Module III

Refrigeration and air conditioning

3.1. Refrigeration

Refrigeration is the process of maintaining a system at a temperature below the temperature of its surroundings. It can be accomplished by removing heat from the system. For example the household refrigerator absorbs heat from the food products and release this heat into the room where it is kept and thus a constant temperature is maintained inside the refrigerator cabinet. The equipments employed to maintain the system at a lower temperature is termed as refrigerating system and the system which is kept at lower temperature is called refrigerated system. The working fluid used in a refrigerating system is known as refrigerant.

Refrigeration may be obtained by adopting either natural methods or artificial methods. Natural methods include melting of ice. When ice melts, the heat from its surroundings flows into the ice and the surrounding space gets cooled. The natural methods of refrigeration were used in early days. Now, with the development of artificial means of refrigeration (mechanical refrigeration) the application of natural methods becomes insignificant. Hence the term refrigeration is actually used in these days for cooling by mechanical means.

The applications of refrigeration can be broadly classified into three groups as (i) Industrial processes which includes processing of food stuffs, farm crops, photographic materials, petroleum and other chemical products, treatment of concrete for dams, processing in textile mills, printing works etc.

(ii) Preservation of perishable goods which includes storage and transportation of food stuffs (eg. Fish, fruits, vegetables, meats, dairy products, poultry products etc).

(iii) Providing comfortable environment which includes comfort air conditioning of residences, hospitals, theatres, offices etc.

3.2. Types of refrigerators.

There are two types of mechanical refrigerators.

i) Air refrigerator in which air is the working fluid and

ii) Vapour refrigerator in which vapours like ammonia, carbon dioxide, sulphur dioxide, freon etc. are used as the working fluid.

3.3. Unit of refrigerating capacity

The rate of heat absorbed from a body or space to be cooled is termed as refrigerating effect. The standard unit of refrigeration is ton refrigeration or simply ton.

The rate of heat absorbed by the system from the body to be cooled , equivalent to the latent heat of fusion of one ton of ice from and at 0°C in 24 hours is called one ton refrigeration. The term ton refrigeration is a carry over from the time ice was used for cooling. This unit of refrigerating capacity is currently used in USA, UK and India. In many countries the standard MKS unit of kcal per hr. is in use. In general, one ton refrigeration always means 3.5167 kJ of heat removal per second.

3.4. Coefficient Of Performance (COP)

The effectiveness of a refrigerator is expressed by a term known as coefficient of performance. It is the ratio of desired refrigerating effect to the work spent to produce the refrigerating effect

$$\text{COP} = \frac{\text{Desired refrigerating effect}}{\text{Work spent in producing the refrigerating effect}}$$

domestic purpose COP b/w 1 & 2

COP of a refrigerator will be greater than unity.

3.5. Vapour compression refrigeration system

only vapour should enter the compression system

In a vapour compression refrigerator the working fluid is a vapour which readily evaporates and condenses. During the evaporation process it absorbs heat and gets converted from liquid to vapour . During the condensing process it rejects heat and gets converted from vapour to liquid.

3.6. Simple vapour compression system

A simple vapour compression system of refrigeration consists of the following basic components:

i) Compressor

ii) Condenser

iii) Expansion valve

iv) Evaporator

The line diagram of the arrangement is shown in Fig. 3.1.Let the vapour leaving the evaporator be dry saturated. This dry saturated vapour at pressure p_1 and temperature T_1 is drawn into the compressor cylinder during its suction stroke and during the compression stroke the vapour is compressed isentropically to pressure p_2 and temperature T_2. This process is shown by line 1-2 in the P-H diagram as well as in the T-S diagram. At the end of compression the vapour is in a superheated state. The vapour at this condition passes to the condenser in which cooling water is circulated to remove heat from the vapour. The vapour is first cooled to the saturation temperature and further removal of latent heat of condensation it condenses to liquid till point 3 is reached. The high pressure liquid is expanded in an expansion valve (throttle valve). The pressure of liquid is lowered to p_1 and the condition obtained after the constant enthalpy expansion process is shown by point 4. During throttling the liquid partly evaporates and after throttling we get wet vapour at the low temperature T_1 and low pressure p_1. This wet vapour passes through the evaporator coils immersed in the

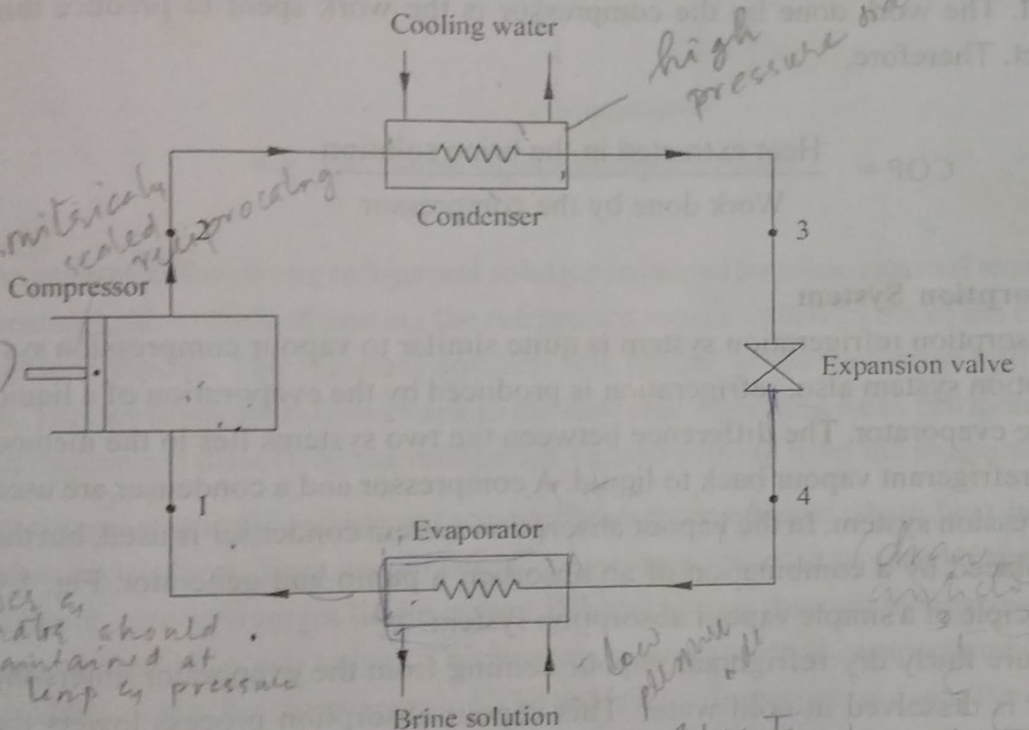


Fig. 3.1. Simple vapour compression system

brine solution. The wet refrigerant vapour absorbs latent heat of vaporisation from the brine solution and evaporates. After evaporation the vapour reaches the condition given by point 1 ie., dry saturated at pressure p_1. This completes one cycle of operation. The cold brine solution is circulated in coils around the space to be refrigerated . Since the condition of vapour entering the compressor is dry saturated, the cycle is also called simple saturated cycle. Fig. 3.2 and 3.3 shows the simple saturated cycle on T-S and P-H diagrams.

$$COP = \frac{H_1 - H_4}{H_2 - H_1}$$

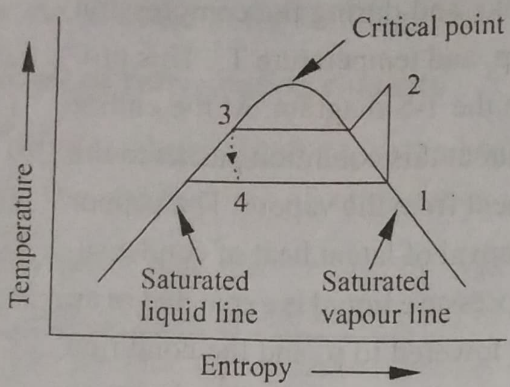


Fig. 3.2.. T-S diagram

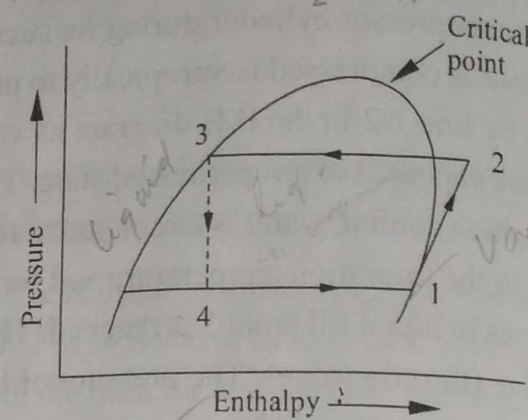


Fig. 3.3. P-H diagram

The net refrigerating effect of this system is the heat absorbed by the refrigerant from the brine solution. The work done by the compressor is the work spent to produce this refrigerating effect. Therefore,

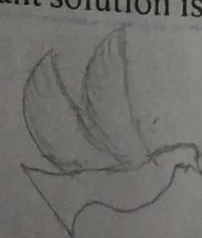
$$COP = \frac{\text{Heat extracted in the brine solution}}{\text{Work done by the compressor}}$$

3.7. Vapour Absorption System

R_{12} or R_{23}

The vapour absorption refrigeration system is quite similar to vapour compression system. In the absorption system also, refrigeration is produced by the evaporation of a liquid (refrigerant) in the evaporator. The difference between the two systems lies in the method of converting the refrigerant vapour back to liquid. A compressor and a condenser are used in a vapour compression system. In the vapour absorption system condenser is used, but the compressor is replaced by a combination of an absorber, a pump and generator. Fig. 5.4 illustrates the principle of a simple vapour absorption system.

The low pressure fairly dry refrigerant vapour coming from the evaporator enters the absorber where it is dissolved in cold water. This vapour absorption process lowers the pressure in the absorber which in turn draws more refrigerant vapour from the evaporator. Also, due to the absorption of the vapour in cold water, the latent heat of condensation and the sensible heat of solution are liberated which raise the temperature of the solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat generated. This is necessary to increase the absorption capacity of water, because at low temperature water absorbs more refrigerant. This solution in the absorber is called a strong solution, as it is rich in refrigerant. This strong refrigerant solution is then pumped to the generator by a liquid pump.



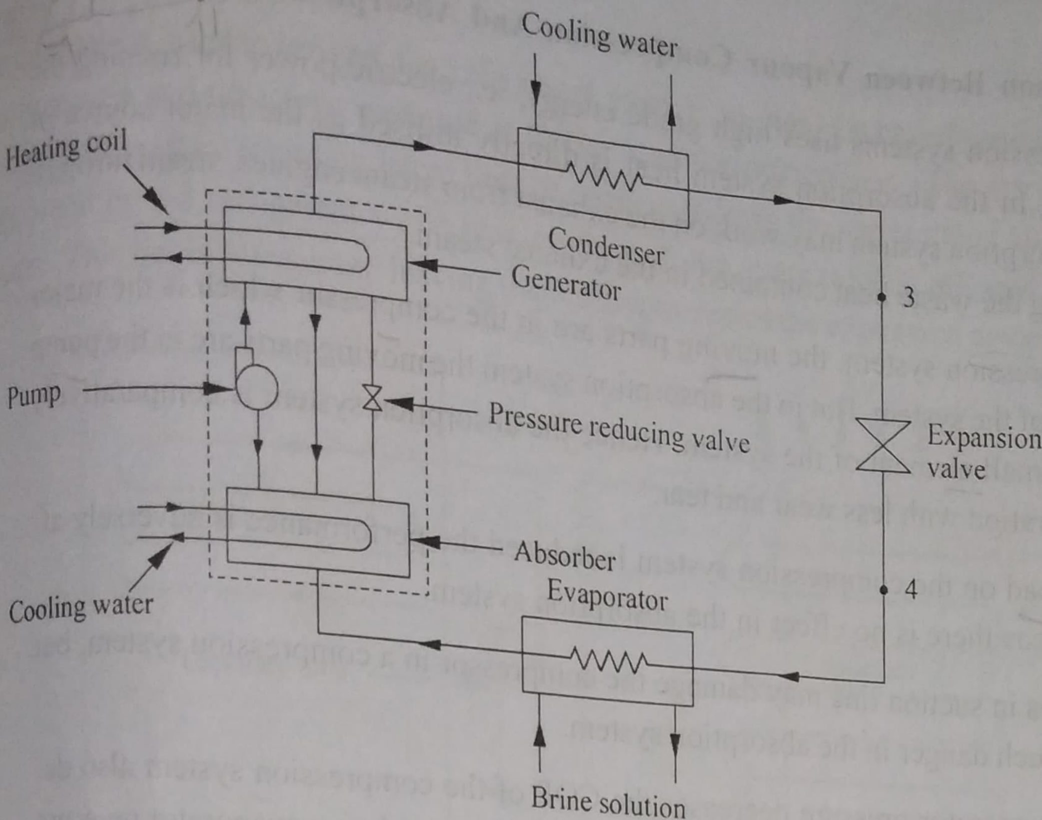


Fig. 3.4. Simple vapour absorption system

In the generator, the strong refrigerant solution is heated by some external means (usually steam heating). As a result of heating the refrigerant vapour is driven out of the solution as a high pressure vapour. The resultant solution left behind in the generator will be a weak solution. This weak solution flows back to the absorber where the weak refrigerant solution becomes the solvent dissolving the refrigerant vapour coming from the evaporator.

From the generator the refrigerant vapour flows to condenser where heat is rejected to the condensing medium. Thus vapour cools and gets condensed at its saturation temperature . This high pressure refrigerant liquid is then allowed to pass through the narrow opening of the expansion valve (throttle valve). This process reduces the high temperature of the liquid to a low value suitable for the evaporator. The cold liquid is then passed into the evaporating coils of the evaporator. Here it collects heat from the brine solution and gets vapourised. This low temperature brine solution is then circulated in coils around the space to be refrigerated. The refrigerant vapour issuing from the evaporator is now almost dry and is allowed to mix with the weak solution contained in the absorber. This completes one cycle of operation.

The net refrigerating effect of this machine is the heat absorbed by the refrigeran t in the evaporator. The total energy supplied in operating the machine is the sum of the work done by liquid pump and the heat supplied to the generator. Then,

$$\text{COP} = \frac{\text{Heat extracted in the evaporator}}{\text{Work done by pump + Heat supplied to the generator}}$$

3.8. Comparison Between Vapour Compression And Absorption Systems.

1. The compression systems uses high grade energy, ie., electric power for running the compressor. In the absorption system heat is directly utilised as the major source of energy. Absorption system may work on the exhaust from steam engines, steam turbines etc., utilising the waste heat contained in the exhaust steam.

2. In the compression system, the moving parts are in the compressor which is the major component of the system. But in the absorption system the moving parts are in the pump which is a small element of the system. Hence the absorption system is comparatively quiet in operation with less wear and tear.

3. When the load on the compression system is reduced the performance is adversely affected whereas there is no effect in the absorption system.

4. Liquid traces in suction line may damage the compressor in a compression system, but there is no such danger in the absorption system.

5. When the evaporator pressure decreases the COP of the compression system also decreases considerably. But, the absorption system can work on lower evaporator pressure without lowering COP.

6. Automatic operation for controlling the refrigerating capacity of the absorption system is easy compared to the compression system.

3.9. Domestic refrigerator

A schematic diagram of a domestic refrigerator is shown in Fig. 3.5. It consists of the following four basic componants

(i) Evaporator (ii) Compressor (iii) Condenser and (iv) Expansion device (Capillary tube).

