CONTENT

CHAPTER

1 SOURCES OF ENERGY

STRUCTURE

1.0 LEARNING OBJECTIVE

After going through this chapter, you will be able to:

- differentiate between the conventional energy sources and non-conventional energy sources
- describe the nuclear energy and tidal energy
- discuss about the hydal source
- defined the celestial energy

1.1 ENERGY

It is defined as a capacity to do work and the rate at which energy is consumed is called power.

Energy source:

These are the material objects that contain a capacity to do work.

Forms of energy or types of energy:

It's been classified into:

- Mechanical
- Ocean thermal
- Biomass

- Electrical
- Geothermal
- Biofuel
- Solar
- Chemical
- Tidal energy
- Wind
- Nuclear

Energy sources are classified into two forms:

- Capital energy
- Celestial energy.

Capital energy:

The energy that exist in the earth. *eg.,* fossils fuels, nuclear fuels, heat trap.

Cellestrial energy:

The energy that comes from outer space. *e.g.,* Electromagnetic, gravitational, particle energy from stars, moon and planets, potential energy of metroids, etc.

The sources of energy are further classified into:

- Conventional energy and
- Non-conventional energy.

Conventional energy sources: It can be classified into:

- Fossil fuels
  - → Solid fuel - Coal, coke, anthracites
  - → Liquid fuel - Petroleum and derivative
  - → Gaseous fuel - Natural gas, petroleum
- Hydal energy
- Nuclear energy source

Non-conventional energy source: It can be classified into following forms:

- Solar energy
- Wind energy
- Biomass and biogas
- Ocean thermal energy
- Tidal energy
- Geothermal energy

The difference between conventional and non-conventional source of energy.

Conventional energy sources	Non-conventional energy sources
• These are exhaustible sources of energy. • The sources can't be used again and again. • They have limited stock in nature. • These sources are also called non-renewable energy sources. • Conventional sources are expansive but reliable. • Energy transmission cost is very high.	• These are non-exhaustible sources of energy. • Can be used. • Unlimited stock. • Renewable energy sources. • Non-conventional sources are cheaper but non-reliable. • It's very low.

Conventional Energy Sources

Fuels: These are further classified into chemical fuel and nuclear fuel. Chemical fuels are sub classified into natural or primary fuel and secondary fuel.

Fuel	Primary	Secondary
Solid	Wood, peat liquid etc.	Charcoal, coke etc.
Liquid	Petroleum	Kerosene, gasoline, alcohol, benzoyl, fuel oil etc.
Gas	Natural gas	L.P.G., producer gas, coal gas, biogas etc.

Hydal source: It is an indirect source of solar energy. The water from the surface of the earth gets evaporated by solar heat, which results in rainfall. The rain-water flowing as rivers can be stored at higher levels by constructing dams and this potential energy of water is converted into electrical using hydroelectric power plant as shown in figure 1.1.

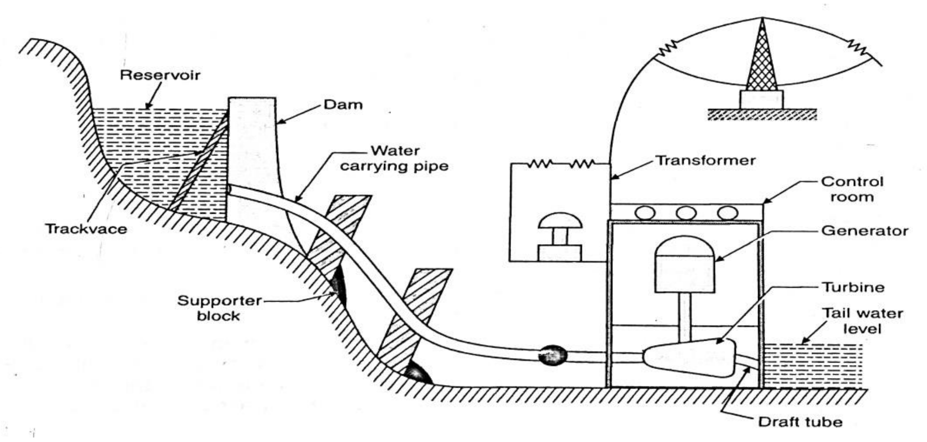


Fig. 1.1

Working: Water from the reservoir through the penstock enters the generator turbine where it epigeous the wave causing a rotary motion to the shaft which in turn connected to the generators where electricity is generated. The used water passes to the used water storage tank through a tail race (draft tube).

Nuclear energy: The chemical energy released in nuclear transformation resulting from the rearrangement of atoms and redistribution of e^-. There are two types of radiations.

Fusion process: In this process when light mass nuclei, such as deuterium or tritium (forms of n) are combined and the excess binding energy is released when two nuclei of deuterium are forced together they momentarily form an unstable nuclei and immediately releases one neutron and becomes helium or releases one proton and becomes tritium. The resulting nucleus has less mass than the two original nuclei the difference in mass gets converted into energy.

Fission process: This process involves splitting the nucleus of heavy atoms like uranium or plutonium in a controlled nuclear chain reaction.

During fission heat is released and this can be used to generate high pressure steam to drive turbo generators to produce electricity.

Most of the nuclear power plants are based on the fission process of the nucleus of U-235. This nucleus is relatively unstable and can split into two or more fragments when struck by a neutron.

Solar energy: Sun is the main source of all life on earth. All forms of energy available on the face of the earth are derived from the sun. The sun is considered to of a sphere of intensely hot gaseous matter continuously generating heat by thermonuclear fusion reactions, which converts hydrogen atoms to helium atoms, releasing an enormous amount of heat/radiant energy called solar energy.

The sun radiates energy at the rate of 4×10^{24} kW in the form of em radiation 30% of this energy is reflected or scattered back into space and 23% is consumed in the process of evaporation and convention and the remaining 47% is absorbed by atmosphere, land surface and the oceans, which converts heat into atmospheric temperature.

Solar energy can be converted into useful energy by three processes:

- Helios chemical process
- Helios electrical process
- Helios thermal process

Helios chemical process: It is a photosynthesis process with complex biochemical reaction in which the plants using solar energy produces energy rich molecules of starch and cellulose.

This process is a form of biochemical conversion of solar energy into chemical energy known as "Bio energy" which is stored in plants.

Helios electrical process: In this process using the principal of photovoltaic cell, the solar energy is directly converted into electrical energy, using photovoltaic cells. The material used in photovoltaic cell is the semiconducting materials such as silicon, Germanium, Cadmium etc. These materials had the capacity of generating electric power on the small scale.

Helios thermal process: In this process solar energy is directly converted into heat energy or thermal energy using solar collectors. Basically the solar collectors are of two types:

- Flat plate collector
- Focusing collector

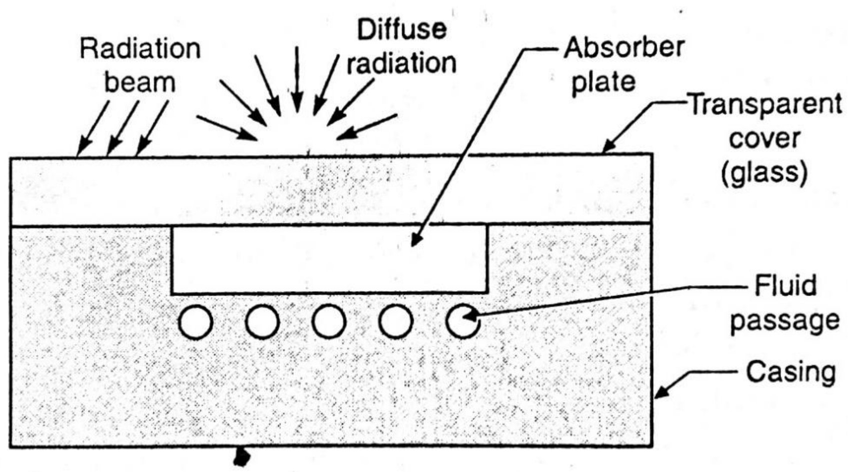


Fig. 1.2

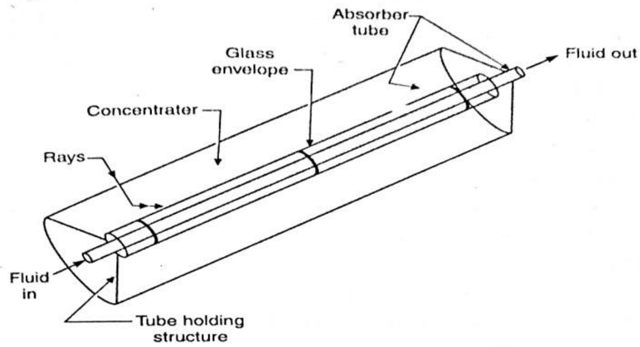


Fig. 1.3

Wind energy

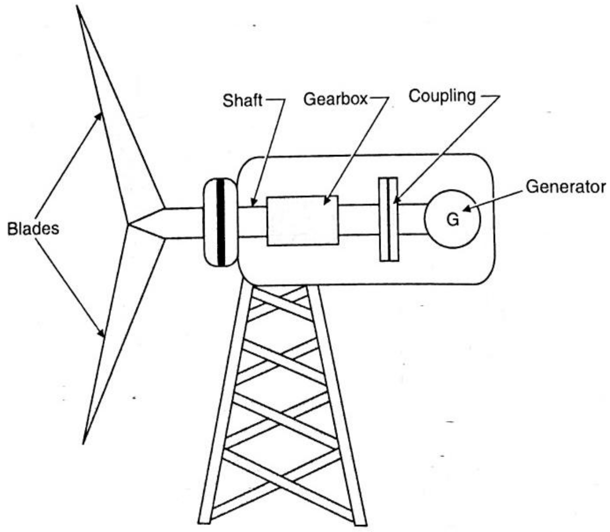


Fig. 1.4

The kinetic energy of large masses of air moving over the earth's surface due to uneven heating of the earth's surface by the sun. The kinetic energy of wind can be converted into mechanical work by wind mills/wind turbines; figure shows the schematic diagram of a wind mill for generating electricity.

It consists of specially designed blades connected to a shaft. The shaft in turn connected to a generator fixed in the axis of the wind mill.

Operation: The blades of the wind mill rotates due to the kinetic energy of the flow of wind which make the shaft to rotate in turn, the shaft drives the generator to produce electricity.

Apart from power generation wind mills can be used for pumping underground water for drinking and irrigation purpose.

Advantages

- Freely available in nature and environmental friendly.
- Inexhaustible.
- Cheap source of power generation.
- It's an effective method of supplying energy to remote areas.

Disadvantages

- Wind is not always predictable.
- Wind mills cannot be located everywhere.

Geothermal Process

It is the heat energy stored deep inside the earth, it is found in the form of heat contains of the hot dry rocks.

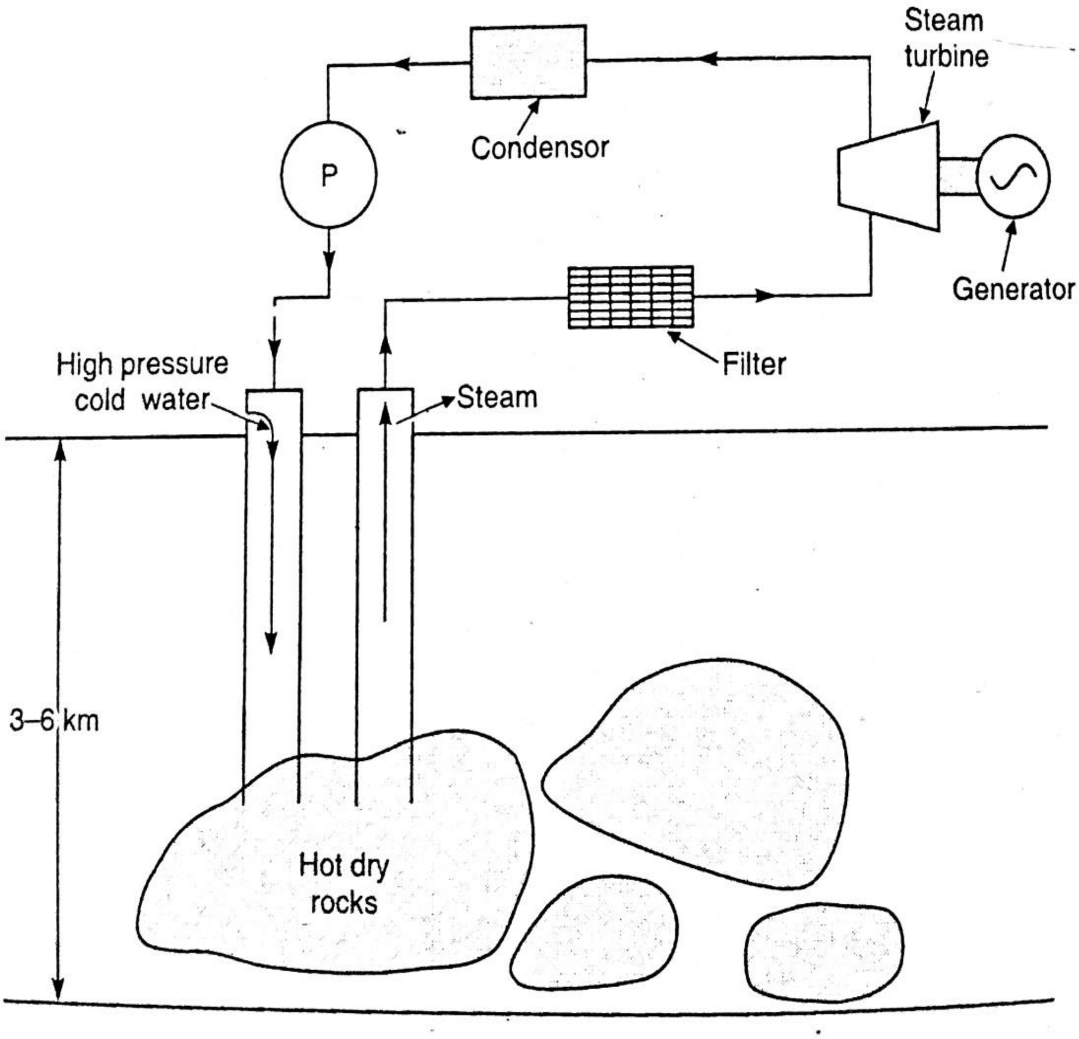


Fig. 1.5

Working: Initially the hot zones deep inside the earth are identified and the heat is trapped by drilling deep holes of about 3–6 km inside the earth. Cold water is forced through the hole deep down to the hot zone, due to high temperature, water gets converted into steam. This high pressure and high temperature steam drawn to the surface of the earth and is passed through a steam separator/filter to remove impurities. This purified steam under high temperature and pressure enters the turbine and expands by doing work in the turbine. The expanded steam is condensed in the condenser. Then condensate is pumped back to the hot dry rocks and the cycle repeats.

The first geothermal power station was built at Landrello, Italy; later on it is built by Japan, Philippines and New Zealand.

Tidal Energy

The periodic rise and fall of sea water is called tides. They are caused by the joint action of the sun and moon along with the gravitational pull, and rotational action of the earth.

A dam is built across the tidal ridge to create a pool or a tidal basin, water turbines coupled with generators are installed in the dam. When high tide occurs water from the ocean flows into the tidal basin there by rotating the turbines. Thus the generators produce electricity. During low tides water flows from the basin is allowed to flow the ocean which again rotates the turbines.

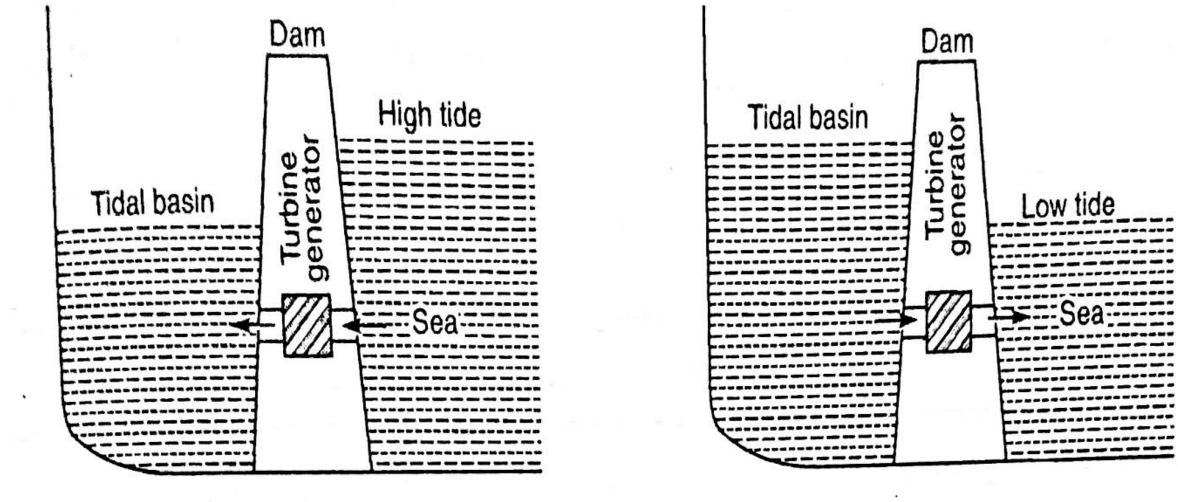


Fig. 1.6 Ocean Thermal Energy Conversion Power Plants

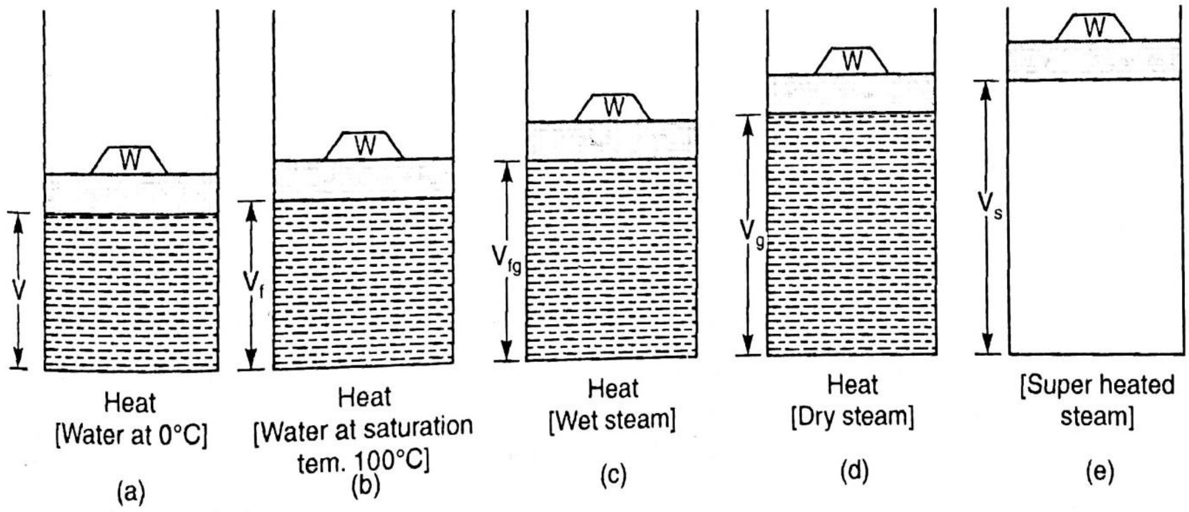


Fig. 1.7

The ocean covers more than 70%, of earth surface. Water in the ocean absorbs the heat energy radiated by sun. This makes them the world's largest solar energy collector and energy storage system.

The temperature of water at upper surface of sea is more than the deeper portion as long as the temperature differs by about 20°C [36°F], an OTEC. System can produce an significant amount of power. Figure shows line diagram of a OTEC plant. It consists of a turbine generator, an evaporator, condenser and a pump. The system works on a closed cycle that uses a low boiling point working fluid such as ammonia (NH_3).

System can produce a significant amount of power. Figure shows line diagram of an OTEC plant. It consists of a turbine generator, an evaporator, condenser and a pump. The system works on a closed cycle that uses a low boiling point working fluid such as ammonia (NH_3).

Working: The warm water from upper surface of ocean is drawn into evaporator in which liquid (NH_3) absorbs heat from water as a result, ammonia vaporizes and this high pressure ammonia vapour passes through turbine were it expands and runs the turbine and power is generated by the generator.

After doing work the low pressure NH, vapour passes through the condenser where it condensed to liquid ammonia, by giving away the heat to cold water, circulating from ocean. The NH_3, is then pumped into evaporator and thus the cycle repeats.

The first OTEC was built by French Man George Clode in 1929 in Cuba.

SUMMARY

- Hydal source is an indirect source of solar energy. The water from the surface of the earth gets evaporated by solar heat, which results in rainfall.
- Fission process involves splitting the nucleus of heavy atoms like uranium or plutonium in a controlled nuclear chain reaction.
- Helios chemical process is a photosynthesis process with complex biochemical reaction in which the plants using solar energy produces energy rich molecules of starch and cellulose.
- Helios electrical process using the principal of photovoltaic cell, the solar energy is directly converted into electrical energy, using photovoltaic cells.

REVIEW QUESTIONS

1. Define energy and its types, differentiate conventional and non-conventional source of energy.
2. Write notes on (a) primary fuel (b) secondary fuel.
3. Briefly describe conventional energy sources.
4. Describe wind energy and its advantages and disadvantages.
5. Discuss briefly tidal energy.

CHAPTER

2 SOURCES OF ENERGY

STRUCTURE

2.0 LEARNING OBJECTIVE

After going through this chapter, you will be able to:

- describe steam and its properties
- discuss term related to steam formation
- calculate the dryness fraction

2.1 STEAM

Steam is the most commonly used heat transport. It has high thermal capacity. It is used as the working fluid in steam turbine.

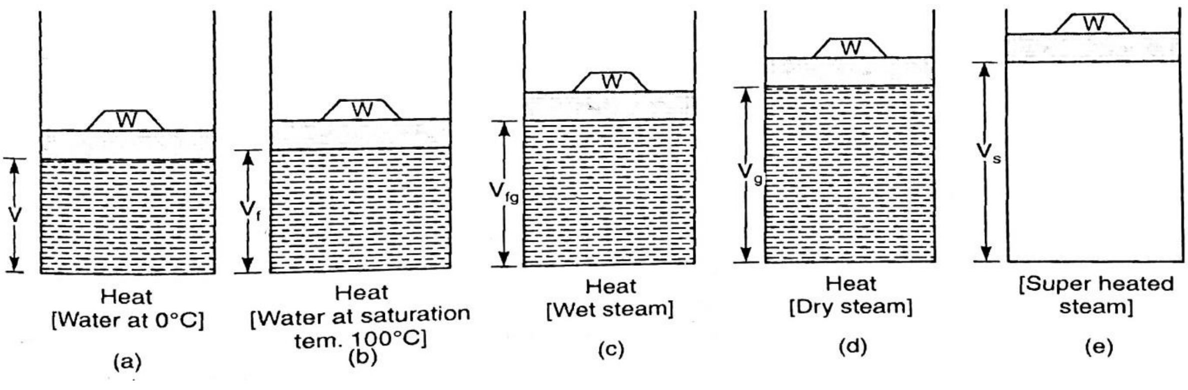


Fig.2.1

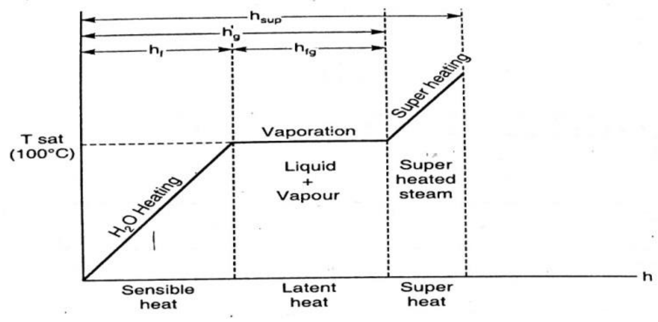


Fig.2.2

υ = volume of water at 0°C

υ_f = volume of water at saturation temperature

υ_{fg}= volume of wet steam

υ_g = volume of dry steam

υ_s = volume of super-heated steam

x = dryness fraction of steam

t_{sat} = saturation temperature

t_{sup} = super saturation temperature

h_f = sensible heat of water

h_{fg} = latent heat of water/hidden heat

h_g =enthalpy of dry saturated steam [Hg)

$h_g = h_f + h_{fg} \rightarrow Dry$

$h_g = h_f + xh_{fg} \rightarrow Wet$

Total heat of super-heated steam

$$h_{sup} = h_g + C_p\,(T_{sup} - T_{sat})$$

$$Q = Cp\Delta T$$

Consider a piston cylinder arrangement as shown in figure 2.1(a). 1 kg of water is collected into cylinder at 0°C and the piston is loaded with weight (w), to ensure constant pressure process.

When water is heated in cylinder its temperature increases till the boiling point. This point is also known as saturation temperature of formation of steam (T_{sat}). During this process there is slight increase in volume of water as shown in figure 2.1(b) further addition of heat does not cause any increase in temperature but there will be change in phase or state of water to steam till the complete water is converted to steam. As long as the steam is in contact with water it's called wet steam shown in figure 2.1(c) if all water particles associated with steam are evaporated the steam so obtained is called dry saturated steam shown in figure 2.1(d). If dry saturated steam is further heated at constant pressure, temperature and volume increases and the steam so obtained is called and shown in figure 2.1(e) super-heated steam which behaves like perfect gas.

The different stages of formation of steam are also shown in temperature- enthalpy diagram.

Terms related to steam formation

Sensible Heat: It is defined as amount of heat required to raise the temperature of 1 kg of water from 0°C to its saturation temperature. (100°C) it's also called total heat of water or enthalpy of water denoted by h_f.

Latent Heating/Hidden Heat (h_{fg}): It's the amount of heat required to convert 1 kg of water at saturation temperature to dry saturated steam at constant temperature and pressure, it's denoted by (h_{fg}).

Total Heat of Evaporation (h_g): It's the amount of heat required to convert 1 kg of water from 0° to dry saturated steam it's also known as enthalpy dry saturated steam.

$$h_g = h_f + h_{fg} \rightarrow \text{for dry steam}$$
$$h_g = h_f + xh_{fg} \rightarrow \text{for wet steam}$$

Conditions of Steam

- Wet steam
- Dry steam
- Super-heated steam
- Dryness fraction

Dryness Fraction: It's defined as amount of dry steam present in wet steam mixture. Viz. in a sample of wet steam

Let m_g = mass of dry steam
m_f = mass of water particles

$$x = \frac{m_g}{m_g + m_f}$$

Total heat of dry steam

$$h_{gwet} = h + xh_{fg}$$
$$h_{gdry} = h_f + h_{fg}$$

Total heat of super-heated steam

$$h_{sup} = h_g + C_p\,(T_{sup} - T_{sat})$$

Specific Volume: It is defined as the volume occupied by a unit mass of a substance m^3/kg or it is defined as volume occupied by water at saturation temperature "C_p".

Specific Volume of Dry Saturated Steam

V_g = its volume occupied by 1 kg of dry saturated steam at given pressure υ_g.

Specific Volume of Super-Heated Steam: Its volume occupied by 1 kg of super-heated steam at given pressure.

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

$$\frac{P_1 v_1}{T_1} = \frac{P_2 v_2}{T_2} \qquad v_2 = v_1 \left(\frac{T_1}{T_2} \right)$$

Specific Volume of Wet Steam: It's the volume occupied by 1 kg of wet steam.

$$v = xv_g + (1-x)\, v_f$$

Note. Practically the value of $(1-x)$ is negligible so it is neglected

$$v = xv_g$$

Enthalpy: It's defined as sum of internal energy and product of pressure and
volume

$$h = u + Pv$$

u = Internal energy

Pv = Work done

Enthalpy of dry saturated steam

$$h_g = h_f + h_{fg}$$

$$h_g = h_f + xh_{fg}$$

External work of evaporation: When water is evaporated to get steam its volume increases and external work is done by the steam due to increase in its volume. This process is known as external work of evaporation.

$$E = P\,(v_g - xv_f) \text{ kJ/kg}$$

P = pressure (Pa)

v_g = volume of steam (kg/m^3)

v_f = volume of water in steam (kg/m^3)

x = dryness fraction

Note. xv_f is negligible

$E = Pv_g$ kJ/kg

PROBLEMS

Problem 1: Find the enthalpy of gas at $\overline{12}$ absolute pressures:

a) when steam is dry saturated

b) the steam is 22% wet

c) steam is super-heated to 250°C.

Sol. Case

a) From steam

For $\overline{12}$ AP 88°C

$h_f = 798.6$
$h_{fg} = 1986.2$
$= 2784.8$
$h_g = 798.6 + 0.78$
$= 2347.83$ kJ/kg
$T = 250°C$
$h_g = h_g + h_{fg}$
$= 1714.1 + 1087.3 = 2801.4$

Problem 2: Find specific volume, enthalpy and L.E. of steam at pressure of 10 absolute when steam is 12% dry.

$x = 0.92$
$T_s = 179.9$
$v_f = 0.001127$ m^3/kg
$v_g = 0.1943$
$h_f = 762.8$ kJ/kg
$h_{fg} = 2013.6$ kJ/kg
$h_g = 2776.2$ kJ/kg

Sol. $v = xv_g$
$= 0.17848$ m^3/kg
$= 0.92x$
$u = h - pv$
$h_{sup} = 2776.2 - 10\ (0.1943)$
$= 2758.32$ Dry

Problem 3: Find specific volume and enthalpy of 1 kg of steam at 0.8 x 10^4 Pa when D.F. = 0.90, steam is super-heated to temperature of 300 specific heat of super-heated steam is 2.25 kJ/kg.

Sol. $v_f = 0.001115$
$v = xv_f$
$= 0.9 \times 0.001115$
$= 1.0035 \times 15^{-3}$ m^3/kg

Specific volume, $v_g = \frac{T_{sup}}{T_{sat}}$

$$= \frac{0.240\times(300+273)}{170.4+273}$$

$$= \frac{0.240\times573}{443.4} = 0.31014 \text{ m}^3/\text{kg}$$

Enthalpy of wet steam, $h_g = h_f\ xh_{fg}$
$= 721.1 + 0.9 \times 2048.0$
$=2564.3$

Wet steam, $h_{wet} = h_f + xh_{fg}$
Dry steam, $h_g = h_f + h_{fg}$
Super-heated steam, $h_{sup} = h_g + C_p\ (T_{sup} - T_{sat})$
Wet steam, $v_{wet} = xv_g,\ v_g$
$v_g = 0.24$ m3/kg
$h_f = 721.1$ kJ/kg
$h_{fg} = 2048.00$

h_g = 2769.1 kJ

$$\upsilon_{sup} = \frac{0.24(300+273)}{170+273}$$

= 0.3104 m3/kg

Enthalpy of wet steam

$h_{wet} = h_f + xh_{fg}$
= 721.1 + 0.90 (2048)
= 2564.3 kJ/kg
$h_{sup} = h_g + C_p\ (T_{sup} - T_{sat})$
h_{sup} = 3060

Problem 4: Calculate the specific volume and enthalpy of 8 kg of steam at 1.2
MPa when

a) Steam is 12% wet, DF = 0.88

b) Steam is super-heated to 300°C assume that specific heat, C_p=2.25 kJ/kg,
υ_g = 0.163.

Sol.

$\upsilon = x\upsilon_g$
= 0.88 × 0.163
= 0.14344 m^3/kg
$h_{wet} = h_f + xh_{fg}$
= 798.6 + 0.88 (1986.2)
= 798.6 + 1747.856
= 2546.456 kJ/kg
$h_{sup} = h_g + C_p\ (T_{sup} - T_{sat})$
= 2784.8 +2.25 (300 + 273 - 188 + 273)
= 2784.8 +2.25 (112)
= 3036.8 kJ/kg.

$$\upsilon_{sup} = \upsilon_{sat} \times \frac{T_{sup}}{T_{sat}} = \frac{0.163 \times 573 \times 8}{188+273}$$

= 1.62608

SUMMARY

- Steam is the most commonly used heat transport. It has high thermal capacity. It is used as the working fluid in steam turbine.

- All water particles associated with steam are evaporated the steam so obtained is called dry saturated steam. Sensible heat is defined as amount of heat required to raise the temperature of 1 kg of water from 0°C to its saturation temperature. (100°C) it's also called total heat of water or enthalpy of water denoted by h_f.

- Total heat of evaporation (h_g) the amount of heat required to convert 1 kg of water from 0° to dry saturated steam it's also known as enthalpy dry saturated steam.

REVIEW QUESTIONS

1. Enthalpy of 1 kg of steam at 8 pressures is 2373.5 kJ/kg, find condition of steam.

2. Steam initially at 9 D_f = 0.98%, find quality of steam and also temperature of steam.

3. At each of following condition when steam losses 50 kJ of heat at constant pressure steam remains at same pressure and resire 150 kJ/kg of heat.

4. By actual measurement the enthalpy of saturated steam at 190°C is 2500 kJ/kg, what is the quality of steam, if 500 kJ of steam is added at constant pressure what is the final state of steam? Also find its final temperature.

5. Determine density initially at pressure 10 to having, D_f = 0.78 if 500 kJ of heat is added at constant pressure, find the condition of steam and internal energy of final state of steam assuming specific heat of super-heated steam as 2.1 K.

