MODULE-I: ENERGY RESOURCES, BASIC CONCEPTS OF THERMODYNAMICS AND STEAM FORMATION

INTRODUCTION

ENERGY:

"Energy" is a word derived from the Greek word "*Energia"*, meaning capacity to do work. Energy is defined as the capacity either latent or apparent to do work. Energy exists in various forms such as mechanical energy, electrical energy, thermal energy and chemical energy. One form of energy can be readily converted into another form, but the total amount of energy remains constant before and after the transformation.

Energy is the basic ingredient of all modern societies. Energy is required to fulfill the basic needs of food, housing, clothing, medical aid and education, etc, as well as for travel and communication. More and more production of energy per person enhances the comforts, conveniences and pleasures of life. Hence energy can be treated as an essence of modern civilization and the per capita consumption of energy is regarded as an index of advancement of a society.

Various sources of energy:

The various sources of energy are (i) Fossil fuels, (ii) Atomic fuels (nuclear energy), (iii) Flow of river water (hydro energy), (iv) Sun (solar energy), (v) Wind, (vi) Tides, (vii) Earth (geothermal energy), (viii) Bio-mass, etc

Different sources of energy:

The sources of energy are classified in the following two ways:

(a) Conventional and non- conventional sources of energy

(b) Renewable and non-renewable sources of energy

Conventional energy sources

The sources of energy which provide a net supply of energy are called **conventional sources of energy.** Most of our present energy needs come mainly from the fossil fuels (coal, petroleum etc.) and hydel sources, which are relatively cheaper. These are useful for mass generation of power.

The ever increasing demand in energy is leading to depletion of the fossil fuels. Hydel source cannot be used always since it is not available everywhere and also due to variations in the hydrological cycle. Moreover, the cost of generation is also high due to high initial investments and transmission problems. In view of the above, other sources of energy which are inexhaustible in nature are being sought after.

Non-conventional energy sources

The alternate energy sources that are being harnessed are, solar energy, wind energy, tidal energy, ocean thermal energy, geothermal energy, bio energy, fuel cells, solid wastes, hydrogen energy etc. These inexhaustible sources of energy are called **non-conventional energy sources.** These sources of energy which provide energy is in dilute form. These are useful for generating power in lesser magnitude. The renewable sources of energy are defined as the energy sources which are continuously produced in nature and are essentially inexhaustible or non-depletable. These energy sources replenish themselves naturally in a relatively short time and therefore will always be available.

E.g. of renewable energy sources: direct solar energy, wind energy, tidal energy, hydel energy, ocean thermal energy, bio energy, geothermal energy, peat, fuel wood, fuel cells, solid wastes, hydrogen energy etc.

Of the above renewable energy sources, geothermal energy, peat and fuel wood must be used at a rate less than their renewal rate in the nature, to allow them to build up again in nature.

The non-renewable energy sources are defined as the energy sources which have been accumulated over the ages and not quickly replenish able when they are exhausted. E.g. Fossil fuels (coal, petroleum and petroleum products), nuclear fuels and heat traps

Non-renewable sources of energy are those which occur once in nature and on usage they practically cease to form under new geological conditions. They are also called as **exhaustible** or **depletable** sources of energy. Fossil fuels and nuclear fuels are non-renewable sources of energy.

Difference between Conventional and non- conventional sources of energy:

Conventional sources of energy	**Non- conventional sources of energy**
These are widely used and economical	These are rarely used and initial cost is high
Most of them are exhaustible	Most of them are in-exhaustible
Most of them are pollute the environment	Most of them are environment friendly
They are reliable (continuous supply of energy is possible)	They are not reliable (continuous supply of energy is not possible)
Energy transmission cost is high	Energy transmission cost is low
Example: Fossil fuels, Hydel energy	Example: solar, wind, tidal etc.

Difference between Renewable and non-renewable sources of energy:

Renewable sources of energy	**Non- Renewable sources of energy**
These are in-exhaustible	These are exhaustible
Freely available and environment friendly	Not freely available & hazardous to environment
Initial cost is high but maintenance cost is low	Initial cost is low but maintenance cost is high
Energy concentration varies from region to region	Energy concentration almost same in all region
Example: solar, hydel, wind, tidal etc.	Example: Fossil fuels, nuclear fuels.

Hydro-Energy:

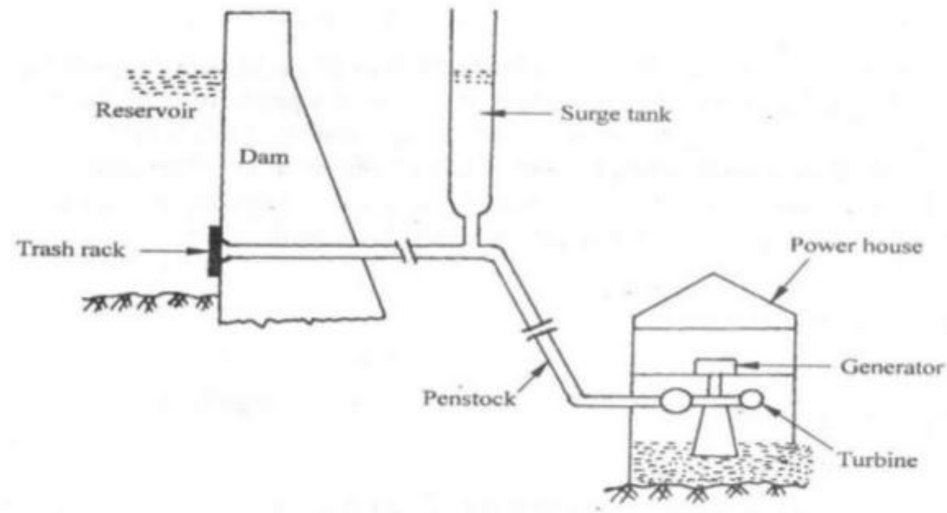


Figure 1.1

Hydroelectric power (often called hydropower) is considered a renewable energy source. A renewable energy source is one that is not depleted (used up) in the production of energy. Through hydropower, the energy in falling water is converted into electricity without "using up" the water.

An impoundment is simply a dam that holds water in a reservoir. The water is released when needed through a penstock, to drive the turbine (remember turbines are just advanced waterwheels). The flowing water causes the turbine to rotate, converting the water's kinetic energy into mechanical energy. The mechanical energy produced by the turbine is converted into electric energy using a turbine generator.

Wind energy:

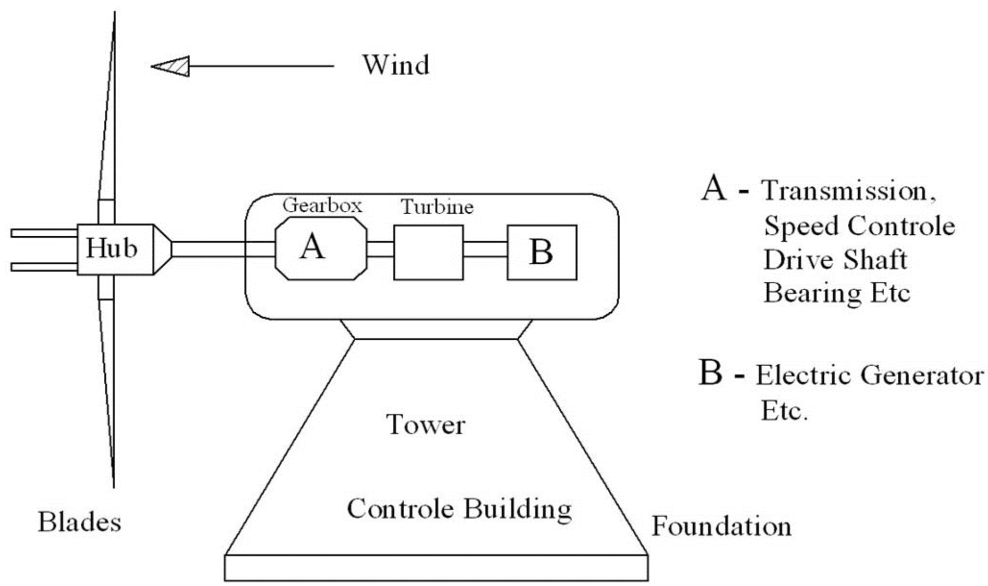


Figure 1.2

Winds arise primarily from temperature difference of the earth's surface resulting from unequal exposure to (or absorption of) solar radiation. Wind possesses kinetic energy. The kinetic energy of wind can be converted into mechanical energy that can be utilized to perform useful work or to generate electricity. Wind energy conversion devices are commonly known as **wind turbines.** The wind turbine consists of a number of vanes or blades radiating from a hub or central axis. When the wind blows against the vanes of a wind turbine, rotational motion is caused in the wind turbine. Thus, the kinetic energy of wind is converted into mechanical work. This mechanical work can be used directly to run a machine or to run a generator to produce electricity. Wind energy can be utilized in places wind velocity is considerably high. An ideal wind speed that can be utilized to extract energy lies between a speed 10 km/hr to 50 km/hr.