Evaporator

It is the equipment in which liquid refrigerant evaporates. In a typical refrigerator it is located in the freezer compartment of the refrigerator. The latent heat of vaporisation is absorbed from the refrigerator cabinet. Thus the liquid refrigerant entering the evaporator leaves the evaporator as a vapour.

Compressor

The low pressure vapour leaving the evaporator enters the compressor where the pressure of vapour is increased. The pressure is increased to enable the refrigerant to condense and to release the heat in the condenser. This high pressure vapour enters the condenser.

Condenser

The equipment used to convert the refrigerant vapour to liquid is called condeser. It is usually a wire and tube type mounted at the back of the refrigerator. The refrigerant vapour is condensed by releasing latent heat of condensation to the surrounding air. The heat absorbed by the refrigerant while passing through the evaporator is released in the condenser. This liquid refrigerant leaving the condenser enters the expansion device.

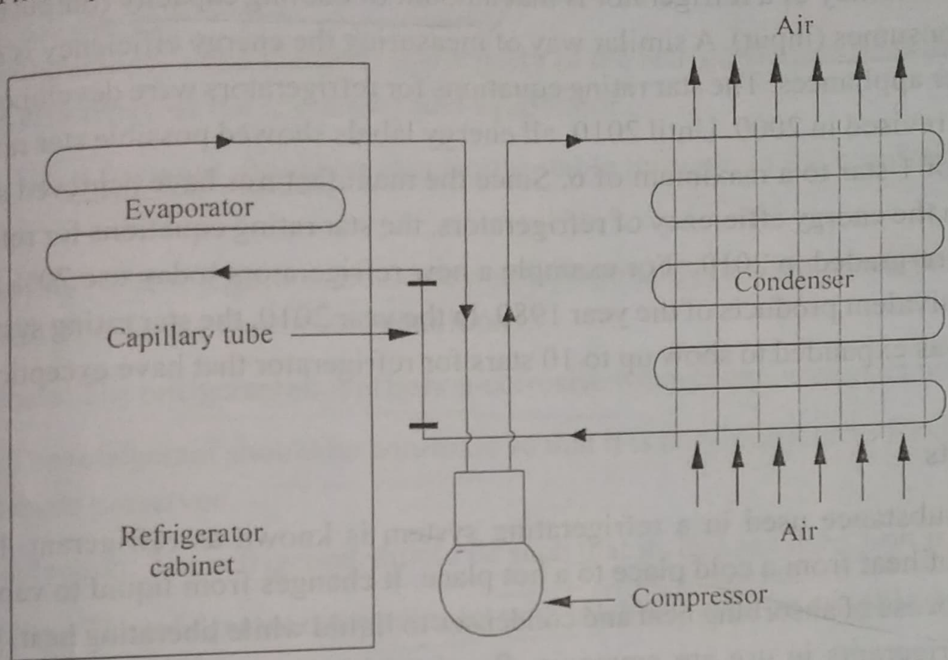


Fig. 3.5. Domestic refrigerator

Expansion device

The high pressure of liquid refregerent is reduced to the low pressure of evaporator by passing through a pressure reducing device called expansion device. In the refrigerator a long narrow tube called capillary tube is used as the expansion device. The low pressure refrigerent leaving the capillary tube enters the evaporator and thus one cycle of operation is completed.

The freezer compartment of the refrigerator is the coldest part of the cabinet. Justbelow the freezer there is a chiller tray. The bottom most portion which is meant for vegetable is the least cold region. The cold air being heavier flows down from the freezer to the bottom region of the refrigerator. The warm air being lighter arises from the bottom region to the top, gets cooled and again flows down. Thus a natural convection takes place which maintains a temperature gradient between the top and bottom of the refrigerator cabinet.

In modern nofrost refrigerators the evaporator is located outside the freezer compartment. Cold air is made to flow by forced convection using a fan.

3.10. Energy efficiency rating

Energy efficiency is defined as the energy service per unit of energy consumption. It is simple and fairly good way of comparing the energy consumption of products that perform a similar task. The efficiency of a refrigerator is that amount of cooling capacity (output) per unit of energy it consumes (input). A similar way of measuring the energy efficiency is also developed for other appliances. The star rating equations for refrigerators were developed in 1986. These were revised in 2000. Until 2010, all energy labels showed possible star rating from a minimum of 1 star to a maximum of 6. Since the manufactures have achieved substantial increase in the energy efficiency of refrigerators, the star rating equations for refrigerators was again re-graded in 2010. For example a new refrigerators today use 70% less energy than an equivalent products of the year 1980. In the year 2010, the star rating system for refrigerators was expanded to show up to 10 stars for refrigerator that have exceptional energy efficiency.

3.11. Refrigerants

The working substance used in a refrigerating system is known as refrigerant. It is actually a carrier of heat from a cold place to a hot place. It changes from liquid to vapour state during the process of absorbing heat and condenses to liquid while liberating heat. The most common refrigerants in use are ammonia, fluorinated hydrocarbons (trade name - Freon), carbon dioxide, sulphur dioxide, air, water etc.

The important properties to be possessed by an ideal refrigerant are :

1. Condensing and evaporating pressure: Both condensing and evaporating pressure of the refrigerant should be above atmospheric pressure to avoid leakage of air into the system. But the pressure should not be very high as it requires heavy compressor, condenser etc. which increases the cost of the system.

2. Critical temperature : The critical temperature of the refrigerant should be high enough as compared to the condensing temperature, to reduce the power requirements.
   Critical temp > Condensing temp

3. Freezing temperature : The freezing temperature of the refrigerant should be much below the operating temperature of the plant to prevent the solidification and choking of the flow.

4. Specific heat : The specific heat of the refrigerant liquid should be low to minimise the amount of vapour formed during the throttling process.

5. Latent heat of vapourization: The latent heat of vapourisation of the refrigerant should be

R12 Reciprocating
R22 compressor

high to reduce the quantity of refrigerant to be circulated.

6. Specific volume: The specific volume of the refrigerant vapour should be low to reduce the size of the compressor.

7. Viscosity : Viscosity of the refrigerant should be low to reduce pressure drops, size of pipes, valves etc.

8. Thermal conductivity : The thermal conductivity of the refrigerant should be high to increase the efficiency of the condenser and evaporator..

9. Stability: The refrigerant should be chemically stable throughout the required range of operation.

10. Inflammability : The refrigerant should be non-inflammable (ie, it must not easily catch fire) to avoid fire during overheated conditions.

11. Corrosiveness: The refrigerant should be non-corrosive when comes in contact with metals.

12. Toxicity: The refrigerant should be non-toxic so that it is non-injurious to food stuff and other materials preserved.

13. Leakage detection: The refrigerant should be such that its leakage detection is simple.

14. Oil solubility : The refrigerant must not react with oil, but it must be mixable with the oil for better lubrication of the compressor.

15. Electrical resistance: The refrigerant should have high electrical resistance.

16. Availability : The refrigerant should be cheap and easily available.

3.12. Impact of refrigerants on enviornement

The most commonly used halo-carbon refrigerants are the chloro-fluoro derivatives of methane and ethane. The fully halogenated refrigerants with chlorine atom in their molecules are referred to as chloro-fluoro-carbon (CFC) refrigerants. The refrigerents R - 11, R - 12, R - 13, R113, R114 and R115 are CFC refrigerants. The refrigerants which contain hydrogen atoms in their molecule along with chlorine and fluorine atoms are referred to as hydro-chloro-fluro-carbon [HCFC] refrigerents. The refrigerents R -22, R 123 are HCFC refrigerents. The refrigerents which does not contain chlorine atom in their molecules are referred to as hydro-fluoro carbon [HFC] refrigerents. R134a and R152a are HFC refrigerants. The refrigerents which do not contain chlorine and fluorine atoms in their molecules are referred to as hydro carbon (HC) refrigerents. [R-290 and R600a are HC] refrigerents.

Refrigerents have a large impact on environment. Research showed that once CFC reaches the stratosphere the ultraviolet rays form the sun break down the compound, releasing chlorine. This chlorine deplete the ozone layer. The ozone layer is a layer in the almosphere which contains a high concentration of ocone. Ozone is a naturally forming molecule that helps to absorb the ultraviolet rays from the sun. The harmful ultraviolet rays are considered to be responsible for skin cancer.

One chlorine atom can destroy 10^5 ozone molecules. The relative ability of a substance to deplete the ozone layer is known as ozone depletion potential (ODP). The ODP of refrigerents F - 11 and F - 12 is one. The HCFC refrigerators have a relatively low ODP. The ODP of R-22 is 0.05 and that of HFC refrigerents is zero. Hence the HFC refrigerents do not cause any ozone deplition.

Another impact of refrigerant on environment is the global warming effect which cause serious changes in the enviornment. Global waming means the increase in average temperature of earth. One of the cause of global warming is the use of CFC refrigerents. The ability of a substance to contribute to global warming is measured by the global warming potential (GWP). The GWP of R22 is 100.

3.13. Psychrometry

The properties of moist air are called psychrometric properties and the subject which deals with the behaviour of moist air is known as psychrometry. It is the foundation on which most of the air conditioning calculations are based. Several special terms used in the study of psychrometry are defined below:

1. Dry air: Dry air is a mixture of oxygen, nitrogen, carbon - dioxide, hydrogen, argon, neon, helium etc with oxygen and nitrogen as its major constituents. The volumetric composition of air is 79 % nitrogen and 21 % oxygen.

2. Moist air: It is ordinary atmospheric air which is a mixture of dry air and water vapour.

3. Saturated air: It is the air which contains maximum amount of water vapour which the air can hold at a given temperature and pressure. The maximum quantity of water vapour that can be present in the air depends up on the temperature and pressure of air.

4. Specific or absolute humidity or humidity ratio: It is defined as the ratio of the mass of water vapour to the mass of dry air in a given volume of moist air..

5. Relative humidity: It is the ratio of mass of water vapour in a given volume of moist air at a given temperature to the mass of water vapour contained in the same volume of moist air at the same temperature when the air is saturated.

6. Dry bulb temperature: It is the temperature of air measured by an ordinary thermometer.

7. Wet bulb temperature: It is the temperature recorded by a thermometer, when its bulb is

covered by a wet cloth and is exposed to a current of moving air. The difference between the dry bulb temperature and wet bulb temperature is known as wet bulb depression and it depends on the relative humidity of air. If relative humidity is high , the rate of evaporation from the wet cloth is low and hence wet bulb depression will be low. When air is dry saturated the DBT and WBT are the same.

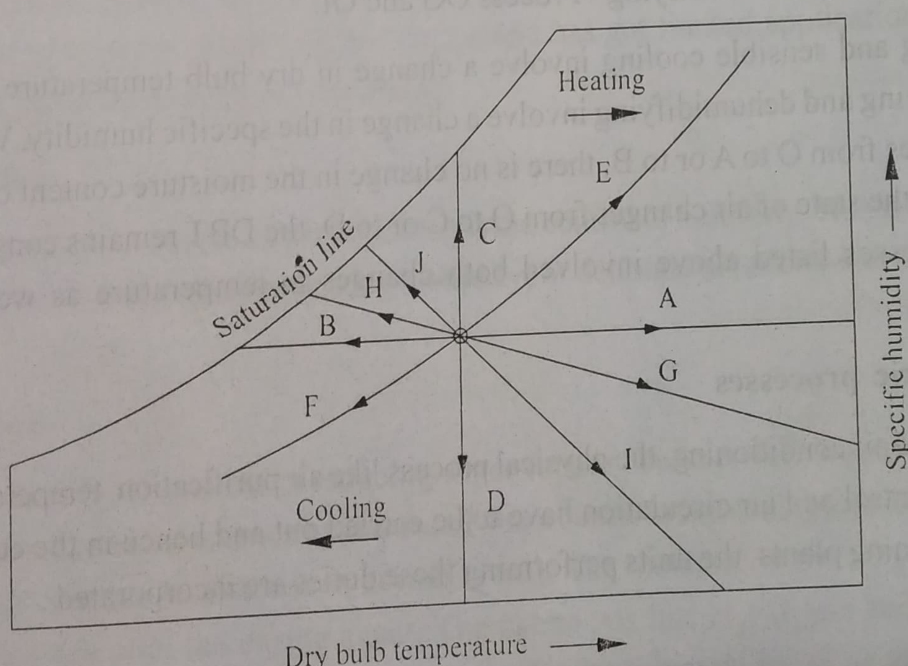
8. Dew point temperature: It is the temperature at which the condensation of moisture begins when the air is cooled at constant pressure . The difference between dry bulb temperature and dew point temperature is known as dew point depression.

9. Sensible heat of air: It is the enthalpy of dry air which can be calculated by measuring its dry bulb temperature.

10. Total heat: The total heat of moist air is the sum of sensible heat of dry air and sensible plus latent heat of water vapour present in it.

3.14. Psychrometric chart

A psychrometric chart is the graphical representation of the various thermodynamic properties of moist air. The chart enables the properties of moist air to be read off directly.



AOB - Constant dew point temperature line. COD - Constant dry bulb temperature line, EOF - Constant relative humidity line, GOH - Constant wet bulb temperature line. IOJ - Constant specific volume line.

Fig. 3.6. Psychrometric chart

Fig. 3.6 shows a typical psychrometric chart constructed for a particular value of barometric pressure. The vertical scale of the chart is the specific humidity and the horizontal scale is the dry bulb temperature. In addition, it contains the following lines.

i) Dry bulb temperature lines: These are vertical lines drawn parallel to the ordinate.

ii) Specific humidity lines: These are horizontal lines drawn parallel to the abscissa.

iii) Wet bulb temperature lines: These are straight lines which extend diagonally.

iv) Relative humidity lines: These are curved lines parallel to the saturated line. The saturation line represents 100 % relative humidity

v) Specific volume lines: These are straight inclined lines and uniformly spaced. These lines gives the volume of dry air in m^3/kg

vi) Dew points temperature lines: These are horizontal lines, non uniformly spaced and drawn upto saturation curves.

The various basic process involved in air conditioning are :

i) Sensible heating - Process OA, (ii) Sensible cooling - Process OB, (iii) Humidifying - Process OC, (iv) Dehumidifying - Process OD, (v) Heating and humidifying - Process OE, (vi) Cooling and dehumidifying - Process OF, (vii) Cooling and humidifying - Process OH and OJ, (viii) Heating and dehumidifying - Process OG and OI.

Sensible heating and sensible cooling involve a change in dry bulb temperature. The process of humidifying and dehumidifying involve a change in the specific humidity. When the state of air moves from O to A or to B, there is no change in the moisture content of the air. Similarly when the state of air changes from O to C or to D, the DBT remains constant. The last four processes listed above involved both changes in temperature as well as humidity.

3.15. Phychrometric processes

In order to achieve air conditioning, the physical process like air purification, temperature control, humidity control and air circulation have to be carried out and hence in the equipments of air conditioning plants, the units performing these duties are incorporated .

1. Air purification

The air taken from the atmosphere carries dust, bacteria and odours which are harmful for human health. In order to safeguard the health of occupants, it is necessary to remove all possible harmful ingredients from the air before admitting into the air conditioning system.

The air purification is carried out by following one or more of the methods like air filtration, air sterilization, and air ionization and odour suppression. Most of the dust particles are removed by air filters. Ingredients like bacteria are killed by air sterilization. The adoption of a particular type of air filter depends upon the nature of the dust, diameter of the dust particle and the concentration of dust in air.

2. Temperature control

Temperature control is a major process in air conditioning system . It is intended to regulate the dry bulb temperature by various psychrometric processes. This is attained by simple heating or cooling , which may be associated with humidification process.

