KeralaNotes

KTU STUDY MATERIALS

BASICS OF MECHANICAL ENGINEERING

EST120

Module 5

Related Link :

- KTU S1/S2 STUDY MATERIALS
- KTU S1/S2 NOTES
- KTU S1/S2 SYLLABUS
- KTU S1/S2 TEXTBOOK PDF
- KTU S1/S2 PREVIOUS YEAR SOLVED QUESTION PAPER

Module 5

Refrigeration: Unit of refrigeration, reversed Carnot cycle, COP, vapour compression cycle (only description and no problems); **Definitions of** dry, wet & dew point temperatures, specific humidity and relative humidity, Cooling and dehumidification, Layout of unit and central air conditioners; **Description about working with sketches of:** Reciprocating pump, Centrifugal pump, Pelton turbine, Francis turbine and Kaplan turbine. Overall efficiency, Problems on calculation of input and output power of pumps and turbines (No velocity triangles); **Description about working with sketches of:** Belt and Chain drives, Gear and Gear trains, Single plate clutches.

Refrigeration

Refrigeration is the process of maintaining a system at a temperature below the temperature of its surroundings. Refrigeration means the cooling of or removal of heat from a system. It can be accomplished by removing heat from the system.

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 is generally produced in one of the following three ways :

- by melting of a solid
- by sublimation of a solid and
- by evaporation of a liquid.

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. Now, with the development of artificial means of refrigeration (mechanical refrigeration) the application of natural methods becomes insignificant.

Most of the commercial refrigeration is produced by the evaporation of a refrigerant. ***Mechanical refrigeration depends upon the evaporation of liquid refrigerant and its circuit includes the equipments naming evaporator, compressor, condenser and expansion valve***.

The applications of refrigeration can be broadly classified into three groups as

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

- **Providing comfortable environment** which includes comfort air conditioning of residences, hospitals, theatres, offices etc.

The major applications of refrigeration systems

1. Ice making
2. Transportation of foods above and below freezing
3. Industrial air conditioning.
4. Comfort air conditioning
5. Chemical and related industries
6. Medical and surgical aids
7. Processing food products and beverages
8. Oil refining and synthetic rubber manufacturing
9. Manufacturing and treatment of metals
10. Freezing food products
11. Miscellaneous applications:
    - Extremely low temperatures
    - Building construction etc.

Refrigeration Systems – Classifications

1. Ice refrigeration
2. Air refrigeration system
3. Vapour compression refrigeration system
4. Vapour absorption refrigeration system
5. Special refrigeration systems :
    a. Adsorption refrigeration system
    b. Cascade refrigeration system
    c. Mixed refrigeration system
    d. Vortex tube refrigeration system
    e. Thermoelectric refrigeration
    f. Steam jet refrigeration system.

Unit of refrigeration

The capacity of a refrigerating machine is generally expressed in tons of refrigeration (TR). The rate of heat absorbed from a body or space to be cooled is termed as refrigerating effect. The rating of a refrigeration machine is obtained by refrigerating effect or amount of heat extracted in a given time from a body. The standard unit of refrigeration is ton refrigeration or simply ton.

"A ton of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one ton (1000kg) of ice from and at 0° C in 24 hours."

Or

“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.” One ton of refrigeration(1TR) is equivalent to 210KJ/min or 3.5KW.

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.*** It is defined as the ratio of heat absorbed by the refrigerant while passing through e evaporator to the work input required to compress the refrigerant in the compressor.

C.O.P = (Desired refrigeration effect)/ (Work spent in producing the effect)

If, Rn = net refrigerating effect and W = work expanded in by the machine during the same interval of time,then

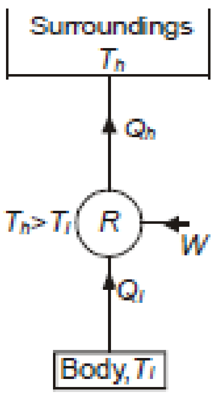
C.O.P = Rn/W

C.O.P of a refrigerator will be greater than unity (C.O.P > 1).

Reverse Carnot Cycle

Carnot cycle can also be used for getting the refrigeration effect upon its reversal. If a machine working on reversed Carnot cycle is driven from an external source, it will work or function as a refrigerator. Since it is a reversible cycle, all four processes can be reversed.

A refrigerator or heat pump that operates on the reversed Carnot cycle is called a Carnot refrigerator.



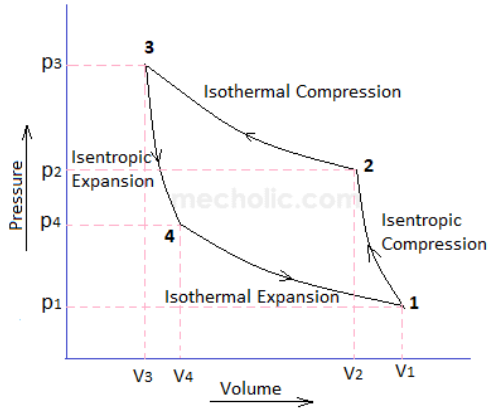
(a) Refrigerator

Here, the refrigerated space/body is to be maintained at low temperature T_l for which heat Q_l should be removed at constant rate and rejected to surroundings at high temperature, The Amount of heat rejected to surroundings is Q_h while the net work done upon refrigerator is W.

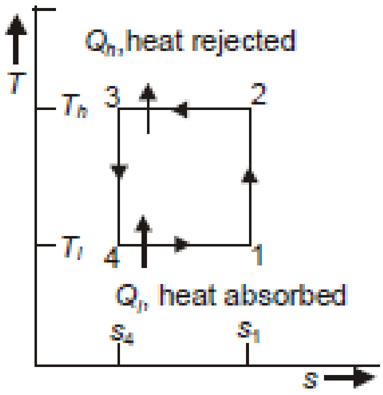
Reverse Carnot cycle consists of two isentropic processes and two isothermal processes. They are;

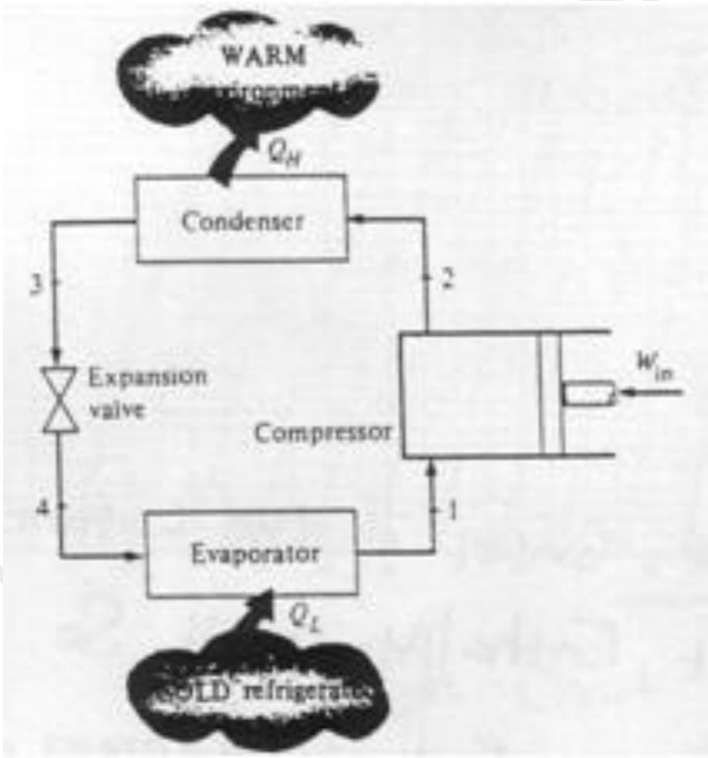
- 3–4 Reversible adiabatic expansion (isentropic expansion)
- 4–1 Reversible isothermal heat absorption, Q_l at temperature, T_l
- 1–2 Reversible adiabatic compression (isentropic compression)
- 2–3 Reversible isothermal heat rejection, Q_h at temperature, T_h

P-V and T-S diagrams of reversed Carnot cycle are shown below.



Fig(1) p-v diagram





Starting from point 3, the clearance space of the cylinder is full of air, the air is then expanded adiabatically to point 4 during which its temperature falls from T_3 (T_h) to T_4 (T_l), the cylinder is put in contact with a cold body at temperature T_4 (T_l). The air is then expanded isothermally to the point 1, as a result of which heat is extracted from the cold body at temperature T_4 (T_l). Now the cold body is removed; from 1 to 4 air undergoes adiabatic compression with the assistance of some external power and temperature rises to T_2 (T_h). A hot body at temperature T_2 (T_h) is put in contact with the cylinder. Finally the air is compressed isothermally during which process heat is rejected to the hot body.

For cyclic process;

Net work $W = Q_h - Q_l$

$Q_h = T_h (S_2 - S_3)$ and $Q_l = T_l (S_1 - S_4)$

Since $S_2 = S_1$ and $S_3 = S_4$; $Q_h = T_h (S_1 - S_4)$

$W = T_h (S_1 - S_4) - T_l (S_1 - S_4)$ => $W = (S_1 - S_4)(T_h - T_l)$

$$\text{COP} = \frac{Q_l}{W} = \frac{T_l(S_1 - S_4)}{(T_h - T_l)(S_1 - S_4)} = \left\{\frac{T_l}{T_h - T_l}\right\}$$

The coefficient of performance of refrigerator depends upon the two temperature values i.e. low temperature T_l and high temperature T_h. For COP value to be high the low temperature T_l should be high while higher temperature T_h should be small.

The reverse Carnot cycle is the most efficient refrigeration cycle operating between two specified temperature levels. It sets the highest theoretical COP.

Practically the reversed Carnot cycle cannot be used for refrigeration purpose as the adiabatic process requires very high speed operations, whereas isothermal process requires very low speed operations.

Practically, the lower temperature requirement is decided by the user while higher temperature is generally fixed by the atmospheric temperature value. Thus, it could be said that for certain low temperature to be maintained, COP of refrigerator shall be more during cold days as compared to hot days.

$COP_{\text{cold days}} > COP_{\text{hot days}}$ because $T_{h,\text{ cold days}} < T_{h,\text{ hot days}}$.