The utilization of wind energy for electric power generation is illustrated in figure 1.2. The set up consists of a wind turbine keyed to the turbine shaft. The rotational motion of the wind turbine caused due to wind blow is transmitted to the generator through a gear box. A step up transmission is usually required to match the relatively slow speed of the turbine to the higher speed of an electric generator. The combination of wind turbine and generator is usually referred to as an **aerogenerator.** The electrical energy so generated is obtained through the leads. The set up (usually called tower) consists of wind speed and direction indicator, with the aid of which the tower can be turned to the direction of wind blow.

Solar Energy:

Solar energy refers to the energy produced and radiated by the sun, i.e. sun's energy which reaches the earth. Solar energy can be converted directly or indirectly into other forms of energy, such as heat and electricity which can be utilized by man. The heat energy contained in the rays of the sun is absorbed by a black surface. This heat may then be used in various ways, which may be divided broadly into two classes as

(a) Direct thermal applications: Helio-electrical and Helio-thermal process

(b) Indirect thermal applications: Biomass energy (Helio-chemical), wind energy, tidal energy, ocean thermal energy etc.

Helio-electrical Process:

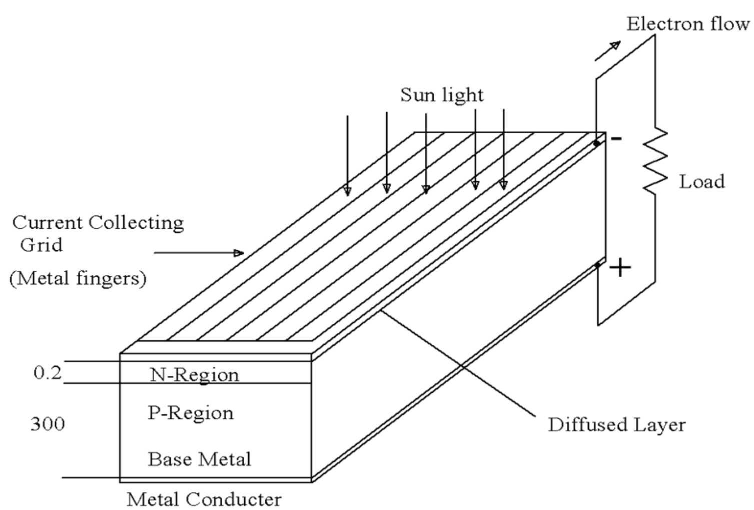


Figure 1.3

Conversion of solar energy into electrical energy can be achieved by the photovoltaic effect caused by the solar radiations. Photo-voltaic effect can be observed in variety of materials but best performance is given by semiconductors (like silicon).

Since silicon is a tetravalent material has four valence electrons. After doping with pentavalent material (like arsenic, phosphorous) it forms N-type semiconductor and the same with trivalent material (like boron) it forms P-type semiconductor. When P-N junction of semiconductor is exposed to sunlight, a voltage around 0.5 volts is built up around the junction and current depends on the exposed area of cell. By applying external load, current is made to flow through the conductor, it will continue as long as the free electrons and holes are formed due to solar radiation.

Helio-Thermal Process:

The heating property of solar radiation is used in the devices to meet the thermal energy needs. It is necessary to collect and concentrate the solar radiation in an efficient manner to arrive a reasonably high-temperature heat source. The collectors gather the sun's energy and direct it onto receivers that contain the working fluid.

Basically two types of collectors are used and they are flat plate collectors and concentrating collectors.

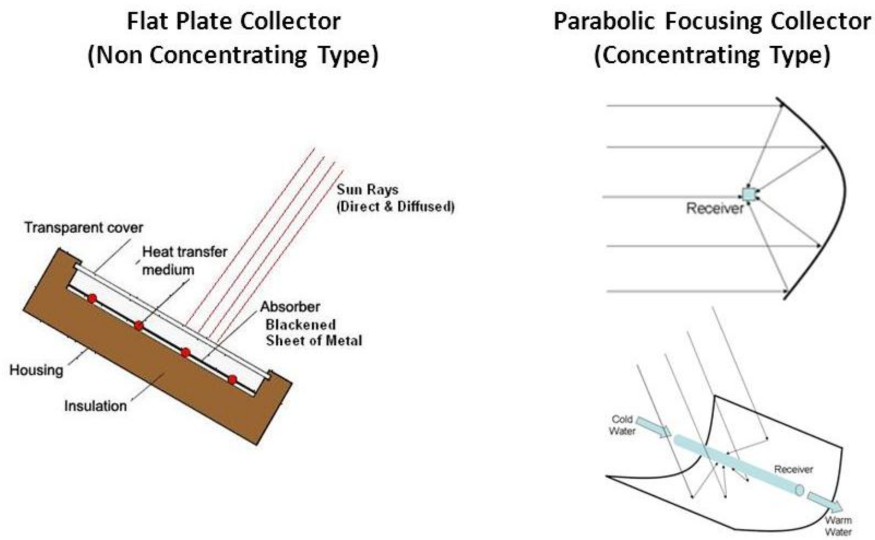


Figure 1.4

In flat plate collectors the incident solar radiation is absorbed by the collectors surface itself, which are usually coated with black paint (usually electroplated), covered with transparent glass cover on top and insulated all around to prevent the heat loss from the collector surface. The black collector surface gets heated up and then in turn transfers the heat to the fluid passing through the tubes which are either welded or soldered or are integral part of the collector plate. Flat plate collectors are usually sloped and oriented in one particular direction and are capable of collecting both diffuse and beam radiation. Since there are no moving parts in it, the repair and maintenance cost is also nil or negligible. A maximum of 100°C can be easily achieved using flat plate collectors and are more popularly used in solar water heating applications and solar air heaters as they are relatively cheaper as compared to the cost of concentrating collectors.

In concentrating collectors the incident solar radiation falls on a large curved surface from where it is reflected and focused on to focal point or line depending upon the type of the geometrical construction of the concentrating collector.

Helio-chemical Process:

The most important chemical reaction on the earth is the reaction of sunlight and green plants. Radiant energy of the sun is absorbed by the green pigment chlorophyll in the plant and is stored within the plant in the form of chemical bond energy.

The visible light having wavelength below 700A° is absorbed by the green chlorophyll which becomes activated and passes its energy on to water molecules. A hydrogen atom is released and reacts with the carbon dioxide molecules, to produce H_2CO and oxygen. H_2CO is the basic molecule forming carbohydrate. The oxygen librated is from H_2O molecule and not from CO_2. This process is called as carbon fixation or carbon assimilation.

The process of photosynthesis has two main steps:

(i) Splitting of H_2O molecules into H_2 and O_2 under the influence of chlorophyll and sunlight. This phase of reaction is called the light-reaction. In this reaction, light absorbed by chlorophyll causes photolysis of water. O_2 escapes and H_2 is transformed into some unknown compounds. The solar energy is converted into potential chemical energy.

(ii) In the second step, hydrogen is transferred from this unknown compound to CO_2 to form starch or sugar. Formation of starch or sugar is dark reaction not requiring sunlight.

However, photosynthesis concepts is less attractive as the average efficiency of solar energy conversion in plants is about 1% and overall efficiency of the conversion of sunlight to electricity would be about 0.3% compared to 18 to 21% for photo-voltaic cells. Still worldwide photosynthetic activity can store more than 15times as much energy as consumed by all nations of the world.

Nuclear energy:

Nuclear energy is the energy released during nuclear fission or fusion, especially when used to generate electricity. Nuclear fuel is any material that can be consumed to derive nuclear energy. The most common type of nuclear fuel is fissile elements that can be made to undergo nuclear fission chain reactions in a nuclear reactor. The most common nuclear fuels are 235U and 239Pu.

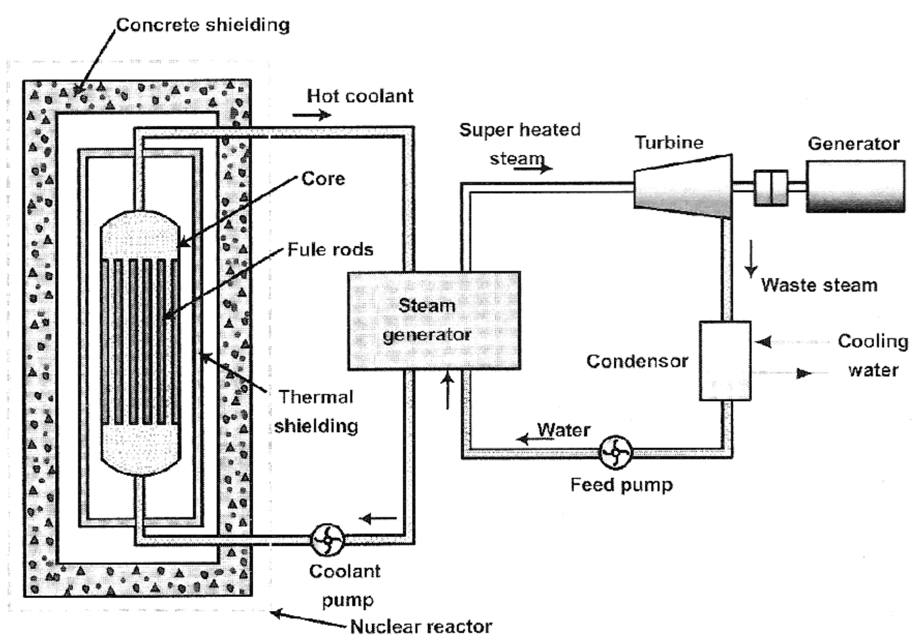


Figure 1.5

The basic nuclear generating station energy cycle is shown in Figure. Fuel containing fissile material (Uranium) is fed to the reactor where fission takes place. The energy liberated appears in the form of heat, which is used to boil water in Heat exchanger or steam generator. The steam produced from the boiling water spins a turbine-generator set, where the heat is converted first to kinetic energy and then it will converts to mechanical energy in the turbine and to electricity by the generator.