Cooling of air means lowering its dry bulb temperature. It can be attained by passing the air over evaporator coils of a refrigerating system. In a small room air conditioner the intake air is forced to flow over the evaporator coil directly. In such a case the relative humidity aspect is neglected or is of such order that it gets adjusted by itself. In most cases, an indirect evaporator system is used for cooling the air. In such cases chilled water (or chilled brine solution) is used to cool the air. The chilled water after absorbing heat from the air rejects heat to the refrigerant in the evaporator.

Heating of air, to raise the dry bulb temperature, can be achieved by passing the air over heated surfaces. The heating surfaces are usually located outside the room to be conditioned. The heated air flows to the room by fan action. Warm air heating system, hot water heating system, steam heating system and electrical heating system are some of the commonly used heating systems. Electrical heating system has got limited applications and is used only where electrical energy is very cheap.

3. Humidity control

The third important process in air conditioning is the control of humidity. This is achieved by the process of humidification (increasing humidity) or dehumidification (decreasing humidity).

i) Dehumidification

Dehumidification is the process of reducing water vapour content of air. It can be accomplished by the use of an air washer or by the use of absorbents. In the absorption method, air is passed through a chemical (known as drying agent). The moisture in the air enters into chemical combination with the drying agent. The chemicals like H_2SO_4 and NH_3 are normally used as drying agents. Dehumidification can also be achieved by using absorbents. These are materials having capacity to absorb moisture . Common absorbents in use are: activated alumina, calcium chloride and silica gel. Normally, this method of dehumidification is used in small air conditioners.

ii) Humidification

Humidification is accomplished by addition of steam or hot water to air. The different types of humidifiers are:

i) Steam humidifier, (ii) Atomisation type humidifier, (iii) Impact type humidifier, (iv) Forced evaporation humidifier

Steam humidifiers are simplest type in which steam is directly injected to the air stream through a nozzle. But, this type is seldom used for comfort air conditioning as the temperature control is difficult and it carries odours which are unpleasant to the occupants.

In atomization type humidifiers, compressed air is used to draw water by aspiration from a supply tank and blow it in the form of fine mist into the duct carrying the air to the conditioned space.

The impact type humidifier , makes use of fine jet of water which is directed against a hard target. The water breaks up into fine spray. The air is forced into the chamber using fans which picks up water by evaporation. Eliminators are placed in the path to remove water droplets carried with the air.

In the forced evaporation type humidifier, air is allowed to mix with water vapour formed by the evaporation of water

4. Air distribution

The object of air distribution is to create the proper combination of temperature, humidity and air motion in the conditioned room. The temperature variation within the room should not exceed 2°C. The desirable air movement is 7.5 m/min, limited to a maximum of 15 m/min. Flow direction of air towards the face of the occupants is preferred and also downward flow of air is preferable over upward flow.

3.16. Window air conditioning

A window air conditioner consists of a case divided into two parts, outdoor and indooor parts, by a partition. The outdoor part consists of compressor, condenser and a fan. The indoor part consists of evaporator and a fan. Capillary tube is provided in between the condenser and evaporator. The outdoor portion ramains outside the window sill. Dampers are provided at the front of indoor portion for changing the direction of airflow.

Low pressure vapour drawn from the evaporator is compressed to a high pressure and is delivered to the condenser. In the condenser the refrigerant vapour is condensed by releasing latent heat of condensation to the surrounding air. This hot air is driven out using a fan. The high pressure liquid refrigerant enters the capillary tube where the pressure is reduced. This low pressure liquid vapour enters the evaporator. This liquid re-

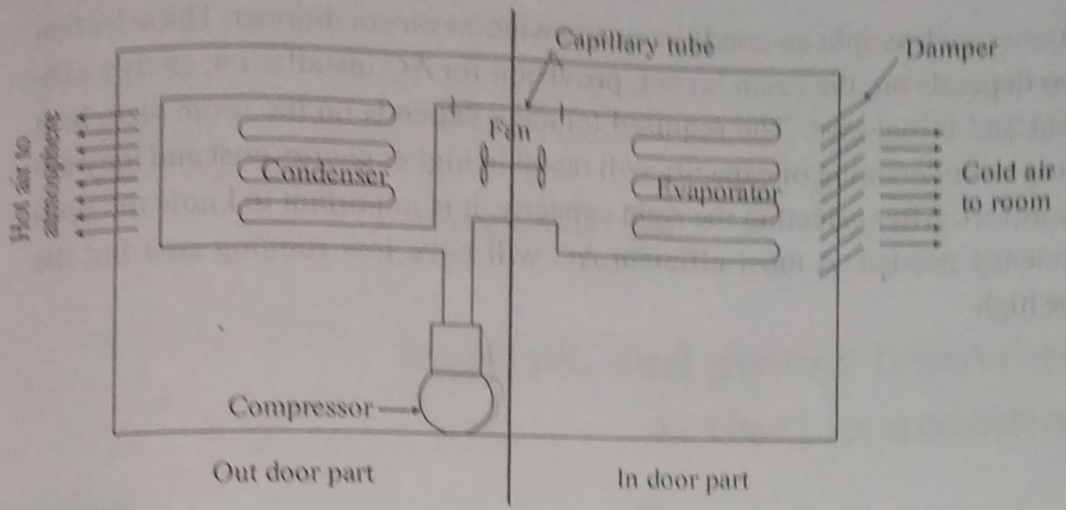


Fig. 3.7. Window Air conditioning system

frigerant evaporates by absorbing latent heat of vaporization from the surrounding air. This cold air is delivered to the room using a fan. The direction of air flow can be changed using a damper. The low pressure refrigerant vapour leaving the evaporator is sucked into the compressor and is compressed to very high pressure. This high pressure vapour is condensed in the condenser. Thus one cycle of operation is completed.

3.17 Split air conditioner.

The working principle of a split air conditioner is same as that of room air conditioner. In window air conditioner, the indoor and outdoor parts are kept in a single casing and the casing is divided into two parts. In the split air conditioner the unit consisting of evaporator and fan is located inside the room and the other unit consisting of compressor, condenser and the fan can be kept anywhere outside the room. The indoor and outdoor units are connected by extended suction and liquid pipelines. The system works on vapour compression cycle.

Advantages of split air conditioner.

1. It occupy only very small space in the room.
2. Since the compressor is kept out side the room, the noise inside the room due to working of compression is less
3. Wide opening of wall or window is not required.

3.18. Section criteria of air conditioner.

The selection of air conditioner depends on many factors, such as usage, type of air conditioner, tonnage, star rating, features etc. Based on usuage one of the selection criteria is the size of the room or building to be cooled. The required capacity of air conditioner increases with increase of size of room or building to be cooled. Other usuage factors are heat load of the room, usuage duration, comfort requirement etc. There are different types of room air conditioner such as split air conditioner and window air conditioner. The selection between these two depends on, the room layout, provision for AC installation, energy efficiency requirement and initial cost. The required tonnage depends on the room size, heat load etc. Oversizing or undersizing of capacity will result in higher energy cost and may not get the required comfort. After selecting the right capacity, it is important to know the optimum energy efficiency needed. A most efficient AC will have low running cost but the buying cost will be high.

2.34 Pumps

Pump is a mechanical device used to increase the pressure energy of a liquid. In most of the applications, pump is used for lifting liquids from a lower to higher level. This is achieved by creating a low pressure at the inlet and a high pressure at the outlet of the pump. Due to the low pressure at the inlet of the pump, liquid is lifted from the sump to the pump. Due to high pressure at the outlet of the pump the liquid is lifted from the pump to the required height.

2.35 Classification of pumps

Based on the working principle, pumps are classified as positive displacement and rotodynamic pumps. Reciprocating pump, gear pump, screw pump, vane pump etc., are examples of positive displacement pumps. Centrifugal pump, propeller pump etc, are examples of rotodynamic pumps. Based on a number of stages in which the pressure of the liquid is increased, rotodynamic pumps are classified as single stage and multistage pumps.

2.36 Reciprocating pump

It is a positive displacement pump in which the required low pressure at the inlet and the required high pressure at the outlet of the pump is obtained by the reciprocating

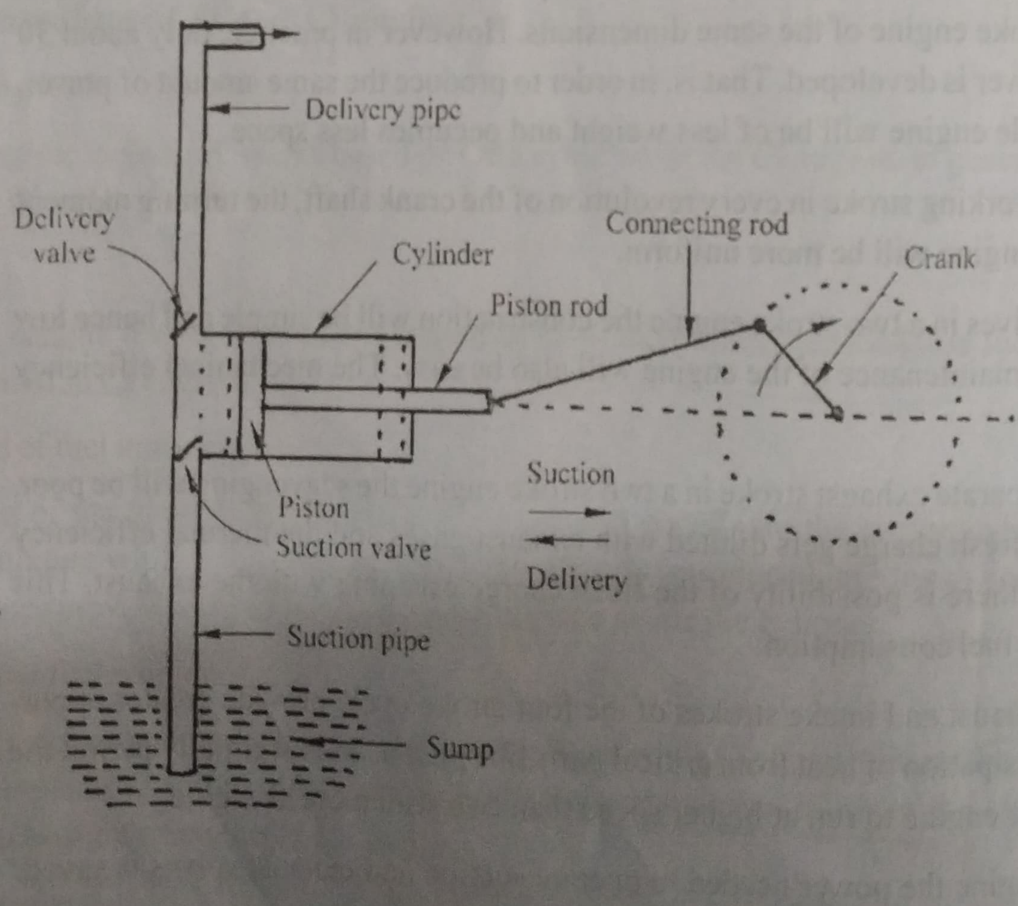


Fig. 2.17 Reciprocating pump.

motion of a piston or plunger inside a close fitting cylinder. The following are the main components of a reciprocating pump. 1. Cylinder, 2. Piston, 3. Piston rod, 4. Connecting rod, 5. Crank, 6. Strainer, 7. Suction pipe, 8. Suction valve, 9. Delivery valve, 10. Delivery pipe.

Working principle

Refer Fig. 2.17. Movement of piston towards right creates a vacuum inside the cylinder and atmospheric pressure forces the liquid up through the suction pipe into the cylinder. During the movement of piston towards left liquid is pushed into the delivery pipe. The suction and delivery pipes afe provided with non-return valves. These non- return valves or one way valves ensure unidirectional flow of liquid. Thus the suction valve allows the liquid only to enter the cylinder and prevents the flow of liquid from the cylinder to the suction pipe. Similarly the delivery valve allows the liquids only to discharge from the cylinder and prevents the flow of liquid from the delivery pipe to the cylinder. The movement of piston inside the cylinder is obtained by connecting the piston rod to a crank by means of a connecting rod. The crank is rotated using an electric motor. Thus when the crank rotates, the piston reciprocates inside the cylinder, alternately filling and emptying the cylinder. The volume of liquid delivered is constant regardless of pressure and is varied only due to the change of speed of rotation of the crank. A strainer is provided at the end of suction pipe in order to keep leaves, wooden pieces and other rubbish away from the pump.

2.37 Centrifugal pump

It is a rotodynamic pump in which the required low pressure at the inlet of pump and the high pressure at the outlet of the pump is obtained mainly due to centrifugal action. When a certain mass of liquid is made to rotate by an external force, it is thrown away from the axis of rotation and a centrifugal head is impressed which enables the liquid to rise to a higher level. In centrifugal pumps, in addition to the centrifugal action, as the liquid passes through the revolving wheel or impeller, the angular momentum of the liquid changes which also results in increasing the pressure of the liquid.

Impeller , casing , delivery pipe, suction pipe, foot valve and strainer are the main components of a centrifugal pump. Refer Fig.2.18. The impeller is a wheel or rotor which is provided with a number of curved blades or vanes. It is mounted on a shaft which is coupled to an electric motor. Casing is an air tight chamber which surrounds the impeller. The shape of the casing is such that the sectional area of flow around the periphery of the impeller gradually increases towards the delivery pipe. This gradual increase in area gradually reduces the velocity of the liquid leaving the impeller to that in the delivery pipe. This reduction in the kinetic energy of the liquid while passing through the casing is converted into useful pressure

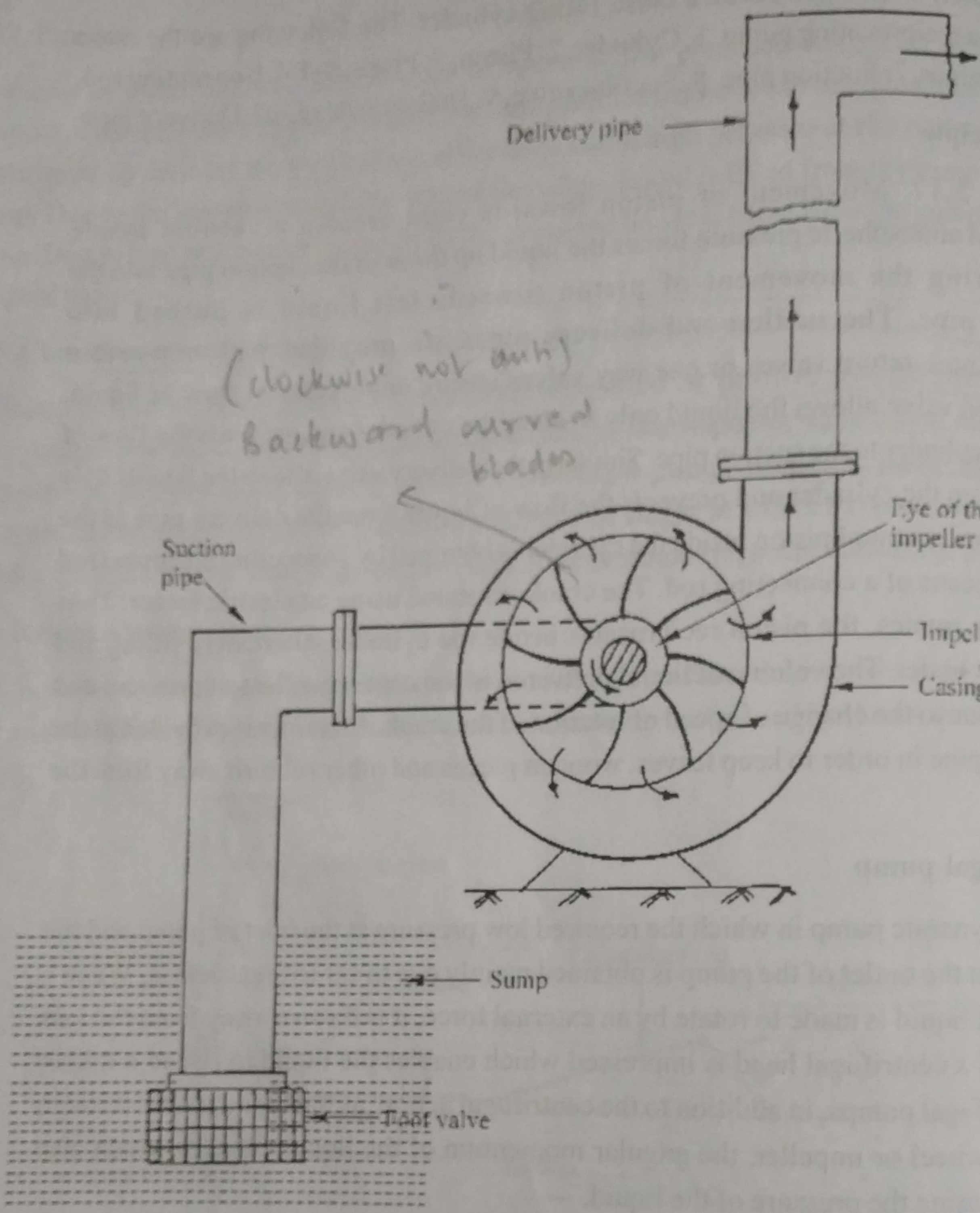


Fig. 2.18 Centrifugal pump

energy. Suction pipe connects the centre of the impeller to the sump from which liquid is to be pumped . The lower part of the suction pipe is fitted with a foot valve and a strainer. The liquid after filtering by the strainer passes through the foot valve. The foot valve is a non-return valve which opens only in the upward direction. Through the foot valve liquid enters the suction pipe. Delivery pipe connects the outlet of the pump to the delivery point. A valve is provided on the delivery pipe, closed to the outlet of the pump, to control the flow of liquid through the delivery pipe.

