to engine exhaust and placed at the bottom of the chimney provides the induced draught.

The fire box has a grate at the bottom and an ash pit below the grate. The opening in the front portion of the ash box, serves as a passage for the air from outside being pushed in by the movement of the railway. A fire door is provided at the rear end of the fire box for feeding the coal. The brick arch above the grate serves to deflect the combustion gases up the fire box. It also prevents the unburnt coal particles and ash from entering into the fire tubes. The safety valves and other accessories are mounted on the top of the drum.



(1) Shell
(2) Fire tubes
(3) Blast pipe
(4) Smoke box
(5) Smoke box door
(6) Chimney
(7) Superheater header
(8) Superheater tubes
(9) Steam dome
(10) Steam regulator
(11) Mounting for safety valve
(12) Mounting for whistle
(13) Leaver to operate regulator
(14) Fire hole
(15) Damper
(16) Grate
(17) Ash pit
(18) Brick arch

Fig. 2.4 Locomotive boiler.

Working: Water is filled nearly to three-fourth of the drum so as to submerge the fire tubes and top surface of the fire box. Coal is fed onto the grate through the fire door. Air is supplied through the bottom of the grate. The combustion gases are deflected up the fire box, heating the water surrounding the fire box. Then they flow through the fire tubes to the smoke box, heating water surrounding the tubes and the steam in the superheater U tubes. From the smoke box, flue gases escape to the atmosphere through the chimney. The movement of the railway causes a strong artificial draught. The exhaust pipe placed below the chimney provides an additional induced draught.

The steam formed as a result of the heat addition is stored in the steam dome. It is nearly dry. This steam is passed through the superheater tubes before being supplied to the engines. The pressure is maintained constant by controlling the fuel feeding and burning rate.

Advantages

1. It is compact.
2. It has high steaming capacity to meet the sudden demands for steam.
3. There is no brickwork, no heavy foundation and no tall chimney.
4. It is comparatively cheap.
5. It is portable.

Disadvantages

1. Sluggishness in water circulation.
2. Difficult to reach the interior of the drum for cleaning purposes.
3. Liability to corrosion is more.

2.2.4 Comparison of Water Tube and Fire Tube Boilers

1. Steam drum of a water tube boiler has smaller diameter than fire tube boiler. Hence, it can withstand higher pressure. The steam pressure can be higher in water tube boiler than in fire tube boiler.
2. Water tubes in a water tube boiler provide larger heat transfer area. The heat transfer efficiency is better. Steam can be produced at much faster rate than in fire tube boiler.
3. Water supplied to water tube boiler has to be more pure, free from contaminants to prevent corrosion and scaling of the tubes.
4. Cleaning and repair can be done more easily in water tube boilers than in fire tube boilers.
5. Failure of tubes in water tube boilers is less dangerous and damaged water tubes can be replaced more easily.

6. Furnace in water tube boilers is outside the drum. The modifications to the furnace can be done without much difficulty. In fire tube boilers the furnace is enclosed inside the drum and any modification to it cannot be done so easily.
7. Fire tube boilers are more compact and can be transported in ready-to-install condition. Heavy foundations are not required. Water tube boilers require complicated brickwork. They require heavy foundation. They have to be assembled on site. Thus, installation time is more for water tube boilers.
8. Fire tube boilers are portable and are suitable for mobile applications. The water tube boilers are suitable for stationary power stations.

2.2.5 Boiler Mountings and Accessories

Mountings

These are devices essential for the safety and control of the boiler operation. They are listed below.

1. Water level indicators.
2. Pressure gauge.
3. Safety valves.
4. Feed check valve.
5. Stop valve.
6. Blow off cock.
7. Fusible plug.

They are directly mounted on the boiler drum.

Accessories

They are devices required for improving the efficiency of steam generation. They are not mounted on the boiler drum but are a part of the system. They are listed below:

1. Economiser
2. Air preheater
3. Steam separator
4. Superheater
5. Steam trap
6. Feed pump

The functions of these devices are explained in the following sections:

Water level indicator consists of a vertical glass tube placed between two pipes. The top pipe is connected to the steam space and the bottom pipe is connected to the water space. The steam cock on the top controls the connections to the steam space. The water cock on the bottom pipe controls the connection to the water space. When the cocks are open the water level in the glass tube is equal to the level of water in the drum. This level should not be below the minimum level mark on the glass tube.

The periodic readings of the level are taken and recorded.

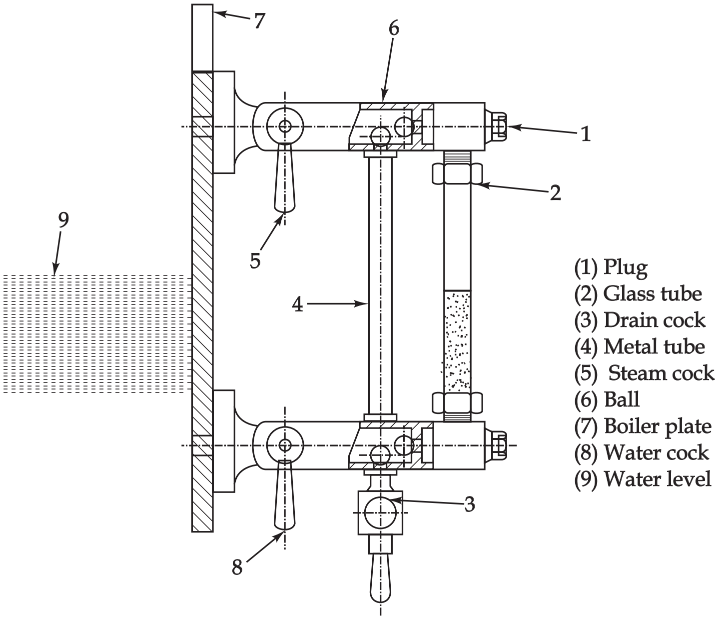


Fig. 2.5 Water level indicator.

Pressure gauge

Usually, Bourdon pressure gauge is used to measure steam pressure. The gauge essentially consists of a phosphor bronze tube of elliptical cross section. The tube is bent in the form of a spiral of three-fourths turn. One end of the tube is connected to a hollow block, the block in turn is connected to a U tube siphon. The siphon is filled with water. The other end of the siphon is connected to the steam space of the boiler. The other end of the spiral tube is closed and free. This end is connected to a toothed sector through a lever mechanism. The toothed sector activates the pinion at centre. The pinion carries a pointer which moves on a graduated circular scale.

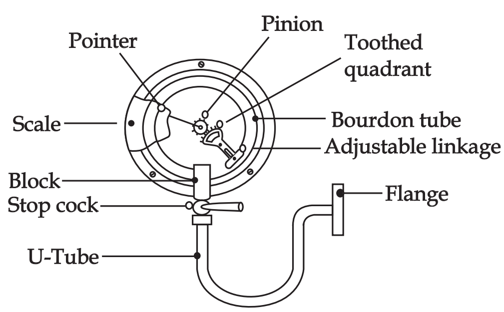


Fig. 2.6 Pressure gauge.

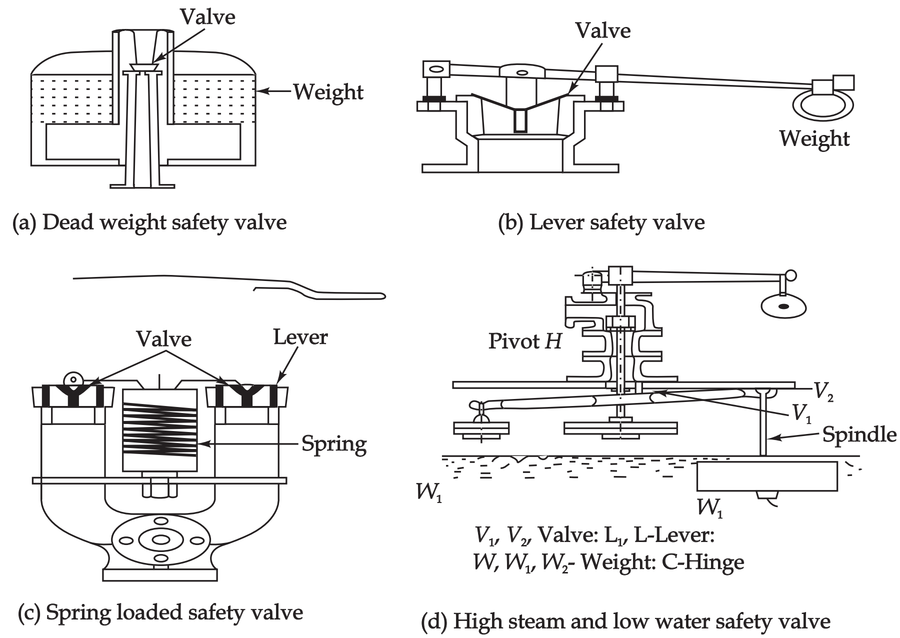


Fig. 2.7 Safety valves for boilers.

When the cock is open the steam pressure acts on the water in the siphon tube and spiral tube. The spiral tube tends to straighten out. The free end moves and activates the pinion. The dial moves on the scale and indicates the pressure. The periodic readings of the pressure are noted and recorded.

Safety valves

The following safety valves are normally used:

(a) Dead weight safety valve
(b) Lever safety valve.
(c) Spring loaded safety valve.
(d) High steam and low water level safety valve.

Safety valves are mounted on the boiler drum and are connected to the steam space. The valves are designed to operate at a predetermined pressure. Whenever the pressure of the steam exceeds the value, the valve opens and releases the steam. The steam so released operates a siren. On the release of the excess steam, the pressure inside the boiler is reduced and the valve is closed. The low water safety valve performs an additional function as explained below.

This valve is activated by a float placed in water. Whenever water level goes down, the float also moves down. This movement operates the valve through a lever mechanism. The valve opens and releases steam through a siren. This gives warning to the operator to feed water.

Blow-off cock

It is a simple on off valve connected to the bottom most portion of the boiler. When it is open, the water gushes out carrying sediments collected in the boiler. It is required for periodic cleaning and inspection.

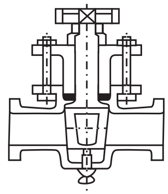


Fig. 2.8 Blow-off cock.

Fusible plug

Fusible plug is a safety device used to extinguish fire in fire tube boilers, whenever water level in the drum goes below the normal level. The device is mounted on the crown portion of the fire box or furnace or combustion chamber.

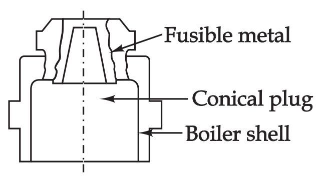


Fig. 2.9 Fusible plug.

In the normal conditions the plug is submerged in water and the fusible metal is intact and holds the conical plug in place. Whenever water level goes below the normal level, the plug is open to steam space, the fusible metal is now heated and melts. The conical plug falls in the fire box. The steam enters the fire box through the opening and extinguishes the fire. The plug is designed to operate in extreme situations.

Economizer

The economizer is basically a heat exchanger to recover the heat from the flue gases. It consists of a number of vertical tubes between the inlet header at the bottom and outlet header at the top. It is placed in the passage of the flue gases to the chimney. The feed water enters the inlet header and moves up the tubes to the outlet header at the top. The water receives heat from the hot flue gases flowing across the tubes and temperature increases. The thermal level of the water entering the boiler is higher. The heat requirements, in the boiler to raise steam is reduced and the fuel consumption is reduced. The heat carried away by the flue gases is also reduced. Thus, the overall efficiency of the boiler is increased.

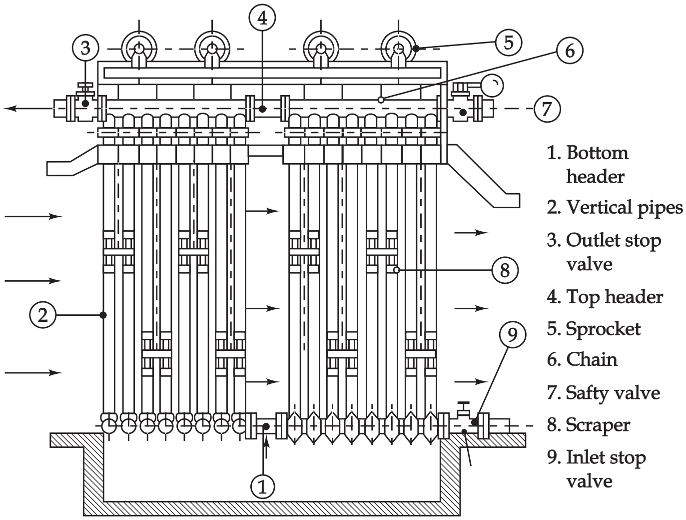


Fig. 2.10 Economiser.

The economiser is provided with a safety valve and a blow-off cock. Advantages of the ecnomiser are:

1. Fuel economy.
2. Increase in steam generation rate.
3. Long life of the boiler. Increase in the overall efficiency of the boiler.

Air preheater

A air preheater is a heat exchanger to recover heat from the flue gases by preheating the inlet air. It consists of a number of tubes through which the flue gases are made to flow. The inlet air is made to flow across the tubes many times over by providing baffles across the bank of tubes. The inlet air absorbs the heat from the flue gases and its temperature is increased. The hot air improves the combustion process

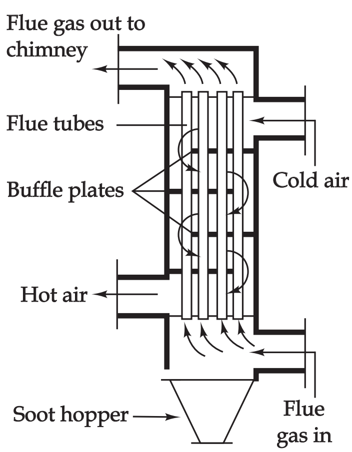


Fig. 2.11 Air preheater.

reducing the formation of soot, smoke and ash. The inferior quality of fuel can be burnt. Thus, the combustion efficiency is increased and the overall efficiency of boiler is also increased.

Superheater

A superheater consists of a number of U tubes between the inlet header and the outlet header. The inlet header is connected to the steam space through an anti-priming pipe. The outlet header is connected to the steam stop valve. The superheater coils are placed in the passage of the flue gases. The steam in the coils receives heat from the flue gases and gets superheated. This superheating reduces the condensation loss in the steam mains and in the engine cylinder. More work is extracted from the superheated steam in the engines and turbines due to the increased temperature range. The absence of moisture in the inlet steam reduces the corrosion of the turbine blade.

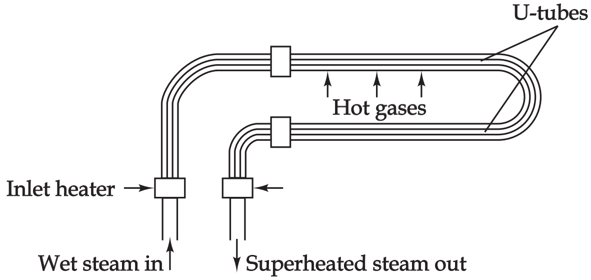


Fig. 2.12 Superheater.

Steam trap and steam separator are the devices used to remove the condensate from the steam mains.

Steam trap

It is mounted on a small bypass pipe branching from the main steam line. The steam does not pass through it. The device collects the condensate water particles from the steam mains and discharges periodically.

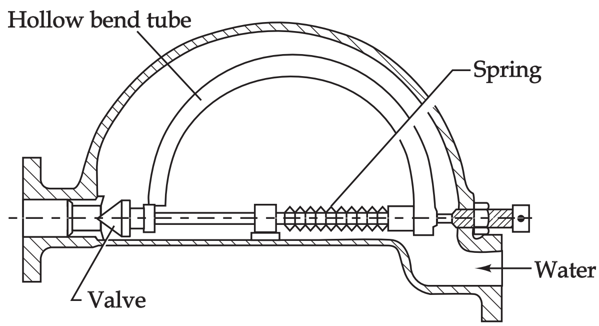


Fig. 2.13 Steam trap.

Steam separator

It is a device mounted on the main steam pipe very close to the engine or turbine. In this device water particles are removed from the steam by changing its direction of flow. Due to the higher inertia, the water particles cling to the baffle plates and only the dry steam leaves the separator.

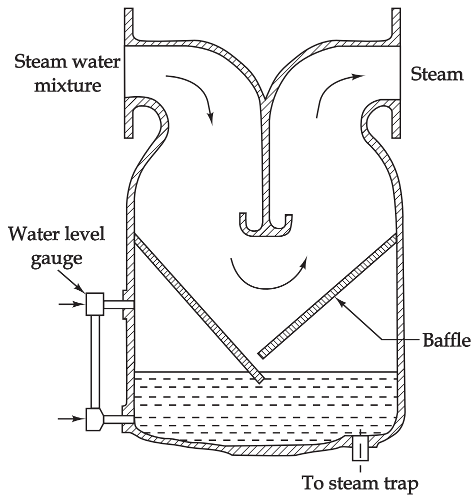


Fig. 2.14 Steam separator.

Injector

A injector consists of a steam cone, combining cone and a delivery cone. A conical spindle is placed at the top end of the steam cone and controls the quantity of the

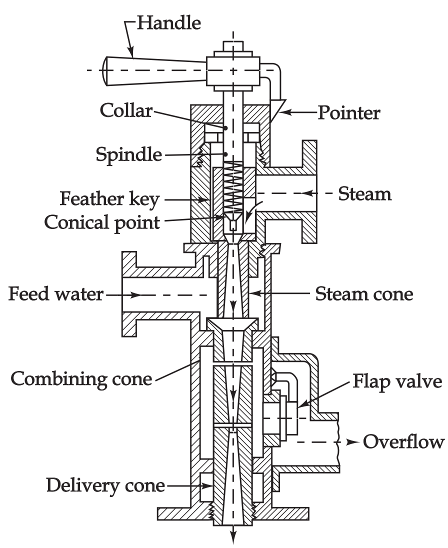


Fig. 2.15 Injector.

steam entering the steam cone. The bottom end of the steam cone rests on the top of the combining cone. The space between the steam cone and the combining cone acts as a water pump due to the vacuum created by the flow of the steam through the cone.

The quantity of the water pump is regulated by the movement of the steam cone and the amount of the steam supplied by the movement of the conical spindle with the help of the handle at the top. The steam and water mix in the combining cone and are injected into the drum through the delivery cone. The movement of the spindle is indicated by the pointer attached to its handle at the top.

EXERCISES

1. Explain a boiler and its functions.
2. How are boilers classified?
3. Differentiate between the following.
   (a) Internally fired and externally fired boilers.
   (b) Fire tube and water tube boilers.
4. Name fire tube boilers and describe one of them.
5. Sketch and describe a water tube boiler.
6. Sketch and describe Lancashire boiler.
7. What are the boiler mountings?
8. What are the functions of the mountings?
9. What are the boiler accessories?
10. What are the functions of the boiler accessories?
11. Differentiate between the boiler mountings and accessories.
12. Explain the necessity of the mountings on the boiler.
13. Differentiate between steam trap and steam separator.
14. Differentiate between safety valve and stop valve.
15. Name the boiler accessories useful in heat recovery. Explain their effectiveness on the boiler operation.
16. Name the devices which ensure safe operation of the boiler.
17. Explain the basic functioning principle of safety valves.
18. Explain the functions of economizer and air preheater.

3 Turbines

CHAPTER 3

3.1 STEAM TURBINES

From the early days of reciprocating steam engines, attempts have been made to obtain power from steam by using a purely rotary engine, similar to water wheels and wind mills. The first rotary machine was made by Hero of Alexandria in AD 50

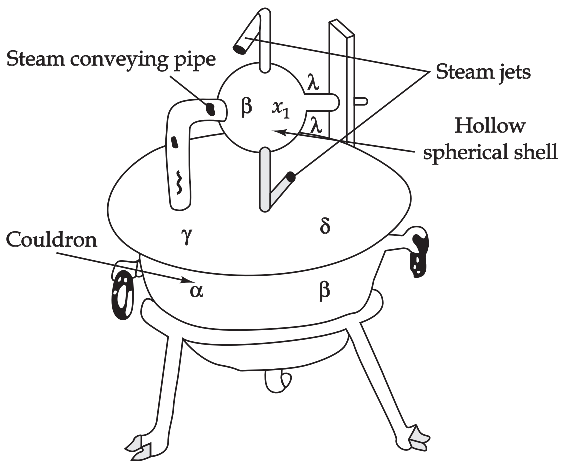


Fig. 3.1 (a) Hero's turbine.

In this model (Fig 3.1a) a hollow spherical shell is mounted on two pivots, one pivot conveyed steam from couldron below to the shell. The steam is made to flow out through two nozzles mounted tangentially on two radial arms attached to the ball. The reaction of the steam jets from the nozzles causes rotary motion of the ball. This is the principle of pure reaction turbine.

In the year 1629, Giavanni Branca developed another type of turbine. In this (Fig 3.1 (b)) steam is made to expand through a stationary nozzle. The high velocity jet impinges on a set of vanes fixed on a disk. The vanes deflect the jet of steam through an angle. The resulting change in momentum causes rotation of the vanes. This is the principle of a pure impulse turbine.

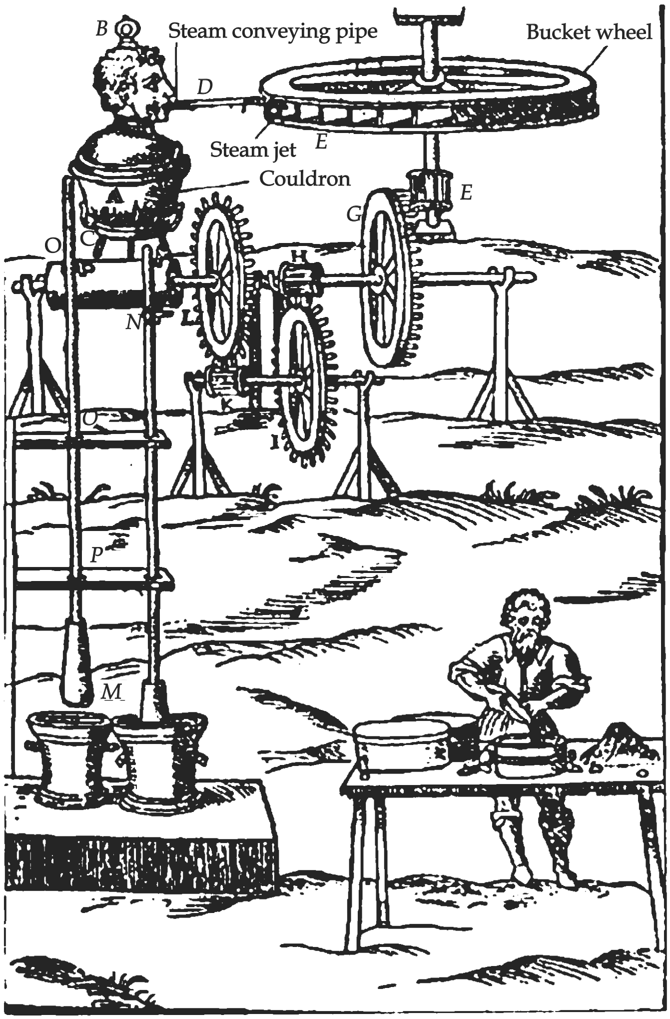


Fig. 3.1 (b) Branca's turbine.

A simple impulse turbine developed by De Laval in 1889 is shown in Fig. 3.2. The working of this turbine is explained below. As the steam flows through the stationary nozzle (A), it expands. The pressure energy is converted into kinetic energy. A high velocity jet comes out of the nozzle. This jet is made to impinge on the set of bent blades fixed on the circumference of a disc keyed to the shaft. As the steams flow over the blades, it is deflected through an angle. This change in direction causes an impulse on the blades. The blades move and rotate the shaft.

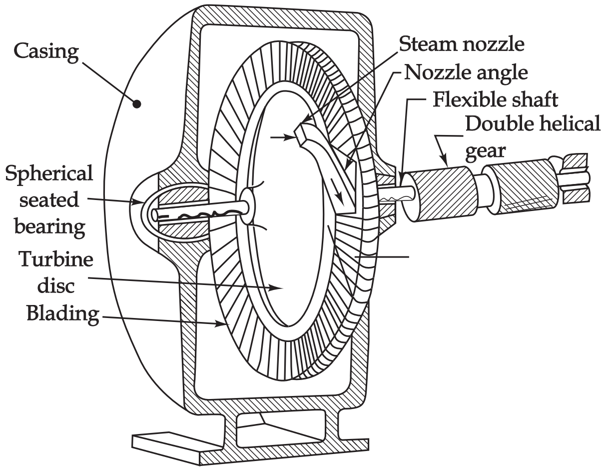


Fig. 3.2 De Laval model.

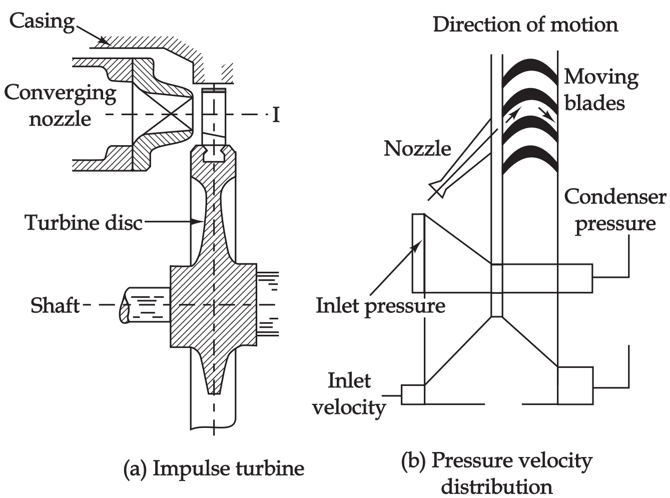


Fig. 3.3 Impulse turbine

The simple impulse turbine developed by De Laval revolved at a phenomenal speed of 30,000 rpm. The single-stage model has the following disadvantages.

1. The high rotational speed of the shaft necessitates a speed reduction unit.
2. The exit velocity of the steam is very high and hence a large quantity of kinetic energy is lost.
3. There is a large amount of steam consumption.
4. Due to high pressure difference the leakage and friction losses are more.
5. The overall efficiency of the turbine is less.

To overcome these defects, the following three methods of compounding are adopted:

1. Velocity compounding.
2. Pressure compounding.
3. Pressure velocity compounding.

3.1.1 Velocity Compounding

Here additional sets of fixed and moving blade rings are provided after the first set. The high velocity steam from the first set of moving blades passes over to a set of fixed guide blades. These blades are bent in reverse direction. They change the direction of the steam flow and guide it onto the second set of moving blades mounted on the same hub. More kinetic energy is absorbed in this set. One or more sets of fixed and moving blades may be added for further absorption of kinetic energy.

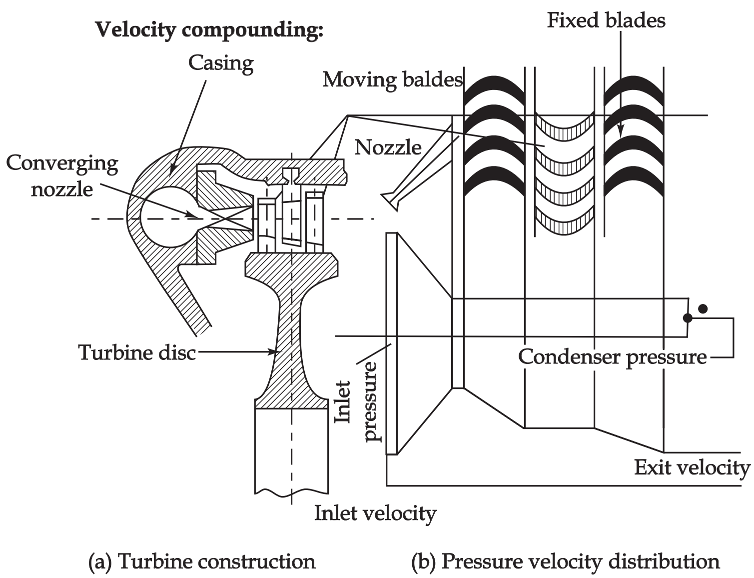


Fig. 3.4 Two-stage velocity compounded turbine.

Energy absorbed in each stage is equalized and output shaft speeds are much lower and practically acceptable.

3.1.2 Pressure Compounding (Rateau-1898)

Steam pressure is made to drop in a number of stages by arranging several De Lavel turbines in series on a common shaft. Steam expands to an intermediate pressure in each nozzle set. Steam jet velocity is small and kinetic energy absorbed by each moving blade is also small. Thus, the rotational speeds are in the practically acceptable range. The frictional losses are also less. Thus, pressure compounding produces a highly efficient turbine. But because of more number of nozzles and accompanied sealing arrangements these turbines are very expensive.

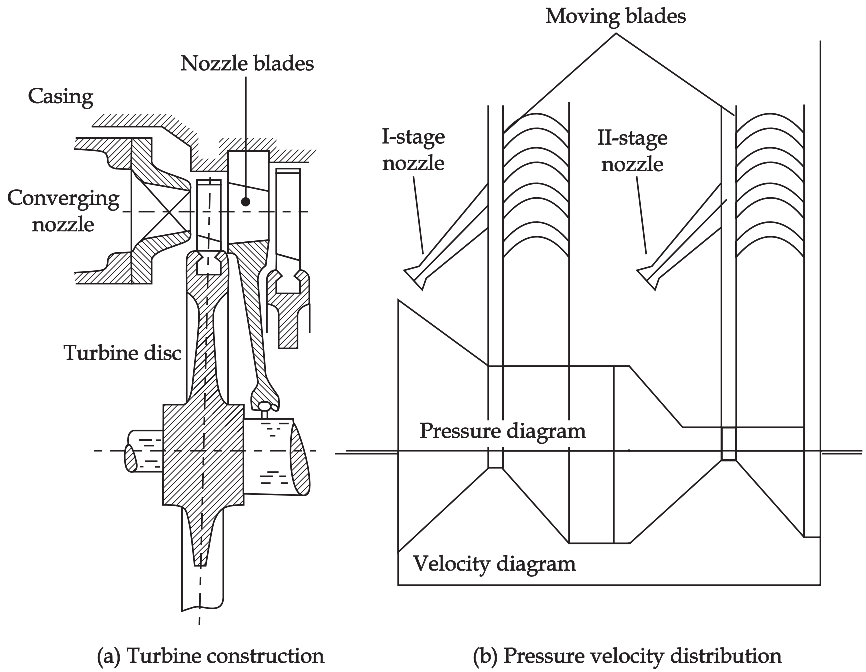


Fig. 3.5 Two-stage pressure compounded turbine.

3.1.3 Pressure Velocity Compounding

This is an attempt to combine the advantages of velocity and pressure compounding. This is equivalent to putting two or three units of velocity compounded turbines in series with a common shaft. Steam expands to an intermediate pressure in the first nozzle set and the resulting velocity is compounded in two or three stages.

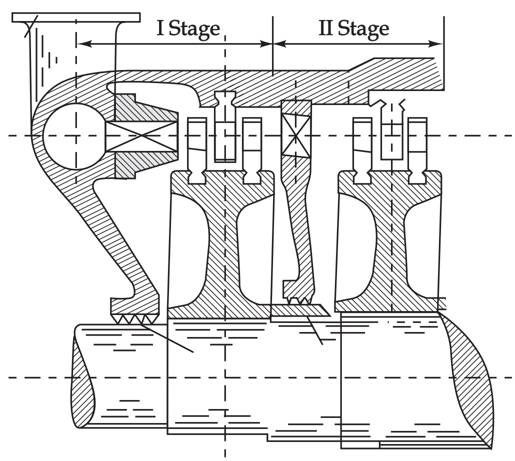


Fig. 3.6 (a) Turbine construction.

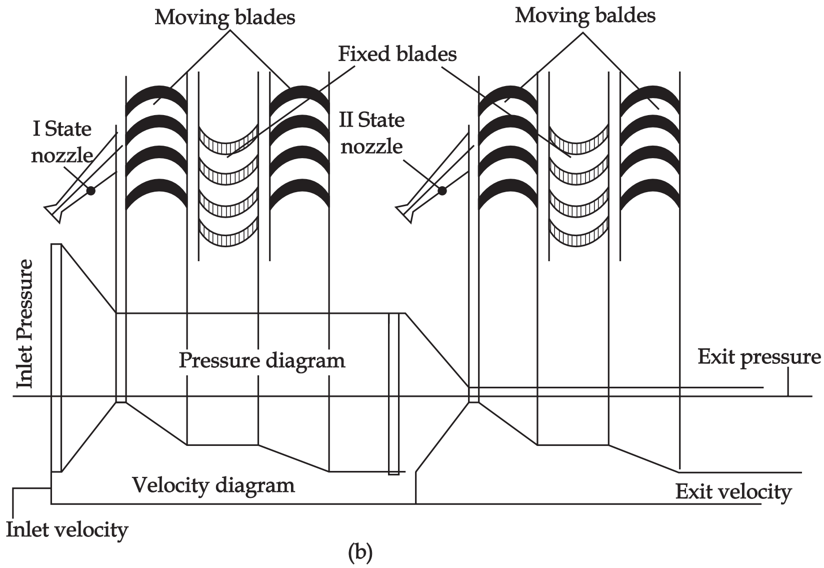


Fig. 3.6 (b) Pressure velocity distribution.