CHAPTER

3 BOILERS

STRUCTURE

3.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- know about the boiler
- explain the water tube boiler
- describe the Lancashire boiler
- discuss about the boiler mounting and accessories

3.1 BOILER

Boiler is a closed metallic vessel in which steam is generated to the desired temperature and pressure from water. Its main function is to generate steam at the desired condition.

Classification of Boilers. Boilers are classified based on the following:

- Based on contents inside the tube:
  - ❖ Fire tube boiler
  - ❖ Water tube boiler

a) Fire Tube Boiler

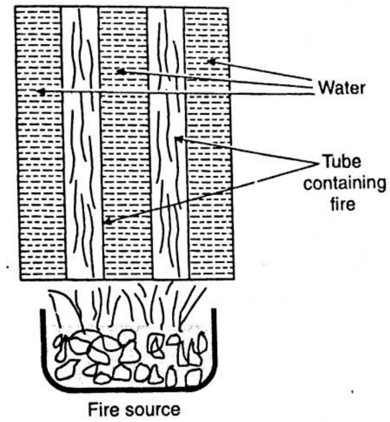


Fig. 3.1

In the fire tube boiler the product of combustion passes through the tube.

For example: Lancashire boiler
Locomotive boiler
Cochran boiler

b) Water Tube Boiler

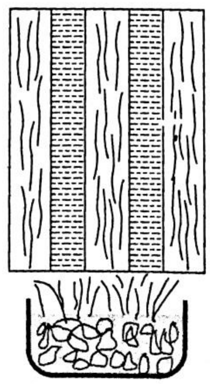


Fig. 3.2

In water tube boilers the water flows inside the tube and surrounded by the product of combustion.

For example: Babcock Wilcox Boilers
Sterling Boilers.

- Based on its uses (stationary boilers)
  Babcock and Wilcox boiler (mobile boiler)
  Locomotive, Marine and Portable boiler.

- Based on location of furnace
  Internally Fired Boilers.
  In this the furnace is placed in the region of boiling water.

For example: Lancashire boiler.
Externally fire boiler.

In this the furnace is placed outside the region of boiling water.

For example: Babcock
Wilcox boiler

- Based on the axis of shell/tube
  Horizontal tube → Lancashire boiler
  Vertical tube → Cochran boiler
  Inclined tube → Babcock and Wilcox boiler.

- Based on method of circulation of water
  Natural circulation boiler
  Forced circulation boiler.

Working of Water Tube Boiler. [Babcock and Wilcox boiler].

Boiler is filled with sufficient quantity of water. The fuel/coal is charged through grates and hot gases of combustion first rises up then comes down and again rises up due to presence of baffle and finally escapes through chimney.

Steam mixture moves up through the uptake header into the boiler's shell, as steam is saturated from water and collects in the steam space, from the steam space the steam is fed to the super heater. Steam can be trapped through steam tap valve.

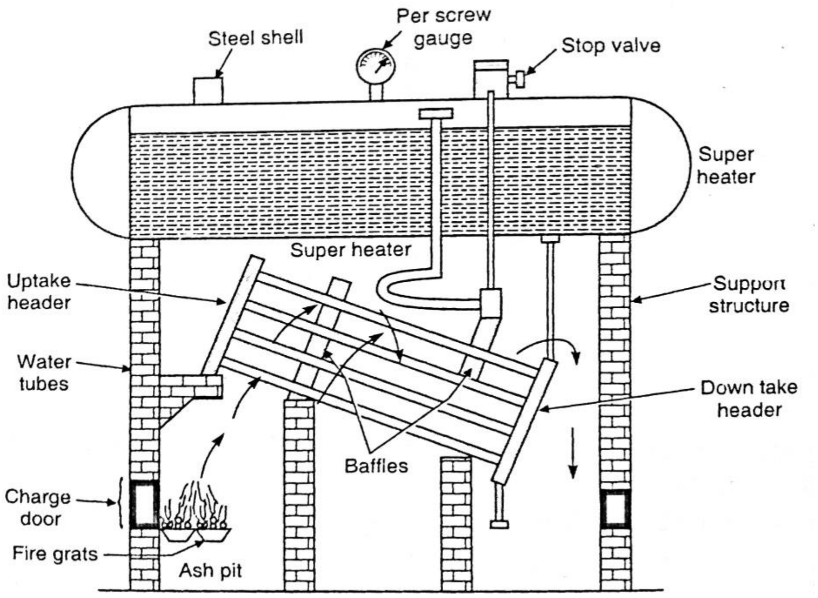


Fig.3.3

Merits and demerits of water tube over fill tube.

Merits

- Its evaporating capacity is considerably high and therefore it can produce high pressure steam.
- Quick generation of steam takes place.
- It has less thermal stress due to circulation of water.

- Heating surface are more effective because hot gases travel perpendicular to the direction of water flow.
- For given space it consumes less power.
- The boiler can be easily transported and its parts can be separated easily.
- Ease of cleaning, inspection and repair.
- It is suitable for large power plant.

Demerits

- It is less suitable for impure water as a small deposit of scale causes over heating
- Careful attention is required for its operation.
- Operation and maintenance cost is high.

Working of Lancashire Boilers (Working of fire tube boiler].

Boiler is filled with sufficient quantity of water, fuel is charged through furnace door. The fuel burns in grates and product of combustion first pass through fire tubes and then returns along through the brick build fuel passage, below the boiler's shell to the front end. Here the hot gases divide, and flow along the two side flues to the raise end and then pass to the chimney. The steam is accumulated in the steam space above the surface of water and can be tapped off through the steam stop valve connected to a priming tube.

Merits of Fire Tube Boiler over Water Tube Boiler

- Fire tube boiler has greater reliability low initial cost, simplicity and rigid construction.
- It has a large volume of water hence, more flexible and can meet any demand of steam.
- Temperature failure of forced water supply does not cause damage to boiler
  because of rigid construction.
- Simple to operate than water tube boiler.

Demerits

- It requires more time to generate steam in the beginning.
- Large diameter of shell limits the maximum steam pressure and temperature.
- Due to low rate of steam production, fire tube boiler is not suitable for steam power plants.
- Transportation of FTB is inconvenient. Exposure to high temperature of boiler is hazardous and dangerous.
- Bursting of fire tube in the boiler a serious problem in FTB.

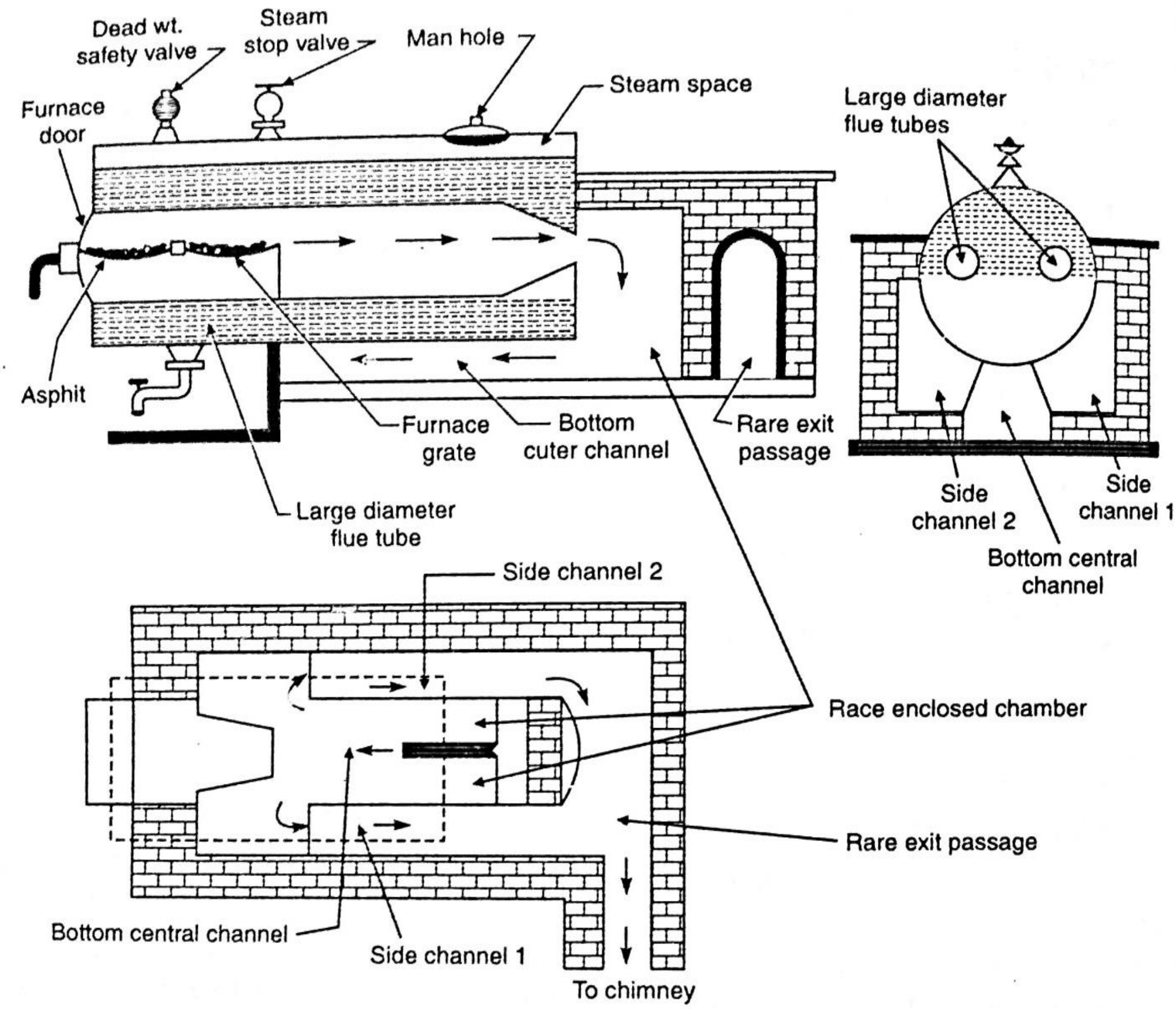


Fig. 3.4

Boiler Mounting and Accessories

Boiler mountings are derives/fittings mounting over the boiler shell in order to ensure safe operation and efficient working.

Boiler mounting

- Water level indicator
- Pressure gauge
- Steam stop valve
- Feed valve/feed check valve
- Blow off cock
- Fusible plug
- Safety valve

Functions of Boiler Mounting

Water level indicator: It is also known as water gauge, it is used to indicate the level of water in the water drum/shell.

Pressure gauge: It indicates the pressure of steam inside the boiler.

Steam stop valve: It regulates the flow of steam, it is also known as junction valve or stop valve.

Feed valve/feed check valve: It regulates and controls the supply of water to the boiler.

Blow off cock: It is used to flush water from the boiler to discharge mud and sediments collected at the bottom of boiler; it's also used to empty the boiler for cleaning and inspection purpose.

Fusible plug: It protects boiler from overheating and acts as a fuse.

Safety valve: It presents boiler from explode due to internal pressure of steam. The most commonly used safety valves are

- Dead weight safety valve
- Lever safety valve
- Spring loaded safety valve
- High steam and low water safety valve

Accessories

- Economizer
- Super heater
- Air pressure heater
- Feed pump
- Steam separator
- Steam trap

Economizer: It is a device used to heat the feed water by utilising the heat of exhaust glue, before leaving the chimney.

Advantages:

- Fuel economy.
- Increase steam generation value.
- Long life of boiler.

Super heater: It is used to increase temperature of saturated steam without increasing its pressure.

Advantages:

- It increases efficiency of boiler (power plant).
- It eliminates the corrosion of turbine parts.
- It reduces condensation losses.
- It reduces the specific steam consumption of turbine engines.

Air pressure-heater: It is used to pressure-heat air used for combustion by utilizing the heat of exhaust flue.

Feed pump: It is used to feed water into the boiler shell.

- Pumps are further classified into
- Reciprocating pump
- Rotary pump
- Centrifugal pump

Steam separator: It is used to separate water particles present in steam before it enters the turbine/engine.

Steam trap: It is a device used to trap steam accumulated in steam pipe along with water particles.

SUMMARY

- Boiler is a closed metallic vessel in which steam is generated to the desired temperature and pressure from water.
- Water level indicator is also known as water gauge, it is used to indicate the level of water in the water drum/shell.
- Super heater is used to increase temperature of saturated steam without increasing its pressure.
- Steam separator is used to separate water particles present in steam before it enters the turbine/engine.

REVIEW QUESTIONS

1. Describe briefly boilers and its types.

2. Write down merits and demerits of fire tube boiler over water tube boiler.

3. Explain working of water tube boiler.

CHAPTER

4 PRIME MOVERS

STRUCTURE

4.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- define the prime mover
- explain the impulse turbine
- describe the gas turbine
- discuss about the steam turbine

4.1 PRIME MOVERS

Definition: Prime mover is a device which converts various sources of energy available in nature in useful mechanical rotatory motion of shaft which in turn connected to machines or generator produces useful energy. Any device which is responsible of moment of the object/machine is a prime mover.

Classification: Prime movers are classified based on type of energy utilised. They are thermal prime mover, and Hydraulic prime mover.

Thermal prime mover is further classified into steam turbine/gas turbine and IC engine.

Hydraulic prime mover is classified into water turbine. Steam turbine is a thermal prime mover which converts heat energy of steam to mechanical energy in form of rotation of shaft.

In steam turbines the heat energy of steam is first converted into a nozzle.

Steam turbine is further classified into two groups:

- Impulse turbines
- Reaction turbines

Impulse Turbine

Simple impulse turbine is shown in figure 4.1. It consists of the set of nozzles followed by series of moving blades. The blades are attached over the rim of wheel and the wheel is connected to a turbine and shaft is connected to generator, as the steam flows through the nozzle the pressure falls from inlet pressure to exit pressure condenser pressure.

Due to relatively high pressure of expansion its velocity increases from P to Q as shown in velocity diagram. This high velocity steam impinges on moving blades due to which the wheel rotates at very high speed thus the K.E. of steam is converted into mechanical (energy) work (rotation of shaft). Thereby it is converted into electrical energy.

For example: DE level turbine.

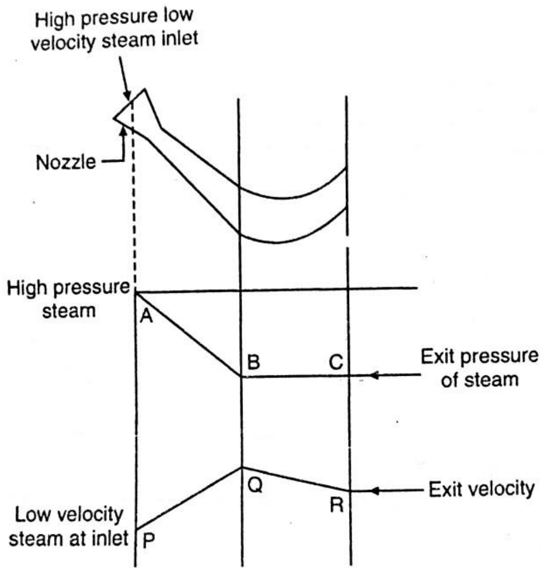


Fig. 4.1

Reaction Turbine

Working of reaction turbine: In reaction turbine steam directly passes into the moving blades through the fixed blades. The fixed blades shape is designed such that the flowing steam between the blades causes nozzle effect and steam pressure decreases gradually. The rotation of shaft carrying the moving blades is the result of both impulse and reaction force therefore, it is also known as impulse- reaction turbine.

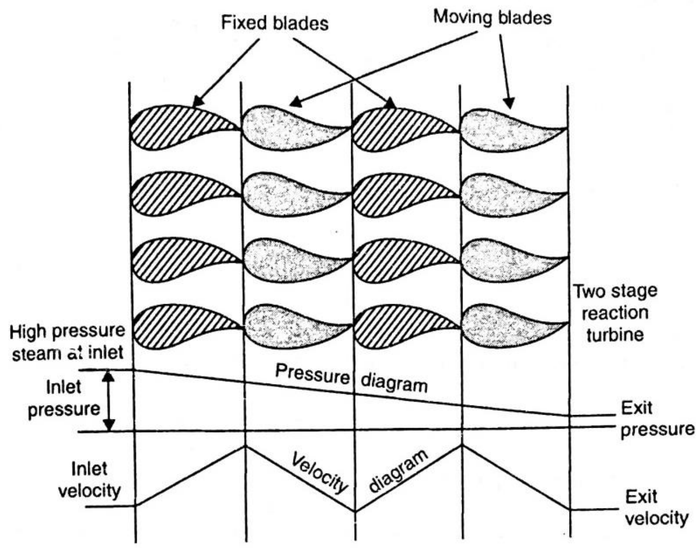


Fig.4.2

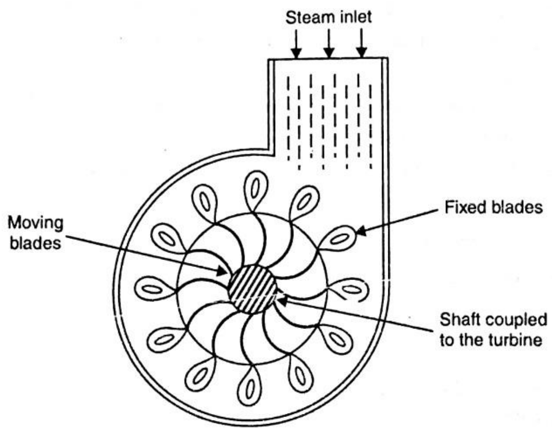


Fig.4.3

Difference between reaction and impulse turbine

Impulse Turbine	Reaction Turbine
• Driving force is only due to impulsive force of steam. • Steam expands completely in the nozzle. • Pressure of steam remains constant both at inlet and exit of turbine. • Blades have symmetrical profile.	• Driving force is due to both, impulsive force of the incoming steam and the reaction force of the outgoing steam. • Steam expands gradually as it passes over the fixed blades and moving blades. • Pressure decreases from inlet to exit of turbine. • Blades have aero foil profile. • Do not require compounding.

• Impulse turbine requires compounding. • It occupies less space. • Suitable for small capacity power plants.	• It occupies large space at the same capacity. • Suitable for large and medium power plants.

Compounding of steam turbine (impulse turbine): In impulse turbine when the steam is expanded from boiler pressure (event pressure) to condenser pressure in a single stage the speed of rotor becomes very high 30000-40000 rpm, this speed will induce enormous centrifuges stress on the rotor blades and on the bearings and also it exceeds the maximum allowable pressure limits with a large steam velocity, results in undesirable friction losses and reduction in turbine efficiency.

To overcome these disadvantages the speed of rotor must be reduced and it is achieved by compounding to steam turbine.

There are three methods of compounding a simple turbine (impulse):

- Pressure compounding
- Velocity compounding
- Pressure-velocity compounding

Advantages of Steam Turbine

- High thermal efficiency,
- Much higher speed can be achieved.
- It rotates at constant speed.
- It develops torque at uniform rate and does not require flywheel.
- In the absence of reprobating parts the balancing problem is minimized.
- Less loss, low maintenance, longer life occupies less space.
- No internal lubrication is required.

Gas Turbine

Gas turbine is a rotary machine which uses gas as a working fluid. The hot gases produced by combustion are directly used to run the turbine.

It consists of three main components namely:

- Compressor
- Combustion chamber
- Turbine

The air after being compressed by the compressor is heated either by directly burning the fuel or by burning the fuel externally. The hot air with or without the product of combustion is expanded in the turbine resulting in mechanical work output. Gas turbine can be used for power generation and it produces large quantity of power.

Classification of Gas Turbine

Gas turbines are classified into two groups:

a) Open cycle gas turbine
b) Close cycle gas turbine

Open Cycle Gas Turbine

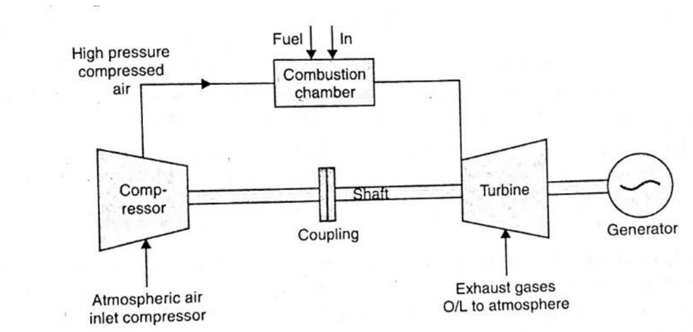


Fig. 4.4

Construction: A simple construction pressure open cycle gas turbine is shown in figure 4.4. It consists of compressor, combustion chamber and a turbine. Both turbine and compressor are mounted on a common shaft.

Compressor draws air from atmosphere and compresses to high pressure. This compressed air passes to the combustion chamber. Where fuel is burnt at constant pressure. The mixture of hot gasses and compressed air is made to flow through the turbine blades where the heat energy is converted into mechanical work in the form of rotation of shaft, which can be connected to a generator for power generation or to any engine for useful work.

The expanded gases (exhaust gas) coming out from turbine and discharged to the atmosphere. The compressor operates by utilizing the power generated by turbines.

The principle of working of OPCGT in OPCGT, the working fluid is the atmospheric air and heat ejection process takes place in atmosphere and turbine exhausts in discharge to the atmosphere.

Close Cycle Gas Turbine

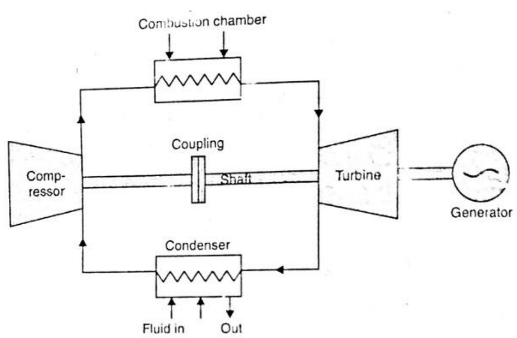


Fig. 4.5

Principle of working: In close cycle gas turbine the heat ejection process is
performed in the condenser/heat exchangers. The same working fluid is used. The working fluid does not come in contact with the product of combustion.

Construction: As shown in figure. A close cycle gas turbine consists of combustion chamber, compressor, turbine and condenser. Both compressor and turbine are mounted on a common shaft, working fluids such as air, argon, helium, nitrogen, CO_2 etc., are used.

Operation: Air, working fluids is compressed in compressor and passes through the combustion chamber where the working fluid gets heated up by utilizing the heat of product of combustion. A working fluid will not come in contact with the product of combustion. This high pressure and high temperature fluid is made to flow through the turbine where expansion of hot gas takes place and the heat energy is converted into mechanical work in the form of rotation of shaft.

The working fluid after doing work passes through the condenser where it gets condensed to atmospheric temperature and pressure. This condensed fluid passes through the compressor where it gets compressed and the cycle repeats.

Advantages of Gas Turbine over Steam Turbine

- The working fluid is easily available.
- It does not require bulky and expensive boiler.
- Less initial and operating cost.
- More compact (less weight/unit watt).
- Easy start and control.
- Working fluid is used directly to run the turbine without producing intermediate fluid (Steam).
- Gas used in gas turbine is a cheaper source.

Advantages and Disadvantages over IC Engine

Advantages of Gas Turbine over IC

- Gas turbine does not require flywheel because the torque of the shaft is continuous and uniform (torque → turning movement of the shaft).
- Perfect balancing is possible (as there are low sliding parts in gas turbine).
- High mechanical efficiency.
- Low grade fuels can be used in gas turbine hence cheaper power production.
- Simple lubrication and ignition system.
- Less weight/kg watt.
- Less pressure ratio.
- Less pollution and low maintenance cost.

Disadvantage of Gas Turbine Over IC

- Low thermal efficiency.
- Life of turbine blades is less due to high operating temperature.
- Speed reduction units are essential due to high operation speed (compounding).
- Difficult to control the flow of fluid in the combustion fuel.

Uses of Gas Turbine

- Gas turbine is used for power generation, marine operation (in ships), and in locomotives.
- It is used in turbojets and turbo propellers (Airplanes).
- It is used for super charging heavy duty diesel engines and it is also used for aviation purpose.
- Gas turbines are used in steel industries, oil refineries, and in chemical industries.

Water Turbines

Water turbine is a hydraulic prime mover in which water is used as a working fluid. The potential and kinetic energy of water is converted into mechanical energy in the form of rotation of shaft.

Classification: Water turbines are classified based on the following:

1. Types of energy available at the inlet of turbine.

a) Impulse turbine. The energy available is only kinetic energy of water e.g., peloton-wheel.
b) Reaction turbine. Both pressure energy and kinetic energy are available
at the inlet of turbine. e.g., Kaplan turbine and Francis turbine.

2. Based on direction of flow of water through the turbine.

a) Tangential flow turbine. Water flows along tangent through the runner.
b) Radial flow turbine: A Water flow is radial direction through the runner. It is further classified into:
- Inward radial flow
- Outward radial flow

c) Axial flow: Water flows in the direction parallel to the axis of the runner e.g., Kaplan turbine.
d) Mixed flow turbine. In this, water flows radially into the runner and leaves out axially e.g., modern Francis turbine.

3. Based on head water available.

a) High head - Pelton wheel/ Impulse turbine.
b) Medium head - Francis turbine.
c) Lower head - Kaplan turbine.

A. Impulse turbine (Pelton wheel)/high head

The pelton wheel is the most commonly used type of impulse turbine. It works under high heads, and requires small quantity of water.

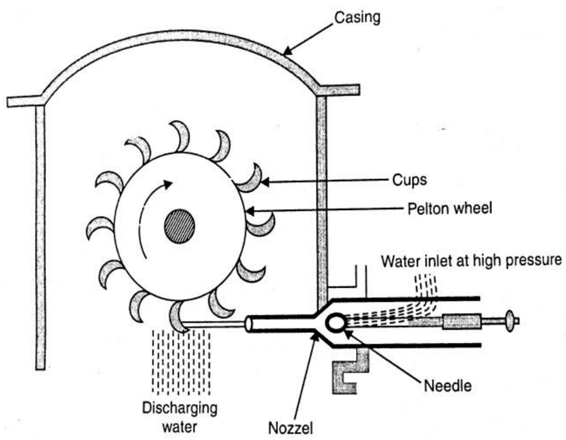


Fig. 4.6

The figure shows the schematic diagram of pelton wheel. The water from a high head source is supplied to the nozzel provided with a needle which controls the quantity of water flowing out of the nozzel.

The pressure energy of water is converted into velocity energy as it flows jet striking the cups makes the pelton wheel to rotate in the direction of the jet. Thus the pressure energy of the water is converting. Thus the pressure inside the casting of the turbine will be at atmospheric pressure.

B. Reaction turbine/Francis turbine. (Medium head)

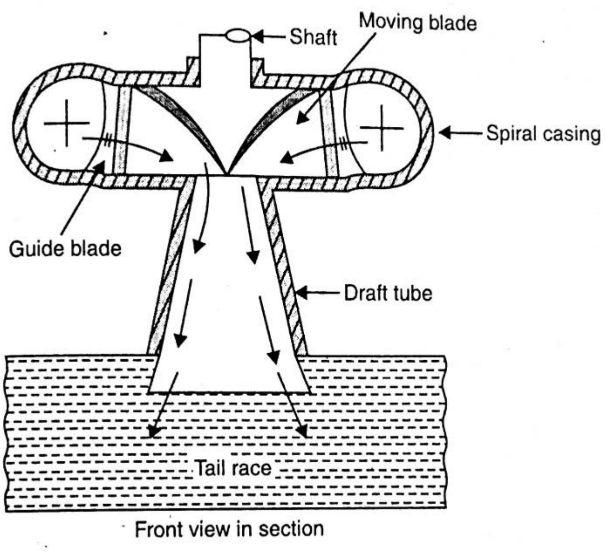


Fig. 4.7

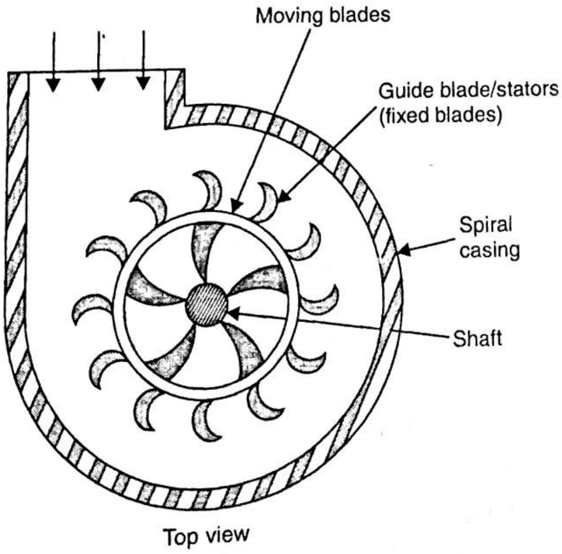


Fig. 4.8

It is a mixed flow reaction turbine used for medium head, and it requires large quantity of water, figure shows a Francis turbine.

Working: Water from reservoir flows through the penstock and enters the spiral casing where a part of potential energy of water is converted into kinetic energy in the casing.

Water flows through the guide blade (find blades), gets deflected and then flows radially, into the moving blades. The blades passage act as a nozzle and the remaining part of potential energy is also converted to kinetic energy and this high velocity water leaving blades. Causes a reaction force on the runner, this force sets the runner into rotary motion. Water after doing work discharge to the tail race via draft tube.

C. Lower head- Kaplan turbine

It is in axial flow low head reaction turbine and is used when large quantity of water at low heads.

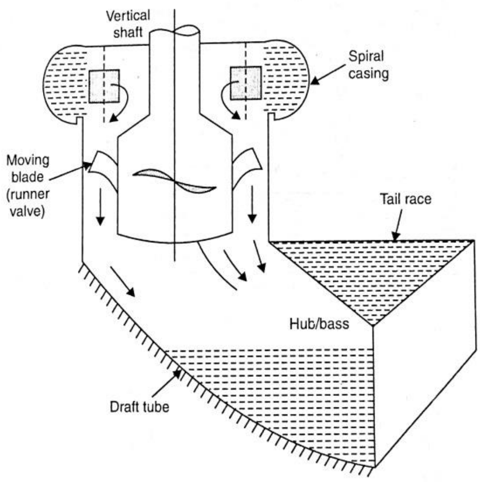


Fig. 4.9

Working: Water from reservoirs flows through the penstock and enters spiral casing where part of potential energy is converted into kinetic energy. This high velocity water enters the moving blades through the fixed blades; fixed blades are arranged such that the outlet of fixed blades acts as a nozzle where the remaining potential energy is convert, end into kinetic energy. When the water leaves the moving blades at high velocity reaction force is setup. This force rotates the runner.

Water after doing work water discharges to the tail race through draft tube; draft tube has increasing cross-section area, decreases the discharged pressure of water.

Additional information: Kaplan turbine is setup in:
- Tungabhadra in Karnataka
- Nizam sagar in Andhra Pradesh
- Kolhapur in Maharashtra
- Kota in Madhya Pradesh,

SUMMARY

- Prime mover is a device which converts various sources of energy available in nature in useful mechanical rotatory motion of shaft which in turn connected to machines or generator produces useful energy.

- The air after being compressed by the compressor is heated either by directly burning the fuel or by burning the fuel externally.

- Water turbine is a hydraulic prime mover in which water is used as a working fluid. The potential and kinetic energy of water is converted into chemical energy in the form of rotation of shaft.

- The pressure energy of water is converted into velocity energy as it flows through the nozzle. The jet of water with a high velocity infringes as it flows through the nozzle, on to the curved blades known as pelton cups.

REVIEW QUESTIONS

1. Differentiate between reaction turbine and impulse turbine.

2. Describe the advantages and disadvantages of gas turbine over IC engine.

3. Explain the prime movers and classify them.

4. Write short note on (a) steam turbine (b) gas turbine.

5. Discuss about the water turbines and its working.

CHAPTER

5 INTERNAL COMBUSTION ENGINES

STRUCTURE

5.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- differentiate between external combustion engine and internal combustion engine
- describe the suction stroke
- explain the indicated power
- discuss about the IC engine terminology

5.1 INTERNAL COMBUSTION ENGINES

Heat engine: It is a thermal prime mover which converts chemical energy of fuel into heat energy (by combustion of fuel) and utilizes the energy to perform useful mechanical work.

Heat engines are classified into two:

- External combustion engine (ECE)
- Internal combustion engine (ICE)

External combustion engine: If the combustion of fuel takes place outside the working cylinder, the engines are termed as E.C. engines.
e.g., Steam turbine, steam engines and closed cycle gas turbine.

Internal combustion engine: If the combustion takes place inside the working cylinder of the engine, the engine is termed as IC engine. e.g., Engines of cars, scooters, automobiles, busses, trucks, locomotives, agricultural and earth moving machines, power generation unit etc.