FOSSIL FUELS:

Fuel is a substance which, when burnt, i.e. on coming in contact and reacting with oxygen or air, produces heat. Thus, the substances classified as fuel must necessarily contain one or several of the combustible elements: carbon, hydrogen, sulphur, etc. In the process of combustion, the chemical energy of fuel is converted into heat energy.

1. Solid Fuels:

Solid fuels are mainly classified into two categories:

I. Natural fuels: wood, coal, etc.
II. Manufactured fuels: charcoal, coke, briquettes, etc.

Wood:

The most commonly used and easily obtainable solid fuel is wood. It is the oldest type of fuel which man had used for centuries after the discovery of the fire itself. Charcoal is an artificial fuel obtained from wood.

Coal:

Coal is a combustible black or brownish-black sedimentary rock usually occurring in rock strata in layers or veins called coal beds or coal seams.. The major chemical elements in coal are: carbon, hydrogen and oxygen.

There are two types of coals: i) Bituminous coal ii) Anthracite coal.

Charcoal:

Charcoal is a produce derived from destructive distillation of wood, being left in the shape of solid residue. Charcoal burns rapidly with a clear flame, producing no smoke and developing heat of about 6050 cal/kg.

Coke:

It is obtained from destructive distillation of coal, being left in the shape of solid residue. Coke can be classified into two categories: soft coke and hard coke. Soft coke is obtained as the solid residue from the destructive distillation of coal in the temperature range of 600-650oC. It contains 5 to 10% volatile matter. It burns without smoke. It is extensively used as domestic fuel. Hard coke is obtained as solid residue from the destructive distillation of coal in the temperature range of 1200-1400oC. It burns with smoke and is a useful fuel for metallurgical process.

Advantages of solid fuels:

(a) They are easy to transport.
(b) They are convenient to store without any risk of spontaneous explosion.
(c) Their cost of production is low.
(d) They possess moderate ignition temperature.

Disadvantages of solid fuels:

(a) Their ash content is high.
(b) Their large proportion of heat is wasted.
(c) Their combustion operation cannot be controlled easily.
(d) Their cost of handling is high.

2. <u>Liquid fuels</u>:

Liquid fuels include Gasoline, Diesel oil, Kerosene, Heavy oil, Naptha, Lubricating oils, etc. These are obtained mostly by fractional distillation of crude petroleum or liquefaction of coal.

Gasoline or Petrol:

The straight run gasoline is obtained either from distillation of crude petroleum or by synthesis. It contains some undesirable unsaturated straight chain hydrocarbons and sulphur compounds. It has boiling range of 40-120oC.

Diesel Fuel:

The diesel fuel or gas oil is obtained between 250-320oC during the fractional distillation of crude petroleum. This oil generally contains 85% C. 12% H. Its calorific value is about11000 kcal/kg.

The suitability of a diesel fuel is determined by its cetane value. Diesel fuels consist of longer hydrocarbons and have low values of ash, sediment, water and sulphalt contents.

Kerosene Oil:

Kerosene oil is obtained between 180-250oC during fractional distillation of crude petroleum. It is used as an illuminant, jet engine fuel, tractor fuel, and for preparing laboratory gas. With the development of jet engine, kerosene has become a material of far greater importance than it is used to be. When kerosene is used in domestic appliances, it is always vaporized before combustion. By using a fair excess of air it burns with a smokeless blue flame.

Advantages of liquid fuels:

a. They possess higher calorific value per unit mass than solid fuels.
b. They burn without dust, ash, clinkers, etc.
c. They are easy to transport through pipes.
d. They can be stored indefinitely without any loss.
e. They are clean in use and economic to handle.
f. They require less excess air for complete combustion.
g. They require less furnace space for combustion.

Disadvantages of liquid fuels:

a. The cost of liquid fuel is relatively much higher as compared to solid fuel.
b. Costly special storage tanks are required for storing liquid fuels.
c. There is a greater risk of five hazards, particularly, in case of highly inflammable and volatile liquid fuels.
d. For efficient burning of liquid fuels, specially constructed burners and spraying apparatus are required.

3. Gaseous fuels:

Gaseous fuels occur in nature, besides being manufactured from solid and liquid fuels.

Natural Gas:

Natural gas is generally associated with petroleum deposits and is obtained from wells dug in the oil-bearing regions. The approximate composition of natural gas is :

$$CH_4 = 70.9\%, C_2H_6 = 5.10\%, H_2 = 3\%, CO + CO_2 = 22\%$$

Producer Gas:

Producer gas is essentially a mixture of combustible gases carbon monoxide and hydrogen associated with non-combustible gases N_2, CO_2, etc. It is prepared by passing air mixed with little steam (about 0.35 kg/kg of coal) over a red hot coal or coke bed maintained at about 1100oC in a special reactor called gas producer. It consists of a steel vessel about 3 m in diameter and 4 m in height. The vessel is lined inside with fire bricks. It is provided with a cup and cone feeder at the top and a side opening for the exit of producer gas. At the base it has an inlet for passing air and steam. The producer at the base is also provided with an exit for the ash formed.

Advantages of gaseous fuels:

a. They can be conveyed easily through pipelines to the actual place of need, thereby eliminating manual labour in transportation.
b. They can be lighted at ease.
c. They have high heat contents and hence help us in having higher temperatures.
d. They can be pre-heated by the heat of hot waste gases, thereby affecting economy in heat.
e. Their combustion can readily by controlled for change in demand like oxidizing or reducing atmosphere, length flame, temperature, etc.
f. They do not require any special burner.
g. They are free from impurities found in solid and liquid fuels.

Disadvantages gaseous fuels:

a. Very large storage tanks are needed.
b. They are highly inflammable, so chances of fire hazards in their use is high.

Combustion and Combustion products:

The term combustion refers to the exothermal oxidation of a fuel, by air or oxygen occurring at a sufficiently rapid rate to produce a high temperature, usually with the appearance of a flame.

As most of the fuels contain carbon or carbon and hydrogen, the combustion involves the oxidation of carbon to carbon dioxide and hydrogen to water. Sulphur, if present, is oxidised to sulphur dioxide while the mineral matter forms the ash. Complex fuels like coal undergo thermal decomposition during combustion to give simpler products which are then oxidised to carbon dioxide, water etc.

e.g.: Coke on combustion gives carbon dioxide

Coal → Coke + Coal gas

$C \text{ (coke)} + O_2 \rightarrow CO_2$

Calorific Value of a Fuel:

The calorific value of a fuel is defined as the quantity of heat liberated by the complete combustion of unit weight of the fuel in air or oxygen, with subsequent cooling of the products of combustion to the initial temperature of the fuel.

It is expressed in kJ/kg

The calorific value of a fuel depends upon the nature of the fuel and the relative proportions of the elements present, increasing with increasing amounts of hydrogen. Moisture if present considerably reduces the calorific value of a fuel. The calorific value may be theoretically calculated from the chemical composition of the fuel.

BIO-FUELS

Biofuels are energy sources made from living things, or the waste that living things produce. Supporters of biofuels argue that their use could significantly reduce greenhouse gas emissions; while burning the fuels produces carbon dioxide, growing the plants or biomass removes carbon diozide from the atmosphere.

Ethanol:

Ethanol can be produced by the action of microorganisms and enzymes through the fermentation of sugar cane. Ethanol can be used in petrol engines as a replacement for gasoline; it can be mixed with gasoline to any percentage. Most existing car petrol engines can run on blends of up to 15% bioethanol with petroleum/gasoline. Ethanol has a smaller energy density than that of gasoline; this means it takes more fuel (volume and mass) to produce the same amount of work. An advantage of ethanol (CH_3CH_2OH) is that it has a higher octane rating than ethanol-free gasoline available at roadside gas stations, which allows an increase of an engine's compression ratio for increased thermal efficiency. In high-altitude (thin air) locations, some states mandate a mix of gasoline and ethanol as a winter oxidizer to reduce atmospheric pollution emissions.

Advantages:

- Unlike petroleum, ethanol is a renewable resource
- Ethanol burns more cleanly in air than petroleum, producing less carbon (soot) and carbon monoxide
- The use of ethanol as opposed to petroleum could reduce carbon dioxide emissions, provided that a renewable energy resource was used to produce crops required to obtain ethanol and to distil fermented ethanol

Disadvantages:

- Ethanol has a lower heat of combustion (per mole, per unit of volume, and per unit of mass) that petroleum
- Large amounts of arable land are required to produce the crops required to obtain ethanol, leading to problems such as soil erosion, deforestation, fertiliser run-off and salinity.