The steam from the first stage passes through the second set of nozzles expanding to the next lower pressure stage. The resulting. velocity is again compounded in two or three stages. This is continued until the pressure drops to the exhaust pressure. The turbine has larger pressure drop in each stage. The velocities obtained in each stage are moderately high.

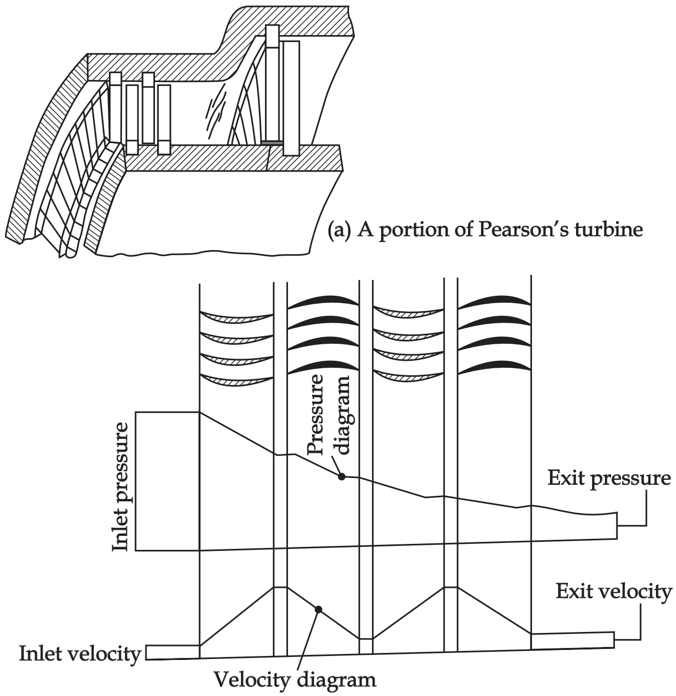
The optimum combination of cost and efficiency is attained in this type of turbine. This method is adopted in Curtis and Moore turbines.

3.1.4 Reaction Turbine

(Pearson's turbine) Realising the inefficiency of working with high velocity steam, Sir Pearson (1884) proposed to expand the steam continuously as it flows through the fixed and moving blades.

It is like a pressure compounded turbine with the nozzles being replaced by a ring of fixed blades with converging passages between the adjacent blades. The moving blades also have converging passage between them. The steam as it passes through the fixed blades, expands to an intermediate pressure and the steam jets are directed on to the moving blades. As the steam passes over these blades, it gets deflected and also expands causing both impulse and reaction on the moving blades. The steam passes to the next set of fixed and moving blades, until the pressure drops to the condenser pressure.

The pressure drop and gain in velocity of steam during its flow over the fixed blades are arranged to be equal. This ensures equal drop in pressure and velocity over moving blades. Pearson's turbine uses this impulse reaction principle.



(a) A portion of Pearson's turbine

(b) Pressure, velocity distribution

Fig. 3.7 Two-stage reaction turbine.

The pressure drop in each stage is small. The leakage is not a serious problem. The lower speeds of steam result in lower rotational speeds. The frictional losses are less and the turbine is much more efficient.

3.1.5 Comparison of Impulse and Reaction Turbines

1. In impulse turbines the expansion of steam occurs in the stationary nozzles and there is no pressure drop across the moving blades, whereas in reaction turbines the pressure drop occurs over both stationary and moving blades.
2. The blades in the impulse turbines are symmetrical, whereas in reaction turbines they have an aerofoil cross section providing convergent passage between the blades.
3. The steam velocities are very high in impulse turbines and are moderate in reaction turbines.
4. The frictional losses are more in impulse turbine than in reaction turbines.
5. Reaction turbines are more efficient than the impulse turbines.
6. Impulse turbines occupy less space than reaction turbines.
7. Reaction turbines are costlier than impulse turbines.
8. For large power stations, reaction turbines are better suited than impulse turbines.
9. Vibrations are less in reaction turbines.

3.1.6 Comparison of Turbines with Other Prime Movers

1. Much higher speeds and far greater speed ranges are possible in turbines than in reciprocating engines.
2. Perfect dynamic balance is possible in turbines, but this is not possible in reciprocating engines.
3. A turbine extracts more power from a given steam, than a steam engine.
4. Enormous quantities of power can be produced by turbines whereas capacities of reciprocating engines are limited.
5. Materials are used to their best advantage in turbines.
6. Turbines are more durable than other prime-movers.
7. Steam consumption remains comparatively constant in steam turbines, whereas in steam engines, the consumption increases with years of service.
8. Turbines provide a more uniform torque.
9. Turbines require less lubrication resulting in reduced maintenance cost.
10. Exhaust steam from turbines is comparatively free from oil.
11. Overload capacity of turbines is more than that of steam engines.
12. Governing is simpler in turbines.

3.2 GAS TURBINES

A gas turbine is a thermal prime mover, which converts heat energy of the hot air or burnt gases into mechanical work, in the form of rotation of the shaft. It works similar to steam turbines, but the working medium is hot air or burnt gases in place of steam.

Gas turbines are used in aircraft (due to the higher power to weight ratio). They are also used in trains, ships, tanks, power plants and turbojets. Fuels used for running gas turbines include coal, kerosene, coal gas, gasoline, etc.

Classification of gas turbines

There are mainly two types, based on the flow of the working substance during running of the turbines.

1. Constant pressure open cycle gas turbine.
2. Constant pressure closed cycle gas turbine.

3.2.1 Constant Pressure Open Cycle Gas Turbine

Working Principle: Here the fuel is burnt in a combustion chamber at constant pressure with highly compressed air. The products of combustion hot gases at high temperature and high pressure flow through the turbine, and develop mechanical work and convert heat energy to mechanical energy.

Construction: Following is the line diagram of an open cycle gas turbine.

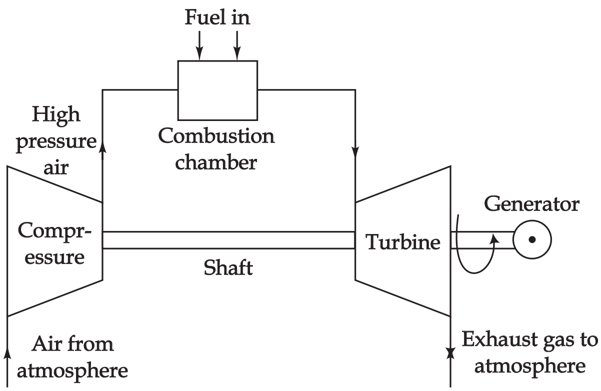


Fig. 3.8 Open cycle gas turbine.

Main components of an open cycle gas turbine are

(a) Rotary compressor.
(b) Combustion chamber.
(c) Reaction turbine.
(d) Generator.

Compressor turbine and generator are mounted on a common shaft, and certain power is used for running the compressor.

The compressor draws air from the atmosphere and compresses it to a high pressure. The compressed air flows into the combustion chamber, where the fuel is at constant pressure and the burnt, hot gases are at high pressure and high temperature flow through the blades of reaction turbine and develop mechanical energy by rotation of the turbine shaft. The turbine shaft is coupled to the generator for developing electrical energy or any other device like ship's propeller for developing useful work.

The burnt or exhaust gases coming out of the turbine are exhausted in the atmosphere. Hence, it is called open cycle gas turbine.

3.2.2 Constant Pressure Closed Cycle Gas Turbine

Working Principle: In this turbine, working medium air or gas (nitrogen, argon, helium, carbon dioxide) does not come in direct contact with burnt gases but heat energy of fuel combustion is transferred to the working medium in the heat exchanger and the working medium is cooled in a intercooler and recirculated for the next cycle.

Construction: Main components of a closed cycle gas turbine are:

(a) Compressor (rotary)
(b) Heater or exchanger
(c) Turbine (reaction)
(d) Generator

In the working of gas turbine, initially working medium (air or stable gas) is compressed to a high pressure by rotary compressor and flows into the heat exchanger. In heater or heat exchanger, externally burnt fuel supplies heat energy to the working medium by means of heat transfer from burnt gases.

Now high pressure and high temperature working medium develops mechanical energy as it expands in the turbine and the turbine shaft is coupled to the generator, for developing useful energy.

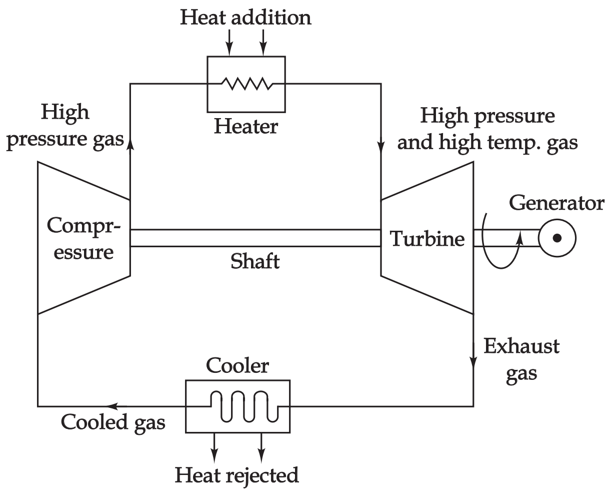


Fig. 3.9 Line diagram of closed cycle gas turbine.

From the turbine, working fluid (air or gas) at low pressure passes through the intercooler and is cooled to low temperature. This cold working medium is recirculated into the compressor from the next cycle. Hence, this is called closed cycle gas turbine.

3.2.3 Comparison Between Open and Closed Cycle Gas Turbines

Open Cycle Gas Turbine	*Closed Cycle Gas Turbine*
1. Combustion chamber is small in size and combustion product is working medium	1. Large heat exchanger is necessary to transfer heat energy to working medium (air or gas)
2. Initial cost is less	2. Cost is more due to heat exchanger and intercooler
3. Maintenance cost is less	3. Comparatively high cost
4. Weight of turbine per kW power developed is very low and suitable for aircraft engines	4. Weight to power ratio is high and not suited to aircraft engines
5. Burnt gases are exhausted to atmosphere from the turbine	5. Working medium is (air or gas), which is cooled and recirculated

Contd...

6. Fresh air enters the cycle in each operation	6. Same working medium recirculated
7. Since compressed air mixes with burnt gases, mass of working medium increases	7. Mass of working medium remains same
8. Since burnt gases come in contact with blades of turbines, they are subjected to corrosion	9. Efficiency is comparatively higher

3.2.4 Advantages of Gas Turbines over Steam Turbines

1. Initial investment and maintenance costs are less.
2. Weight to power developed is low.
3. Commonly used for aircraft, rockets, jet engines.
4. Boiler and feed water are not required.
5. Most reliable prime mover.
6. Lubrication is simple.

3.2.5 Advantages of Gas Turbines Over Internal Combustion Engines

1. Economy of fuel (any fuel can be used)
2. Weight to power output is low.
3. More reliable prime mover.
4. Mechanical efficiency is higher.
5. Lubrication is simple.
6. No vibrating parts, hence balancing problem is avoided.

3.3 HYDRAULIC OR WATER TURBINES

Hydraulic turbine is a prime mover which converts hydraulic energy of water into mechanical energy. This mechanical energy, in turn, is converted into electrical energy by an electrical generator coupled to the turbine shaft.

Hydraulic power plants are constructed near a large water reservoir and generate electricity by utilizing the water energy. Hydraulic turbines are very useful as they respond to sudden increase in the electricity demand. They are environment friendly, no fuel is required, maintenance is negligible, hence more economical than thermal power plants.

3.3.1 Classification of Hydraulic Turbines

Hydraulic turbines are developed to generate power and depends on availability of water head, quantity of water, type of energy available at the inlet of the turbine. Classification of turbines is based on:

1. **Type of energy available at the inlet of the turbine**
   (a) **Impulse turbine:** The energy available at the inlet of the turbine is only kinetic energy, e.g., Pelton turbine.

(b) **Reaction turbine:** At the inlet of the turbine, both kinetic energy and pressure energy are available, e.g., Kaplan turbine, Francis turbine and propellor turbine.

2. **Available head at the inlet of the turbine**

(a) **High head turbines:** When the head is available in between 100-1000 metres, at the inlet of the turbine, they are called impulse or high head turbines, e.g., Pelton turbine.

(b) **Medium head turbine:** Water head is available between 50 and 100 metres, e.g., Francis turbine.

(c) **Low head turbines:** Head available at the entry of the turbine is less than 50 metres, e.g., Kaplan turbine.

3. **Direction of water flow through the runner of turbine**

(a) **Tangential flow turbine :** Water flows along the tangential direction to the runner, e.g., Pelton wheel.

(b) **Axial flow turbine:** In this turbine, water flows in a parallel direction to the axis of the turbine, e.g., Kaplan turbine.

(c) **Radial flow turbine:** Water flows in radially inward or radially outward direction through the runner, e.g., Thomson turbine, Francis turbine.

(d) **Mixed flow turbine:** Water flows radially inwards along the runner and leaves axially, e.g., modern Francis turbine.

3.3.2 Pelton Turbine (Pelton Wheel)

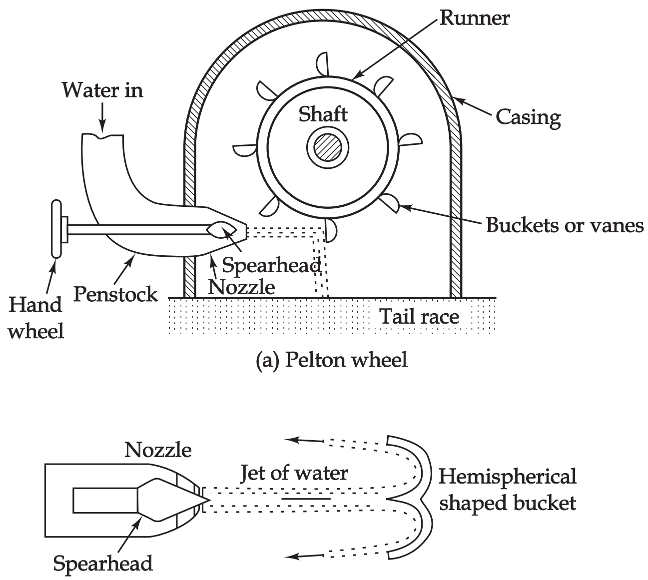
Pelton turbine is classified as an impulse turbine, with tangential flow. It is used for high head and small discharge of water.

Working of Pelton turbine

The main components of Pelton turbine are:

(a) Runner and buckets
(b) Nozzle with a spearhead
(c) Turbine casing

The runner of this turbine is a circular wheel with a series of evenly spaced buckets, which are fixed on the periphery. Cup-shaped buckets or vanes are shaped like a bowl or a double hemispherical cup. The water jet strikes the cup and splits and flows tangentially along the surface of the vane. This helps to eliminate the axial thrust on the bearing and the output shaft nozzle with spearhead controls the rate of water flow into the turbine, by operation of a hand wheel. Number of nozzles depend on the power requirement. The nozzle is arranged around the runner wheel such that the water jet emerging from the nozzle is tangential to the circumference of the runner wheel.



(a) Pelton wheel

(b) Flow of water on bucket

Fig. 3.10 Pelton wheel.

Turbine casing is provided as a cover to prevent splashing of water and helps the water outflow into the tail race.

Working: Water from a reservoir having high potential energy (high head) flows through a pipeline (penstock) and enters the nozzle. In the nozzle, high head of water flow is completely converted to the kinetic energy and water jet from the nozzle with high velocity strikes the buckets or vanes. Number of vanes are circumferentially fitted on runner and water jet strikes the vanes continuously. This helps in rotation of the runner shaft and kinetic energy of water is converted to mechanical energy and turbine shaft is coupled to a generator, to develop electricity. After doing useful work, water flows into the tail race, e.g., Pelton turbines at Sharavathi (Karnataka), Koyana (Maharashtra).

3.3.3 Francis Turbine

Francis turbine is a reaction turbine with mixed flow and used for medium heads. Main components of this turbine are as follows:

(a) Runner
(b) Guide wheel
(c) Spiral casing
(d) Draft tube

Runner is a circular wheel on which a number of curved blades are fixed—between 16 and 24. This runner is coupled to a rotating vertical shaft.

Guide wheel is a stationary wheel around the runner of the turbine. Number of guide blades (which are stationary) are fitted on the guide wheel. The guide blades guide the water to strike the moving blades at a particular angle and the blade design creates nozzle effect on water, i.e., pressure energy of the water is converted to kinetic energy as it flows through the blades.

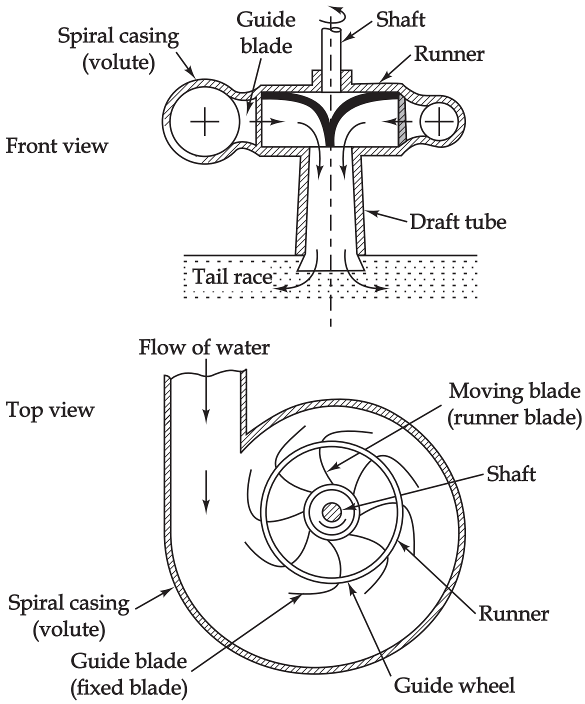


Fig. 3.11 Francis turbine.

The spiral casing is a closed passage surrounding the guide blades and its cross–sectional area gradually decreases along the flow direction. The spiral casing is also known as scroll casing or volute.

Draft tube is a tube or pipe with diverging cross–sectional area, fitted at the exit of the turbine for discharge of water to the tail race.

Working: Water from reservoir flows through the penstock and enters the spiral casing. The water flow is directed by guide vanes and as water flows radially inwards, pressure energy is converted to kinetic energy. As the water flows over the moving blades, there is reaction. Force on the runner of the turbine and the runner begins rotary motion. Hence, hydraulic energy is converted into mechanical energy and this, in turn, is coupled to a generator for developing useful electrical energy.

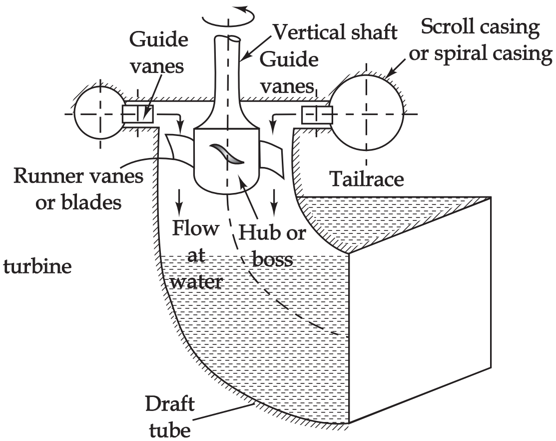
Francis turbines are installed at:

1. Shivan Samudram (Karnataka)
2. Bhakra (Punjab)
3. Gandhi Sagar (Rajasthan)

3.3.4 Kaplan Turbine

Kaplan turbine is classified as a low head, high discharge reaction turbine. This turbine is commonly used for power generation from rivers with low head. Main components of Kaplan turbine are scroll casing, hub, fixed blades, guides vanes and draft tube.

(a) Kaplan turbine



(b) Kaplan turbine runner

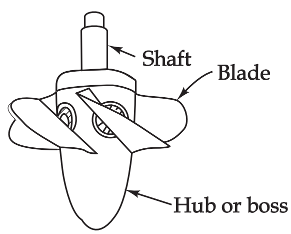


Fig. 3.12 Kaplan turbine.

The Kaplan turbine has a hub (boss) fixed to a vertical shaft. The runner blades attached to the hub are adjustable, depending on load. Runner has only 4 to 8 blades and fixed blades guide water flow into the turbine through the scroll casing.

Working: As water flows from reservoir through the penstock and into scroll casing, part of its potential energy is converted into kinetic energy and the guide blades permit axial water flow through the runner blades. This increases the velocity of water flow and reaction force causes the runner to rotate. The runner shaft in turn is connected to generator for developing useful electrical energy. Water flow leaves the turbine through the draft tube, into the tailrace.

Kaplan turbines are installed at

1. Tungabhadra (Karnataka)
2. Srisailam (Andhra Pradesh)

3.5.5 Comparison between Impulse and Reaction Turbines

Impulse Turbine	*Reaction Turbine*
1. Only kinetic energy is available at the entry to the turbine	1. Both pressure and kinetic energies are available at entry to turbine
2. No pressure drop during working	2. Pressure changes through the guide and runner blades.
3. Used for high head	3. Used for medium and low heads
4. Nozzle is necessary	4. Spiral casing and blade passage act as nozzle
5. Construction is simple	5. Reaction turbines have sophisticated fabrication (blades, casing)
6. Draft tube not required	6. Draft tube is essential
7. For same head and same discharge, rotation of impulse turbine is low	7. For same head, and same discharge, rotation of reaction turbine is higher
8. Pelton turbine	8. Francis turbine and Kaplan turbine

EXERCISES

1. Explain the working principle of a steam turbine.
2. How are steam turbines classified?
3. Explain the working principle of a simple impulse turbine.
4. What is velocity compounding? Why it is necessary?
5. What is pressure compounding? Explain.
6. What are the advantages of pressure compounding over velocity compounding?
7. Explain the pressure-velocity compounding and its merits.
8. Compare the impulse and reaction turbines.
9. Describe the working principle of a reaction turbine.
10. What are the advantages of steam turbine over other prime movers.

CHAPTER 4

Internal Combustion Engines

In internal combustion engines, fuel oil or gas is burnt in the combustion chamber inside the cylinder. The heat energy released is converted into kinetic energy by the slider crank mechanism comprising piston-connecting rod-crank shaft assembly. They are commonly used in scooters, cars, trucks, ships, locomotives, earth moving equipment and for power generation.

They have the following advantages over steam engines and turbines.

1. They are compact and light in weight.
2. They have high efficiency.
3. They are designed and manufactured in various capacities.
4. They are specially suitable for mobile applications.
5. They cost comparatively less.
6. The starting and stoping is fast and easy.
7. Governing is simple.

4.1 CONSTRUCTION OF I.C. ENGINE

The basic components are the cylinder with cover, piston, connecting rod, crankshaft, crankcase and flywheel. The cylinder and cover assembly is designed to provide for combustion chamber and the passages for incoming charge and outgoing exhaust gases. There may be a valve gear mechanism for controlling these passages or they may be controlled by the piston itself. There are other accessory systems for fuel supply and fuel ignition and also for governing the power generated.

Working: When a piston is in O.D.C position, the input charge, i.e., pure air or fuel-air mixture, is sucked into the cylinder. It is compressed into the combustion chamber by the inward motion of the piston. Just before the piston reaches I.D.C position, the fuel is ignited and burnt. The heat energy released increases the pressure and temperature of the charge in the combustion chamber. Under this pressure, the piston moves outward. On reaching O.D.C. the exhaust gases are released. The linear motion is converted into the rotary motion by the connecting rod and crank assembly. The cycle of operations, namely suction, compression, ignition, expansion, exhaust repeats successively and produces continuous rotation of the shaft.

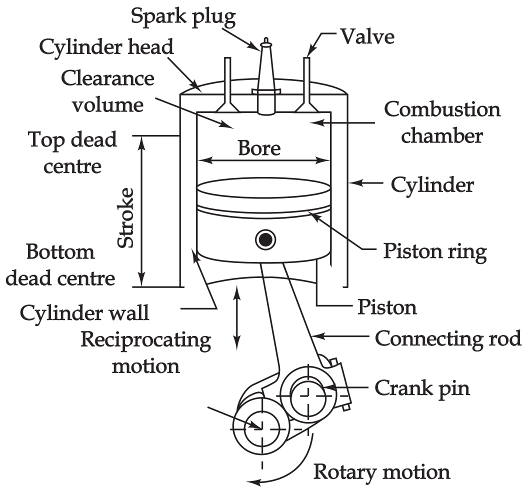


Fig. 4.1 (a) I. C. Engine fundamentals.

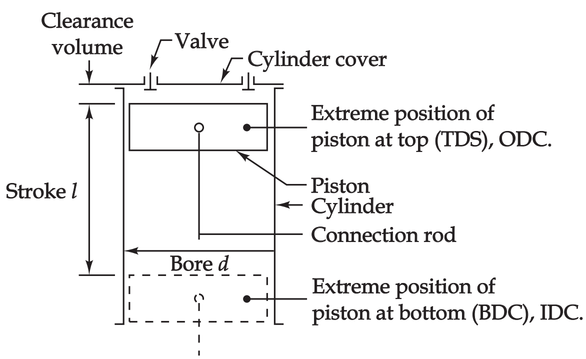


Fig. 4.1 (b) I.C. Engine terminology.

4.2 CLASSIFICATION

I.C. engines are classified based on different criteria.

(a) **Type of the thermodynamic cycle adopted**

(i) Otto cycle or constant volume-cycle engine.

(ii) Diesel cycle or constant pressure cycle engine.

(iii) Dual combustion cycle engine.

The cycle of operation of I.C. engines consists of suction, compression, combustion, expansion and exhaust. In all the three cycles mentioned above, the expansion and compression, follow adiabatic process, the exhaust occurs at constant volume. The combustion process is different in each of them. In Otto cycle, the combustion takes place at constant volume. It occurs almost instantaneously. In the diesel cycle, the combustion takes place at constant pressure and occupies a part of the expansion stroke. In dual combustion cycle the combustion takes place partly at constant volume and partly at constant pressure.

(b) **Type of fuel used**

1. Petrol engine.
2. Diesel engine.
3. Gas engine.
4. Kerosene engine.
5. Biofuel engine.

The diesel engine works on diesel cycle, whereas all other engines adopt the Otto cycle.

(c) **Number of strokes per cycle**

1. **Four-stroke engine:** Two revolutions of the shaft, i.e., four strokes of the piston are required for completing one cycle.
2. **Two-stroke engines:** The cycle of operation is completed in two strokes of the piston or one revolution of the crankshaft.

(d) **Method of ignition**

1. **Spark ignition (S.I.) engines:** The charge is ignited by the spark produced by a spark plug operated by instantaneous high voltage. This method is adopted in petrol and gas engines.
2. **Compression ignition (C.I.) engines:** The combustion is started by the injection of fuel in the form of fine spray into the highly compressed air. The high temperature of the compressed air is sufficient to start and maintain the combustion. This method is adopted in diesel engines.

(e) **Number of cylinders**

(1) Single-cylinder engines.
(2) Multi-cylinder engines.

(f) **Position of cylinders**

(1) Horizontal engines.
(2) Vertical engines.
(3) V engines.
(4) Radial engines.
(5) Opposed piston engines.

(g) **Method of cooling**

(1) Air cooled engines.
(2) Water cooled engines.

4.3 PETROL ENGINES

All modern petrol engines work on Otto cycle performed in two or four strokes. The distinguishing feature of any petrol engine is the carburetor. The function of a carburetor is to supply the cylinder, a mixture of finely divided petrol and air in correct proportions regardless of service conditions, pressure or speed. A typical carburetor is shown in Fig. 4.2. It is mounted on the inlet air passage.

The heart of the carburetor is the nozzle (A) placed at the throat of the venturi pipe and connected to a float chamber (B). The float chamber contains petrol at constant level and provides constant head over the nozzle orifice. The throttle valve (C) placed at the outlet of venturi pipe controls flow of air through a pipe. The flow causes vacuum at the throat of the venturi and the petrol is sprayed into the air stream through the nozzle. The compensating jet (D) provides (sprays) additional fuel to maintain currect air-fuel ratio at high speed. The idling jet (E), placed at the level of the throttle valve, provides rich mixture for starting the engine.

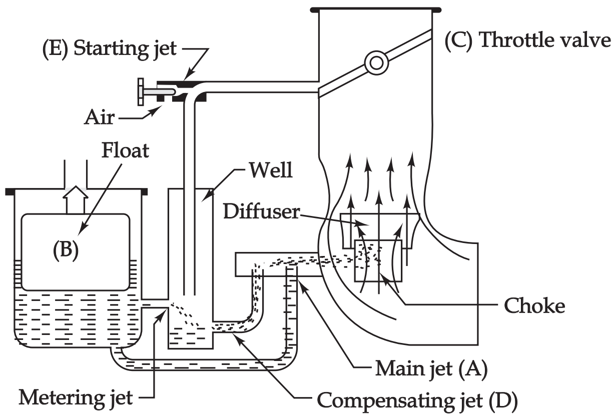


Fig. 4.2 Carburetor.

4.3.1 Four-Stroke Petrol Engines

In a four-stroke engine, the cylinder cover has inlet and outlet ports closed by spring controlled valves. The valves are operated by valve gear mechanisms actuated by cams. The camshaft is driven by the main shaft at half the speed. The cyclic events in a four-stroke engine is described below (Fig. 4.3 and Fig. 4.4).

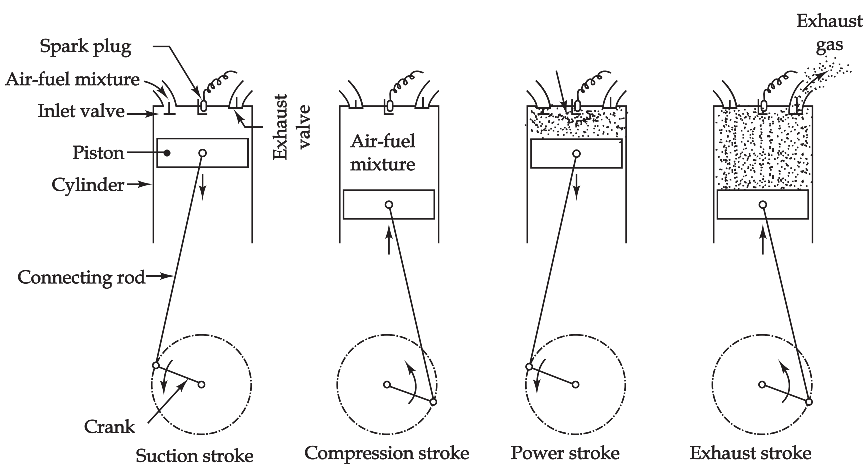


Fig. 4.3 Four-stroke cycle petrol engine.

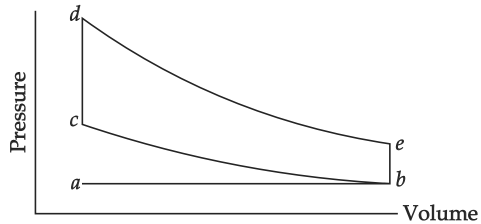


Fig. 4.4 Indicator diagram for one cycle.

1. **Suction stroke (a-b):** The piston moves out towards O.D.C. due to the inertia of the flywheel and inlet valve is open. The charge-fuel air mixture from the carburator enters the cylinder and fills it until the piston reaches O.D.C. position.
2. **Compression stroke (b-c-d):** As the piston starts moving in towards the I.D.C. the inlet valve is closed, the charge is compressed into the combustion chamber. The compression ratio may range from 6 to 9.
3. **Expansion stroke (d-e):** As the piston reaches I.D.C, the charge is ignited by a spark produced by the spark plug. Combustion takes place almost instantaneously. The energy released, increases the pressure and temperature of the gases. The gases expand during work on the piston. Kinetic energy of the flywheel increases.
4. **Exhaust stroke (e-b-a):** At the end of expansion stroke, the exhaust valve is opened and the combustion products are pushed out by the inward moving piston until it reaches I.D.C. position. Energy for the motion of the piston is provided by the flywheel at the expense of its kinetic energy. Then the exhaust valve is closed and inlet valve is opened. The cycle is repeated for continuous power.

The net work output per cycle is the difference between the work done during the expansion stroke and the energy used during the remaining three strokes.

4.3.2 Two-Stroke Cycle Petrol Engine

In two-stroke engines, the inlet and outlet ports are provided in the lower portion of the cylinder. The inlet-port, i.e., suction port is connected to the sealed crankcase by a transfer pipe. The exhaust port, in most cases, is provided on the opposite side of the suction port and at a slightly higher level. There is a third port, called induction port (transfer port) at the lowest portion of the cylinder. It is connected to the outlet of the carburetor and opens into the crankcase. All these ports are closed by the piston. The movement of the piston controls the operation of these ports.

When the piston is at its topmost position, the induction port (transfer port) is uncovered by the piston, and the charge, i.e., the fuel-air mixture from the carburetor, enters crankcase. As the piston moves down, the induction port is closed by the piston and the charge is compressed to some extent, When the piston uncovers, the suction port, the compressed-charge enters the cyliner through transfer port, and drives out the exhaust gases.