Advantages of ICE over EC Engines

1. IC engines have high efficiency.
2. Light weight.
3. Easy to start.
4. Occupies less space.
5. Low cost.

Classification of IC engines: These are classified as follows:

1. According to the type of fuel used :
   - **a)** Petrol engine
   - **b)** Diesel engine
   - **c)** Gas engine
   - **d)** Bi fuel engines (gaseous fuels like natural gas, biogas are used as a working fluid, whereas petrol is used as staring fuel).
2. According to the number of strokes per cycle :
   - **a)** Two stroke engine. The working cycle is completed in two different strokes.
   - **b)** Four stroke engine. The working cycle is completed in four different strokes.
3. According to the method of ignition :
   - **a)** Spark ignition engine. In this fuel is ignited by an electric spark.
   - **b)** Compression ignition engines. In this engine the fuel is ignited as it comes in contacts with the compressed air.
4. According to cycle of combustion :
   - **a)** Otto cycle. Combustion takes place at constant volume.
   - **b)** Diesel cycle. Combustion takes place at constant pressure.
   - **c)** Dual combustion. In these engines the combustion of fuel first takes place at constant volume and then at constant pressure.
5. According to the number of cylinders :
   - **a)** Single cylinder engine.
   - **b)** Multi cylinder engine. It consists of 2, 3, 4, 6 and 8 cylinders.
6. According to arrangement of cylinders;
   - **a)** Vertical engine. The cylinder is arranged in vertical position.

b) Horizontal engine. The cylinder is arranged in horizontal position.
c) Radial engine. Cylinders are arranged along circumference of the circle.
d) Inline engine. Cylinders are arranged in a line.
e) V engine. It is a combination of two inline engines equally set at an angle.
f) Opposed engine. Cylinders are arranged opposite to each other.

7. According to the method of cooling:

a) Air cooled engines,
b) Water cooled engines.

8. According to the uses :

a) Stationary engine
b) Automobile engine
c) Locomotive engine
d) Marine engine
e) Aircraft engine.

Principle parts of IC engines:

Parts of IC engine:

a) Cylinder
b) Cylinder head
c) Piston
d) Piston rings
e) Connecting rod
f) Crank shaft
g) Fly wheel

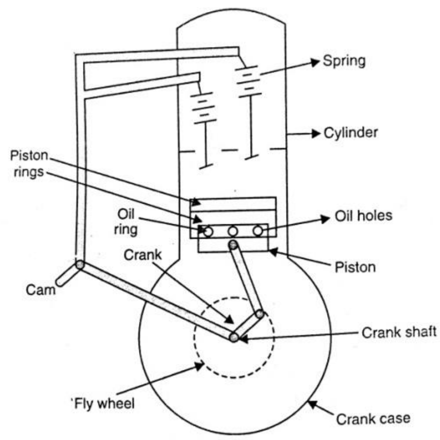


Fig. 5.1

Cylinder: Cylinder is considered as heart of the engine. It is a cylindrical shaped vessel. Its function is, it contains the working fluid under a high pressure and it guides the piston for smooth functioning. Cylinder is made of gray cast iron (GCS) and steel alloys.

Cylinder head: Top end of the cylinder is closed by a removable cylinder head. It consists of inlet valve and exhaust valve which are operated by means of cams; it is made of cast iron or its alloy.

Piston: It is cylindrical shaped component that fixed perfectly inside the cylinder its function is to compress the charge inside the cylinder during compression stocks and it recovers the impulsive force produced by the combustion of fuel.

Piston rings consists of

a) Compression rings
b) Oil rings.

These rings are inserted at the top portion of the piston and their function is to mention a pressure tight seal between the piston and the cylinder, it also transfers the heat from piston head to the cylinder walls.

The function of oil ring is to lubricate the piston and cylinder, and also it removes unwanted lubricating oil from the surface of cylinder walls, so as to minimize the flow of oil into the combustion chamber.

Connecting rod: The main function of connecting rod is to transmit the movement of piston to the crank shaft. It is made of carbon steel or alloy steel.

Crank shaft: The function of crank shaft is to convert reciprocating motion of the piston into rotatory motion of the shaft. Crank shaft is usually made of carbon steel.

Fly wheel: The fly wheel is rotating mass which is used as a energy storing device. It absorbs mechanical energy by increasing its angular velocity, during the power stroke and it delivers energy by decreasing its velocity during suction, compression and exhaust strokes. It is made of cast iron.

IC engine terminology:

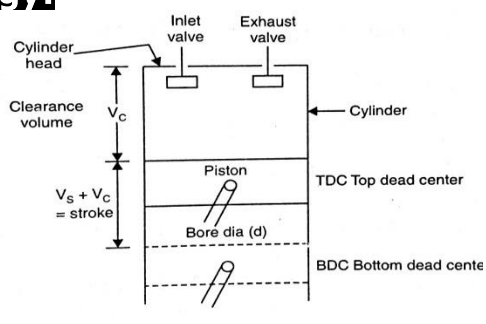


Fig. 5.2

- **Bore:** The inside diameter of the cylinder is called the bore.
- **Strokes:** The linear distance travelled by the piston from TDC to BDC is called strokes.
- **TDC:** The top most position of the piston in the cylinder is called top dead center in the case of horizontal engine, it is known as IDC = Inner dead center.

- **BDC.** The lowest position of the piston at the bottom end of the cylinder in
  called BDC. In case of horizontal engine it is known as ODC = Outer dead center.
- **Clearance Volume (V_c).** It is the volume contain in the cylinder above the top of the piston when a piston at TDC.
- **Compression Ratio (R_C/R_V).** It is the ratio of total cylinder volume to the clearance volume and is given by

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

Where V_c = clearance volume
V_s = stroke volume

Note: V_s= Stroke volume (distance between BDC-TDC) also known as swept volume.

- **Cycle of operation:** It is defined as the number of strokes of the piston required to complete one cycle. There are two cycle engines :

  a) Two stroke engines
  b) Four stroke engines

In four-stroke cycle engines, four strokes of the piston are required or two revolutions of the crank shaft to complete one cycle.

In two-stroke cycle engine, there only two-strokes of the piston is required only one revolution of the crank shaft to complete the cycle.

Four stroke petrol engine:

A four-stroke cycle petrol engine operates on otto cycle (constant volume cycle) the ignition in this engine is due to a spark, hence it is also known as spark ignition engine.

The four different strokes are:

- Suction stroke
- Compression stroke
- Power/working/expansion stroke
- Exhaust stroke

The construction and working of the four stroke petrol engine is shown in figures 5.1 to 5.4 along with *p-v*-diagram.

Suction stroke: The piston moves from TDC to BDC by crank shaft. (The crank shaft rotates either by the movement of fly wheel or by electric starting motor). During this stroke the inlet valve remains open and the exhaust valve is closed. During this stroke an appropriate air fuel mixture v drawn in the cylinder, due to the downward movement of the piston, this is represented by line AB is *p-v*-diagram.

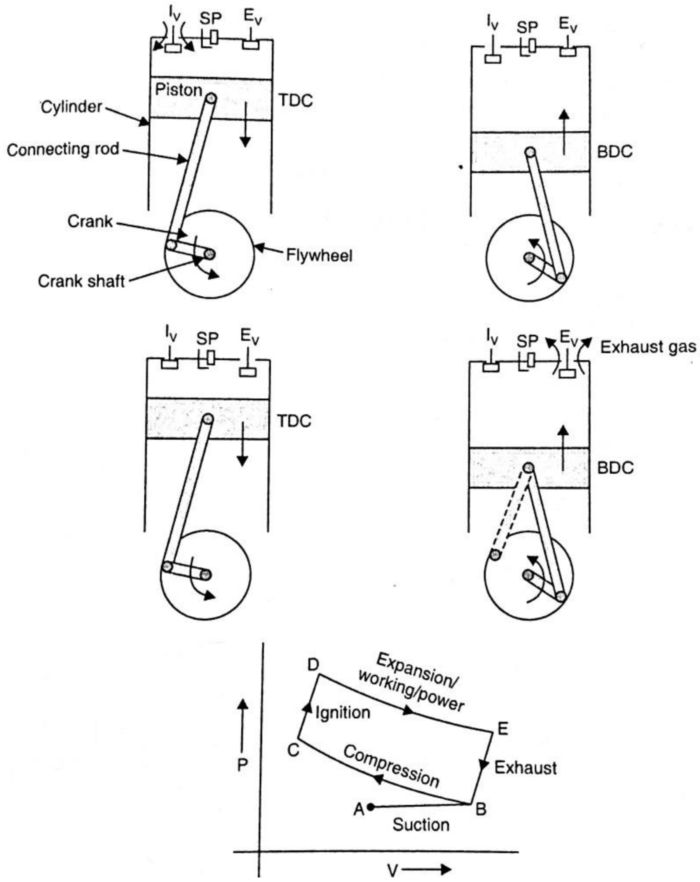


Fig. 5.3

Compression stroke: During this stroke the piston moves from BDC to TDC thus compressing the air fuel mixture due to which both pressure and temperature of charge increases and is represented by the line BC in p-v-diagram.

Just before the end of this stroke spark plug initiates the spark, which ignites the mixture and combustion takes place at constant volume, represented by the line CD is the p-v-diagram. During this stroke both the inlet and exhaust valve remains closed.

Working power stroke: Due to combustion the gases produced, exerts pressure on the piston and this pressure forces the piston (moves the piston) from TDC to BDC and the work is obtained of this stroke, and expansion of gases is shown by the line DE on the p-v-diagram.

During this stroke both the I_V and E_V remains closed.

Exhaust stroke: During this stroke the inlet valve remains closed and the exhaust valve open. The greater part of the burned gases escapes, because of their own expansion, and the drop in pressure at constant volume is represented by EB on p-v- diagram. During this stroke the piston moves from BDC to TDC and pushes the remaining gases to the atmosphere.

Once the system reaches to TDC the exhaust valve closes and the cycle is completes.

The cycle is repeated again and again in a rubbing engine.

Four stroke cycle diesel engine:

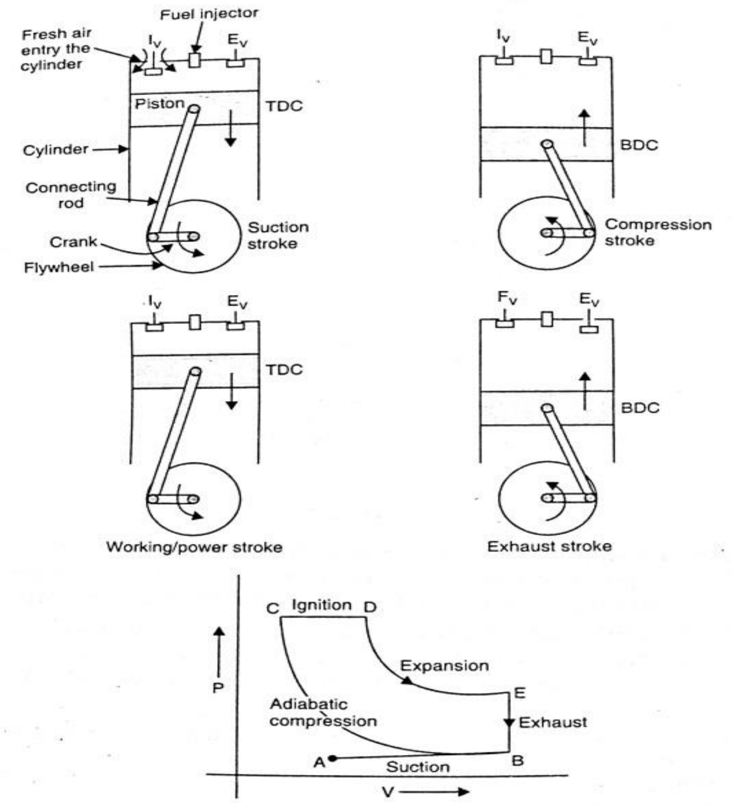


Fig.5.4

1) In four- stroke cycle diesel engine works on diesel cycle also known as constant press cycle.

2) Since ignition in these engines is due to the temperature of compressed air, they are also called compression ignition engines.

(i) **Suction stroke:** During this stroke piston moves from TDC to BDC. By the rotation of crankshaft the inlet valve remains open, whereas the exhaust valve is closed. During this stroke air is drawn into the cylinder due to the downward movement of the piston. It is represented by line AB in p-v-diagram.

(ii) **Compression stroke:** The air is compressed to a high pressure and temperature as the piston moves from BDC to TDC. It is represented by line BC to TDC. It is represented by line BC on p-v-diagram. Just before the end of this stroke, a measured quantity of fuel (diesel) is injected into the hot compressed air, in the form of fine spray using a fuel injector. The fuel starts burning at constant pressure represented by a line CD on p-u-diagram. At point D fuel supply is cut off and both inlet and exhaust valves are closed.

(iii) Expansion stroke. During this stroke expansion of gases takes place,
which exerts pressure on the piston. The piston moves from TDC to BDC and hence the work is done in this stroke. Both inlet and outlet valves remains closed during this stroke and the expansion of gases is represented by a line DE on the p-v-diagram.

(iv) Exhaust stroke. During this stroke, inlet valve remains closed and exhaust valve opens the greater part of the gases escapes cos of the own expansion. Also the piston moves from BDC to TDC and pushes the remaining gases to the atm. It is represented by line EB. When the piston reaches TDC, the exhaust valve closes and the cycle is completed and further repeated.

Comparison between petrol and diesel engines

Petrol engine	Diesel engine
• Works on otto cycle.	• Works on diesel cycle.
• Fuel used is petrol.	• Fuel used is diesel.
• Spark ignition engine.	• Compression ignition engine.
• In petrol engine, both air and fuel mixture is compressed.	• Only air is compressed
• It is a constant volume cycle.	• Constant pressure cycle.
• Compression ratio ranges from 1: 4 to 1: 10.	• Compression ratio ranges 1:12 to 1:22.
• Less thermal efficiency more fuel consumption.	• Less fuel consumption.
• Easy to start even in cold weathers.	• Difficult to start in cold weather, hence it requires additional heater to run the engine.
• Less initial cost and more running cost.	• More initial cost and less running cost.
• Light weight and occupies less space.	• Heavy weight and occupies more space.
• Used in light vehicles such as scooters.	• Used in heavy vehicles such as trucks.

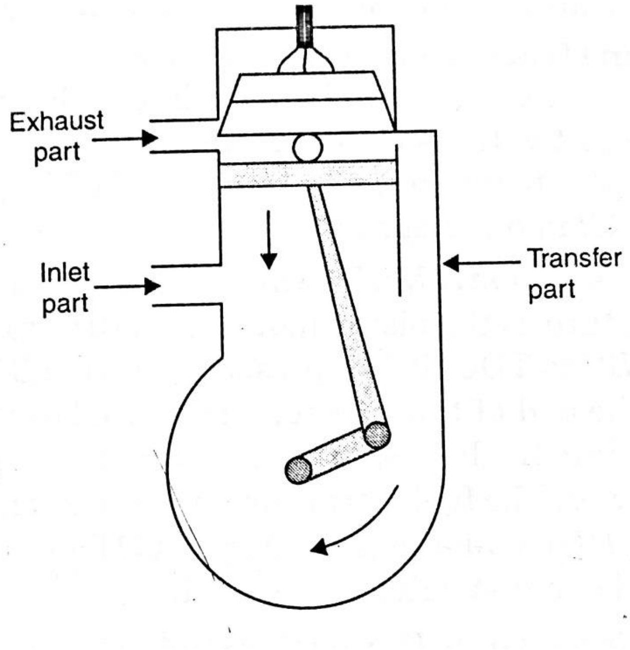


Fig. 5.5

In two stroke engines there are only two strokes, downward and upward
stroke. There are three parts (1) inlet part, (ii) Exhaust part (iii) transfer part. In this engine all the operations of the working cycle are completed in two strokes which require one complete revolution of the crankshaft. In this engine there are no suction and exhaust stroke, instead they are preformed along with compression.

They are classified into:

a) Two stroke petrol engine (2 SPE)
b) Two stroke diesel engine (2 SDE)

It works on otto cycle and has two-stroke namely downward stroke and upward stroke.

Downward stroke: At the beginning of this stroke, the piston is at TDC in figure 5.1, at this position, the charge (air-fuel mixture) present in the cylinder of previous cycle is compressed in the meantime inlet part will be open, fresh charge enters the crank case as shown.

The compressed charge in the cylinder is ignited by the means of spark plug, combustion takes place.

The piston moves downwards from TDC-BDC and the power is transmitted to the crankshaft. This causes the shaft to rotate at high speed. Work is obtained in this stroke. Further downward movement of the piston as shown, a part of burnt gases escapes out due to their own expansion.

Further downward movement in covers the TP as shown in figure 5.3. Meanwhile the piston compresses the charge in the crank case by the bottom side of the piston, this compressed charge riches into the cylinder through transfer part and drives out the remaining exhaust gases, from the cylinder through exhaust part. "This process of sweeping out the exhaust gases with the help of fresh charge is known as scavenging". The deflector at the top end of the piston deflects the fresh charge towards the top of the cylinder.

Upward stroke: During this stroke the piston moves from BDC-TDC in the meantime, it closes the transfer part thereby stopping the flow of fresh charge into the cylinder showed in figure 5.4. Further movement closes the EP and the compression of charge begins. In the meantime, inlet part is open and the upward movement of the piston creates suction in the crank case, fresh charge enters the crank case as shown in the figure. The compression of the charge at the top end of the piston continues till the piston reaches TDC. Thus the cycle is completed.

Difference between four-stroke and two-stroke engines

Four-stroke engine	Two-stroke engine
• One working stroke/power stroke for every two revolution of crank shaft.	• One power stroke for revolution of crank shaft.
• It has inlet and exhaust valve.	• It has IP, EP, and TP.
• Flywheel is essential cas torque is uneven.	• Flywheel is not required because torque is even.
• Less fuel consumption.	• More.
• Engine is heavy and bulky.	• Low thermal efficiency.
• Engine design is complicated.	• Simple lubricating system.
• High thermal efficiency.	• Less initial cost.
• Complicated lubricating system.	• Engine design is simple.
• More initial cost.	• Light and compact.

Formula used in solving IC engine problems:

1. **Break powers.** It is defined as the power available at the other end of the shaft for useful work. It is denoted by BP.

$$BP = 2\pi NT$$

where N = speed of shaft in RPS (revolution per second)
T = torque which can be measured using dynamometer.

Case 1: Prone Break Dynamometer or Belt Dynamometer

$$\text{Torque } T = wR$$

where w = effective load on the break drum
R = effective radius of the break drum.

Case 2: Rope Break Dynamometer

$$\text{Torque } T = (w - SR)$$

where w = effective load on the break drum
S = spring constant
R = effective radius of the break drum.

2. **Indicated power (IP).** It is defined as the total power developed by the engine with in the cylinder and it is denoted by "I.P.".

$$\text{I.P.} = P_m \text{ LAN} \frac{x}{n}$$

Where P_m = mean effective pressure $\left(\frac{a}{L} \times S\right)$

L = length of strokes
A = area of cylinder
N = speed a RPS
x = number of cylinder
n = number of strokes
n=1 → 2 stroke
n = 2 → 4 stroke.

3. **Frictional power.**

$$FP = I.P. - B.P.$$

4. **Mechanical efficiency.** It is defined as the ratio of break power to the indicated power of the engine.

$$\% \, \eta_{\text{mech}} = \frac{BP}{IP} \times 100$$

5. **Indicated thermal efficiency**

$$\eta_{\text{ITE}} = \frac{IP}{m_f \times C_{vf}}$$

Where m_f = mass of fuel consumed in kg/sec
C_{vf} = calorific value of the fuel in kJ/kg K.

6. **Break thermal efficiency**

$$\eta_{\text{BTE}} = \frac{BP}{m_f \times C_{vf}}$$

PROBLEMS

Problem 1: Four-stroke single cylinder engine running at 450 rpm has a bore
diameter of 100 mm at stroke length of 6.5 cm and it has spring value of 10 bar/cm. Calculate the indicated power of the engine.

Sol.

$$\text{IP} = P_m \text{ LAN} \frac{x}{n}$$

$$P_m = \frac{a}{L} \times S = \frac{4\text{cm}^2}{6.5\text{cm}} \times \frac{10 \text{ bar}}{\text{cm}} = 6.15 \text{ bar}$$

1 bar = 100 kPa

6.15 bar = 615 kPa

L = 120 mm = 0.12 mtr.

$$A = \frac{\pi d^2}{4} = \frac{\pi(0.1)^2}{4} = 7.85 \times 10^{-3}$$

$$N = \frac{450}{60} = 7.5\ Rps.$$

$x = 1$

n = 2, four stroke

$$IP = 615 \times 0.12 \times 7.85 \times 10^{-3} \times 7.5 \times \frac{1}{2}$$

IP = 2.17 kW

Problem 2: The following observations were obtained during a test on four stroke diesel engine:

a) Cylinder dia = 25 cm
b) Stroke length = 40 cm
c) Crank shaft speed = 250 rpm
d) Break load = 70 kgs
e) Break drum dia = 2 mts.
f) Pm (mean effective pressure) = 6 Bar
g) Diesel consumption = 0.1 m^3/min.
h) Specific gravity of diesel = 0.78 kg/m^3
i) C_{vf} = 43900 kJ/kg

Calculate, break power, indicated power, frictional power, break thermal efficiency and indicated thermal efficiency.

Sol. BP = $2\pi NT$ T = W x R

W = 70 x 0.98

$$= \left(2\pi \times \frac{250}{60}\right) \times \left(\frac{70 \times 9.81 \times 1}{1000}\right) kNm$$

= 17.9 kW

$$IP = P_m\ LAN\ \frac{x}{n}$$ | $$A = \frac{\pi(25\times10^{-2})^2}{4} = 0.049 m^2$$

$$= 6 \times 100 \times 40 \times 10^{-2} \times 0.049 \times \frac{250}{60} \times \frac{1}{2}$$

= 24.5 kW

FP = IP-BP

= 24.5 - 17.9 = 6.6 kW

$$\%\ \eta_{mech} = \frac{BP}{IP} \times 100 = \frac{17.9}{24.50} \times 100$$

= 72.9%

$$\eta_{BTC} = \frac{BP}{m_f \times C_{vf}} = \frac{17.9}{1.3 \times 10^{-3} \times 43900}$$

$= 0.313$

where $m_f = 0.1\ m^3/min. \times 0.78\ kg/m^3$

$= 0.078$ kg/min

$= \frac{0.078}{60} = 1.3 \times 10^{-3}$ kg/sec

M_f = Fuel consumption × sp. Gravity

$$\eta_{ITE} = \frac{IP}{m_f \times C_{vf}} = \frac{24.54}{1.3 \times 10^{-3} \times 43900}$$

$$\eta_{ITE} = 42.9\%$$

Problem 3: A single cylinder four stroke engine runs at 1000 rpm and it has
a bore of 115 mm and has stroke length of 140 mm. The break load is 6 kgs and the break drum has an effective radius of 600 mm, the mechanical efficiency was found to be 80%, calculate break power, indicated power, frictional power, and mean effective pressure.

Sol. $L = 140$ mm $= 140 \times 10^{-3}$ m

Cylinder dia R = 600 mm = 600 × 10-3 m

Break load = 6 kgs

C.S. speed = 1000 rpm

$x = 2$

$N = \frac{1000}{60} = 16.66$

$BP = 2\pi NT$ $\qquad T = \omega R$

$= 2\pi \times 16.66 \times 3.53 \times 10^{-4}$

$= 3.89$ kW $\qquad = \frac{6}{1000} \times 9.81 \times 600 \times 10^{-3}$

$IP = P_m\ LAN\ \frac{x}{n}$ $\qquad = 3.53 \times 10^{-4}$

$L = 140 \times 10^{-3}$ m

$A = \frac{\pi(115 \times 10^{-3})^2}{4} = 0.010$

$P_m = \frac{0.010}{140 \times 10^{-3}} \times \frac{1000}{60} \times \frac{1}{2} = 383\ kPa$

= 3.83 bar

η_{mech} = 80 % = 0.8 = $\frac{BP}{IP}$

IP = $\frac{3.64}{0.8}$ = 4.55 kW

FP = IP-BP
= 4.5 - 3.6
= 0.9 kW

Problem 4: Following observations were recorded during o test of four-stroke single cylinder engine:

Area of indicated diagram = 3 cm^2
Length of indicated diagram = 5 cm
Spring constant = 100 $N/cm^2/cm$
Engine crank shaft speed = 500 rpm
Cylinder dia = 150 mm
Stroke length = 200 mm

Sol. IP = $P_m\, LAN\, \frac{x}{n}$

A = 3 x 10^{-4} m

L = 5 x 10^{-2} m

N = 500 rpm

n = 2

x = 1

S = 100 $N/cm^2/cm$

$= \frac{100}{100}$ N/m= 1N/m=1×10^{-3} =kN/m

P_m = $\frac{a}{L} \times S$

$= \frac{3\times10^{-4}}{5\times10^{-2}} \times 1 \times 10^{-3}$

= 6 x 10^{-5}

IP = 6 × 10^{-5} × 5 × 10^{-2} × 3 × 10^{-4} × $\frac{500}{60} \times \frac{1}{2}$

= 3.75 × 10^{-9}

Problem 5: Find the indicated powers for four-stroke petrol engine having a
swept volume of 6 liters and running speed of 1000 rpm of the mean effective pressure is 600 kN/m^2.

Sol. $IP = P_m\, LAN \frac{x}{n}$ $\quad LA$ = swept volume

$$IP = 600 \times 6 \times 10^{-3} \times \frac{1000}{60} \times \frac{1}{2}$$

$$= 30 \text{ kW.}$$

Problem 6: A single cylinder four-stroke IC engine has a swept volume of 6 litres and running at a rated speed of 300 rpm, at full load the torque developed was measured with a belt dynamometer whose pully dia is 1 m, the tension in the tight side, and slack side of ine belt in 700 N and 300 N respectively, 4 kg of full was consumed in one hour. The indicated mean effective pressure is 6 bar and calorific value of fuel is 42000 kJ/kg. Calculate

A = break power
B = IP
C = Mechanical efficiency
D = Indicated thermal efficiency
E = Break thermal efficiency
F = Break specific fuel consumption.

Sol. $BP = 2\pi NT$ $\quad T = (T_1\text{-}T_2)\ R$

$$= 2\pi \frac{300}{60} \times 0.2 \qquad = (700\text{-}300)\ 0.5 = 200 \text{ Nm} = 0.2 \text{ kNm}$$

$$= 6.283 \text{ kW}$$

$$IP = P_m\, LAN\ \frac{x}{n} \qquad P_m = 6 \text{ bar} = 6000 \text{ kPa}$$

$$= 600 \times 6 \times 10^{-3} \times \frac{300}{60} \times \frac{1}{2}$$

$$IP = 9 \text{ kW}$$

$$\eta_{mech} = \frac{BP}{IP} \times 100 = \frac{6.283}{9} \times 100 = 69.8\%$$

$$\eta_{\text{ITE}} = \frac{IP}{m_f \times C_{vf}} = \frac{9}{\frac{4\,kg}{3600} \times 42000}$$

$$= \frac{9}{1.11 \times 10^{-3} \times 42000} = 0.193 \text{ kJ/sec}$$

$$\%\eta_{\text{ITE}} = 19.3\%$$

$$\eta_{\text{BTE}} = \frac{BP}{m_f \times C_{vf}} = \frac{6.28}{4/3600 \times 42000} = 0.134$$

$$\%\eta_{\text{BTE}} = 13.47\ \%$$

$$I_{\text{SFC}} = \frac{\text{fuel consumed kg/hr}}{BP}$$

$$I_{SFC} = \frac{\text{fuel consumed}}{IP}$$

$$= \frac{4 \text{ kg/hr}}{6.28\ kW} = 0.636 \text{ kg/h kW}$$

$$I_{SFC} = \frac{4}{9} = 0.4 \text{ kg/h kW}$$

$$= 0.636 \text{ kg/h kW}$$

Problem 7: The following observations were recorded during a test on a single cylinder 4- stroke engine:

a) Bore dia = 25×10^{-2} mts
b) Stroke = 40×10^{-2} mts
c) Crank speed = 250 rpm 250/60 rps
d) Effective load = 700 N
e) Diameter of break drum = 3 mts
f) Mean effective pressure = 7 bar
g) Fuel consumption = 0.0013 kg/sec = m_f
h) C_v of fuel = 44000 kJ/kg K

Sol. BP = $2\pi NT$ T = WR

$$= 2\pi \times \frac{250}{60} \times 1.05 \qquad = 700 \text{ x } 1.5$$

$$= 27.48 \text{ Kw} \qquad = \frac{1050}{100} = 1.05$$

$$A = \frac{\pi d^2}{4}$$

$$IP = P_m\ LAN\ \frac{x}{n}$$

$$= 700 \times 40 \times 10^{-2} \times \frac{250}{60} \times \frac{\pi(25 \times 10^{-2})^2}{4} \times 0.5$$

$$= 28.58 \text{ kW}$$

$$FP = IP - BP$$

$$= 28.58 - 27.48 = 1.1$$

$$\%\ \eta_{mech} = \frac{BP}{IP} \times 100 = \frac{27.48}{28.58} \times 100$$

$$= 96.15\%$$

$$\eta_{\text{ITF}} = \frac{IP}{m_f \times C_{vf}} \times \frac{28.58}{0.0013 \times 44000} \times 100$$

$$= 49.9\%$$

$$\eta_{\text{BTF}} = \frac{BP}{m_f \times C_{vf}} = \frac{27.4}{0.0013 \times 44000} \times 4800$$

Problem 8: A single cylinder four-stroke IC engine has a bore of 180 mm. Stroke of 200 mm with rated speed of 300 rpm, torque on the break drum is 200 Nm mean effective pressure (P_m) = 600 kN/m². It consumes 4 kg/h of fuel the C_{vf} of fuel = 42000 kJ/kg.

Sol.

$$n = 1$$

$$x = 2$$

$$\text{Stroke} = 200 \text{ mm}$$

$$\text{Torque} = 200 \text{ Nm}$$

$$\text{Rated speed} = 300 \text{ rpm}$$

$$P_m = 600 \text{ kN/m}^2$$

$$\text{Fuel consumption} = 4 \text{ kg/h}$$

$$C_{vf} = 42000 \text{ kJ/kg K}$$

$$BP = 2\pi NT$$

$$= 2 \times \pi \times \frac{300}{60} \times \frac{200}{1000}$$

$$= 6.28$$

$$IP = P_m LAN\frac{x}{n}$$

$$= 600 \times 0.2 \times 0.025 \times \frac{1}{2} \times \frac{300}{60}$$

$$= 7.5 \text{ kN}$$

$$FR = IP - BP$$

$$= 7.5 - 6.28 = 1.22 \text{ kN}$$

$$\%\ \eta_{mech} = \frac{BP}{IP} = \frac{6.28}{7.5} \times 100 = 83.7\%$$

$$\%\ \eta_{\text{ITF}} = \frac{IP}{m_f \times C_{vf}} = \frac{7.5}{\frac{4}{3600} \times 42000} = 10.08\%$$

$$\%\eta_{\text{BTF}} = \frac{BP}{m_f \times C_{vf}} = \frac{6.28}{1.11 \times 10^{-3} \times 42000} = 13.47\%$$

SUMMARY

- Heat engine is a thermal prime mover which converts chemical energy of fuel into heat energy (by combustion of fuel) and utilizes the energy to perform useful mechanical work.
- Cylinder is considered as heart of the engine. It is a cylindrical shaped vessel. Its function is, it contains the working fluid under a high pressure and it guides the piston for smooth functioning.
- The function of crank shaft is to convert reciprocating motion of the piston into rotatory motion of the shaft. Crank shaft is usually made of carbon steel.
- The fly wheel is rotating mass which is used as a energy storing device.
- The top most position of the piston in the cylinder is called top dead center in the case of horizontal engine, it is known as IDC = Inner dead center.
- A four-stroke cycle petrol engine operates on otto cycle (constant volume cycle) the ignition in this engine is due to a spark, hence it is also known as spark ignition engine.

REVIEW QUESTIONS

1. Describe the internal combustion engines and its classification.
2. Differentiate between compression stroke and exhaust stroke.
3. Discuss about the principle parts of IC engine.
4. Distinguish between the petrol engine and diesel engine.

CHAPTER

6 REFRIGERATION AND AIR CONDITIONING

STRUCTURE

6.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- explain the coefficient of performance
- describe the vapour absorption refrigeration system
- distinguish between the VCRS and VARS
- discuss about the desirable properties of refrigerant.

6.1 REFRIGERATION AND AIT CONDITIONING

Refrigeration: Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere. This means the removing of heat from a substance to be cooled; Heat always passes downhill, from a warm body to a cooler one, until both bodies are at the same temperature.

Unit of Refrigeration: It is expressed in terms of tons of refrigeration (TOR). It is defined as the amount of heat extracted/removed from 1000 kg of water initially at 0°C to convert it into ice in 24 hrs (1 ton - 3.5 kJ/sec).

Coefficient of performance (COP): The performance of a refrigerator is expressed in terms of COP; it is defined as the ratio of amount of heat extracted from the refrigerator to the amount of work done is given by the equation:

$$COP = Q/w$$

Types of Refrigeration System

1) Vapour Compression System (VCRS)
2) Vapour Absorption System (VARS)

Vapour Compression Refrigeration System "VCRS"

Principal of operation: In VCRS, refrigerant vapour absorbs heat from the evaporator (cooling cabinet) and rejects heat in the condenser; the condensing media is atmospheric air or water. During heat absorption the refrigerant changes its phase from liquid to vapour. During heat rejection the refrigerant changes again from vapour to liquid phase.