- Major environmental problems would arise out of the disposal of waste fermentation liquors.
- Typical current engines would require modification to use high concentrations of ethanol

Biodiesel:

It is produced from oils or fats using transesterification and is a liquid similar in composition to fossil/mineral diesel. Chemically, it consists mostly of fatty acid methyl (or ethyl) esters (FAMEs). Feedstocks for biodiesel include animal fats, vegetable oils, soy, rapeseed, jatropha, mahua, mustard, flax, sunflower, palm oil, hemp, field pennycress, Pongamia pinnata and algae. Pure biodiesel (B100) currently reduces emissions with up to 60% compared to diesel

Advantages of biodiesel fuel:

• An excessive production of soybeans in the world makes it an economic way to utilize this surplus for manufacturing the Biodiesel fuel.

• One of the main biodiesel fuel advantages is that it is less polluting than petroleum diesel.

• The lack of sulfur in 100% biodiesel extends the life of catalytic converters.

• Another of the advantages of biodiesel fuel is that it can also be blended with other energy resources and oil.

• It can also be distributed through existing diesel fuel pumps, which is another biodiesel fuel advantage over other alternative fuels.

• The lubricating property of the biodiesel may lengthen the lifetime of engines.

Disadvantages of biodiesel fuel:

• At present, Biodiesel fuel is bout one and a half times more expensive than petroleum diesel fuel.

• It requires energy to produce biodiesel fuel from soy crops; plaus there is the energy of sowing, fertilizing and harvesting.

• As Biodiesel cleans the dirt from the engine, this dirt can then get collected in the fuel filter, thus clogging it. So, filters have to be changed after the first several hours of biodiesel use.

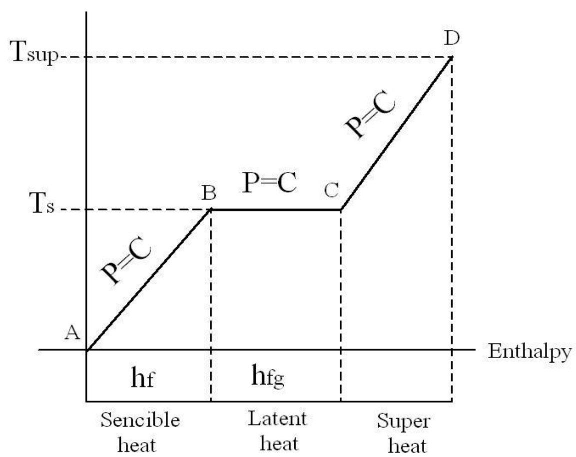
• Biodiesel fuel distribution infrastructure needs improvement, which is another of the biodiesel fuel disadvantages.

FORMATION OF STEAM:

The process of generation of steam can be represented through a temperature – enthalpy diagram as shown in the figure 1.6.

Consider 1 kg of water at 0^0 C taken in a cylinder with a pressure P applied by a weight 'w' on a free frictionless piston as shown in the figure 1.7. When it is heated keeping the pressure constant, its volume increases with increase of temperature, until it reaches a point (point B in the figure 1.6) when steam begins to form. This temperature (T_s) at which steam begins to form is called the **saturation temperature**. The saturation temperature is different for different pressures and it increases with rise of pressure. The saturation temperature at atmospheric pressure of 1 bar is 100^0 C.

When steam begins to form at saturation temperature, some water particles may be present in it (Fig1.7c). If the steam contains water particles in suspension, it is called **wet steam**.



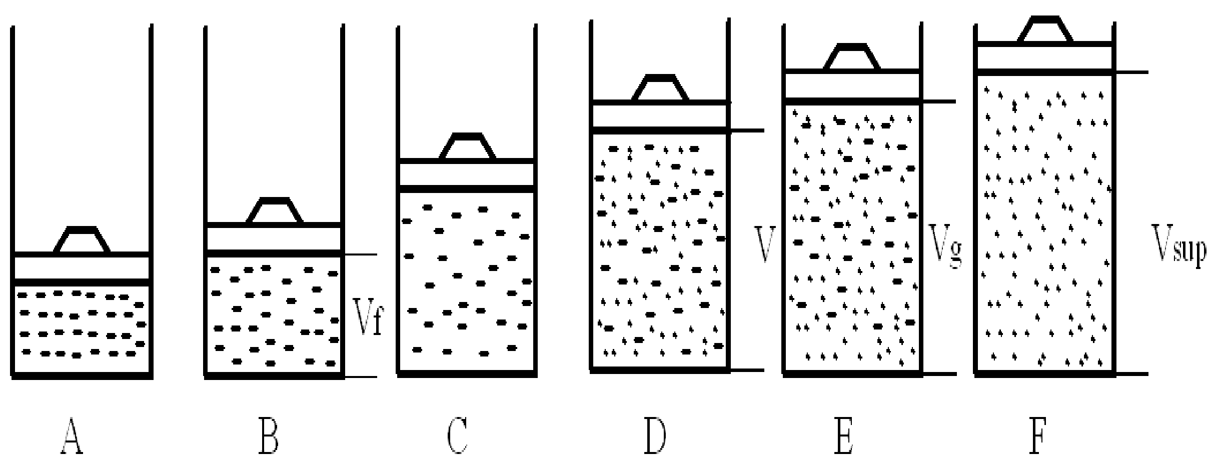


Figure 1.7

On further heating beyond the point 'B', the whole amount of water will be converted to steam without any further rise of temperature. At the saturation temperature if the steam contains no water particles, it is **dry saturated steam**.

If the dry saturated steam is further heated beyond point 'C', at the same pressure the temperature of steam rises above the saturation temperature. The steam which is at a temperature greater than saturation temperature is called **superheated steam**.

Thus, during the formation there are three states of steam namely wet steam, dry steam and superheated steam.

(i) Enthalpy of Water:

The total amount of heat required to raise the temperature of 1 kg of water which is initially at 0^0 C to its saturation temperature, at a given constant pressure is called the **enthalpy of water**. It is also called **sensible heat**. It is denoted by 'h_f' and expressed in '**kJ / kg**'.

(ii) Enthalpy of Evaporation:

The total amount of heat required to convert 1 kg of water which is initially at its saturation temperature to dry saturated steam at the same saturation temperature and at the given constant pressure is called **enthalpy of evaporation**. It is also called the **latent heat of vaporization of steam**. It is denoted by 'h_{fg}' and is expressed in '**kJ / kg**'.

(iii) Enthalpy of Steam:

The total amount of heat required to generate 1 kg of dry saturated steam from 1 kg of water which is initially at 0^0 C and at a given constant pressure is called the **enthalpy of steam**. It is denoted by 'h_g' and expressed in '**kJ / kg**'. Enthalpy of steam is equal to the sum of enthalpy of water (h_f) and enthalpy of evaporation (h_{fg}).

Thus it can be expressed as $h_g = h_f + h_{fg}$ kJ / kg

(iv) Enthalpy of Wet Steam:

Enthalpy of wet steam is defined as the "total amount heat of required to generate 1 kg of water which is initially at 0˚C to 1 kg of wet steam at the specified dryness fraction". It is denoted by 'h_w' and expressed in '**kJ / kg**'

Enthalpy of wet steam, $h_w = h_f + x\, h_{fg}$ kJ / kg

Where, x = dryness fraction of steam

(v) Enthalpy of Superheated Steam:

The total amount of heat required to generate 1 kg of superheated stream at the stated superheated temperature from 1 kg of water which is initially at 0^0 C and at a given constant pressure is called the **enthalpy of superheated steam**. It is denoted by 'h_s' and expressed in '**kJ / kg**'.

Enthalpy of superheated steam, $h_s = h_g + h_{sup}$

Where, 'h_{sup}' is the heat supplied during superheating, i.e., the heat supplied to the dry saturated steam to attain superheated temperature 't_{sup}'.

'h_{sup}' is also called the **enthalpy of superheat**. It can be determined by using the equation

$$h_{sup} = C_p\,(t_{sup} - t_s) \quad \text{kJ / kg}$$

The difference between the superheated temperature (t_{sup}) and the saturation temperature (t_s) is called the **degree of superheat**.

(vi) Dryness fraction:

Dryness fraction of steam is defined as the ratio of mass of dry steam actually present in a wet steam to the total mass of wet steam".

Dryness fraction, $$x = \frac{Mass\ of\ dry\ steam\ in\ wet\ steam}{Total\ mass\ of\ wet\ steam}$$

$$x = \frac{m_d}{m_w + m_d}$$

Where, m_d — Mass of dry steam.

m_w — Mass of suspended water molecules. (x should always be less than 1)

(vii) Specific Volume:

The volume of a unit mass of steam at a given pressure is called the *specific volume of steam*. It is expressed in m^3 / kg.

As steam exists in three states, the specific volume is considered for all the three states.

(viii) Specific volume of dry saturated steam:

The volume of a unit mass of dry saturated steam at a given pressure is called the *specific volume of a dry saturated steam*. It is denoted by '$\mathbf{v_g}$' and expressed in '$\mathbf{m^3}$ **/ kg**'.