Working principle

After priming, the impeller is rotated by means of an electric motor. Filling the suction pipe and casing with the liquid to be pumped is known as priming. Priming is required to remove air and vapour from the suction pipe and casing. The removal of air from the casing is required because the vaccum crated in the eye of the impeller is proportional to the density of the liquid that is in contact with the impeller. If the impeller is made to rotate in the presence of air, the vacuum created may not be sufficient to lift the water from the sump to the eye of the impeller. Therefore it is essential to prime a centrifugal pump before it can be started. The rotation of the impeller in the casing full of liquid produces a forced vortex which imparts a centrifugal head to the liquid. This results in an increase of pressure of liquid. If the speed of the impeller of the pump is sufficiently high, the pressure of liquid in the impeller will be increased. When the delivery valve is opened the liquid within the impeller flows in an outward direction, therby leaving the vanes of the impeller at the outer circumference with high velocity and pressure. The vacuum created at the eye of the impeller causes the liquid from the sump to rush through the suction pipe, replacing the liquid which is being discharged from the impeller. While the liquid flows through the rotating impeller it receives energy from the vanes which results in an increase of both pressure and velocity. The kinetic energy thus increased is converted into pressure energy while flowing through the volute casing. Thus the liquid is discharged from the pump to the delivery pipe with very high pressure.

2.38 Comparison of centrifugal and reciprocating pumps

1. The flow of liquid from a centrifugal pump is smooth and even whereas that from a reciprocating pump is pulsating.
2. Centrifugal pumps are suitable for large discahrge and low heads. Reciprocating pumps are suitable for high heads and low discharge.
3. Initial cost of centrifugal pump is less compared to the initial cost of reciprocating pumps.
4. Centrifugal pump is compact and occupies less floor space. The floor space required for a reciprocating pump is about 6 to 8 times that for a centrifugal pump.
5. Efficiency of a low head centrifugal pump is more than that of a low head reciprocating pump.
6. For small discharge and high head, the efficiency of a reciprocating pump is more than that of a centrifugal pump.
7. A centrifugal pump needs priming wheras no priming is required in a reciprocating pump.

8. Highly viscous liquid such as oils, muddy and sewage water, paper pulp etc. can be easily handled by centrifugal pumps. Valves and glands in reciprocating pumps cause trouble when it is used to pump the above said liquids.

9. Compared to reciprocating pump, the installation of centrifugal pump is easy.

10. Construction of centrifugal pump is simple. More number of parts in the reciprocating pump make the construction complicated.

11. Maintenance cost of centrifugal pump is low.

12. Due to the high speed of centrifugal pump, impeller can be directly coupled to an electric motor. In the case of reciprocating pump, some speed reduction device is required.

13. Centrifugal pump has no reciprocating parts and hence the wear and tare is less.

Gear

14. For a given discharge, the weight of centrifugal pump is less than the weight of a reciprocating pump.

2.39 Rotory pump

Gear pump is a rotary pump and in appearance it resembles a centrifugal pump. It is a positive displacement pump, which can pump thick and viscous liquid such as vegetable oils, greases, tar etc., and also lighter liquid such an gasoline, alcohol etc.

It consists of two identical intermeshing spur gears working with a fine clearance inside a suitably shaped casing. One of the gears is keyed to the driving shaft of a motor and the other revolves idly. Liquid entrained in the spaces between the teeth and the casing is carried round the gears from the suction side to the discharge side. Liquid cannot flow back to the suction side due to the meshing of gears. A single gear pump can build up pressure as high as

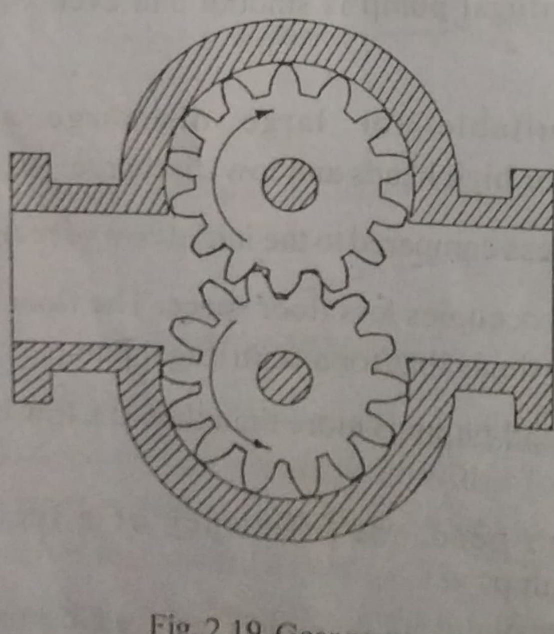


Fig. 2.19. Gear pump

15 MPa. Due to possibility of internal leakage it is generally used for a delivery pressure upto 1 MPa only.

4.11. Belt drive

Whenever power is to be transmitted from one shaft to another which are at a considerable distance apart, a belt drive is generally used. Pulleys are mounted on the driver and driven shafts and an endless belt is fitted tightly over these pulleys. The factor responsible for power transmission, or in other words making the belt and pulleys run together, is the frictional resistance between the belt and the pulley. The amount of power transmitted depends upon the velocity of belt, the tension under which the belt is placed on the pulleys and the arc of contact of the belt and smaller pulley.

Types of belts

Though there are many types of belts for transmission of power, flat belts and V-belts are widely used. Flat belts are used to transmit moderate amount of power. These are used upto 10 m distance between driving and driven shafts. V-belts are more suitable for transmission of large amount of power between two shafts having a short center to center distance. The ideal distance is 1.25 to 1.5 times the diameter of the larger pulley.

The belts used for transmission of power must have larger strength, flexibility and life and must have a high coefficient of friction. In addition to leather belts, belts made of rubber, balata and cotton or fabric are also widely used. Rubber belts, consisting of layers of fabric impregnated with a rubber composition and having a thin layer of rubber on the faces, are very flexible but are quickly destroyed if allowed to come in contact with oil or grease. Balata belts are similar to rubber belts except that balata gum is used in place of rubber. It

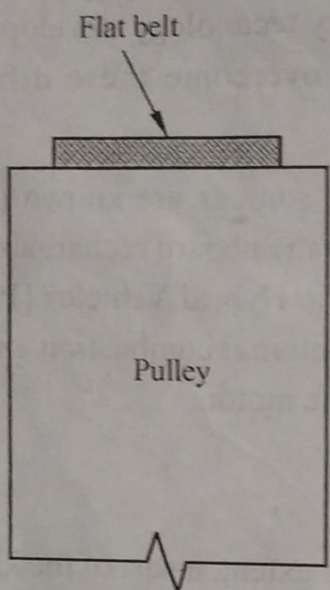


Fig. 4.3. Flat belt

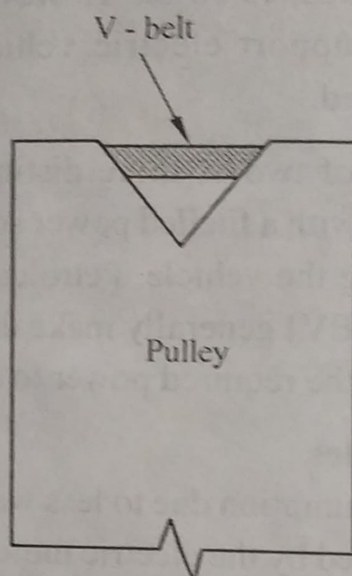


Fig. 4.4. V - belt

is about 25 % stronger than rubber belt. Cotton or fabric belts are made from canvas or cotton duck in which a number of layers, depending upon the thickness desired are put and stitched together. These are treated with linsoil to make it water proof. The cotton belts are cheaper and suitable for rough service where little attention is needed.

Types of belt drives

i) Open belt drive

It is used with shafts arranged in parallel and to be rotated in the same direction. The

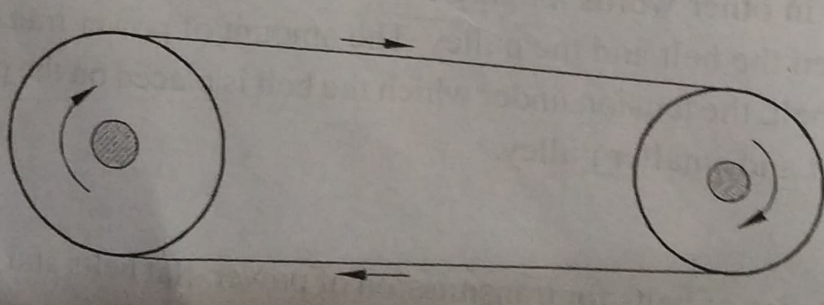


Fig. 4.5. Open belt drive.

driver pulley pulls the belt from one side and delivers the same to the other side. Hence the tension on the former side will be greater than the later side. The side where tension is more.

is called tight side and the other side is called slack side.

ii) Crossed belt drive

It is used with shafts arranged in parallel and to be rotated in opposite directions. At the point where the belt crosses, it rubs against itself and wears. In order to minimize wear, the

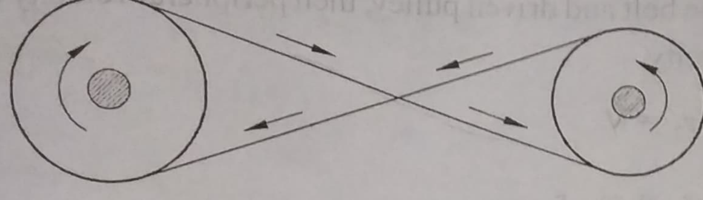


Fig. 4.6. Crossed belt drive

shafts should be placed at a minimum distance of 20 b, where b is the width of belt. Also the speed of the belt should be less than 15 m/sec.

4.12. Velocity Ratio and slip of belt drive

In belt drive the power is transmitted by the frictional resistance between the belt and pulleys. If the frictional resistance between the driver pulley and belt is insufficient then it may cause some forward motion of the driver pulley without carrying the belt with it. Similarly if the frictional resistance between the belt and driven pulley is insufficient it may cause some forward motion of the belt without carrying the driven pulley with it. In such a case the difference between the speed of driver pulley and belt, belt and driven pulley is called slip and is generally expressed as percentage.

Velocity ratio of a belt drive

It is the ratio of velocities of the driven shaft and the driver shaft.

r_1 = radius of driver pulley

ω_1 = angular velocity of driver pulley

$= \frac{2\pi N_1}{60}$ where N_1 is the speed of the driver pulley

r_2 = radius of the driven pulley

ω_2 = angular velocity of driven pulley

$= \frac{2\pi N_2}{60}$ where N_2 is the speed of the driven pulley

Peripheral velocity of driver pulley = $\omega_1 \; r_1$

Peripheral velocity of driven pulley = $\omega_2 r_2$

If there is no slip between the belt and driver pulley, then belt velocity will be equal to peripheral velocity of driver pulley.

Velocity of belt, $V = \omega_1 r_1$

If there is no slip between the belt and driven pulley, then peripheral velocity of the driven pulley will be equal to belt velocity.

ie., $\omega_2 r_2 = V$

$$\omega_1 r_1 = \omega_2 r_2$$

$$\frac{\omega_2}{\omega_1} = \frac{r_1}{r_2} = \frac{d_1}{d_2}$$ where d_1, d_2 are the diameter of the driver and driven pulleys.

or $$\frac{\frac{2\pi N_2}{60}}{\frac{2\pi N_1}{60}} = \frac{d_1}{d_2}$$

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}$$

ie., Velocity ratio, $\dfrac{\text{speed of driven shaft}}{\text{speed of driver shaft}} = \dfrac{\text{diameter of driver pulley}}{\text{diameter of driven pulley}}$

If the thickness of the belt, t, is also considered, then

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}$$

Effect of slip on velocity ratio

Let s_1 % be the slip between the driver pulley and belt

s_2 %, slip between belt and driven pulley.

ω_1, ω_2, angular velocities of driver and driven pulleys.

N_1, N_2, speed of the driver and driven pulleys

r_2, r_1, radii of the driver and driven pulleys

d_1, d_2, diameters of driver and driven pulleys, then,

Peripheral velocity of driver $= \omega_1 \; r_1$

Velocity of belt $= s_1\%$ less than peripheral velocity of driver

$$= (100 - s_1)\,\%\; \omega_1 \; r_1$$

$$= \frac{(100 - s_1)}{100}\,\omega_1 r_1$$

$$= \left(1 - \frac{s_1}{100}\right)\,\omega_1 r_1$$

Peripheral velocity of the driven pulley $= s_2\%$ less than the velocity of the belt.

ie., $\omega_2 \; r_2 = (100 - s_2)\,\%$ of the velocity of the belt.

$$= \frac{(100 - s_2)}{100} \times \left(1 - \frac{s_1}{100}\right)\,\omega_1 r_1$$

$$\therefore \; \frac{\omega_2}{\omega_1} = \frac{r_1}{r_2}\left(1 - \frac{s_1}{100}\right)\left(1 - \frac{s_2}{100}\right)$$

$$= \frac{r_1}{r_2}\left(1 - \frac{s_2}{100} - \frac{s_1}{100} + \frac{s_1 s_2}{100 \times 100}\right)$$

Neglecting thevery small value term $\dfrac{s_1 \; s_2}{100 \times 100}$

$$\frac{\omega_2}{\omega_1} = \frac{d_1}{d_2}\left(1 - \frac{s_1}{100} - \frac{s_2}{100}\right)$$

$$\text{ie., } \frac{\omega_2}{\omega_1} = \frac{d_1}{d_2}\left(1 - \frac{s_1 + s_2}{100}\right)$$

$$\frac{\;\frac{2\pi N_2}{60}\;}{\;\frac{2\pi N_1}{60}\;} = \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$ where s is the total percentage of slip

ie., $s = s_1 + s_2$

$$\therefore \; \frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$

From the above equation it can be seen that as slip increases the velocity ratio decreases.