VAPOUR COMPRESSION REFRIGERATION SYSTEM

In this system, a liquid refrigerant is used which is alternately evaporates and condenses for absorbing heat from the refrigerated space and for rejecting heat to the surroundings. 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.

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

1. Compressor
2. Condenser
3. Expansion valve
4. Evaporator

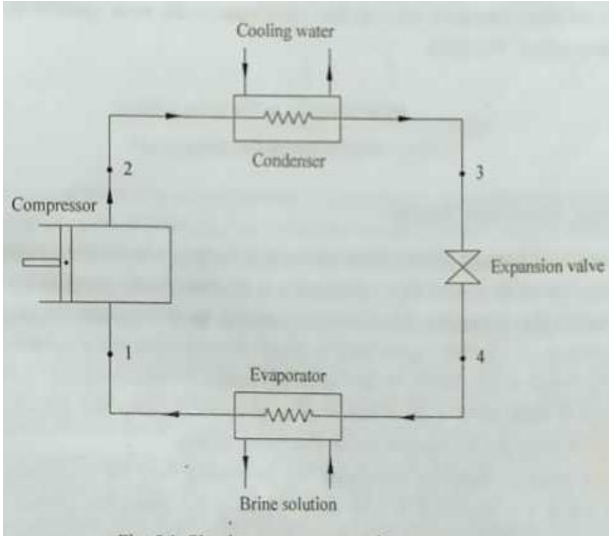
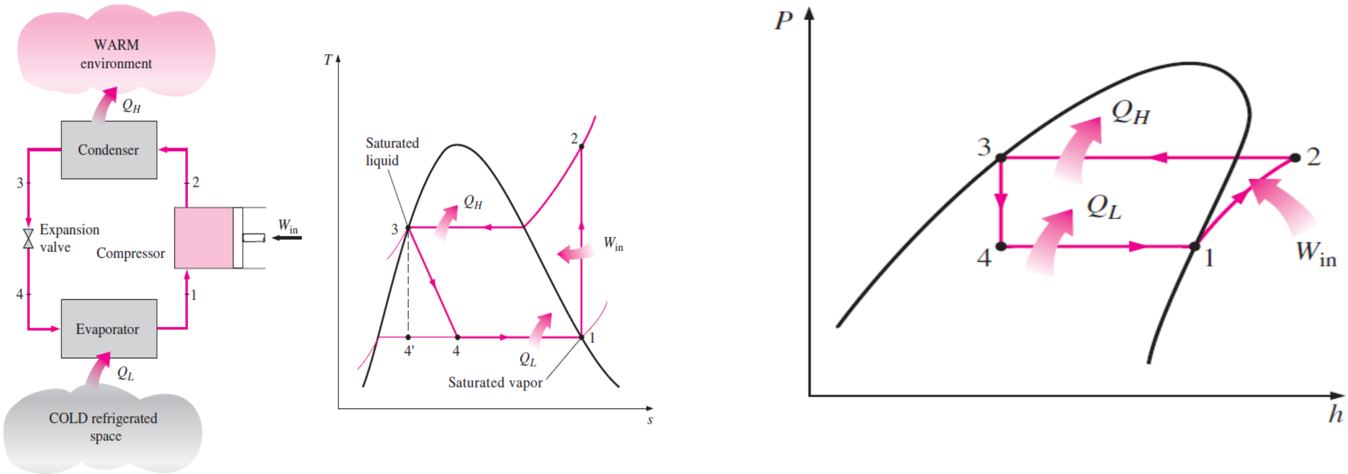


Fig. 5.1. Simple vapour compression system

The processes are

- **1- 2 Isentropic compression in compressor**
- **2-3 Condensation(Constant-pressure heat rejection in a condenser)**
- **3-4 Isenthalpic expansion process (Throttling in an expansion device)**
- **4-1 Evaporation (Constant-pressure heat absorption in an evaporator)**



The line diagram of the arrangement is shown in fig.5.1. The vapour at pressure p_1 and temperature T_1 is drawn into the compressor is compressed isentropically to pressure p2, 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 (constant enthalpy expansion process) (throttle valve). The pressure of liquid is lowered to p1 (p1 = p4) and the condition obtained after the is shown by point 4. During expansion in expansion valve (throttling) the liquid partly evaporates and after throttling we get wet vapour at the low temperature T1, and low pressure p_1. This wet vapour passes through the evaporator coils. The wet refrigerant vapour absorbs latent heat of vaporisation from the refrigerated space and evaporates. After evaporation the vapour reaches the condition given by point 1. This completes one cycle of operation.

AIR CONDITIONING

The science of air conditioning, deals with supplying and maintaining a desired internal atmospheric condition irrespective of external Conditions.

"***Air conditioning is the process of controlling and maintaining the internal atmosphere in a confined space. It involves the control of temperature, humidity, motion of air and purity of atmosphere in the space of interest***".

This involves the simultaneous control of air purity, air motion, temperature and humidity of the air inside an enclosed space.

- Air temperature is controlled by cooling or heating the air.
- Humidity is controlled by adding or removing water vapour to or from the air.
- Air motion is controlled by appropriate air distribution equipment
- Air purity is controlled by filtering and removing undesirable contaminants from the air.

Air conditioning applications are two types: comfort and industrial.

Any air conditioning application having the primary intention of human health and comfort is called comfort air conditioning. **Any air conditioning which is not primarily meant for human comfort is industrial air conditioning.** Basically, the equipment and process involved in both types of air conditioning is the same. The difference lies in the required inside conditions.

Applications of air conditioning are

- Domestic applications
- Industrial applications
- Commercial applications
- Transport applications

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. 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.

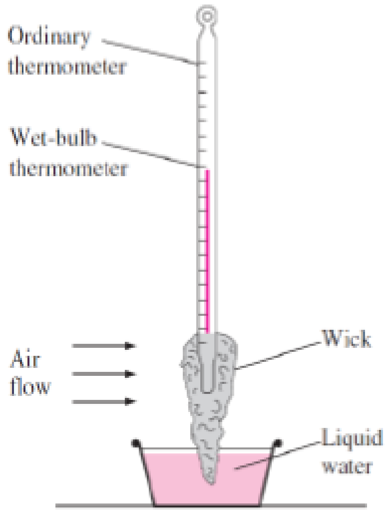
3. Saturated air: It is the air which contains maximum amount of water vapour which the air can hold at a given temperature and pressure. The maximum quantity of water vapour that can be present in the air depends up on the temperature and pressure of air.

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. It is generally expressed as grams of water per kg of dry 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 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 heat that changes the temperature of a substance when added to or abstracted from it.

10. Latent Heat: It is the heat that does not affect the temperature but changes the state of substance when added to or abstracted from it.

11. 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.

Psychrometer is an instrument containing dry bulb thermometer arid wet bulb thermometer. The difference in the reading of these two thermometers gives measure of relative humidity of air surrounding the psychrometer.

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.

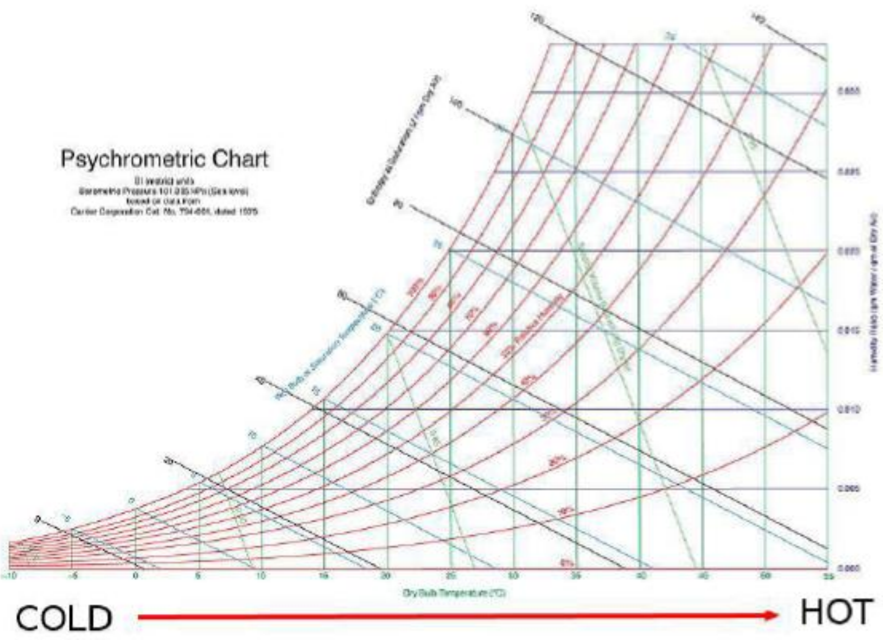
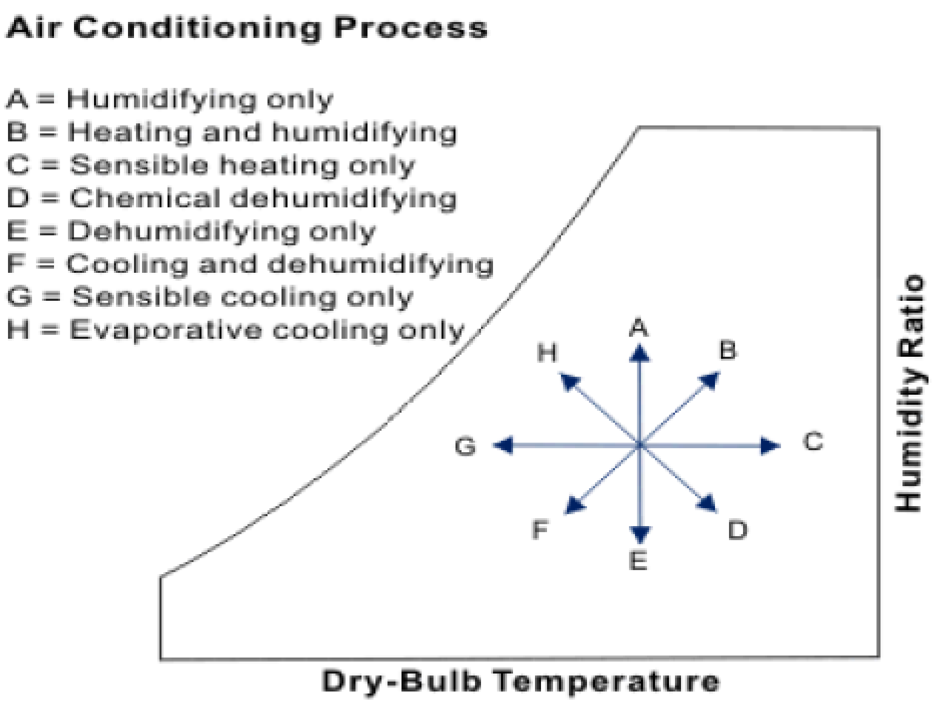


Fig. shows a typical psychrometric chart. The vertical scale of the chart is the specific humidity and the horizontal scale is the dry bulb temperature. In addition, it contains the following lines.