(ix) Specific volume of wet steam:

The volume of a unit mass of wet steam at a given pressure is called *specific volume of wet steam*. It is denoted by '$\mathbf{v_w}$' and expressed in '$\mathbf{m^3}$ **/ kg**'.

Wet steam consists of saturated liquid in suspension. If in 1 kg of wet steam there is 'x' kg of dry steam, then '(1 – x)' kg will be the saturated liquid. Therefore specific volume of wet steam $v_w = xv_g + (1-x)\, v_f \quad m^3/\text{kg}$

Since '$(1-x)\, v_f$' is too small quantity it is neglected. Hence

Specific volume of wet steam, $\mathbf{v_w = xv_g} \quad m^3/\text{kg}$

(x) Specific volume of the superheated steam: The volume of a unit mass of superheated steam at a given pressure is called the *specific volume of superheated steam*.

Since superheated steam behaves like a perfect gas, its specific volume can be determined by using Charles law as follows:

$$\frac{v_g}{T_s} = \frac{v_{sup}}{T_{sup}}$$

$$V_{sup} = V_g \frac{T_{sup}}{T_s}$$

where, v_g —Specific volume of dry saturated steam at pressure 'p'

T_s —Saturation temperature, K

T_{sup} —Specified superheated temperature, K

v_{sup} — Specific volume of superheated steam at pressure 'p'

(xi) Internal energy of steam: When water vaporizes and gets converted into steam there is a considerable increase in its volume. Thus some amount of external work is done during vaporization. This external work can be expressed as product of pressure and volume of steam. Thus the external work done, for the three states of steam are as follows:

pv_g for dry saturated steam

pv_w for wet steam

pv_{sup} for superheated steam

Internal energy of steam is the actual energy stored in steam which can be utilized for doing external work. It is equal to the difference between the total heat of steam and the external work done during vaporization. It is denoted by '**U**' and expressed in '**kJ / kg**'. Thus,

Internal energy of dry saturated steam : $U_g = h_g - pv_g$ kJ / kg

Internal energy of wet steam : $U_w = h_w - pv_w$ kJ / kg

Internal energy of superheated steam : $U_{sup} = h_s - pv_{sup}$ kJ / kg

Where 'p' is in 'kN / m^2'

THERMODYNAMICS:

1. **System boundary:** The real or imaginary surface which surrounds the system is called system boundary
2. **Surrounding**: The region outside the system is called the surrounding.

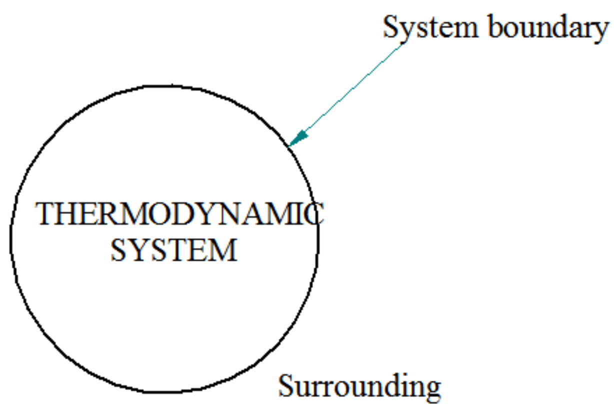
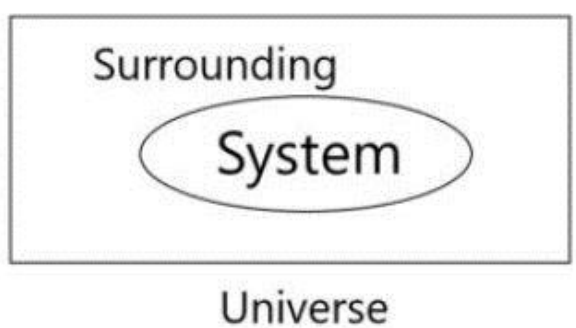


Fig: Thermodynamic system

3. **Universe**: System and Surrounding put together is known as **Universe**



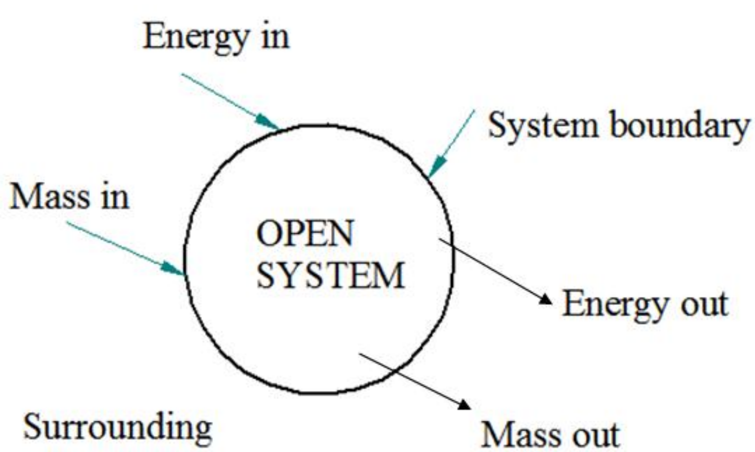
TYPES OF THERMODYNAMICS SYSTEMS:

a) Open system

b) Closed system

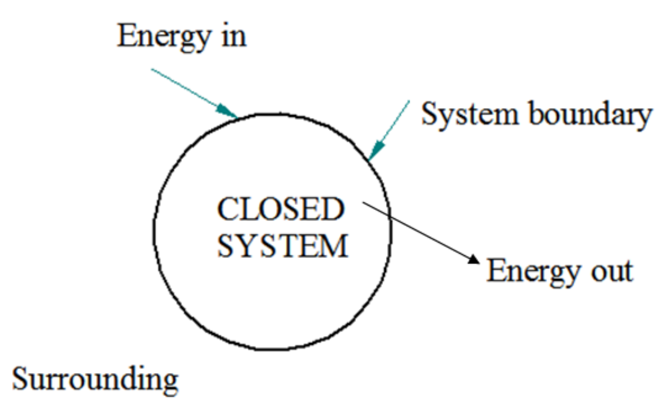
c) Isolated system

a) **Open system:** The open system is one in which both mass and energy (heat/work) cross the boundary of the system.



Examples of open system: Water Pump, scooter engine

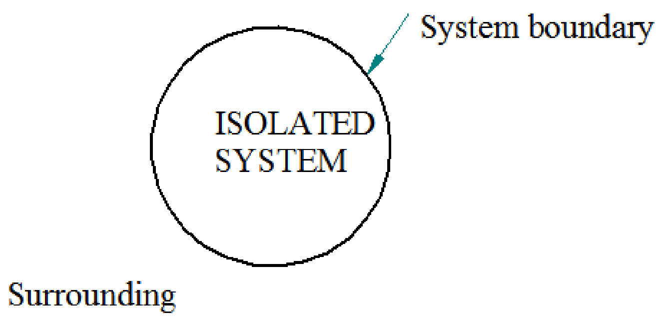
b) **Closed system:** The closed system is one in which only energy (heat/work) crosses the boundary of the system. It has fixed mass



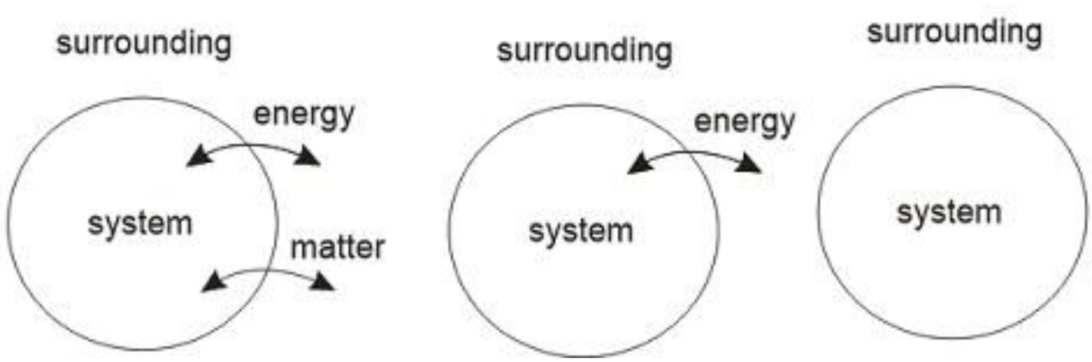
Example of closed system: Car battery, Tea kettle, Water in a tank

c) **Isolated system:** The isolated system is one in which neither energy(heat/work) nor mass crosses the boundary of the system. This system does not interact with the surrounding. Therefore it has fixed mass and energy.

- No such system physically exists. Universe is the only example, which is perfectly isolated system



NOTE:



Open system Closed system Isolated system

THERMODYNAMIC STATE: The condition of a system at a particular moment is called its state.