Working: The system consists of compressor condenser, expansion valves, and evaporators as shown in figure. The different process of a VCRS is represented on a pressure enthalpy diagram.

Process 1 to 2

Compression: In this process the low temperature and low pressure refrigerant leaving the evaporator coil enters the compressor at point 1 and gets compressed to a condenser pressure at point 2. The temperature of refrigerant increases during compression and this high pressure and compression vapour enters the condenser. Due to compression wih internal energy and enthalpy increases with increase in pressure from Pe to Pc as shown in pH diagram.

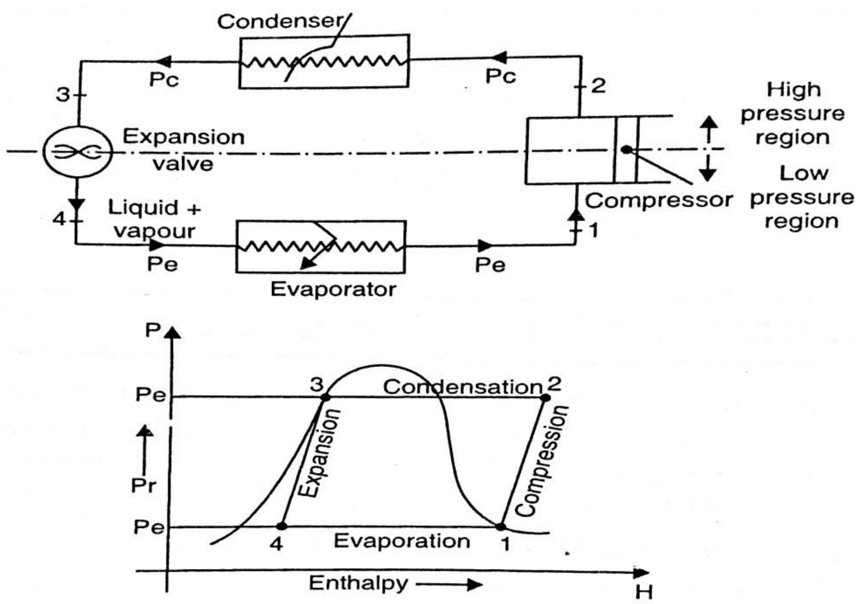


Fig. 6.1

Process 2-3

Condensation: During this process condensation takes place with exchange of heat from refrigerant to the atmospheric air. The latent heat gained by the refrigerant in the evaporator is rejected to the surrounding media due to this heat transfer the high pressure vapour cools and changes its phase from vapour to liquid represented by point 3 on pH diagram.

Process 3-4

Expansion: During this process the liquid refrigerant (condensate) enters the expansion valve at point 3. Expansion takes place, both temperature and pressure of refrigerant drops steadily. And this low temperature-pressure two phase mixture enters the evaporator at point 4.

Process 4-1

Evaporation: The two phase liquid vapour refrigerant mixture enters the evaporator coil and absorbs heat from the refrigerated space and changes its phase from liquid to vapour. "This process of absorption of heat is known as refrigerating effect", at the end of evaporation the refrigerant vapour at low pressure enters the compressor at point 1 and thus the cycle repeats.

Vapour Absorption Refrigeration System

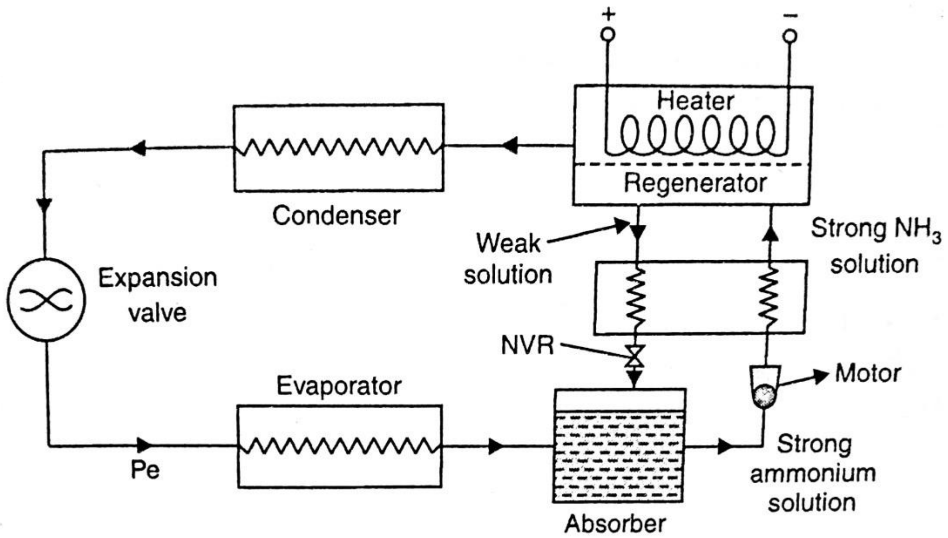


Fig. 6.2

Working: Simple vapour absorption system is show in figure. The low pressure ammonia vapour passing the evaporator is absorbed by the water in the absorber, strong ammonia solution is pumped to the generator where it gets heated with the help of an external source-heater, due to reduced solubility of ammonia in water, the vapour separated from the solution and this vapour passes through the condenser where it gets condensed. This high pressure liquid ammonia is expanded in expansion valve to a low pressure and temperature liquid ammonia. This low pressure-temperature liquid ammonia passes to the evaporator where it extract, heat from the surrounding and gets vaporized to a low pressure vapour and the cycle repeats.

The week, hot ammonia solution, from the generator passes through the heat exchanges where it exchanges heat to the incoming low temperature strong NH_3 solution and there by increases the overall performance of the system. The week ammonia solution from the heat exchanger enters the absorber through a NVR.

VCRS	VARS
• The input energy is heat energy,	• The input energy is mechanical energy
• Operation is noisy due to the pressure of reciprocating compressor	• Quite in operation as there is non-compressor
• Chances of leakage of refrigerant are more.	• No leakage.
• High maintenance cost.	• Low maintenance cost.
• Performance at partial load is poor.	• System is not affected by variation in load.

Refrigerant: It is a medium of heat transfer. This absorbs heat in the evaporator at low temperature and rejects in the condenser at high temperature and pressure.

Desirable properties of refrigerant: An ideal refrigerant should possess the following properties:

Thermodynamic properties:

1) Low boiling point
2) Low freezing point
3) High latent heat of evaporation
4) High critical temperature.

Physical properties:

1) High thermal conductivity 'k'
2) High electrical insulation
3) Low specific heat
4) Low viscosity.

Chemical properties:

1) Non toxic
2) Non flammable
3) Non explosive
4) Non corrosive.

Other properties:

1) Ease of availability
2) High COP
3) Ease of handling.

Types of refrigerants:

1) **Ammonia (NH_3):** It is used in ice plants. It is highly toxic, inflammable irritating and corrosive hence not used in domestic refrigerator. It has a B.P. of -33.3°C.

2) **CO_2 :** It is nontoxic, nonflammable, its boiling point is- 77.6° C used in ships.

3) **Sulphur dioxide:** It is a colorless. It possess irritating odor has high B.P. of -10°C. This refrigerant was used earlier in house hold refrigerator.

4) **Freon-12 (R-12):** It is the most widely used refrigerant it has a B.P. of - 29.8°C. Its properties are non-explosive, non-flammable, non-corrosive. It is used in domestic refrigerators, water coolers and room air conditioners.

5) **Freon-22 (R-22):** It is a high pressure refrigerant, it has a B.P. of - 40.8°C and it is used in large capacity AC plants cold storages plants etc.

Air conditioning: It is defined as the process which cools, heats, cleans and circulates air by controlling the moisture called tent to the human comfort.

Air conditioning system is gradually divided into two parts:

1) Comfort air conditioning
2) Industrial air conditioning.

The controlled atmosphere which gives max comfort to the human is known as comfort air conditioning system is used in houses, offices, shops, restaurants, theaters and hospitals.

The conditioned atmosphere, which is required, for the processing and manufacturing in an industry is known as industrial air conditioning system. Used in food processing, paper mills, textiles, and dairy products and machine tools industries.

Psychometric Properties:

- **DBT (dry bulb temperature).** It is the temperature of air, measured by thermometer when its bulb is dry.
- **WBT (wet bulb temperature).** It is defined as the temperature of air measured by thermometer when the bulb is covered with a wet cloth.
- **DPT (Dew point temperature).** It is the temperature at which the moisture present in the air begins to condense when the air is cooled.
- **Specific humidity.** It is defined as the mass of water vapour present in unit mass of air.

Room air conditioner:

Description: Figure shows a window air conditioning system. It consists of the basic components of VCRS say → compressor, condenser, expansion valve, and evaporator along with a motor with common shaft, attached with a condenser fan and a blower. The complete unit is a rectangular box. With a partition between die evaporator which is exposed to the room and the condenser unit, which is exposed to the atmosphere.

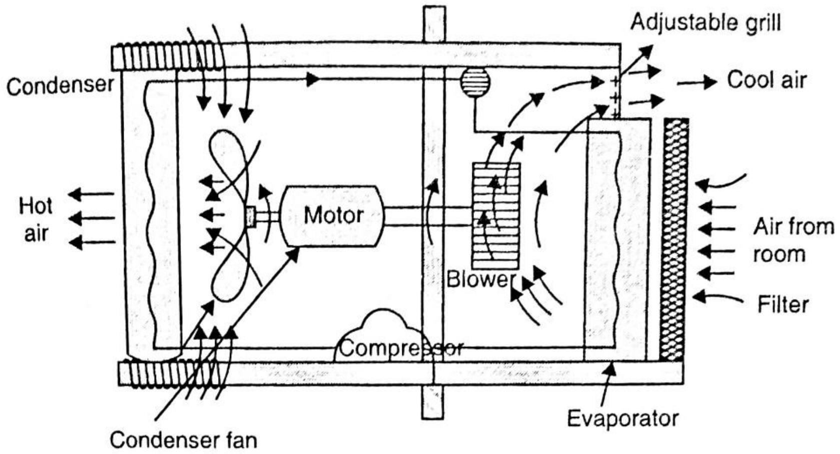


Fig. 6.3

Working: The low temperature and high pressure refrigerant from condenser
passes through the expansion valve, expansion takes place which reduces both the temperature and pressure of the refrigerant. This L.P. and LT. refrigerant passes to the evaporator coil. In evaporator the blower continuously draws the air from the room through air filter, over the evaporator coils. Where it gets cooled below the DPT (draw point temp.).

The refrigerant absorbs heat from the air and evaporates, the air which is just cooled enters the room, through adjustable grill, and thus the room gets cooled.

The high temperature, low pressure refrigerant from evaporator drawn by the compressor, compressed to high pressure and temperature which passes to the condenser coils where it condensed by the atmospheric air with the help of a condenser fan. This low temperature high pressure vapour refrigerant, passes to the expansion valve and the cycle repeats.

SUMMARY

- Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere. This means the removing of heat from a substance to be cooled.
- The performance of a refrigerator is expressed in terms of COP; it is defined as the ratio of amount of heat extracted from the refrigerator to the amount of work.
- The two phase liquid vapour refrigerant mixture enters the evaporator coil and absorbs heat from the refrigerated space and changes its phase from liquid to vapour.
- WBT (wet bulb temperature) is defined as the temperature of air measured by thermometer when the bulb is covered with a wet cloth.
- Specific humidity is defined as the mass of water vapour present in unit mass of air.

REVIEW QUESTIONS

1. Describe the refrigeration and air conditioning.

2. What are types of refrigeration system? Explain in details.

3. Write short note on

  a) thermodynamic properties

  b) physical properties

  c) chemical properties of refrigerant.

4. Describe the room air conditioner working.

CHAPTER

7 WELDING, SOLDERING AND BRAZING

STRUCTURE

7.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- Explain the plastic welding
- discuss the types of arc welding process
- describe the natural flame and oxidizing flame
- discuss about the soldering

7.1 WELDING

It is a process of joining two metal pieces by the application of heat, with or without the application of pressure and filler material, welding produces a permanent joint

Classification: It is classified into two groups:

- Plastic welding (pressure welding).
- Fusion welding:

Plastic welding: In this the metal pieces to be joined are heated to a plastic state and then joined together by the application of pressure without the application of filler material.
e.g., Resistance welding, forge welding.

Fusion welding: In this process the metal piece to be joined are heated to molten state and allowed to solidify without the application of pressure. A filler material is used during the welding process.
e.g., are welding, gas welding, termit welding.

Arc welding:

It is a process, in which heat is produced from an electric arc between the work piece and the electrode. The electrode (filler metal) is heated to a liquid state and deposited into the joint to make the weld. The electrical energy is converted into intense heat. In the arc which is in the temperature range of 4000-5000°C.

The basic circuit diagram is shown in figure. It consists of a transformer/ power supply device, electrode holder and a work piece. The function of welding machine (transformer) is to generate low voltage around 50 volts and a high current of about 100 amps. The current may be a AC or DC, current and the polarity depends on type of electrode, base metal and the type of joint to be welded.

The various arcs welding process are:

1. Carbon arc welding.
2. Submerged arc welding.
3. Gas metal arc welding.
4. Gas tungsten arc welding.

MIG-Metallic inert gas welding
TIG-Tungsten inert gas welding

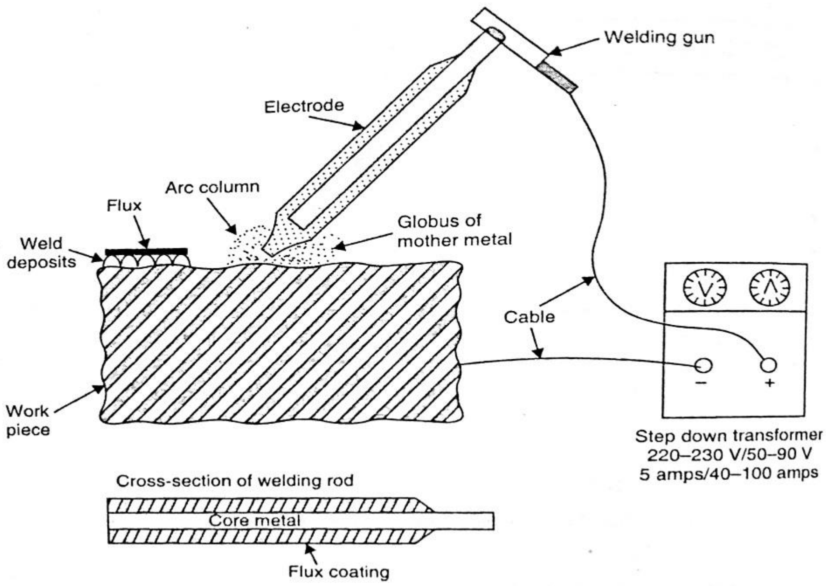


Fig. 7.1

Types of electrode:

There are two types of arc welding electrode:

1. Consumable electrode.
2. Non consumable electrode.

(1) Consumable electrodes are further classified into

a) Coated electrode.
b) Non- coated electrode/Base electrode.

(a) **Coated electrode.** In coated electrode the metallic rod is coated with flux. Flux improves the quality of weld, by eliminating the oxides.

- It is most widely used in commercial welding.
- Electrodes are coated with silicate binders, oxides, carbonates, fluorides, metal alloys etc.

(b) **Plane base electrode.** Base electrodes have limited use it is used for welding wrought Iron and low/medium carbon steel. They are used as filler material for various welding operation.

(2) Non consumable electrode.

These are made of carbon, graphite, tungsten. These electrodes do not get consumed during welding.

Functions of coating:

- Coating provides a protecting atmosphere. Stabilizes the arc.
- Provides slag to protect the molten metal from oxidation.
- Performs metallurgical refining.
- It adds allowing element to the weld.
- Increases deposition efficiency.
- Slow down the cooling rate of the weld.

Advantages of welding:

- It is a permanent joint.
- Properly made weld can be stronger than the parent metal.
- It's portable/movable and can be used where ever required.
- The welding process allows considerable freedom of design.
- The welding equipment is inexpensive.
- No holes are required for joining as in the case of nuts and bolts.

Disadvantages:

- Welding process requires a skilled operator (welder).
- Fixture is required to hold the part in position for welding.
- Each part of weld must be cut to size, before it can be welded.
- Clearance of residual stress in the welded joints.

Defects in welding:

(1) Porosity. It is a group of small holes formed on the surface of the metal during the welding process.

(2) Blow holes. It is comparatively a big hole, or a isolated cavity which occurs mainly due to entrapped gasses.

(3) Inclusive. The presence of non-metallic substance in the metal is called inclusive. Inclusive decreases the strength of the joint.

(4) Undercut. In undercut a grove shaped in formed in the base metal along the side of the weld bad. It is due to non-uniform flow of filler metal or improper positioning of electrode or excessive heating.

(5) Spatter. The small pear or particle which are thrown out of the arc during
welding, these spatters gets deposited on the base metal.

(6) Cracks. Cracks may be of microscopic scale or microscopic scale depending upon their size, cracks arises due to uneven heating and cooling and also due to the presence of sulphur and carbon in the base metal.

Gas welding:

(1) It is a process of joining metal pieces using heat obtained by combustion of mixes' gases.

(2) The gases may be oxygen with any fuel gas fuel gases such as acetylene, hydrogen, natural gas, petroleum gas, produces gas etc.

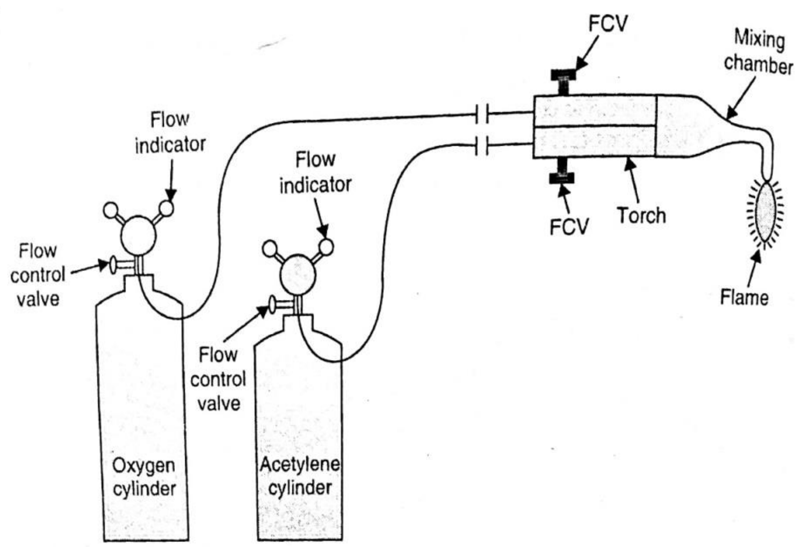


Fig. 7.2

Description of gas welding (oxyacetylene gas):

In oxyacetylene weld, the heat generated by the flame obtained by the combustion of oxygen and acetylene is used during this process the joint is heated to a fusion state and filler material is used to supply additional material to the weld.

Filler metals are available in the form of a rod or wire. These filler metals are made of metals suitable for welding the parent metal. Fluxes are often uses to clean the surface.

Different flames of oxyacetylene weld:

During the process of oxyacetylene welding the cylinders are connected through a regulated valve and pressure gauge. The three different fames obtained are:

(1) Natural flame,
(2) Oxidizing flame.
(3) Carbonizing flame.

1. **Natural flame:** It is obtained by supplying equal amount of oxygen and acetylene. The flame has two zones :

   a) Inner luminous core at the tip of the torch.
   b) An outer envelope slightly bluish in color.

   The maximum temperature of about 300 3500°C is obtained at the tip of the luminous core. A natural flame is widely used in welding steel, cast iron, copper aluminum etc.

2. **Oxidizing flame.** As shown is figure 7.3. This flame is obtained when there is excess of oxygen, the flame is similar to the natural flame in appearance accept the inner luminous cone is shorter and the outer envelope appearance to be narrow.

   This flame is used in welding of brass and bronze.

3. **Carbonizing flame/Reducing flame.** As shown in figure 7.3. This flame
   occurs when there is a access of acetylene. It has three distinct zones between the luminous cone and outer envelope there is an intermediate cone of whitish colour the length of which is a result of amount of excess acetylene.

   This flame is used in welding of nickel, non-ferrous material.

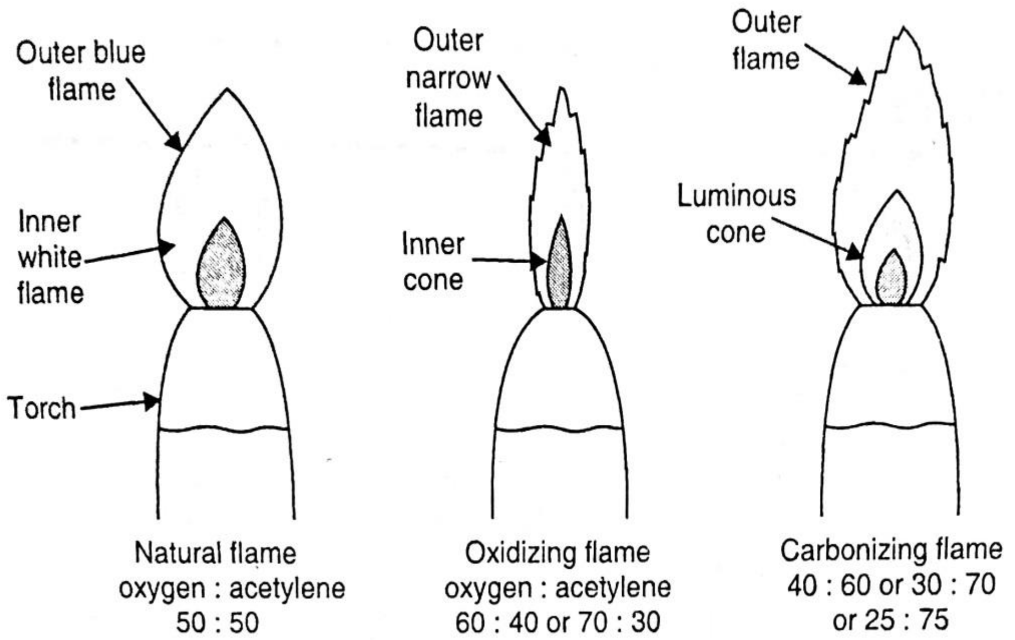


Fig. 7.3

Advantages of gas welding:

- No electricity is required.
- Equipment is portable.
- Requires little maintenance.
- Practically all metals can be welded.
- Metal cutting is a major advantage of this welding.

Disadvantages of gas welding:

- It is slower than electric arc welding.
- Not suitable for heavy section.
- The gas used is explosive hence need to be handled carefully.
- Prolong heating of joints, results in loss of corrosive resistance.

7.2 SOLDERING

It is the process of joining two metal pieces by the addition of filler material with the application of heat below 450°C.

The filler material is named as solder:

- It is an alloy of lead and tin in various proportions.
- Fluxes are used in soldering the function of flux is to permit the molten.
- Solder to flow properly into the joint. The different fluxes used are zinc chloride and ammonium chloride.
- Soldering is used in manufacturing electric circuits (PCB) also in sheet metal work.

Advantages:

- It is a simple and economical process.
- It requires low heat producing device and hence low metallurigical damage
  to the base metal.

7.3 BRAZING

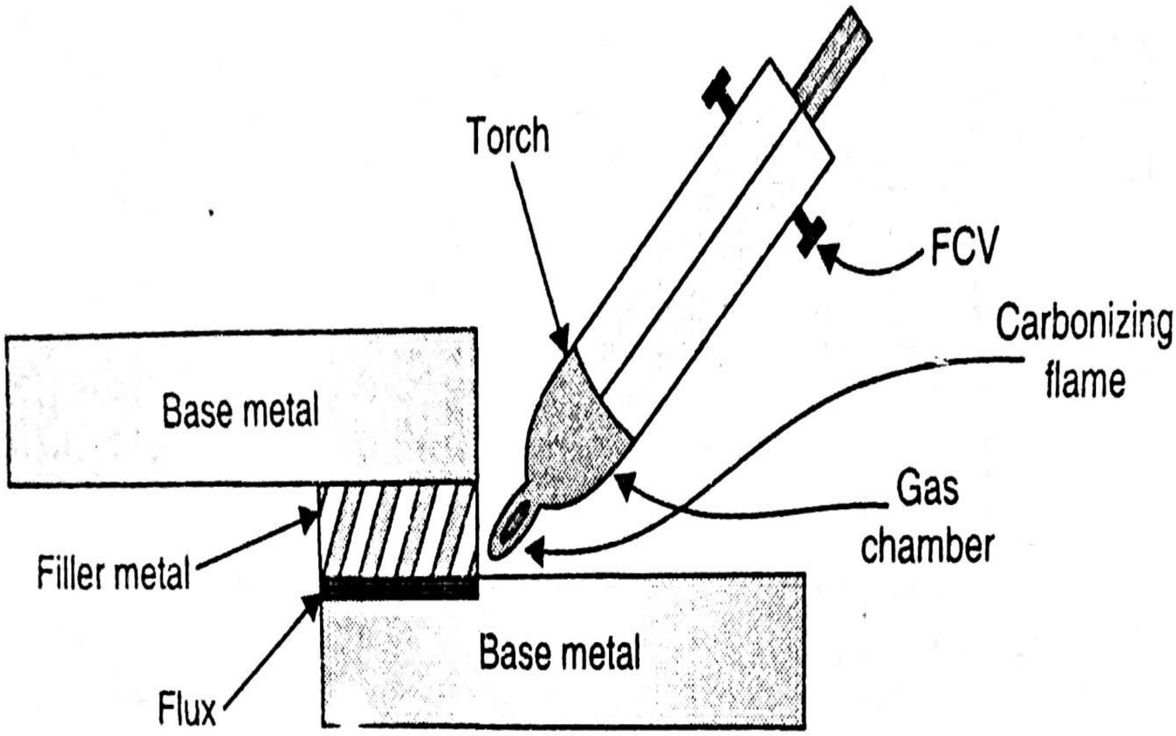


Fig. 7.4

Brazing is a process of joining two metal pieces by the addition of non-ferrous commonly used filler metals are copper-copper alloys, silver and silver alloys.

Operation: The surface to be joined must be clean by removing oxides and gases and flux if applied to the surface (fluxes are used to prevent oxidation of base metal and filler metal) commonly used fluxes are boric acid, borate, fluorides and chlorides.

The filler metal is placed between the two surfaces to be joined and heated using the carbonizing flame. The molten metal fills the space (gap) between the two surfaces. Brazing is used for manufacturing of heat exchanges, radiators tanks and pipes.

Advantages:

- Dissimilar metals can be joined.

- Brazing will avoid metallurgical damage to the base metal.
- Strong joints are obtained by brazing.
- It is economical and quick process.
- It requires less heat in compare to welding process.

Difference between brazing and soldering

Brazing	Soldering
• Melting point is about 450°C. • Dissimilar metals can be joined easily. • Good surface finish. • Stronger joints can be obtained in brazing. • Fluxes used in brazing are borax, borate and fluoride etc.	• Below 450°C. • Only similar metals can be joined. • Does not yield a good finish • Comparatively less strong joints. • Aluminum chloride and zinc chloride.

SUMMARY

- Welding is a process of joining two metal pieces by the application of heat, with or without the application of pressure and filler material, welding produces a permanent joint.
- Arc welding is a process, in which heat is produced from an electric arc between the work piece and the electrode.
- In coated electrode the metallic rod is coated with flux improves the quality of weld, by eliminating the oxides.
- Porosity is a group of small holes formed on the surface of the metal during the welding process.
- The small pear or particle which are thrown out of the arc during welding, these spatters gets deposited on the base metal.

REVIEW QUESTIONS

1. Differentiate between breezing and soldering.
2. Describe the advantages and disadvantages of gas welding.
3. Write short note on (a) carbonizing flame (b) oxidizing flame.
4. Describe the process of welding and give its classification.
5. Explain the process of soldering and brazing and differentiate them.

CHAPTER

8 MACHINE TOOLS

STRUCTURE

8.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- differentiate between head stock and tail stock
- describe the taper turning by swiveling the compound rest
- discuss about the drilling
- explain the drilling machine operations
- describe the cylindrical grinding machine

8.1 INTRODUCTION

A machine tool is a power driven machine used to produce the desired shape and size from a given material by means of a cutting tool. The excess material removed to obtained the desired shape is called 'chips' of the various machine tools the most commonly used machines such as lathe, drilling machine, milling machine and grinding machine are discussed in this chapter.

8.2 LATHE

The lathe is the oldest of all machine tools and perhaps the most basic tool used in industries. A lathe is defined as a machine tool used to remove excess material by forcing a cutting tool against a rotating workpiece. Lathes are also called turning machines'. Since the workpiece is turned or rotated between two centers.

‘Lathes are primarily used to produce cylindrical, plain and tapered surfaces and also used for knurling and thread cutting on metal parts. Besides these, they can also be used to perform various operations such as drilling, boring, reaming grinding etc.

Classification of Lathes

Lathes are classified based on their construction and functions as follows:

(a) **Speed Lathe:** It is also called, because of its high spindle speeds. It is the simplest of all lathes and is used in wood working, metal spinning, polishing, buffing etc.

(b) **Bench Lathe:** It is so called, because it is mounted on a bench. It is used per machining smooth and light jobs.

(c) **Engine Lathe:** It is one of the most widely used lathes and is so called in view of the fact that earlier lathes were driven by steam engines. It is a general purpose turning machine used to perform a variety of operations. It is also called 'center lathe'. Since the workpiece is made to rotate between two centers-one being the 'live center' (rotating) and the other 'dead center' (supporting).

(d) **Tool Room Lathe:** It is a modern engine lathe equipped with some extra attachments to make it suitable for more accurate and precision type of work carried out in a tool room. It is used for the production of small tools and dies, gauges etc.

(e) **Capsturn and Turret Lathe:** It is a modern engine lathe with special tooling facilities used to perform many operations simultaneously. Hence, it is used in mass projection.

8.3 MAJOR PARTS OF A LATHE (CENTER LATHE/ ENGINE LATHE)

The figure shows the major parts of a center lathe. It consists of:

1) Bed

2) Head stock
3) Tail stock
4) Carriage
5) Feed rod
6) Lead screw

1) Bed: It is a rigid structure which forms a base or foundation to support all the other parts such as head stock, tail stock, carriage, etc. It is usually made of gray cast iron'. At the top of the bed are the guide ways, which guides for accurate movement of carriage and tail stock.

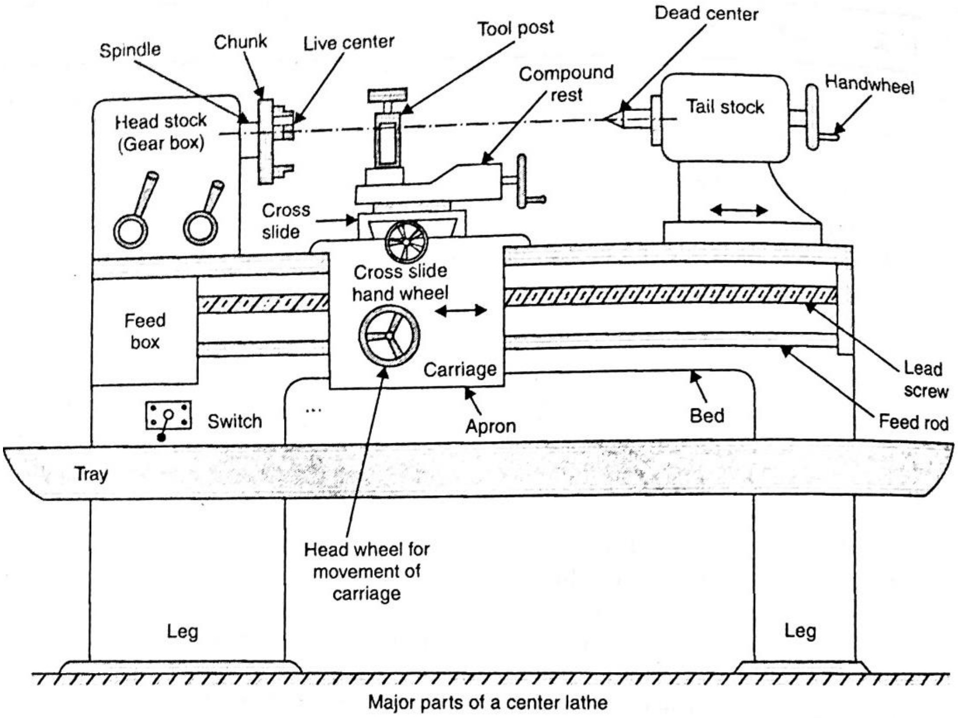


Fig. 8.1

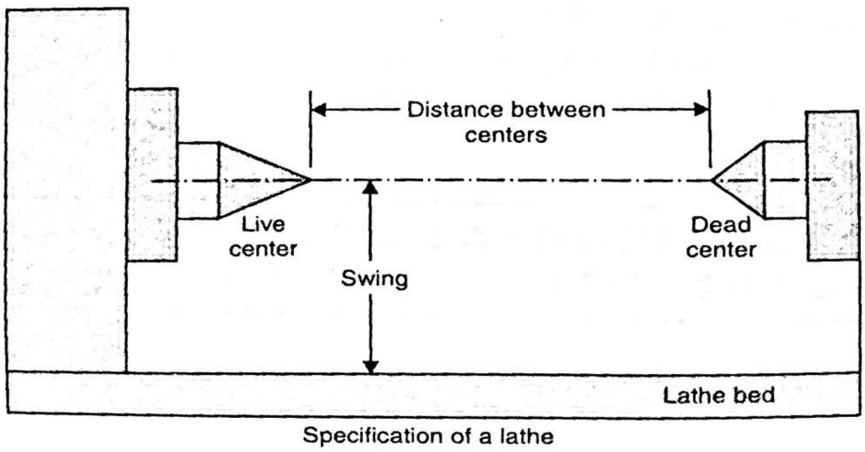


Fig. 8.2

2) Head stock: The head stock is mounted at the end of the bed. It contains gears or pulleys by means of which the workpiece can be rotated at different speeds. The head stock spindle is provided with a 'live center' or 'chuck' to support one end of the workpiece while it is being rotated.