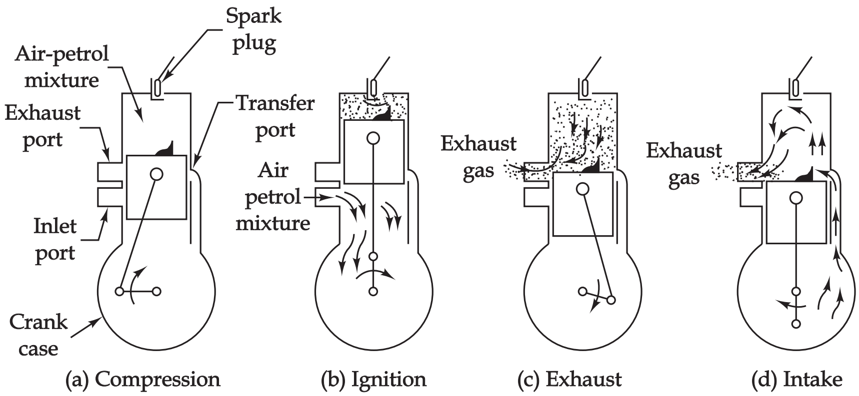


Fig. 4.5 Two-stroke cycle petrol engine.

As the piston moves up, it closes the suction port and then the exhaust port. The charge is compressed into the combustion chamber. Then at I.D.C position the spark plug produces a spark and the fuel is ignited. The energy released increases the pressure. The gases expand pushing the piston out. Towards the end of expansion stroke, the piston uncovers the exhaust port and the gases are released to the atmosphere. Then the suction port is opened. The fresh charge enters and drives out the exhaust gases. completely. The cycle repeats itself. In this engine, the two events exhaust and suction occurs almost simultaneously. The compression, combustion, expansion occur as usual. The cycle of operations is completed during the upward and downward strokes of the piston, i.e., one revolution of the crank. During the expansion stroke the energy is released. The kinetic energy of the flywheel is increased. The compression takes place at the expense of the kinetic energy of the fly wheel. The net difference is the output from the engine.

4.4 DIESEL ENGINE

In diesel engines, diesel cycle is adopted. Diesel engines are characterized by the fuel injection equipment. It consists of a fuel pump and a fuel injector. A typical system is shown in Fig. 4.6. The fuel pump is a plunger pump operated by the camshaft. It compresses the diesel to a high pressure at the correct time for the injection of the fuel. The fuel injector is mounted on the engine cover. The fuel injector consist of an automising orifice closed by the conical end of a spring loaded spindle. The spindle is lifted from its seat when the oil pressure is suddenly increased by the fuel pump and fuel is sprayed into the hot air in the combustion chamber in the form of fine particles. The high temperature of the air is sufficient to ignite the fuel. The combustion takes place at constant pressure. The high pressure gases produced, expand and push the piston out, doing work on it. Thus, the chemical energy is converted into kinetic energy. The cycle of operations may be completed in four or two strokes of the piston.

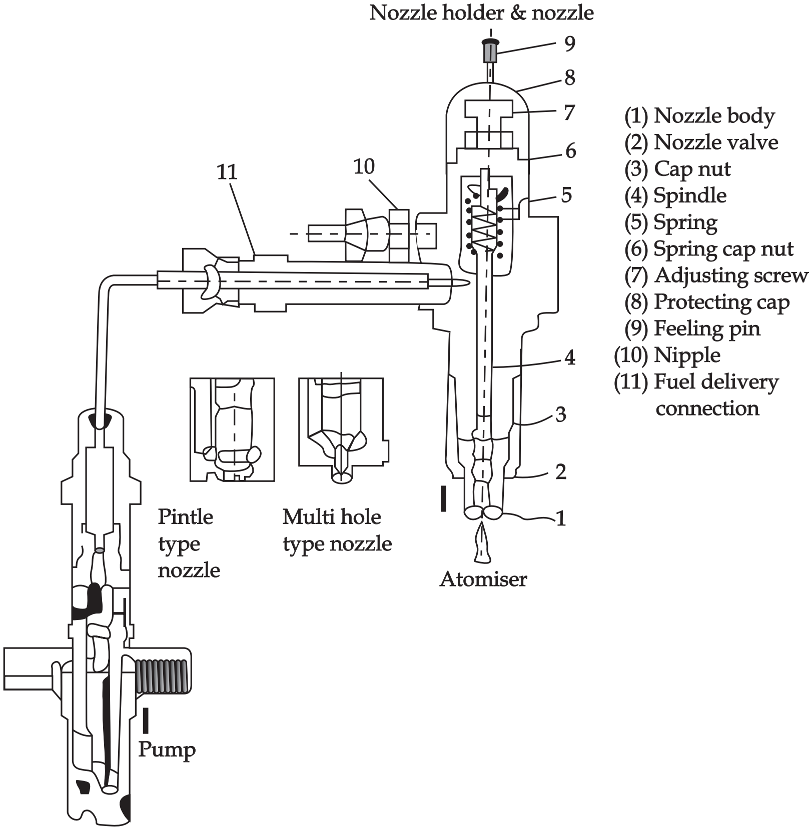


Fig. 4.6 Fuel injection for diesel engine.

4.4.1 Four-Stroke Diesel Engine

The main events of the diesel cycle, namely, suction, compression, combustion and expansion and exhaust occupy one stroke each. They are describe below.

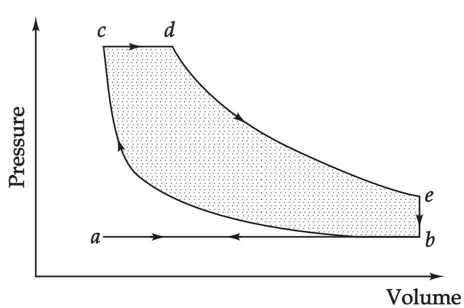


Fig. 4.7 Indicator diagram for diesel cycle.

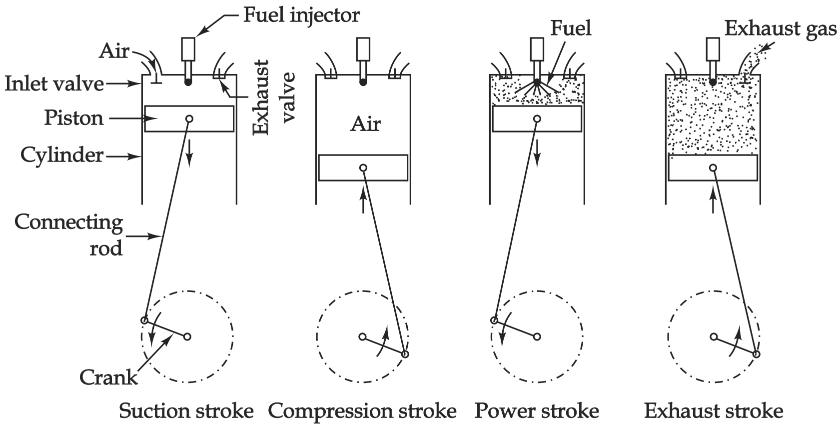


Fig. 4.8 Operations of four-stroke diesel cycle.

1. **Suction stroke (a-b):** When the piston is moving out and the inlet valve is open, the fresh air from atmosphere is sucked in through the air filter. At the end of the stroke, the inlet valve is closed, and suction is complete.
2. **Compression stroke (b-c):** Both the inlet and outlet valves are closed. The piston compresses the air into the combustion chamber. The compression ratio is in the range of 12 to 16. The pressure and temperature are very high at the end of the stroke.
3. **Expansion stroke (c-d-e):** At the end of compression stroke the fuel is injected in the form of fine spary, into the compressed air. The high temperature causes the ignition of the fuel and combustion spreads. The gases expand at constant pressure. After the combustion is completed, the expansion continues adiabatically. The work is done on the piston and the kinetic energy of the flywheel is increased.
4. **Exhaust stroke (e-b-a):** At the end of the expansion stroke, the exhaust valve is opened. The gases are released to the atmosphere. The inward motion of the piston, pushes out the exhaust gases. At end of this stroke, exhaust valve is closed and suction valve is opened. Immediately after I.D.C. position, suction for the next cycle starts. The cycle of operations is repeated successively, causing continuous rotation of the shaft and fly wheel.

4.4.2 Two-Stroke Diesel Engine

In this engine, the overhead valves in the cylinder cover and their operating mechanisms are absent. Instead the exhaust port, suction port and induction parts (transfer port) are provided on the side of the cylinder. They are covered by the piston. Their opening duration is controlled by the movement of the piston. The cycle of events, i.e., suction, compression, ignition, expansion and exhaust are completed in two strokes only as described below.

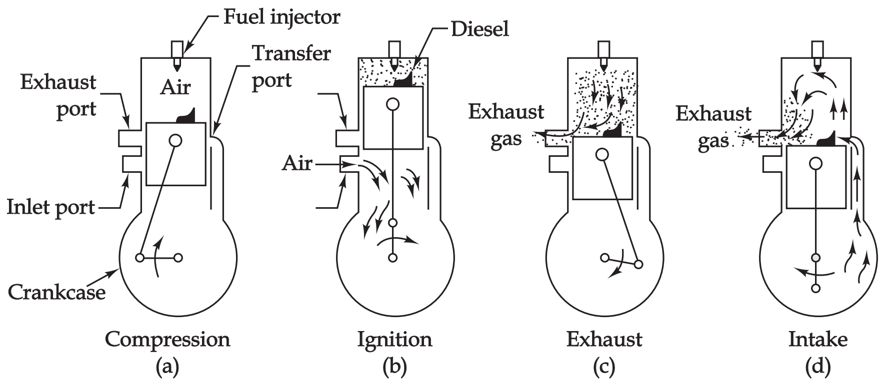


Fig. 4.9 Two-stroke cycle diesel engine.

1. **Inward stroke:** When the piston is at O.D.C. the exhaust and suction ports are open. The partially compressed air in the crankcase enters the cylinder through the suction port and drives out the burnt gases from the cylinder. As the piston moves in, the suction and exhaust ports are closed and the air is compressed into the combustion chamber. As the piston reaches I.D.C. position, the fuel is sprayed in the combustion chamber and is self-ignited.
2. **Out stroke or expansion stroke:** As the fuel starts burning, the energy released causes the expansion of the gases at constant pressure. On completion of the combustion, the expansion continues adiabatically. Thus, the piston is pushed out and the work is done on it. This results in increase of the kinetic energy of the flywheel. As the piston reaches O.D.C. position, the exhaust port is uncovered first and the exhaust gases are released to atmosphere. Then the suction port is also opened causing inflow of the compressed air and the cycle repeats. When the piston is in topmost position (i.e., I.D.C.), the induction port is opened to crank case and fresh air is drawn in and is compressed during the downward motion of the piston. This air enters the cylinder through the suction port when piston is in O.D.C. position.

Thus, all events of the cycle are completed within the two strokes, i.e., one revolution of the shaft.

4.5 COMPARISON OF TWO-STROKE AND FOUR-STROKE ENGINES

1. Power developed by two-stroke engine is more than the four-stroke engine for the same cylinder dimensions.
2. Scavenging is better in four-stroke engines than in two-stroke engines. Hence, the i.m.e.p. and thermal efficiency are better for four-stroke engines.
3. Compression is better maintained in four-stroke engines.

4. Variation in torque output is less in two-stroke engines. Hence, in two-stroke engine, the flywheel size is smaller and the torsional vibrations are also less.
5. Valve gears are absent in two-stroke engines. Hence, the two-stroke engine is simpler in construction and lighter in weight.
6. Because of sudden release of exhaust gases, the two-stroke engines are much more noisy than four-stroke engines.
7. There is 30% to 50% loss of inlet charge in two-stroke engines. This loss is almost absent in four-stroke engines.
8. Fuel and lubricating oil consumption is less in four-stroke engines.
9. Valves of four-stroke engines wear more rapidly and require greater care. In the two-stroke engines the ports do not require any special attention. Maintenance of two-stroke engine is simpler than for four-stroke engines.
10. Speed reversal in four-stroke engines is almost impossible whereas in two-stroke engines, it can be achieved.
11. Cylinder wear is more in two-stroke engines than in four-stroke engines.
12. With only three cylinders, two-stroke engine can be started in any position.
13. Two-stroke engines can work with inferior fuel because of the absence of the valve.
14. Spare parts required for two-stroke engines are less than for four-stroke engine.
15. Crankcase of a two-stroke engine has to be leak-proof whereas for four-stroke it can be open.
16. Cooling requirements of a two-stroke engine are more than the four-stroke engine due to greater heat transfer through the cylinder wall.
17. Two-stroke engines require smaller space and lighter foundation.
18. Two-stroke engines can be started more easily.
19. Volumetric efficiency of a two-stroke engine is smaller than that of four-stroke engines.
20. Two-stroke engines are used for lighter vehicles like scooters and motorcycles. Four-stroke engines are used for cars, buses and trucks.

4.6 COMPARISON OF PETROL AND DIESEL ENGINES

1. The working cycle is Otto cycle in petrol engines whereas it is diesel cycle in diesel engines.
2. Compression ratio for petrol engines is in the range of 6 to 9 whereas it is 12 to 16 in diesel engines.
3. In petrol engines, fuel is supplied with the inlet air. But in diesel engines, it is sprayed in the compressed air at the end of compression stroke.
4. The carburetor is the characteristic feature of petrol engines. The injector is the distinguishing feature of diesel engines.

5. The ignition is caused by a spark plug in petrol engines. Whereas in diesel engines, no external heat source is required. Ignition is caused by the high temperature of the compressed air.
6. Vibrations are more in diesel engines than petrol engines.
7. Construction of a diesel engine has to be more robust than a petrol engine. Diesel engines are heavier than petrol engines.
8. Diesel engines produce more power and hence they are used for heavy vehicles like buses, trucks, tractors and locomotives. Petrol engines are used for lighter vehicles like scooters, motorcycles and cars.
9. Initial cost of diesel engines is more than that of petrol engines.
10. Running (or operating) cost of petrol engines is more than that for diesel engines.
11. Petrol engines are started more easily than diesel engines even in cold weather.

4.7 EVALUATION OF INDICATED POWER AND BRAKE POWER

4.7.1 Indicated Power

It is the power produced inside the cylinder. It is the net result of work output during expansion minus the work consumed in suction, compression and exhaust. It is normally measured by the indicator diagram with pressure as ordinate and piston movement as abscesa. The average height of this diagram represents the mean effective pressure.

$$P_m = \frac{a}{l} s \text{ N/m}^2 \text{ or pascal} \qquad (1)$$

where a = area of the indicator diagram in mm^2

l = length of the indicator diagram in mm

s = spring value of the spring used in the indicator (N/m^2/mm)

The work done per cycle = $P_m.\ A.\ L$

where A = area of stroke in m^2

L = length of the piston in m

The work done/min $W = P_m.\ A.\ L.\ n$

where n = number of working cycles per min

= $N \rightarrow$ speed of the engine for two-stroke engine

= $N/2$–for four-stroke engine

N = speed of engine in RPM

Then the incidated power developed (I.P.) is

$$\text{I.P.} = \frac{P_m LA\, n}{60 \times 1000} \text{ kW} \qquad (2)$$

$$= \frac{P_m LA\, N}{60 \times 1000} \text{ kW for two-stroke engines}$$

$$= \frac{P_m LA\, N}{120 \times 1000} \text{ kW for four-stroke engines}$$

When P_m is expressed in bars

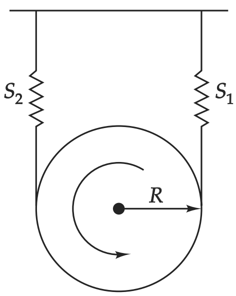
$$\text{I.P.} = \frac{100\, P_m\, LA\, N}{60} \text{ kW for two-stroke engine.}$$

$$= \frac{100\, P_m\, LA\, N}{120} \text{ kW for four-stroke engine.}$$

Note: The above equations for indicated power are applicable to single cylinder engines. For multi-cylinder engines, the equations are to be multiplied by a factor *K* which represents number of cylinders in the engine.

4.7.2 Brake Power (B.P.)

It is the power available at the output shaft and is measured by a brake.



Brake torque

$$T = W \times R \tag{3}$$

where, $W = S_1 - S_2$ net brake load.

R = radius of brake drum in metres.

N = speed of engine in RPM

$$\text{Brake power B.P.} = \frac{2\pi NT}{60 \times 1000} \text{ kW} \tag{4}$$

4.7.3 Friction Power

The difference between I.P. and B.P. is the power lost in overcoming friction in piston cylinder interface, connecting rod bearings and main crankshaft bearings.

$$\text{Frictional power F.P.} = \text{I.P.} - \text{B.P.} \tag{5}$$

4.7.4 Efficiencies

The ratio of B.P. to I.P. is called mechanical efficiency.

1. Mechanical efficiency

$$\eta_{mech} = \frac{\text{B.P.}}{\text{I.P.}} \times 100 \tag{6}$$

2. Indicated thermal efficiency $= \dfrac{\text{Energy released in the cylinder}}{\text{Energy in the fuel}}$

$$\eta_{ith} = \left[\frac{\text{I. P.} \times 3600}{W_f.CV}\right] \times 100 \qquad (7)$$

where, W_f = (m_f) = fuel consumed in kg/hr

CV = calorific value of the fuel in kJ/kg

3. Similarly, brake thermal efficiency is

$$\eta_{6th}\ (\%) = \frac{\text{B. P.} \times 3600}{W_f.CV} \times 100 \qquad (8)$$

4. Specific fuel consumption

Mass of fuel consumed to develop unit power. It can be expressed on B.P. and I.P. basis and is expressed in $\frac{\text{kg}}{\text{kWhr}}$

$$\text{BSFC} = \left(\frac{M_f}{\text{B.P.}}\right), \frac{\text{kg}}{\text{kWhr}}$$

$$\text{ISFC} = \left(\frac{M_f}{\text{I.P.}}\right), \frac{\text{kg}}{\text{kWhr}}$$

where M_f : Mass rate of fuel consumed in $\frac{\text{kg}}{\text{W}}$

B.P. : Brake power in kW

I.P. : Indicated power in kW

EXAMPLE 4.1

A four-stroke I.C. engine has a piston diameter of 150 mm and stroke of 180 mm. The speed is 500 rpm. If MEP = 8 bar, calculate the indicated power.

Solution

$$\text{I.P.} = \frac{100\, P_m\, \text{LAN}}{2 \times 60}$$

$$= \frac{100 \times 8 \times 0.18 \times \frac{\pi}{4}(.15)^2 \times 500}{2 \times 60}$$

$$= 10.6 \text{ kW}$$

EXAMPLE 4.2

The following data refer to a single-cylinder four-stroke diesel engine.

Cylinder diameter = 160 mm

Stroke = 250 mm

Compression ratio = 15 : 1

Speed = 500 rpm
Indicator diagram area = 206.00 mm^2
Length of the diagram l = 30.0 mm
Spring value S = 0.11 $N/mm^2/mm$
Oil consumption, W_f = 3.5 kg/hr
Calorific value C_v = 39900 kJ/kg

Find the thermal efficiency.

Solution

$$\text{MEP } P_m = \frac{a}{l}s = \frac{206}{30} \times .11 = 0.755 \text{ MPa} = 7.55 \text{ bar}$$

(i) P_m in MPa

$$\text{I.P.} = \frac{P_m LAN}{60 \times 1000} = \frac{0.755 \times 250 \times \frac{\pi}{4}(160)^2 \times \frac{500}{2}}{60 \times 1000} = 15.81 \text{ kW}$$

(ii) P_m in bars

$$\text{I.P.} = 100 \times 7.55 \times 0.250 \times \frac{\pi}{4}(0.160)^2 \times \frac{500}{60 \times 2}$$
$$= 15.81 \text{ kW}$$

$$\text{Thermal efficiency : I. Th. } \eta = \frac{\text{I.P.} \times 3600}{W_f . C_v}$$

$$\eta_{ith} = \frac{15.81 \times 3600}{3.5 \times 39{,}900}$$
$$= 40.76\%$$

EXAMPLE 4.3

The following observations are made during a test on a two-stroke diesel engine.

Bore diameter = 200 mm
Stroke = 250 mm
Speed = 350 rpm
Brake drum diameter = 1.2 m
Net brake load = 450 N
Mean effective pressure = 2.8 bar
Oil consumption = 3.6 kg/hr
Calorific value of the fuel = 42,000 kJ/kg

Determine

(a) I.P.
(b) B.P.
(c) F.P.
(d) Mech. efficiency
(e) Indicated thermal efficiency
(f) Brake thermal efficiency

Solution

$$A = \frac{\Pi}{4}\left(\frac{200}{1000}\right)^2 .\, m^2 = 0.031416\ m^2$$

$$n = N = 350 \text{ rpm}$$

(a) $$\text{I.P.} = \frac{100 P_m L A N}{60} = \frac{100 \times 2.8 \times 0.25 \times .031416 \times 350}{60} = 12.83 \text{ kW}$$

(b) $$\text{B.P.} = \frac{2\Pi NT}{60 \times 1000} = \frac{2\ NWR}{60 \times 100} = \frac{2\Pi \times 350 \times 450 \times 0.6}{60 \times 100} = 9.896 \text{ kW}$$

(c) $$\text{F.P.} = \text{I.P.} - \text{B.P.}$$
$$= 12.83 - 9.89$$
$$= 2.93 \text{ kW}$$

Mech (d) $$\eta = \frac{\text{B.P.}}{\text{I.P.}} = \frac{9.896}{12.83} = 0.7713$$

(e) $$\eta_{ith} = \frac{\text{I.P.} \times 3600}{W_f . C_V} = \frac{12.83 \times 3600}{3.6 \times 4200} = .3055 = 30.55\%$$

$$\eta_{bth} = \frac{\text{B.P.} \times 3600}{W_f . C_V} = \frac{9.89 \times 3600}{3.6 \times 42000} = 0.2356 = 23.56\%$$

EXAMPLE 4.4

A single-cylinder four–stroke engine runs at 1000 rpm and has a bore of 115 mm and has a stroke of 140 mm, the brake load is 60 N at 600 mm radius and the mechanical efficiency is 80%. Calculate the brake power and mean effective pressure.

Data: $i = 1$, 4-stroke engine

∴ $$N = 1000 \text{ rpm}$$

∴ $$N_s = \frac{1000}{60} = 16.67 \text{ rps,}$$

$$n = \frac{16.67}{2} = 8.335, \text{ cycle, } d = 115 \text{ mm} = 0.115 \text{ m}$$

∴ $$a = \frac{\pi (0.115)^2}{4} = 0.0104 \text{ m}^2$$

$W = 60N$, $R_e = 600$ mm $= 0.6$ m, $\eta_m = 80\%$, $L = 140$ mm $= 0.14$ m.

To find: B.P. and P_m

Solution

Torque, $T = W R_e = 60 \times 0.6 = 36$ N-m

Brake power, B.P. = $2\pi n'T/1000 = 2\pi 16.67 \times 36/1000 = 3.77$ kW …(3b)

Mechanical efficiency,

$$\eta_m = \frac{\text{B.P.} \times 100}{\text{I.P.}}\text{; } 80 = 3.77 \times 100/\text{I.P.}$$

$\therefore$ I.P. = 4.713 kW...

But I.P. = 100 P_m L a in;

$$4.713 = 100 \times P_m \times 0.148 \times 0.0104 \times 8.335$$

$\therefore$ Mean effective pressure, P_m = 3.88 bar

EXAMPLE 4.5

The following observations were recorded during a test on a four-stroke engine. Bore – 25 cm stroke = 40 cm, crank speed = 250 rpm, net load on the brake drum = 700 N, diameter of brake drum = 2 m; indicated mean effective pressure = 6 bar, fuel consumption = 0.0013 kg/s, specific gravity of fuel = 0.78, calorific value of fuel = 43900 kJ/kg. Determine (i) B.P. (ii) I.P. (iii) F.P. (iv) mechanical efficiency (v) indicated and brake thermal efficiency.

Data: Four–stroke engine

$$\therefore \quad = \frac{n'}{2}\text{; } d = 25 \text{ cm} = 0.25 \text{ cm}$$

$$\therefore \quad a = \frac{\pi \times 0.25^2}{4} = 0.049 \text{ m}^2$$

$$L = 40 \text{ cm} = 0.4,\ \text{n} = 250 \text{ rpm}$$

$$\therefore \quad n' = \frac{250}{60} = 4.17\ \rho\text{; and}$$

$$N = \frac{n'}{2} = \frac{4.17}{2} = 2.085,$$

$$W = 700N,\ D = 2 \text{ m}$$

$$\therefore \quad R_e = \frac{2}{2} = 1 \text{ m},\ P_m = 6 \text{ bar, m} = 0.0013 \text{ kg/s}$$

$$\rho = 0.78 \text{ and } C = 43,\ 900 \text{ kJ/kg}$$

[Hint: Specific gravity value is an additional data since mass m is already given in kg/s]

To Find: H.P., I.P., F.P., η_m, η_i, η_b

Assumption: Single cylinder engine, i = 1. It is understood since it is not given.

Solution

Torque, $T = WR_e = 700 \times 1 = 700$ N-m [Fig. 7.11 case (i)]

Brake power,

$$\text{B.P.} = \frac{2\pi n'T}{1000} = \frac{2\pi \times 4.17 \times 700}{1000} = 18.34 \text{ kW} \quad (3b)$$

Indicated power,

$$\text{I.P.} = 100\ P_m\ \text{LaiN} = 100 \times 6 \times 0.4 \times 0.049 \times 1 \times 2.085 \quad (2a)$$

$$\text{I.P.} = 24.52 \text{ kW}$$

Friction power, F.P. = I.P. – B.P. = 24.52 – 18.34 = 6.18 kW

$$\text{Mechanical efficiency, } \eta_m = \frac{\text{B.P.} \times 100}{\text{I.P.}} = \frac{18.34 \times 100}{24.52} = 74.8\% \quad (5)$$

$$\text{Indicated thermal efficiency, } \eta_i = \frac{\text{I.P.} \times 100}{Cm} = \frac{24.52 \times 100}{43900 \times 0.0013} = 42.96\% \quad (6)$$

$$\text{Brake thermal efficiency, } \eta_b = \frac{\text{B.P.} \times 100}{Cm} = \frac{18.34 \times 100}{43900 \times 0.0013} = 32.14\% \quad (7)$$

EXAMPLE 4.6

A four-cylinder two-stroke petrol engine develops 30 kW at 2500 rpm. The mean effective pressure on each piston is 8 bar and mechanical efficiency is 80%. Calculate the diameter and stroke of each cylinder, stroke to bore ratio is 1.5. Also calculate the specific fuel consumption if brake thermal efficiency is 28%. The calorific value of the fuel is 43,900 kJ/kg.

Data: i = 4, B.P. = 30 kW,

Two-stroke engine $N = n'$, n = 2500 rpm

$$\therefore \quad = N\ n' = \frac{2500}{60} = 41.67 \text{ rps}, \ P_m = 8 \text{ bar}, \ \eta_m = 80\%, \ \frac{L}{d} = 1.5$$

$$\therefore \quad L = 1.5, \ \eta_b = 28\%, \ C = 43900 \text{ kJ/kg}.$$

To find: d, L and brake SFC.

Solution

We know that $\eta_m = \dfrac{\text{B.P.}}{\text{I.P.}} \times 100$

$$\text{I.P.} = \frac{\text{B.P.} \times 100}{\eta_m} = \frac{30 \times 100}{80} = 37.5 \text{ kW}$$

But $\quad \text{I.P.} = 100 P_m\ \text{La i n}$

$$37.5 = 100 \times 8(1.5d)\left(\frac{\pi d^2}{4}\right) \times 4 \times 41.67$$

Solving for diameter, d = 0.062 m or d = 0.062 × 1000 = 62 mm

∴ Stroke, $L = 1.5\ d = 1.5 \times 62 = 93$ mm

We know that, $\eta_b = \dfrac{\text{B.P.} \times 100}{C_m}$

$$\therefore \quad {}^*m = \frac{\text{B.P.} \times 100}{\eta_b . C} = \frac{30 \times 100}{28 \times 43900} = 2.441 \times 10^{-3} \text{ kg/s}$$

Then, brake SFC = $\dfrac{3600 \text{ m}}{BP}$

$$\text{Brake SFC} = \frac{3600 \times 2.441 \times 10^{-3}}{30} = 0.293 \text{ kg/kW hr.}$$

Note: Mass of fuel, m may also be calculated as follows.

We know that $\eta_i = \dfrac{\text{I.P.} \times 100}{Cm}$

Also, $\eta_i = \dfrac{\eta_b \times 100}{\eta_m}$

Equating equations (6) and (8)

$$\frac{\text{I.P.} \times 100}{Cm} = \frac{\eta_b \times 100}{\eta_m}$$

$$\therefore \quad m = \frac{\text{I.P.} \times \eta_m}{C\eta_b} = \frac{37.5 \times 100}{43900 \times 28} = 2.441 \times 10^{-3} \text{ kg/s}$$

EXAMPLE 4.7

The indicated power of a two-stroke petrol engine is 5 kW. The piston speed being 100 m/min. The mean effective pressure is 5 × 10^5 N/m^2. Find the diameter of the piston.

Data: Two-stroke engine

∴ $N = n'$; I.P. = 5 kW,

$$V_p = 100\frac{m}{\text{min}} = \frac{100}{60} = 1.67\frac{m}{s} = 2Ln';\ P_m = \frac{5 \times 10^5 N}{m^2} \div 10^5 = 5 \text{ bar}.$$

To find: d.

Assumption: Let i = 1

Solution

$$\text{I.P.} = 100\ P_m La\ i\ N = 100\ P_m L\left(\frac{\pi d^2}{4}\right) i\ n'...$$

Rewrite as, I.P. = $(2Ln')50\ P_m\ \pi d^2\ i/4 = V_p \times 12.5 P_m\ \pi d^2 i$

Piston dia, $d = \sqrt{\text{I.P.}/V_p 12.5 P_m \pi i} = \sqrt{5/1.67 \times 12.5 \times 5\pi \times 1}$

$= 0.1236$ mt

EXAMPLE 4.8

A six-cylinder four-stroke I.C. engine develops 50 kW of indicated power at mep of 700 KPa. The bore and stroke lengths are 70 mm and 100 mm respectively. If the engine speed is 3700 rpm, find the average misfires per unit time.

Data: $i = 6$, for four-stroke engine

$\therefore \quad N = \frac{n'}{2}$; I.P. = 50 kW

$P_m = 700 \text{ kPa} \div 100 = 7 \text{ bar}$

$d = 70 \text{ mm} = 0.07 \text{ m}$

$\therefore \quad a = \frac{\pi(0.07)^2}{4} = 3.85 \times 10^{-3} \text{ m}^2$;

$L = 100 \text{ mm} = 0.1 \text{ m}$,

$n = 3700$ rpm

$\therefore \quad n' = \frac{3700}{60} = 61.66$ rps.

$N = \frac{61.66}{2} = 30\ 83$ explosions/s, which are actual.

To Find: Average misfires/s, per min and per hour.

Solution

From data: Actual explosions/s, $N_{act} = 30.83$

But based on the engine details, I.P. = $100\, P_m\, La \times 3.85 \times 10^{-3} \times 6 \times N_{th}$

$50 = 100 \times 7 \times 0.1 \times 3.85 \times 10^{-3} \times 6 \times N_{th}$

$\therefore \quad N_{th} = 30.92$ explosions/s

$\therefore$ Number of misfires/s = $N_{th} - N_{act} = 30.92 - 30.83 = 0.09$

or number of misfires/min = $0.09 \times 60 = 5.4$

or number of misfires/hr = $5.4 \times 60 = 324$

EXERCISES

1. What is an internal combustion engine?
2. How are I.C. engines classified?
3. Define the following.
   (a) Bore.
   (b) Stroke
   (c) I.D.C. or T.D.C.
   (d) O.D.C. or B.D.C.
   (e) Clearance volume
   (f) Compression ratio

4. What are the distinguishing features of petrol engines?
5. What is the type of combustion in petrol engines?
6. What are the applications of petrol engines?
7. What are the identifying characteristics of a diesel engine?
8. Explain the nature of combustion in diesel engines?
9. Where are the diesel engines used?
10. What are distinguishing features of a two-stroke engines?
11. What are the physical features that identify the four-stroke engine?
12. Coment on the statement "For the same dimensions and speed the power developed by a two-stroke engine is double the power developed by four-stroke engines."
13. Compare petrol engines with diesel engines.
14. State the advantages and disadvantages of the two-stroke engine over the four-stroke engines.
15. Define the following:
    (a) Indicated power.
    (b) Brake power.
    (c) Indicated thermal efficiency.
    (d) Brake thermal efficiency.
    (e) Mechanical efficiency.
16. The following observations were made during a test on a four-stroke petrol engine.

Area of indicator diagram	300 mm^2
Length of the indicator diagram	400 mm
Indicator spring constant	1000 bar/m
Speed in rpm	500
Diameter of cylinder	160 mm
Stroke of the piston	200 mm
Fuel consumed	2.8 kg/hr
Calorific value of the fuel	40, 000 kJ/kg
Brake drum diameter	1.2 m
Load on the brake pan	380 N
Spring balance reading	50 N

Calculate:

(i) I.M.E.P.
(ii) I.P.
(iii) B.P.
(iv) F.P.
(v) I.Th.
(vi) B.Th
(vii) Mechanical efficiency.