So the effect of slip is to reduce the velocity ratio of the system. If the effect of belt thickness and slip are considered, then velocity ratio,

$$\frac{N_2}{N_1} = \frac{(d_1 + t)}{(d_2 + t)} \left(1 - \frac{s}{100}\right)$$

Problem 4.1

A horizontal shaft running at 200 rpm is driving a shaft parallel to it at 300 rpm. The pulley on the driving shaft is 50 cm diameter. Find the diameter of the driven pulley under the following conditions :- (i) Neglecting belt thickness, (ii) Taking 0.5 cm for belt thickness (iii) Assuminf a slip of 5 % in the later case.

Solution:

Given: $N_1 = 200$ rpm $\qquad t = 0.5$ cm

$N_2 = 300$ rpm $\qquad s = 5$ %

$d_1 = 50$ cm

To find : d_2

(i) Neglecting belt thickness,

We have,

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}$$

$$d_2 = \frac{N_1 d_1}{N_2} = \frac{200 \times 50}{300} = 33.33 \text{ cm}$$

$$d_2 = 33.33 \text{ cm}$$

(ii) Considering the belt thickness,

We have,

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}$$

$$d_2 + 0.5 = (50 + 0.5) \times \frac{200}{300}$$

$$d_2 = 33.17 \text{ cm}$$

(iii) Considering slip and belt thickness, We have,

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}\left(1 - \frac{s}{100}\right)$$

$$d_2 + t = \frac{N_1}{N_2} \times (d_1 + t)\left(1 - \frac{s}{100}\right)$$

$$d_2 + 0.5 = \frac{200}{300}(50 + 0.5)(1 - 0.05)$$

$$d_2 = 31.48 \text{ cm.}$$

Problem 4.2.

An engine running at 150 rpm drives a line shaft by means of a belt. The engine pulley shaft is 75 cm diameter and pulley on the line shaft is 45 cm. A 90 cm diameter pulley on the line shaft drives a 15 cm diameter pulley keyed to a dynamo shaft. Find the speed of the dynamo shaft, when (i) there is no slip (ii) there is a slip of 2 % at each drive.

Solution:

Given:

$N_1 = 150$ rpm $\quad d_3 = 90$ cm

$d_1 = 75$ cm $\quad d_4 = 15$ cm

$d_2 = 45$ cm $\quad s = 2$ %

To find: N_4

(i) When there is no slip

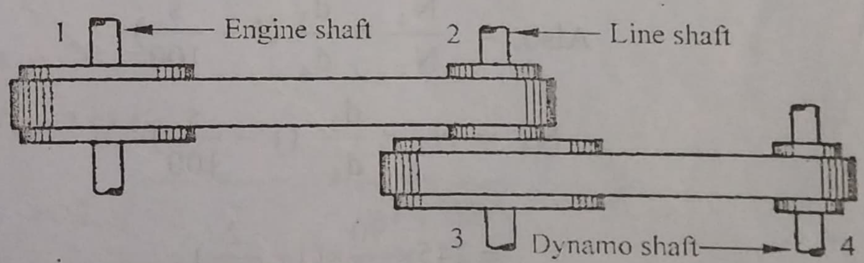


Fig. 4.7.

We have,

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}$$

$$N_2 = N_1 \times \frac{d_1}{d_2} = 150 \times \frac{75}{45}$$

$$N_2 = 250 \text{ rpm}$$

$$N_3 = N_2$$

(Pulleys 2 & 3 are on the same shaft)

$$\text{Also, } \frac{N_4}{N_3} = \frac{d_3}{d_4}$$

$$N_4 = N_3 \times \frac{d_3}{d_4}$$

$$= 250 \times \frac{90}{15}$$

$$N_4 = 1500 \text{ rpm}$$

(ii) When there is 2 % slip,

We have, $$\frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$

$$N_2 = N_1 \times \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$

$$= 150 \times \frac{75}{45} \times \left(1 - \frac{2}{100}\right)$$

$$N_2 = 245 \text{ rpm}$$

$$N_3 = N_2 = 245 \text{ rpm}$$

$$\text{Also, } = \frac{N_4}{N_3} = \frac{d_3}{d_4}\left(1 - \frac{s}{100}\right)$$

$$N_4 = N_3 \times \frac{d_3}{d_4}\left(1 - \frac{s}{100}\right)$$

$$= 245 \times \frac{90}{15} \times \left(1 - \frac{2}{100}\right)$$

$$N_4 = 1440.6 \text{ rpm.}$$

4.13. Calculation of length of belt

(a) Open belt drive

In open belt drive, the two pulleys rotate in the same direction.

Let x = distance between centres of pulleys

r_1, r_2 = radii of larger and smaller pulleys respectively

L = total length of belt.

The belt leaves the larger pulley at A and C and the smaller pulley at D and F. Through O_2 draw O_2G parallel to CD. Since angle O_1 CD is 90°, O_2G will be perpendicular to O_1C. Let angle O_1O_2G be α, then it can be shown that O_1A, O_1C, O_2D and O_2F make angle α with the vertical. Hence the arc of contact between the belt and larger pulley is $(\pi + 2\alpha)$ radian and arc of contact between the belt and smaller pulley is $(\pi - 2\alpha)$ radian. The total length of belt is the sum of the length of belt in contact with larger pulley, length of belt in contact with the smaller pulley and the length of belt not in contact with the pulleys.

$$\text{ie., } L = \text{Arc ABC} + \text{Arc DEF} + (CD + AF)$$

$$\text{Arc ABC} = (\pi + 2\alpha)\, r_1$$

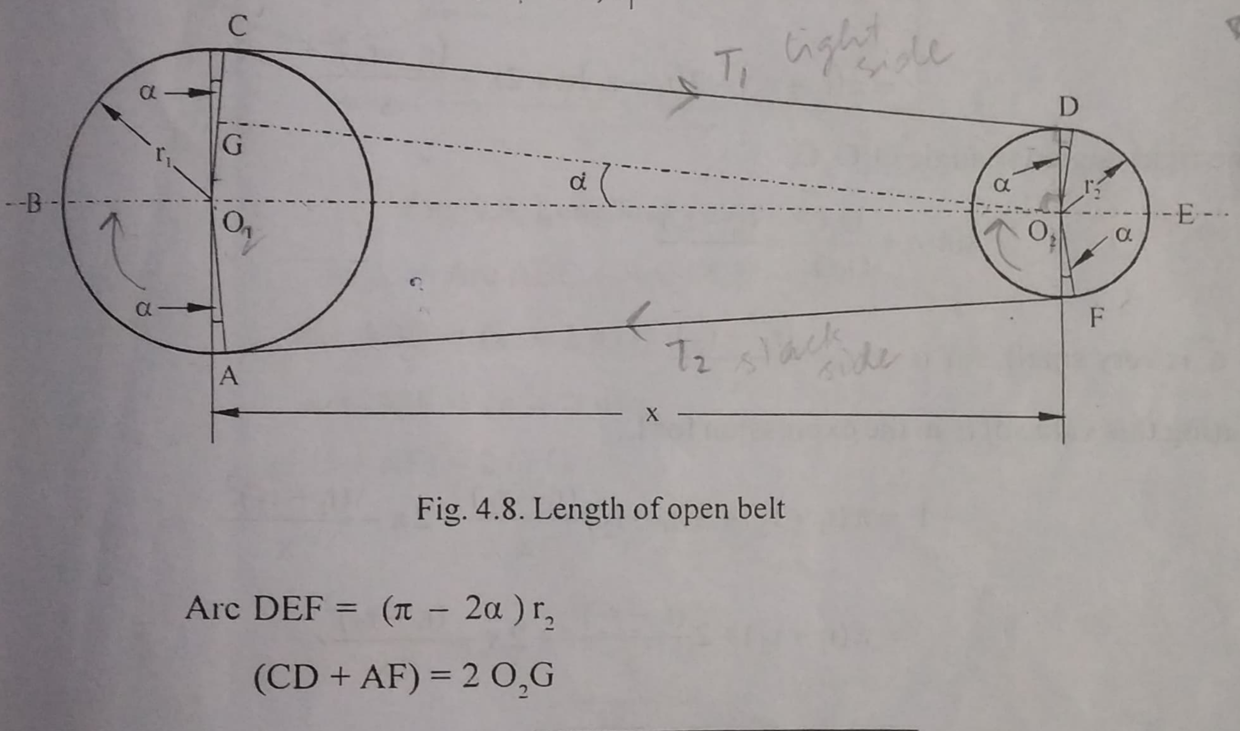


Fig. 4.8. Length of open belt

$$\text{Arc DEF} = (\pi - 2\alpha)\, r_2$$

$$(CD + AF) = 2\, O_2G$$

$$= 2\sqrt{(O_1O_2)^2 - (O_1G)^2}$$

$$= 2\sqrt{x^2 - (r_1 - r_2)^2}$$

$$= 2x\sqrt{1 - \left(\frac{r_1 - r_2}{x}\right)^2}$$

Expanding $\sqrt{1 - \left(\frac{r_1 - r_2}{x}\right)^2}$ using Binomial theorem,

$$\sqrt{1-\left(\frac{r_1-r_2}{x}\right)^2} = 1-\frac{1}{2}\left(\frac{r_1-r_2}{x}\right)^2 + \text{high powers of}\left(\frac{r_1-r_2}{x}\right)$$

Neglecting higher powers of $\left(\frac{r_1-r_2}{x}\right)$,

$$CD + AF = 2x\left[1-\frac{1}{2}\left(\frac{r_1-r_2}{x}\right)^2\right]$$

$$= 2x - \frac{(r_1-r_2)^2}{x}$$

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

$$= \pi r_1 + 2r_1\alpha + \pi r_2 - 2r_2\alpha + 2x - \frac{(r_1-r_2)^2}{x}$$

$$= \pi(r_1+r_2) + 2(r_1-r_2)\alpha + 2x - \frac{(r_1-r_2)^2}{x}$$

From the right angled triangle O_1O_2G,

$$\sin\alpha = \frac{O_1G}{O_1O_2} = \frac{(r_1-r_2)}{x}$$

Since α is very small, $\sin\alpha = \alpha = \frac{(r_1-r_2)}{x}$

Substituting this value of α in the expression for L,

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

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

$$L = \pi(r_1+r_2) + \frac{(r_1-r_2)^2}{x} + 2x \quad \ldots\ldots\ldots\ldots\ldots(i)$$

(b) Crossed belt drive

In cross belt drive, the two pulleys rotate in opposite directions.

Let, x = distance between centres of pulleys.

r_1, r_2 = radii of larger and smaller pulleys respectively

L = total length of belt.

The belt leaves the larger pulley at A and C and smaller pulley at D and F. Through O_2

draw O_2G parallel to CD. Since angle O_1 CD is 90°, O_2G will be perpendicular to O_1C. Let angle O_1O_2G be α, then O_1A, O_1C, O_2D and O_2F make angle α with the vertical. Hence the arc of contact between the belt and each pulley is $(\pi + 2\alpha)$ radian.

Total length of belt is the sum of the length of belt in contact with larger pulley, length of belt in contact with smaller pulley and the length of belt not in contact with the pulleys.

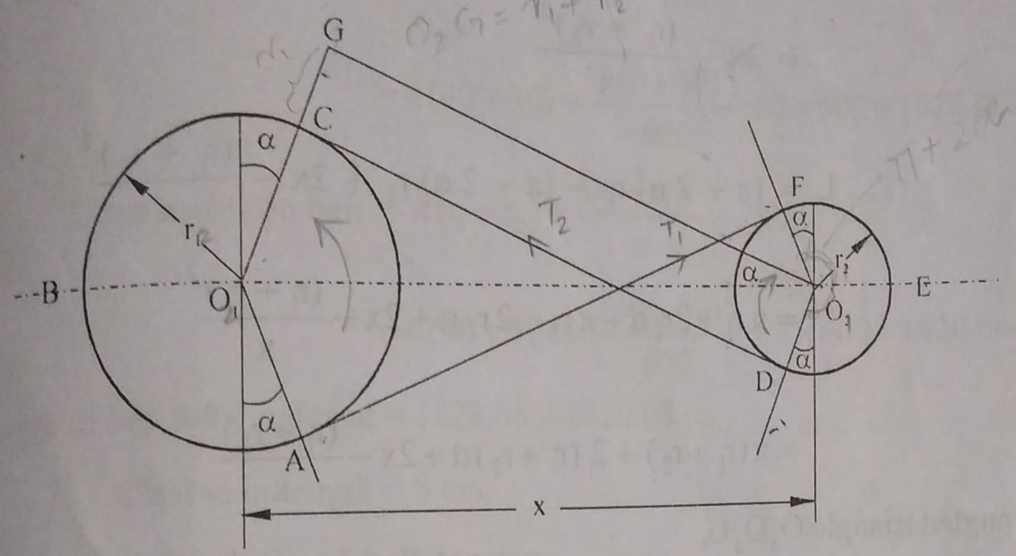


Fig. 4.9. Length of cross belt

L = AF + arc FED + DC + arc CBA

ie., L = Arc ABC + Arc DEF + (CD + AF)

Arc ABC $= (\pi + 2\alpha)\, r_1$

Arc DEF $= (\pi + 2\alpha)\, r_2$

$(CD + AF) = 2\, O_2G$

$$= 2\sqrt{(O_1O_2)^2 - (O_1G)^2}$$

$$= 2\sqrt{x^2 - (r_1 + r_2)^2}$$

$$= 2x\sqrt{1 - \left(\frac{r_1 + r_2}{x}\right)^2}$$

Expanding $\sqrt{1 - \left(\frac{r_1 + r_2}{x}\right)^2}$ by Binomial theorem,

$$\sqrt{1 - \left(\frac{r_1 + r_2}{x}\right)^2} = 1 - \frac{1}{2}\left(\frac{r_1 + r_2}{x}\right)^2 + \text{higher powers of } \frac{r_1 + r_2}{x}$$

Neglecting higher powers of $\left(\frac{r_1 + r_2}{x}\right)$

$$(CD + AF) = 2x\left(1 - \frac{1}{2}\left(\frac{r_1 + r_2}{x}\right)^2\right)$$

$$= 2x - \frac{(r_1 + r_2)^2}{x}$$

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

$$= \pi r_1 + 2r_1\alpha + \pi r_2 + 2r_2\alpha + 2x - \frac{(r_1 + r_2)^2}{x}$$

$$= \pi(r_1 + r_2) + 2(r_1 + r_2)\alpha + 2x - \frac{(r_1 + r_2)^2}{x}$$

From the right angled triangle O_1O_2G,

$$\sin\alpha = \frac{O_1G}{O_1O_2} = \frac{(r_1 + r_2)}{x}$$

Since α is small, $\sin\alpha = \alpha = \frac{(r_1 + r_2)}{x}$

Substituting this value of α in the expression for L,

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

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

$$\text{ie., } L = \pi(r_1 + r_2) + \frac{(r_1 + r_2)^2}{x} + 2x \quad \text{.......................(ii)}$$

Comparing equations (i) and (ii), it can be seen that the length of belt required to connect two pulleys at a fixed distance apart is more for a cross belt drive than for an open belt drive.

Problem 4.3.

Two parallel shafts 6 meters apart are provided with 60 cm and 80 cm diameter pulleys and are connected by means of a cross belt. The direction of rotation of the follower pulley is to be reversed by changing over to an open belt drive. How much length of the belt has to be reduced?