- Dry bulb temperature lines
- Specific humidity lines
- Wet bulb temperature lines.
- Relative humidity lines
- Specific volume lines
- Dewpoints temperature lines



The various basic process involved in air conditioning are:

1. Sensible Heating(C): Increase the dry bulb temperature of air without change in its specific humidity(moisture content), using heating coil.

2. Sensible Cooling(G): Decreases dry bulb temperature of air without change in its specific humidity(moisture content), using cooling coil.

3. Humidification(A): Increase the specific humidity without change in dry bulb temperature, using humidifier.

4. Dehumidification(E): Decreases the specific humidity without change in dry bulb temperature, using dehumidifier.

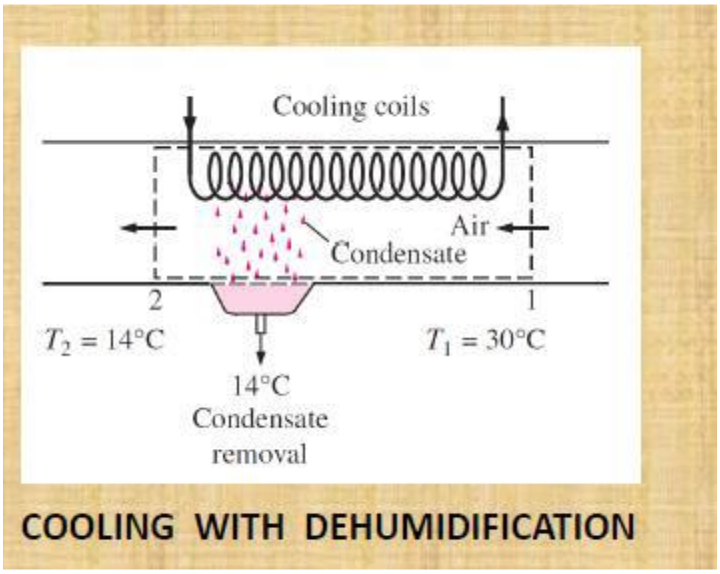
5. Heating with Humidification(B): Increases both dry bulb temperature and specific humidity of air, using high temperature steam.

6. Heating with Dehumidification(D): Increases the dry bulb temperature and decreases the specific humidity of air, using silica gel or alumina.

7. Cooling with Humidification(H): Decreases the dry bulb temperature and increases the specific humidity of air, using cold water.

8. Cooling with Dehumidification (F): Decreases both dry bulb temperature and specific humidity of air, using cooling coil with very low temperature “

Whenever air is made to pass over a surface or through a spray of water that is at a temperature less than the dew point temperature of the air, condensation of some of the water vapour in air will occur simultaneously with the sensible cooling process.



Air conditioning system

Factors affecting comfort air conditioning

1. Temperature of the air – A human feels comfortable when the air is at 220C – 260C. This is maintained by cooling or heating process.

2. Humidity of the air - Increasing or decreasing the humidity during winter and summer A/C system respectively. Relative humidity should not be less than 60% during summer air conditioning system whereas in winter air conditioning not less than 40 %.

3. Purity of air - People donot feel comfortable if the air is contaminated.

4. Motion of air - Equi-distribution of air throughout the room

Comfort air-conditioning

The comfort air conditioning intends to provide a comfortable environment for human beings round the year. Human beings are comfortable in wide range of relative humidity varying from 30 to 70%. The temperature range for human comfort is 22 to 260C. The factors which determine the effectiveness of air conditioning for human comfort are

- Air purity
- removal of moisture emitted by occupants,
- removal of heat emitted by occupants,
- sufficient air motion and uniform air distribution,
- Supply of oxygen and removal of Carbon dioxide,
- Control of moisture content of air.

Classification of air conditioning system

1. According to purpose

a. Comfort air conditioning

b. Industrial air conditioning

2. According to the season of the year

a. Winter air conditioning system

b. Summer air conditioning system

c. Year round air conditioning system

3. According to the arrangements of equipment's

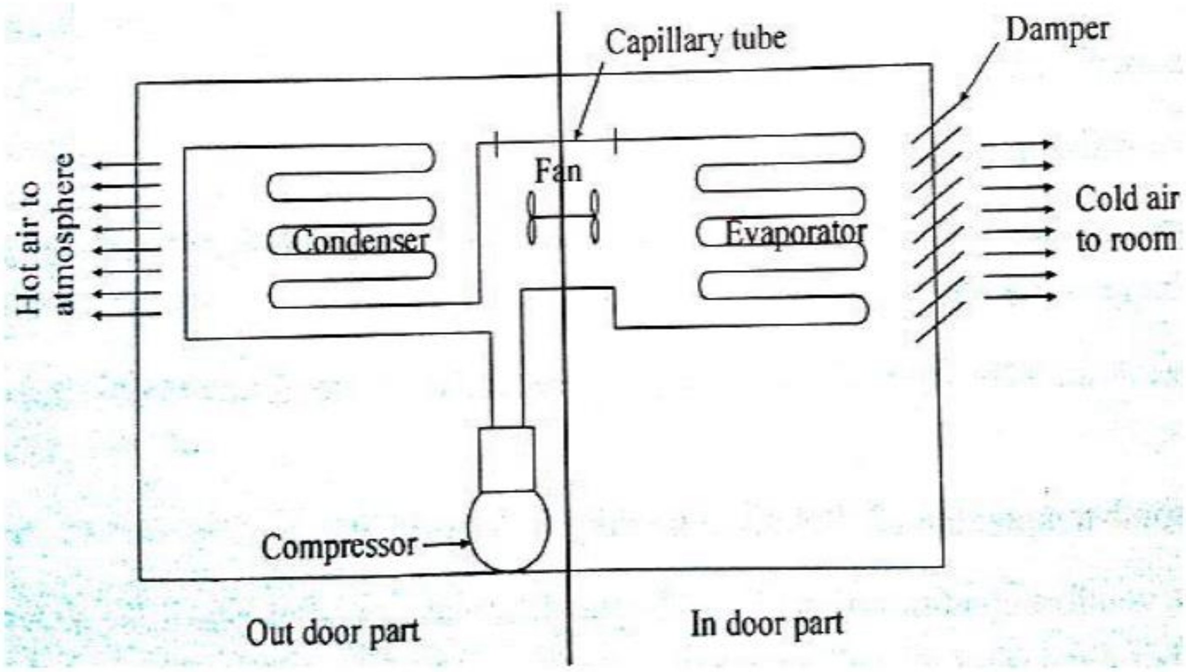
a. Unitary air conditioning system

b. Central air condition system

Unitary systems. (Unit air conditioners)

The components of unitary air conditioned system are assembled in the factory itself. These assembled units are usually installed in or immediately adjacent to a zone or space to be conditioned. The package units are available in the size ranges of greatest usage to obtain economics of factory production.

Window air conditioner is a type of unit air conditioner. Window Air-Conditioner is also called as room air conditioner, which is installed on the window of a room or wall opening**. It works on principle of vapour compression refrigeration system.** The refrigerant used is Freon-12(R -12) or Freon 22(R-22). A package unit is a self-contained unit because the complete unit including evaporator and condensing unit is all incorporated in a common enclosure. The normal capacity of such a unit is 1 and 1.5 TR. There are window mounting models which are normally capable of cooling, heating, cleaning and circulating the air.

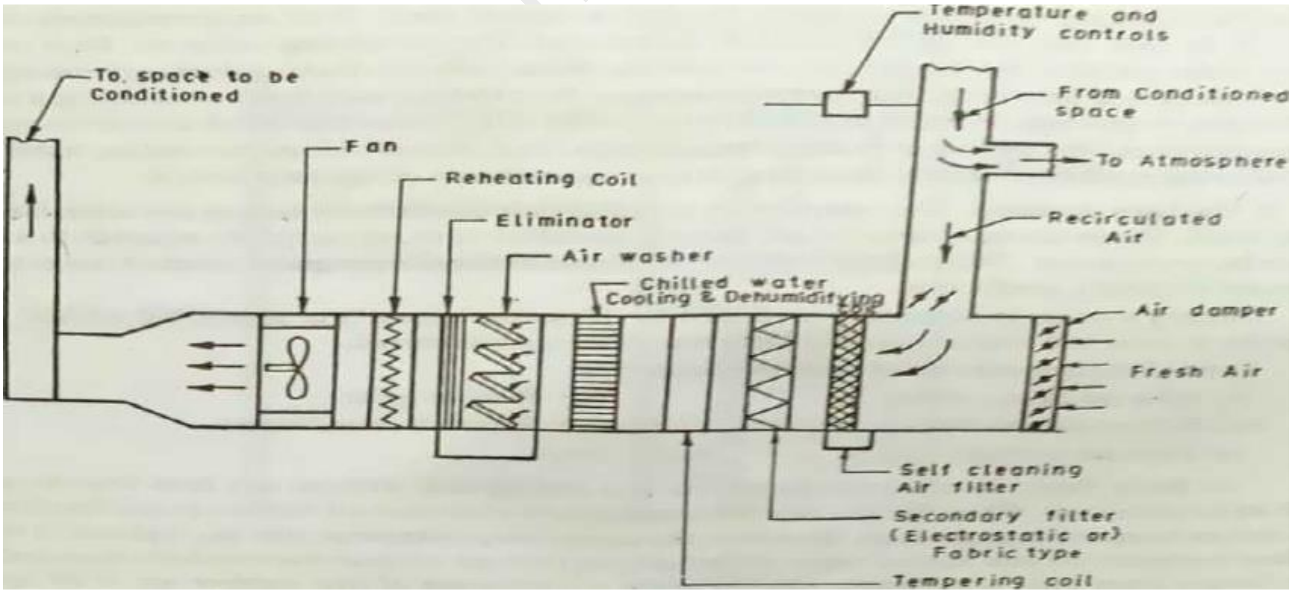


Working: Low pressure vapour refrigerant from the evaporator is sucked by compressor and is compressed to a high pressure & is delivered to the condenser. In the condenser, the refrigerant vapour is condensed to liquid by releasing latent heat of condensation to the surrounding air. Hot air formed is driven out using a fan. High pressure liquid refrigerant enters the capillary tube where the pressure is reduced. This low pressure liquid-vapour refrigerant enters the evaporator. Liquid refrigerant evaporates by absorbing latent heat of vaporization from the surrounding air. This cold air is delivered to the room using a fan. Direction of air flow can be changed using a damper. Low pressure vapour refrigerant is again sucked by compressor. Thus one cycle of operation is completed.