17. The following observations are made during a test on a four-stroke single cylinder diesel engine.

    Engine cylinder diameter 200 mm
    Stroke of the piston 400 mm

Area of the indicator diagram	580 mm^2
Length of the indicator diagram	75 mm
Spring value for the indicator	900 bar/m

Calculate:

(i) I.M.E.P. (ii) I.P.

18. The following data refer to a test on a petrol engine.

Indicated power	40 kW.
Brake power	35 kW.
Fuel for brake power	0.3 Kg/BP hr
Calorific value of the fuel	44,000. kJ/kg

Calculate:

(i) I. Th. η (ii) B. Th. η

(iii) Mech η

19. A four-cylinder four-stroke petrol engine develops indicated power of 20 kW at 1200 rpm. The mean effictive pressure is 6.0 bar. The stroke-bore ratio is 1.5. Determine the dimensions of the cylinder.
20. For a four-stroke petrol engine, the following data are given:

I.M.E.P.	6 bar
Diameter of piston	150 mm
Average speed of the piston	70 m/min.

Calculate the indicated power.

CHAPTER 5

Machine Tools

Machine tools are machines or devices used to shape machine components. They can broadly be classified into two groups:

1. Metal cutting machine tools.
2. Metal forming machine tools.
   1. **Metal cutting machine tools:** These machines remove the excess material in the form of chips for shaping the components. They are lathe, milling machine, shaping machine, drilling machine, grinding machine, special purpose machine, etc.
   2. **Metal forming machine tools:** These machines do not remove the materials, but shape the components by cold or hot forming operations. They are presses used for drawing, bending and cutting operations, rolling machines, extrusion machines, etc.

In the following paragraphs, we will study a few of the metal cutting machine tools like lathe, milling machine, drilling machine, grinding machine, etc.

5.1 LATHE

It is a machine tool used to produce round and tapered components. The workpiece rotates about the lathe axis, and the single point cutting tool has linear motion both along and across the lathe bed. There are various types of lathes—engine lathe, capstan lathe, turret lathe, etc. A typical engine lathe is described below.

Construction: The lathe has following components:

Bed frame: It consists of guideways to guide the carriage and tailstock along the bed. The bed is supported by two supports on the two ends. The left support houses the driving motor and supports the headstock and feed gearbox, etc.

Headstock: It houses the main spindle and the drive mechanism. The drive mechanism consists of a system of pulleys and gears designed to give varying number of speeds to the spindle. The spindle is hollow. The front end of the spindle is threaded to receive the chuck and faceplate. A short job held in chuck, need not be supported at the other end. When the job is long, it is supported at the other end by the tailstock dead centre. When the drive is through the faceplate, the job is held between the live centre at the

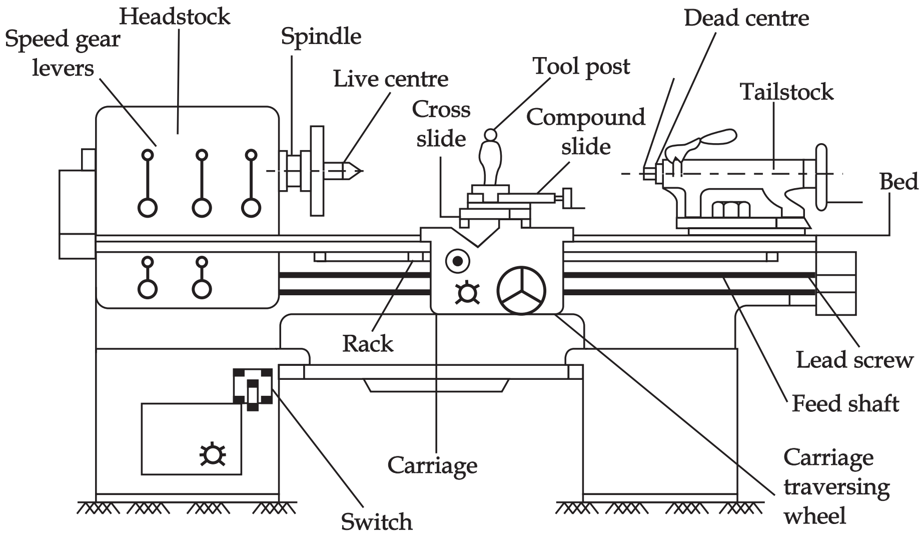


Fig. 5.1 Lathe.

spindle and dead centre at the tailstock end. The drive is provided by a carrier fixed as left end of the job and in the contact with the faceplate pin.

Tailstock: It houses a hollow spindle. The front end of the spindle is tapered and receives a dead centre to support the right end of the job. The rear end of the spindle has internal threads and engages with screw with hand wheel. By operating the hand wheel, the spindle can be given a small axial motion. For larger axial movements of the dead centre, the tailstock is moved manually along the guideways. It can be locked at a convenient position and then hand wheel is used for short axial motions.

Carriage: It consists of the following components:

(i) Saddle
(ii) Cross-slide
(iii) Compound slide
(iv) Tool post
(v) Apron

(i) **Saddle:** It is an H-shaped casting supported and guided by guideways on the bed frame. It can be moved in the axial direction by the rack and pinion arrangement. The rack is fixed on the underside of the bedframe and the pinion is carried on the spindle of a hand wheel supported in the apron.

(ii) **Cross-slide:** It is mounted on the dovetail guide on top surface of the saddle and can be moved in the transverse direction by rotating the cross-slide hand-wheel, through a nut and screw arrangement. This provides the crossfeed to the tool.

(iii) **Compound slide:** It rests on the top surface of the cross slide plate with dovetail guide on the top face and another casting with female dovetail engaging with male dovetail guide of the bottom plate. The top plate has a screw with a handle engaging with the nut on the bottom plate. The arrangement provides the motion of the top plate on the guideways of the bottom plate. The bottom plate can be swivelled about the vertical axis by a desired angle and clamped in position. Then the tool post mounted on the top plate moves along an inclined path by the operation of the compound slide hand wheel.

(iv) Tool post: It is device mounted in the T slot on the top face of the compound slide. It may be a cylindrical or square block, clamped in position by the T bolt. The cylindrical post with slot supports only one cutting tool whereas square post supports four tools.

(v) **Apron:** It is a housing fixed to the front of the saddle. It houses the longitudinal hand wheel of the rack and pinion mechanism, the half nut with handle, and cone clutch with worm wheel. The half nut engages with the lead screw and gives motion to the carriage during the thread cutting operation. The worm wheel meshes with worm on the feed rod. When the cone clutch is engaged, the carriage is given automatic axial motion. This is used for giving automatic longitudinal feed to the tool.

Lead screw: It is a threaded shaft supported in bearings in brackets fixed on the end supports. At the left end it is coupled to the output shaft of the feed gearbox. The half nut in the apron is engaged on the lead screw for thread cutting operation. The correct speed ratio between the lead screw and work spindle is achieved by mounting specified change gears between the main spindle and the input shaft of the feed gearbox.

Feed rod: It is similar to lead screw and placed below it and is coupled to another output shaft of the feed gearbox. The feed rod provides automatic feed motion to the carriage. The feed rod rotates at many speeds and provides many feed rates.

Feed gearbox: It is an arrangement of gears to provide a series of speeds to feed rod and lead screw. Normally, it is a Norton type gearbox. In this gearbox, there are only two shafts. The input shaft carries a cluster of gears with gradually decreasing diameters. The output shaft carries a sliding bracket assembly which consists of a sliding gear on the shaft and planetary gear in constant mesh with the sliding gear. By moving the bracket axially and swinging the planetary gear is made to engage with one of the gears on the input shaft. As this engagement is shifted to different gears, a series of speed ratios are obtained and the output shaft rotates at a series of speeds.

Change gear assembly: These are gears placed between the main spindle and the input shaft of the feed gearbox or lead screw in case feed gearbox is not provided.

The gears on the main spindle and input shaft can be changed as per the selection depending upon the pitch of the thread to be cut. The gap between these two gears is filled by intermediate gears mounted on a swinging bracket. By changing the position of the bracket, one or two intermediate gears are placed between them. This provides for the reversal of the direction of rotation of the lead screw and hence the direction of motion of the carriage.

5.2 SPECIFICATIONS OF THE LATHE

The following specifications are required for identifying a lathe:

1. Overall length of the bed.
2. The maximum distance between the centres.
3. Height of the spindle axis above the saddle.
4. Height of the lathe axis above the bed ways.
5. The gap in the bed.
6. Large diameter of the job that can be turned.
7. Number and range of spindle speeds.
8. Number and range of feed rates.

5.3 LATHE OPERATIONS

The following operations can be performed on a lathe:

1. Plane turning
2. Step turning
3. Facing
4. Taper turning
5. Thread cutting
6. Drilling
7. Reaming
8. Boring
9. Knurling
10. Milling
11. Shaping
12. Grinding

Some of these operations are described below:

5.3.1 Plane Turning

The single point cutting tool, mounted on the tool post, is brought to the rotating workpiece by moving the cross slide. Then the carriage is moved longitudinally towards the headstock.

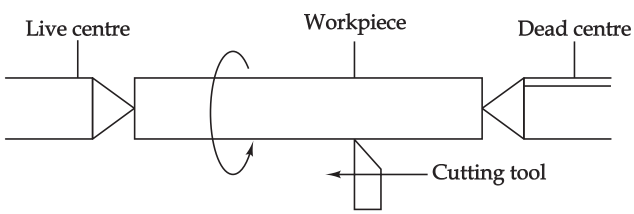


Fig. 5.2 Plane turning.

The tool removes the excess material on the workplace and produces a cylindrical surface of desired diameter. If the excess material is more, more than one passes may be required to produce the desired diameter.

5.3.2 Step Turning

Normally a parting tool is mounted on the tool post and fed radically to reduce the diameter to the desired value.

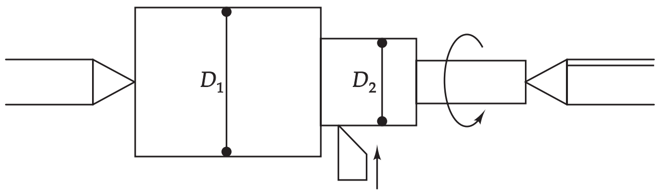


Fig. 5.3 Step turning.

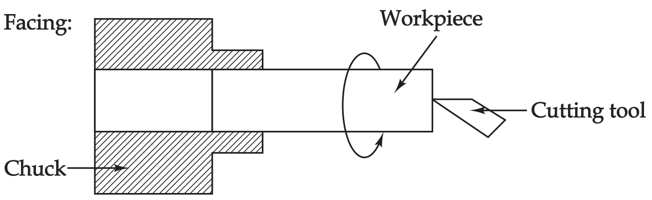


Fig. 5.4 Facing.

The job is held in a chuck and the V-tool is set at an angle and positioned at the centre of the face and moved radically out producing a face perpendicular to the axis of the job. Alternatively, the tool may be adjusted and positioned at the outer surface and moved radically in towards the centre.

5.3.3 Taper Turning

It is the process of producing conical surface. Various methods used for the purposes are:

1. Broad nosed tool method.
2. Swivelling compound rest method.
3. Tailstock offset method.
4. Taper turning attachment method.

   1. **Broad nosed tool or form tool method:** Whenever the length of the taper is very small a broad tool with its cutting edge ground inclined to the required taper is fed radially until the desired size is reached.

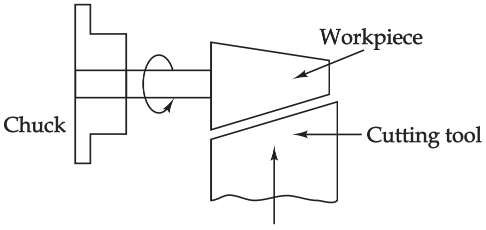


Fig. 5.5 Taper turning by broad nosed tool.

2. **Swivelling compound rest method:** The compound rest is swivelling and set at an angle equal to the taper angle and the tool is fed along the inclined path, producing the required taper. A number of passes may be required to attain the desired size. The length of the taper produced is limited by the travel of the compound rest slide.

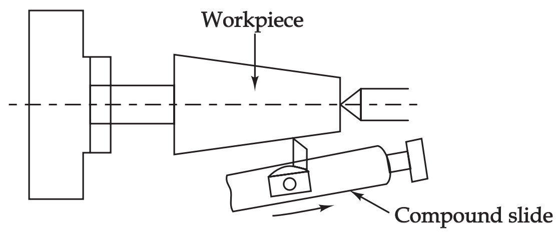


Fig. 5.6 Taper turning by swivelling compound rest method.

3. **Tailstock offset method:** In this method the central line of the job is set at an angle by offsetting the dead centre by an amount ‘e’ from the lathe axis towards the operator. This is achieved by moving the body of the tailstock. The tool is fed longitudinally as in plane turning. The surface produced is a tapered surface.

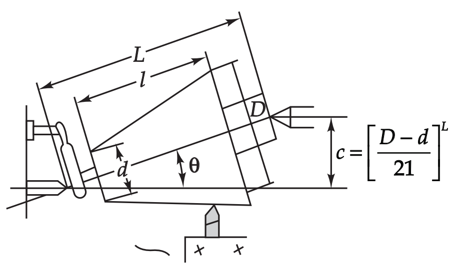


Fig. 5.7 Taper turning by tailstock offset method.

4. **Taper turning attachment:** It is a bracket attached to the rear end of the lathe

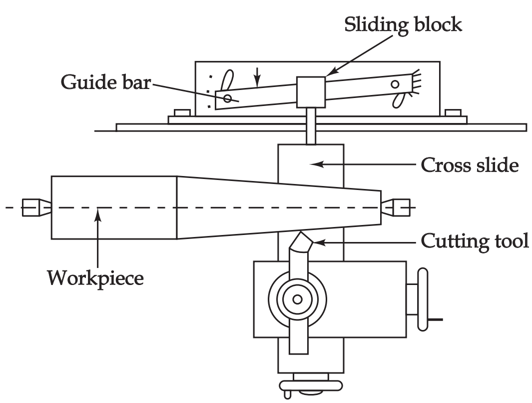


Fig. 5.8 Taper turning by taper turning attachment.

bed. It has a guide bar, which can be set to the desired angle. The cross slide is freed from its screw and attached to the sliding block on the guide bar. As the carriage is moved longitudinally the tool is made to move parallel to the guide bar axis. This produces desired taper on the workpiece.

5.3.4 Thread Cutting

The cutting tool is ground to the specified shape, depending upon the type of the thread being cut and fixed correctly in the tool post. It is brought to bear against the workpiece at the starting point of the threads. The half nut is engaged on the lead screw with the help of an indexing dial. The carriage moves longitudinally and the tool tip produces a helical groove on the work surface. A number of passes are made with a small depth of cut for each pass. When the desired depth is reached the process is stopped. The helix angle of the thread is set by choosing proper change gears or proper feed rate on the feed gearbox.

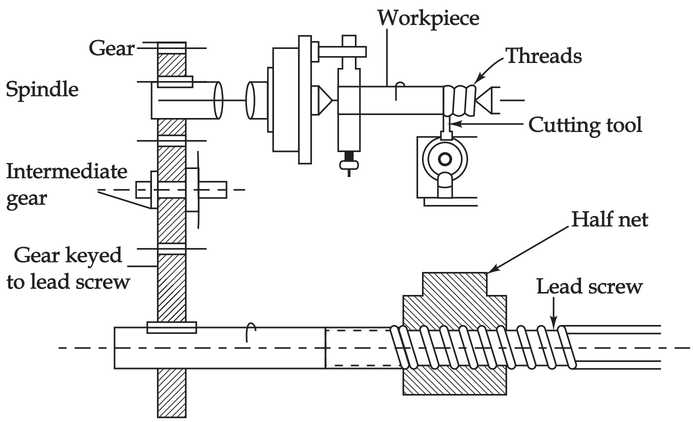


Fig. 5.9 Thread cutting.

Drilling and reaming

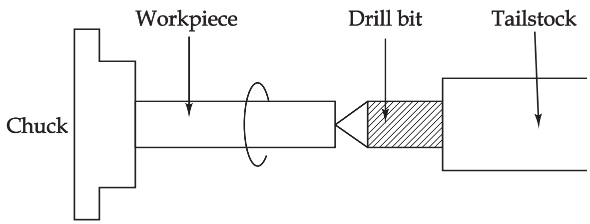


Fig. 5.10 Drilling.

The job is held in a chuck and the drill bit is fixed in the tailstock spindle and set to the centre of the face of the job. The job is rotated and drill bit is fed gradually by rotating the tailstock hand wheel. This produces a hole in the workpiece. The drilled hole is reamed by fixing a reamer in place of drill bit in the tailstock spindle.

5.3.5 Boring

This is the process of enlarging drilled hole or an existing hole. A boring tool is fixed in the tool post and moved to the internal surface of the hole. The tool is fed axially with a small cut. By each pass, the diameter is increased by a small value. The process is repeated until the desired diameter is attained.

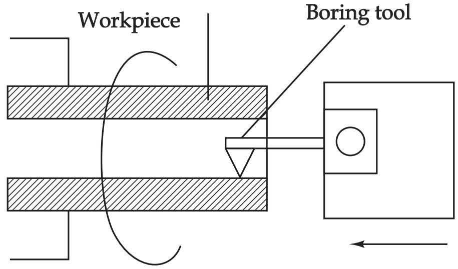


Fig. 5.11 Boring.

5.4 MILLING MACHINE

Milling is a multipoint cutting operation. Cutters used are cylindrical blanks with a number of cutting edges on the cylindrical surfaces and the lateral faces. The cutter is mounted on an arbor fixed in machine spindle. The workpiece is fixed on the table and brought under the cutter. As the cutter rotates and the workpiece traverses under it, a small layer of material is removed in form of small chips. The kind of the surface produced depends upon the shape of the cutter. The plane surfaces and slots of various shapes are produced by the usual milling operations. By mounting the cylindrical work on a special attachment on the work table, straight and helical teeth can be cut on the cylindrical surface. Special cutters called gear teeth cutters are used for the purpose.

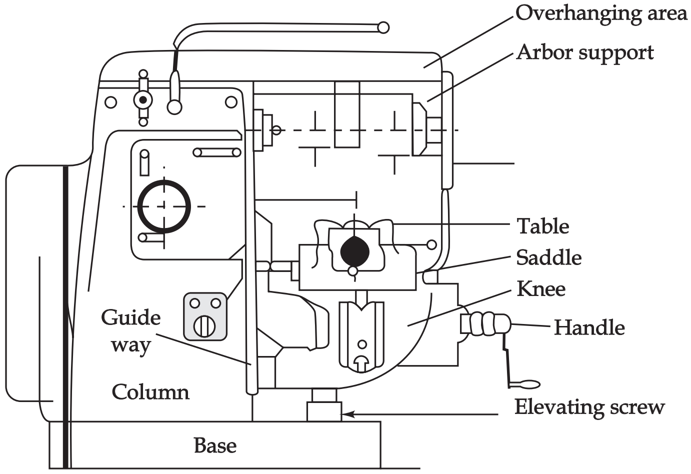


Fig. 5.12 Horizontal milling machine.

There are mainly two types of milling machines:

1. Horizontal milling machine
2. Vertical milling machine

5.4.1 Horizontal Milling Machine

The main parts of the machine are:

(i) Base plate	(ii) Column
(iii) Knee type table assembly	(iv) Horizontal spindle assembled
(v) Overhanging arm	(vi) Drive mechanism

The base plate is a rectangular casting and rests on the ground. The column is of rectangular box section. It is fixed to the base at the bottom and carries the overhanging arm at the top. It supports the spindle assembly placed in the upper portion. The front face of the column is provided with guideways. The knee-type table assembly is supported on a vertical screw and moves up and down the guideways. The table assembly consists of the knee base saddle and the work table. The knee base engages with vertical guideway one on the column face. The dovetail guideways are provided on its top face with axis perpendicular to the column face. The saddle is placed on guideways and can be moved in the cross direction. The work table is placed on guideways on the saddle. It can transverse in the transverse direction.

The work table has T-slots on its surface to facilitate fixing of the job and accessories. The motor and the drive mechanism are also housed in the column. The spindle is hollow and receives a mandrel or arbor with cutter. The other end of the mandril is supported by the overhung arm.

The workpiece is mounted on the table and brought under the cutter by the use of elevating hand wheel and cross feed hand wheel. As the work transverses under the rotating cutter, machining takes place.

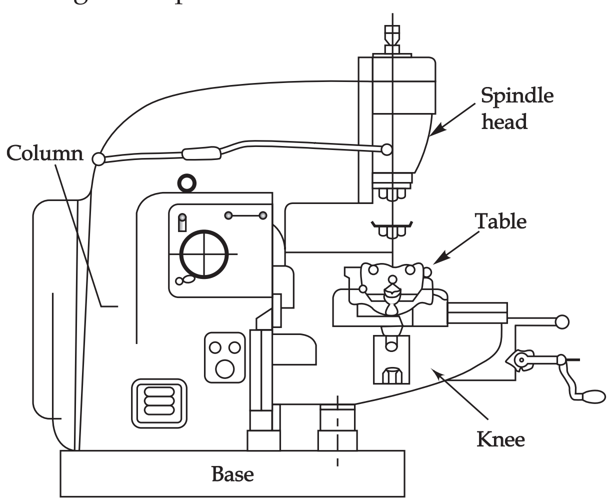


Fig. 5.13 Vertical milling machine.

5.4.2 Vertical Milling Machines

The basic components or parts are the same as for the horizontal milling machine. The overhung arm is the integral part of the column and houses the vertical spindle assembly. The cutters are mounted on a mandril and the mandril is inserted into the hollow spindle and fixed. As the spindle rotates, cutters rotate in the horizontal plane. The job is mounted on the work table and brought upto the tool face by operating the elevating and cross feed hand wheels. As the work table is given transverse motion, the top surface of the workpiece is machined. The machine is suited for machining plane surfaces, slots and die sinking operations.

5.4.3 Milling Operations

Milling operations are named after the type of the cutter used. They are listed below:

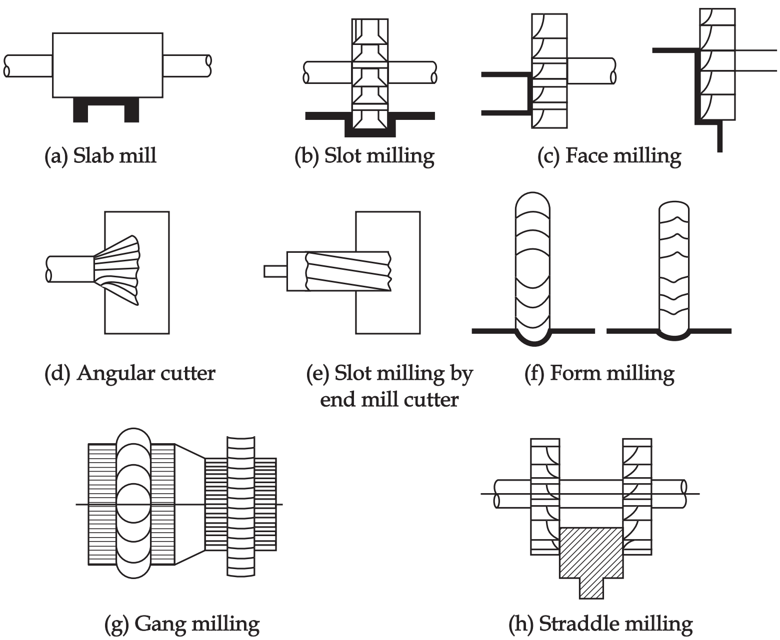


Fig. 5.14 Various milling operations.

1. **Slab milling (Fig 5.14a):** It is milling a plane surface by using slab milling cutter. There are two types of operations namely, (i) up milling (ii) down milling

   (i) **Up milling:** The job is fed against the cutter rotation. The cutter rotation is opposite to the feed motion. The chips move up the job.

   (ii) **Down milling:** The job is fed into cutter. The cutter rotation and feed motion are in the same direction. The chips move down the job. The chip removal is easy and the cutting force is less than up milling.

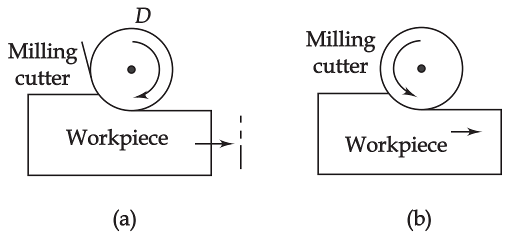


Fig. 5.15

2. **Slot milling (Fig. 5.14b):** This is the process of cutting rectangular slots using slotting milling cutter. The T-slot can be machined in a vertical milling machine after the rectangular slots are milled.
3. **Face milling (Fig. 5.14c):** It is the process of milling plane surfaces using face milling cutter. Vertical surfaces are produced by the cutter in horizontal milling machines. The top surfaces are machined by the face milling cutters in vertical milling machine. The job is fed into the cutter. The cutter speed and feed motion are in the same direction. The chips move down the job. The chip removal is easy and the cutting terse is less than up milling. The job is fed against the cutter rotation. The cutter speed is opposite to the feed motion. The chips move up the job.
4. **Angular milling (Fig. 5.14d):** It is the process of producing inclined surfaces using angular milling cutters. The dovetail grooved V-guides are machines by using these cutters.
5. **Form milling:** It is machining a specified surface profile by using form cutter with matching profile.

Example of application of these operations as shown in Fig. 5.14.

5.5 DRILLING MACHINE

Drilling is the operation of making a round hole in a workpiece by using a tool called drill bit. The drill bit is a fluted member with cylindrical or tapered shank and with conical end. The conical ends of the flutes are the cutting edges. The drill bit shank is inserted into the spindle nose and rotated with it. The conical end of the drill bit is pressed against the job. The cutting edge removes the material in the form of chips which come out through the flute spaces. This produces a round hole in the job. Various types of drilling machines are:

1. Bench drilling machine
2. Pillar drilling machine
3. Radial drilling machine
4. Multiple spindle drilling machine
5. Gang drilling machine

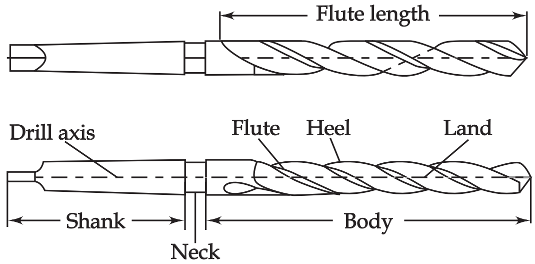


Fig. 5.16 Drill bit nomenclature.

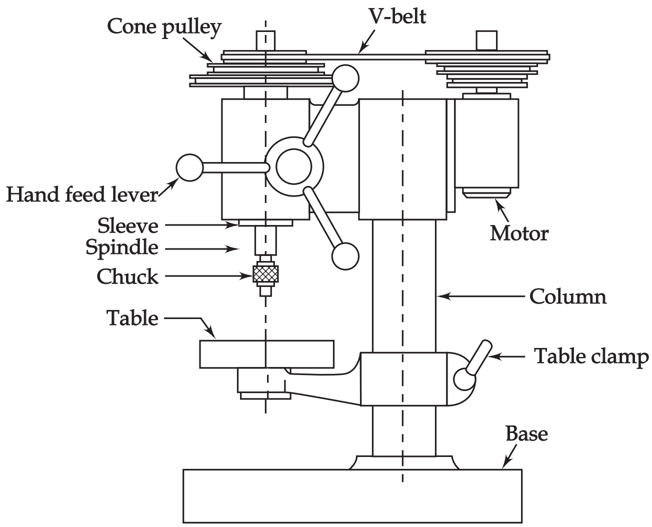


Fig. 5.17 Bench drilling machine.

These machines are almost similar except for the size. Pillar drilling machine is bigger than bench drilling machine and can drill holes of larger diameter. Salient features of these machines are:

(a) Base (b) Column
(c) Drilling head (d) Work table

(a) **Base:** It is a rectangular C.I. plate with T-slots on its surface. It rests on a bench or RCC platform and supports the steel column.

(b) **Column:** It is a hollow cylindrical member fixed vertically to the base plate at the bottom. At the top it supports a drill head with the drive mechanism. A bracket is clamped to the middle of the column for supporting the work table.

(c) **Drill head:** It is a cast iron box housing the spindle assembly and a pinion and star lever assembly. The pinion engages with the rack on the bush of the spindle. As the star lever is rotated, the pinion activates the rack on the bush and the spindle is given a vertical motion. The spindle is hollow with more taper at the bottom end. The drill chuck shank is held in the tapered portion. The top end of the spindle carries a cone pulley driven by a motor fixed on a bracket attached to the column on the opposite side. The drive is a through belt.

(d) Work table: It is a rectangular or circular plate with T-slots on its surface. It is carried on a bracket clamped to the column. The position of the bracket can be adjusted as per the height of the job. The workpiece is clamped on the work table. The drill bit is inserted into the drill cluck in the spindle. Star lever is operated and spindle is lowered so that the drill bit point rests against the workpiece at punch mark indicating the position of the hole to be drilled. As the drill bit is fed into the job, a hole is drilled. After reaching the required depth, the drill bit is withdrawn.

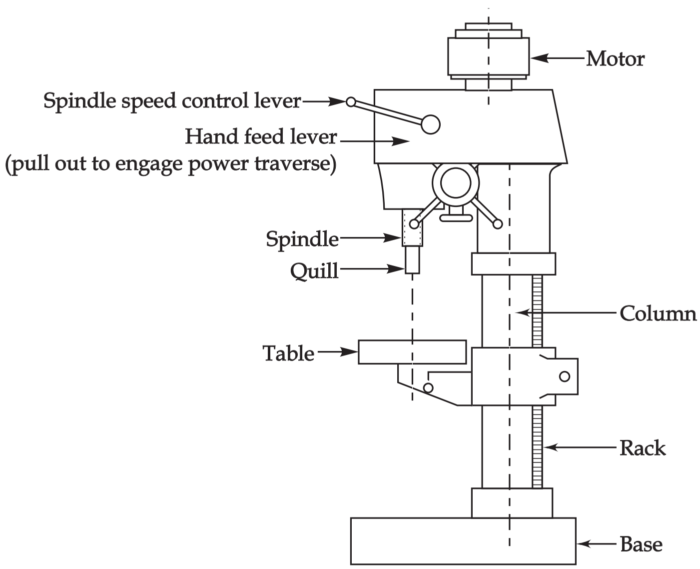


Fig. 5.18 Pillar drilling machine.

5.5.1 Radial Drilling Machine

The main parts of the radial drilling machines are

(i) Drill head
(ii) Radial arm
(iii) Vertical column
(iv) Base

(i) **Drill head:** It is C.I. housing for the spindle assembly and the drive mechanism. It is supported on the radial arm guideways. It can be moved along the arm and clamped at a specified position.

(ii) **Radial arm:** It consists of a split cylinder enveloping the vertical column and a radial arm attached to it. The arm is a box structure, having flat guideways on top and side surfaces. It supports and guides the drill head. The arm can be rotated about the column and moved up and down the column and clamped at the desired position.

(iii) **Column:** It is a hollow cylindrical member fixed to the base at the bottom. The outer surface of the column is smooth to facilitate easy movement of the arm.

(iv) **Base:** It is a rectangular heavy casting with T-slots on the top face and ribs on the underside. It supports the column and serves as platform for placing the job.

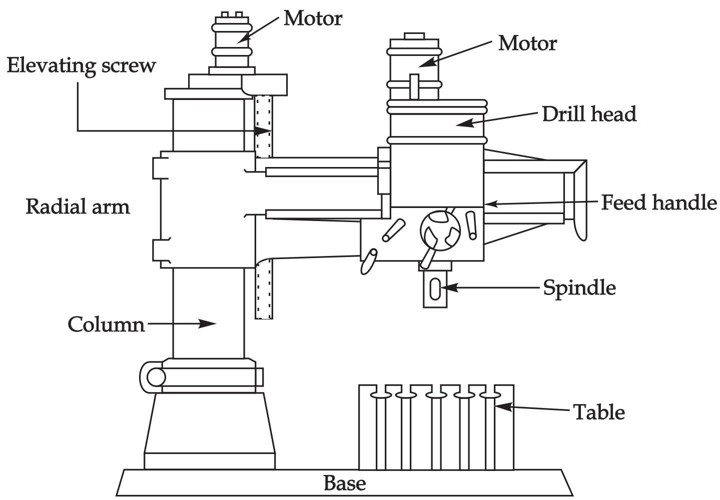


Fig. 5.19 Radial drilling machine.

5.5.2 Operations

The workpiece is placed on the base table. The drill bit is brought to bear on the workpiece at the desired location by rotating the arm and moving the drill head. Then they are clamped in position and the drilling operation is carried out. The machine is suitable for heavy jobs.

Operations on drilling machine: In addition to drilling the following operations can be done by the drilling machine

(i) Reaming
(ii) Countersinking
(iii) Boring
(iv) Counterboring

(i) **Reaming (Fig. 5.20a):** Smoothing a drilled hole by the use of a reamer is called reaming. The reamer is a straight fluted drill. The number of flutes are more than two. The reamer is inserted into the machine spindle. It is rotated and fed into the drilled hole. The cutting edges on the flutes remove a small layer of the material and make the hole smooth true and accurate.