Solution:

Given: $d_1 = 80$ cm, $r_1 = 40$ cm $d_2 = 60$ cm, $r_2 = 30$ cm

$x = 6$ m $= 600$ cm

To find: Change in length of belt

$$\text{Length of cross belt} = \pi(r_1 + r_2) + \frac{(r_1 + r_2)^2}{x} + 2x$$

$$= \pi(40 + 30) + \frac{(40 + 30)^2}{600} + 2 \times 600 = 1428.08\,\text{cm}$$

$$\text{Length of open belt} = \pi(r_1 + r_2) + \frac{(r_1 + r_2)^2}{x} + 2x$$

$$= \pi(40 + 30) + \frac{(40 - 30)^2}{600} + 2 \times 600 = 1420.08\,\text{cm}$$

Length of belt to be reduced = 1428.08 – 1420.08

Change in length = 8 cm

4.14. Expression for ratio of belt tensions. (Deriv. not reqd.)

Fig. 4.10 shows a driven pulley rotating in the clockwise direction.

The angle of contact between the belt and pulley is θ radian. Let the tight side tension be T_1 and slack side tension T_2. Consider a short length MN of belt, which substends an angle $\delta\theta$ at the pulley centre. Let T be the tension at the end M and $T + \delta T$, the tension at the end N. The difference in tension is due to the friction between the length MN of the belt and pulley. The frictional force depends upon the normal reaction Rn between length MN of belt and pulley and is equal to μRn where μ is the coefficient of friction between the belt and pulley. The belt MN is in equilibrium under the action of four forces,

(i) Tension T at M (ii) Tension $T + \delta T$ at N

(iii) Normal reaction Rn, and (iv) Frictional force μRn

Resolving the forces vertically,

$$T\sin\frac{\delta\theta}{2} + (T + \delta T)\sin\frac{\delta\theta}{2} - Rn = 0$$

Since $\frac{\delta\theta}{2}$ is very small, $\sin\frac{\delta\theta}{2} \approx \frac{\delta\theta}{2}$

$$\therefore T\frac{\delta\theta}{2} + (T + \delta T)\frac{\delta\theta}{2} - Rn = 0$$

$$T\frac{\delta\theta}{2} + T\frac{\delta\theta}{2} + \frac{\delta T.\delta\theta}{2} - Rn = 0$$

Since $\frac{\delta T.\delta\theta}{2}$ is very small, it can be neglected

$$\therefore\ T\ \delta\theta = Rn \text{ ....(i)}$$

Resolving the force horizontally,

$$(T + \delta T)\cos\frac{\delta\theta}{2} - T\cos\frac{\delta\theta}{2} - \mu Rn = 0$$

Since $\frac{\delta\theta}{2}$ is very small $\cos\frac{\delta\theta}{2} \approx 1$

$$\therefore (T+\delta T) - T - \mu Rn = 0$$

$$\text{ie., } \delta T = \mu Rn$$

Substituting the value of Rn from equation (i)

$$\delta T = \mu T\delta\theta$$

$$\frac{\delta T}{T} = \mu\delta\theta$$

Integrating between corresponding limits,

$$\int_{T_2}^{T_1}\frac{\delta T}{T} = \mu\int_0^{\theta}\delta\theta$$

$$\ln\left(\frac{T_1}{T_2}\right) = \mu\theta$$

$$\text{or, } \boxed{\frac{T_1}{T_2} = e^{\mu\theta}}$$

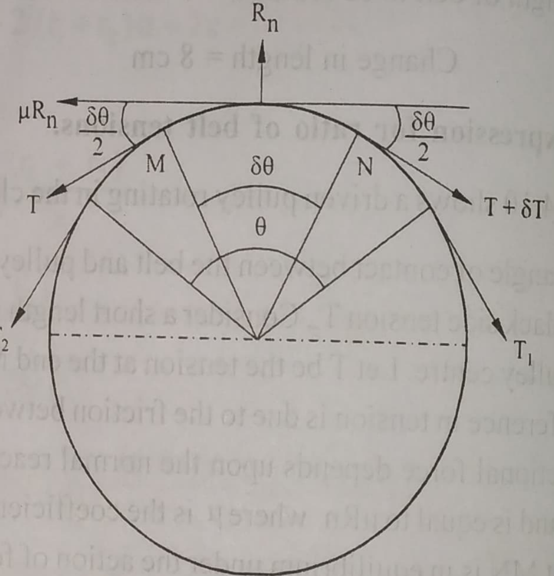


Fig. 4.10. Ratio of belt tensions

where θ is the arc of contact of belt and smaller pulley, in radian.

Problem 4.4.

A belt , 250 mm. wide and 9 mm .thick is used to transmit power from one pulley to another. The angle of contact at the smaller pulley is 120° and coefficient of friction between belt and pulley is 0.35. Determine the tight side and slack side tensions, if the stress in the belt on tight side is 200 N/cm²

Solution:

Given: $b = 250\text{ mm} = 25\text{ cm}$ $\mu = 0.35$ $t = 9\text{ mm} = 0.9\text{ cm}$

$$\theta = 120^{\circ} = \frac{\pi}{180} \times 120 \text{ radian} \quad f_1 = 200 \text{ N/cm}^2$$

To find : T_1, T_2

Tension on the tight side = stress × area of cross section of belt

$$= 200 \times 25 \times 0.9 = 4500 \text{ N}$$

$$T_1 = 4.5 \text{ kN}$$

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

$$\frac{4.5}{T_2} = e^{0.35 \times \frac{\pi}{180} \times 120^{\circ}} = 2.08$$

$$T_2 = \frac{4.5}{2.08} = 2.16$$

$$T_2 = 2.16 \text{ kN}$$

4.15. Power transmitted by belt drive

Knowing the tension on the two sides of the belt and the belt velocity, power transmitted can be calculated.

Let T_1 = tight side tension, N.

T_2 = slack side tension, N.

r = radius of pulley, m.

ω = angular velocity, rad/s

V = velocity of belt, m/s.

N = speed of pulley, rpm.

The effective turning force at the circumference of the pulley is the difference between the two tensions, T_1 and T_2.

Effective turning force = $(T_1 - T_2)$

Torque exerted on the pulley = Force × radius

$$= (T_1 - T_2)\, r$$

Work done/s = Torque × angular velocity

$$= (T_1 - T_2)\, r \times \omega$$

But $\omega \times r = V$, velocity of belt in m/s.

Rate of work done or power transmitted $= (T_1 - T_2) \times V$ N m/s

$$= (T_1 - T_2) \times V \text{ Watts}$$

$$\text{Since } V = \omega \times r = \frac{2\pi N}{60} \times r = \frac{\pi d N}{60}$$

$$\text{Power transmitted} = (T_1 - T_2)\frac{\pi\, dN}{60} \text{ Watts}$$

Note:- In the above expression, if d is the diameter of driver pulley then N should be the speed of driver pulley and if d is the diameter of driven pulley then N should be the speed of driven pulley.

Problem 4.5.

An open belt drive transmits 36 kW with a belt velocity of 5 m/s. Determine the tensions on each side of the belt, if the coefficient of friction is 0.3 and the angle of lap is 180°.

Solution:

Given: $V = 5$ m/s. $P = 36$ kW $= 36000$ Watts $\mu = 0.3$

$$\theta = 180^{\circ} = \frac{\pi}{180} \times 180 = \pi \text{ radian}$$

To find: T_1, T_2

$$\text{We have, } \frac{T_1}{T_2} = e^{\mu\theta}$$

$$T_1 = T_2\, e^{\mu\theta} = T_2\, e^{0.3 \times \pi}$$

$$T_1 = 2.57\, T_2$$

$$P = (T_1 - T_2)\, V$$

$$36000 = (2.57\, T_2 - T_2)\, 5$$

$$T_2 = 4586 \text{ N}$$

$$\text{Since } T_1 = 2.57\, T_2$$

$$T_1 = 2.57 \times 4586 = 11786$$

$$T_1 = 11786 \text{ N}$$

Problem 4.6.

A flat belt 68.5 mm × 10 mm, running on a pulley 1 m diameter is to transmit power at 200 rpm. Taking angle of lap as 170° and coefficient of friction as 0.25, determine the maximum power that can be transmitted, if the stress on the belt is not to exceed 200 N/cm².

Solution:

Given: $d = 1$ m $N = 200$ rpm $b = 68.5$ mm $= 6.85$ cm

$f_t = 200$ N/cm² $t = 10$ mm $= 1$ cm $\theta = 170° = 2.97$ radian

$\mu = 0.25$

To find: max. power

Maximum Tension, $T_1 = f_t \times b \times t$

$= 200 \times 6.85 \times 1$

$= 1370$ N

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

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

$1370 = T_2 \, e^{0.25 \times 2.97} = 2.1 \, T_2$

$T_2 = 652.38$ N

Power transmitted $= \frac{\pi \, d \, N}{60} (T_1 - T_2)$

$= \frac{\pi \times 1 \times 200}{60} (1370 - 652.38) = 7514.9$

$= 7514.9$ Watts

Problem 4.7.

A flat belt is installed with an initial tension of 2 kN. The angle of lap on the smaller pulley is 150°. The friction coefficient between the belt and pulley surface is 0.3. The belt runs at a speed of 20 m/s. Determine the power that can be transmitted by the above drive, if it is assumed that the belt is perfectly elastic and the centrifugal effect is ignored.

Solution:

Given: $T_o = 2$ kN $= 2000$ N $\mu = 0.3$

$\theta = 150° = 2.62$ rad $V = 20$ m/s.

To find: P

$$T_o = \frac{T_1 + T_2}{2}$$

$$\therefore T_1 + T_2 = 2T_O = 2 \times 2000 = 4000 \text{ N} \text{ ....(i)}$$

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

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

$$T_1 = T_2 \times e^{0.3 \times 2.62}$$

$$T_1 = 2.19\, T_2$$

From (i)

$$2.19\, T_2 + T_2 = 4000$$

$$T_2 = 1253.92 \text{ N}$$

$$T_1 = 2.19 \times 1253.91 = 2746.08 \text{ N}$$

$$P = (T_1 - T_2)\, V$$

$$= (2746.08 - 1253.92) \times 20$$

$$= 29843.2 \text{ N. m/s.}$$

$$P = 29.84 \text{ kW}$$

imp *

Problem 4.8.

The distance between the centres of two pulleys of 300 mm and 750 mm. diameter is 1.5 m. The pulleys are connected by leather belt, 150 mm. wide and 10 mm. thick, by open belt drive. The maximum tension of the belt should not exceed 14 N/mm. width of belt . Assuming the coefficient of friction between the belt and pulley as 0.25, determine the maximum power that can be transmitted at a belt speed of 9 m/s.

Solution:

Given: $x = 1.5 \text{ m} = 1500 \text{ mm}$ $w = 150 \text{ mm}$ $d_1 = 750 \text{ mm}$

$r_1 = 375 \text{ mm}$ $t = 10 \text{ mm}$ $d_2 = 300 \text{ mm}$ $r_2 = 150 \text{ mm}$

$\frac{T_1}{w} = 14 \text{ N/mm}$ $V = 9.\text{m/s}$

To find: P

$$T_1 = 14 \times w$$

$$= 14 \times 150 = 2100 \text{ N}$$

For an open belt drive

$$\theta = 180 - 2\alpha \text{ (Refer fig.3.8)}$$

$$\sin\alpha = \frac{r_1 - r_2}{x} = \frac{375 - 150}{1500} = 0.15$$

$$\alpha = \sin^{-1} 0.15 = 8.627^{\circ}$$

$$\therefore \theta = 180 - 2\alpha = 180 - 2 \times 8.627 = 162.746^{\circ}$$

$$= \frac{\pi}{180} \times 162.746 = 2.84 \text{ rad}$$

$$\frac{T_1}{T_2} = e^{\mu\theta} = e^{0.25\times2.84} = 2.034$$

$$T_1 = 2.034\, T_2$$

$$2100 = 2.034\, T_2$$

$$\therefore T_2 = 1032.45 \text{ N}$$

$$P = (T_1 - T_2)\, V$$

$$= (2100 - 1032.45)\, 9 = 9607.95$$

$$P = 9.61 \text{ kW}$$

4.16. Rope drive

Ropes for transmitting power are usually made of cotton and are of circular cross-section. Ropes are used when considerable power is to be transmitted over long distances. The ropes are housed in grooves provided in the pulley. The groove angle varies from 40° to 60°, but is generally 45°. One of the advantages of rope drive is that a number of separate drives may be taken from one driving pulley by providing a number of grooves in the pulley.

Whenever large amount of power is to be transmitted over long distance wire rope is used. Wire ropes are made from cold drawn wires. The cold drawn wires are twisted together to form what is called a strand . A number of such strands are then twisted together to form a rope. This type of construction enables the rope to be wrapped around a pulley without undue bending stress in the wire. Ropes are usually designated by specifying number of strands and number of wires on it. For example, 6 × 19 rope means the rope has 6 strands and each strands is having 19 wires in it.

The various materials used for rope making are wrought iron, cast steel, extra strong cast steel. Ropes of aluminium alloys, copper bronze andd stainless steel are also used.Ropes are usually galvanized to protect them against corrosion.

Ropes may be classified according to the direction of twist of the individual wires and that of strands relative to each other. Two types of windings are in use.

These are:

i) Regular lay ropes : In this the direction of twist of wires in the strands is opposite to the direction of twist of the strands in the rope.

ii) Long lay ropes: In this, the direction of twist of wires and strands in a rope is the same.

4.17. Chain Drive

Chain drive consists of an endless chain running over special profile toothed wheels called sprockets. One of the sprockets will be the driver and the other driven. The smaller sprocket is called pinion and the bigger one is called wheel. The chain is made up of plates, pins and bushing. These parts are usually made of high grade steel.

From the application point of view chain drives are classified as power transmission chains, hoisting chains and pulling chains. Power transmission chains are used when power is to be transmitted from one shaft to another. Hoisting chains are used for lifting loads. Pulling chains are used in elevators, conveyors etc.

Main types of chains used to transmit power are:

i) Roller Chain: Refer Fig. 4.11. It consists of rollers, bushes, pins inner plates and outer plates. The pin passes centrally through the bush and the roller surrounds the bush. The roller turns freely on the bush and the bush turns freely on the pin. Two adjacent rollers are held by two inner plate (roller link plates). These inner plates connect the two bushes as shown in the figure. The bushes turn freely on the inner plates. Two adjacent bushes are held by two outer plates called pin link plates. These outer plates connect the two central pins and keep them in position. To prevent the sliding of outer plates laterally outwards, the pin ends are hammered to the shape of rivet head. In order to reduce friction all the contact surfaces are lubricated.

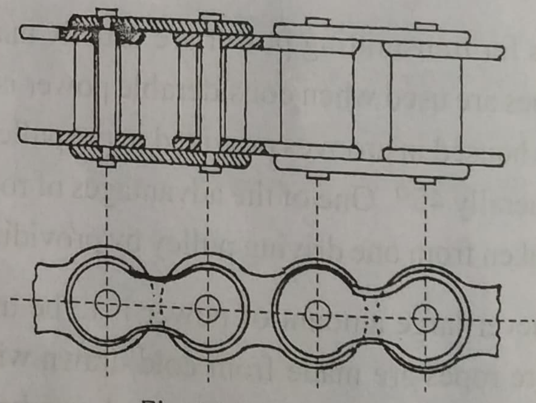


Fig. 4.11. Roller chain

ii) Silent or inverted tooth chain: Refer Fig. 4.12. It consists of special profile plates corresponding to the profile of the sprocket teeth. These types of chains are more complex in design and require careful maintenance. It is employed when heavier loads are to be transmitted and maximum quietness is desired .