Advantages of unitary system:

- There is saving in the installation and assembly labour charges.
- Zoning and duct work eliminated.
- In unitary system exact requirement of each separate room is met whereas in central system the individual needs of separate rooms cannot the met.
- Failure of the unit puts off conditioning in only one room whereas the failure of the central plant off-sets all the rooms to be served.
- Only those rooms which need cooling will have their units running, whereas the central plant will have to run all the time for the sake of only a few rooms.
- The specific feature of a unitary system is that there in Individual room-temperature control,

Central Air conditioning system



Central air conditioning systems are suitable for air conditioning large space such as big factory spaces, theatres, cinemas, exhibition halls, restaurants etc. where no sub division exists. The central systems are generally employed for the loads above 25TR and 2500 m3/min of conditioned air. **In this system, equipments such as fans, coils, filters and their encasement are designed for assembly in the field.** A central system serves different rooms, requires individual control of each room. **The condenser, compressor, dampers, heating, cooling and humidifying coils and fan are located at one place.** The conditioned air is carried to different rooms by means of supply ducts and returned back to the control plant through return ducts.

Working: Outdoor air enters from a intake and the air after passing through damper passes through filters. Filters may be of a mechanical cleaned type, replaceable cell type or may be electrostatic. The cleaned air then passes to the conditioning equipment in the following order: Tempering (Preheater) coil, Cooling coil, Humidifier (Air washer), Heating coil and finally fan. Tempering coil is used to preheat the cleaned air. Cooling and dehumidification is achieved by using cooling with chilled water. Air washer controls the humidity in the air. Eliminator is used to remove water droplets from the air and final reheating coil is used to heat the air to the required temperature.

Advantages of central system

- Low investment cost as compared to total cost of separate unit.
- Space occupied is unimportant as compared to a room unit conditioner which must be placed in the room.
- Better accessibility for maintenance.
- The running cost is less per unit of refrigeration.
- Noise and vibration troubles are less to the people in air conditioned places as the air conditioning plant is far away from the air-conditioned places.
- The exhaust air can be returned and partly reused with obvious saving in heating and refrigeration.

Disadvantages of central system

- It results in large size ducts which are costly and occupy large space.

Hydraulic machines are machinery and tools that use liquid fluid power to do simple work, operated by the use of hydraulics, where a liquid is the powering medium.

Hydraulic Pumps

Pumps are hydraulic machines which convert the mechanical energy into hydraulic energy. Pump is generally used for raising liquid from low level to high level. Hydraulic pumps can be classified into two

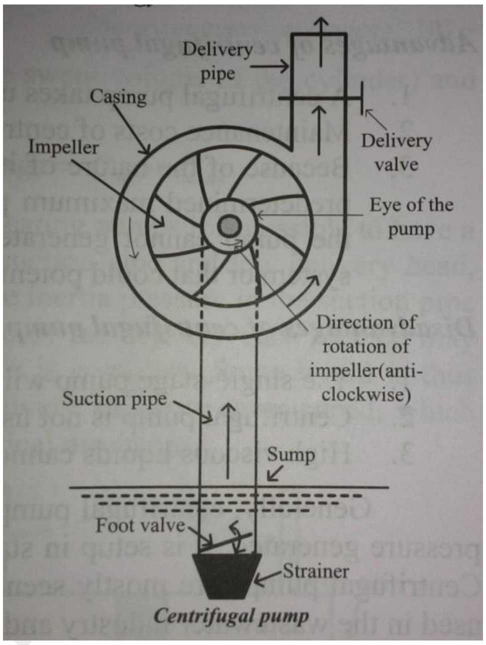
1) Centrifugal pump

2) Reciprocating pump

1) Centrifugal pump

A centrifugal pump is a roto dynamic pump that uses a rotating impeller to create flow by the addition of energy to a fluid.

The main parts of a centrifugal pump are



Centrifugal pump

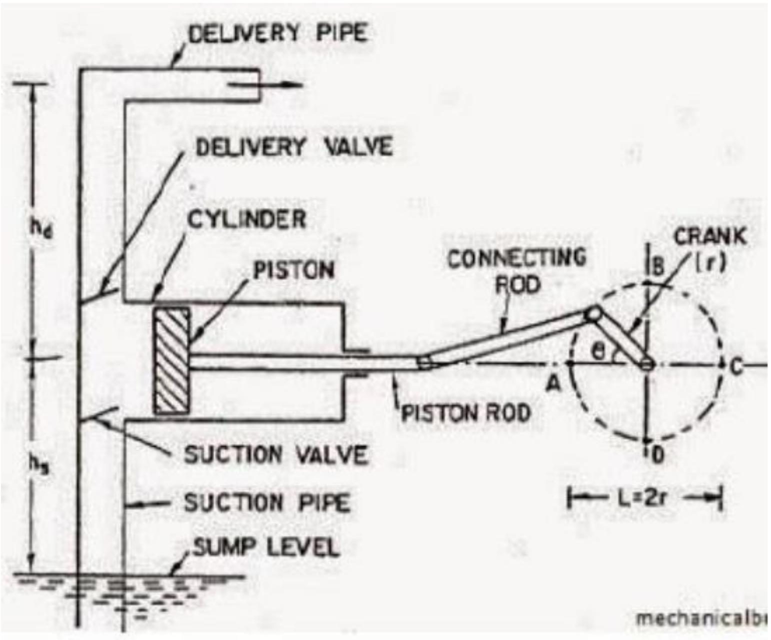
- **Impeller:** Rotating solid disc with curved blades. Impeller is mounted on a shaft connected to the shaft of an electric motor. As the impeller rotates, fluid is drawn into the impeller inlet(eye of pump) is accelerated as it is forced radially outwards
- **Casing:** Air tight passage around the impeller
- **Suction pipe and delivery pipe:** Pipe whose one end is connected to the inlet of pump and other end dipped in a sump is known as suction pipe. Pipe whose one end is connected to the outlet of the pump and the other end delivers the working fluid at a required height is known as delivery pipe.

Working of a centrifugal pump

Working fluid enters the pump at the centre of a rotating impeller. Impeller imparts centrifugal force on the liquid entrapped in the impeller and throws the liquid towards the outer periphery of the impeller. Outward movement of liquid in the impeller creates a partial vacuum near the eye of the impeller. Consequently, liquid from the sump is sucked in towards the impeller eye and enters through the inlet tip of impeller vanes. Thus, there is a continuous flow of liquid from the sump to the casing. The liquid leaving the impeller vanes is at a higher pressure and velocity. The velocity head is converted to pressure head in the casing.

2) Reciprocating pump

Reciprocating pump is a positive displacement pump. It creates the lift and pressure by displacing the liquid using a moving mechanical element called plunger (piston) inside a cylinder.



The main parts of a reciprocating pump are

- **Cylinder with valves at inlet and delivery:** Suction and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valves are one-way valves or non-return valves, which allow the water to flow in one direction only.
- **Plunger or piston:** Piston reciprocates in the closely fitted cylinder.
- **Connecting rod and crank mechanism:** Crank and connecting rod mechanism is operated by a power source.
- **Suction and delivery pipe with one way valve:** One end of suction pipe remains dip in the liquid and other end attached to the inlet of the cylinder. One end of delivery pipe attached with delivery part and other end at discharge point.

Working of Reciprocating pump

Working of reciprocating pump is similar to that of reciprocating engines. Piston moves from left to right (crank moves from A to C) creates a vacuum inside the cylinder and atmospheric pressure forces the liquid up through the suction pipe (suction valve is opened when crank is at B) into the cylinder. Delivery valve will be closed during this stroke. During the return

stroke (crank moves from C to A), the pressure developed in the fluid opens the delivery valve (when crank is at D), closes the inlet valve and pushes the fluid through the delivery valve. This pump is suitable for high heads and low discharge.

HYDRAULIC TURBINES

A hydraulic turbine is a rotary machine that converts kinetic energy and potential energy of water (hydraulic energy or hydro-potential) into mechanical work. Mechanical energy developed by turbines is used to run electric generators coupled to the shaft of turbines. Hydroelectric power is the cheapest source of power generation.

Flowing liquid, mostly water, when pass through the Hydraulic Turbine it strikes the blades of the turbine and makes the shaft rotate. There are different forms of Hydraulic Turbines in use depending on the operational requirements. For every specific use a particular type of Hydraulic Turbine provides the optimum output.