(ii) **Countersinking (Fig. 5.20b):** Countersinking is the operation of enlarging top portion of the drilled hole into conical shape by using a countersinking tool in place of drill bit. The tool has cutting edges on its conical end. They remove the material from the cylindrical hole and convert it to a conical hole. This type of finishing is required for accommodating the counter sunk screws. This tool may also be used for deburning the drilled hole.

(iii) **Boring (Fig. 5.20c):** If the correct size of drill bit is not available, immediate smaller size drill bit is used to drill a hole. Then a single point cutting tool, fixed in a tool holder, is used to enlarge the hole to the required diameter. The cutting tool is set in the tool holder such that the point is at a correct distance from the axis of the tool holder. The tool holder shank is inserted into the spindle and tool is fed into the drilled hole. The tool point enlarges the hole diameter. This is called boring operation.

(iv) **Counterboring (Fig. 5.20d):** Counterboring is the boring operation limited to a small portion at the top end of the hole.

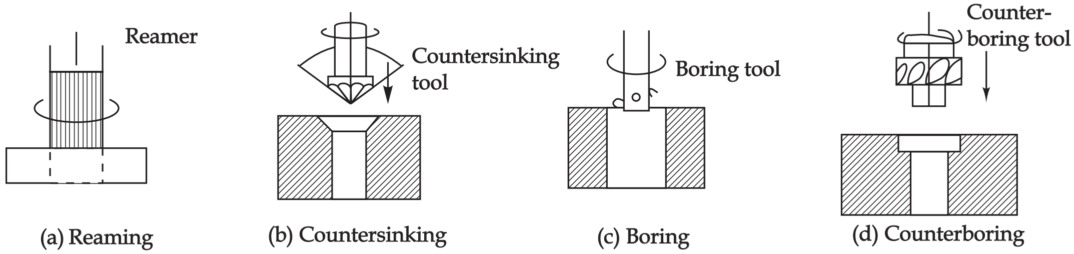


Fig. 5.20

5.6 GRINDING MACHINE

Grinding is the metal removal process by the action of a rotating abrasive wheel. The wheel contains a large number of abrasive particles embedded in a bonding material. Each particle acts as a miniature cutting point. As the wheel is pressed against the job surface and rotated, the innumerable cutting points remove the small irregularities on the surface and make it smooth and true. Thus, the grinding wheel cuts the tool in the grinding process.

5.6.1 Grinding Wheel

Mounted wheel is shown in Fig. 5.21 below.

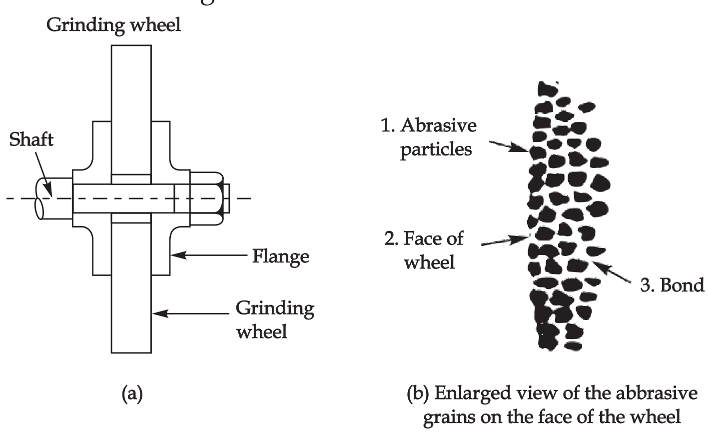


Fig. 5.21

5.6.2 Method of Mounting Grinding Wheel

It is a disk formed by pressing abrasive particles called girts in the matrix of bonding material called bond. The grinding wheel is specified by the type of the abrasive grain size, grade, structure and bond type.

The abrasives used are of two types:

(i) Natural (ii) Artificial

Natural abrasives are emery, sandstone, quartz, corundum and diamond. Artificial abrasives are aluminium oxide, silicon carbide and artificial diamond.

Abrasive grain size: The grain size refers to the fineness of the abrasive particles. The finer the particles smoother will be the surface. Fine particles can grind harder materials with greater accuracy.

Structure: Structure refers to the spacing of the abrasive grains. The wheels with wider spacing are used for soft materials and those with closer spacing are used for hard materials.

Bond: The bond is the medium which hold the particles together in the form of a wheel. The bond materials used are vitrified silicate, shellac, resinoid, rubber, etc.

5.6.3 Grade of the Wheel

It refers to the strength of the holding medium, i.e., bond. The binding strength depends upon the amount of the bond material in making the wheel. The increased amount of bond material increases the strength and makes the wheel harder but the abrasive spacing is increased. The wheel becomes suitable for soft materials. The saying is "a hard wheel for soft work and a soft wheel for hard work".

5.6.4 Types of Grinding Machines

There are three different types of grinding machines. They are as follows:

1. **Surface grinding machines:** There are two versions

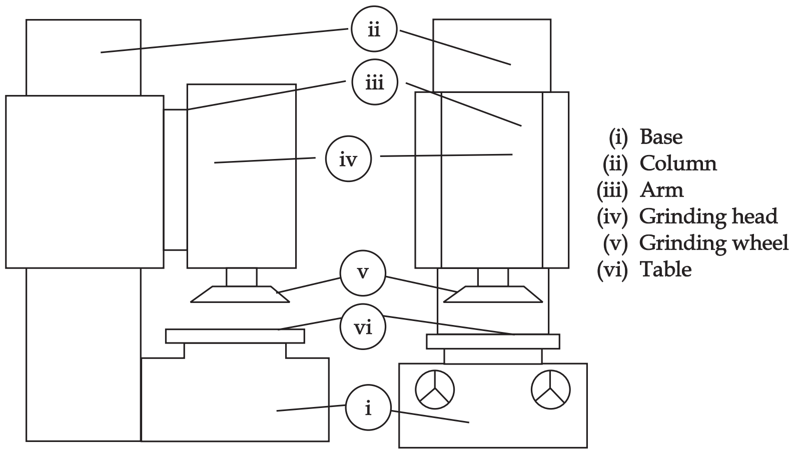
   (a) Vertical spindle type (b) Horizontal spindle type

   (a) **Vertical spindle surface grinder:** The base is a rectangular plate. It is placed on a platform or foundation. It supports the work table. At one side the column is fixed to it. The arm bracket is clamped to the column and carries the grinding head. The grinding head houses the vertical spindle and drive mechanism. The grinding wheel is mounted on a mandrill and fixed to the spindle nose. The work is placed on the table, the table traverses under the wheel and the top surface is ground by the grinding wheel.

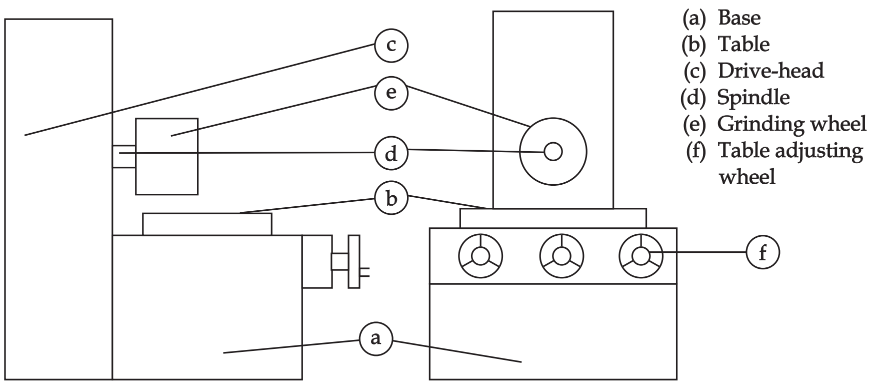
   (b) **Horizontal spindle grinding machine:** The main parts are:

   (a) Base (b) Table (e) Grinding wheel

   (c) Drive head (d) Spindle (f) Table adjusting wheel



(a) Vertical spindle grinding machine



(b) Horizontal spindle grinding machine

Fig. 5.22 Grinding machines

The base is the supporting structure for the table and drive head. The table has cross-wise and transverse motions. The drive head is a housing for the drive mechanism and the horizontal spindle assembly. The grinding wheel is mounted on a mandrill. The mandrill is inserted into the spindle. The wheel rotates as the spindle rotates.

The job is mounted on the tabletop and is brought under the wheel. As the table transverses, the top surface of the work is ground by the rotating grinding wheel. By manipulating the cross-feed and transverse feeds, the entire surface of the work is ground. With cup or ring wheel, the vertical surfaces can be ground by this machine.

2. **Cylindrical grinding machine:** The machine consists of the following parts,

1. Bed frame	2. Table
3. Headstock	4. Tailstock
5. Grinding head	6. Spindle assembly

The bed frame is C.I. box structure. It supports the work table and grinding head. The work table has T-slots on its surface. The headstock and tailstock are mounted on it. The cylindrical job is held between headstock and tailstock centre and rotated by the headstock spindle. The table has longitudinal and cross motions. The grinding head is placed behind the table. It supports the spindle assembly. The spindle axis is horizontal and parallel to the table axis. The spindle receives wheel assembly and rotates it. In the universal version the grinding head can be rotated and the table can be swivelled about the vertical and horizontal axes.

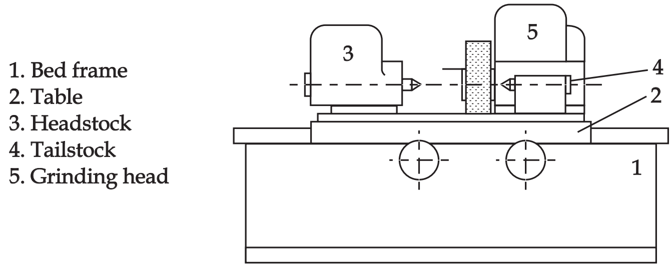


Fig. 5.23 Cylindrical grinding machine.

Centreless Grinding

The job is held between the centres and held pressed against the grinding wheel. Both the wheel and the job rotate and grinding takes place. By the transverse motion of the table the full length of the job is ground.

The machine has two grinding wheels with their axes at the skew and rotated in the same direction. The job is fed between them. It is rotated and pushed forward by these wheels. In this process the job is ground. The jobs of the same size can be continuously fed and ground. The operation is very fast and is suited for mass production.

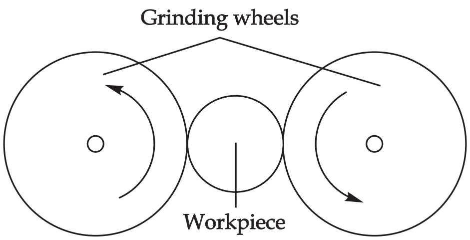


Fig. 5.24 Centreless Grinding.

EXERCISES

1. What is lathe?
2. Enumerate the lathe operations.
3. Name the main parts of lathe.

4. What is a carriage? what are its components?
5. What is the purpose of a headstock?
6. What is the function of a tailstock?
7. Explain in brief the parts of a lathe?
8. Explain the methods of taper turning?
9. Explain with sketch the taper turning attachment method.
10. Describe the tailstock offset method.
11. Describe the thread cutting operation.
12. What are the specifications of a lathe?
13. What is milling?
14. Name the main types of milling machines.
15. Enumerate the operations that can be performed on a milling machine.
16. Explain up milling and down milling.
17. What is an arbor ? what are its functions?
18. Sketch and describe horizontal milling machine.
19. Describe the parts of a vertical milling machine.
20. Name the operations that can be performed on a horizontal milling machine.
21. What are the operations done by vertical milling machine?
22. Name the types of drilling machines.
23. Name the operations done on a drilling machine.
24. What is reaming?
25. Explain countersinking and counterboring.
26. Sketch and describe a bench drilling machine.
27. Sketch and describe a radial drilling machine.
28. What is grinding?
29. Name the abrasive materials used in a grinding wheel.
30. What are the bond materials used in making a grinding wheel?
31. What are the characteristics that specify a grinding wheel.
32. What are grinding operations?
33. Describe with sketch a surface grinding machine.
34. Explain the main features of a cylindrical grinding machine.
35. Explain the centreless grinding.

CHAPTER **6**

Automation and Applications

6.1 INTRODUCTION

The dictionary defines *automation* as "the technique of making an apparatus, a process, or a system operate automatically."

We define automation as "the creation and application of technology to monitor and control the production and delivery of products and services."

Automation is the use of control systems and information technologies to reduce the need for human work in the production of goods and services. In the evolution of industrialization, automation follows mechanization. Whereas mechanization provided human operators with machinery to assist them with the muscular requirements of work, automation greatly decreases the need for human skills and mental requirements as well. In the process and manufacturing industries, the highly competitive environment has resulted in a great demand for industrial control systems/automation in order to streamline operations in terms of speed, reliability, quality and precise product output. Automation control system is able to control a process with minimal or no human assistance and has the ability to initiate, adjust and measure the variables in the process.

6.1.1 Classification of Automation

(a) **Permanent Fixed Automation**

- This control system is designed to perform a specific task.
- Functions of a control circuit is fixed and permanent.
- It will be complicated if we do other tasks apart from the prescribed task.

(b) **Programmable**

- Programmable automation control system that can perform several programmed tasks.
- Functions of a control circuit are programmed by the user and can be modified.
- When the task to be performed by machines is changed, changes only need to be done by making modifications to the machine control program.

(c) **Flexible automation**

- Flexible automation is a complex control system that can perform several tasks.
- Flexible to accommodate changes in product variety, batches and production schedule.
- Uninterrupted production of different products/batches or mix of products.
- New additional programmes can be prepared off-line and transmitted to the main computer without affecting running system.

6.1.2 Types of Control Systems

1. Pneumatic control systems
2. Hydraulic control system
3. Electrical control system

(1) **Pneumatic Control System**

- Pneumatic control system is a system that uses compressed air to produce power/energy to perform any task.
- Pneumatic systems are found in many industrial systems such as food industry, petrochemical industry and industrial robotics.
- Pneumatic systems require:
  (a) Compressed air supply.
  (b) Control valve.
  (c) Connecting tube.
  (d) Transducers.
- Pneumatic control system can be controlled both — manually and automatically.
- Easy installation.
- Simple design.

(2) **Hydraulic Control System**

- Hydraulic control system is a system that uses fluid to generate power/energy.
- Hydraulic systems are used in the automobile industry such as power systems, braking systems, cranes, car jack, satellite and others.
- The fluid used is oil.
- A hydraulic system requires:
  (a) Hydraulic fluid supply.
  (b) Control valve.
  (c) Cylinder.
- Hydraulic control system can be controlled both — manually and automatically.

- Complex to assemble
- Potential leakage will lead to pollution.

(3) **Electrical Control System**

- A control system that uses an electric current; either direct current (DC) or alternating current (AC) as a source of supply.
- Electrical control systems generally require:
  - (a) Electricity (DC) or (AC)
  - (b) Input elements (switches, sensors, transducers, valves, electronic components, etc.)
  - (c) Output elements (motor, lights, etc.)
  - (d) Extension cable
- Simple system
- Widely used in homes and industry

6.1.3 Advantages and Disadvantages of Automation Control in Industry

Advantages

(a) Replacing human operators in tasks that involve hard and repetitive physical work.

(b) Replacing humans in tasks done in dangerous environments (i.e,. fire, space, volcanoes, nuclear facilities, underwater, etc.)

(c) Performing tasks that are beyond human capabilities of size, weight, speed, endurance, etc.

(d) Economy improvement: Automation improves the economy of enterprises, society and of humanity. For example, when an enterprise invests in automation, technology recovers its investment.

(e) Reduces operation time and work handling time significantly.

Disadvantages

(a) Unemployment rate increases due to machines replacing humans and putting them out of their jobs.

(b) Requires skilled manpower.

(c) Technical limitations: Current technology is unable to automate all the desired tasks.

(d) Security threats/vulnerability: An automated system may have limited level of intelligence, hence it is most likely susceptible to commit error.

(e) Unpredictable development costs: Research and development cost of an automated process may exceed the cost saved by automation itself.

(f) High initial cost: Automation of a new product or plant requires a huge initial investment in comparison with the unit cost of the product, although the cost of automation is spread in many product batches of future.

6.1.4 Applications

Automation finds applications in almost all industries, as shown below:

- **Manufacturing**, including food and pharmaceutical, chemical processes, textiles, automobile and air space.
- **Transportation**, including automotive, air, and rail.
- **Utilities**, including water and wastewater, oil and gas, electric power, and telecommunications.
- **Defense:** Spaying, exploration bomb disposal, rescue and security operations.
- **Facility operations**, including security, environmental control, energy management, safety, and other building automation.

Automation influences all functions within industry from installation, integration, and maintenance to design, procurement, and management. Automation even reaches into the marketing and sales functions of these industries. Automation involves a very broad range of technologies including robotics and expert systems, telemetry and communications, electro-optics, cyber security, process measurement and control, sensors, wireless applications, systems integration, test measurement, and many more.

6.2 ROBOTICS

The notion of putting machines to work for us to perform routine tasks on command can be credited to great thinkers like Aristotle (384–322 BC). The first reference to the word robot is made in a play by Czech writer Karel Capek (1921) R. U. R (Rossum's Universal Robots). The word comes from the Czech "robota" which means serf or one in subservient labour.

6.2.1 Definition of Robot: Robot Institute of America

A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.

Robot is an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications ISO 8373-definition.

6.2.2 Robotics

It is the branch of technology that deals with the design, construction, operation, and application of robots as well as computer systems for their control, sensory feedback, and information processing. These technologies deal with automated machines that can take the place of humans in dangerous environments or manufacturing processes, or may or may not resemble humans in appearance, behaviour, and/or cognition. Many of today's robots are inspired by nature contributing to the field of bio-inspired robotics.

Laws of Robotics

Issac Asimov, a science fiction writer during 1970 in a story titled 'Runaround', coined the word 'robotics' and proposed three "Laws of Robotics" and later added the "zeroth law"

- Law 0: A robot may not injure humanity or through inaction, allow humanity to come to harm.
- Law 1: A robot may not injure a human being or through action, allow a human being to come to harm, unless this would violate a higher order law.
- Law 2: A robot must obey orders given to it by human beings, except where such orders would conflict with a higher order law.
- Law 3: A robot must protect its own existence as long as such protection does not conflict with a higher order law.

Study of robotics encompasses kinematics, dynamics, controls, sensing and intelligence. Kinematics deals with the motion of the links of the robot. Kinematics may further be divided into (i) direct kinematics and (ii) inverse kinematics. In direct kinematics given the link lengths and the orientation of the links we find the position and orientation of the end effector. Inverse kinematics deals with given the link lengths, position and orientation of the end effector what are the orientations of the links? Dynamics of robot deals with motion of links including the end effector under the action of external wrenches (forces and torques) from the actuators. To ensure that the robot follows the desired motion trajectory the feedback control is used. Sensors are used to measure the position, orientation and/or forces of the links and end effector. Robots are generally mounted with vision and touch sensors. Robots which can adapt to changes in environment are said to be intelligent.

6.2.3 Components of a Robot

- Manipulator linkage
- Sensors
- Actuator
- Controller system
- Feedback system
- Computer interface

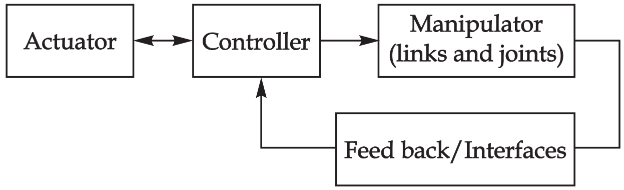


Fig. 6.1

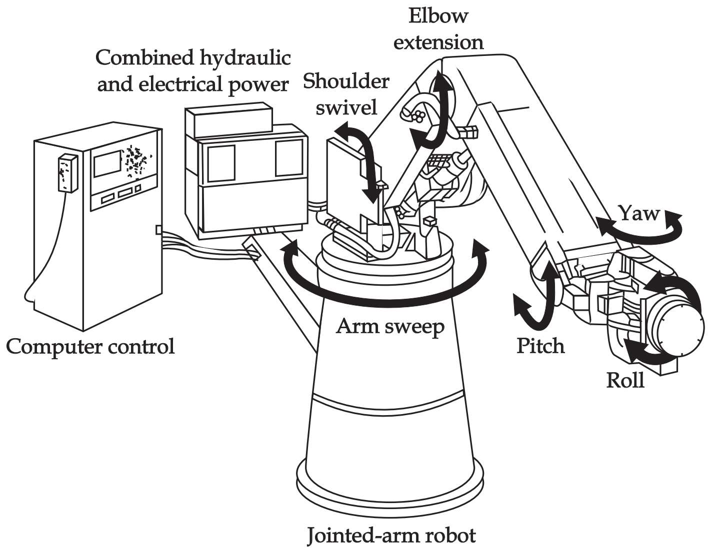


Fig. 6.2 Components of a robot.

The manipulator is the basic work handling component of robot. It consists of an arm and a wrist. It is made of a series of links and joints.

Sensors

(a) Vision sensor
(b) Tactile sensor
(c) Proximity sensor
(d) Range sensor
(e) Velocity sensor
(f) Voice sensor

Actuaters

(a) Electric motors for rotary motion
(b) Linear actuators for linear motion (pneumatic, hydraulic, electric)
(c) Elastic actuators
(d) Mucle wire (shape memory alloy)
(e) Piezo motors
(f) Electroactive polymers
(g) Elastic nanotubes

6.2.4 Robot Classification

1. Based on mechanical configuration
   (a) Cartesian coordinate configuration
   (b) Cylindrical configuration
   (c) Polar configuration
   (d) Revolute or jointed arm configuration

2. Based on control method
   (i) Non-servo controlled (ii) Servo controlled
3. Based on type of actuators
   (i) Electric (ii) Hydraulic
   (iii) Pneumatic

Robotic configurations

A robot requires 6 degrees of freedom in 3D space. First three joints help in reach and last three joints are in the wrist for orientation. The configurations based on the first three joints are:

Table 6.1

Sl No.	*Configuration*	*Joint 1*	*Joint 2*	*Joint 3*
1	Cartesian (3 Linear axes)	X: base travel	Y: height	Z: reach
2	Cylindrical (1 Rotary and 2 Linear axes)	θ: base rotation	φ: height	Z: reach
3	Polar (2 Rotary and 1 Linear axes)	θ: base rotation	φ: elevation angle	Z: reach
4	Articulated (3 Revolute joints)	θ: base rotation	φ: elevation angle	ψ: reach angle
5	Spherical (Rotary joints are coincident)	θ: base rotation	φ: elevation angle	ψ: reach angle

(a) **Rectangular co-ordinate system:** This is also known as cartesian co-ordinate system. In this system there are three basic movements along three rectangular axes. These motions are provided by rectangular box type sliding joints. The vertical motion is provided by the joint on the vertical column of the robot base. The two horizontal motions are provided by the joints on the horizontal arms—one mounted on the column and another on mounted the first horizontal arm. The confugeration is suited for straight line movements and side to side movements. These robots are used for pick and place operations as in material handling, machine loading, etc.

(b) **Cylindrical co-ordinate system:** This system has two linear motions and one rotational motion. The rotational motion is provided by rotary joint between the base and the column. The vertical movement is provided by the linear joint between the column and the horizontal arm. The horizontal motion is due to the sliding joint on the arm. The motion envelope of the end point is cylindrical. This type is suited for motions around the fixed base as in assembly operations, material loading on machine tool–table, spot welding, etc.

(c) **Spherical co-ordinate system:** This is also called polar co-ordinate system. This has two rotations and one linear motion. There is rotation between the base and the column and also between column and the arm. The linear motion is given by the sliding joint on the arm. This is used in spot welding, gas welding, arc welding, machine loading, etc.

(d) **Revolute co-ordinate system:** This configuration is also called 'anthropomorphic' or 'joined arm' and reassembles a human arm. It has three rotational motions. The base revolves about the vertical axis. The base and arm (shoulder) and another arm (elbow) have rotary joints. This type is used for spray painting, arc welding, gas welding, material handling in die casting machines. Several variations of this geometry have been developed for specific applications.

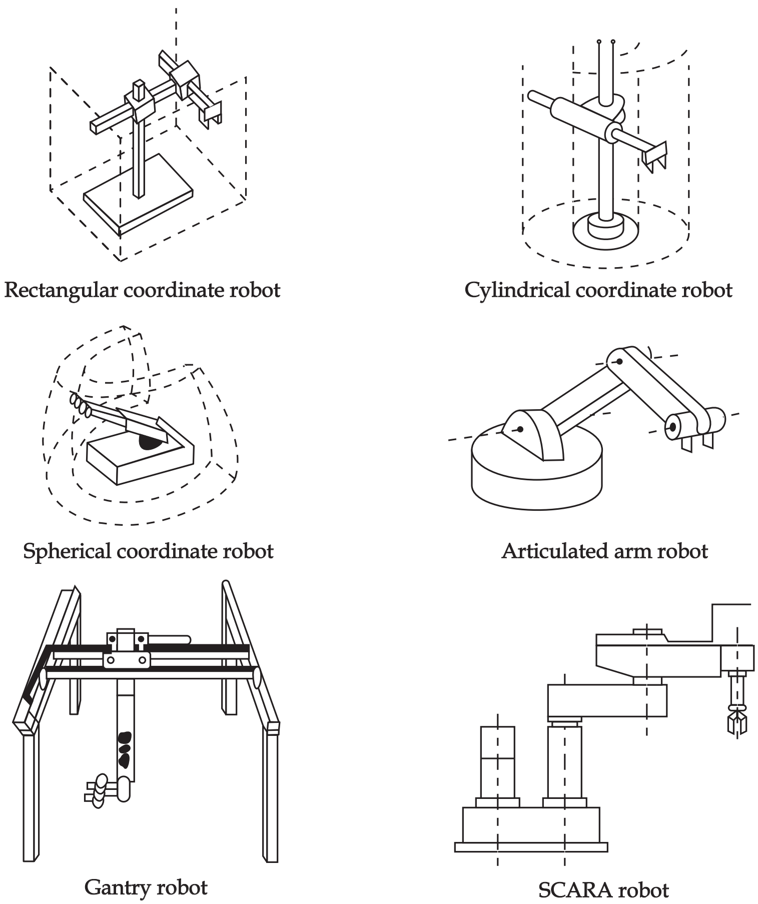


Fig. 6.3 Robot configurations according to their motion.

6.2.5 Comparison of Actuators

Hydraulic:

Advantages:

(1) Good for heavy pay load.

(2) High power/weight ratio.

(3) System is stiff.

(4) High accuracy and better response.

(5) No reduction gear needed.

Disadvantages

(1) Not fit for clean room applications.
(2) Can be expensive and noisy.
(3) Viscosity of oil changes with temperature.
(4) Susceptible to dirt.
(5) Large inertia on the actuator.

Electrical:

Advantages

(1) Available in all sizes.
(2) Control is better.
(3) Good for clean room applications.
(4) Reliable and low maintenance.
(5) Higher compliance than hydraulic system.

Disadvantages:

(1) Needs reduction gears.
(2) Requires breaking system to hold at a position.
(3) Not suitable for explosive environment.

Pneumatic

Advantages

(1) Simple and inexpensive comparatively.
(2) No leakage or sparking.
(3) Low pressure compared to hydraulic actuators.
(4) Good for on-off applications.
(5) Compliant system.

Disadvantages

(1) Noisy systems.
(2) Requires air pressure and air filters.
(3) Linear control is difficult.
(4) Can't hold the load.
(5) Lowest power to weight ratio.

6.2.6 Applications of Robots

(1) **Industrial applications:** Pharmaceutical industry, textile industry, chemical industry, mining, construction industry, energy sectors. In the areas of material handling (material transfer, machine loading and unloading), operations, palletizing, de-palletizing, operations: welding(spray and spot), paint scrapping and spraying, assembly and inspection, logostics and product.

(2) **Household sector:** Cleaning, security, maintenance.
(3) **Health care:** Patient care and monitoring, surgery, micro-surgery, rehabilitation-prosthetic arm, robotic wheel chair.
(4) **Service sector:** Traffic control, transport sector, firefighting, managing shopping mall, maintenance and repair, disaster recovery.
(5) **Agriculture sector:** Ploughing, sowing, transplanting, plucking, harvesting and packing.
(6) **Research:** Space exploration, undersea exploration, nuclear research and geological exploration.
(7) **Military applications:** Spying, exploration, bomb disposal, rescue and security operations. Autonomous navigation and mission planning.
(8) **Entertainment applications:** Animation.
(9) **Cognitive applications:** Development of intelligent agents which learn through interaction with the surroundings and are capable of collecting information about their environment and of independently identifying options for acting. Handling of deformable and piece goods.

6.2.7 Advantages and Disadvantages of Robot Systems

Advantages

(1) Can perform repetitive work 24/7.
(2) Perform tasks faster than humans and much more consistently and accurately.
(3) They cannot harm you unless they are programmed to.
(4) They can produce a greater quantity in a shorter amount of time.
(5) They can work at a constant speed with no breaks, days off, or holidays.
(6) They can perform applications with more repeatability than humans.
(7) Robots save workers from performing dangerous tasks.
(8) They can work in hazardous conditions, such as poor lighting, toxic chemicals, or tight spaces.
(9) They are capable of lifting heavy loads without injury or tiring.
(10) Robots increase worker safety by preventing accidents since humans are not performing risky jobs.
(11) They also reduce the amount of waste due to their accuracy.
(12) Robots save money in the long run with quick ROIs (return on investment), fewer worker injuries (reducing or eliminating worker's compensation etc.), and with using less materials.

Disadvantages

(1) People can lose jobs in factories.
(2) It needs a supply of power.
(3) It needs maintenance to keep it running.

(4) It costs money to make or buy a robot.
(5) Need to get people trained to fix them if anything wrong happens.
(6) Need a very intelligent crew.
(7) If you make a very amazing robot with amazing quality and it breaks, it might be very hard to fix.
(8) They can be very hard to programme.
(9) They can reproduce but it could cost money for the materials.
(10) They cannot recharge themselves.

6.3 NUMERICAL CONTROL OF MACHINE TOOLS

Formerly, machine tools were operated by skilled machinists. Judgements about the speeds, feeds, tool configurations were done by him. The product quality depended on his craftsmanship, knowledge and skill. It is rare that two expert operators produce identical parts. In fact, even one operator may not produce identical products successively. The production rate also is very slow. The complex shapes of aircraft-parts cannot be produced by the manual methods.

In 1947, John C Parson of Parson Corporation, Machigan, attempted to introduce the concept of numerical control to produce the rotor blades for US Airforce.

In 1951, the servomechanism lab of MIT was given the full responsibility of developing the NC machine. A prototype of NC machine was successfully demonstrated in 1952. In 1955 seven companies had tape controlled machines. As many as 100 NC machines were exhibited in Machine–Tool-Exhibition in Chicago in 1960. Nowadays CNC machining centres are replacing the conventional machine tools in the manufacturing industry.

Numerical control of machine tools may be defined as a method of automation of various functions of machine tools by a taped coded-progamme consisting of precise instructions about the methodology and movements, in the form of letters, numbers and symbols. The progamme is generated manually.

Nowadays a dedicated computer is used to generate the progamme. Then the system is called Computer Numerical Control (CNC for short) of machine tools.

6.3.1 Components of NC Systems

1. Tape punch converts the written instructions into a corresponding hole pattern.
2. Tape reader reads the hole pattern and converts the instructions to a corresponding electrical signal.
3. Controller receives the electrical signal and causes the machine to perform the intended operation.
4. NC machine responds to signal from the controller and performs the required motions to manufacture the part, e.g., spindle rotation, table or spindle movement along programmed axes.

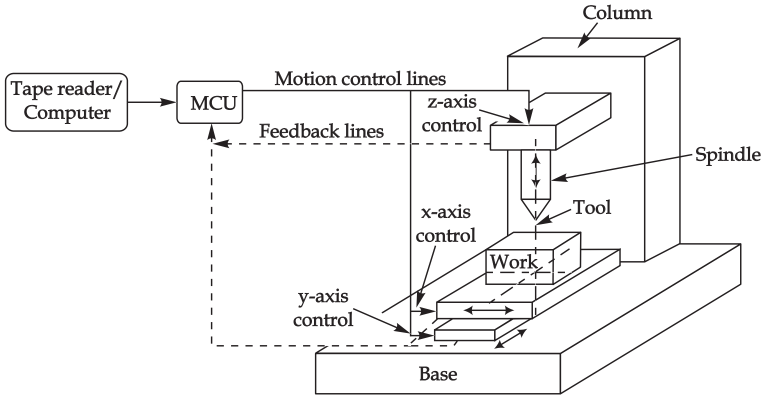


Fig. 6.4 Basic NC system.

6.3.2 Advantages of NC Machines

1. Improved quality of the product due to better control of the tool motions. The operator's errors are eliminated.
2. The repeatability of the quality.
3. The reduced lead time—Due to the reduced set-up time, achieved by the elimination of the special jigs and fixtures and the associated time in design and manufacture of the same.
4. Reduced labour cost per part.
5. Reduced inspection time.
6. Longer tool life.
7. Flexibility in component design—The modification of the component design can be easily accommodated by reprogramming and altering the tape.
8. Smaller batches can be handled economically.
9. Reduced production time.
10. Reduced scrap.
11. Accurate costing and scheduling.
12. Continuous operation.