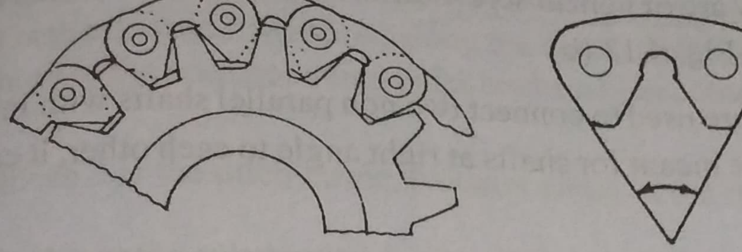


Fig. 4.12. Silent chain

4.18. Gear Drive

The term gear is generally used to denote toothed wheel. For transmission of power one gear is mounted on the driving shaft and another one of the driven shaft, their teeth meshing with each other. The distance between the two shafts should be just sufficient to enable meshing of the gear teeth. If the driving and driven shafts are at a long distance so that a direct meshing of two gears is not possible, then required number of gears may have to be incorporated in between the two gears so as to make the drive possible.

Gear teeth are formed either by casting or by machine cutting. The cutting of gear teeth is done by milling, shaping or hobbing. A variety of materials are used for the manufacture of gears depending on requirement. The cheapest material used is ordinary grey iron. For heavy duty gears cast steel and alloy steel are preferred. Non-ferrous metals like phosphor bronze, nickel, manganese etc. are used under corrosive environments.

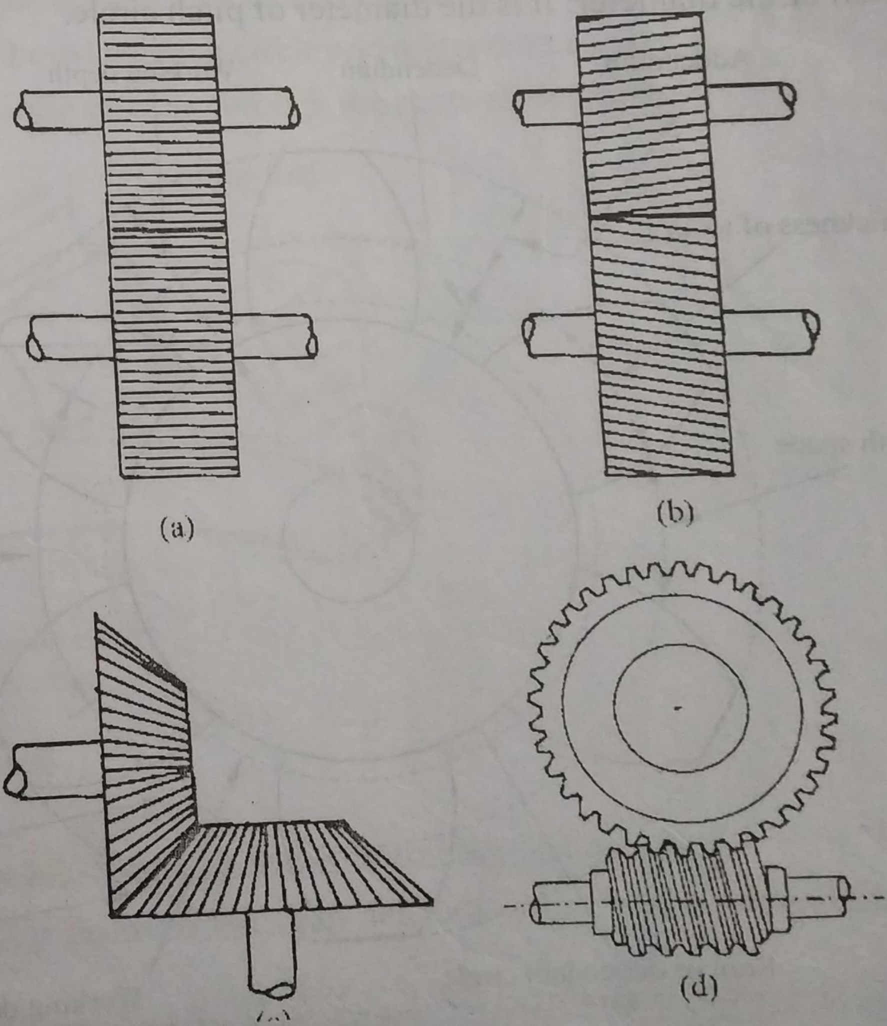


Fig. 4.13.

There are many types of gears and the following are the important ones:

i) Spur gears: Spur gears are those which have teeth cut parallel to the axis of the shaft . Spur gears are used to transmit power between parallel shafts. Fig. 4.13. (a)

ii) Helical gears: Helical gears are used in the same way as spur gears, but the teeth cut on the periphery are of helical screw form. A helical tooth is thus inclined at an angle to the axis of the shaft. Fig. 4.13 (b)

iii) Bevel gears : Bevel gears are used to connect two non parallel shafts with intersecting axes. Even though bevel gears are meant for shafts at right angle to each other, it can also be used for any angle. Fig. 4.13 (c)

iv) Worm gears: Worm gears are used for power transmission between non-intersecting shafts that are generally at right angles to each other. The worm gearing consists of worm and worm wheel. A worm is a threaded screw and is used as the driver. The worm wheel is a toothed wheel. The teeth of the worm wheel remain engaged with the threads of the worm. Fig. 4.13 (d).

4.19. Gear terminology

Various terms used in the study of gears have been explained below:

1. Pitch cylinders: Pitch cylinders of a pair of gears in mesh are the imaginary cylinders which by rolling together transmit the same motion as the pair of gears.
2. Pitch circle: It is the circle with radius equal to the radius of the pitch cylinder .
3. Pitch circle diameter: It is the diameter of pitch circle.

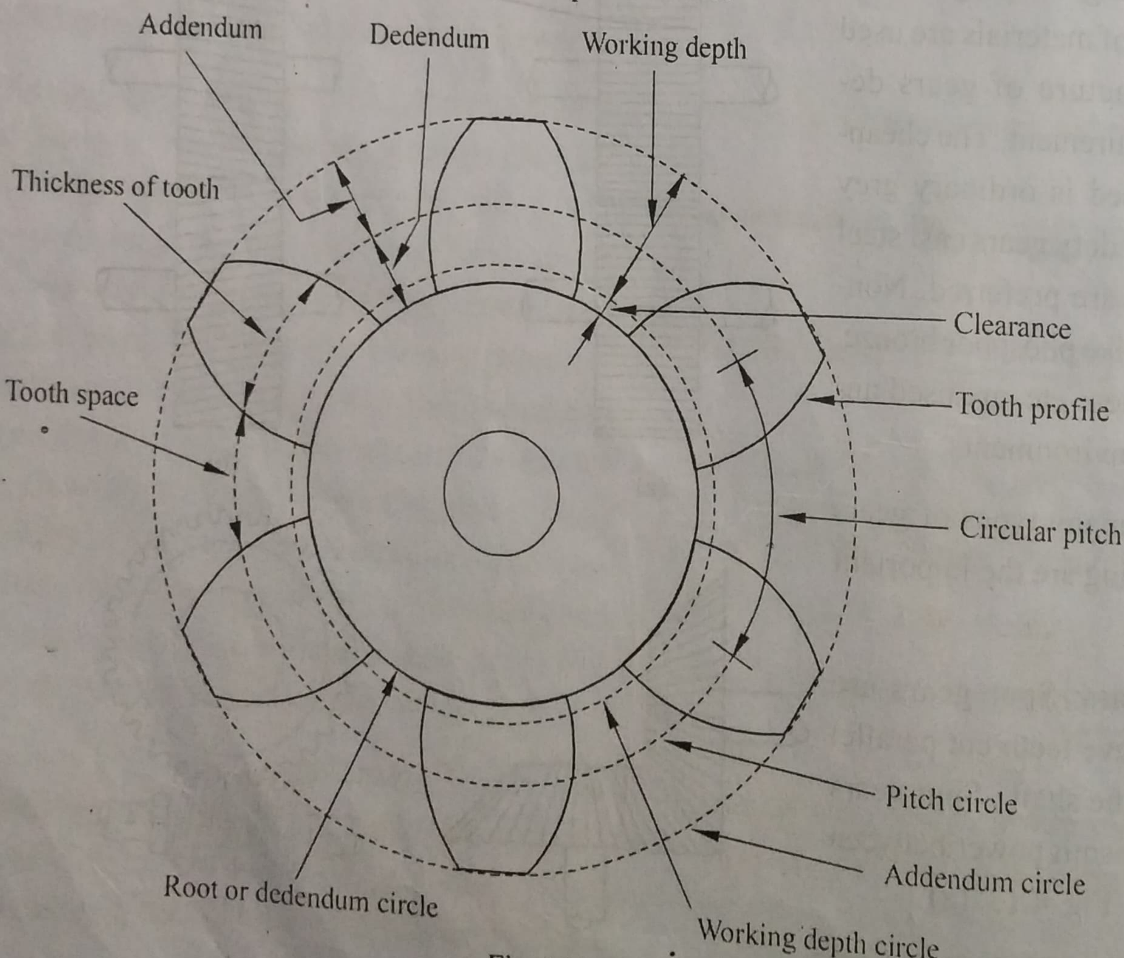


Fig. 4.14.

4. Pitch point: It is the point of contact of two pitch circles.
5. Circular pitch: It is the distance measured along the circumference of pitch circle from a point from one tooth to the corresponding point on the adjacent tooth. It is denoted by p_c.

$$p_c = \frac{\pi d}{T}$$, where d is the pitch circle diameter and T is the number of teeth.

6. Pitch angle: It is the angle substended by the circular pitch at the centre of the pitch circle.
7. Diametral pitch: It is the number of teeth per unit length of the pitch circle diameter. It is denoted by P.

$$P = \frac{T}{d}$$

8. Module: It is the ratio of pitch circle diameter in millimeter to the number of teeth. It is denoted by m.

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

9. Addendum circle: It is the circle passing through the tips of teeth.
10. Addendum: It is the radial distance between pitch circle and addendum circle.
11. Dedendum or root circle: It is the circle passing through the roots of the teeth.

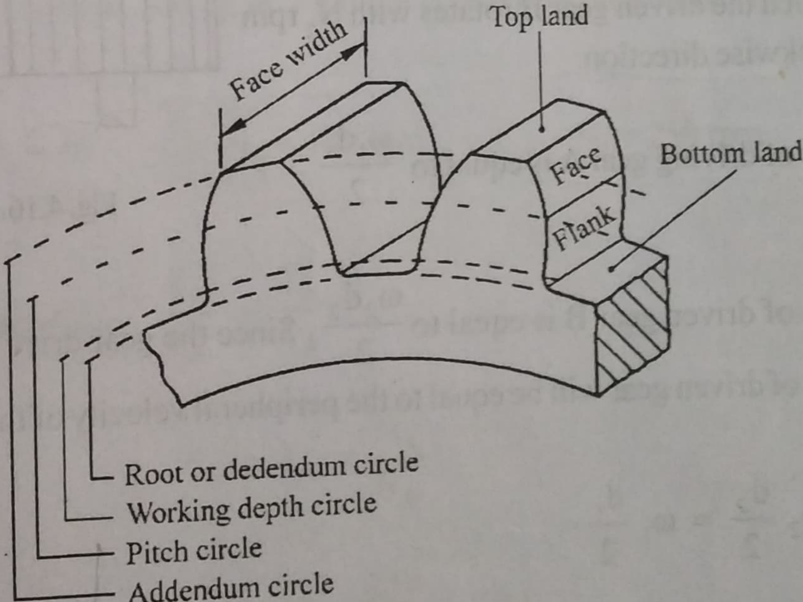


Fig.4.15.

12. Dedendum: It is the radial distance between pitch circle and dedendum circle.
13. Full depth of teeth: It is the radial distance between dedendum circle and addendum circle

Full depth = Addendum + Dedendum

14. Clearance: It is the radial difference between the addendum and the dedendum of a

tooth.

15. Top land: It is the surface at the top of tooth.
16. Bottom land: It is the surface at the root of tooth, in between two adjacent teeth.
17. Tooth thickness: It is the width of the tooth measured along the pitch circle
18. Tooth space: It is the width of space between the two adjacent teeth measured along the pitch circle.
19. Backlash: It is the difference between the tooth space and the tooth thickness, measured along the pitch circle.
20. Face: It is the tooth surface between the pitch circle and the top land.
21. Flank: It is the tooth surface between the pitch circle and the bottom land.
22. Face width: It is the length of tooth measured parallel to the axis of gear.
23. Profile: It is the curve formed by the face and flank of the tooth.

4.20. Velocity ratio of gear drive

The gear ratio is defined as the ratio of the speed of driven gear to the speed of driving gear. It is denoted by the letter 'G'. A schematic diagram of two mating spur gears A and B is shown in Fig. 4.16. Let the pitch circle diameters of A and B be d_1 and d_2 respectively.

In case the driving gear A rotates with N_1 rpm (ω_1 rad/sec) in clockwise direction, then the driven gear B rotates with N_2 rpm (ω_2 rad/sec) in anticlockwise direction.

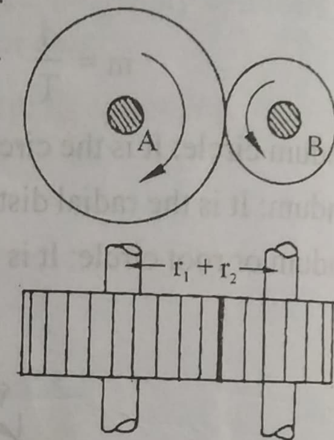


Fig. 4.16.

The peripheral velocity of driving gear A is equal to $\frac{\omega_1 d_1}{2}$

The peripheral velocity of driven gear B is equal to $\frac{\omega_2 d_2}{2}$. Since the gear drive is positive, the peripheral velocity of driven gear will be equal to the peripheral velocity of the driver gear.

Hence,
$$\omega_2 \frac{d_2}{2} = \omega_1 \frac{d_1}{2}$$

$$\frac{\omega_2}{\omega_1} = \frac{d_1}{d_2}$$

$$\text{or } \frac{N_2}{N_1} = \frac{d_1}{d_2} \text{ ....(i)}$$

Circular pitch of gear A, $p_{C1} = \pi \dfrac{d_1}{T_1}$ where T_1 is the number of teeth on driving gear A.

Circular pitch of gear B, $p_{C2} = \pi \dfrac{d_2}{T_2}$ where T_2 is the number of teeth on driven gear B.

Two gears will mesh together correctly, only if the gears have the same circular pitch.

$$\therefore p_{C1} = p_{C2}$$

$$\pi \frac{d_1}{T_1} = \pi \frac{d_2}{T_2}$$

$$\text{or} \quad \frac{d_1}{d_2} = \frac{T_1}{T_2} \quad \text{.....................(ii)}$$

From (i) and (ii)

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}.$$

i.e., Velocity ratio or gear ratio, 'G', $\dfrac{N_2}{N_1} = \dfrac{T_1}{T_2} = \dfrac{d_1}{d_2}$

Problem 4.9.

Two spur wheels, A and B, on parallel shafts, are in mesh. A has 40 teeth and rotates at 250 r.p.m. B is to rotate at 100 r.p.m. Find the number of teeth on B.

Solution:

Given: $T_A = 40$ $N_B = 100$ rpm $N_A = 250$ rpm

To find: T_B

We have, $\dfrac{N_B}{N_A} = \dfrac{T_A}{T_B}$

$$T_B = T_A \times \frac{N_A}{N_B}$$

$$= 40 \times \frac{250}{100} = 100$$

$$T_B = 100$$

Problem 8.10.