Classification of turbines

Turbines can be classified on the basis of:

1. Head and quantity of water available

a) **High head turbine:** Head is more than 250m, low discharge, eg. Pelton turbine

b) **Medium head turbine:** 60m to 250m, medium discharge types, eg. Francis turbine

c) **Low head turbine:** Head will be below 60m, high discharge, eg. Kaplan turbine

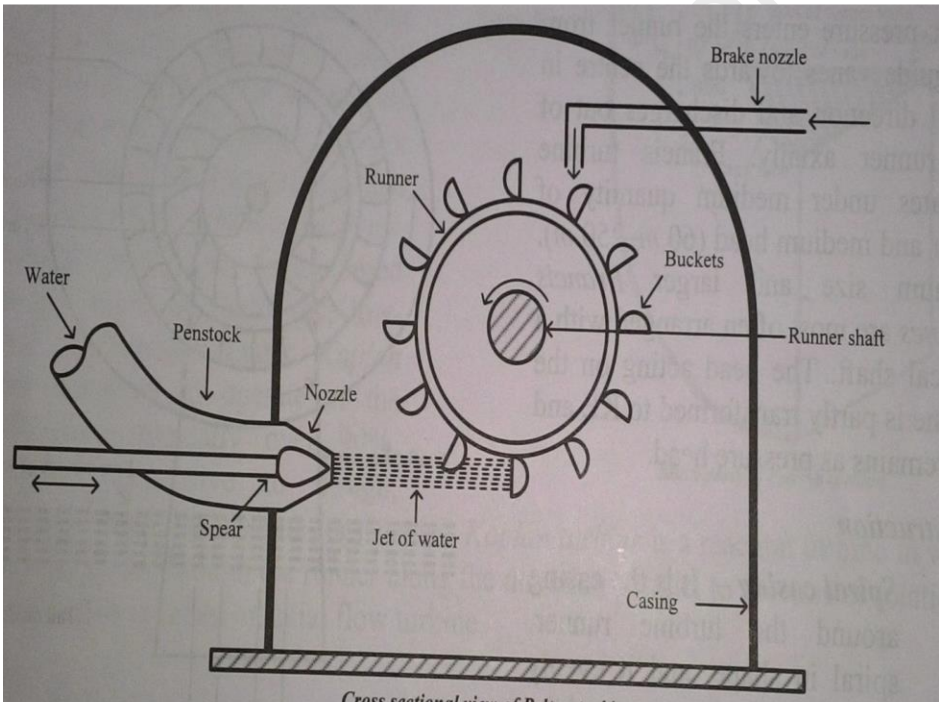
2. Action of water on moving blades

a) **Impulse turbine:** Water possess only kinetic energy at the inlet of the turbine, eg. Pelton turbine.

b) **Reaction turbine:** Water possess both kinetic energy and pressure energy at the inlet, eg. Francis and Kaplan turbine.

Pelton Wheel

A Pelton wheel is an impulse-type water turbine invented by Lester Allan Pelton in the 1870s. **The Pelton wheel extracts energy from the impulse of moving water.** Nozzles direct forceful, high-speed streams of water against a series of spoon-shaped buckets, also known as impulse blades, which are mounted around the outer rim of a drive wheel - also called a runner.



Cross sectional view of Pelton turbine

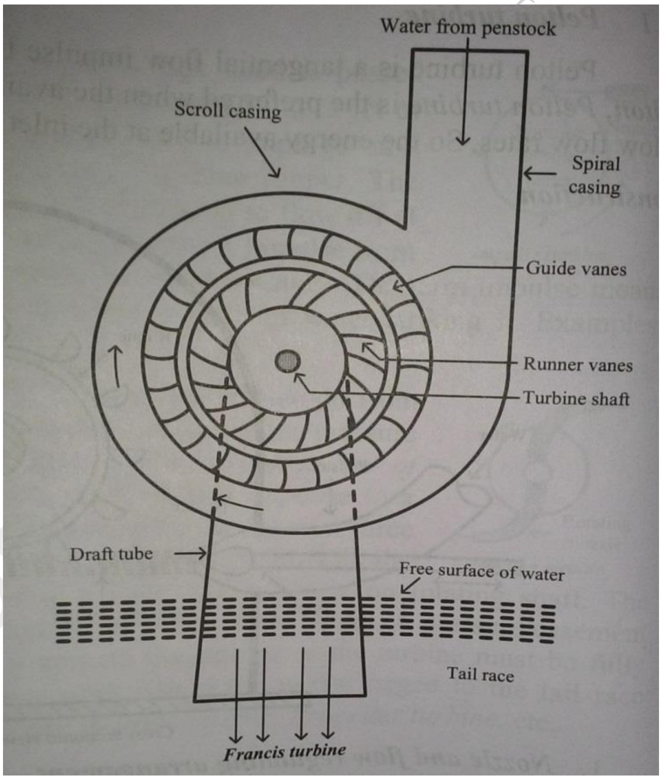
Main Parts of a Pelton Turbine

- **Nozzle and flow regulating arrangement**
- **Runner and buckets:** Runner is a circular disc on the periphery of which a number of buckets are fixed.
- **Casing:** Prevent the splashing of water.
- **Breaking jet:** Used to stop the runner.

Working

Nozzle directs the water against buckets mounted around the runner. When the water jet strikes the bucket, the impulse energy of the water jet exerts torque (pressure) on the bucket-and-wheel system, spinning the wheel (runner). In the process, the water jet's momentum is transferred to the wheel and hence to a turbine. The runner shaft is connected with the generator, thus the electricity is produced.

Francis Turbine



Francis turbine

The Francis turbine is a type of water turbine that was developed by James B. Francis**. It is an inward-flow reaction turbine that combines radial and axial flow concepts.** Francis turbines are the most common water turbine in use today. They operate in a water head from 40 to 600 m (130 to 2,000 ft) and are primarily used for electrical power production.

Main parts of Francis Turbine

- **Spiral casing:** Maintain a uniform velocity around the guide vanes.
- **Guide vanes:** Around the circumference of the runner. It acts like a nozzle to increase the velocity of water. It also regulates the amount of water inlet to the turbine.
- **Runner and runner vanes:** Runner vanes have aerofoil like structure. Pressure difference on the blades causes the rotation.
- **Draft tube:** Water flows from runner outlet to tail race through draft tube.

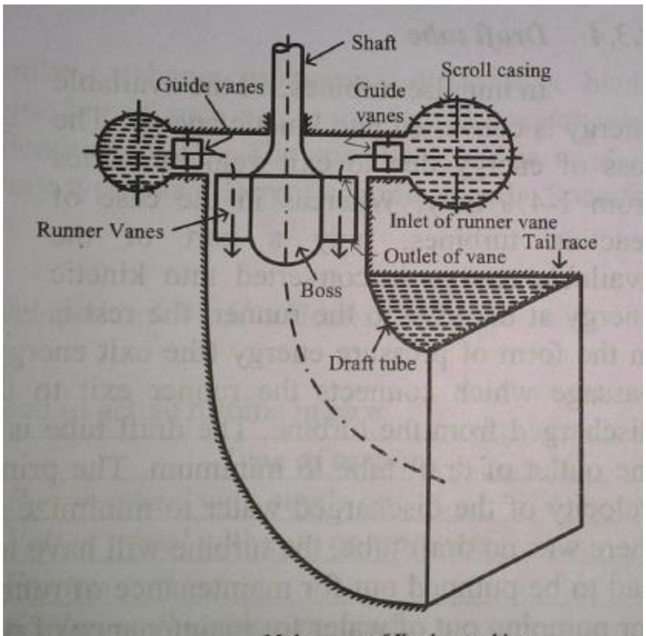
Working

The Francis turbine is a type of reaction turbine, a category of turbine in which the working fluid comes to the turbine under immense pressure and the energy is extracted by the turbine blades from the working fluid.

The water is allowed to enter the spiral casing of the turbine, which lead the water through the stay vanes and guide vanes. Water enters the runner from the guide vanes towards the centre in radial direction and discharges out of the runner axially. The impulse and reaction force of water rotates the runner and the runner shaft is connected with the generator, thus the electricity is produced.

Kaplan turbine

The Kaplan turbine is a propeller-type water turbine which has adjustable blades. It was developed in 1913 by Austrian professor Viktor Kaplan. Kaplan turbines are now widely used throughout the world in high-flow, low-head power production. They cover the lowest head hydro sites and are especially suited for high flow conditions. The design combines features of radial and axial turbines.



Main parts of Kaplan turbine

Main parts of a Kaplan Turbine

- **Scroll casing**
- **Guide vanes:** Used to turn the water through 900
- **Hub and vanes:** Vanes are fixed to hub. Vanes are adjustable. Vanes are adjusted according to the flow rate. Vanes are aerofoil shaped profile
- **Draft tube**

Working

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. Power is recovered from both the hydrostatic head and from the kinetic energy of the flowing water. The inlet is a scroll-shaped tube that wraps around the turbine's guide vane. Water is directed tangentially through the guide vane and spirals on to a propeller shaped runner, causing it to spin. The runner rotates the generator producing power. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy.

TURBINE EFFICIENCIES

The following efficiencies are generally used.

1. Hydraulic efficiency: It is defined as the ratio of the power produced by the turbine runner and the power supplied by the water at the turbine inlet.

$$\eta_H = \frac{\text{Power produced by the runner}}{\rho\, Q\, g\, H}$$

where Q is the volume flow rate and H is the net or effective head. where Q is the volume flow rate and H is the net or effective head.

2. **Volumetric efficiency:** It is possible some water flows out through the clearance between the runner and casing without passing through the runner. Volumetric efficiency is defined as the ratio between the volume of water flowing through the runner and the total volume of water supplied to the turbine.

$$\eta_v = \frac{Q - \Delta Q}{Q}$$

Indicating Q as the volume flow and ΔQ as the volume of water passing out without flowing through the runner.

3. **Mechanical efficiency**: The power produced by the runner is always greater than the power available at the turbine shaft. This is due to mechanical losses at the bearings, windage losses and other frictional losses.

$$\eta_m = \frac{\text{Power available at the turbine shaft}}{\text{Power produced by the runner}}$$

4. **Overall efficiency:** This is the ratio of power output at the shaft and power input by the water at the turbine inlet.

$$\eta_0 = \frac{\text{Power available at the turbine shaft}}{\rho\, QgH}$$

Power Output of the hydraulic turbine

$$\boxed{P = Q * \rho * g * H * \eta}$$

Where

P = electric power in kVA

Q = flow rate in the pipe (m3/s) ρ = density (kg/m3) g = Acceleration of gravity (m/s²)

H = waterfall height (m) η = global efficiency ratio

PUMP Performance

The input power "P" of a pump is the mechanical power in kW or Watt taken by the shaft or coupling. So the input power of the pump also called Break Horse Power (BHP). Pump input BHP is the power delivered to the pump shaft and is designated as brake horsepower. so pump input power also called as pump shaft power

Pump output power is called as Water Horse Power (WHP) or Hydraulic power and it is useful work delivered by the pump and is usually expressed by the formula

$$\text{P in Watt} = \frac{Q \times H \times \rho \times g}{100 \times \eta}$$

where η is in percentage (e.g. 75%)

Pump Efficiency

The overall efficiency of a pump is defined as

$$\eta_0 = \frac{\rho Q g H}{P}$$

where, Q is the volume flow rate of the fluid through the pump, and P is the shaft power, i.e. the input power to the shaft. H is the differential head.