6.3.3 CNC—Computer Numerical Control System

The CNC machine has an added feature of an onboard computer called Machine Control Unit—MCU for short. The machine functions are coded into the computer ROM at the time of the manufacture and they will not be erased, when the machine is turned off. The MCU has a keyboard for Manual Data Input (MDI) of part programme. Such programmes are stored in Random Access Memory (RAM). They can be played back, edited, processed by the control unit. They are lost whenever the machine is turned off, but can be saved in auxiliary storage devices such as punched tape, magnetic tape, etc. The modern MCUs have graphic screens. The programme and the tool path generated can be displayed on the screen. The error, if any, can be corrected before execution.

The components of a CNC system are as follows (shown in the Figure below).

1. Part programme
2. Part programme input device
3. Machine control unit—It generates, stores and processes CNC programmes. It also contains machine motion controller in the form of an executive software.
4. Drive system.
5. Machine tool—It is capable to respond to the signals from the MCU and perform the desired operations for the manufacture of the part.
6. Feedback system.
7. Display unit.

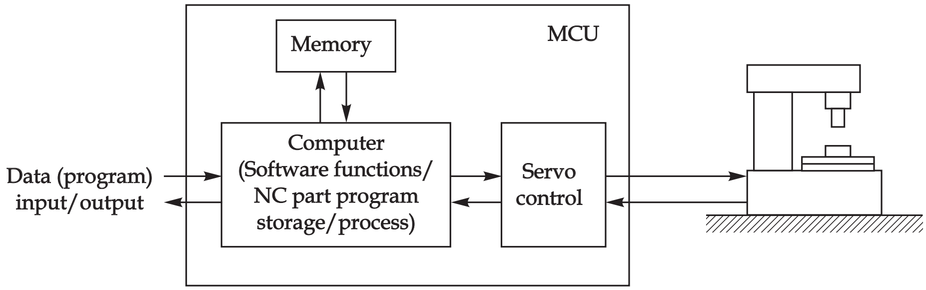


Fig. 6.5 Basic CNC sysem.

6.3.4 Advantages of CNC Machines

1. The new functions can be programmed directly into the MCU, eliminating the necessity of additional hardware.
2. The part programme can be written, stored and executed directly into the CNC machine.
3. The macros and subroutines can be stored in MCU and can be used for subsequent programming.
4. Any portion of the entered programme can be played back and edited. The tool path can be displayed on the screen and correction can be made if necessary.
5. Background tape preparation can be done
6. Several CNC machines can be linked to the main computer. Programmes written in the main computer can be downloaded to any CNC machine in the network. This is known as direct numerical control (DNC).
7. Several DNC systems can be networked to form a larger distributive numerical control system.
8. Many different programmes can be stored in MCU.
9. The programme can be input from flash or floppy disks or downloaded from local networks.
10. The tool offset data and tool–life management is possible.

6.3.5 Classification of CNC Machines Controls

(a) Based on motion—point–to-point or continuous path.
(b) Based on positioning system—incremental or absolute.
(c) Based on control loops—open loop or closed loop.
(d) Based on the number of axes of motion.

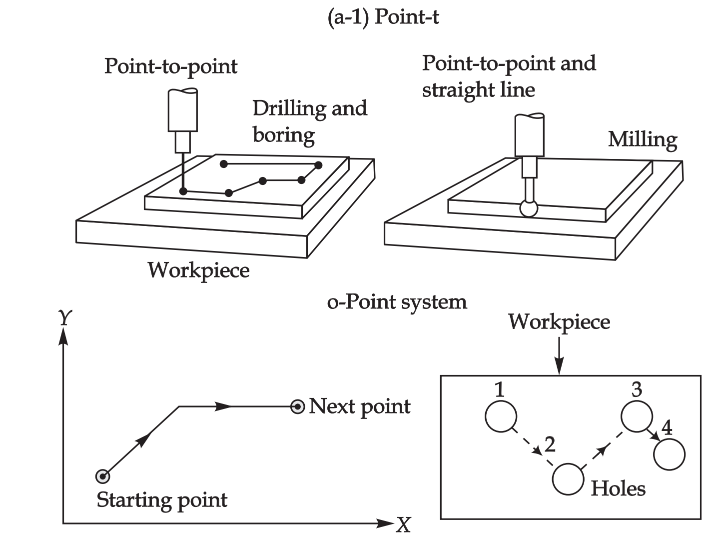


Fig. 6.6 Point-to-point path cutting.

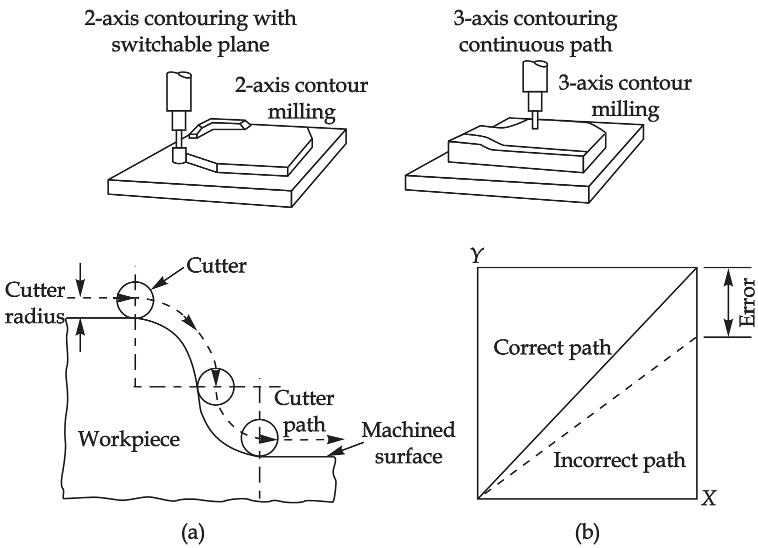


Fig. 6.7 (a) Continuous path cutting and (b) position error caused by the velocity error.

In this system the tool and workpiece are held at a particular location, while the tool does the operation (drilling). After the completion of the operation, the tool or the workpiece is moved to the next position of operation. The cycle is repeated until all operations are completed. In this system the feed rate and the speed of the cutting tool (or workpiece) slide, has no effect on machining process. The dimensional information to be given to the machine are a series of positions of the slides of the tool and/or workpiece. The servosystem moves the slides to the position and no slide movement occurs until the cutter has retracted back. The machines using the system are drilling, boring, taping machines.

In this system, while the cutting operation is in progress, the slides of tool and/or workpiece move continuously to generate angular surfaces, two-dimensional curves, or three-dimensional contours. Milling machines adopt this system. Each axis moves continuously at different velocity. The error in velocity affects the cutter position. The accuracy of motion is very much important. The slide motions and feed rates should be programmed properly.

(b-1) Incremental system

In this system the distances are measured from one point to the next point.

The movement from point A(2, 3) to point B(6, 8) is specied by x = 4, y = 5.

The drilling 5-holes at five different locations—The commands for x direction are specified as x = 500, +200, +600, –300, –700, –300.

Advantages are:

1. Inspection of the programme is simple because the sum of the commands for each axis must be zero. A non-zero sum indicates an error.
2. The mirror image programming is easy. It involves only the change of the signs of the commands.

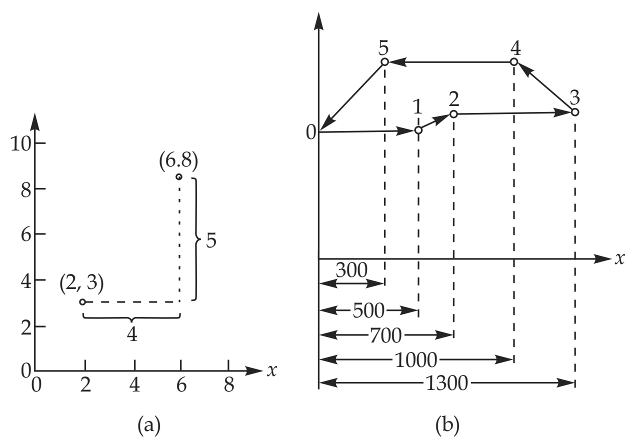


Fig. 6.8 (a) Incremental system. (b) absolute systems.

(b-2) Absolute system

In this system the movement commands are with reference to origin.

The movement from A (2, 3) to B (6, 8) is specified as x = 6, y = 8.

Drilling 5 holes at different locations–The commands for x direction are x = + 500, +700, +1000, +1300, +300.

Advantages are:

1. Interruptions caused by tool breakage or tool change or checking the parts do not affect the position at the interruption.
2. Dimensional data can be changed easily.

(c-1) Open-loop system

Here the command for the movement of the slides are given to the stepper motor. For each signal the stepper motor moves by a fixed angle and causes a fixed movement of the slide. The command determines the amount of movement of the tool or the workpiece. There is no surety that the correct position is reached. Any possible error cannot be detected and corrected. The load torque due the cutting forces, the backlash in the lead screw, may cause error in the actual position reached. Hence, this system is more suited for cases with no resisting force. Laser cutting is typical example for the use of this system.

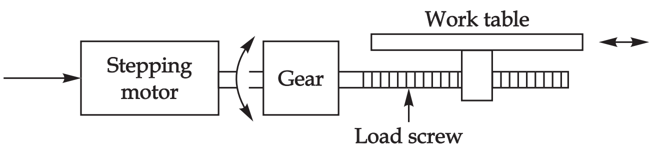


Fig. 6.9 Open-loop system.

(c-2) Closed-loop system

The closed loop system is provided with a feedback system. The feedback loop gives the information about the error in the position reached. The input device compares this data with desired data and the corrective action is taken. The corrected signal to the servomotor ensures that the position is reached.

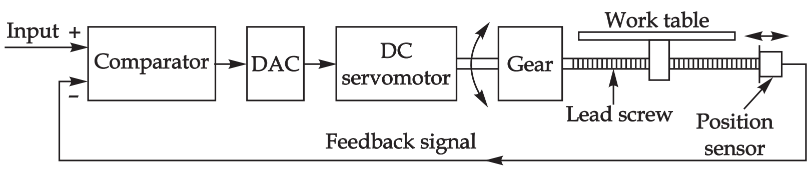


Fig. 6.10 Closed-loop system.

Based on number of axes of control

(d-1) 2 and 3 axes CNC machines

Two axes machines have movements along two axes as in lathe. The saddle moves longitudinally along the bed and cross slide moves transversely on the saddle. The 3-axes machines there is motion along the vertical direction of the table as in milling machines. The simultaneous control of the three motions complex surfaces can be machined.

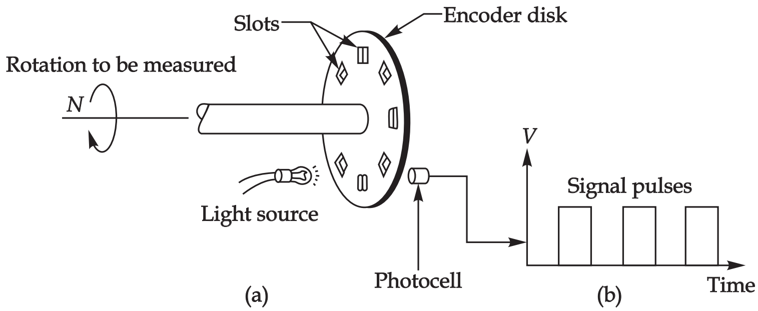


Fig. 6.11 Optical encoder.

(d-2) 4 and 5 axes CNC machines

Milling CNC centres have two more motions in addition to the *x*, *y*, *z*, motions. The rotary motion of the spindle and the rotary motion of the index table. The 5-axes milling centre is more popular version.

6.3.6 Applications of CNC Machines

CNC machines are widely used in manufacturing industry. They are best suited for the following situations.

1. Parts with complicated contours.
2. Parts requiring close tolerance and/or good repeatability.
3. Parts requiring expensive jigs and fixtures.
4. Parts that have several engineering changes as in the development stages.
5. Whenever human errors are likely to prove extremely costly.
6. Parts are required urgently.
7. Small batch production or short production runs are required.

6.3.7 Commonly used CNC Machines

- Lathe/turning centre.
- Milling/milling centre.
- Drilling machine,
- Grinding machine.

- Turret press and punching machine.
- Wirecut electro discharge machine (EDM).
- Laser cutting machine
- Water jet cutting machine.
- Co-ordinate measuring machine
- Filament winding machine for composites.
- Electronics assembly machine.

6.3.8 Industry-Wise Applications

The CNC systems are applied in the following industries:

- Automotive industry.
- Aerospace industry.
- Machinery industry.
- Electrical industry.
- Instrumentation industry.

The merits and demerit of CNC machines can be summarised as follows.

Merits

- Ease of use—The operator can be trained easily.
- The operator can manage several CNC machines at the same time.
- The advanced CNC machines do not need any operator.
- High efficiency–These machine can operate almost continuously, 24 hours a day, 365 days a year.
- High flexibility—Capabilities of machines can be expanded by the software updates.
- Design changes can be accommodated easily.
- Prototypes are not required, saving time and money.
- Quality of production—High dimensional accuracy can be achieved.
- Parts are identical to each other.
- Reduced wastage—Scrap and rejection is less.

Demerits

- High initial cost—The machines are very costly.
- Tooling is expensive.
- High mentenace cost—expensive repairs.

EXERCISES

Automation

1. Define and explain automation.
2. What is classification of automation?

3. Explain the features of fixed automation.
4. Explain programmable automation.
5. Explain flexible automation.
6. What are the control systems used in automation?
7. Explain any one type of control system.
8. Compare various control systems.
9. What are the advantages and disadvantages automation?
10. What are the fields of application of automation?

Robotics

11. Define a robot and robotics.
12. State the laws of robotics.
13. How are the robots classified?
14. What are the components of a robot?
15. Explain with sketches the configurations of robots.
16. What are actuators? Explain various actuators.
17. Name the sensors used in robots.
18. What the advantages and disadvantages of robots?
19. What are applications of robots?
20. List advantages of electrical, hydraulic and pneumatic drives.

CNC Machines

21. Explain with block diagram an NC system.
22. What are the advantages of an NC system?
23. What are the disadvantages of an NC system?
24. Explain with block diagram a CNC system.
25. What are advantages of CNC over NC system?
26. What are the classifications of machine tool motion controls?
27. Explain the open loop and closed control systems.
28. Explain point-to-point and continuous control systems.
29. Explain absolute and incremental systems.
30. List applications of CNC systems?

CHAPTER 7

Engineering Materials

7.1 FERROUS METALS

7.1.1 Cast Irons

They are the most widely used materials. They have the following characteristics:

(i) They can be easily cast into a variety of shapes.
(ii) They can be machined with available tools.
(iii) They have high compressive strength and are suitable for components subjected to compressive loads.
(iv) They have good wear resistance combined with vibration damping capacity. Due to this, they are suitable for machine beds, guides and frames.
(v) Cast irons are not affected by small variations of the temperature.
(vi) They have low notch sensitivity.
(vii) The major drawback of cast irons is their brittleness. They fail without any plastics deformation.
(viii) They are weak in tension and are less suitable for components subjected to tensions.

There are four types of cast irons, namely:

1. Grey cast irons.
2. White cast irons.
3. Malleable cast iron.
4. Nodular cast irons.

1. **Grey cast irons** have 2% carbon in the form of ferrite, pearlite and graphite in the form of fine flakes distributed throughout the structure This imparts good machineability.
2. **White cast iron** has cementite and pearlite and no graphite. This is produced by chilling process. The structure is very hard and wear resistant. A portion of grey iron components requiring wear resistance can by chilled and white structure can be produced, retaining the tough grey structure in the remaining portion.
3. **Malleable cast iron** has graphite in the nodular from. It has better tensile strength and ductility. The structure is produced by prolonged annealing process.

4. **Nodular cast iron** has the nodular graphite structure in the as cast condition. This is achieved by the addition of magnesium and cesium during the casting process. Nodular cast iron has high tensile strength and high modulus of elasticity. It has applications in situations requiring shock and impact resistance.

Alloy cast irons: Nickel chromium and mdybdencem are added as alloying elements to improve the tensile strength and impact resistance and hardness without losing its machinability.

The major applications of cast irons are,

(i) Machine tool beds, frames, tables, guides, gears, levers, sprockets, hydraulic cylinders and dies.
(ii) I.C. engines cylinders, cylinder heads, piston and piston rings, crank ease, exhaust manifolds, flywheel, brake drum, brakeshoe, etc.
(iii) Hydraulic cylinders, pipes fittings, valve bodies and dome covers.

7.1.2 Steels

Steels have wide range of mechanical properties and extensive applications. They may be grouped under the following categories:

(i) Plain carbon steels.
(ii) Alloy steels.
(iii) Stainless steels
(iv) Free cutting steels.
(v) Cast steels.

Plain carbon steels: They contain carbon from 0.2% to 0.8% and a small percentage of manganese, silicon, sulphur and phosphorus. They were designated by the letter C followed by a number, representing the average carbon percentage multiplied by 100. A steel with 0.35% to 0.45% carbon is represented as C40.

In the new BIS system, the designation has three parts.

(i) A figure indicating 100 times the average percentage of carbon.
(ii) A letter C.
(iii) A figure indicating 10 times the average percentage of manganese.
(iv) For alloy steels, the symbol of significant element with its average percentage is added after the number indicating carbon content without letter C.

For example, 55C8-represents a plain carbon steel with 0.55% carbon and 0.8% manganese.

The following are the applications of these steels.

Low carbon steels: [Steels containing up to 35% carbon, C10, C20, C30]. They are used for automobile bodies, hoods, cam and camshaft, gudgeon pin, chain-wheel and spindle, rocker arm, lever, etc.

Medium carbon steel: [Steels containing up to 35% to 55% carbon, C40, C45, C50, C55.]. They are used for transmission shafts, crankshafts, spindles, connecting rods, gears, worms, bolts, studs, cylinders. cams, sprockets, etc.

High carbon steels: Steels containing carbon from 60% to 80%, C60, C65 are used for machine tool spindles, high tensile bolts, springs, etc.

Alloy steels: The term alloy steel refers to steels with one or two alloying elements in sufficiently large quantities to modify its properties satisfactorily. The effects of various alloying elements are explained as follows:

- **Chromium:** The presence of chromium increases toughness, hardness and resistance to wear and corrosion.
- **Nickel:** The addition of nickel increases the strength, toughness without losing ductility. It prevents distortion during heat-treatment.
- **Manganese:** It is a deoxidizing and desulfurizing agent. It increases hardness and strength and counteracts the brittleness due to sulphur. It prolongs the transformation time so that oil quenching becomes possible.
- **Silicon:** It is a deoxidizing agent and stabilizes carbides of other alloying elements. It reduces the hysteresis loss and improves the magnetic permeability.
- **Molybdenum:** It improves hardness and toughness and hardenability. It also improves the creep properties.
- **Vanadium:** It is a strong deoxidizing agent. It increases the hardening range and retains hardness at elevated temperature. It increases the endurance strength. It is used for tool steels.
- **Tungsten:** It produces a fine dense structure and adds both toughness and hardness. It is widely used in tool steels.

Applications of the alloy steels are as follows:

Chromium and nickel steels: (4OCrl, 40Ni3, 35Nil Cr60, 30 NilCrl) are used for gears, connecting rods, crankshafts, camshaft, gear shafts and high strength bolts.

Manganese steels: (27 Mn_2, 37 Mn_2) are used for transmission shafts, axles and welded parts.

Chrome-vanadium steels: (5OCrl V23) are used for leaf and coil springs.

Stainless steels: They are alloy steels with more than 12% chromium. Nickel and molybdenum and additional alloying elements to improve the corrosion and heat resisting properties.

Chromium steels with 12 to 16% Cr are magnetic and hardenable. They are used for hydraulic pumps, valves, steam valves.

Chromium steels with more 16% Cr are magnetic but non-hardenable. They have good ductility but low strength at high temperature. They are used for cold-press-work. Chrome-nickel and chrome-vanadium steels have austenitic instructure. They are non-magnetic, resistant to corrosion, hardenable and weldable. They are used for springs and high temperature applications.

Free-cutting-steels: They are carbon and manganese steels with a small percentage of sulphur. They have good machinability. 10C8S10, 14C12S14 are used for bushes, tappets, gudgeon pin, pawls, worms, pinion motor cycle and cycle components. 25C12S14, 40C10S18, 40C15S12-are used for bolts, studs, etc.

Cast steels: The cast steels have higher strength and stiffness but costlier compared to castirons. They can be cast into intricate shapes. They can be heat-treated. They are classified into two groups.

1. **Carbon steel-castings:** They are used for heavy duty machinery, highly stressed castings, gears and wheels. They are classified into five groups, each group being designated by Grade x-y, where x represents 1/10 of yield strength in MPa, and y represents 1/10 of ultimate tensile strength in MPa. They are Grade 20-40; Grade 23-45; Grade 26-52; Grade 27-54; and Grade 30-57.
2. **High tensile steel castings:** They have higher strength, good toughness, high resistance to wear. They are used for transportation equipment and agricultural machineiy. They are classified into five groups, namely, CS 640; CS 700; CS 840; CS 1030; CS 1230; the number representing the ultimate tensile strength in MPa.

7.2 NON-FERROUS METALS AND ALLOYS

7.2.1 Aluminium and its Alloys

Favourable characteristics of aluminium and its alloys are:

(i) High strength/weight ratio.
(ii) Resistance to corrosion.
(iii) High thermal and electrical conductivity.
(iv) Ease of fabrication–They can be cast, rolled, forged and extruded.

Unfavourable features are:

(i) Low strength and rigidity
(ii) Difficulty in welding.
(iii) Aluminium alloys are available in two forms
   (a) Castings
   (b) Wrought.

The alloys are designated by a digital number system, the alloying elements are represented by the following numbers:

Aluminium	-	1	Magnesium	-	5
Copper	-	2	Magnesium silicide	-	6
Manganese	-	3	Zinc	-	7
Silicon	-	4	Other elements	-	8

The cast alluminium alloys are specified by a four-digit number and wrought aluminium alloys by five-digit-system.

Meaning of the digits is as follows:

The first digit represents the major alloying element

The second digit represents the average percentage of the alloying element halved and rounded off.

Third, fourth, fifth digits identify the minor alloying elements in the order decreasing percentage.

For example 4683 has silicon as major alloying element with average of 12%, Fe and manganese as minor alloying elements; 24345 has copper as major alloying element with average of 8% and manganese silicon and magnesium as minor alloying elements in the decreasing order of percentage.

They are used for:

1. Rapidly reciprocating or oscillating parts like pistons and connecting rods of high speed engines.
2. High rotating parts: pulleys, bearing cages and engine components.
3. Intricate castings of engines and engine components.
4. Cover, hoods and guards of hydraulic machines.
5. Welded cylinders, pressure vessels and structure of aircraft.
6. Forged and deep-drawn parts.

Important applications of typical alloys are:

Alloy		**Applications**
Cast alloys		
4450	–	Cylinder block,valve body and fan blade
4600	–	Water cooled manifolds of engines and pumps
4685	–	I.C. engine piston
2280	–	Connecting rod and flywheel
2285	–	Piston and air-cooled cylinder
2550	–	Hydraulic cylinder and bearing cap
Wrought alloys		
24345	–	Heavy duty forgings and structures
24534	–	Critical parts of aircraft
54300	–	Welded structures like car tanks
64430	–	Roof trusses and deep drawn containers
74530	–	Welded pressure vessels

7.2.2 Copper Alloys

They have the following favourable properties

1. Excellent bearing properties.
2. High thermal conductivity.
3. Good corrosion resistance.
4. Excellent machinability.
5. Ease of fabrication

They are grouped under two broad categories (a) brasses (b) bronzes.

Brasses are copper and zinc alloys. The complex brasses contain additional elements like lead, silicon, manganese, aluminium, iron, nickel, and tin. Brasses are available as cast brasses or wrought brasses. The cast brasses have exellent foundry properties and can be cast into complicated shapes with ease. Wrought brasses can be cold worked. They can be rolled into thin sheets and drawn into thin tubes. They have good corrosion resistance, electrical conductivity and machinability.

Brasses are used for (i) tubings and shells, (ii) wires, (iii) electric fittings and machines (iv) instruments.

Various brasses are:

Gilding brass are used for gold plated articles in jewellery.

Commercial bronze are used for jewellery, forging and stampings.

Red brass are used for tubing and pipings in radiators and condensers.

Low brass are used for deep-drawn articles.

Cartridge brass has better ductility, combined with strength, used for machine screw parts, instruments, lock and watch parts.

Admiralty brass has good corrosion resistance and is used for power plant and chemical equipment.

Aluminium brass is used for tubing and piping in chemical plants.

Bronzes are mainly copper-tin alloys, but other alloying elements like lead, aluminium, beiyllium, silicon may be used as alloying elements and are named accordingly. Bronzes, in general, have high anti-friction properties, good corrossion resistance and good processing properties.

They are widely used for (i) friction joints like sleeve bearings, guides, worm wheels, helical gears and power screws (ii) for water, steam and oil fittings.

Various types of bronzes are:

Silicon bronze: It has good strength and corrosion resistance. It can be cold or hot worked, machined and welded.

Phospher bronze: It is resistant to fatigue and corrosion. It has tensile strength and high capacity to absorb energy. It is used for nut, worm wheel, spring bearings, pumps, etc.

Aluminium bronze: It has high corrosion resistance, high strength and toughness, low friction. It is used for hydraulic valve bearings, cam followers and gears.

Beryllium bronze: It has corrosion resistance, high strength hardness and resistance to wear. It is used for springs subjected fatigue.

Lead bronze: It is a good bearing material, but has low hardness and requires hard backing material.

Babbit metals: They are alloys of soft metals like tin, lead and calcium. They have good anti-friction properties and are used for bearings operating at high speeds under high pressures.

7.3 PLASTICS

There are materials of high-molecular organic compounds, chiefly synthetic processed by heat and pressure. The plastics can be processed, moulded, extruded, machined and bounded. They have a wide range of mechanical and physical properties. Favourable characteristics are:

(i) Low density.
(ii) High thermal and electric resistance (insulation).
(iii) High damping capacity.
(iv) Low coefficient of friction and self-lubrication.
(v) Wear resistance.
(vi) Ease of fabrication into complex shapes.

Unfavourable characteristics are:

(i) Low strength.
(ii) Poor heat resistance.
(iii) High thermal expansion.
(iv) High creep.

There are various types of plastics with different properties. They are grouped under two categories:

(a) Thermoplastics which soften under heat, harden on cooling, and be resoftened again by heating to be formed again.
(b) Thermosetting plastics which undego a chemical change during manufacturing due to high temperature and cure to an infusible shape not permitting any reforming.

Some of the commonly used plastics are:

(i) Nylon (polyamide) has good mechanical strength, resistance to heat and abrasion and has self–lubricating property. It used for bearings, cams, valve-seats, gears.
(ii) Polythene is used for gaskets, washers.
(iii) Delrin (acetal) is used for bearings, cams and gears.
(iv) Texin (polyurethane) is used for bearings, gears, gaskets and seals.
(v) Teflon (polytetrafluoroethylene) is used for piston rings, bearings, gaskets and belows.

7.4 COMPOSITES

Mankind has been aware of composite materials since several hundred years BC and has applied innovation to improve the quality of life. Man understood the fact that mud bricks made sturdier houses if lined with straw. He used them to make buildings that would longer. Ancient Pharaohs made their slaves use bricks with straw to enhance the structural integrity of their buildings, some of which testify the wisdom of the dead civilization even today.

Contemporary composites are results of the research and innovation of past few decades. They have progressed from glass fibre for automobile bodies to particulate composites for aerospace and a range of other applications.

Composite materials (shortened to **composites**) are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons. They are stronger, lighter or less expensive when compared to traditional materials.

Typical engineered composite materials include:

- Composite building materials such as cements, concrete.
- Reinforced plastics such as fibre-reinforced polymer (FRP).
- Metal matrix composites (MMC).
- Ceramic matrix composites (CMC).

Composite materials are generally used for buildings, bridges and structures such as boat hulls, swimming pool panels, race car bodies, shower stalls, bath tubs, storage tanks, imitation granite and cultured marble sinks and counter tops, automobile and aerospace industry. The most advanced examples perform routinely on spacecraft in demanding environments.

The composites consist of two phases:

1. Matrix phase—polymers, metals and ceramics
2. Reinforcing phase—fibres, particles and flakes

The matrix phase serves two paramount purposes, namely, binding the reinforcement phases in place and to distribute the stresses among the constituent reinforcement materials under an applied force. The demands on matrices are many. They may need to be resistant to temperature variations, be conductors or resistors of electricity, have moisture sensitivity, etc. They may offer weight advantages, ease of handling and other merits, depending on the purpose for which matrices are chosen.

7.4.1 Role of Matrices in Composites

1. Transfer stresses between the fibres.
2. Provide a barrier against an adverse environment.
3. Protect the surface of the fibres from mechanical abrasion.
4. Determine inter-laminar shear strength.
5. Determine damage tolerance of composites.

6. Determine in-plane shear strength.
7. Determine the processibility of composites.
8. Determine the heat resistance of composites.

7.4.2 Polymer Matrix Materials

Polymers are ideal matrices because they can be processed easily, possess lightweight and desirable mechanical properties. There are two kinds of polymers, namely, thermosets and thermoplastics.

Thermosets have well-bonded three dimensional molecular structure after curing. They can be retained in partially cured condition over prolonged periods of time. They are flexible and find wide applications in the chopped fibre composites. They are widely used for aerospace components, automobile parts, defense systems.

Thermoplastics have one- or two-dimensional molecular structure and have exaggerated melting point. They soften at elevated temperatures and regain their properties during cooling, facilitating applications of conventional compress techniques to mould the compounds. They have high rigidity, toughness, creep resistance. They are used in automotive control panels, electronic product encasements.

7.4.3 Metal Matrix Materials

Most metals and alloys make good matrices. Only light metals are responsive, with their low density proving an advantage. Titanium, aluminium and magnesium are popular matrix materials. They are used in aircraft applications. Metal matrices offer high strength, fracture strength, and stiffness. However, they are not used as widely as plastics.

7.4.4 Ceramic Matrix Materials

Ceramics have high melting points, good corrosion resistance, high compressive strength and stability at high temperature. They are suitable for high temperature applications but high modulus of elasticity and low tensile strain discourages their use.

7.4.5 Carbon Matrix Materials

Carbon and graphite have high strength and rigidity at temperatures up to 230°C. They have high dimensional stability. They find wide applications in aeronautics, military, and space industry.

7.5 REINFORCEMENTS

Reinforcing constituents in composites, as the word indicates, provide the strength that makes the composite what it is. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements. A reinforcement must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite. This means that the ductility should be minimum or even nil. A composite must behave as brittle as possible.

Reinforcements for the composites can be fibres, fabrics, particles or whiskers. Fibres are essentially characterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does their shapes. Whiskers have a preferred shape but are small both in diameter and length as compared to fibres. Fibres occupy the most volume in a high performance composite and carry the applied load. The fibre type, quantity and orientation have a major influence on the properties of the composite. The specific gravity, tensile strength, compressive strength, fatigue strength, electrical and thermal conductivity of composites are determined by fibres. There are various types of fibres. The glass fibres, carbon fibres, metal fibres, organic fibres (aramid) are widely used. These fibres are available in bundles, woven fabrics and mats.

7.5.1 Manufacturing Methods for Composite Materials

1. Manual lay-up or spray-up
2. Vacuum bagging
3. Autoclave processing
4. Filament winding
5. Pultrusion
6. Matched die moulding (SMC)
7. Resin transfer moulding

All these methods are tailored for the specific materials that are being processed. Polymer chemistry plays important role in selecting the appropriate resin for a given fabrication method.

7.6 CLASSIFICATION OF COMPOSITES

Composite materials are commonly classified as per the following two distinct bases:

1. The first base of classification is usually made with respect to the matrix constituent. The major composite classes include organic matrix composites (OMCs), metal matrix composites (MMCs) and ceramic matrix composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely, polymer matrix composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.
2. The second base of classification refers to the reinforcement form — fibre reinforced composites, laminar composites and particulate composites. Fibre reinforced composites can be further divided into those containing discontinuous or continuous fibres.
    - Fibre reinforced composites are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does

not further increase, the elastic modulus of the composite, the composite is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling.

- Laminar composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.
- Particulate composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

7.7 ADVANTAGES AND DISADVANTAGES OF COMPOSITES

7.7.1 Advantages

(a) High resistance to fatigue and corrosion degradation.

(b) High 'strength or stiffness to weight' ratio. The weight savings are significant ranging from 25-45% of the weight of conventional metallic designs.

(c) Due to greater reliability, there are fewer inspections and structural repairs.

(d) Directional tailoring capabilities to meet the design requirements. The fibre pattern can be laid in a manner that will tailor the structure to efficiently sustain the applied loads.

(e) Fibre to fibre redundant load path.

(f) Improved dent resistance is normally achieved. Composite panels do not sustain damage as easily as thin gauge sheet metals.