3) **Tail stock:** The tail stock is mounted at the right end of the lathe bed. The main functions of tail stock are

- To provide support to the other end of the rotating workpiece (Job).
- To hold a tool for performing operations like drilling, reaming, tapping etc.

The tail stock can be made to slide along the bed and can be clamped at various locations so as accommodate the workpiece of different lengths. It can also be shifted laterally on the bed so as to make it offset for cutting tapers.

4) **Carriage:** The cutting tool is supported, moved and controlled with the help of carriage. It consists of the following parts:

- **Saddle:** The saddle can be made to slide alone the bed-ways and supports the cross slide, compound rest and tool post.
- **Cross-slide:** The cross-slide is mounted on the saddle. It allows the cutting tool to move at right angle to the lathe axis thereby providing the necessary depth of cut to the workpiece.
- **Compound rest:** It is mounted on the cross-slide and supports the tool post. The compound rest has a circular base graduated in degrees. Hence the tool can be swivelled to any angle to obtain taper surface.
- **Tool-post:** It is mounted on the compound rest and is used to hold/support the cutting tool firmly in position during machining.
- **Apron:** The apron is fitted beneath the saddle facing the operator. It houses the gears, levers, hand-wheels and clutches to operate the carriage by hand or by automatic power feed.

5) **Feed rod.** The feed rod is a long shaft that gives automatic feed to the carriage for various operations namely boring, turning etc..., except thread cutting.

6) **Lead screw.** It is a long shaft with square threads cut on it. The rotation of the lead screw facilitates the movement of carriage thread cutting operation.

8.4 SPECIFICATION OF LATHE

The size of the lathe is specified by one or more of the following criteria. Refer figure 8.2.

- **Distance between centers:** It is the maximum length of the job that can be held between the centers. i.e., between live center and the dead center.

- **Swing diameter:** It is the maximum diameter of the workpiece that can revolve without touching the guide ways. Some manufacturers specify 'Height of centers' instead of swing diameter.
- **Height of centers:** It is the height measured from the bed to the lathe center axis. However, any one of the above can be specified.
- **Length of bed:** It indicates the approximate floor space occupied by the lathe.
- Range of spindle speeds.

Lathe Operations

Some of the common operations performed on a lathe are.

Facing

Facing is the operation for generating flat surfaces at the ends of the workpiece as shown in figure. In this operation, the tool is fed perpendicular to the axis of rotation of the workpiece. This operation is also carried out to reduce/cut the workpiece to the required length.

Taper Turning

Taper turning is the process of producing a conical surface from a cylindrical shaped workpiece. A taper is produced, when the cutting tool moves at an angle to the axis of rotation of the workpiece it can be produced by any one of the following methods.

- By swiveling (rotating) of compound rest.
- By off-setting the tail stock.
- By using a taper turning attachment.
- By form tool method.

Taper Turning by Swiveling the Compound Rest

In this method, the compound rest which supports the tool is swiveled to the desired angle at the taper is to be produced. The compound rest has a circular base graded in degrees.

The half taper angle i.e., the angle at which the compound rest to be swiveled is calculated by using

$$\tan \alpha = \frac{D - d}{2.L}$$

Where D = larger diameter of taper in mm
d = smaller diameter of taper in mm
L = length of taper in mm and
α = half of taper angle.

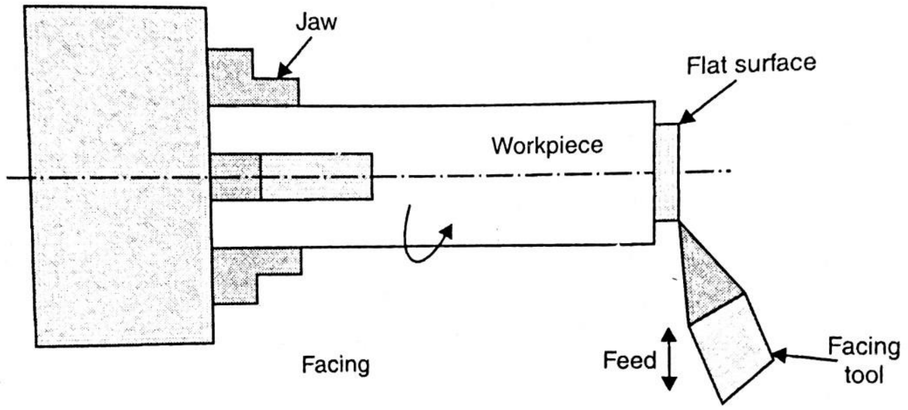
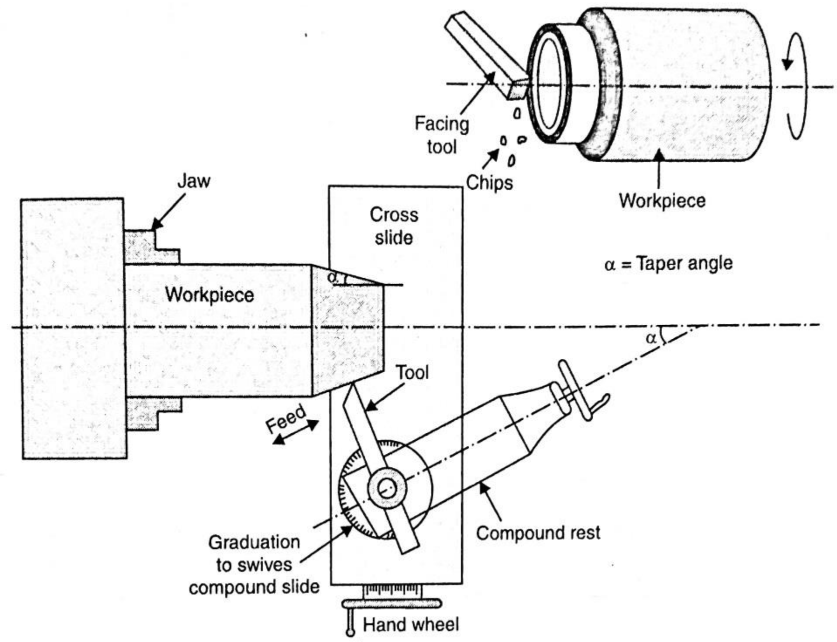


Fig. 8.3



Taper turning by swivelling compound rest

Fig. 8.4

The rotation of the compound rest to the tool to be fed at that angle, there by producing the corresponding taper on the workpiece. This method is suitable for producing steep taper with short lengths.

8.5 DRILLING

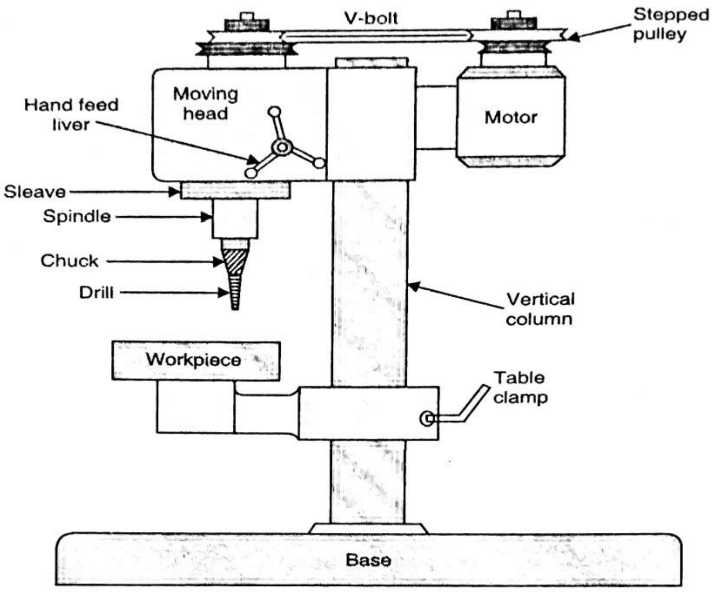
Drilling is the operation of producing a cylindrical hole in a solid workpiece by means of a revolving tool called 'drill bit. The tool is also called 'twist drill. Since it has sharp twisted edges formed around a cylindrical body.

To produce holes of required dimensional accuracy and surface finish. Drilling is followed by another operation called reaming. Drilling operation can also be performed on a lathe, but when performed on a drilling machine, the operation is faster and comparatively cheaper.

The figure shows the drilling operation. The hole is generated by the sharp edges of the rotating drill bit that is forced to move against the rigidly clamped workpiece. The chips (excess material removed) gets curled and escapes through the helical grooves provided in the drill bit.

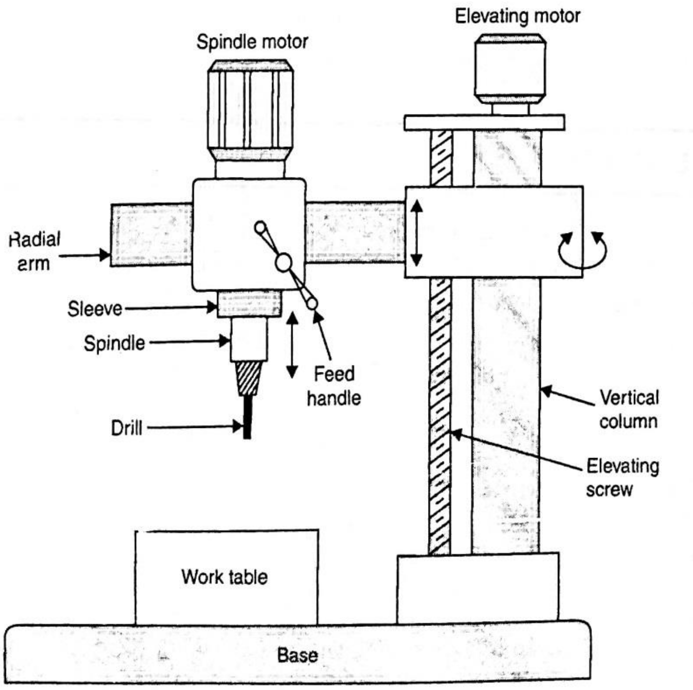
Bench Drilling Machine (Sensitive Drilling Machine)

Bench drilling machine is used for drilling small holes at high speeds in small jobs. The diameter of the hole usually ranger from (5 mm to 15.5 mm). These machines are usually mounted on work-benches and hence the name figure shows a bench drilling machine.



Bench drilling machine

Fig.8.5



Radial drilling machine

Fig.8.6

The details regarding the various parts of the machine are described below. The machine consists of:

(a) **Vertical column:** It is made of a hollow steel pipe mounted over a strong base.

(b) **Work table:** It supports the workpiece to be drilled. The work table is usually provided with T-Slots that helps the workpiece to be clamped rigidly on the table. The work table can be moved up and down and can be clamped to the vertical column at any desired position.

The moving head carries a driving motor and a driving mechanism. The driving mechanism contains a drill spindle that can rotate as well as slide up and down. Power is transmitted from the motor to the spindle through belt drive arrangement. The spindle speed can be varied by altering the belt position on the stepped cone pulley. The lower end of the spindle accommodates a drill chuck used for holding the drill bit rigidly.

This type of machine is used for drilling medium/large diameter holes in heavy workpiece at different locations. The figure shows the parts of a radial drilling machine.

The details regarding various parts of the machine are described below. The machine consists of.

The column is mounted on a large base and supports a radial arm that can be raised or lowered in order to accommodates workpiece of different heights. The radial arm can also be rotated in a complete circle around the column.

The drill head mounted on a radial arm carries a driving motor and a mechanism for revolving and feeding the drill bit into the workpiece. The drill head can be moved horizontally on the guide ways provided in the radial arm and can be clamped at any desired position.

With the combination of the movements of radial arm and the drill head, it is possible to move the drill bit to any desired position on the workpiece.

8.6 DRILLING MACHINE OPERATIONS

The various operations that can be performed on drilling machines are Drilling, Reaming, Boring, Counter boring, Counter sinking, Tapping etc.

The details regarding the above operations are discussed below:

Reaming

It is the operation of finishing a previously drilled hole so as to bring it to the accurate size and also to have a good surface finish. Reaming operation is carried out by means of a multi tooth revolving tool called 'reamer'. The figure shows the reaming operation.

While reaming, the speed of the spindle is reduced to half of that of the drilling. The material removed is very less and hence the drilled hole surface are finished with high accuracy.

Boring

Boring is the operation of enlarging a previously drilled hole, by means of an adjustable cutting tool having only one cutting edge. Refer figure 8.7.

Boring is performed when a drill bit of the required dimension is not available. In such cases, a hole is first drilled to the nearest dimension and the using a single point cutting tool, the size of the hole is enlarged to the required dimension.

Counter Boring

Counter boring is the operation of enlarging one end of a previously drilled hole through a small depth as shown in figure. This operation is performed in order to accommodate the heads of bolts, studs sockets, etc.

The tool used for counter boring is called 'counter box' the tool is provided with a 'pilot' at its bottom whose diameter is equal to that of the previously drilled hole. The pilot guides the tool during cutting.

Counter Sinking

Counter sinking, as shown in figure is the operation of enlarging one end of a cylindrical hole into a conical shape. This operation is performed in order to accommodate the conical head of components such as screws or rivets.

The tool used for this operation is called 'counter sink'. Standard tools (counter sinks) 60°, 82° or 90° included angle and the cutting edges are formed on the conical surface.

Tapping

Tapping is the operation of cutting internal threads in a previously drilled hole. The tool used for the operation is called "Tap'. Refer figure 8.7. Taps are available in standard size. Hence to generate a specific size thread, a hole is first drilled to the nearest dimension and then using a standard size tap, threads are cut in the same way as drilling.

While tapping, the spindle has to rotate at slow speeds compared to drilling.

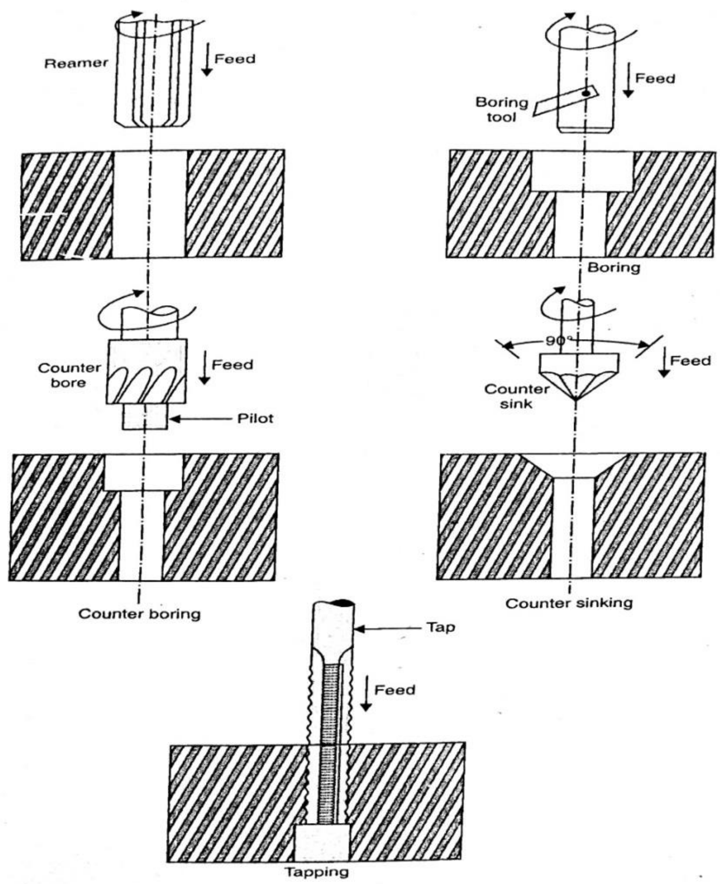


Fig.8.7

Comparison between up milling and down milling

Up milling (Conventional milling)	Down milling (Climb milling)

• The workpiece is fed in the direction opposite to that of the rotating cutter. • Thickness, of chip is minimum at the beginning of cut and reaches to the maximum when the cut ends. • The cutting force is directed upwards and this tends to lift the workpiece from the table. Hence, greater clamping force is necessary. • During up milling, the chip gets, accumulated at the cutting zone. These chips interfere with the revolving cutter thereby impairing the surface finish, difficult for efficient cooling since the cutter rotates in the upward direction carrying away the coolant from the cutting zone. • Use of maching hard surfaces such as castings and forgings.	• The workpiece is fed in the same direction as that of the rotating cutter. • Thickness of chip is maximum at the beginning of cut and reaches to the minimum when the cut ends. • In down milling, the cutting force acts downwards, that tends to keep the workpiece firmly on the table, thereby permitting lesser clamping forces. • The chips do not interfere with the revolving cutter as they are disposed easily by the cutter. Hence, there is no damage to the surface finish. Efficient cooling can be achieved since the coolant can easily reach the cutting zone. • Useful for fishing operation and small work.

Horizontal Milling Machine (Plain Milling Machine)

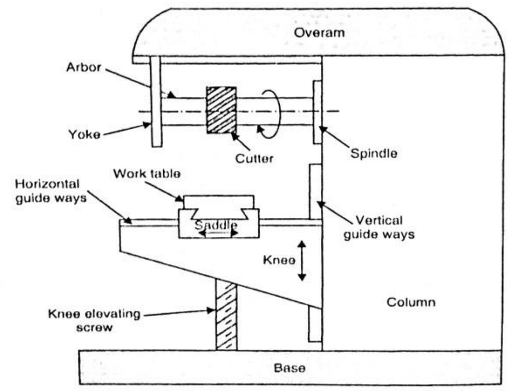
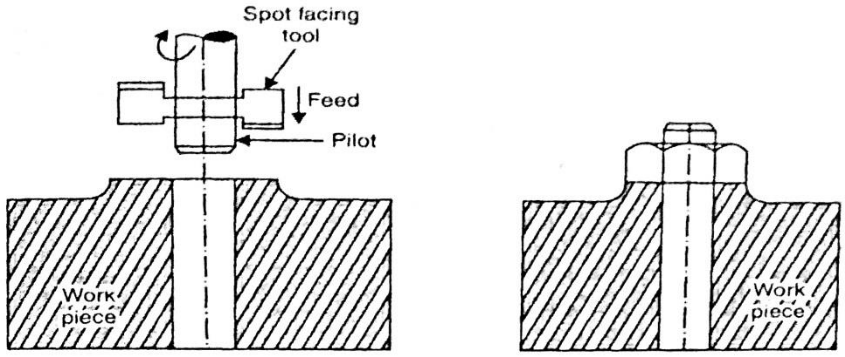


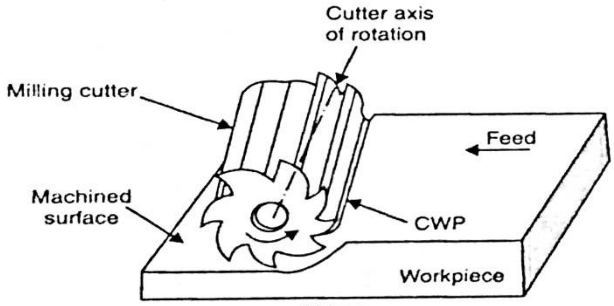
Fig.8.8. Horizontal milling machine

8.7 MILLING

Milling is a process of removing excess material from the workpiece with a rotating cutting tool called 'milling cutter' refer figure. The milling cutter is a multi-point cutting tool with cutting teeth formed on the circumference or on the end fall or on the both. The cutter is made to rotate at high speeds. With suitable speed and multiple cutting edges, material can be removed at a faster rate and also fine surface finish can be obtained.



Spot facing and its use



Milling

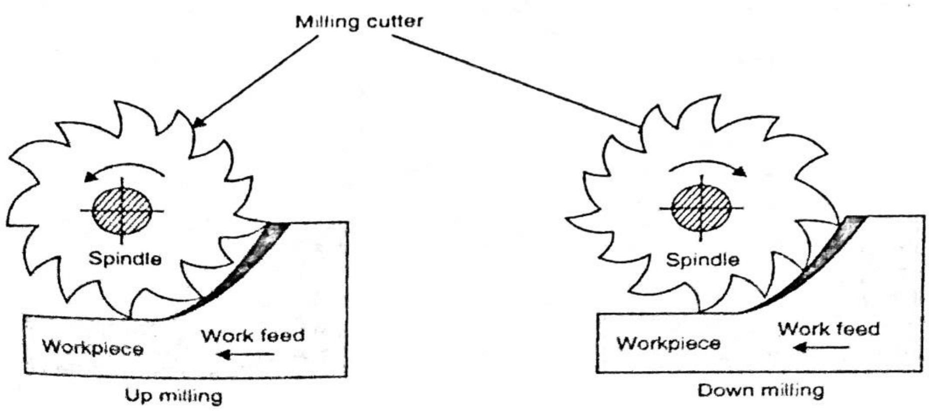


Fig.8.9

Milling process is used for producing flat, contoured or helical surface, for cutting threads, toothed, gears key ways, slots etc.

Note:

1) While machining in lathes, the tool is fed against a rotating workpiece.

2) In drilling the rotating tool is fed against a stationary workpiece.

3) In milling, the workpiece is fed against a revolving tool.

Principle of Milling

Milling works on the principle that, when a workpiece, held rigidly, is fed slowly against a multi-point cutter, revolving at a fairly high speed, material can be removed. As the workpiece advances against the rotating tool, each tooth of the cutter removes metal from the surface of the workpiece to produce the desired shape.

The relative motion between the workpiece and the cutter can be in any direction.

- If the workpiece is fed in the direction opposite to that of the rotating cutter, the process is called 'up milling' or 'conventional milling'. Figure shows the up milling process.
- If the workpiece is fed in the same direction as that of the rotating cutter, it is called down milling or climb milling'. The process is shown in figure

8.9 VERTICAL MILLING MACHINE

The vertical milling machines are similar to the horizontal milling machine except that the spindle is held in a vertical position (at right angles to the work table). Refer figure 8.10

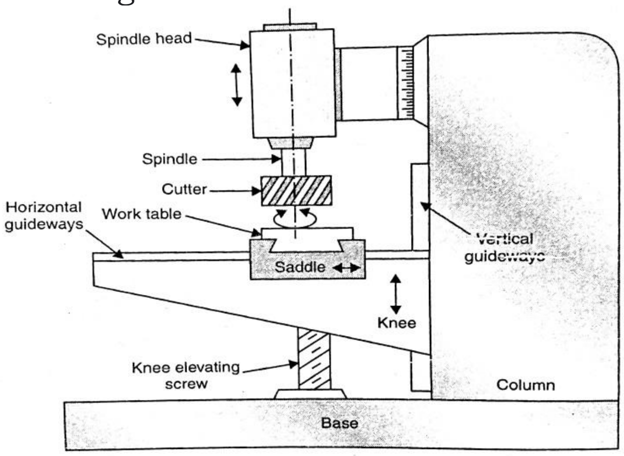


Fig.8.10. Vertical milling machine.

All the other features are similar as in the case of horizontal milling machine. The details regarding the 'spindle' used in vertical milling machine is explained below.

Spindle

The spindle head is fixed to the vertical column. The spindle head may be either of the fixed head type, sliding head type, Swivel head type or it may be a combination of the last two.

- In sliding type, the spindle can be moved up and down to perform operations like grooving, slotting facing, drilling and boring.
- The swivel head type is used to work on angular surfaces.

Generally vertical milling machines are used to perform end milling and face milling operation.

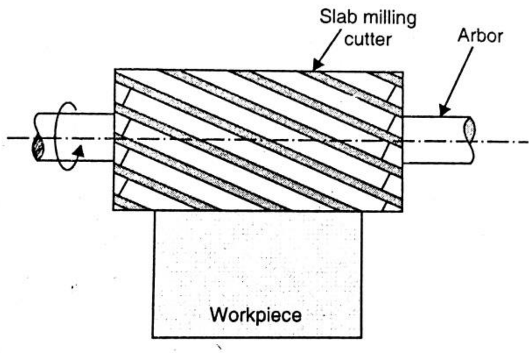


Fig.8.11. Slab milling (plain milling).

Grinding Machines

Grinding machines are classified according to the type of surface produced:

(a) Surface grinding machine

- Horizontal spindle machine
- Vertical spindle machine

(b) Cylindrical grinding machine
(c) Centerless grinding machine
(d) Internal grinding machine and
(e) Special grinding machine

Cylindrical Grinding Machine

This type of grinding machine is used for grinding external cylindrical surfaces that may be plain, tapered or contoured figure shows a cylindrical grinding machine.

In operation, the cylindrical workpiece is made to rotate between the two centers (head stock and tail stock center). An electric motor mounted on the head stock rotates the head stock spindle which in turn rotates the workpiece. The grinding wheel is driven by another electric motor.

The work table is usually made in two parts:

- The upper table carries the head stock and tail stock and can be swiveled by a small angle that enables to grind taper surface.
- The lower table mounted on the horizontal guideways provides longitudinal movement to the upper table and hence the workpiece also.

In operation, both the grinding wheel and the workpiece are made to rotate
in opposite direction. The grinding wheel is made to rotate at higher speeds than that of the workpiece. As the workpiece reciprocates, the grinding wheel comes in contact with the cylindrical surface of the workpiece. The abrasive action of the wheel removes material from the workpiece in the form of the fine chips.

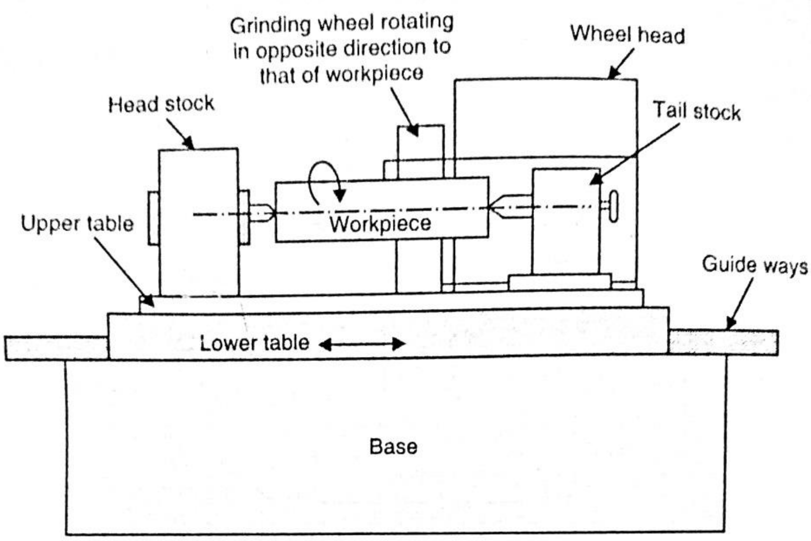


Fig. 8.12. Cylindrical grinding machine.

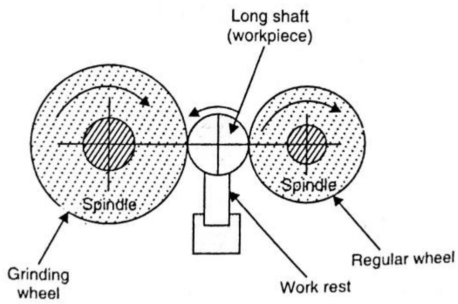


Fig. 8.13. Centerless grinding machine.

Centerless Grinding

Center less grinding is similar to that of cylindrical grinding except the process varies in its principle. This process is used for grinding surfaces of workpiece that cannot be held and rotated between centers. In other words, the workpiece is not rotated between the centers and hence the name' centerless'. This process is primarily useful for grinding long, slender shafts or bars. Figure shows the center less grinding machines.

In this process, the workpiece is supported by the grinding wheel, regulating wheel and a work rest. The grinding operation is performed by the grinding wheel only. The function of the regulating wheel is to help the workpiece to remain in contact with the grinding wheel while in operation. This is required because, the rubber bond and helps in the rotation of the workpiece.

Both the grinding wheels and the regulating wheel rotate in the same direction. The work rest supports the workpiece from the bottom as shown in the figure.

Surface Grinding Machine (Horizontal Spindle Machine)

The figure shows a horizontal type surface grinding machine with the reciprocating table. This type of machine is mainly used for grinding flat surfaces, although and irregular surface can also be finished. It consists of a horizontal spindle carrying the grinding wheel and a reciprocating work table. The workpiece can be directly clamped on the table or by means of a magnetic chunk.

In operation, the rotating grinding wheel is brought in contact with the surface of the workpiece. The grinding wheel as it comes in contact with the workpiece removes material in the form of fine grains (chips). Longitudinal feed to the workpiece is given by reciprocating the table. Vertical downward movement of the wheel gives the required depth of cut.

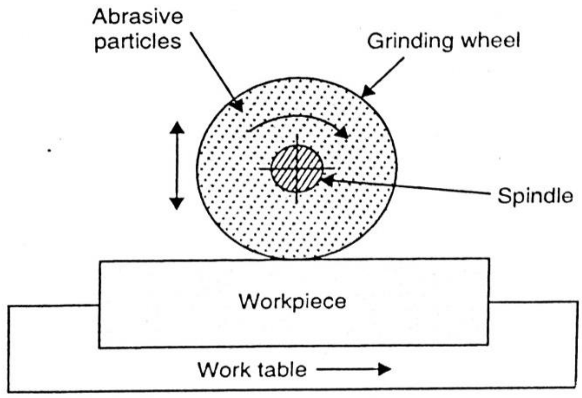


Fig.8.14. Horizontal type surface grinding machine

SUMMARY

- The lathe is the oldest of all machine tools and perhaps the most basic tool used in industries. A lathe is defined as a machine tool used to remove excess material by forcing a cutting tool against a rotating workpiece. Lathes are also called turning machines'.
- Engine lathe is one of the most widely used lathes and is so called in view of the fact that earlier lathes were driven by steam engines.
- The head stock is mounted at the end of the bed. It contains gears or pulleys by means of which the workpiece can be rotated at different speeds.
- Drilling is the operation of producing a cylindrical hole in a solid workpiece by means of a revolving tool called 'drill bit'. The tool is also called 'twist drill'.
- Tapping is the operation of cutting internal threads in a previously drilled hole.
- The tool used for the operation is called 'Tap'.

- Milling is a process of removing excess material from the workpiece with a rotating cutting tool called 'milling cutter'.

REVIEW QUESTIONS

1) What are different types of lathe? Explain in details.

2) Describe the major parts of a center lathe.

3) Differentiate between up milling and down milling.

4) Write short note on (a) cylindrical grinding machine (b) centerless grinding machine.

5) Explain the specification of lathe.

CHAPTER

9 LUBRICATION AND BEARINGS

STRUCTURE

9.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- describe the functions of lubricants and properties of lubricants
- explain the requirements of a good lubricants
- differentiate between liquid lubricant and solid lubricant
- discuss about the journal bearing and thrust bearing

9.1 LUBRICATION

Lubricants are used to reduce friction. Friction is the resistance to relative motion between the two surfaces in contact.

There are three different types of lubricants:

1) Liquid lubricant

2) Solid lubricant
3) Semi solid lubricant

1) **Liquid lubricants:** Liquid lubricants are usually preferred because of its retention and ease of flow. Generally used in bearings, and other moving components.

   Synthetic oils, vegetable oils and mineral oils are some of the liquid lubricants used.

2) **Solid lubricants:** Solid lubricants are used in reducing friction at high temperature and pressure. Graphite is used as the most common solid lubricant. Other solid lubricants are wax, mica, sope stone, French check etc.

3) **Semi solid lubricants:** Grease is a semi solid lubricant having high viscosity than oils, Grease is used for slow speed and high pressure machineries and also in the machines where oil drip from the bearings in undesirable.

Functions of Lubricants

- Lubricant removes frictional heat from the bearings.
- It reduces wear and tear thereby increasing the life of bearings.
- It protects the component from corrosion.
- It reduces friction between sliding surfaces by separating them with a thin film of oil.

Properties of Lubricants

1) **Viscosity:** It is the measure of the internal resistance of the fluid and it indicates the relative resistance to flow, for Lubricants viscosity is an important factor because of its load carrying capacity. The viscous oils can support heavious loads. Viscosity decreases with increase in temperature. Therefore it is desirable that the change of viscosity with temperature be kept to a minimum.

2) **Flash point:** It is the minimum temperature at which lubricating oil gives off sufficient vapour to ignite instantly or introduction of a flame. A good lubricating should have a flash point above the operating temperature,

3) **Pour point:** It is the lowest temperature at which oil ceases to flow when it is cooled.