Methods of Power Transmission

Mechanical power can be transmitted from one shaft to another by following methods

- **Belt drive**
- **Rope drive**
- **Chain drive**
- **Gear drive**

The shaft from which power is transmitted is called *driver shaft* and the shaft to which power is transmitted is called *driven shaft*

Belts

A belt is a thin inextensible band made of leather, rubber, steel, canvas or balata. Belts are used to transmit power between two parallel shafts, which are at a considerable distance apart (large distance).

"A belt is a continuous band of flexible material passing over pulleys to transmit motion from one shaft to another."

Belts are made endless to run over the pulleys mounted on the shafts. Friction between the belt and the pulley is responsible for transmitting power from one pulley to other. Belt drive is a friction drive and it is not a positive drive, since there is always some possibility of slipping between the belt and pulley.

Amount of power transmitted depends on

- Velocity of the belt
- The tension with which the belt is placed under the pulleys
- The arc of contact between the belt and the smaller pulley

Classification of belts (Type of belts)

Belts are generally classified into two;

1. Flat belts
2. V-belts
3. Timing belts
4. Round belt

1. Flat belts

Flat belts are belts with a narrow rectangular cross section and they run on flat pulleys. Flat belts are used for their simplicity and because they are subjected to minimum bending stress on the pulleys. The load capacity of flat belt is varied by varying their width and only one belt is used in each drive. They are used for moderate power transmission and are used in sawmills, conveyors, electrical generators etc.

Advantages

- Simple in construction, smooth operation, low maintenance and long life
- Flexible

Disadvantages

- Not positive drives
- Less efficient
- Not suitable for short distances

Figure 1 Cross section of Flat belt

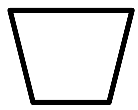


Figure 2 Cross section of a V-Belt

2. V-Belts

A V-belt is a belt of trapezoidal cross section running on pulleys with grooves cut to match the belt (V- grooved pulleys). The normal angle between the sides of the groove is 40 deg. They are usually made of fabric coated with rubber. They are silent and resilient. They are used when the distance between the shafts is too short for flat belt drives. Due to the wedge between the belt and the sides of the grooves in the pulley action (shape of belt and grooves in pulley), the V-belts are less likely to slip, hence more power can be transmitted for the same belt tension. Multiple V belts are used when the power to be transmitted is large for a single belt

• V belts are used in automotives and in agricultural purposes

Advantages

- Transmits higher torque than flat belts
- Suitable for short distance
- Easily installed and removed

- Slip is negligible
- Operation is quiet
- Suitable for large speeds
- No possibility of belt coming out of grooves
- Capable of absorbing high shock.

Disadvantages

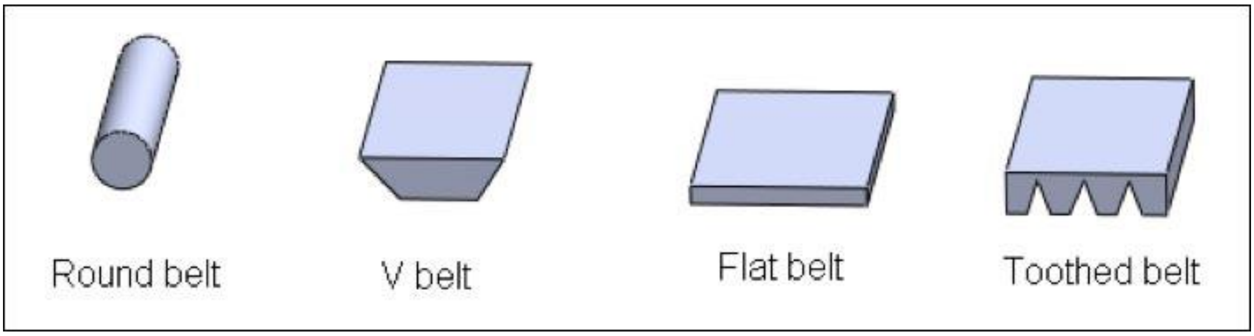
- Not suitable for large distances
- Costly
- V belts cannot be repaired Construction is complicated

Comparison between V-Belt and Flat Belt

V Belt	Flat Belt
Suitable for shorter distance	Suitable for longer distance
Trapezoidal section	Rectangular section
Frictional grip is more	Frictional grip is less
Power transmitted is more	Power transmitted is less
Velocity ratio is high	Velocity ratio is low
Occurrence of slip is seldom possible	Slip occurs easily

3. **Timing Belt: Timing belts are toothed belts that use their teeth for power transmission, as opposed to friction.** This configuration results in **no slippage**, and therefore, the driving and driven shafts remain synchronized. It's more expensive to manufacture due to complexity of the belt and pulley shapes.

4. **Round belts**: Round belts are are generally made of rubber. This type of belt is generally used for light loads, such as in a sewing machine or a vacuum cleaner.



(VERY IMPROTANT) Belt Drives

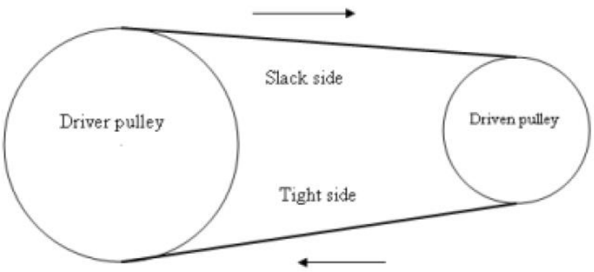
A belt drive consists of the driving and driven pulleys and the belt which is mounted on the pulleys with a certain amount of tension and transmits power by frictional force between belt and pulleys.

Belt drives can be categorised into;

1) Open belt drives
2) Cross belt drives
3) Belt drives with Idler pulleys
4) Compound belt drives
5) Stepped or Cone pulley drives

1. Open belt drives

It is used to transmit power when the distance between the shafts is large and both shafts are parallel. In open belt drives both the shafts rotates in the same direction. When the driver rotates in the clockwise direction, the lower side of the belt is tight and the upper side is slack. Upper side of the belt is called the slack side and the lower side of the belt is called the tight side.



2. Cross belt drives

In cross belt drives the power is transmitted between parallel shafts rotating in opposite direction. Since the angle of contact in this type of drive is more, it can transmit more power than open belt drives. At the point where the belt crosses, it rubs against itself and wear and tear occurs. The drive should operate at low velocity.

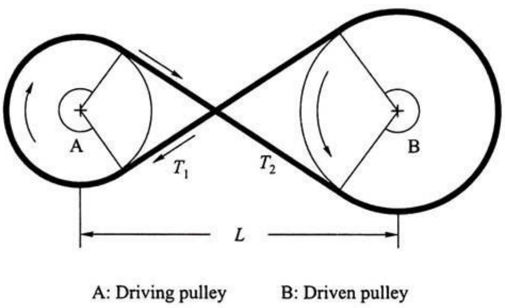
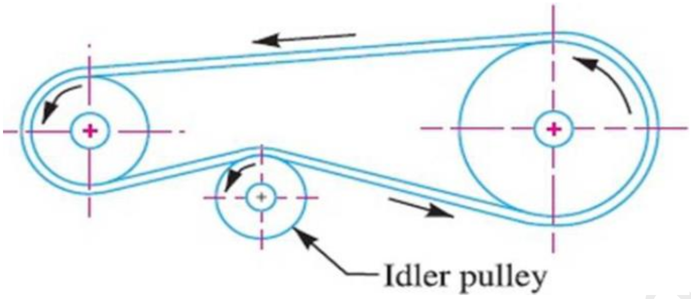


Fig. 9.4 Cross belt drive

3. Belt drives with Idler pulleys

In this drive, a small pulley called idler pulley is placed on the slack side of the belt and nearer to the driven pulley. Idler pulley increases the angle of contact between belt and driver & driven pulleys. The shafts arranged in parallel and rotating in same direction and this drive is provided to deliver high velocity. Idler pulley reduces slip and increases the power transmission efficiency, but reduces belt life.



4. Compound belt drives

It is used when power is transmitted from one shaft to another through a number of pulleys. A single intermediate shaft may contain more than two pulleys.

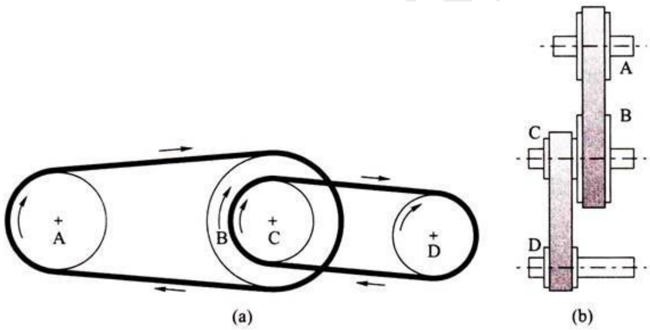


Fig. 9.8 Compound belt drive assembly: (a) side view and (b) top view

As shown in Figs. 9.8(a) and 9.8(b), for A-B combination, A is the driving pulley and B is the driven pulley. For C-D combination, C is the driving pulley and D is the driven pulley. When it is desired to have maximum reduction in the speed, the compound belt drive assembly is considered to be the most important method. It eliminates the larger driven pulley. In this combination, pulley B and C are the compound pulleys, i.e., pulley C is keyed on the same shaft on which pulley B is. D is another pulley. A belt runs over A-B and another belt runs over C-D.

5. Stepped or Cone pulley drives

In case of a stepped pulley system, a single pulley is made in three steps as shown in Fig. 9.6(a). It is made of cast iron. Two such pulleys are mounted on two parallel shafts as shown in Fig. 9.6(b). It is used for changing the speed of driven shaft while the driving shaft is maintained at constant speed.