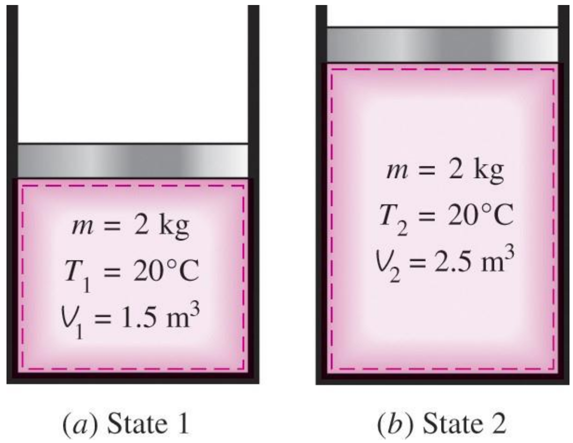


Fig: A system at two different states

THERMODYNAMIC PROPERTIES: The properties describing the state of a system are called thermodynamic properties. These are pressure (P) , Volume (V) , temperature (T) etc

Types of Thermodynamic properties

Thermodynamic properties are generally divided into two types based on their dependence on mass

Intensive properties: A thermodynamic property which is independent of mass is called intensive property. For e.g. Temperature, Pressure etc.

For example if we take one liter of hot water at 50 degree Celsius, then at each and every point of that one liter water temperature will be same. It does not depends on whether the water is one liter or ten liters.

Extensive properties: A thermodynamic property which is dependent on mass is called an extensive property. For e.g. volume, energy, entropy etc.

For example if we take water, then its volume which is a property depends on mass, for half kg of mass volume will be different and for one kg it would be different.

Specific property= Extensive property/mass.

Example:

- Specific volume (v) = Volume(V)/mass(m)
- Specific enthalpy (h) = Enthalpy(H)/mass(m)
- Specific entropy (s) = Entropy(S)/mass(m)

PROCESS AND CYCLE: When a system undergoes changes from one equilibrium state to another is called a *process. A process has a start and end point.*

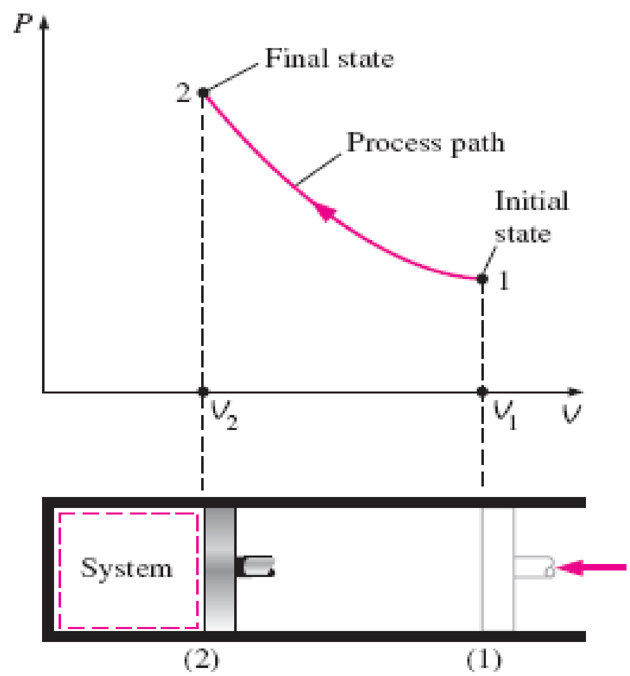


Fig: Process and path

From the above fig it clears that STATE1:P1,V1,STATE 2:P2,V2,PROCESS :1- 2

Types of Process:

a. Isobaric process or Constant pressure process
b. Isochoric process or Constant volume process

c. Isothermal process or Constant temperature process
d. Adiabatic process
e. Quasi-static process

THERMODYNAMIC EQUILIBRIUM

A system is said to be in thermodynamic equilibrium, it should satisfy following three equilibrium

a. Mechanical equilibrium
b. Chemical equilibrium
c. Thermal equilibrium

a. **Mechanical equilibrium**: A system is said to be in mechanical equilibrium when there are no unbalanced forces within the system and also between the system and the surrounding, the system is said to be under mechanical equilibrium
b. **Thermal Equilibrium:** A system is said to be in thermal equilibrium when there is no temperature difference within the system and also between system and surroundings.

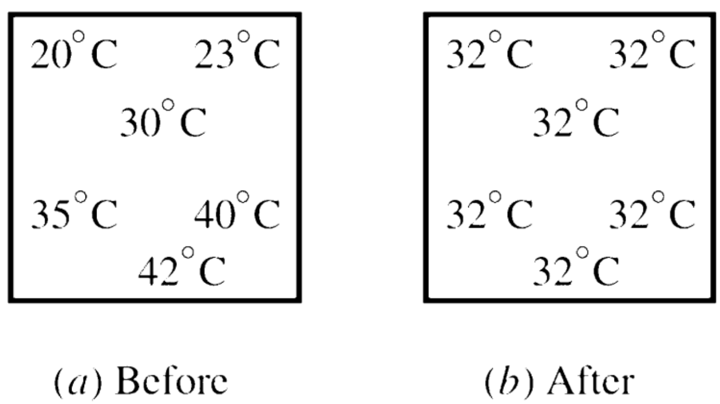


Fig: A closed system reaching thermalequilibrium.

c. **Chemical Equilibrium:** A system is said to be in chemical equilibrium when there is no Chemical reaction within the system

When all the conditions of Mechanical, Chemical and Thermal equilibrium are satisfied, the system is said to be in Thermodynamic equilibrium

LAWS OF THERMODYNAMICS:

1. ZEROTHLAW OF THERMODYNAMICS:

- The Zeroth Law of Thermodynamics states that if two systems are each in thermal equilibrium with third system, then they are also in equilibrium with each other. Thermal equilibrium means
- Let us consider we have system A, system B and System C as shown in following figure.

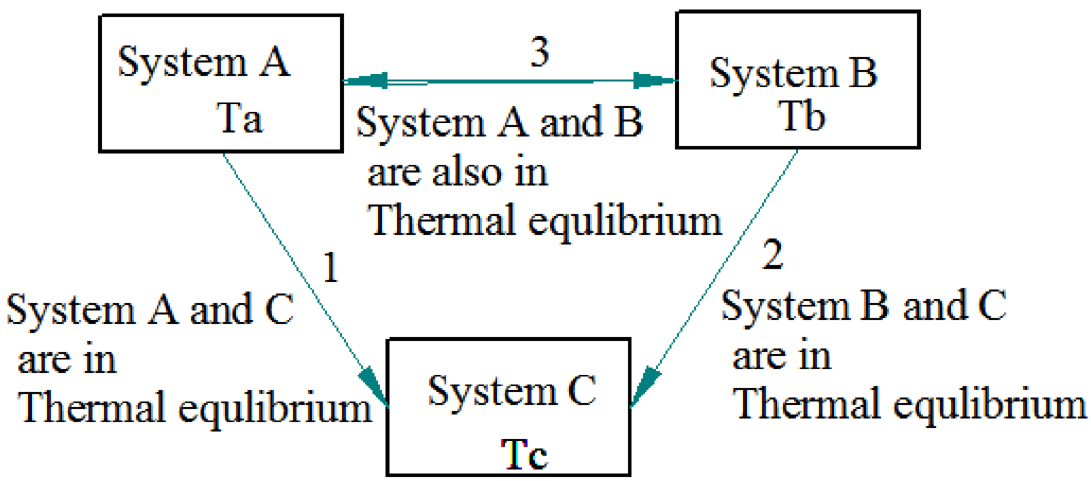


Fig: Zeroth law of thermodynamics

Let temperature of system A is Ta,

Temperature of system B is Tb

Temperature of system C is Tc.

If Ta = Tc and Tb = Tc

If system A is in thermal equilibrium with system C and system B is also in thermal equilibrium with system C. Then according to Zeroth law of thermodynamics, system A and system B will also be in thermal equilibrium with each other.

That is , Ta = Tb

2. FIRST LAW OF THERMODYNAMICS:

First law of thermodynamics for cyclic process

- First law of thermodynamics states that, when a closed system executes a cyclic process then the cyclic integral of the heat is equal to the cyclic integral of the work

Mathematically, the first law of thermodynamics is stated as

- $\oint dQ = \oint dW$
- $\oint dQ - \oint dW = 0$

Extension of First law of thermodynamics for Non cyclic process:

When a closed system undergoes a non-cyclic process, the difference between the net heat transfer and the net work transfer is equal to the change in the energy of the system

$\delta Q - \delta W = dE$

$\delta Q = \delta W + dE$

OR

$Q = W + \Delta U$

Where $E = KE + PE + U$

Total energy content=E= Internal Energy(U) + Kinetic energy + Potential energy

In most of the situations the changes in KE and PE are very small, Thus KE and PE changes can be neglected.

Therefore $\Delta E = \Delta U$

$\Delta E = Q - W$ becomes

$\Delta U = Q - W$

$Q = W + \Delta U$

For e.g. of 10 J of heat supplied to a system out of which 5 J used for doing work work and the remaining 5 J will be stored in the system in the form of energy.

TOTAL ENERGY CONTENT OF A CLOSED SYSTEM

- ΔE= Total energy=Q–W
- Q=ΔE+W
- 'W' amount of work is done by the system
- 'Q' amount of heat absorbed by system
- ΔE refers to the energy change of the system. The net energy transfer (Q – W) would be stored in the system.