4) **Fire point:** It is the minimum temperature at which oil evaporates to burn continuously on introduction of a flame.

5) **Cloud point:** It is the minimum temperature at which oil becomes cloudy when it is cooled.

6) **Oiliness:** It is the ability of oil to maintain an unbroken lubricant film between the rubbing surfaces.

Requirements of Good Lubricants

A good lubricant must have the following requirement:

- High viscosity
- Maximum film strength
- High flash and fire points
- Non volatile
- Non corrosive
- Non poisonous
- Good fluidity at various temperature
- High resistant to temperature and pressure
- High resistant to chemical oxidation.

Lubricator: It is a device used to supply sufficient quantity of lubricant components.

Some of important types of lubricator are:

1) Drop feed lubricator
2) Syphon wick/wick feed lubricator
3) Splash lubricator

1) **Drop feed lubricator:** As shown in figure 9.1 drop feed lubricators consists of oil reservoir (container) with a metal bare which has a dripped hole at the center. The rate of feed is adjusted by means of a screw, screw slightly rises or lowers the needle and the flow of drops can be seen through the glass window. Drops lubricators are commonly used is high speed machinery.

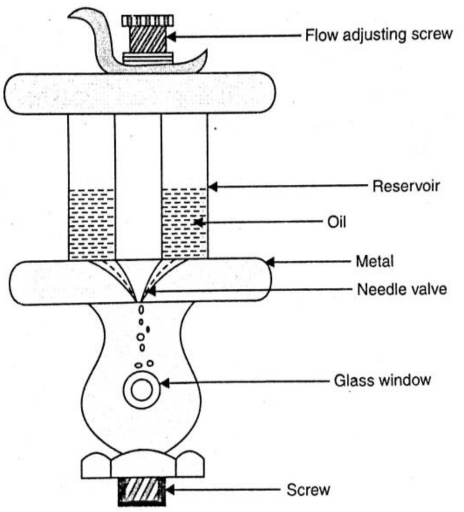


Fig.9.1. Drop feed lubricator

2) **Syphon wick/wick feed lubricator:** As shown in figure 9.2, a syphon wick lubricator works on the principle of capillary action of absorbed material, carrying oil for the purpose of lubrication. It consists of the glass container of oil reservoir with a central tube and a threaded shank, shank can be attached to the oil hole in the machine components where lubrication is necessary. Oil is drawn from the reservoir through the wick

made of wool yarn. The rate of flow being regulated by the number of strains in the yarn. For uniform rate of feed, the discharge end of the wick should be 50 mm, below the lowest level of oil. Wick feed devices are more efficient as they tend to feed at all times even when the machinery is not running. To stop the feed, it is necessary to lift the wick out of oil by means of a suspension hook.

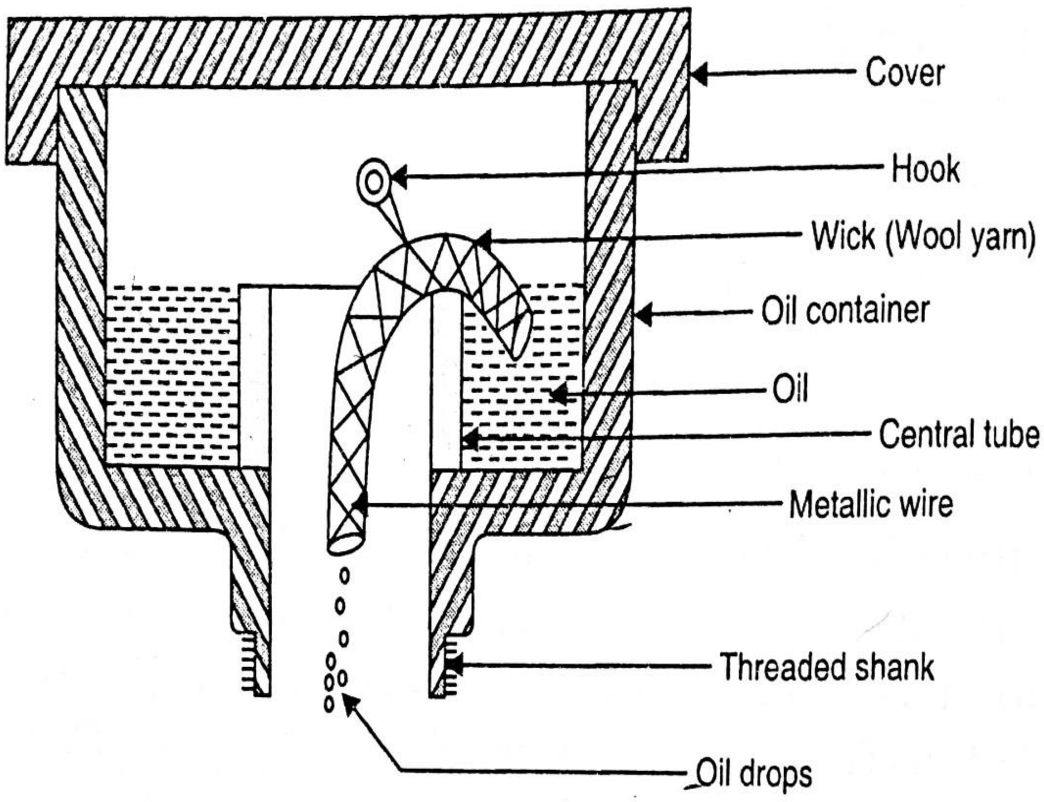


Fig.9.2. Syphon wick/wick feed lubricator

3) **Splash lubricator:** Splash lubricator is used in machines, having crank case or gears in closed in a housing which acts as a reservoir for oil. The soop fixed at lower part of the connecting rod, dips in the oil and carries oil to the top. And is distributed in the form of spray and reaches the cylinder walls, piston rings. Crank pins and crank shaft bearings as shown in figure 9.3. It's efficiency can be maintained by maintaining the oil level. In this system constant supply of oil is possible to all the lubricating parts.

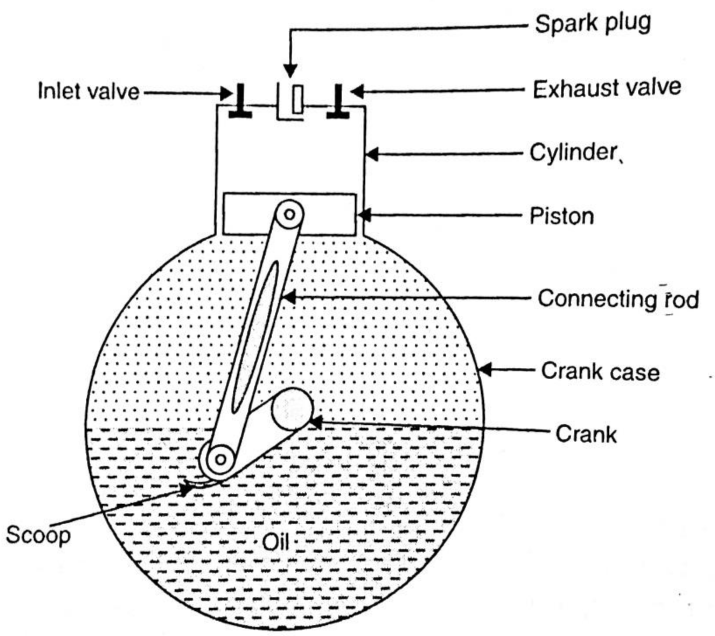


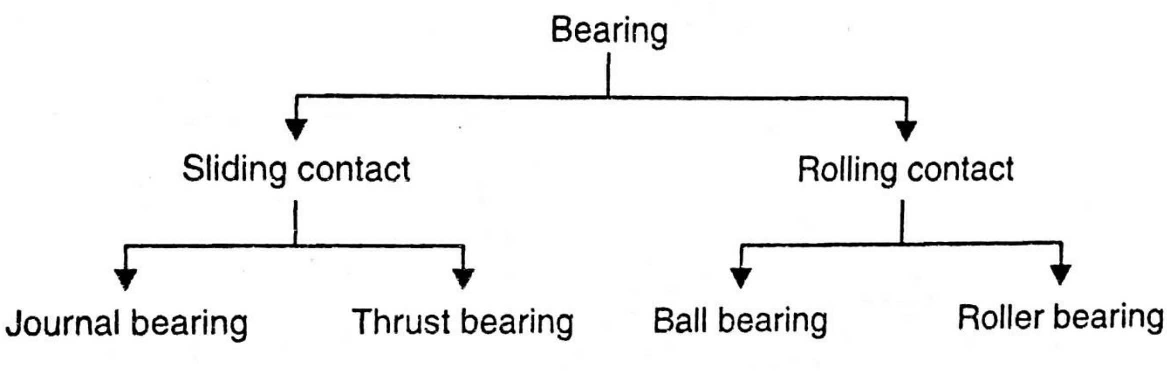
Fig.9.3. Splash lubricator

9.2 BEARINGS

Bearing is a machine component/machine element that holds or supports the rotating shaft also facilitates free and smooth rotation of shaft.

Classification

Bearings are classified according to the nature of contact between the shaft and the working surface.



1) **Journal Bearing (Sliding contact type)**

These are three types of Journal bearing, solid bearing, bush bearing and
Plummer block. Simple Journal bearing is shown in figure above.

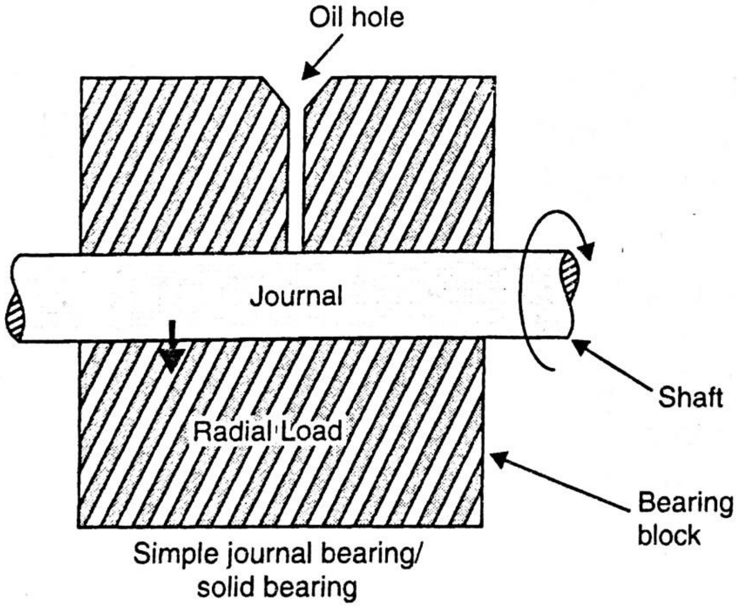


Fig. 9.4

It is used to hold or support the shaft that is subjected to loading perpendicular to the axis of the shaft (Radial loading). The portion of the shaft that is in contact with the bearing surface is known as Journal, hence the name Journal bearing.

2) **Thrust Bearing:** In thrust bearing the load acts along the axis of random of the shaft a simple thrust bearing is shown in figure 9.5.

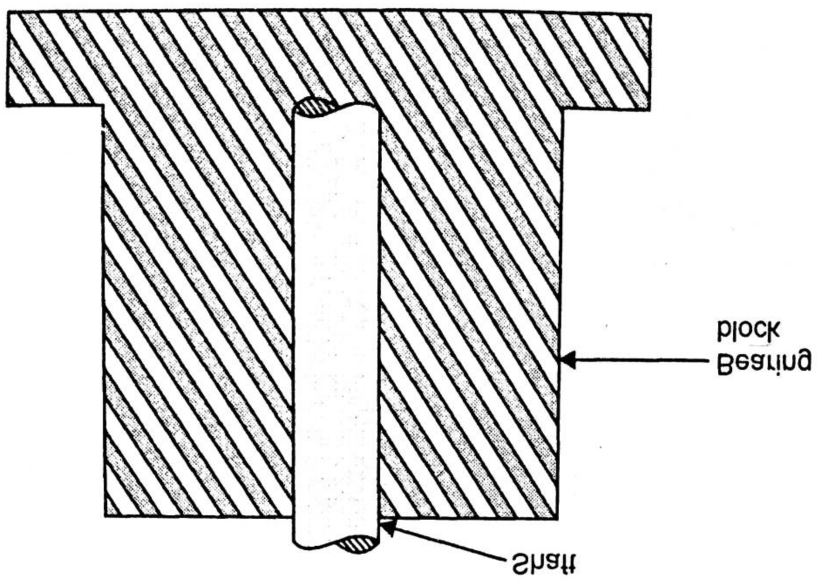


Fig. 9.5

1) **Solid Bearing:** It is a simplest type of Journal bearing. It consists of a rectangular base plate with two holes for the purpose of bolting the bearing.

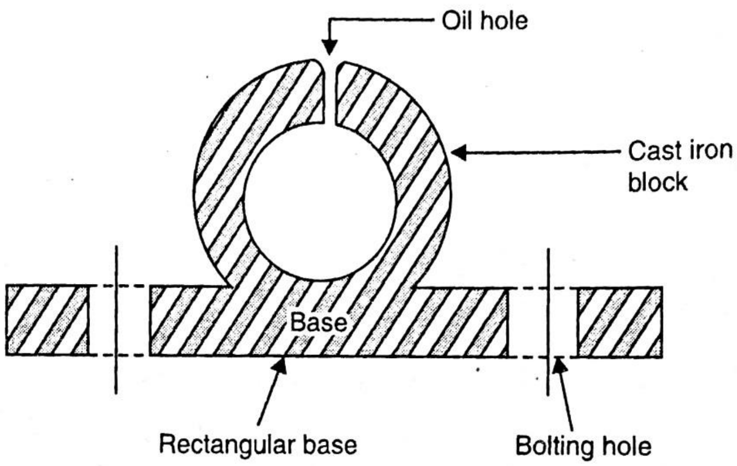


Fig. 9.6

A cylindrical hole is formed in the cast iron machine member/cast iron block. To receive the shaft, which makes a running fit in it, an oil hole is provided at the shaft to lubricate the bearing. It is used for the shafts carrying medium load at the moderate speed.

2) Bush Bearing: It consists of cast iron block and a bush. Bush is made of soft material such as brass, bronze or gun metal. The bush thrust inside the bore with the cast iron block and in prevented from rotating or sliding by means of glib screw, as shown in figure, when the bush gets worn out it can be easily replaced this type of bearings one used in shaft carrying medium loads and rotating at moderate speed.

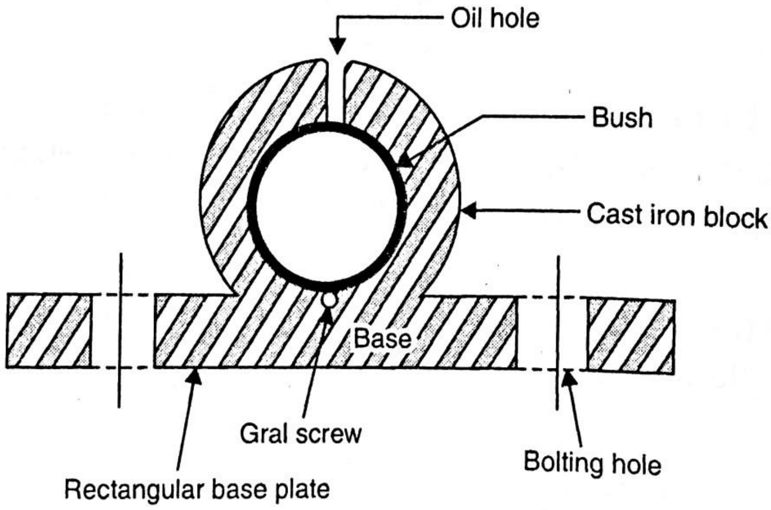


Fig. 9.7

3) Plummer Block

- It is also called split bearing or pedestal bearing and is used when
- A long shaft is required to be supported at intermediate points when it is not desirable to place a shaft in the bearing by introducing it end vise.

Figure shows a half sectional front view of a plummer block, it is split into two parts. The top part is called a cap and the bottom one is called a pedestal (body). Two split bushes called lower split bush and upper split bush made of brass or gun metal are provided as shown in figure. The lower split bush is prevented from rotation by a snug provided at the bottom.

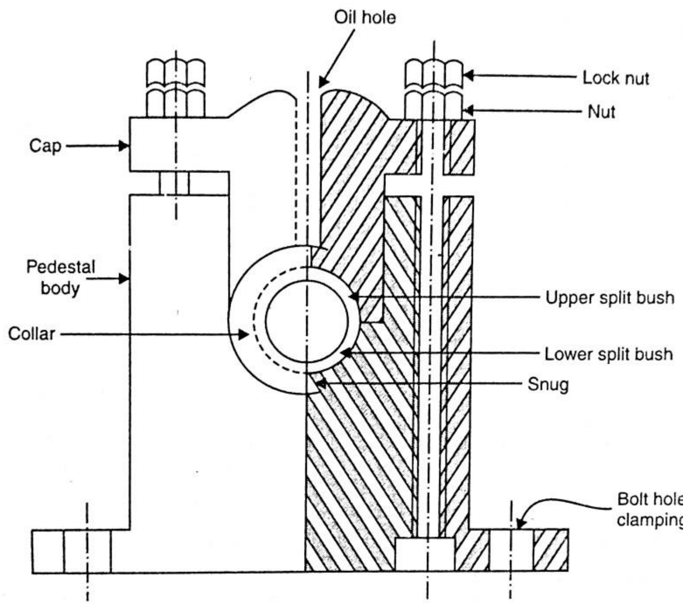


Fig. 9.8

The shaft is placed on the lower split bush and the top split bush is placed over the shaft, the cap is fasten to the body by means of nuts. An oil hole is provided at the top end of the bearing block for lubrication. The rectangular base plate has two holes drilled in it. To clamp the bearing to the rigid base.

Rolling contact bearing: It is also known as anti-friction bearing because the rolling friction is very less compare to the sliding friction. Based on the type of rolling element.

They are classified as:

- Ball Bearing
- Roller Bearing.

Ball Bearing: The cross-section of a ball bearing is shown in figure 9.9. It consists of a set of steel balls positioned between the grooves of the outer ring, and the inner ring. These rings are known as races. The inner race fits the shaft tightly and rotates with the shaft. The outer race fits into the bearing and remains stationary. The balls are retain in position by means of separators, as the shaft rotates. The balls role in between the races, and hence only rolling friction exist between the surfaces. The ball bearings should be lubricated so as to enable the balls to role freely between the rings.

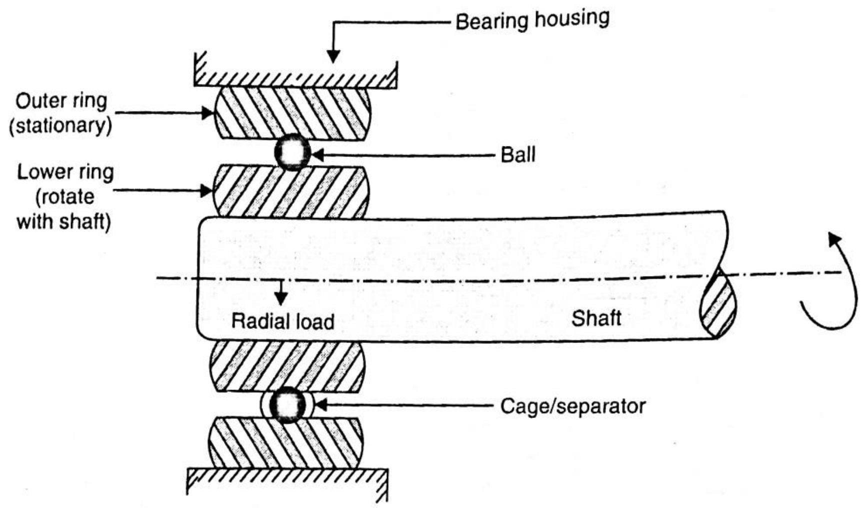


Fig. 9.9

Application of Ball Bearing: Ball bearings are used to support the shaft that are subjected to radial load and thrust load and usually found in relatively small load application. They are widely used in machineries.

Roller Bearing: The cross-section of a simple roller bearing subjected to radial load is shown in figure 9.10. It consists of cylindrical shaped steel rollers positioned between the outer ring and the inner ring these rings are known as races. The inner race fixed tightly with the shaft and rotates with it. The outer race fixed tightly into the bearing housing and remains stationary. The rollers are retaining in position by means of a cage or separator usually made of brass or gun metal.

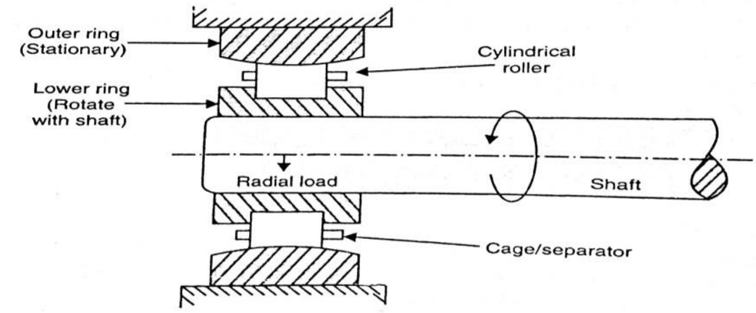


Fig. 9.10

The rollers used may be of cylindrical shape are tapered one. The roller bearing with tapered rollers is shown in figure 9.11.

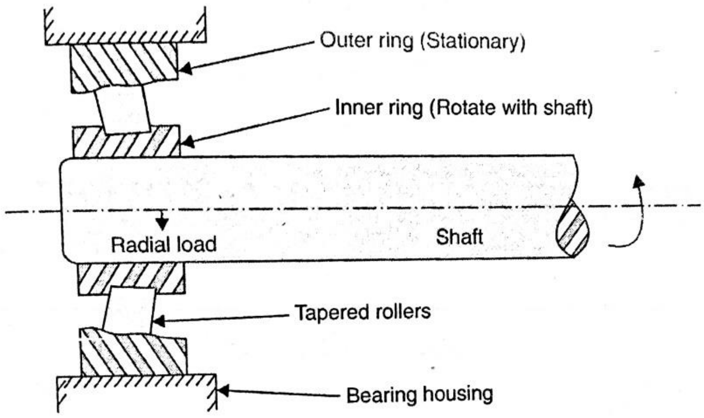


Fig. 9.11

Roller bearings are used when the shaft is subjected to radial load and tapered rollers are used when the shaft is subjected to both radial and axial load.

Application: Roller bearing is suitable for shaft subjected to heavy load.

Advantages and disadvantages of roller bearings over sliding bearings.

Advantages

- Friction developed in roller bearing is very low.
- Accurate shaft alignment can be maintained.

Disadvantages

- The major disadvantage is they are very costly compare to sliding contact bearing.
- More noise at high speed due to rolling of balls/rollers.
- It requires high precision machining for bearing housing.
- Roller bearings are more liable to shock loads.

SUMMARY

- Solid lubricants are used in reducing friction at high temperature and pressure. Graphite is used as the most common solid lubricant.
- Oiliness is the ability of oil to maintain an unbroken lubricant film between the rubbing surfaces.
- Rolling contact bearing is also known as anti-friction bearing because the rolling friction is very less compare to the sliding friction.

REVIEW QUESTION

1) Describe the advantages and disadvantages of roller bearings over sliding
bearings.
2) Differentiate between ball bearing and roller bearing.
3) Write short note on (a) drop feed lubricator (b) splash lubricator.
4) Describe different types of lubricants and explain their properties.

CHAPTER

10 POWER TRANSMISSION

STRUCTURE

10.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- discuss about the velocity ratio in belt drive
- describe the advantages and disadvantages of gear drive
- explain the cross belt drives
- differentiate between open belt drives and cross belt drives
- What are types of gear? Explain in details.

10.1 POWER TRANSMISSION

Power is transmitted from the prime mover to a machine (any machine/lathe, drilling etc.) by means of intermediate mechanism known as drives.

The most commonly used drives are chain drive, belt drives, rope drive and gear drives.

Belt Drives

Belt drives are used to transmit power from one shaft to another placed at a known distance. Belt drives consists of an endless belt wrapped tightly over the pullies known as driving pulley and driven pulley, which in turn fixed on the corresponding shafts. The turning movement of driver shaft is transmitted to the power by frictional resistance between the belt and surface of the pullies. The velocity ratio in belt drive varies due to slip in belts.

Belt Material

Belts used for power transmission must be strong and durable and with high coefficient of friction. The most common belt materials are.....

Leather belts, cotton or fabric belts, rubber belts.

Belts are available in different cross-sections such as, flat belt, round belt and V belts. Flat and V belts are most commonly used.

Advantages

- Flexibility, shock absorption, efficiency at high speed, protection again over loads, good resistance to abrasive and other harmful conditions.
- Simplicity, smooth in operation, low cost, less maintenance and long life.

Disadvantages

- It is not a positive drive.
- Laps in efficiency are possible due to slip and creep.
- Not suitable for short centered distances.
- Comparatively large size.
- Belt joints reduce the life of belt.
- High bearing loads and belt stress.

Applications

- Belt drives are used to connect widely spaced shafts.
- It is used to transmit power directly from the prime mover to any other device.
- Belt drives are largely used for general purpose mills and factories.

Types of Belt Drives

- Open belt drives
- Cross belt drives

Open belt drives

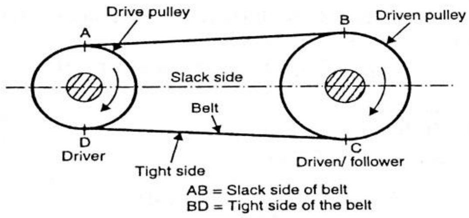


Fig. 10.1

Open belt drive is shown in figure it consists of a driver shaft and a follower shaft, and an endless belt, wrapped over the shaft/pulley. This mechanism is used to connect the shafts which are parallel and rotating with the same direction, when the distance between the shafts is large. The lower side (CD) of the shaft is known as tight sight and the upper side of the shaft (AB) is known as slack side or the loose side.

Cross Belt Drives

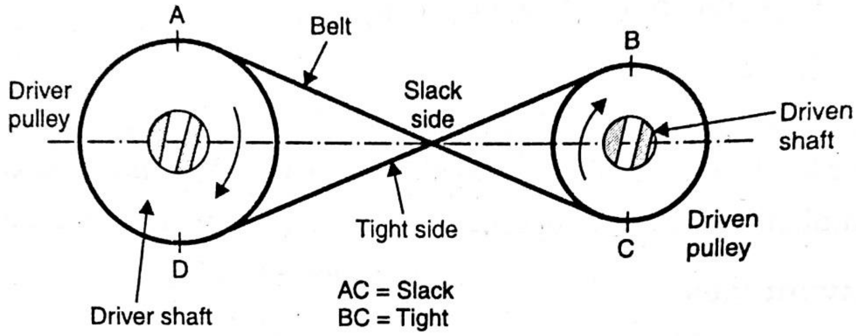


Fig. 10.2

It is shown in figure; it is used to connect the shafts which are parallel and rotating in opposite direction. In this drive the driver pulls the belt from side BD known as tight side of the belt, the opposite side AC is known as the slack side.

Velocity Ratio in Belt Drive

It is defined as the ratio of speed of the driver to the speed of the follower shaft. For positive belt drive the ratio of angular velocity of the driver pulley to the angular velocity of driven pulley is called the velocity ratio or transmission ratio or speed ratio.

d_1 = diameter of the driver shaft
r_1 = radius of the driver shaft
n_1 = speed of the driver shaft
d_2 = diameter of the follower shaft
r_2 = radius of the follower shaft
n_2 = speed of the follower shaft.

Then assuming that there is no slip between the belt and the shaft, the linear speed of the belt for both the shaft is same then

$$\pi d_1 n_1 = \pi d_2 n_2 \text{ (since } \pi \text{ is a constant)}$$

(1) $\frac{n_1}{n_2} = \frac{d_2}{d_1} = \frac{r_2}{r_1}$

(2) Power transmitted by the belt

$$P = \frac{(T_1 - T_2)}{100} k\ watts$$

where T_1 and T_2 are the tension in tight side of the belt and slack side of the belt respectively.

(in Newton).

and V = velocity of belt in m/s = $V = \frac{\pi d_{1n_1}}{60} = \frac{\pi d_{2n_2}}{60}\ m/s$

(3) Ratio of belt tension: $\frac{T_1}{T_2} = e^{\mu\theta}$

where T_1 = tension in tight side
T_2 = tension in slack side
μ = coefficient of friction
θ = angle of contact.

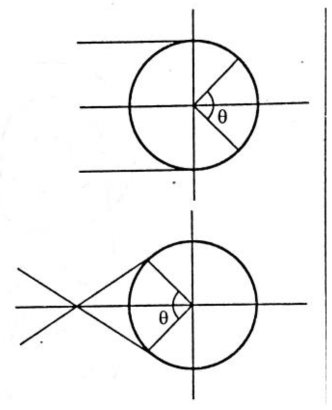


Fig. 10.3

Since θ is not the same for open belt and cross belt drive therefore

(a) θ in open belt drive is given by

$$\theta_0 = \left[180 - 2\, sin^{-1}\left(\frac{r_1+r_2}{c}\right)\right] \frac{\pi}{180} \text{ radian}$$

where c = central distance between the pulley

r_1 = radius of larger pulley
r_2 =radius of smaller pulley.

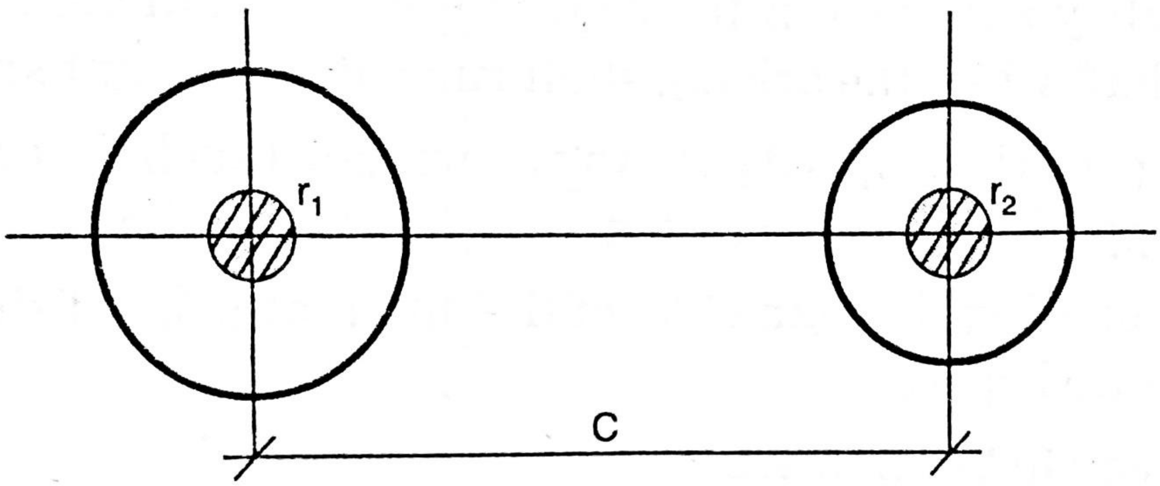


Fig. 10.4

(b) θ in cross belt drive is given by

$$\theta_c = \left[\left[180 - 2\,sin^{-1}\left(\frac{r_1+r_2}{c}\right)\right]\frac{\pi}{180}\right] \text{ radian}$$

(c) Initial tension in belt

$$T_1 = \frac{(T_1 + T_2)}{2}$$

Slip in Belt

A common phenomenon encountered in belt drive is sliping of the belt. The power transmitting from one shaft to the other depends on the friction between the belt and pullet the belt is subjected to intermittent stretching in the tight side, because of which there is always some amount of slip between the belt and the pulley, which results in slight reduction of velocity ratio in belt drives.

Slip may be defined as the relative motion between the pulley and the belt passing over it. It is generally expressed in terms of %slip. The effect of slip on velocity ratio is given by.

$$\frac{n_2}{n_1} = \frac{d_1}{d_2}\left(\frac{100 - S}{100}\right) \text{ where S = \% slip}$$

Stepped pulley

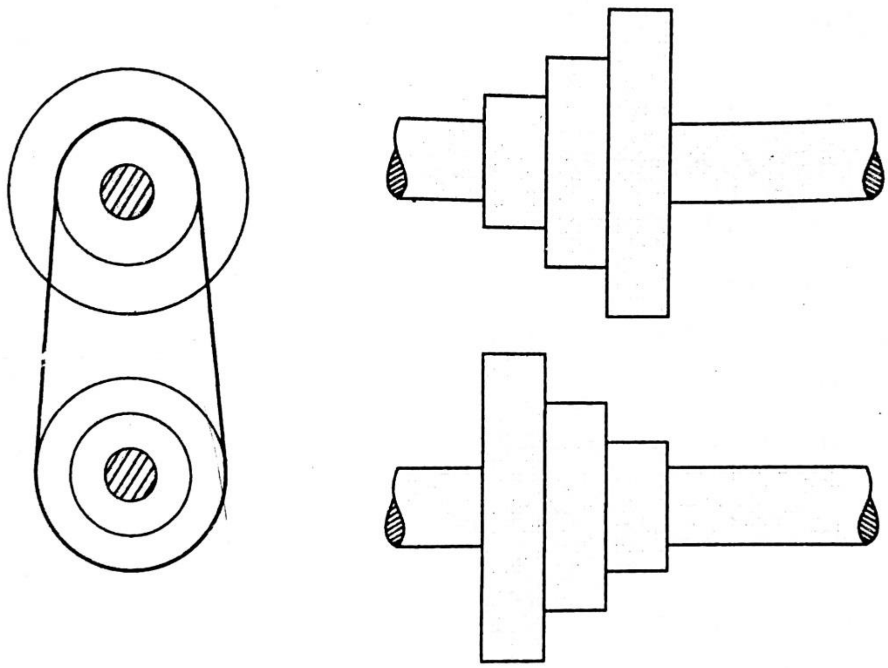


Fig. 10.5

Stepped pulley is shown in figure it is used for changing the speed of the follower/driven shaft when the driving shaft runs at a constant speed.