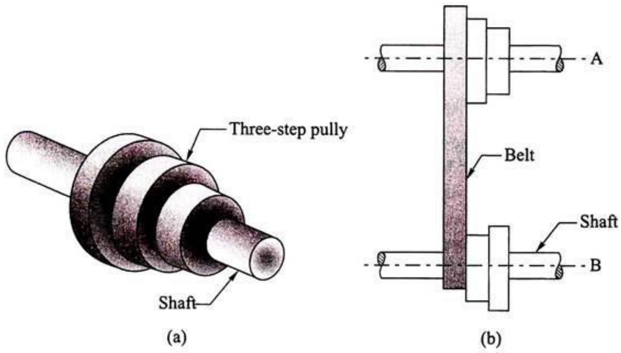


Fig. 9.6 A three-step pulley (a) fixed on a shaft and (b) aligned to transmit power

Applications of Belt drives

(i) To transmit power from low or medium capacity electric motors to operative machines.

(ii) To transmit power from small prime movers (IC Engines) to electric generators, agricultural and other machinery.

Advantages of Belt Drives

(i) They are simple and economical.

(ii) They can transmit power over a medium distance.

(iii) They give smooth operation (Noise and vibrations are damped out)

(iv) They can operate at high speeds of rotation.

(v) They are lubricant free and their maintenance cost is relatively low.

Disadvantages of Belt Drives

(i) Their considerable overall size, usually several times larger than toothed gearing.

(ii) Slip occurs in the belt drives.

(iii) The necessity of belt tensioning devices.

(iv) The necessity to keep oil from getting on the belt.

(v) The relatively short service life in high speed drives.

(vi) Heat build-up occurs. Speed is limited to usually 35 meters per second. Power transmission is limited to 370 kilowatts.

(vii) Operating temperatures are usually restricted to –35 to 85°C.

(viii) Stretching of belt after some time

Chain drives

Chain drive is a way of transmitting mechanical power from one place to another using chains and sprocket. It is often used to convey power to the wheels of a vehicle, particularly bicycles and motorcycles. 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

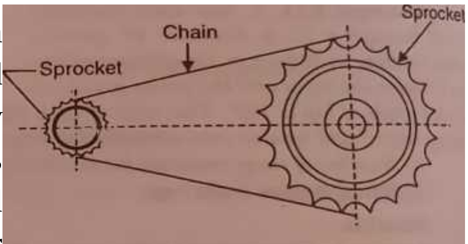


Fig. 6.14. Chain drive.

driven. Smaller sprocket is called pinion and the bigger one is called wheel.

Applications of chain drives

Chain drives are used for

1. Medium centre to centre distances which, in the case of a gear drive, would require idle gears
2. Drives with strict requirements as to overall size or ones requiring positive transmission without slippage.

Main applications of chain drives are; (i) Motor cycles (ii) Bicycles (iii) Conveyers (iv) Agricultural machinery (v) Machine tools (vi) Automobiles etc.

There are two principal types of chain drives :

1) Roller chain drive, and
2) Inverted tooth or silent chain drive.

Advantages and Disadvantages of Chain Drive

Advantages:

1) Efficiency of transmission is very high (upto 98%).
2) More durable.
3) Can carry heavy loads.
4) Can be used where exact timing in-movement is desired.
5) No slip takes place.
6) No initial tension required for operation.
7) A single chain can be used for transmitting motion to several shafts.
8) Smaller overall size than a belt drive.
9) Small forces acting on the shafts since no initial tension is required.
10) Easy replacement of the chain.
11) These permit high speed ratio upto 8 in one step.
12) These can be operated under adverse temperature and atmospheric conditions.

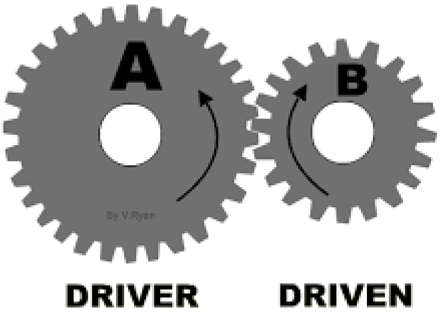
Disadvantages

1) Chain drive requires housing.
2) It needs careful maintenance and accurate mounting.
3) The velocity of the chain, especially with small numbers of teeth on the sprockets, is not constant leading to non-uniform rotation of sprockets.
4) The chain gets stretched and requires a tensioning device.
5) Cost is high comparatively.

GEAR DRIVE

A gear is simply a toothed wheel. It is a wheel provided with teeth which mesh with the teeth on another wheel, or on to a rack, so as to give a positive transmission of power from one component to another. One gear is mounted on the driving shaft and another one on the driven shaft and their teeth is meshing with each other.

Gear drive is a positive drive (no slip) and the axes of the shafts may be parallel or non-parallel. **When two gears of different sizes mesh, the smaller one is called pinion and the larger one is called gear.** When pinion (smaller gear) is the driver, output speed (driver speed) decreases and torque increases. When the gear (larger gear) is the driver, output speed (driver speed) increases and torque decreases.



Gears constitute the most commonly used device for power transmission or for changing power-speed ratios in a power system. **They are used for transmitting motion and power from one shaft to another when they are not too far apart and when a constant velocity ratio is desired.** Gears also afford a convenient way of changing the direction of motion.

Advantages and Disadvantages of Gear drives

Advantages:

1) High efficiency
2) Long service life.
3) High reliability.
4) More compact.
5) Can operate at high speeds.
6) Can be used where precise timing is required.
7) Large power can be transmitted.
8) Constant speed ratio owing to absence of slipping.
9) Possibility of being applied for a wide range of torques, speeds and speed ratios.
10) The force required to hold the gears in position is much less than in an equivalent friction drive. This results in lower bearing pressure, less wear on the bearing surface and efficiency.

Disadvantages:

1) Special equipment and tools are required to manufacture the gears.
2) When one wheel gets damaged the whole set up is affected.
3) Noisy in operation at considerable speeds.
4) Needs lubrication
5) Maintenance cost is high
6) Production cost is high

Classification of gears

Gears are classified into;

1) Spur gears
2) Helical gears
3) Double helical gears
4) Bevel gears
5) Worm gears
6) Rack and pinion

1. 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. They are used in high speed and high load applications. This is the simplest form of geared drive.

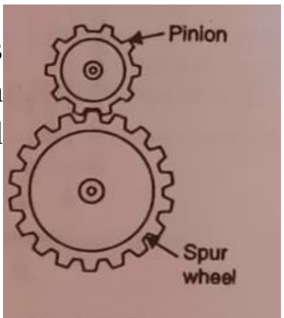
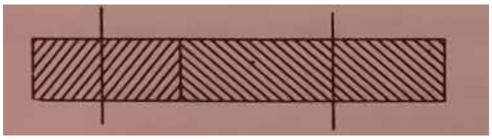


Fig. 6.18. Spur gear.

2. Helical gears



In helical gear, the teeth cut on the periphery are of helical screw form. Helical tooth is inclined at an angle to the axis of the shaft. Helical gears are used to transmit power between parallel shafts and the shafts rotate in opposite directions.

3. Herringbone Gear or Double-Helical Gears

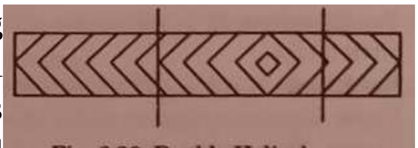
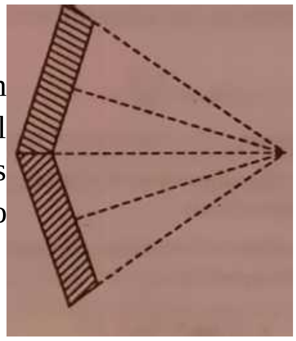


Fig. 6.20. Double Helical gear.

Herringbone gears have opposing helical teeth which nullify two axial thrusts. Load carrying capacity is very high and these gears are used to transmit power between two parallel shafts at high speeds. The two shafts rotate in opposite directions.

4. Bevel Gear



Bevel gears are used to connect two non-parallel shafts with intersecting axes. Teeth of these gears are formed on a conical surface. These gears are used to transmit power between two shafts at any angle, generally the shafts are at right angles. They are used to slow speed applications.

5. Worm Gear

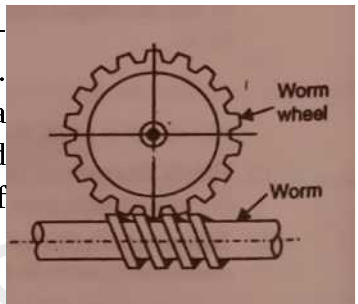


Fig. 6.22. Worm gear.

Worm gears are used for power transmission between non-intersecting shafts that are generally at right angles to each other. Worm gearing consists of worm and worm wheel. Worm is a threaded screw and is used as the driver and worm wheel is a toothed wheel. Teeth of the worm wheel remain engaged with the threads of the worm. Worm gearing is smooth and quiet.

6. Rack and Pinion

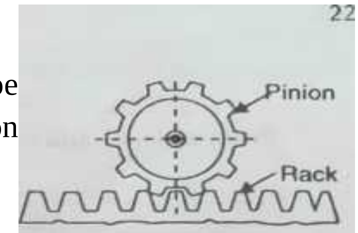


Fig. 6.23. Rack and pinion.

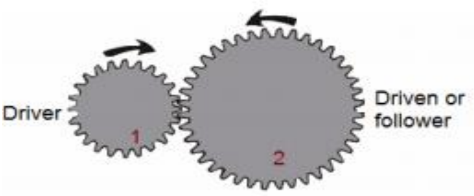
A rack is a spur gear of infinite diameter, thus it assumes the shape of a straight gear. Rack and pinion gears are used to convert rotation (pinion) into linear motion(rack) or vice versa.