CONCEPT OF INTERNAL ENERGY:

Internal energy (U):

- Internal energy is the energy stored in a substance.
- Internal energy is the energy due electron spin and vibrations, molecular motion and chemical bond.
- It is denoted by U
- From first law of thermodynamics we have
- $\Delta E = Q - W$
- $Q = W + \Delta U$

Where E = KE + PE +U

- KE= Kinetic energy
- PE= Potential energy
- U = Internal energy. Therefore,
- In most of the situations the changes in KE and PE are very small, Thus KE and PE changes can be neglected.

Therefore $\Delta E = \Delta U$

$\Delta E = Q - W$ becomes

$\Delta U = Q - W$

- For e.g. of 10 J of heat supplied to a system out of which 5 J used for doing work work and the remaining 5 J will be stored in the system in the form of internal energy.

CONCEPT OF ENTHALPY (H):

- Enthalpy, the sum of the internal energy(E) and the product of the pressure(P) and volume(V) of a thermodynamic system. It is expressed in kJ/kg
- Enthalpy, denoted by the symbol 'H',
- The enthalpy of a thermodynamic system is given by

$$H=U+PV$$

Where

- H is the enthalpy of the system,
- U is the internal energy of the system,
- P is the pressure of the system,
- V is the volume of the system

Heat Engine

- Heat engine is a device operating in a cycle, which converts heat into work continuously
- Ex: Internal combustion engine, Gas turbine
- The parts of heat engine are Source, Working substance and Sink
- **Source**: It is a reservoir of heat at high temperature. Heat engine absorbs the heat from the source
- **Sink:** It is a reservoir of heat at low temperature. Heat engine rejects the heat to the sink
- Working substance may be steam or petrol

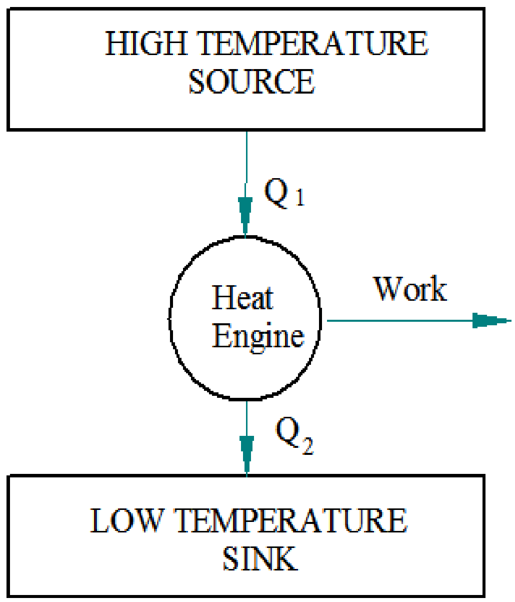


Fig: Heat engine

- Consider a heat engine
- Heat engine absorbs Q1 amount of heat from the source at T1 and converts the part of heat received into mechanical work(W)
- The remaining part of the heat Q2 is rejected to the sink

Expression for the Efficiency of a Heat engine:

$\eta = W/Q1$

- Where, W is the work done by the engine and Q1 is the heat absorbed from the source.

- According to first law net heat transfer=net work transfer
- i.e W=Q1
- η =100%
- So efficiency will be 100% but in actual, this is not possible because there will be some loss of energy in the system. Hence for every engine, there is a limit for its efficiency.

Heat Pump

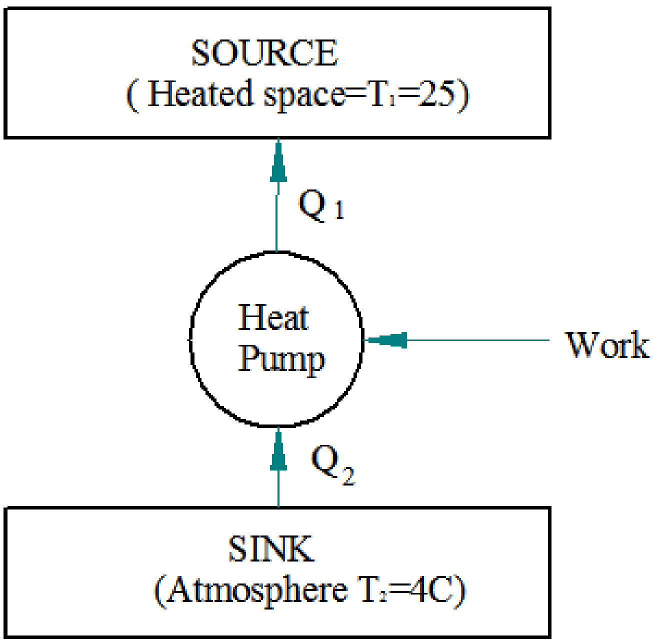


Fig: Heat Pump

- The heat pump is a device used to pump heat into the system.
- It is basically used for heating purpose(maintaining temperature higher than the surrounding)
- Heat pump keeps your home warm rather than just burning fuel in a fireplace or furnace is that a heat pump supplies. It runs on electricity, so you can save substantially on fuel consumption.
- Consider a heat pump as shown in the fig
- Heat pumps transfer heat from a low-temperature source to a high-temperature sink
- Heat Pump takes the mechanical work(W) like electric motor and transfer heat from sink to source

Efficiency of heat pump is known as Coefficient of Performance(CoP)

CoP=Q1/W

If W=0, CoP becomes infinity which is not possible

So some external work must be supplied to the heat pump

SECOND LAW OF THERMODYNAMICS: KELVIN PLANK'S STATEMENT:

- According to Kelvin Plank's Statement "*It is impossible to construct a heat engine that operates in a cycle, whose sole purpose is to convert heat energy from a single thermal reservoir into an equivalent amount of work*"
- Thus according to this statement, there is no engine that can convert all the heat taken from the source into work, without giving any heat into the sink.
- This means that for obtaining continuous work, a sink is necessary.
- In the heat engine, the working substance takes heat from the hot body, converts a part of it into work and gives the rest to the cold body.

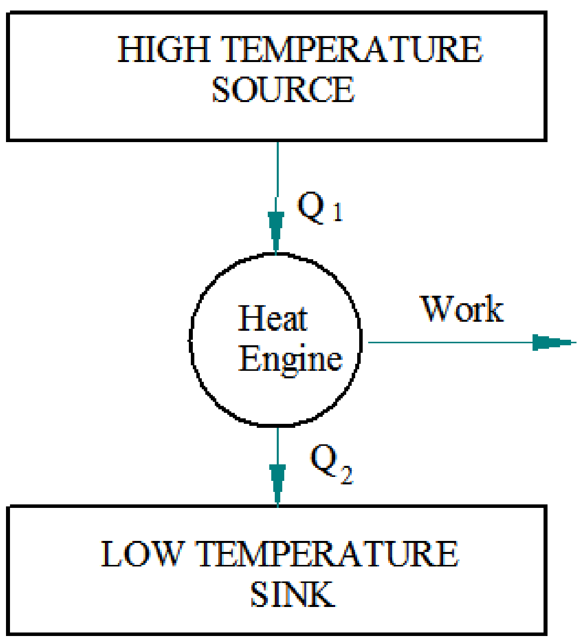


Fig a (Possible)

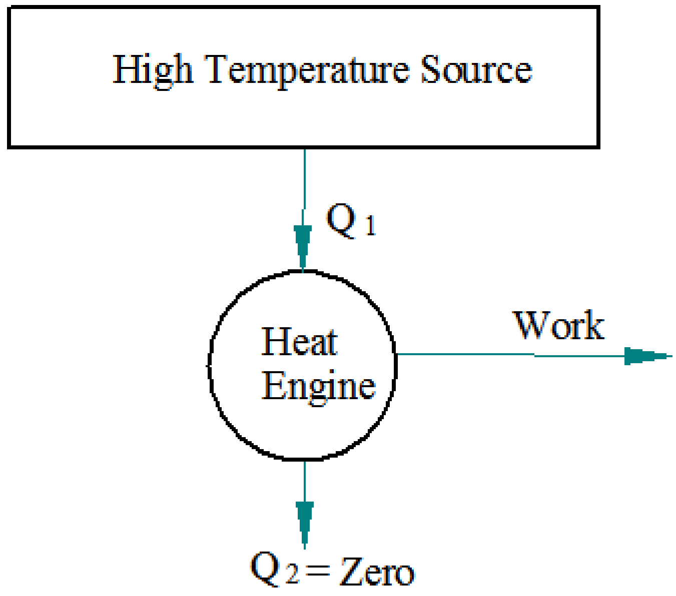


Fig b(Impossible)

- Fig a shows heat engine that obeys the Kelvin-Planck statement of the second law
- Fig b shows heat engine that violates the Kelvin-Planck statement of the second law cannot be built. The above heat engine had Thermal efficiency of 100% which is practically impossible (which cannot be built). This device is called **PMM II**

Second Law of Thermodynamics: Clausius Statement:

- According to Clausius Statement" It is impossible to construct an heat pump *that operates in a cycle,* to transfer heat from a body at a lower temperature to a body at a higher temperature without the assiatnce of external work"
- According to this stamen it clears that It is not at all possible to transfer heat from a cold body to a hot body without the expenditureiof work by an external energy source.