To reduce speed the stepped pulleys are arranged such that the smallest step of one pulley is opposite to the largest step of the other pulley.

By proportionating the diameters of the different pairs of steps it is possible to achieve any desired speed.

Ratio of Belt Tension in V-Belt Drive

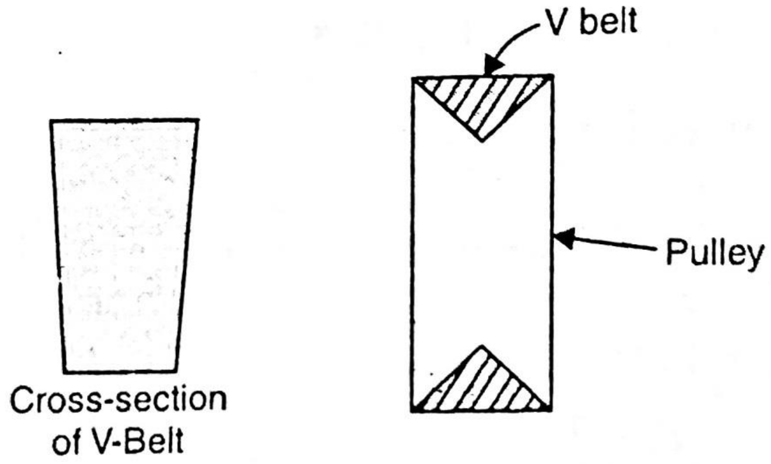


Fig. 10.6

$$\frac{T_1}{T_2} = e^{\frac{\mu\theta}{\sin\alpha}}$$

where T_1 = tension in tight side
T_2 = tension in slack side
μ = coefficient of friction
θ = angle of contact
α = angle of belt (half the angle of belt).

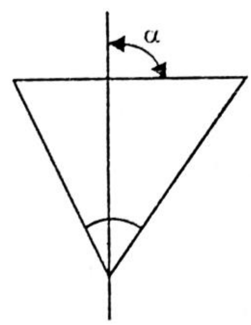


Fig. 10.7

PROBLEMS

Problem 1. A motor runs a lathe at 400 rpm the dia of motor pulley and the lathe pulley are 0.2 m and 0.6 m respectively find the velocity ratio and speed of the motor.

Sol.

Driver	Follower
d_1 = 0.2 m	d_2 = 0.6 m
n_1 = ?	n_2 = 400 rpm

$$\text{Velocity} = \frac{n_1}{n_2} = \frac{d_2}{d_1} \Longrightarrow \frac{n_1}{400} = \frac{0.6}{0.2}$$

n_1 = 1200 rpm

$$\text{Velocity ratio} = \frac{n_1}{n_2} = \frac{d_2}{d_1} = \frac{0.2}{0.6} = 1 : 3$$

Problem 2. Find the power transmitted by the belt running over the pulley of
600 mm dia, at 200 rpm. The coefficient of friction between the belt and the pulley is 0.25, angle of lap is 160° and the maximum tension in the belt is 2500 N.

Sol. Data: $T_1 = 2500$ angle of lap = 160°

$T_2 = ?$

$d = 600 \text{ mm} = 600 \times 10^{-3} = 0.6 \text{ m}$

$\mu = 0.25$

$$\theta = \frac{160 \times \pi}{180}\, radian = 2.79\, radian$$

$$\frac{T_1}{T_2} = e^{\mu\theta} \Longrightarrow e^{0.25 \times 2.79} = e^{0.6975}$$

$$\frac{2500}{T_2} = e^{0.6975}$$

$$\frac{2500}{T_2} = 2.00872$$

$$\frac{1}{T_2} = \frac{2.00872}{2500} = 8.0348 \times 10^{-4}$$

$$\frac{1}{T_2} = \frac{1}{8.0348 \times 10^{-4}} = 1243.7\, N = 1244$$

$$\text{Velocity } V = \frac{\pi d n}{60} = \frac{\pi \times 0.6 \times 200}{60}$$

$$V = 6.28 \text{ m/s}$$

$$\text{Power P} = \frac{(2500 - 1244) 6.28}{1000}$$

$$P = 7.88 \text{ kW}$$

Problem 3. Prime mover running at 230 rpm drives a DC generator by a belt drive, the diameter of the pulley of prime mover is 160 cm and that of a generator shaft is 80 cm. Find the speed of the generator shaft in the following cases:

(a) Neglecting the thickness of the belt
(b) Considering the belt thickness, when the thickness of belt is 6 mm
(c) Considering the belt thickness of and a slip of 3%
(d) Velocity of belt considering belt thickness.

Sol. (a) Neglecting the thickness of belt.

Driver	Follower
$n_1 = 240$	$n_2 = ?$
$d_1 = 160$ cm	$d_2 = 80$ cm
= 1.6 cm	= 0.8 m

r_1 = 0.8 m $\qquad$ r_2 = 0.4 m

t = 6 × 10^{-3} m

$$\frac{n_2}{n_1} = \frac{d_1}{d_2} = \frac{n_2}{240} = \frac{1.6}{0.8} \rightarrow n_2 = 480\, rpm.$$

(b) Considering the thickness

$$\frac{n_2}{n_1} = \frac{d_1+t}{d_2+t} \rightarrow \frac{n_2}{240} = \frac{1.5+(6\times10^{-3})}{0.8\times(6\times10^{-3})} \rightarrow n_2 = 428\, rpm$$

(c) Considering the thickness and % slip

t = 6 × 10^{-3} = 0.006 m^{+2}

$$\frac{n_2}{n_1} = \frac{d_1+t}{d_2+t}\left[\frac{100-S}{100}\right]$$

$$\frac{n_2}{240} = \frac{1.6+0.006}{0.8+0.006}\left[\frac{100-3}{100}\right]$$

n_2 = 463 rpm

(d) Velocity of belt considering t

$$V = \frac{\pi\,(d+t)n_1}{60} = \frac{\pi\,(1.6+0.006)240}{60}$$

= 20.18 m/s.

Problem 4. A shaft running at 150 rpm. Drives another shaft at 250 rpm to
transmit power of 20 kW. The diameter on the output shaft of the follower is 0.6 m and the distance between the centers of the two shaft is 2.7 mts. Assume the co-efficient of friction between the belt and the pulley is 0.25. Find the length of the belt and belt tension for

(a) Open belt drive

(b) Cross belt drive

Sol.

Driver	Follower
n_1 = 150 rpm	n_2 = 250 rpm
d_1 = ?	d_2 = 0.6 m
r_1 = ?	r_2 = 0.3 m
C = 2.7 mts	μ = 0.25
P = 20 kW	L = ?
T_1 = ?	T_2 = ?

We know that

$$P = \frac{(T_1 - T_2)}{1000} \qquad V = \frac{\pi dn}{60} = \frac{\pi\times0.6\times250}{60}$$

$$20 = \frac{(T_1 - T_2)7.85}{1000} \leftarrow V = 7.85\, m/s$$

T_1-T_2 = 2547 N ...(1)

Case I. Open belt drive

Length of belt $L = 2C + \pi (r_1 + r_2) + \frac{(r_1 - r_2)^2}{C}$

To find r_1

We know that $\frac{n_2}{n_1} = \frac{d_1}{d_2} \rightarrow \frac{250}{150} = \frac{d_1}{0.6}$

$d_1 = 1$ mt

$r_1 = d_{1/2} = 0.5$ mt

$L = 2C + \pi (r_1 + r_2) + \frac{(r_1 - r_2)^2}{C}$

$= 2 \times 2.7 + \pi (0.8) + \frac{(0.2)^2}{2.7}$

$L = 7.92$ mt

$$\theta = \left[180 - 2\sin^{-1}\left(\frac{r_1 + r_2}{C}\right)\right] \frac{\pi}{180}\ rad$$

$$\theta = \left[180 - 2\sin^{-1}\left(\frac{0.8}{2.7}\right)\right] \frac{\pi}{180}\ rad$$

$\theta = 2.5$ radian

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

$$\frac{T_1}{T_2} = e^{0.25 \times 2.5} = 1.868$$

$T_1 = 1.868\ T_2$

From equations (1) and (2)

$1.868\ T_1 - T_2 = 2547$

$T_2 = \frac{2547}{0.868} = 2934.3\ N$

$T_1 - 2934.3 = 2547$

$T_1 = 5481.3$ N

Similarly **Case II.**

i.e., for cross belt drive.

We know that $L = 2C + \pi (r_1 + r_2) + \frac{(r_1 - r_2)^2}{C}$

$$\theta_c = \left[180 - 2\sin^{-1}\left(\frac{r_1 - r_2}{C}\right)\right] \frac{\pi}{180}$$

$$\theta_c = \left[180 - 2\sin^{-1}\left(\frac{0.5-0.3}{2.7}\right)\right]\frac{\pi}{180}$$

θ_c = 3 radian

$$L = 2C + \pi\,(r_1 + r_2) + \frac{(r_1 - r_2)^2}{C}$$

$$= 2 \times 2.7 + \pi\,(0.5 + 0.3) + \frac{(0.5+0.3)^2}{2.7}$$

L = 8.150 mt.

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

$$= e^{0.25 \times 3.0}$$

$$\frac{T_1}{T_2} = e^{0.75} \rightarrow 2.117$$

$T_1 = 2.117\ T_2$

From equations (3) and (1)
…(3)

$2.117\ T_1 - T_2 = 2547$

$T_2 = 2280.2$ N

→ $T_1 = 4827.21$ N.

Gear Drives

A wheel provided with TEETH is called a GEAR. In other words, gears are toothed wheels used to transmit power or motion from one shaft to another, where the distance between the two shafts is relatively small. Gears are generally used for one of four different reasons:

(1) To reverse the direction of rotation.

(2) To increase or decrease the speed of rotation.

(3) To move rotational motion to a different axis.

(4) To keep the rotation of two axes synchronized

Types of Gears

There are various types of gears and the selection of a particular type of gear depends on the application. Gears are commonly classified based on the position of axis of the shaft on which the gear in mounted. The most commonly used gears are

(1) Spur gear
(2) Bevel gear

(3) Helical gear
(4) Worm gear and
(5) Rack and pinion.

Spur gears. Spur gear are the simplest and the most commonly used gears designed to transmit motion between two parallel shafts. Refer the figure, the axis of the two shafts i.e., the driving shaft and the driven shafts are parallel to each other. The teeth are cut straight on the periphery (circumference) of the wheel and they are parallel to the axis of the wheel. Spur gears are used in machines tools, gearboxes, wind-up alarm clocks and watches precision measuring instruments etc.

Spur gears are not widely used in automobiles, because each time a gear tooth engages a tooth on the other gear, the collides and this impact makes a noise. It also increases the stress on the gear teeth.

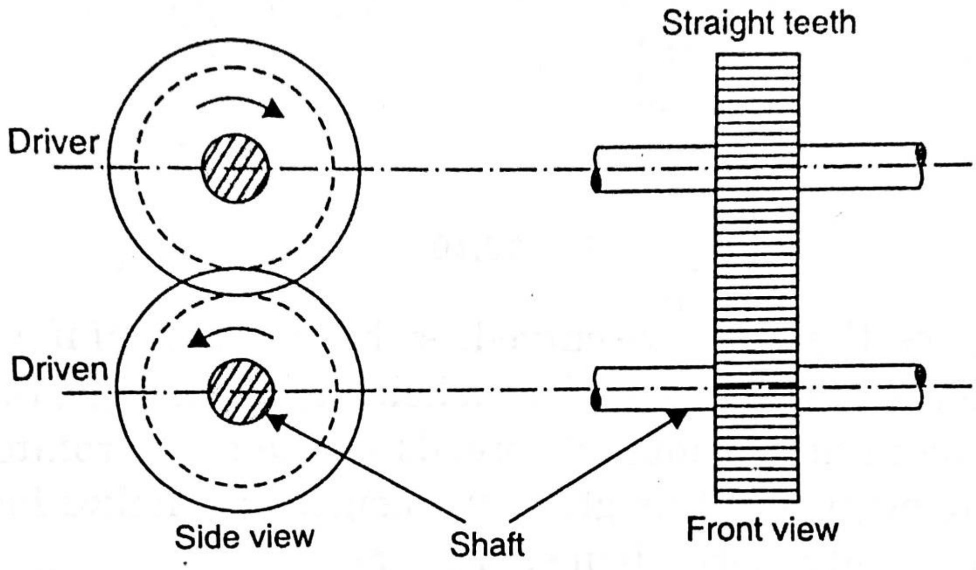


Fig. 10.8

Bevel gears. Bevel gears are used for transmitting power between two intersecting shafts. Refer figure. They are usually mounted on shafts on shafts that are 90° apart, but can be designed to work at other angles as well. The teeth are cut on the outside of conical surface and very in cross-section throughout their length. Since the diameter of the cone is greatest at its base, the teeth will be thicker at the base.

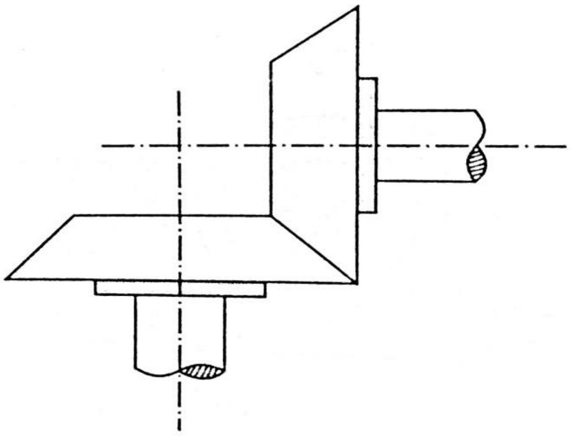


Fig. 10.9

The teeth on bevel gears can be straight or hypoid. Straight bevel gear teeth actually have the same problem as straight spur gear teeth as each tooth engages it impacts the corresponding tooth all at once. The solution to this problem is to curve the gear teeth and such gears are called spiral bevel gears, Refer figure, in these gears, the contact struts at one end of the gear and progressively spreads across the whole tooth.

Helical gears. Helical gears are used to transmit power or motion between parallel or non-parallel but non-intersection shafts, Refer figure 10.10.

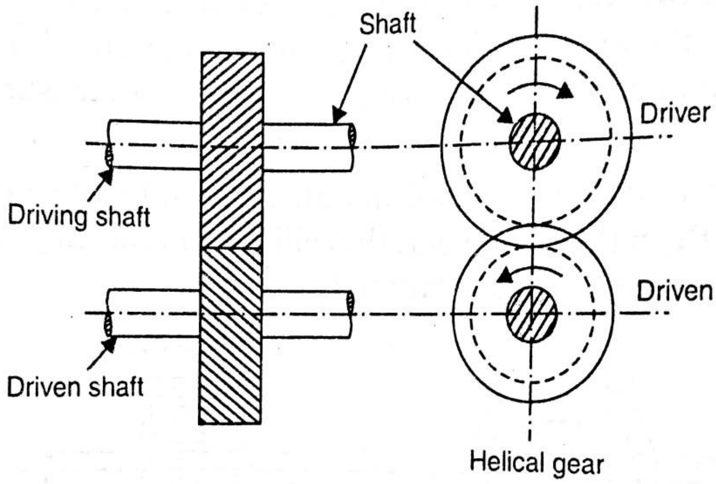


Fig. 10.10

In helical gears, the teeth are curved, each bring helical in shape and hence the name helical gears. When two teeth on a helical gear engage, the contact starts at one end of the teeth and gradually spreads as the gears rotate, until the two teeth are in full engagement. This gradual engagement makes helical gears run much more smoothly and quietly than spur gears.

Helical gears are mostly used in automobile power transmission where smooth and quiet running is necessary at higher speeds.

Worm gears. Worm gears are used to transmit power or motion between two shafts having their axis at right angles and non-intersecting. Refer figure, worm gear is a type of screw gearing that consists of a screw meshing with a helical gear. The screw is called the worm and the gear wheel meshing with the wheel is called worm gear or worm wheel. Worm gears are used when large gear reductions are needed it is common for worm gears to hence reduction of 20 : 1 and even upto 300: 1 or greater.

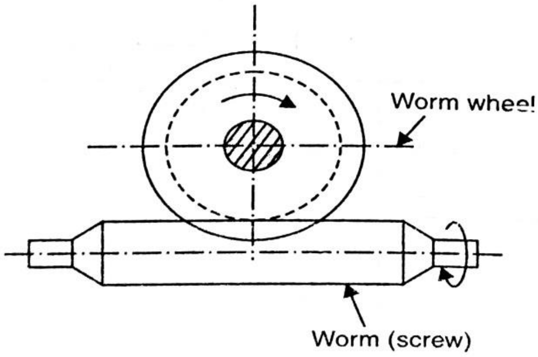


Fig. 10.11

Rack and Pinion. A rack is a gear teeth cut along a straight line, while a pinion is a gear with teeth cut along its periphery.

With the help of rack and pinion, rotary motion can be converted into linear motion.

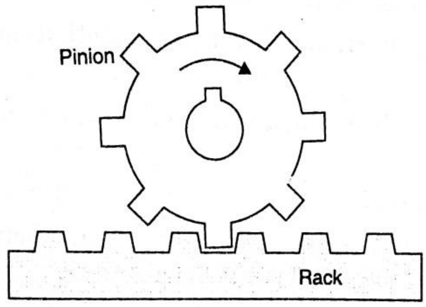


Fig. 10.12

Spur Gear Terminology

The terminology used is spur gear is shown in figure 10.13.

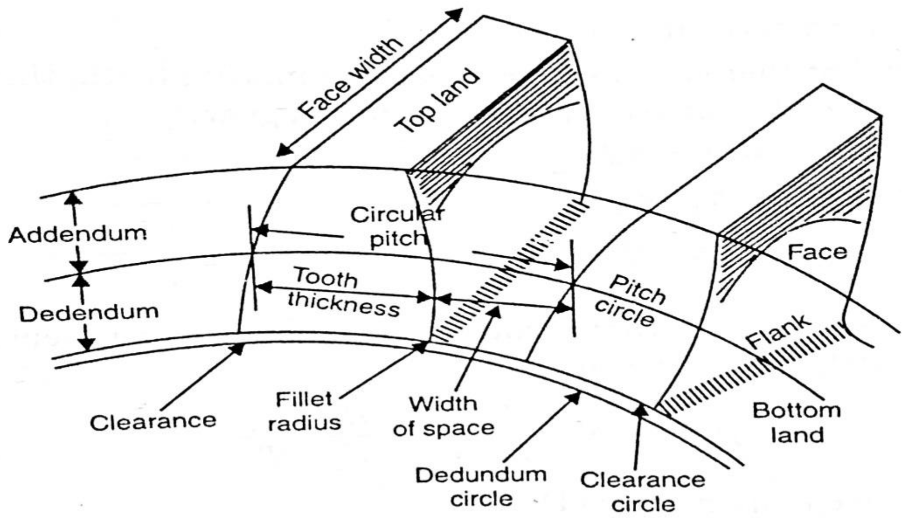


Fig. 10.13

(a) **Pitch Circle.** It is a theoretical or an imaginary circle upon which all computations are made.

(b) **Pitch Circle Diameter (PCD).** It is the diameter of the pitch circle or it is the mean diameter of the gear wheel.

(c) **Pitch (circular path).** It is the distance from a point on one tooth to the corresponding point on the next tooth measured along the pitch circle.

(d) **Module (m).** It is the ratio of the pitch circle diameter of a gear in millimetre to the number of teeth.

$$m = \frac{D}{T}$$

Where D = pitch circle dia in mm and
T = number of teeth.

Module refers to the index of the tooth size.

(e) **Addendum:** It is the radial distance of a tooth from the pitch circle to the top of the tooth.

(f) **Dedendum:** It is the radial distance of a tooth from the pitch circle to the bottom of the tooth.

Velocity Ratio of Gear Drives

Velocity ratio of gear drives is defined as the ratio between the speed of the driven gear (follower) and the speed of the driving gear.

Let d_1 = pitch circle diameter of the driving gear (driver)
d_2 = pitch circle diameter of the driven gear (follower)
T_1 = number of teeth on driving gear

T_2 = number of teeth on driven gear
n_1 = speed of the driving gear
n_2 = speed of the driven gear.

Assuming that there is no slip between the mating teeth, the liner speed of the driving gear must be same as that of the driven gear.

Hence $\pi d_1 n_1 = \pi d_1 n_2$

$d_1 n_1 = \pi d_1 n_2$

$$\frac{n_2}{n_1} = \frac{d_1}{d_2}$$

The circular pitch for both the mating gears remain same. Hence, pitch circle (P) of driver = pitch of driven gear.

$$P_C = \frac{\pi d_1}{T_1} = \frac{\pi d_2}{T_2} \text{ or } \frac{d_1}{d_2} = \frac{T_1}{T_2}$$

Substituting equation (2) in (1)

$$\frac{n_2}{n_1} = \frac{d_1}{d_2} = \frac{T_1}{T_2}$$

The ratio $\boxed{\frac{n_2}{n_1} = \frac{d_1}{d_2} = \frac{T_1}{T_2}}$ is called velocity ratio.

Thus, in gear drives, the speeds are inversely proportional to the pitch circle diameter or inversely proportional to the number of teeth.

Velocity Ratio of Worm Gears

A worm gear consists of a screw called WORM and a wheel called WORM WHEEL.

$$\text{Velocity ratio} = \frac{Speed\ of\ worm}{Speed\ of\ worm\ wheel}$$

$$= \frac{Number\ of\ teeth\ on\ worm\ wheel}{Number\ of\ threads\ on\ worm\ (worm\ shaft)}$$

Advantages and Disadvantages of Gear Drives

Advantages

- Gear drives can be used to transmit power or motion between parallel, non parallel, intersecting and non-intersecting shafts.
- Gear drives are preferred to other drives, especially, when the center distance between the two shafts is very small.
- Power can be transmitted with a constant speed ratio.
- Gear drives have high power transmission efficiency.
- They can be used for low, medium or high speed power transmission.

Disadvantages

- Gear drives are not suitable when the center distance between the two shafts is large.
- Since the teeth of driver and driven gears come in contact with each other, they always require some kind of lubrication.
- Cost for production of gears is high.
- Noise and vibration is a major problem when they rotate at high speed.
- Damage to a single gear teeth effects the whole gear arrangement.

Belt drives	Gear drives
• They are non-positive drives, as there is a reduction in power transmission due to slip.	• They are positive drives.
• Efficient when the center distance between the two shafts is greater.	• Efficient when the center distance between the two shafts is very small.
• Used to transmit power between two parallel shafts.	• Used to transmit power between parallel, non-parallel intersecting and non-intersecting shafts,
• Due to slip, exact velocity ratio cannot be maintained	• Due to two absence of slip, constant velocity ratio can be maintained.
• Only moderate power can be transmitted.	• Can be used for, low, medium or high power transmission.
• Power transmission efficiency is low.	• High power transmission efficiency.
• Lubrication is not required.	• Requires some kind of lubrication.

Gear Trains

Depending on the arrangements of wheels, gear trains are classified as:

(1) Simple gear train
(2) Compound gear train
(3) Reverted gear train and
(4) Epicycle gear train

(To be discussed in this section.)

Simple gear train. A simple gear train consists of a number of gear mounted over shaft carries only one gear.

Let n_1 = speed of gear 1 or driver in rpm
n_2 = speed of gear 2 or driver in rpm
T_1 = number of teeth on gear 1
T_2 = number of teeth on gear 2

We know that, in gear drives, speeds are inversely proportional to the number of teeth.

$$\text{Velocity ratio} = \frac{n_2}{n_1} = \frac{T_1}{Tr_2}$$

Or $$\frac{Speed\ of\ driven}{Speed\ of\ driver} = \frac{number\ of\ teeth\ on\ driver}{number\ of\ teeth\ on\ driven}$$

In certain cases, when power is to be transmitted between two shafts that are at large distance. This can be done by providing one or more intermediate gears as shown in figure 10.14.

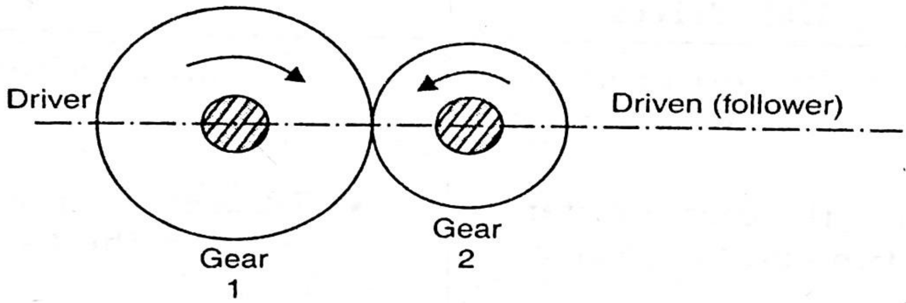


Fig.10.14.

These intermediate gears called ' idle gears'. The idlers gear does not affect the 'velocity ratio' but only serves to fill up the space between the driver and the driven gears. They also help in achieving the required direction of rotation for the driven wheel.

Let n_1, n_2, n_3 and n_4 be the speeds and T_1, T_2, T_3 and T_4 be the number of teeth on gear 1,2,3 and 4 respectively.

Gear 1 drives gear 2

$$\text{Velocity ratio} = \frac{n_2}{n_1} = \frac{T_1}{T_2}$$

Gear 2 drives gear 3

$$\text{Velocity ratio} = \frac{n_3}{n_2} = \frac{T_2}{T_3}$$

Similarly Gear 3 drives gear 4

$$\text{Velocity ratio} = \frac{n_4}{n_3} = \frac{T_3}{T_4}$$

Thus, multiplying equations 1, 2, 3

$$\text{Velocity ratio} = \frac{n_2 \times n_3 \times n_4}{n_1 \times n_2 \times n_3} = \frac{T_1 \times T_2 \times T_3}{T_2 \times T_3 \times T_4}$$

$$\text{Velocity ratio} = \frac{n_4}{n_1} = \frac{T_1}{T_4}$$

$$\text{Velocity ratio} = \frac{Speed\ of\ last\ gear}{Speed\ of\ first\ gear}$$

$$= \frac{Number\ of\ teeth\ on\ first\ gear}{Number\ of\ teeth\ on\ last\ gear}$$

Note:

Case I. Gear train with one idler: Consider a simple gear train with one idler gear as shown in figure.

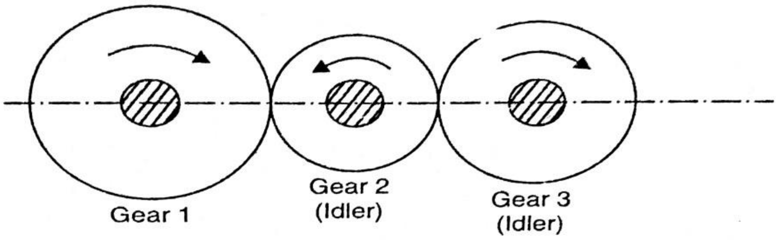


Fig.10.15

(a) Let gear 1 rotates in clockwise direction i.e., gear 1 drives gear 2. Hence gear 2 rotates in counter clockwise direction. Next gear 2 drives gear 3 hence gear 3 rotates in clockwise direction.

Case II. Gear train with two idlers: Consider a simple gear train with 2 idler gears as shown in figure.

(b) The rotation of each gear is shown in the figure.

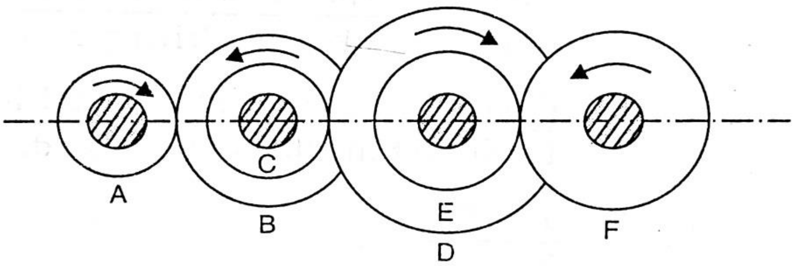


Fig.10.16

Form (a) and (b) it can be concluded that:

- If 'even' number of idler gear are used the first (driver) and last gear (driven) will rotate in opposite directions.
- If 'odd' number of idler gear are used the first (driver) and last gear (driven) will rotate in same directions.

Compound Gear Trains

A compound gear train is the one, in which each shaft carries two or more gears. It was clear that from discussion made in previous section that intermediate gear does not affect the speed ratio. Thus whenever the distance between the two shafts is large and at the same time, higher or much less speed is required, compound gears are provided with intermediate shafts. A compound gear train is shown in figure 10.17.

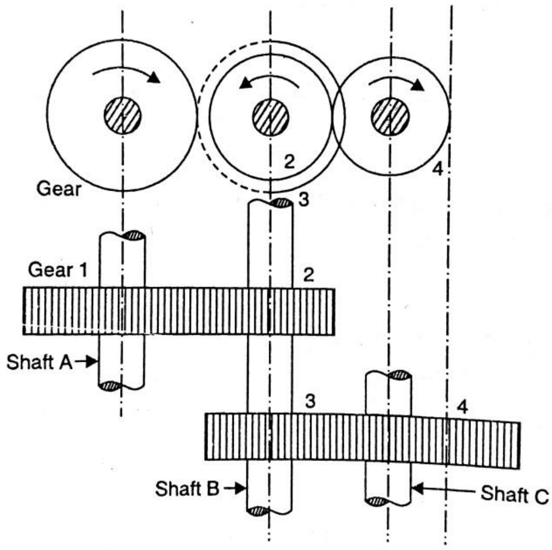


Fig.10.17

In the above gear train, gear 1 and gear 4 are mounted on separate shafts, but gear 2 and gear 3 are mounted (keyed) on a single shaft B. Hence gears 2 and 3 are called compound gears.

Since gear 2 and gear 3 are keyed to same spindle, they rotate at same speed.

Let n_1, n_2, n_3 and n_4 be the speeds

T_1, T_2, T_3 and T_4 are the number of teeth on gears.

Gear 1 drives gear 2

Velocity ratio = $\frac{T_1}{T_2} = \frac{n_2}{n_1}$

Gear 3 drives gear 4

Velocity ratio = $\frac{n_4}{n_3} = \frac{T_3}{T_4}$

Thus, multiplying equations 1, 2, 3

Velocity ratio = $\frac{n_{2} \times n_4}{n_1 \times\ n_3} = \frac{T_1 \times T_3}{T_2 \times T_4}$

n = n_3 since gear 2 and gear 3 are keyed to the same spindle.

Velocity ratio = $\frac{n_4}{n_1} = \frac{T_1 \times T_3}{T_2 \times T_4}$

Velocity ratio = $\frac{Speed\ of\ last\ gear}{Speed\ of\ first\ gear}$

$= \frac{Product\ of\ Number\ of\ teeth\ on\ driver}{Product\ of\ Number\ of\ teeth\ on\ driven}$

PROBLEMS

Problem1. A person riding a bicycle turns the pedal at 40 rpm. Find the speed of the wheel, if the no. of teeth in the driving sprocket is 50 and that in driven sprocket is 25.

Sol. Driving sprocket — Driven sprocket

n_1 = 40 rpm — n_2 = ?

T_1 = 50 teeth — T_2 = 25 teeth

We know that, velocity ratio of gear drives = $\frac{n_2}{n_1} = \frac{T_1}{T_2}$

$$\frac{n_2}{40} = \frac{50}{25}$$

n_2 = 80 rpm

Problem 2. The velocity ratio of a gear drive is 2. The driving wheel has 16 teeth and turns at 120 rpm. Find the rpm and the number of teeth on the driven wheel.

Sol. Driving wheel — Driven

n_1 = 120 — n_2 = ?

T_1 = 16 teeth — T_2 = ?

$$\frac{n_2}{n_1} = 2$$

We know that $\frac{n_2}{n_1} = \frac{T_1}{T_2}$

$$2 = \frac{16}{T_2}$$

T_2 = 8 teeth

$$\frac{n_2}{n_1} = \frac{T_1}{T_2}$$

$$\frac{n_2}{120} = \frac{16}{8}$$

n_2 = 240

Problem 3: A simple gear train consists of three gears, the number of teeth on the driving gear is 60 and on the idler is 40 and on the driven gear is 80. Find the velocity ratio, if the driving gear rotates at 1200 rpm. Calculate the speed of the driven gear.