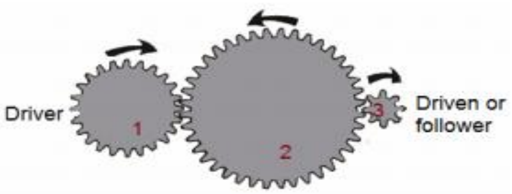
.<u>Types of Gear Trains (VERY IMPORTANT)</u>

A gear train is a power transmission system made up of two or more gears. The gear to which the force is first applied is called the driver and the final gear on the train to which the force is transmitted is called the driven gear. Any gears between the driver and the driven gears are called the idlers. Conventionally, the smaller gear is the Pinion and the larger one is the Gear. The gear trains are of the following types;

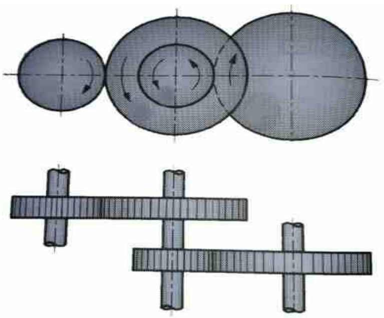
1. Simple gear train   2. Compound gear train   3. Planetary or Epicyclic gear train

<u>**Simple Gear Train**</u> - **Simple gear trains have only one gear per shaft.** The simple gear train is used where there is a large distance to be covered between the input shaft and the output shaft.



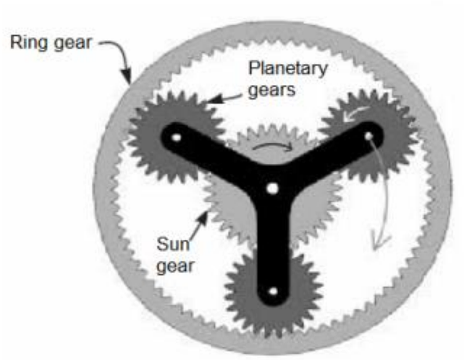


<u>Compound Gear Train</u> - In a compound gear train at least one of the shafts in the train must hold two gears. Compound gear trains are used when large changes in speed or power output are needed and there is only a small space between the input and output shafts.



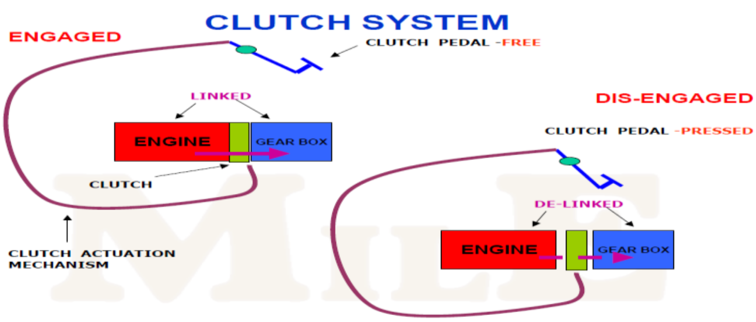
Compound gear train

<u>Planetary Gear Train</u> - A planetary transmission system (or Epicyclic system as it is also known), **consists normally of a centrally pivoted sun gear, a ring gear and several planet gears which rotate between these.** This assembly concept explains the term planetary transmission, as the planet gears rotate around the sun gear as in the astronomical sense the planets rotate around our sun.



<u>Clutch</u>

Clutch is mechanical device which is used to transmit rotating motion or torque from one shaft to another shaft when required. Clutch provides a temporary connection between input and output shaft. Clutch lies between the engine and the gear box. **In the simplest application, clutches connect and disconnect two rotating shafts.** In these devices, one shaft is typically attached to an engine or other power unit (driving member) while the other shaft (the driven member)



When clutch is in engaged position, the engine power flows to the gear box through clutch and from gear box power flows to the wheels. When clutch is in disengaged position, the engine power does not reach to gear box.

Purpose

A clutch is designed with the following requirements

- Allow the vehicle to come to a stop while the transmission remains in gear
- Allow the driver to smoothly take off from a dead stop
- Allow the driver to smoothly change gears
- Must be able to transmit power and torque without slipping

Clutches mainly classified into

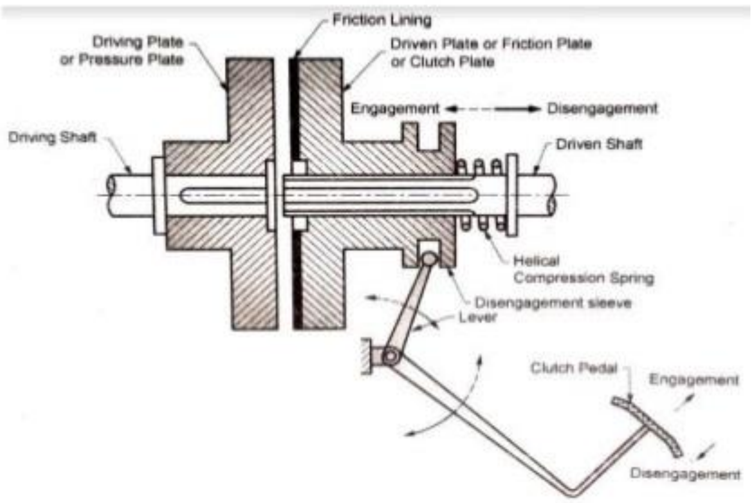
1) Positive clutches
2) Friction clutches

Single Plate Clutch

Single plate clutch is a friction clutch in which Single plate with friction surface is connected to a driven shaft. It consists of

1) a driving member,
2) a driven member, and
3) an operating member

Driving member has a flywheel which is mounted on the engine crankshaft. The driven member is a disc called clutch plate. This plate can slide freely to and fro on the clutch shaft. The operating member consists of a pedal or lever which can be pressed to disengaged the driving and driven plate.



Working

When the clutch is engaged, the clutch plate is gripped between the flywheel and pressure plate. The friction linings are on both sides of clutch plate. Due to friction between flywheel, clutch plate and pressure plate, the clutch plate revolves with the flywheel. As clutch plate revolves the clutch shaft also revolves. Thus, engine power is transmitted to the clutch shaft.

When the clutch pedal is pressed the pressure plate moves back against the spring force and clutch plate becomes free between flywheel and pressure plate. Thus flywheel remains rotating as long as the clutch pedal is pressed, the clutch is said to be disengaged and clutch shaft speed reduces slowly and finally it stops rotating.

Advantages:

- The working of the single plate clutch is smooth i.e. the engagement and disengagement is very smooth in operation.
- Less slip occurs in it.
- Power losses are very less.
- Less heat generates because only single plate is used.
- Single plate clutches have quick operation and respond fast.
- No requirement of coolant because less is generated therefore they are called dry clutches.

Disadvantages:

- It has less torque transmitting capacity
- It has bigger in size even for transmitting less torque.
- It requires high maintenance because they are dry clutches and it is necessary to prevent them from moisture or any leakage of lubricant/oil in machinery.

Problems on calculation of input and output power of pumps and turbines

Pumps

Q1. Estimate the shaft power and motor power requirement to pump 200,000 kg/hr of water available at 250C and atmospheric pressure from a storage tank. The rated differential head requirement is 30 m.

Assume the mechanical efficiency of the pump to be 70%.

Assume the motor efficiency to be 90%.

Ans:

Flow rate (Q) = 200000kg/hr = 0.055m^3/s

Differential head (H) = 30m

Efficiency of pump = 70% = .7

Efficiency of motor = 90% = .9

Shaft power P in watt **= pgQH / efficiency of pump**

= 1000x9.81x0.055x30/(.7)

$= 23123.57W \;\; = \mathbf{23.12kW}$

Motor power requirement = Pump shaft power / motor efficiecny

$= 23123.57/.9$

$= 25692W \quad = \mathbf{25.69kW}$

Q.2 A centrifugal pump using 1kw of electric motor of pumping water against 3m suction head and 7m delivery head. The discharge of the pump is 100litres/minute. Find the efficiency of pump?

Ans:

Electric power supplied, P = 1kw =1000W

Total head, H = suction head + delivery head = 3m+7m =10m

Discharge of the pump, Q =100L/min $= 0.1/60 m^3/s$

Density of water, ρ $= 1000 kg/m^3$

Efficiency of the pump, η $= \rho gQH / P$

$= (1000 \times 9.81 \times 0.1 \times 10) / (1000 \times 60)$

$= 0.1635 = \mathbf{16.35\%}$

<u>Turbine</u>

Q1. Installing a hydraulic turbine generator at a site 70 m below the free surface of a large water reservoir that can supply water at a steady rate of 1500 kg/s. If the mechanical power output of the turbine is 800 kW and the electric power generation is 750 kW, determine the turbine efficiency and the combined turbine generator efficiency of this plant. Neglect losses in the pipes.

Ans:

Effective head = 70m

Volume flow rate Q = 1500kg/s = $1.5m^3/s$

Mechanical Power Output (Power available at the turbine shaft) (PT) = 800kW = 800000W

Electric power output (P) = 750kW = 750000W

Density of water (p) = 1000kg/m3

Acceleration due to gravity (g) = 9.81 m/s2

Turbine efficiency = Power available at the turbine shaft / water power

= (PT)/pgQH

=800000/(1000x1.5x9.81x70)

=.7766 = **77.66%**

Combined Turbine generator efficiency = Global efficiency ratio = Electric power / water power

= P/pgQH

= 750000/(1000x9.81x1.5x70)

=.7281 = **72.81%**

Q.2 To find the power that can be developed by the hydraulic turbine of input power 1000kw, assume an overall efficiency of 0.85

Ans:

Overall efficiency of turbine = 0.85 Input power $= 1000*10^3$ W= 10^6 W

Efficiency = output power/input power

Output power $= 0.85*10^6$W

= 850kW

Q.3 A turbine is working at a head of 250m and the discharge through the penstock is $2m^3/s$. If the efficiency of the turbine is 55%, find the power developed by the turbine?

Head of the turbine, H = 250m Discharge of water, Q $= 2m^3/s$

Efficiency of the turbine, η = 0.55 Density of water, ρ = 1000 kg/m^3

Efficiency of the turbine, η = Power available at the turbine shaft / ρgQH

Power developed by the shaft $= \rho gQH \times \eta$

= 1000 x 9.81 x 2 x 250 x 0.55

= 2697750W = **2697.750kW**

Prepared by,

AKHIL SANKAR K
Assistant Professor,
Department of Mechanical Engineering,
Adi Shankara Institute of Engineering and Technology (ASIET),