(g) It is easier to achieve smooth aerodynamic profiles for drag reduction. Complex double-curvature parts with a smooth surface finish can be made in one manufacturing operation.

(h) Composites offer improved torsional stiffness. This implies high whirling speeds, reduced number of intermediate bearings and supporting structural elements. The overall part count and manufacturing and assembly costs are thus reduced.

(i) High resistance to impact damage.

(j) Thermoplastics have rapid process cycles, making them attractive for high volume commercial applications that traditionally have been the domain of sheet metals. Moreover, thermoplastics can also be reformed.

(k) Like metals, thermoplastics have indefinite shelf-life.

(l) Composites are dimensionally stable, i.e., they have low thermal conductivity and low coefficient of thermal expansion. Composite materials can be tailored to comply with a broad range of thermal expansion design requirements and to minimise thermal stresses.

(m) Manufacture and assembly are simplified because of part integration (joint/fastener reduction) thereby reducing cost.

(n) Improved weatherability of composites in marine environment as well as their corrosion resistance and durability reduce the down time for maintenance.

(o) Close tolerances can be achieved without machining.

(p) Material used is reduced because composite parts and structures are frequently built to shape rather than machined to the required configuration, as is common with metals.

(q) Excellent heat sink properties of composites, especially carbon-carbon, combined with their lightweight have extended their use for aircraft brakes.

(r) Improved friction and wear properties.

(s) Ability to tailor the basic material properties of a laminate allows new approaches to the design of aeroelastic flight structures.

The above advantages translate not only into airplane, but also into common implements and equipment such as a graphite racquet that has inherent damping, and causes less fatigue and pain to the user.

7.7.2 Disadvantage

Some of the associated disadvantages of advanced composites are:

(a) High cost of raw materials and fabrication.

(b) Composites are more brittle than wrought metals and thus are more easily damaged.

(c) Transverse properties may be weak.

(d) Matrix is weak, therefore, low toughness.

(e) Reuse and disposal may be difficult.

(f) Difficult to attach.

(g) Repair introduces new problems, for the following reasons:

- Materials require refrigerated transport and storage and have limited shelf life.
- Hot curing is necessary in many cases requiring special tooling.
- Hot or cold curing takes time.

(h) Analysis is difficult.

(i) Matrix is subject to environmental degradation.

However, proper design and material selection can circumvent many of the above disadvantages.

New technology has provided a variety of reinforcing fibres and matrices and those can be combined to form composites having a wide range of exceptional properties. Since the advanced composites are capable of providing structural efficiency at lower weights as compared to equivalent metallic structures, they have emerged as the primary materials for future use.

In aircraft application, advanced fibre reinforced composites are now being used in many structural applications, viz., floor beams, engine cowlings, flight control surfaces, landing gear doors, wing-to-body fairings, etc., and also major load carrying structures including the vertical and horizontal stabilizers, main torque boxes.

Composites are also being considered for use in improvements to civil infrastructures, viz., earthquake-proof highway supports, power generating wind mills, long span bridges, etc.

7.8 APPLICATIONS

1. Aerospace components like tails, wings, fuselages, propellers are made from composites.
2. They are widely used in space vehicles.
3. They are being used in military vehicles, luxury cars and sports cars.
4. Composite materials are also becoming more common in orthopaedic surgery.
5. Boat hulls, bicycle frames, and racing car bodies are made of composites.
6. Used for fishing rods, storage tanks, swimming pool panels, and baseball bats, as a non-corrosive alternative to galvanized steel in residential as well as commercial applications.
7. Pipes and fittings for various purpose like transportation of potable water, fire-fighting, irrigation, seawater, desalinated water, chemical and industrial waste, and sewage are now manufactured in glass reinforced plastics.

EXERCISES

1. Explain the characteristics of cast iron.
2. List the types of cast iron and their applications.
3. What are types of steel and list their applications.
4. What are non-ferrous alloys? Explain with examples.
5. Explain applications of non–ferrous alloys.
6. What is a composite material? Explain.
7. Differentiate between matrix phase and reinforcing base.
8. Explain the differentness between thermoses and thermoplastics.
9. What is reinforcement in composites? Explain with examples.
10. Differentiate between metals and composts.
11. List the advantages and disadvantages of composites.
12. Explain five important applications of composites.

CHAPTER 8

Metal Fabrication

Metal fabrication is the process of joining metal parts to produce useful components or structures. Riveting was common method used in olden days. Welding has replaced riveting in almost all fields of fabrication. Welding makes a homogeneous and strong joint, which is sometimes stronger than the parent metal.

Generally, joining methods used are welding, brazing, soldering, and adhesive bonding. These methods form a permanent joint between the parts—a joint that cannot be easily separated. Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint. Soldering and brazing, involve melting a lower melting point material between the workpieces to form a bond between them, without melting the workpieces.

8.1 WELDING

Welding is a materials joining process in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat and/or pressure. Many welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and still others by pressure alone, with no external heat supplied. In some welding processes a filler material is added to facilitate coalescence. The assemblage of parts that are joined by welding is called a *weldment.* Welding is most commonly associated with metal parts, but the process is also used for joining plastics.

Types of welding processes

We can divide the welding processes into two major groups:

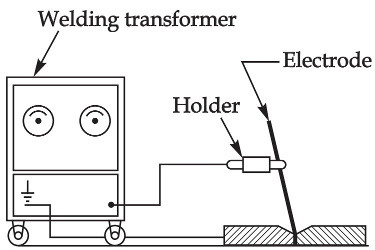
(1) Fusion welding
(2) Solid state welding.

Fusion welding

Fusion welding processes use heat to melt the base metals. In many fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint. A fusion welding operation in which no filler metal is added is referred to as an autogenous weld. The fusion category includes the most widely used welding processes, which can be organized into the following general groups (initials in parentheses are designations of the American Welding Society):

Arc welding

Arc welding refers to a group of welding processes in which heating of metals is accomplished by an electric arc. Some arc welding operations also apply pressure during the process and most utilize a filler metal**.**



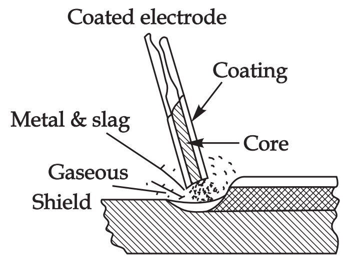


Fig. 8.1 Arc-welding set. **Fig. 8.2** Shielded arc welding.

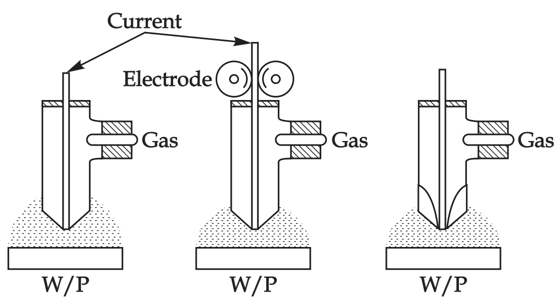


Fig. 8.3 Gas shielded arc welding.

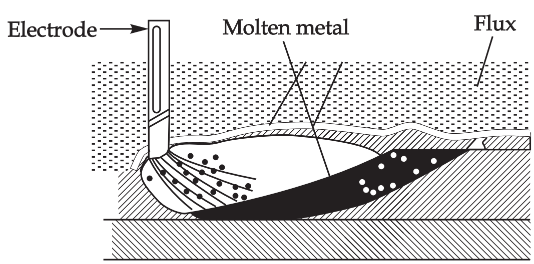


Fig. 8.4 Submerged arc welding.

Principle: The electrode and parent metals are connected to the output terminals of a welding transformer. The electrode is brought very near to the parent metals. An electric arc is produced in the small gap between them. The intense heat generated melts the parent metals and electrode. The molten metal of the electrode fills the gap between the parent metals and fuses with it. The mixture of the molten metal solidifies into continuous and homogeneous metal.

An arc welding set-up consists of the following equipment:

1. AC or DC machine	2. Electrode
3. Electrode holder	4. Cables and connector
5. Cable lug	6. Chipping hammer
7. Earthing equipment	8. Wire brush
9. Helmet	10. Safety goggles
11. Hand gloves	12. Apron sleeves, etc.

There are various methods of arc welding

1. Metal arc welding	2. Gas metal arc welding (MIG)
3. Gas tungsten arc welding (TIG)	4. Submerged are welding
5. Carbon arc welding	

Resistance welding

Resistance welding achieves coalescence using heat from electrical resistance to the flow of a current passing between the adjoining surfaces of the two parts held together under pressure, for example, spot welding and seam welding. The two joining methods are widely used today in sheet metal working.

Principle: The metal parts to be joined are pressed together and high density electric current is passed through them by means of proper electrical circuit. Because of high resistance at the junction a large amount of heat is generated as given by $H = I^2R$

where H = heat generated

I = current in amperes

R = resistance in ohms

This heat makes the metals plastic and are joined by the applied pressure. The diagram shows the set-up for resistance welding. The set-up consists of a stepdown transformer, electrode and work clamping devices. The various welding operations done by resistance welding are:

1. Butt welding.	3. Seam welding.
2. Spot welding.	4. Projection welding.

Oxyfuel gas welding

These joining processes use an oxyfuel gas, such as a mixture of oxygen and acetylene, to produce a hot flame for melting the base metal and filler metal, if one is used. Although Davy discovered acetylene gas early in the 1800s, oxyfuel gas welding required the subsequent development of torches for combining acetylene and oxygen around 1900. During the 1890s, hydrogen and natural gas were mixed with oxygen for welding, but the oxyacetylene flame achieved significantly higher temperatures.

Principle: In this method the heat source is the flame generated by a mixture of gases like acetylene and oxygen in gas torch. The temperature reaches upto 3200°C. The gas welding set-up consists of the following equipment:

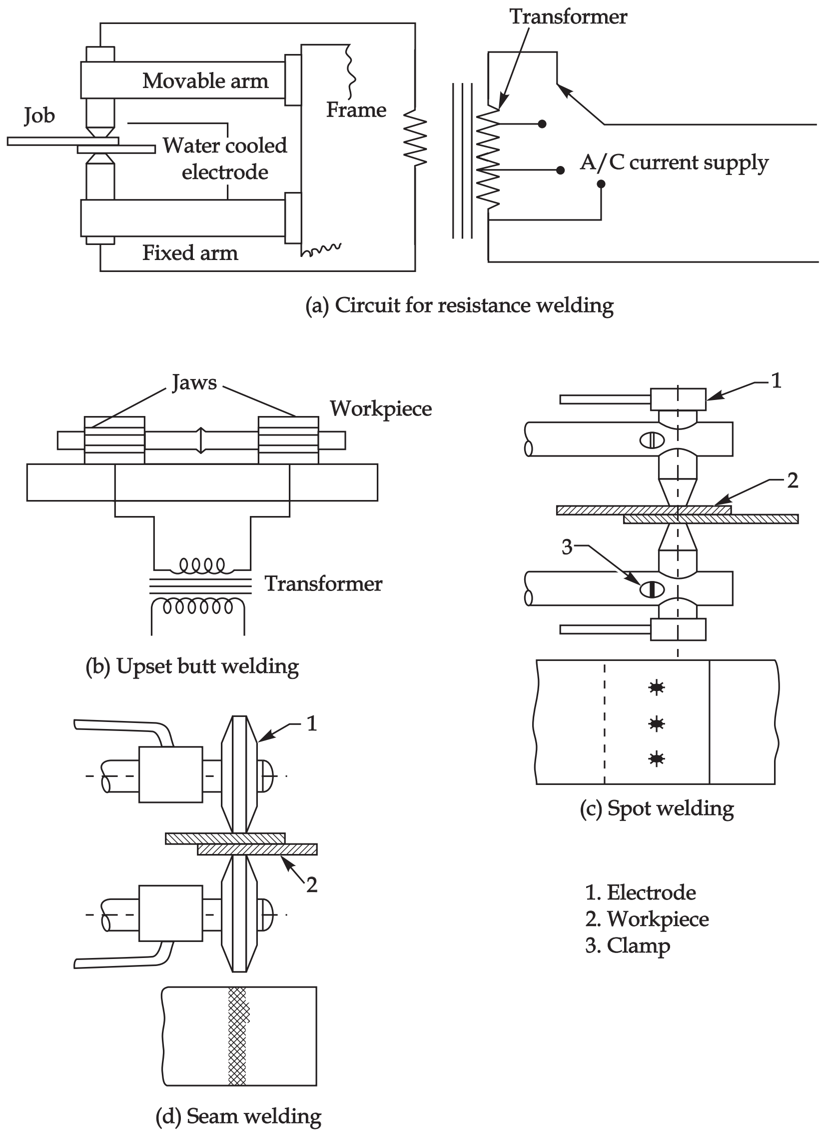


Fig. 8.5 Welding processes

1. An oxygen cylinder with pressure regulator.
2. A cylinder with dissolved acetylene or acetylene gas producer with pressure regulator.
3. Gas torch
4. The rubber tube connectors.
5. Gas lighter.

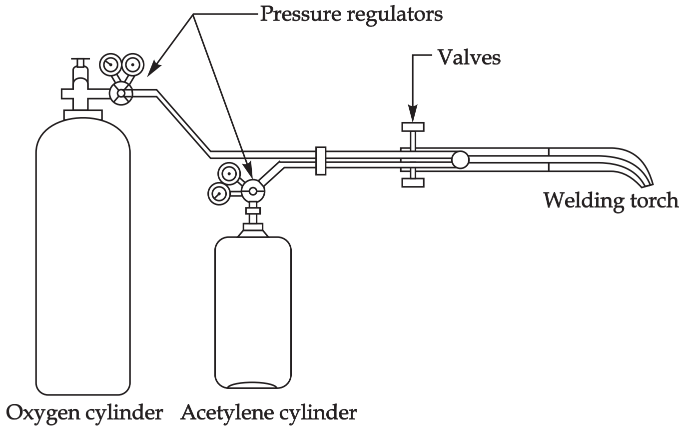


Fig. 8.6 Oxyacetylene welding welding set.

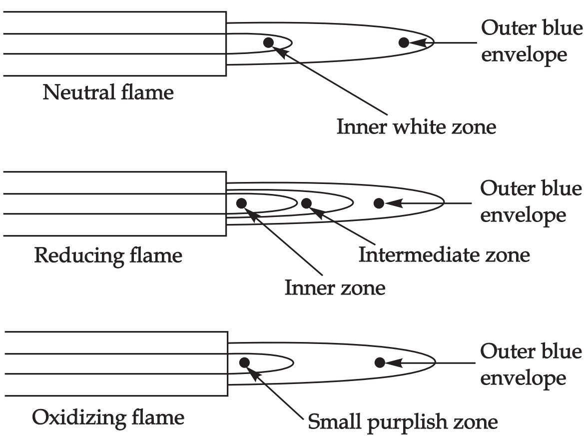


Fig. 8.7 Oxyacetylene welding flames.

Flame: The nature of the flame produced is controlled by the proportion of oxygen and gas. There are three types of flames.

1. **Neutral flame:** When oxygen and acetylene are mixed in chemically correct proportion a neutral flame is produced. The flame has two zones.

   (i) A short brilliant cone, extending a short distance from the tip of the torch.

   (ii) An outer envelope which is faintly luminous and of bluish colour.

   The first zone develops heat and the second zone protects the metal from oxidation. This flame is used for welding steel, strainless steel, cast iron, copper and aluminium.

2. **Reducing flame:** This flame is produced when acetylene is more than required. This flame has three zones.

   (i) Sharply defined inner zone. (ii) Intermediate whitish zone

   (ii) Bluish outer zone.

The flame is used for welding alloy steels, monal metal, nickle, aluminum, etc.

3. **Oxidizing flame:** This flame is produced when the oxygen supply is more than the correct proportions. The flame has two zones.
   (i) A small purplish inner zone (ii) Outer blue envelope.
   This is used for cutting metals.

Arc welding, resistance welding, and oxyfuel gas welding are by far the majority of welding operations performed nowadays.

Solid-state welding (plastic welding)

Solid-state welding refers to joining processes in which coalescence results from application of pressure alone or a combination of heat and pressure. If heat is used, temperature in the process is below the melting point of the metals being welded. No filler metal is utilized. Representative welding processes in this group include:

(i) **Diffusion welding:** Two surfaces are held together under pressure at an elevated temperature and the parts coalesce by solid-state diffusion.

(ii) **Friction welding:** Coalescence is achieved by the heat of friction between two surfaces.

(iii) **Ultrasonic welding:** Moderate pressure is applied between the two parts and an oscillating motion at ultrasonic frequencies is used in a direction parallel to the contacting surfaces. The combination of normal and vibratory forces results in shear stresses that remove surface films and achieve atomic bonding of the surfaces.

Types of joints

There are five basic types of joints for bringing two parts together for joining. The five joint types are not limited to welding; they apply to other joining and fastening techniques as well. With reference to Fig. 8.8, the five joint types can be defined as follows:

(a) **Butt joint:** In this joint type, the parts lie in the same plane and are joined at their edges.

(b) **Corner joint:** The parts in a corner joint form a right angle and are joined at the corner of the angle.

(c) **Lap joint**: This joint consists of two overlapping parts.

(d) **Tee joint:** In a tee joint, one part is perpendicular to the other in the approximate shape of the letter ''T''.

(e) **Edge joint:** The parts in an edge joint are parallel with at least one of their edges in common, and the joint is made at the common edge(s).

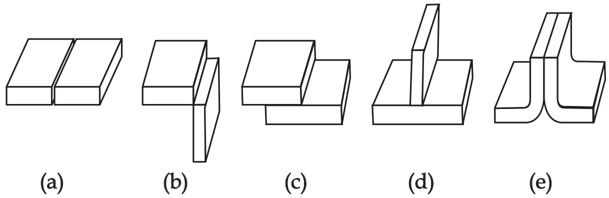


Fig. 8.8 Five basic types of joints: (a) Butt, (b) Corner, (c) Lap, (d) Tee, and (e) Edge.

Types of welds

Each of the preceding joints can be made by welding. It is appropriate to distinguish between the joint type and the way in which it is welded—the weld type. Differences among weld types are in geometry (joint type) and welding process. A fillet weld is used to fill in the edges of plates created by corner, lap, and tee joints, as in Fig. 8.9. Filler metal is used to provide a cross section approximately the shape of a right triangle. It is the most common weld type in arc and oxyfuel welding because it requires minimum edge preparation—the basic square edges of the parts are used. Fillet welds can be single or double (i.e., welded on one side or both) and can be continuous or intermittent (i.e., welded along the entire length of the joint or with unwelded spaces along the length). Groove welds usually require that the edges of the parts be shaped into a groove to facilitate weld penetration. The grooved shapes include square, bevel, *V*, *U*, and *J*.

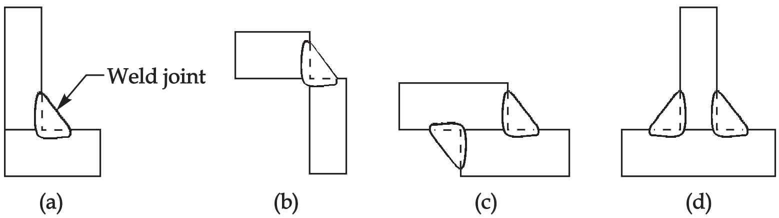


Fig. 8.9 Various forms of fillet welds: (a) Inside single fillet corner joint; (b) outside single fillet corner joint; (c) double fillet lap joint; and (d) double fillet tee joint. Dashed lines show the original part edges.

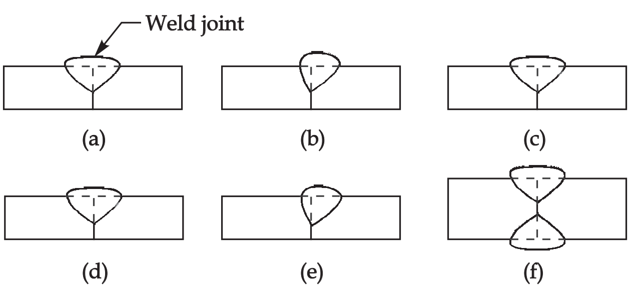


Fig. 8.10 Some typical groove welds (a) square groove weld, one side; (b) single bevel groove weld; (c) single V-groove weld; (d) single U-groove weld; (e) single J-groove weld; (f) double V-groove weld for thicker sections. Dashed lines show the original part edges.

Single or double sides, as shown in Fig. 8.10. Filler metal is used to fill in the joint, usually by arc or oxyfuel welding. Preparation of the part edges beyond the basic square edge, although requiring additional processing, is often done to increase the strength of the welded joint or where thicker parts are to be welded. Although most closely associated with a butt joint, groove welds are used on all joint types except lap. Plug welds and slot welds are used for attaching flat plates, as shown in Fig. 8.11a, using one or more holes or slots in the top part and then filling with filler metal to fuse the two parts together. Spot welds and seam welds, used for lap joints, are diagrammed in Fig. 8.11b. A spot weld is a small fused section between the surfaces of two sheets or plates. Multiple spot welds are typically required to join the parts. It is most closely associated with resistance welding. A seam weld is similar to a spot weld except it consists of a more or less continuously fused section between the two sheets or plates.

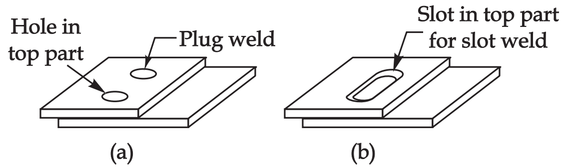


Fig 8.11 (a) Plug weld and slot weld

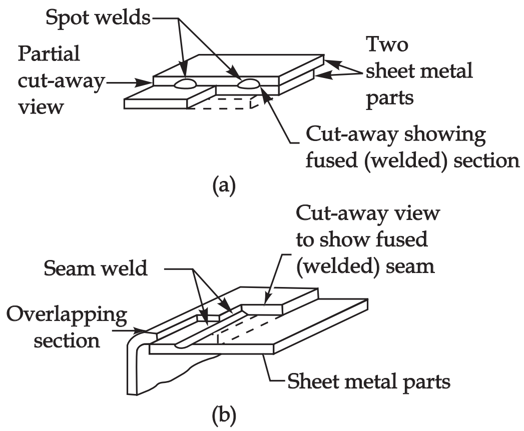


Fig. 8.11 (b) Spot weld; and seam weld.

Welding defects

Various defects produced during welding are explained below.

Cracks: They are produced by the localized high stresses caused by the uneven heating and cooling. These cracks may be microscopic or macroscopic. They can be eliminated by proper weld design and by controlling heating and cooling rates

Porosity: A group of voids may be created by the entrapped gases. They can be avoided by controling the welding process.

Poor fusion: This is lack of proper mixing of the deposited metal and parent metals. This can eliminated by the proper edge preparation

Undercut: There is a groove formed in the parent metal along the sides of the weld. This is caused by the excessive heating of the parent matal or the improper positioning of the welding rod.

Spatter: These are small metal particles deposited on the parent metal along the weld bead. This occurs in arc welding.

Advantages of welding

1. Welding provides a permanent joint. The welded parts become a single entity.
2. The welded joint can be stronger than the parent materials if the filler metal used has strength properties superior to those of the parents, and if proper welding techniques are used.
3. Welding is usually the most economical way to join components in terms of material usage and fabrication costs. Alternative mechanical methods of assembly require more complex shape alterations (e.g., drilling of holes) and addition of fasteners (e.g., rivets or bolts). The resulting mechanical assembly is usually heavier than a corresponding weldment.
4. Welding is not restricted to the factory environment. It can be accomplished "in the field".

Disadvantages of welding

1. Most welding operations are performed manually and are expensive in terms of labour cost. Many welding operations are considered ''skilled trades,'' and the labour to perform these operations may be scarce.
2. Most welding processes are inherently dangerous because they involve the use of high energy.
3. Since welding accomplishes a permanent bond between the components, it does not allow for convenient disassembly. If the product must occasionally be disassembled (e.g., for repair or maintenance), then welding should not be used as the assembly method.
4. The welded joint can suffer from certain quality defects that are difficult to detect. The defects can reduce the strength of the joint.

Applications

The principal applications of welding are:

1. Construction, such as buildings and bridges
2. Piping, pressure vessels, boilers, and storage tanks
3. Shipbuilding
4. Aircraft and aerospace
5. Automotive and railroad.

Welding is performed in a variety of locations and in a variety of industries. Owing to its versatility as an assembly technique for commercial products, many welding operations are performed in factories. However, several of the traditional processes, such as arc welding and oxyfuel gas welding, use equipment that can be readily moved. They can be performed at construction sites, in shipyards, at customers' plants, and in automotive repair shops.

8.2 SOLDERING

Soldering is a process in which two or more metal items are joined together by melting and flowing a filler metal (solder) into the joint, the filler metal having a lower melting point than the adjoining metal. Soldering differs from welding in that soldering does not involve melting the workpieces. In brazing, the filler metal melts at a higher temperature, but the workpiece metal does not melt.

Soldering filler materials are different alloys for different applications. In electronics assembly, the eutectic alloy of 63% tin and 37% lead (or 60/40, which is almost identical in melting point) has been the chosen alloy. Other alloys are used for plumbing, mechanical assembly, and other applications. Some examples of soft solder are tin-lead for general purposes, tin-zinc for joining aluminium, lead-silver for strength at higher than room temperature, cadmium-silver for strength at high temperatures, zinc-aluminium for aluminium and corrosion resistance, and tin-silver and tin-bismuth for electronics.

Common solder formulations based on tin and lead are listed below. The fraction represent percentage of tin first, then lead, totaling 100%.

- 63/37: melts at 183°C (eutectic: the only mixture that melts at a *point*, instead of over a range)
- 60/40: melts between 183°C–190°C
- 50/50: melts between 183°C–215°C

For environmental reasons lead-free solders are becoming more widely used. They are also recommended wherever young children may come into contact with (since young children are likely to place things into their mouths), or for outdoor use where rain and other precipitation may wash the lead into the groundwater. Unfortunately, most lead-free solders are not eutectic formulations, melting at around 250°C, making it more difficult to create reliable joints with them. Other common solders containing bismuth are low-temperature formulations and are often used to join previously-soldered assemblies without unsoldering earlier connections. The solders containing silver are high-temperature formulations and are used for high-temperature operation or for first assembly of items which must not become unsoldered during subsequent operations. Alloying silver with other metals changes the melting point, adhesion and wetting characteristics, and tensile strength. Of all the soldering alloys, silver solders have the greatest strength and the broadest applications. Specialty alloys are available with properties such as higher strength, the ability to solder aluminium, better electrical conductivity, and higher corrosion resistance.

Flux: The purpose of flux is to facilitate the soldering process by removing impurities like dirt, oil, or oxides at the site of the joint. Impurities can be removed by mechanical cleaning or by chemical means. One of the earliest forms of flux was charcoal. It acts as a reducing agent and helps prevent oxidation during the soldering process. Some fluxes go beyond the simple prevention of oxidation and also provide some form of chemical cleaning (corrosion).

For many years, the most common type of flux used in electronics (soft soldering) was the resin from selected pine trees. It was ideal in that it was non-corrosive and non-conductive at normal temperatures but became mildly reactive (corrosive) at the elevated soldering temperatures. For plumbing and automotive applications, muriatic acid based fluxes are used for cleaning of the joint. These fluxes cannot be used in electronics because they are conductive and because they will eventually dissolve the small diameter wires. Many fluxes also act as a wetting agent in the soldering process, reducing the surface tension of the molten solder and causing it to flow and wet the workpieces more easily.

Fluxes for soft solder are currently available in three basic formulations:

1. Water-soluble fluxes—higher activity fluxes designed to be removed with water after soldering.
2. No-clean fluxes—are mild enough and do not "require" removal due to their non-conductive and non-corrosive residue. These fluxes are called "no-clean" because the residue left after the solder operation resembles diluted bird-droppings. No-clean flux residue is acceptable on all three classes of PCBs as defined by IPC-610 finger prints in no clean residue is a class three defect.
3. Traditional resin fluxes—available in non-activated (R), mildly activated (RMA) and activated (RA) formulations. RA and RMA fluxes contain resin combined with an activating agent, typically an acid, which increases the wettability of metals to which it is applied by removing the existing oxides. The residue resulting from the use of RA flux is corrosive and must be cleaned. RMA flux is formulated to result in a residue which is not significantly corrosive, with cleaning being preferred but optional.

Flux performance needs to be carefully evaluated; a very mild 'no-clean' flux might be perfectly acceptable for production equipment, but does not give adequate performance for a poorly controlled hand-soldering operation.

Classification of Soldering Based on the Solder Used and the Temperatures Applied

There are two forms of soldering, each requiring progressively higher temperatures and producing an increasingly stronger joint strength:

1. Soft soldering, which originally uses a tin-lead alloy as the filler metal,
2. Silver soldering, (hard soldering) which uses an alloy containing silver.

Soft soldering is characterized by having a melting point of the filler metal below approximately 400°C. Soft solder filler metals are typical alloys (often containing lead) that have liquidus temperatures below 350°C. In this soldering process, heat is applied to the parts to be joined, causing the solder to melt and to bond to the workpieces in an alloying process called wetting. In stranded wire, the solder is drawn up into the wire by capillary action in a process called 'wicking'. Capillary action also takes place when the workpieces are very close together or touching. The joint's tensile strength is dependent on the filler metal used. Soldering produces electrically conductive, water- and gas-tight joints. Soft solder is so called because of the soft lead that is its primary ingredient. Soft soldering uses the lowest temperatures but does not make a strong joint and is unsuitable for mechanical load-bearing applications. It is also not suitable for high-temperature applications as it softens and melts.

Silver soldering (Hard soldering)

Silver soldering uses silver based solders and is done at higher temperatures, requiring the use of a torch or other high-temperature source. The joint is much stronger than that by soft soldering. This is used to join precious and semiprecious metals such as gold, silver, brass, and copper. The solder is usually referred to as easy, medium, or hard. This refers to its melting temperature, not the strength of the joint. Extra easy solder contains 56% silver and has a melting point of 618°C. Extra hard solder has 80%

silver and melts at 740°C. If multiple joints are needed, then the jeweller will start with hard or extra hard solder and switch to lower temperature solders for later joints. When silver solder melts, it tends to flow towards the area of greatest heat. Jewellers control the direction of solder movement by leading it with a torch. It will even run straight up along a seam. Silver solder is absorbed by the surrounding metal, resulting in a joint that is actually stronger than the metal being joined. This is used by jewellers, machinists and in some plumbing applications.

Soldering operations can be performed with hand tools, one joint at a time, or *en masse* on a production line. Hand soldering is typically performed with a soldering iron, soldering gun, or a torch, or occasionally a hot-air pencil. Sheet metal work was traditionally done with "soldering coppers" directly heated by a flame, with sufficient stored heat in the mass of the soldering copper to complete a joint. The torches or electrically heated soldering irons are more convenient. All soldered joints require the same elements of cleaning of the metal parts to be joined, fitting up the joint, heating the parts, applying flux, applying the filler, removing heat and holding the assembly still until the filler metal has completely solidified. Depending on the nature of flux material used, cleaning of the joints may be required after they have cooled.

Based on the heating source, soldering is classified as follows:

1. Induction soldering
2. Laser soldering
3. Wavelengths
4. Resistance soldering

Soldering defects

Voids: In the joining of copper tube, failure to properly heat and fill a joint, may lead to a 'void' being formed. This is usually a result of improper placement of the flame. If the heat of the flame is not directed at the back of the fitting cup, and the solder wire applied bends opposite the flame, then solder will quickly fill the opening of the fitting, trapping some flux inside the joint. This bubble of trapped flux is the void; an area inside a soldered joint where solder is unable to completely fill the fittings' cup, because flux has become sealed inside the joint, preventing solder from occupying that space.

Cold solder: The most common defect of hand-soldering results from the parts being joined at temperature not exceeding the solder's liquidus temperature, resulting in a "cold solder" joint. This is usually the result of soldering iron being used to heat the solder directly, rather than the parts themselves. Properly done, the iron heats the parts to be connected, which in turn melt the solder, guaranteeing adequate heat in the joined parts for thorough wetting. In electronic hand soldering the flux is embedded in the solder. Therefore, heating the solder first may cause the flux to evaporate before it cleans the surfaces being soldered. A cold soldered joint may not conduct at all, or may conduct only intermittently. Cold soldered joints also happen in mass production, and are a common cause of equipment which passes testing, but malfunctions after sometimes years of operation.

Corrosion: An improperly selected or applied flux can cause joint failure. If not properly cleaned, a flux may corrode the joint and cause eventual joint failure. Without flux the joint may not be clean, or may be oxidized, resulting in an unsound joint.

In electronics non-corrosive fluxes are often used. Therefore, cleaning of flux may be a matter of aesthetics or to make visual inspection of joints easier in specialised 'mission critical' applications such as medical devices, military and aerospace, for satellites also to reduce weight slightly but usefully. In high humidity, even non-corrosive flux might remain slightly active, and therefore flux must be removed to reduce corrosion over time. In some applications, the PCB might also be coated in some form of protective material such as a lacquer to protect it and exposed solder joints from the environment.