Sol. (a) Let gear 1 rotate in clockwise direction

Gear 1	Gear 2	Gear 3
T_1 =60	T_2 = 40	T_3 = 80

n1 = 1200 rpm

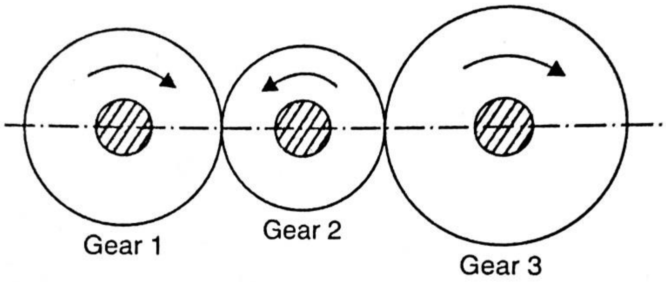


Fig.10.18.

We know that velocity ratio = $\frac{n_2}{n_1} = \frac{T_1}{T_3}$

$$= \frac{n_2}{1200} = \frac{60}{80}$$

n_3 = 900 rpm

(b) Velocity ratio

$$\frac{n_3}{n_1} = \frac{900}{1200} = \frac{3}{4}$$

$$\frac{n_3}{n_1} = 3{:}4$$

Problem 4. In a compound gear train of wheels ABC and D have 15, 30,20 and 40 teeth respectively. The wheels B and C are keyed to the same spindle. If the wheel A runs at 400 rpm. Find the speed of wheel D. Sketch the arrangement if B meshes with A and C meshes wid D.

Sol. Assuming the gear 'A' to rotate in clockwise direction.

Gear A drives Gear B and Gear C drives Gear D.

Driving wheel Driven

Gear A Gear C Gear B Gear D

T_A = 15 T_c = 20 T_B = 30 T_D = 40

n_A = 400

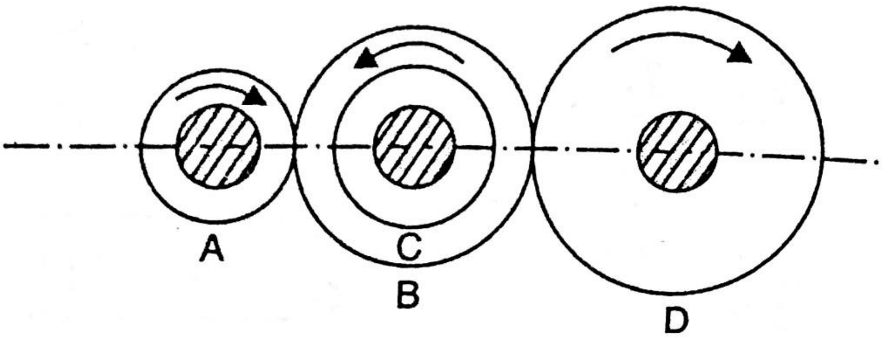


Fig. 10.19

We know that, velocity ratio for compound gear train

$$= \frac{Product\ of\ Number\ of\ speed\ of\ driven\ gears}{Product\ of\ Number\ of speed\ of\ driver\ gears}$$

$$= \frac{Product\ of\ Number\ of\ teeth\ on\ driver\ gears}{Product\ of\ Number\ of\ teeth\ on\ driven\ gears}$$

$$\frac{n_B.n_D}{n_A.n_C} = \frac{T_A.T_C}{T_B.T_D} \qquad ...(1)$$

Since B and C are keyed to the same spindle, they rotate at same speeds.

$n_B = n_C$

Equation (1) becomes.

$$\frac{n_D}{n_A} = \frac{T_A.T_C}{T_B.T_D}$$

$$\frac{n_D}{400} = \frac{15 \times 20}{30 \times 40}$$

$n_D = 100$ rpm   Speed of wheel D

Problem 5: Figure shows the gears used in a machine tool. The shaft from the motor is connected to gear A and rotates at 950 rpm. Gear wheels B, C, D and E are fixed to parallel shafts rotating together. Gear G is fixed on the output shaft. Determine the speed of gear F. The number of teeth on each gear are given below.

Gear	A	B	C	D	E	F
Number of teeth	20	50	25	75	25	65

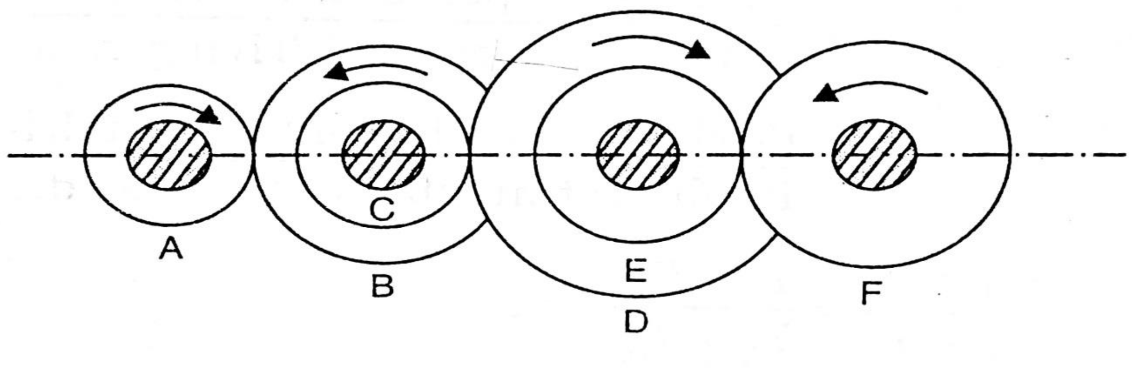


Fig. 10.20.

Sol. Let gear A rotate in clockwise direction

Driving gears   Driven gears

Gear A	Gear C	Gear E	Gear B	Gear D	Gear F
T_A = 20 Teeth	T_C = 25	T_E = 25	T_B = 50	T_D = 75	T_F = 65
n_A = 950 rpm					n_p = ?

We know that

$$\text{Velocity ratio} = \frac{Product\ of\ Number\ of\ speed\ of\ driven\ gears}{Product\ of\ Number\ of speed\ of\ driver\ gears}$$

$$= \frac{Product\ of\ Number\ of\ teeth\ on\ driver\ gears}{Product\ of\ Number\ of\ teeth\ on\ driven\ gears}$$

$$\frac{n_F}{n_A} = \frac{n_A.n_C.n_E}{n_B.n_D.n_F}$$

$$\frac{n_F}{950} = \frac{20 \times 25 \times 25}{50 \times 75 \times 65} \rightarrow n_F = 48.72\ rpm$$

Problem 6. A compound gear consists of 4 gears. P, Q, R, Shaving 20, 40, 60 and 80 teeth respectively. The gear P is keyed to the driving shaft, gear S to driven shaft Q and R are compound gears, Q meeting with P and R meshes S, if P rotates at 150 rpm, what is the rpm of gear 'S' show gear arrangement.

Sol.

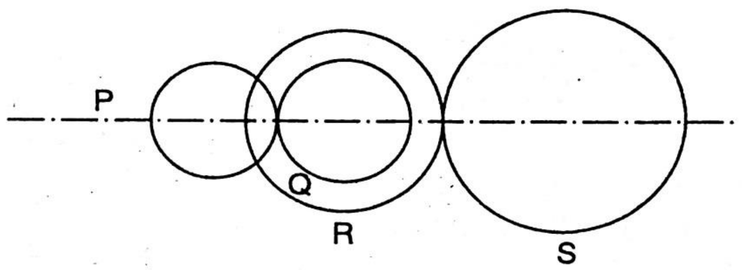


Fig. 10.21.

Driver		**Driven**	
Gear P	Gear R	Gear Q	Gear S
T_P = 20 n_P = 150	T_R = 60	T_Q = 40	T_S = 80

We have

$$\text{Velocity ratio} = \frac{Product\ of\ speeds\ of\ driven\ gears}{Product\ of\ speeds\ of\ driving\ gears}$$

$$= \frac{Product\ of\ Number\ of\ teeth\ on\ driver\ gears}{Product\ of\ Number\ of\ teeth\ on\ driven\ gears}$$

$$\frac{n_Q \times n_S}{n_P \times n_R} = \frac{T_P \times T_R}{T_Q \times T_S}$$

$n_Q = n_R$ since they are keyed to the shaft

$$\frac{n_S}{n_P} = \frac{T_P \times T_R}{T_Q \times T_S}$$

$$\frac{n_S}{150} = \frac{20 \times 60}{40 \times 80}$$

n_S = 56.25 rpm

Approximate rpm of gear S = 56.

SUMMARY

- Belt drives are used to transmit power from one shaft to another placed at a known distance.
- Spur gear is the simplest and the most commonly used gears designed to transmit motion between two parallel shafts.
- Bevel gears are used for transmitting power between two intersecting shafts.
- Helical gears are used to transmit power or motion between parallel or non- parallel but non-intersection shafts.
- Worm gears are used to transmit power or motion between two shafts having their axis at right angles and non-intersecting.
- Pitch circle is a theoretical or an imaginary circle upon which all computations are made.
- Addendum is the radial distance of a tooth from the pitch circle to the top of the tooth.
- Dedendum is the radial distance of a tooth from the pitch circle to the bottom of the tooth.
- A simple gear train consists of a number of gear mounted over the shaft that each shaft carries only one gear.

REVIEW QUESTIONS

1. What are types of belt drives? Explain in details.
2. Write short note on (a) super gear (6) bevel gear (c) helical gear.
3. Differentiate between belt drives and gear drives.
4. Discuss about the power transmission briefly.

CHAPTER

11 MECHATRONICS

STRUCTURE

11.0 LEARNING OBJECTIVES

After going through this chapter, you will be able to:

- describe the advantages and disadvantages of open loop control system
- discuss about the concept of mechatronics system
- differentiate between measurement system and control system
- define the mechatronics
- what are types of control system? Explain in details

11.1 MECHATRONICS

Mechatronics can be defined as the integration of mechanical engineering with electronic, electrical, computer, control engineering for design and manufacturing of engineering products.

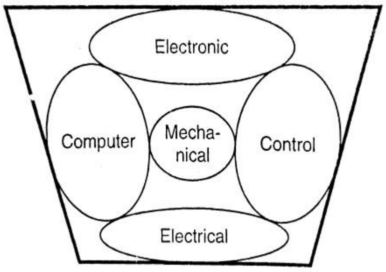


Fig.11.1 Mechatronics product

Concept of Mechatronics System

In any mechatronics system, the mechanical element does the actual operation.

- Electrical elements provide the necessary power for functioning of other elements.
- The electronic elements, usually a microprocessor controls and co-ordinates the functions of various elements based on the input.
- Control elements; control the output of the system in a desired manner.

Application

Mechatronics finds its applications in Robots, manufacture of CNC. Machines, Automobiles, Printing machines, Automatic camera, Washing machines etc.

Systems of Mechatronics

A system may be defined as a device that has an input and an output. The block diagram of a system is shown below.

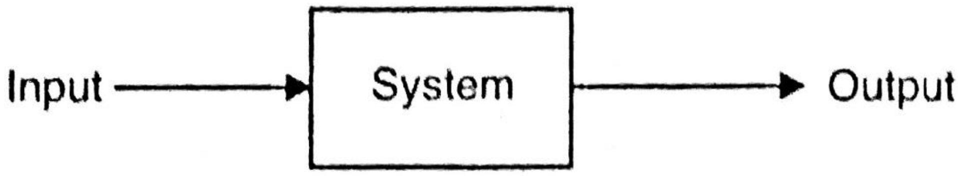


Fig.11.2. Block diagram of system

For example, an electronic motor can be considered as an 'Electric System that receives the electrical energy (input) and transforms into mechanical energy of rotation of shafts at the output. The block diagram for the above system is

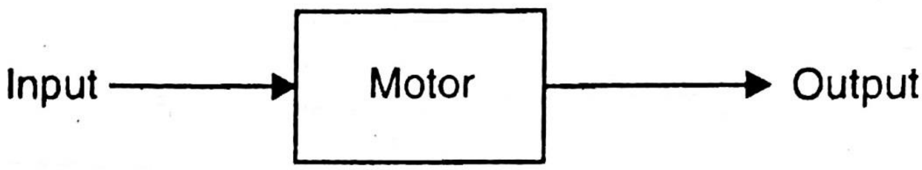


Fig.11.3. Electric system

There are two important systems involved in mechatronics. They are

1) **Measurement system and**
2) **Control system**

1) Measurement system: It is defined as a system used for measuring various parameters. The input is the quantity to be measured and the output is the value of that quantity.

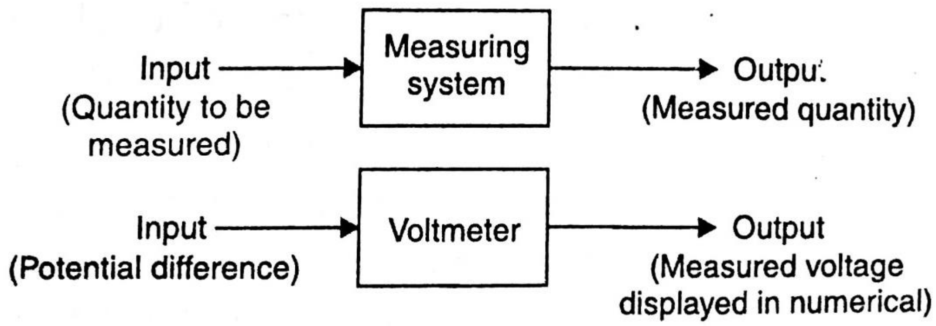


Fig. 11.4

E.g. **Voltmeter.** The input is the voltage across two power liner and the measured voltage is displayed in numerical as output.

2) Control system: The control system is a device, that controls the output of a system to be at same specific value, or changes the output of a system in some desired manner.

Fig. 11.5

E.g. **Thermostat.** A thermostat in an electric water heater acts as a control system. The thermostat cuts off the power supply as soon as the temperature of the water reaches a preset value.

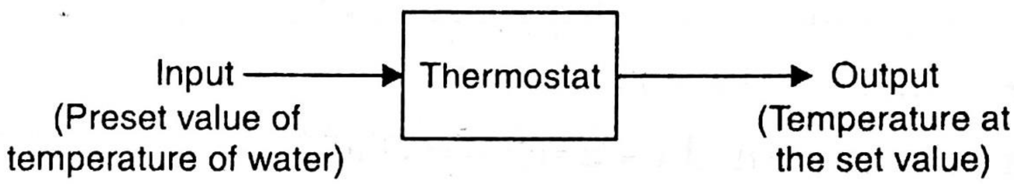


Fig. 11.6

Elements of Measurement System

A group of elements used to measure a physical quantity constitute a measurement system. The measurement system consists of three basic elements viz.

- Sensor
- Signal conditioner and
- Display device

The block diagram of a generalized measurement system is shown below.

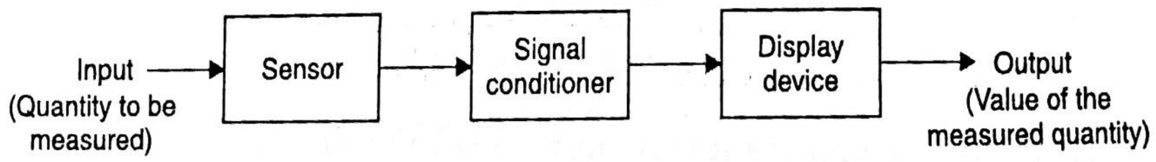


Fig. 11.7

Sensor/transducer. A sensor is a device that senses or detects the input and converts it into a suitable form. The sensor gives into output as a signal to the next stage called the 'Signal conditioner'.

Signal conditioner. The signal conditioner receives the signal from the sensor and converts/amplifies the signal into a desired condition so as to make it suitable either for display or send the amplified signal to a control system for actual control.

Display system. The display system receives the modified amplified signal from the signal conditioner and displays the result as output. The display system can be an indicating instrument (like switch (ON/OFF)) or recording instrument, where the output is displayed in the form of text or numerical value.

The functions of the above elements can be best understood by considering a digital thermometer.

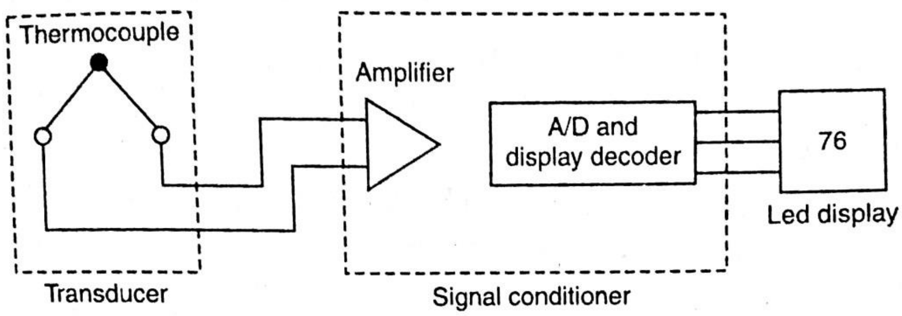


Fig. 11.8. Block diagram of digital thermometer.

Fig.11.8. Block diagram of digital thermometer

Here the thermocouple acts as a transducer as it converts the temperature into voltage. It responds to the variation of heat of a substance and sends the signal in the form of e.m.f. Since the generated e.m.f. is very small, it needs to be amplified. The low voltage signal is fed to an amplifier, where it gets amplified and the amplified signal is fed to an analog/digital converter that converts the analog voltage signal to digital signal. Finally LED displays the value of the temperature in numericals.

Types of Control Systems

There are two types of control systems. They are

1) **Open loop control system and**
2) **Closed loop control system.**

1) Open loop control system: Any system which does not automatically correct, for variations in its output are called open loop control system. In open loop control system, there is no feedback from the output to the input.

The output remains constant input signal provided the external conditions remain unaltered. But any variations in the external conditions or internal parameters of the system may cause the output to vary from the desired value. Hence, such systems are inaccurate and unreliable. The block diagram of an open loop control system is shown in figure 11.9.

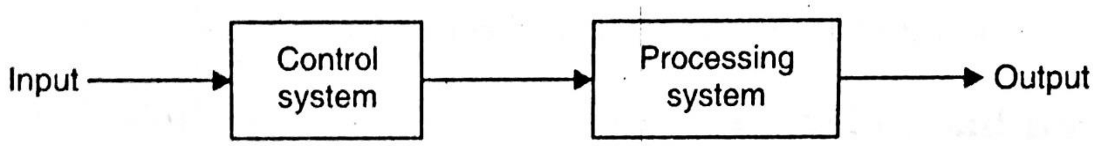


Fig.11.9. Block diagram of open loop control system

Example1. Room heater

Assume that the room is to be heated by an electric heater controlled by a switch. The amount of heat generated by a room heater is dependent on the input of electric current.

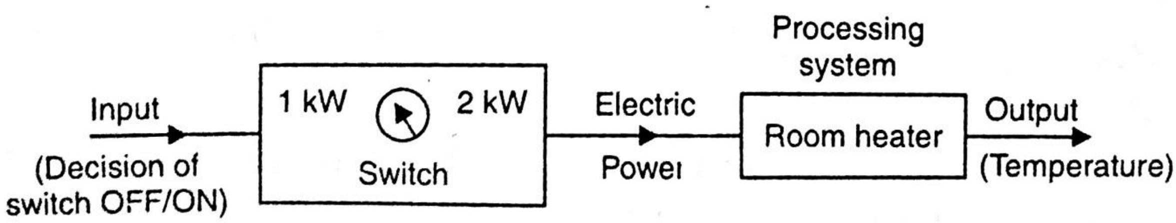


Fig. 11.10

If a person turns on the 1 kW switch. The room will heat up and reach particular temperature. But any variations such as low voltage or when the windows being opened, reduces the temperature in the room. There is no heat adjustment to compensate this variations.

Thus, there is no information feed back to the heating system. Such a system that does not automatically correct for variations in its output is called an open loop control system.

Example2. Water tank without water level controller

Consider a water pump without water level controller. Assume that the tank is half full and when the water is to be pumped to the tank, the motor is switched on. After a short time, the motor is switched OFF without knowing whether the tank is fully filled or not. Thus the control action (Switching OFF Motor) is independent of the output (whether tank is fully filled or not).

2) **Closed loop control system:** Any system that can automatically correct
for variations in its output is called a closed loop control system. The changes in the output can be corrected in the desired manner by means of feedback elements. In other words, a closed loop system has a feedback from the output to the input.

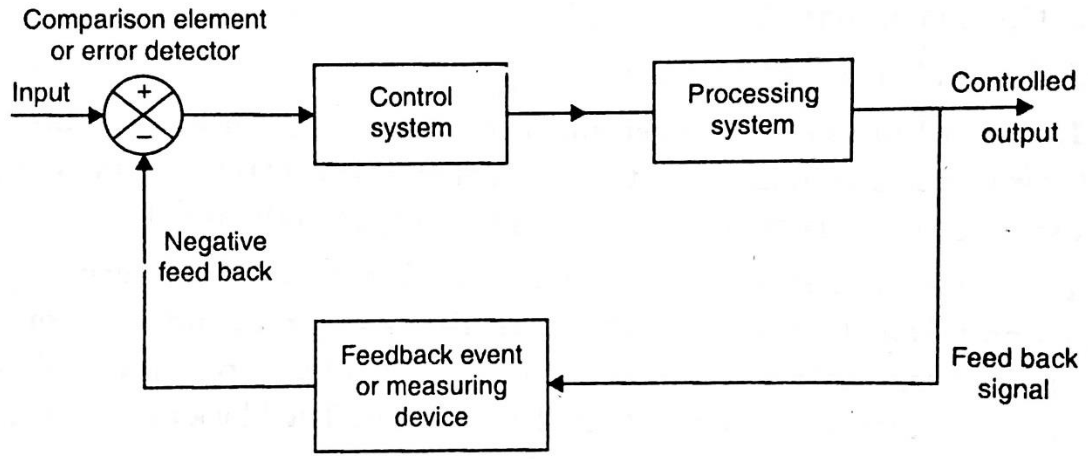


Fig.11.11. Block diagram of a closed loop control system

(a) **Feedback element.** The conditions at the output are feed back to the input through feedback elements.

(b) **Error detector or comparison element.** The error detector receives the feedback and compares it with the reference input. The error signal is then passed to the control system.

(c) **Control system.** It receives the error signal from the error detector and decides the necessary action to be taken.

(d) **Processing system.** The processing system alerts the conditions so as to obtain the desired output.

Example. Consider the case of a water level controller for a overhead tank
as shown in figure 11.12.

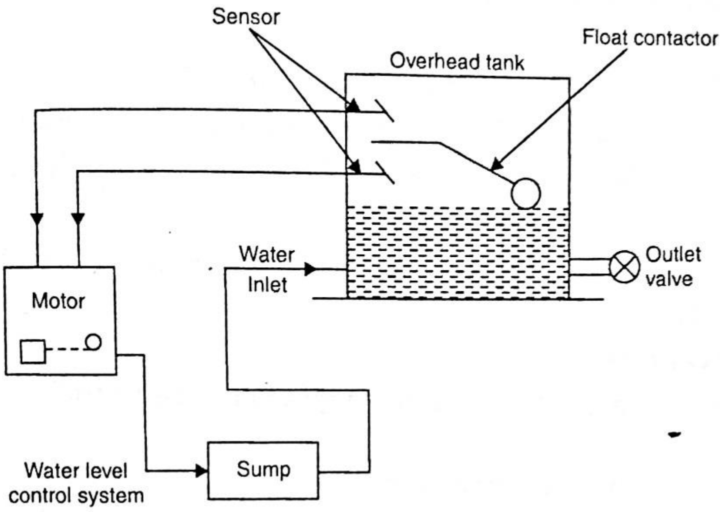


Fig.11.12. Water level controller for overhead tank

The block diagram for the above system is shown in figure 11.13.

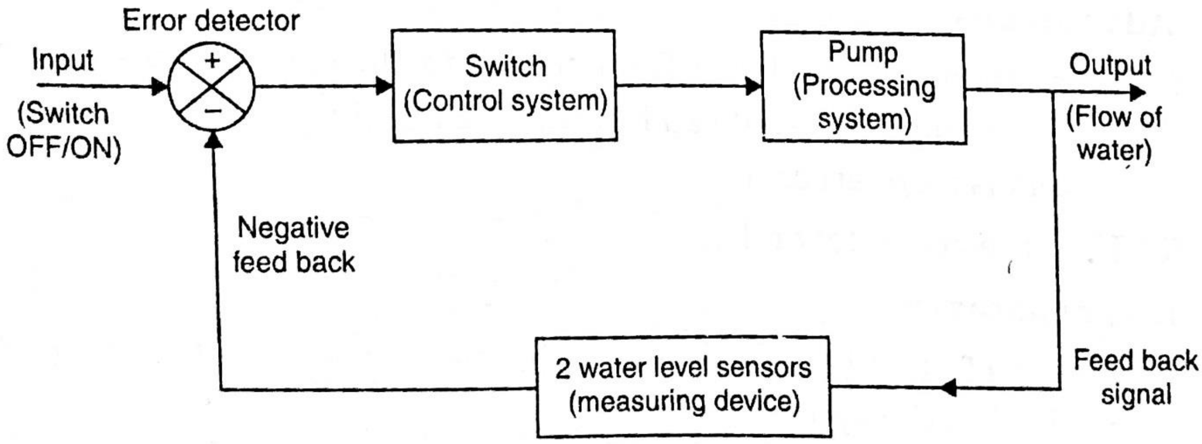


Fig.11.13. Block diagram for water level controller system

Consider the working of a water pump with water level controller. Two sensors, one to sense minimum water level and other to sense the maximum level of water are immersed in the tank as shown in the figure.

When the water level in the tank falls to the minimum level, the float contactor touches the lower sensor, and immediately, Feedback signals are sent to the electronic water level control system to switch ON the pump motor.

The water from the sump flows into the tank and when it reaches the maximum level, the float contactor touches the upper sensor and immediately, feedback signals are sent to the water level control system to switch OFF the motor.

Thus, with the help of feedback signals, the output can be controlled in the desired manner. Hence, in a closed loop control system, the control action is dependent on the output.

Other examples of closed loop control system are automatic iron box, controlling speed of a vehicle, room temperature controller, etc.

Advantages and Disadvantages of Open Loop Control System

Advantages

(a) Open loop control systems are simple in construction.

(b) They are less expensive due to the absence of control comparison elements.

(c) Less maintenance due to the absence of complex elements.

(d) No stability problem.

(e) This type of system is convenient when the output may be different from what is desired.

Disadvantages

(a) Since there is no feedback, the output cannot be controlled in the desired way.

(b) The system in inaccurate and unreliable.

(c) Disturbances and changes in calibration cause errors and the output may be different from what is desired.

Advantages and Disadvantages of Closed Loop Control System

Advantages

(a) Since there is a feedback from output to the input, any errors can be detected and the output can be controlled in the desired way. Hence, the system is more accurate.

(b) They are accurately reliable.

Disadvantages

(a) Design of closed loop system is difficult since complex elements are involved in the system.

(b) Stability is a major problem in closed loop system since they may tend to over correct the errors that may cause oscillations.

(c) More expensive

(d) Maintenance cost is high.

Microprocessor Based Controllers

Most of the control systems used in mechanical machines/devices are operated by means of cams, levers etc. These devices after continuous use have to be replaced and also the control actions are quite slower with the advancement in electronic technology, use of microprocessors are finding wide applications in mechanical fields.

A microprocessor is an Integrated Circuit (IC) chip that carries out control functions. Microprocessors are widely used for process control applications in which variables like temperature pressure, fluid flow, liquid level, etc., are controlled efficiently.

In all microprocessor based system, control systems two types of microprocessors are used.

- **Embedded, microprocessor-controller.** Embedded micro-controller is a micro-processor with memory integrated in one chip and programmed to perform only a specific task.
- **Programmable logic controller.** This is a microprocessor based controller that uses programmable memory to store instructions to perform various functions such as logic, sequence, timing counting and arithmetic etc. Such controllers can be easily reprogrammed so as to meet different functional requirements.

Figure shows a programmable logic controller

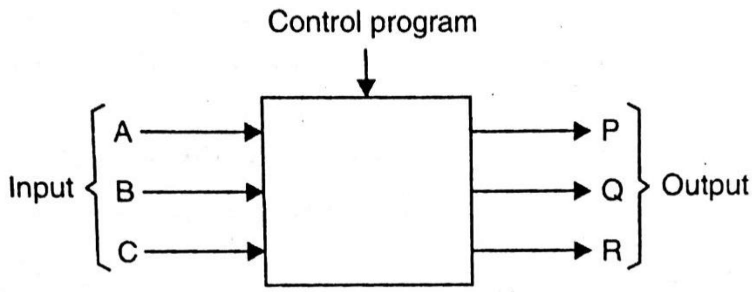


Fig.11.14. Programmable logic controller

For each one of the inputs, the controller gives the desired output. An example is given to illustrate the use of microprocessor based systems.

Example. Engine Management System

Consider the engine of a car that is of 4-stroke engine. In a 4-stroke IC engine, there are several cylinders, each of which has a piston connected to a common crankshaft and each of which carries out a 4-stroke sequence of operations.

The ignition and fuel required for each of the cylinder is controlled by the engine management system.

- In a 4-stroke engine, when the piston moves downwards, suction valve opens and air fuel mixture enters into the cylinder.
- When the piston moves up, suction valve closes and the air-fuel mixture is compressed.
- When the piston reaches the top end of the cylinder, the S-plug ignites the mixture.

For ignition to take place at the right time, the crankshaft driver a distributer that makes electrical contacts for each spark plug in turn and a timing wheel, this timing wheel generates pulses to indicate the position of crankshaft.

The microprocessor then adjusts the timing at which high voltage pulses are sent to the distributor so that the spark occurs at the right time. The quantity of intake of air-petrol mixture is controlled by the microprocessor that activates a solenoid to open the inlet valve.

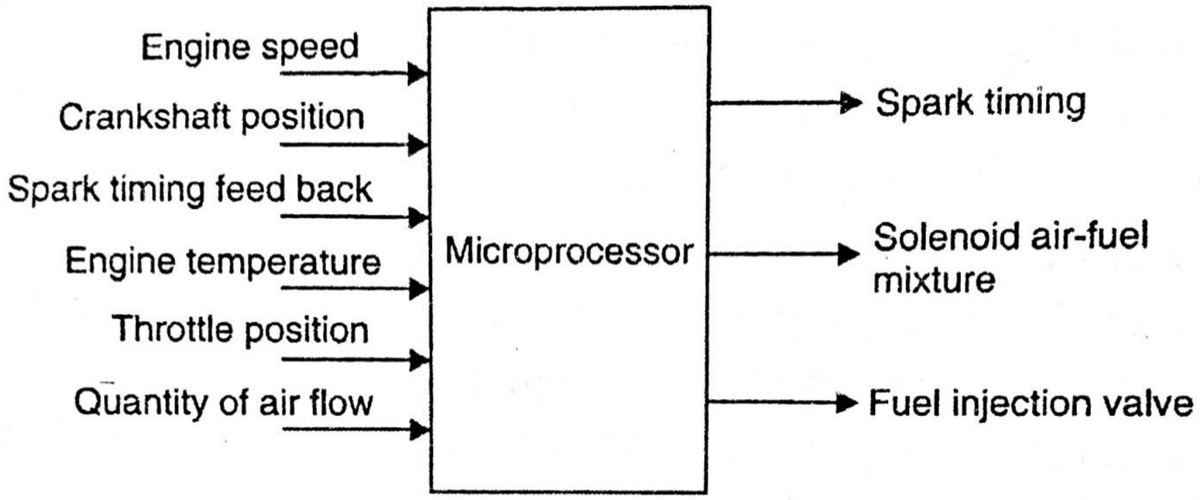


Fig.11.15. Engine management system

The amount of fuel to be injected (by carbonator) into the air stream can be determined by an input from a sensor of the mass rate of air flow or computed from other requirements. The microprocessors then give the output to control the fuel injection valve.

Thus, the value timing, ignition timing air-fuel mixture, fuel injection is all controlled by the microprocessor depending on the speed and load on the engine.

Applications of Microprocessor Based Controllers

- It is used to control the ignition timing and air-fuel mixture supply in multi cylinder IC engine

- In automatic electronic cameras
- Microwave ovens
- Video recorders
- CNC machines
- Robots etc.

SUMMARY

- Measuring system is defined as a system used for measuring various parameters. The input is the quantity to be measured and the output is the value of the quantity.
- An electronic motor can be considered as an 'Electric System' that receives the electrical energy (input) and transforms into mechanical energy of rotation of shafts at the output.
- A sensor is a device that senses or detects the input and converts it into a suitable form. The sensor gives into output as a signal to the next stage called the signal conditioner.
- Thermostat in an electric water heater acts as a control system. The thermostat cuts off the power supply as soon as the temperature of the water reaches a preset value.

REVIEW QUESTIONS

1) Describe the advantages and disadvantages of closed loop control system.

2) Explain the elements of measurement system.

3) Differentiate between open loop control system and closed loop control system.

4) What are important systems involved in mechatronics? Explain in details.

5) Define Mechatronics and what are the application areas of mechatronics?