Two mating spur gears have 60 and 40 teeth . Their common module is 5 mm. Determine the centre to centre distance between the gears axis.

Solution:

Given: $T_1 = 60$

$m = 5$ mm

$T_2 = 40$

To find : L

$$\text{Module, } m = \frac{d}{T}$$

$$d_1 = mT_1 = 5 \times 60 = 300 \text{ mm.}$$

$$d_2 = mT_2 = 5 \times 40 = 200 \text{ mm}$$

We have,

$$L = r_1 + r_2 = \frac{d_1}{2} + \frac{d_1}{2} = \frac{300}{2} + \frac{200}{2}$$

$$= 150 + 100 = 250$$

$$L = 250 \text{ mm.}$$

4.21. Comparison and fields of application.

Belt drive is commonly used for transmission of power when exact velocity ratio is not required. Flat belts are used when the distance between the shafts is more and only moderate amount of power is to be transmitted . When the distance between the shafts is less and a large amount of power is to be transmitted, the V - belts are used. Belt drive is comparatively cheaper than other drives.

Some of the advantages of flat belts are:

i) Can be used with high speed drives.

ii) Can be used in industrial and abbrassive environment.

iii) Absorbs shock and vibrations.

iv) Offers longer life when properly maintained.

Some of advantages of V- belts are:

i) Can be used for high speed ratios as high as 10:1.

ii) No possibility of belt coming out of grooves.

iii) Low percentage of slip.

iv) A number of drives can be taken from a single pulley by providing a number of grooves on the same pulley.

Rope drives are used for transmission of large amount of power over long distances. Wire ropes are extensively used in elevators, mine hoist, cranes, conveyors, hauling devices, tramways, lifting tackless, suspension bridges etc. Manila ropes are used only for hoisting in very small capacity hoists.

The following are the advantages of rope drives.

i) Smooth and silent operation.

ii) Less weight

iii) Ability to withstand shocks

iv) Longer life

Chain drives are used in bicycles, motorcycles, agriculture machinery, rolling mills, conveyors , transport mechanisms etc.

Advantages of chain drives are:

i) Can provide non-slip drive

ii) Very high efficiency

iii) Less load on shafts

iv) Occupies less space

v) Can be operated at adverse temperatures.

vi) Can transmit motion to several shafts by a single chain.

Disadvantages of chain drives are:

i) High cost

ii) More weight

iii) Velocity fluctuations due to stretching during use.

iv) Needs accurate mounting and careful maintenance

Gear drives are used when positive drives are necessary and when the centre to centre distance between the shafts is relatively short. Also gears are used whenever motion is to be transmitted between non parallel and non-intersecting shafts. Gears are of great practical utility in almost all kinds of precission engineering works. Hardened gear find application in aircraft, automobile and other industries.

fully inside the female cone which is connected to the driver shaft. For disengaging the clutch the male cone is pulled out by means of the action of spring (not shown in Fig. 4.19) The spring force separates the contact surface.

4.25. Gear trains

Any combination of gear wheels by means of which motion is transmitted from one shaft to another shaft is called gear train. The following are the different types of gear trains.

1. Simple gear train
2. Compound gear train
3. Reverted gear train
4. Epicyclic gear train

Simple gear train

A simple gear train is one in which each shaft carries one gear only. Each of the intermdiate gear acts both as a driven and as a driver. These intermediate gear have no effect on the velocity ratio and hence these gears are known an idlers. Fig. 4.20 (a) shows a simple gear train with one idler and Fig. 4.20 (b) shows a simple gear train with two idler.

Referring Fig. 4.20 (a),

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} ; \frac{N_3}{N_2} = \frac{d_2}{d_3}$$

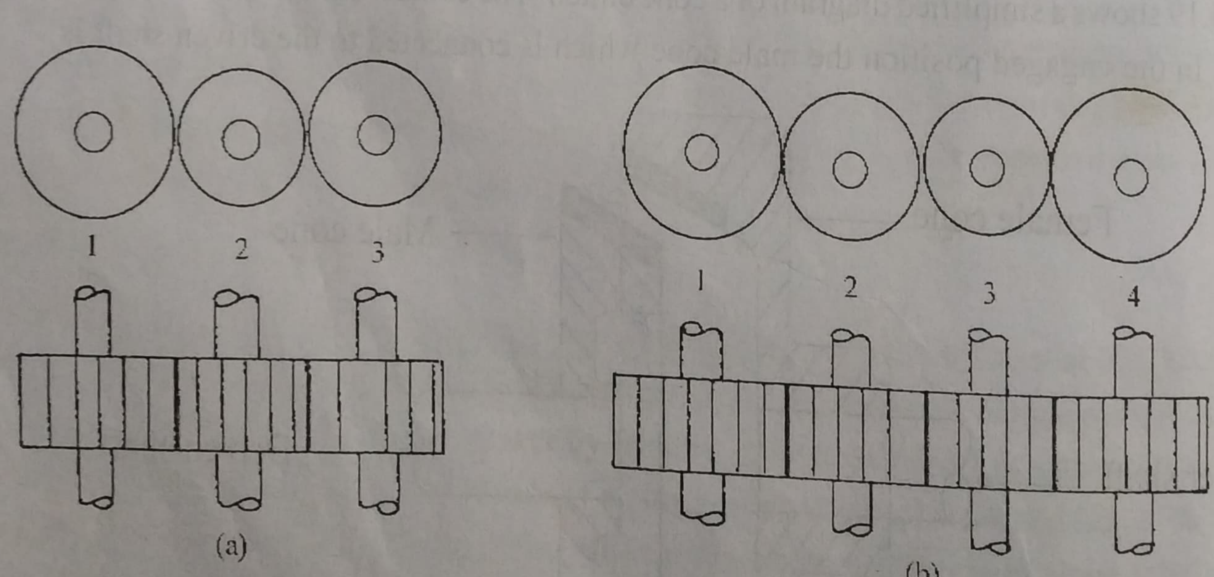


Fig. 4.20. Simple gear train

$$\frac{N_2}{N_1} \times \frac{N_3}{N_2} = \frac{d_1}{d_2} \times \frac{d_2}{d_3}$$

$$\frac{N_3}{N_1} = \frac{d_2}{d_3} \quad \text{.........................(i)}$$

Referring Fig. 4.20 (b),

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}; \ \frac{N_3}{N_2} = \frac{d_2}{d_3}; \ \frac{N_4}{N_3} = \frac{d_3}{d_4}$$

$$\frac{N_2}{N_1} \times \frac{N_3}{N_2} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_2}{d_3} \times \frac{d_3}{d_4}$$

$$\frac{N_4}{N_1} = \frac{d_1}{d_4} \quad \text{.......................(ii)}$$

From equations (i) and (ii), it can be seen that the speed ratio is independent of the number and diameter of intermediate gears. It can also be seen that when the number of idlers is odd, the driver and driven gears rotates in the same direction and when the number of idlers is even, the driver and driven gears rotate in opposite directions. In simple gear train the function of idlers is to fill the gap between the of rotation of the driven gear as required.

Compound gear train

When a series of gears are connected in such a way that two or more gears rotates about same axis, it is called a compound gear train. The intermediate shafts carryy more than one gear. The speed ratio depends on the diameter of driver, the driven and the intermediate gears. Refer Fig. 4.21. Gears 1 and 3 are driver gears 2 and 4 are the driven gears.

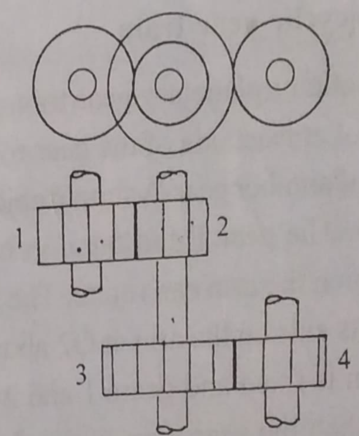


Fig. 4.21. Compound gear train

Referring Fig. 4.21.

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}; \ \frac{N_4}{N_3} = \frac{d_3}{d_4}$$

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_3}{d_4} \quad (N_3 = N_2)$$

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4}$$

$$\frac{\text{Speed driven gear}}{\text{Speed of driver gear}} = \frac{\text{Product of diameter of driver gears}}{\text{Product of diameter of driven gears}}$$

Reverted gear train

A reverted gear train is one in which the axes of the first and last gears coincide. Such an arrangement is shown in Fig. 4.22, which has its application as a speed reducer.

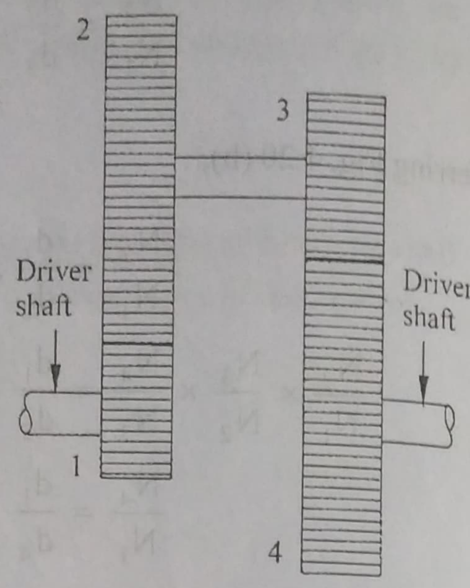


Fig. 4.22. Reverted gear train

Referring Fig. 4.22,

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}; \quad \frac{N_4}{N_3} = \frac{d_3}{d_4}$$

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_3}{d_4} \quad (N_3 = N_2)$$

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4}$$

$$= \frac{\text{Product of diameters of driver gears}}{\text{Product of diameters of driven gears}}$$

Since $d_1 \times d_3$ is less than $d_2 \times d_4$, N4 will be less than N_1. Hence the speed of the driven shaft will be less than the speed of driver shaft.

4.26. Epicyclic gear train

Epicyclic or planetary gear train is one in which the axis of rotation of at least one of the gear rotate about the fixed axis of rotation of another gear. A simple epicyclic gear train is shown in Fig. 4.23. The gear 1 and the arm have a common axis at O_1, about which the arm can rotate. The gear 2 meshes wit h gear 1 and has its axis on the arm at O2 about which the gear 2 rotates. If the arm is fixed and gears 1 and 2 are free to rotate about O_1 and O_2, then the gear train is simple gear train. If the gear 1 is fixed and the arm is free to rotate about the axis O_1, then the gear train is called epicyclic gear train. The advantage of gear train is that a very high velocity ratio can be obtained with moderate diameter gears. The differntial mechanism used in automobile is a common example of the application of epicyclic gear train.

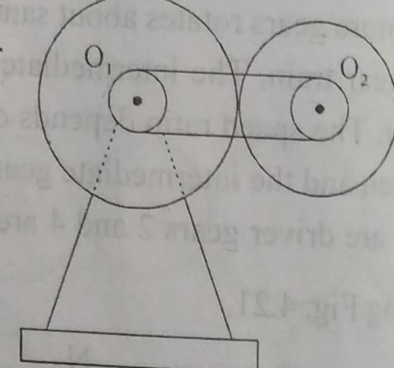


Fig. 4.23. Epicyclic gear train.

4.27. Brakes

Brakes are one of the most important safety features of the vehicle. There are different types of brakes. The brakes used to stop a vehicle while driving are known as the service brakes. Vehicles also equipped with other braking systems, including anti-lock and emergency brakes.

Disc Brakes

Disc brakes consist of a disc brake rotor, which is attached to the wheel, and a caliper which holds the disc brake pads. Hydraulic pressure from the master cylinder causes the caliper piston to clamp the disc brake rotor between the disc brake pads. This creates friction between the pads and rotor, causing the vehicle to slow down or stop.

Emergency Brakes

Vehicles also equipped with a secondary braking system, known as emergency, or parking brakes. Emergency brakes are independent of the service brakes, and are not powered by hydraulics. Parking brakes use cables to mechanically apply the brakes (usually the rear brake). There are a few different types of emergency brakes, which include: a stick lever located between the driver and passenger seats; a pedal located to the left of the floor pedals; or a push button or handle located somewhere near the steering column. Emergency brakes are most often used as a parking brake to help keep a vehicle stationary while parked. They are also used in emergency situations, in case the other brake system fails.

Anti-Lock Brakes

Computer-controlled anti-lock braking systems (ABS) is an important safety feature which is equipped on most newer vehicles. When brakes are applied suddenly, ABS prevents the wheels from locking up and the tires from skidding. The system monitors the speed of each wheel and automatically pulses the brake pressure on and off rapidly on any wheels where skidding is detected. This is beneficial for driving on wet and slippery roads. ABS works with the service brakes to decrease stopping distance and increase control and stability of the vehicle during hard braking.

Problems for practice

Problem 1.

Two parallel shafts, connected by a crossed-belt, are provided with pulleys 480 mm and 640 mm in diameters. The distance between the centre lines of the shafts is 3 m. Find how much the length of the belt should be changed if it is desired to alter the direction of rotation of the driven shaft. [Ans: 102.4 mm]

Problem 2.

A shaft runs at 80 rpm and drives another shaft at 150 rpm through belt drive. The diameter of the driving pulleys is 600 mm. Determine the diameter of the driven pulley in the following cases.

(i) Neglecting belt thickness,
(ii) Taking belt thickness as 5 mm,
(iii) Assuming for case (ii) a total slip of 4%.

[Ans: (i) 320 mm, (ii) 317.7 mm, (iii) 304.76 mm]

Problem 3.

With the help of a belt, an engine running at 200 rpm, drives a line shaft. The diameter of the pulley on the engine is 80 cm and the diameter of the pulley on the line shaft is 40 cm. A 100 cm diameter pulley on the line shaft drives a 20 cm diameter pulley keyed to a dynamo shaft. Find the speed of the dynamo shaft when :
(i) there is no slip, (ii) there is a slip of 2.5% at each drive. [Ans: 2000 rpm, 1901 rpm]

Problem 4.

A belt is running over a pulley of diameter 120 cm at 200 rpm. The angle of contact is 165° and co-efficient of friction between the belt and pulley is 0.3. If the maximum tension in the belt is 3000 N, find the power transmitted by the belt. [Ans: 21.8 kW]

Problem 5.

A 100 mm wide and 10 mm thick belt transmits 5kW between two parallel shafts. The distance between the shaft centres is 1.5 m and the diameter of the smaller pulley is 440 mm. The driving and driven shafts rotate at 60 rpm and 150 rpm respectively. Find the stress in the belt if the two pulleys are connected by :
(i) an open belt, and (ii) a cross belt. The coefficient of friction is 0.22.

[Ans: (i) 3.16 N/mm^2, (ii) 2.34 N/mm^2]

Problem 6.

2.5 kW of power is transmitted by an open-belt drive. The linear velocity of the belt is 2.5m/s. The angle of lap on the smaller pulley is 165°. The coefficient of friction is 0.3. Determine the effect on power transmission in the following cases:
(i) Initial tension in the belt is increased by 8%,
(ii) Initial tension in the belt is decreased by 8%,
(iii) Angle of lap is increased by 8% the same speed and the tension on the tight side, and
(iv) Coefficient of friction is increased by 8%.

[Ans: (i) 8%, (ii) 8%, (iii) 5%, (iv) 7%]

Problem 7.

A Vee belt of 6.5 cm^2 cross-section has a groove angle of 30° and an angle of lap of 160°, $\mu = 0.1$. The mass of the rope is 1.45 kg/metre run. The maximum safe stress is 840 N/cm^2. Calculate the power that can be transmitted at 25 m/s. [Ans: 15.77 kW]