Dry joint: Movement of metals being soldered before the solder has cooled will cause a highly unreliable cracked joint. In electronics' soldering terminology this is known as a 'dry' joint. It has a characteristically dull or grainy appearance immediately after the joint is made, rather than being smooth, bright and shiny. This appearance is caused by crystallization of the liquid solder. A dry joint is weak mechanically and a poor conductor electrically.

In general, a good looking soldered joint *is* a good joint. As mentioned it should be smooth, bright and shiny. If the joint has lumps or balls of otherwise shiny solder the metal has not 'wetted' properly. Not being bright and shiny suggests a weak 'dry' joint. However, technicians trying to apply this guideline when using lead-free solder formulations may experience frustration, because these types of solders readily cool to a dull surface even if the joint is good. The solder looks shiny while molten, and suddenly hazes over as it solidifies even though it has not been disturbed during cooling.

Excessive use of solder: In electronics a 'concave' fillet is ideal. This indicates good wetting and minimal use of solder (therefore minimal *heating* of heat sensitive components). A joint may be good, but if a large amount of unnecessary solder is used then more heating is obviously required. Excessive heating of a PCB may result in 'delamination', the copper track may actually lift off the board, particularly on single sided PCBs without through hole plating.

Advantages and disadvantages of soldering

Advantages

1. Easy to make and easy to repair.
2. Energy required is low.
3. Cost involved is less.
4. High degree of control on the process is possible.
5. Joints last for long period.

Disadvantages

1. Strength of the joint is low and hence cannot be used for load bearing applications.
2. This cannot be used for high temperature applications.
3. Thick parts cannot be joined efficiently.
4. After soldering flux cleaning is required to prevent corrosion.

Applications of soldering

Soldering is used in plumbing, electronics, and metal work from to jewellery. Soldering provides reasonably permanent but reversible connections between copper pipes in plumbing systems as well as joints in sheet metal objects such as food cans, roof flashing, rain gutters and automobile radiators. Jewelry components, machine tools and some refrigeration and plumbing components are often assembled and repaired by the higher temperature silver soldering process. Small mechanical parts are often soldered or brazed as well. Soldering is also used to join lead came and copper foil in stained glasswork. It can also be used as a semi-permanent patch for a leak in a container or cooking vessel. Electronic soldering connects electrical wiring and electronic components to printed circuit boards (PCBs).

8.3 BRAZING

Brazing is a metal-joining process whereby a filler metal is heated above the melting point and distributed between the two or more close-fitting parts by capillary action. The filler metal is brought slightly above its melting (liquidus) temperature while protected by a suitable atmosphere, usually a flux. It then flows over the base metal (known as wetting) and is then cooled to join the workpieces together. It is similar to soldering, except that the temperatures used to melt the filler metal are higher for brazing.

Filler materials

A variety of alloys are used as filler metals for brazing depending on the intended use or application method. In general, braze alloys are made up of three or more metals to form an alloy with the desired properties. The filler metal for a particular application is chosen based on its ability to wet the base metals, withstand the service conditions required, and melt at a lower temperature than the base metals or at a very specific temperature.

Braze alloy is generally available as rod, ribbon, powder, paste, cream, wire and preforms (such as stamped washers). Depending on the application, the filler material can be pre-placed at the desired location or applied during the heating cycle. For manual brazing, wire and rod forms are generally used as they are the easiest to apply while heating. In the case of furnace brazing, alloy is usually placed beforehand since the process is usually highly automated. Some of the more common types of filler metals used are

- Aluminium-silicon
- Copper
- Copper-silver
- Copper-zinc (brass)
- Gold-silver
- Nickel alloy
- Silver

Flux

In the case of brazing operations not contained within an inert or reducing atmosphere environment (i.e., a furnace), flux is required to prevent the formation of oxides while the metal is heated. The flux also serves the purpose of cleaning any contamination left on the brazing surfaces. Flux can be applied in different forms such as flux paste, liquid, powder or pre-made brazing pastes that combine flux with filler metal powder. Flux can also be applied using brazing rods with a coating of flux, or a flux core. In either case, the flux flows into the joint when applied to the heated joint and is displaced by the molten filler metal entering the joint. Excess flux should be removed when the cycle is completed because flux left in the joint can lead to corrosion, impede joint inspection, and prevent further surface finishing operations. Phosphorus-containing brazing alloys can be self-fluxing when joining copper to copper. Fluxes are generally selected based on their performance on particular base metals. To be effective, the flux must be chemically compatible with both the base metal and the filler metal being used. Self-fluxing phosphorus filler alloys produce brittle phosphides if used on iron or nickel. As a general rule, longer brazing cycles should use less active fluxes than short brazing operations.

Atmosphere

As brazing work requires high temperatures, oxidation of the metal surface occurs in an oxygen-containing atmosphere. This may necessitate the use of an atmospheric environment other than air. The commonly used atmospheres are combusted fuel gas, ammonia, nitrogen, hydrogen, corbon monoxide, noble gas and vacuum.

Types of brazing

Torch brazing

- Torch brazing is by far the most common method of mechanized brazing in use. It is best used in small production volumes or in specialized operations, and in some countries, it accounts for a majority of the brazing taking place. There are three main categories of torch brazing in use—manual, machine, and automatic torch brazing.
- *Manual torch brazing* is a procedure where the heat is applied using a gas flame placed on or near the joint being brazed. The torch can either be hand held or held in a fixed position depending on whether the operation is completely manual or has some level of automation. Manual brazing is most commonly used on small production volumes or in applications where the part size or configuration makes other brazing methods impossible. The main drawback is the high labour cost associated with the method as well as the operator skill required to obtain quality brazed joints. The use of flux or self-fluxing material is required to prevent oxidation. Torch brazing of copper can be done without using flux if it is brazed with a torch using oxygen and hydrogen gas, rather than oxygen and other flammable gases.
- *Machine torch brazing* is commonly used where a repetitive braze operation is being carried out. This method is a mix of both automated and manual operations with an operator often placing brazes material, flux and jigging parts while the

machine mechanism carries out the actual braze. The advantage of this method is that it reduces the high labour and skill requirement of manual brazing. The use of flux is also required for this method as there is no protective atmosphere, and it is best suited to small to medium production volumes.

- *Automatic torch brazing* is a method that almost eliminates the need for manual labour in the brazing operation, except for loading and unloading of the machine. The main advantages of this method are: a high production rate, uniform braze quality, and reduced operating cost. The equipment used is essentially the same as that used for machine torch brazing, with the main difference being that the machinery replaces the operator in the part preparation.
- **Furnace brazing**

Furnace brazing is a semi-automatic process used widely in industrial brazing operations due to its adaptability to mass production and use of unskilled labour. There are many advantages of furnace brazing over other heating methods that make it ideal for mass production. One main advantage is the ease with which it can produce large number of small parts that are easily jigged or self-locating. The process also offers the benefits of a controlled heat cycle (allowing use of parts that might distort under localized heating) and no need for post-braze cleaning. Common atmospheres used include: inert, reducing or vacuum atmospheres all of which protect the part from oxidation. Some other advantages include: low unit cost when used in mass production, close temperature control, and the ability to braze multiple joints at once. Furnaces are typically heated using either electric, gas or oil depending on the type of furnace and application. However, some of the disadvantages of this method include: high capital equipment cost, more difficult design considerations and high power consumption.

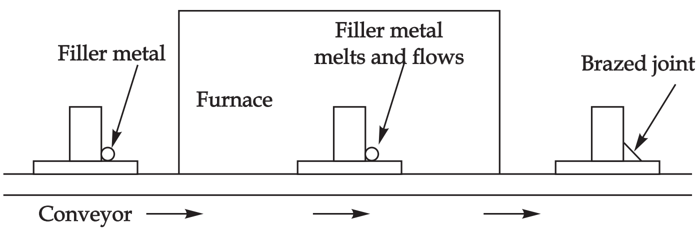


Fig. 8.12 Furnace brazing schematic.

Braze welding

Braze welding is the use of a bronze or brass filler rod coated with flux to join steel workpieces. The equipment needed for braze welding is basically identical to the equipment used in brazing. Since braze welding usually requires more heat than brazing, acetylene or methylacetylene-propadiene (MAP) gas fuel is commonly used. The name comes from the fact that no capillary action is used.

Braze welding has many advantages over fusion welding. It allows the joining of dissimilar metals, minimization of heat distortion, and can reduce the need for extensive pre-heating. Additionally, since the metal joints are not melted in the process, the components retain their original shape; edges and contours are not eroded or changed by the formation of a fillet. Another effect of braze welding is the elimination of residue stresses that are often present in fusion welding. This is extremely important in the repair of large castings. The disadvantages are the loss of strength when subjected to high temperatures and the inability to withstand high stresses.

Carbide and ceramic tips are plated and then joined to steel to make tipped band saws. The plating acts as a braze alloy.

Cast iron welding

Welding of cast iron is usually a brazing operation, with a filler rod made chiefly of nickel being used although true welding with cast iron rods is also available. Ductile cast iron pipe may be also "cadwelded," a process which connects joints by means of a small copper wire fused into the iron when previously ground down to the bare metal, parallel to the iron joints being formed as per hub pipe with neoprene gasket seals. The purpose behind this operation is to use electricity along the copper for keeping underground pipes warm in cold climates.

Vacuum brazing

Vacuum brazing is a material joining technique that offers significant advantages: extremely clean, superior, flux-free braze joints of high integrity and strength. The process can be expensive because it must be performed inside a vacuum chamber vessel. Temperature uniformity is maintained on the workpiece when heating in a vacuum, greatly reducing residual stresses due to slow heating and cooling cycles. This, in turn, can significantly improve the thermal and mechanical properties of the material, thus providing unique heat treatment capabilities. One such capability is heat-treating or age-hardening the workpiece while performing a metal-joining process, all in a single furnace thermal cycle.

Vacuum brazing is often conducted in a furnace; this means that several joints can be made at once because the whole workpiece reaches the brazing temperature. The heat is transferred using radiation, as many other methods cannot be used in vacuum.

Dip brazing

Dip brazing is especially suited for brazing aluminium because air is excluded, thus preventing the formation of oxides. The parts to be joined are fixtured and the brazing compound applied to the mating surfaces, typically in slurry form. Then the assemblies are dipped into a bath of molten salt (typically NaCl, KCl and other compounds) which functions both as heat transfer medium and flux.

Advantages and disadvantages of brazing

Advantages

1. Thermal distortions are less because of the low temperatures.
2. Residual stresses are also less.
3. Dissimilar metals and non-metals can be joined.

4. The process can be easily automated.
5. It allows much tighter control over tolerances.
6. Produces a clean joint without the need for secondary finishing.
7. Complex and multi-part assemblies can be brazed economically.
8. Brazing can be coated or clad for protective purposes.
9. Brazing is easily adapted to mass production.

Disadvantages

1. Lack of joint strength as compared to a welded joint due to the softer filler metals used. The strength of the brazed joint is likely to be less than that of the base metal but greater than the filler metal.
2. Brazed joints can be damaged under high service temperatures.
3. Brazed joints require a high degree of base-metal cleanliness when done in an industrial setting.
4. Some brazing applications require adequate fluxing agents to control cleanliness.
5. Joint colour is often different from that of the base metal, creating an aesthetic disadvantage.
6. Large and thick sections cannot be brazed efficiently.

Comparison of Welding Soldering and Brazing

Table 8.1 Comparison between welding, soldering and brazing processes

Sl. No.	*Welding*	*Soldering*	*Brazing*
1.	It is a high temperature process where base metals are heated above their melting temperature.	Low temperature process. Base metals are not melted.	Base metals are not melted, but broadly heated to a suitable temperature.
2.	Filler metal used is of the same material as that of the base metal.	Filler metal is not the same as that of the base metal.	Filler metal is not the same as that of the base metal.
3.	Joint is formed by the solidification of the molten filler metal with the molten base metal.	Joint is formed by means of diffusion of the filler metal into the base metal.	Joint is formed by means of diffusion of the filler metal into the base metal associated with surface alloying.
4.	Strength of welded joint is much stronger than the base metal.	Strength of the soldered joint is comparatively low.	Strength of the brazed joint lies between the welded and soldered joints.
5.	Since welding takes place at high temperatures, the metal adjacent to the weld portion called the heat affected zone is affected to a large extent.	There is no heat affected zone, as the process is carried at low temperatures.	Although base metals are heated, the heat affected zone is not too much when compared to welding.

Contd..

6.	Welded joints require certain finishing operations like grinding, filing, etc.	Joints can be used without any finishing operations.	In some cases, brazed joints require finishing operations.
7.	Welding produces stronger joints. Hence, the process is used for fabrication and structural applications.	Joint formed is comparatively weak and hence used in light metal applications and electronics industries.	Used in arts, jewellery works and in some industries.

EXERCISES

1. What is welding?
2. Classify the welding methods.
3. Explain with sketches resistance welding.
4. Explain the principle of arc welding.
5. List the arc welding equipment.
6. Name the various arc welding methods.
7. Sketch and describe a gas welding set-up.
8. Explain the types of flames.
9. Describe the welding defects.
10. Describe the soldering operation
11. Explain brazing operation.
12. Differentiate between soldering and brazing.

CHAPTER 9

Refrigeration and Air Conditioning

9.1 REFRIGERATION

The process of refrigeration is the method of the removal of heat from a body to maintain its temperature less than its surroundings. Methods of lowering temperature of a fluid are based on the following principles.

1. Temperature of a body is the measure of the molecular energy in the body. To reduce the temperature, we must reduce this energy. This is achieved by causing the fluid to do mechanical work at the expense of its internal energy. This happens in adiabatic expansion.
2. A small increase in specific heat of air with reduction in pressure will permit a slight reduction in temperature about 0.25°C for each atmp, drop in pressure, even if no external work is done. This is known as "Joule-Thomson cooling effect".
3. If the pressure over a liquid is lowered sufficiently, evaporation takes place. The latent heat for evaporation is drawn from the liquid itself and the temperature is reduced. This is the oldest and most widely used method of cooling. Storing drinking water in earthen vessel during summer days, is an example. Most of the refrigerators produce cold by a change of state from liquid to vapour.

In simple machines operating on the above methods, the working fluid is expelled and wasted. In the method (3) this wastage can be avoided. The vapour formed may be absorbed by a substance that has chemical affinity like ammonia vapour being absorbed in water. Then the two can be separated by the application of heat. The porous materials like charcoal or silica-gel can also be used as absorbing medium. The vapour is released by heating the absorbing medium. The released vapour is condensed and sent back to the evaporator for continuing the cooling. This forms the basic principle of vapour absorption refrigerator.

Alternatively, the vapour may be compressed mechanically in a compressor to a temperature high enough to reject the heat to a natural sink. This is the basic principle of a vapour compression refrigerator. In both the methods described above addition of heat or work is necessary to transport heat from a cool body to a hot body. This follows from the second law of thermodynamics.

9.2 MAIN PARTS OF A REFRIGERATOR

1. **Evaporator:** It contains refrigerant fluid at low pressure and temperature. The refrigerant evaporates taking heat from the surrounding fluid or atmosphere.
2. **Compressor:** It is a reciprocating type compressor. The vapour formed in the evaporator is sucked by the compressor and compressed to high pressure and temperature. This increases the thermal level of the vapour,
   or alternatively,
   - **Absorber:** It contains the absorbing agent which absorbs the vapour from the evaporator.
   - **Heater:** Here the absorbent is heated to release the refrigerant vapour. This increases the thermal level of the vapour.
3. **Condenser:** It is a heat exchanger where heat is removed from the vapour and it is condensed by using a cooling medium, mostly water.
4. **Expansion valve:** The high pressure liquid refrigerant from the condenser is throttled to the evaporator pressure through this valve.

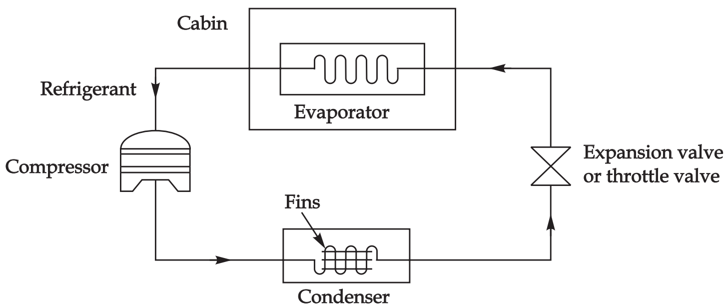


Fig. 9.1 Principal parts of a mechanical refrigerator.

9.3 TYPES OF REFRIGERATORS principles of refrigeration

On the principles described above there are two types of refrigerators:

1. Vapour-Compression-Refrigerator (VCR)
2. Vapour-Absorption-Refrigerator (VAR)

9.3.1 Vapour Compression Refrigerator

Mr. Joule Parkins invented the vapour compression refrigerator in 1834. Further progress was made by Prof Linde of Munich by the introduction of his ammonia compressor.

The system consists of an evaporator, compressor, condenser and expansion valve connected as shown in Fig. 9.2. In the evaporator (*A*) the refrigerant absorbs heat from the body to be cooled and vaporises. Compressor (*B*) sucks in this vapour during the suction stroke and compresses to a higher pressure and temperature during the compression stroke. The hot vapour from the compressor enters the condenser (*C*) and loses heat to the cooling water or air and gets condensed. The high pressure liquid is

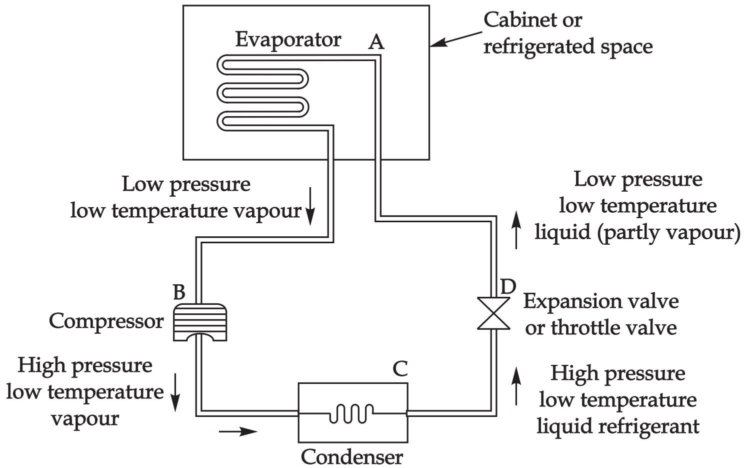


Fig. 9.2 Vapour compression refrigeration cycle.

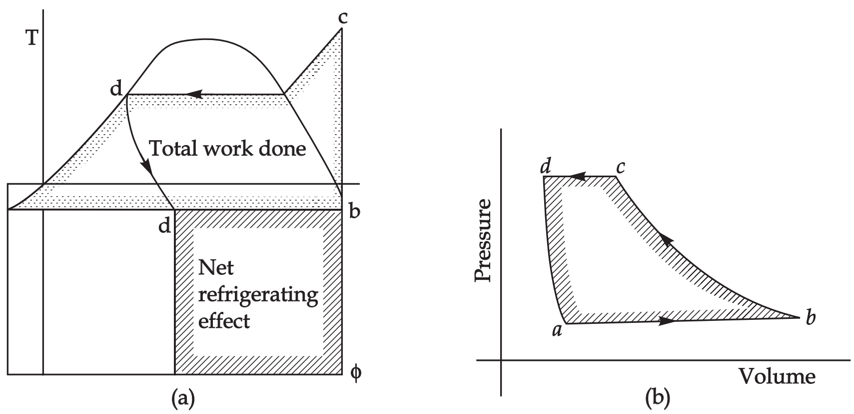


Fig. 9.3 (a) T-ϕ-diagram (b) P-V diagram.

throttled to the low pressure of the evaporator through the expansion valve (*D*). Thus, the cycle is completed. The continuous circulation of the refrigerant produces cold in the evaporator. The above operations are shown on T–ϕ chart in Fig. 9.3. The performance of refrigerator is measured by the coefficient of performance defined as follows:

$$\text{C.O.P.} = \frac{\text{Net refrigerating effect}}{\text{Work done in the compressor}} = \frac{H_b - H_d}{H_c - H_b}$$

H_b, H_c, H_d represent enthalpies at positions, b, c and d respectively.

9.3.2 Vapour Absorption Refrigerator

The machine depends upon the use of two substances, which have a affinity for each other but the union may be broken easily by the application of heat. The principle combinations are sulphuric acid and water or ammonia and water. Ammonia based system is described here.

The low pressure ammonia in the evaporator (*A*), evporates by taking the heat from the surroundings. The ammonia vapour enters the absorber-B and is absorbed by cold water. The strong ammonia solution formed is pumped to the generator (*D*) through a heat exchanger (*C*). This heat exchanger reheats the strong ammonia solution and cools the weak ammonia solution before it is sprayed in the absorber. This accelerates the absorption. In the generator, the strong ammonia is heated by using any heating source. Ammonia is released and flows to the condenser (*E*). The very weak ammonia solution flows back to the absorber via heat exchanger (*C*). In the condenser (*E*), ammonia vapours are cooled and condensed, by the circulating cooling water. The high pressure liquid ammonia is expanded to the low pressure of evaporator through the throttle valve (*F*), and flows into the evaporator coils. The cycle continues.

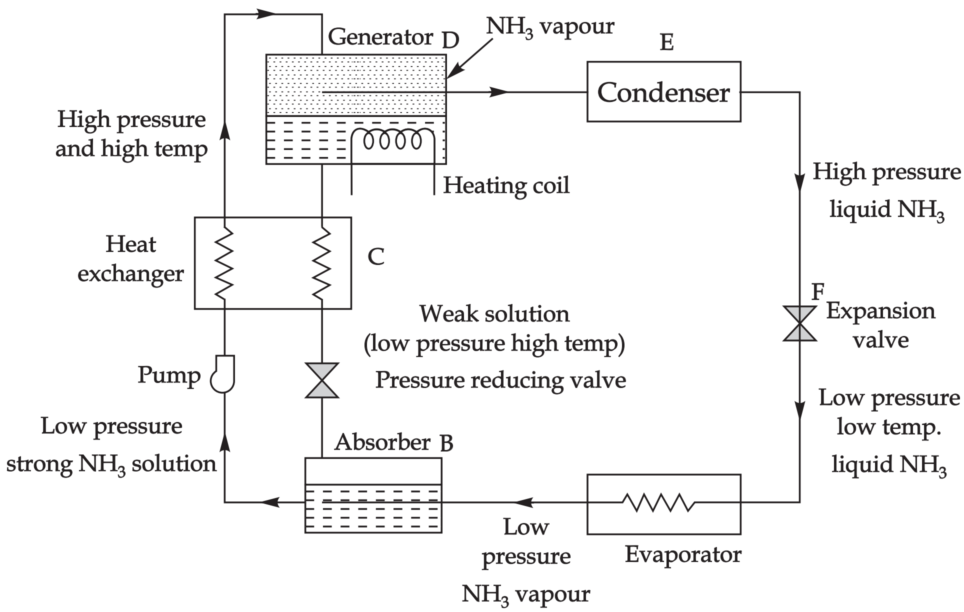


Fig. 9.4 Vapour absorption refrigeration cycle.

The heat exchanger between the absorber and generator increases the overall performance by utilizing heat in the weak ammonia solution. This also improves the absorption efficiency.

9.4 COMPARISON OF TWO SYSTEMS

1. Vapour absorption system requires two working fluids whereas the vapour compression system works with only one fluid.
2. Absorption system is silent in operation, whereas the compression system is accompanied by vibration and noise.
3. Performance of compression system is better than that of absorption system.
4. Charging of refrigerant is simpler in compression system.

5. Chances of leakage are more in compression system than in absorption system.
6. Maintenance is simpler and less in absorption system.

9.5 PROPERTIES OF GOOD REFRIGERANT

1. Low boiling point and low freezing point.
2. High latent heat of evaporation.
3. High critical temperature.
4. Low specific heat.
5. High thermal conductivity.
6. Low viscosity.
7. Non-toxic, non-corrosive, non-inflammable.
8. Ease of leakage identification.
9. Ease of handling.

9.6 TYPES OF REFRIGERANTS

Some of the commonly used refrigerants are as follows:

1. **Ammonia (NH_3):** It is a widely used refrigerant in various applications, such as ice manufacturing plants and cold storages.

   Ammonia has boiling point of –33.3°C, easily soluble in water, produce high refrigeration effect. It is economical, but not miscible with lubricating oil, toxic in nature, irritating and corrosive. Ammonia is not suitable for domestic refrigerators due to food destroying properties.
2. **Sulphur dioxide (SO_2):** This refrigerant is non-flammable, non-corrosive and dissolves in oil. It has a boiling point of –10°C resulting in low refrigerating effect. It has odour and suffocating and forms sulphuric acid in presence of moisture. For present applications, SO_2 is not used in refrigeration systems due to its corrosive nature.
3. **Carbon dioxide:** It is non-toixc, non–flammable, odourless and cheap refrigerant. It has a boiling point of –77.6°C. It has low specific volume, size of refrigeration is very compact. It is commonly used in large ships, air-conditioning in theaters.
4. **Freon or R-series Refrigerants:** These refrigerants are highly efficient in achieving cooling effect, with better refrigeration properties.
   (a) **Freon 12 (R_{12}):** This has chemical formula CCl_2F_2 (dichloro difluoromethane) which is non-flammable, non-corrosive, non-explosive and odourless. Boiling point of Freon 12 is –29.8°C and has a low specific volume. It is widely used in applications such as domestic refrigerators, water coolers, air conditioners, automobiles, etc.
   (b) **Freon 22 (R_{22}): It is denoted as $CHClF_2$ (Chloro difluoromethane),** which has similar refrigeration properties. Its boiling point is –40.8°C and low specific volume. It is commonly used in large capacity plants like air conditioning.

5. **Modern Refrigerants-HFC (Hydro Fluoro Carbon):** The new refrigerants contain several fluorine atoms, but no chlorine atom and does not deplete Ozone layer. They have favourable thermodynamic properties and safe operating properties, and are used as a substitute for freon refrigerants which deplete Ozone layer. R_{134A} (Tetra fluoro methane CH_2FCF_3) is an HFC compound with no chlorine content. Its boiling point is –15°C and is non-corrosive, non–toxic.

   R_{134A} is widely used for air conditioning and commercial refrigeration, automobile air conditioning, other HFC Refrigerants are R40TC, R410A.

9.7 REFRIGERATION UNITS

1. **Tonne of refrigeration (TOR):** The capacity of the refrigeration system is expressed in terms of tonnes of refrigeration.

   It is defined as the amount of heat energy absorbed from water at temperature of 0°C to produce one tonne of ice at 0°C in 24 hours.

   In S. I. units,

   I tonne = 210 kJ/min = 3.5 kJ/sec

   I tonne = 3.5 kW

2. **Coefficient of Performance (COP):** This term is used for measuring performance of refrigerators and COP is defined as the ratio of amount of heat energy removed from a given space to the amount of work supplied for removal of heat energy.

   $$\therefore \quad \text{COP} = \frac{\text{Amount of heat removed}}{\text{Work supplied}} = \frac{Q}{W}$$

   where Q and W are measured in kJ/s or kW. This unit gives us a parameter to measure the efficiciency of a refrigerator unit. Higher value of COP means efficiency of the unit is more and has better refrigeration effect.

3. **Relative COP:** It is defined as the ratio of actual COP to the theoretical COP of the refrigerator.

   $$\text{i.e., relative COP} = \frac{\text{Acutal COP}}{\text{Theoretical COP}}$$

   $$\text{where actual COP} = \frac{Q}{W} \text{ for a working refrigerator}$$

   $$\text{Theoretical COP} = \frac{Q_{th}}{W_{th}} \text{ for a theoretical unit}$$

With theoretical laws of thermodynamics where Q and W are measured during performance and, Q_{th}, W_{th} are theoretical values of heat energy extracted and work supplied.

9.8 AIR CONDITIONING

Air conditioning works on the same principle as that of refrigeration, but conditioning of air is for a large space, such as cooling of a room, building, commercial complex, offices, etc. Along with cooling of air, it also cleans the air and controls moisture percentage in air.

Largely, air conditioning is defined as a process of simultaneous control of temperature, humidity (moisture content in air), cleaning of air and controls movement of air in closed space as required for human comfort.

9.8.1 Principle of Air Conditioning

Air conditioning works on similar principle as that of refrigeration, without an insulated cabin and cooling is achieved by vapour compression refrigeration cycle. The refrigerant, commonly freon is made to circulate through various components like evaporator, compressor, condenser and expansion value to complete the working cycle. The refrigerant flowing through the evaporator coils, absorbs heat from the warm air inside the room and cools the air to low temperature for human comfort.

Heat absorbed by the refrigerant is discharged to atmosphere as it flows through the condenser coils and cools to liquid phase and is recirculated through the expansion valve and evaporator coils.

9.8.2 Room Air Conditioner

This is the simplest type of air conditioner used for cooling a single room and fits into a window of the room as in Fig. 9.5.

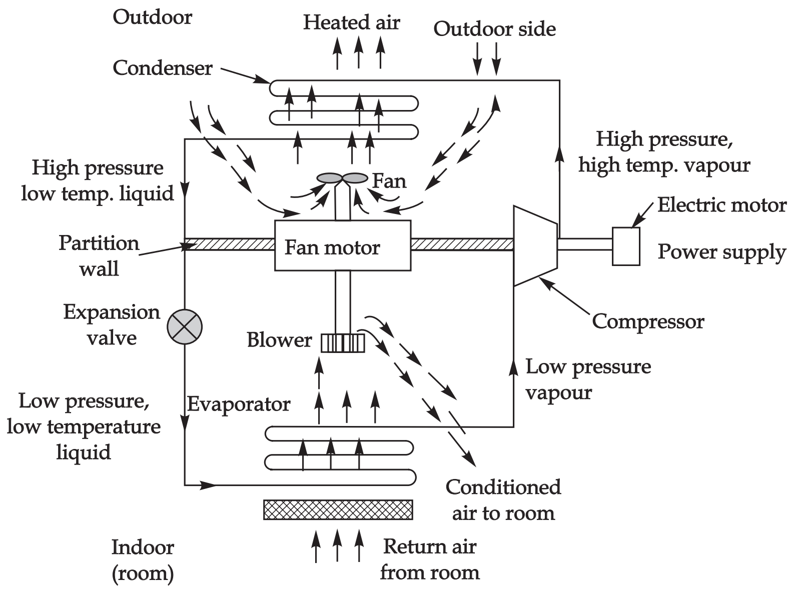


Fig. 9.5 Room air conditioner.

An air conditioner consists of a compressor condenser, expansion valve and an evaporator. Other parts of the system include an air filter, and a double shaft motor which drives both fan at one end and a blower at the other end. The evaporator and expansion valve are located in the room and the compressor and condenser outside the room, and are separated by an insulated partition wall.

Working: Blower draws the warm air from the room through the air filter and flows over the evaporator coils. Liquid refrigerant at low temperature and low pressure absorbs the heat energy from the warm air and cools the air to lower temperature. The refrigerant absorbs heat and changes to vapour phase at low pressure and high temperature. The vapour refrigerant is drawn by the compressor and compressed to high pressure and high temperature and flows through the condenser. Heat energy is rejected to circulating air around the condenser and refrigerant cools to liquid phase at low temperature and high pressure. The refrigerant passes through the expansion valve to low pressure, low temperature liquid refrigerant and is then recirculated through the evaporator coils in the room. The blower delivers the cold air to the room to be air conditioned with required humidity in the room.

The same principle is employed for larger spaces, such as buildings, offices and theatres, where central air conditioning is employed.

Central air conditioning uses ducts or pipeline to distribute cold and/or dehumidified air to more than one room. In this case, warm air is drawn through air filters and cooled to low temperature. The cold air then passes through the long ducts into the room for air conditioning and the cycle is repeated. Since the components such as condenser, fan and compressor are located centrally the noiselevel within the room is reduced.

9.9 APPLICATIONS OF AIR CONDITIONING

Air conditioning has wide range of applications such as human comfort and industrial applications.

9.9.1 Air Conditioning for Human Comfort

Indoor environment is conditioned to suit human comfort despite variations in the external atmosphere, such as:

1. In residential buildings.
2. Hospitals, computer Laboratories.
3. Commeriel buildings such as shopping malls, theaters, offices, hotels, etc.
4. Transportation vehicles, like trains, ships, cars, etc.

9.9.2 Air Conditioning for Industrial Applications

Atmosphere suitable for a process is obtained by controlling the conditions despite variations in inside or outside atmospheric conditions.

1. Nuclear power plant.
2. Electronic industry.
3. Chemical and biological laboratories.
4. Textile industry.
5. Food processing industry, etc.

EXERCISES

1. Explain refrigeration.
2. What are the basic concepts of refrigeration?
3. Explain the principles of refrigeration.
4. Describe the working of a vapour absorption refrigerator.
5. Explain the operation of the vapour compression refrigerator.
6. Compare the absorption system with compression system.
7. Enumerate the characteristics of a good refrigerant.
8. Name the commonly used refrigerants.
9. Explain the basic principle of air conditioning.
10. List the fields of application of air conditioning.

Index

ELEMENTS OF MECHANICAL ENGINEERING

Elements of Mechanical Engineering introduces the fundamentals of mechanical engineering to the first year students of all engineering branches. It covers the topics in Thermal Engineering, Manufacturing Engineering, Automation and Materials Science.

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