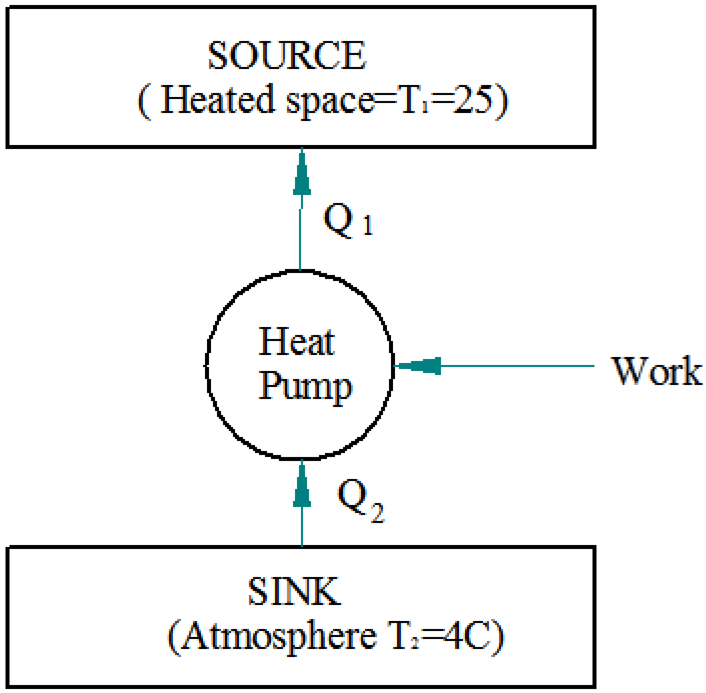


Fig a (Possible)

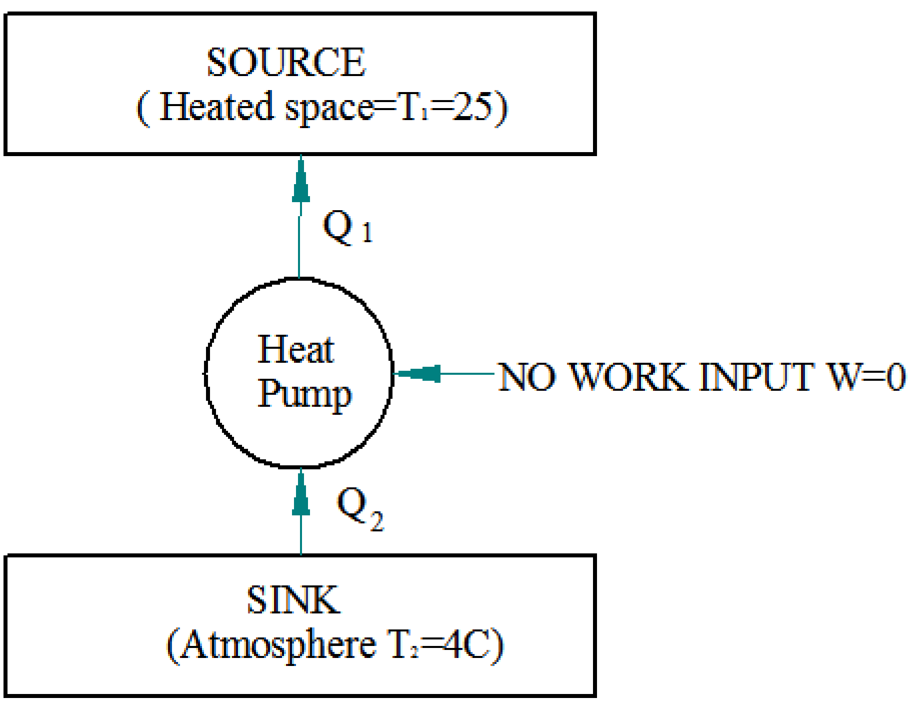


Fig b(Impossible)

- Fig a shows heat engine that obeys Clausius statement of the second law
- Fig b shows heat engine that violates Clausius statement of the second law cannot be built. The above heat which is practically impossible (which cannot be built)

CONCEPT OF WORK AND HEAT:

Mechanics definition of work :

According to Mechanics, Work is defined as the product of force(F) and the distance moved(S) in the direction of force

Mathematically, $W = F \times d$

Where:

W = work (J)

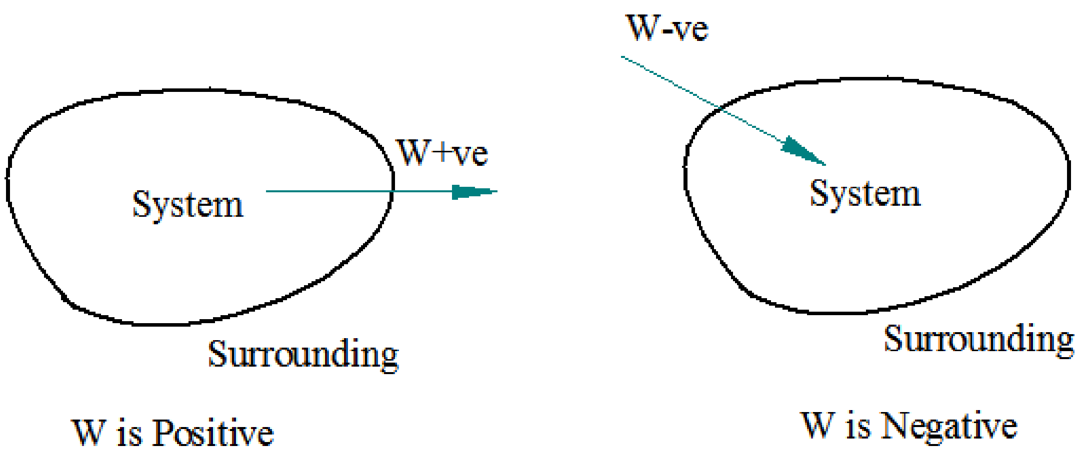
F = force (N)

d = displacement (m)

Thermodynamic definition of work:

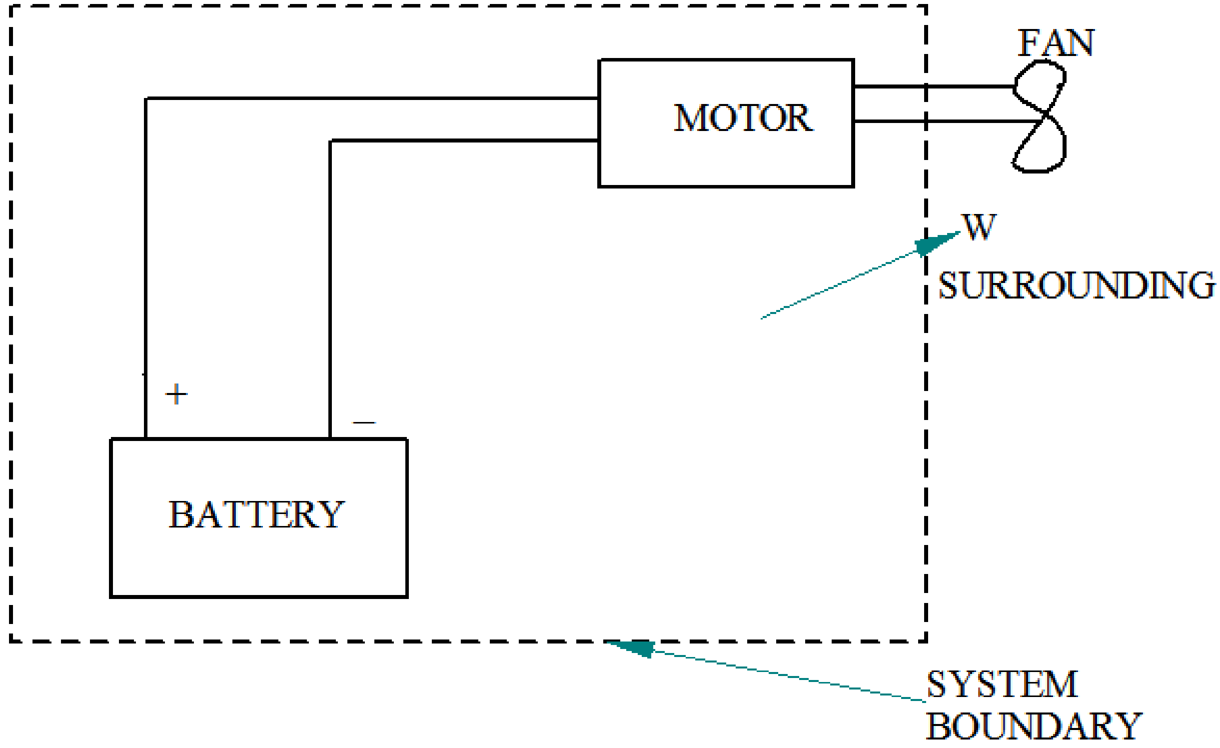
- Work is said to be done by a system , if the sole effect external to the system can be reduced to the raising of a weight.
- Work is said to be done by the system if the total effect outside the system is equivalent to the raising of weight
- The weight may not actually be raised, but the effect external to the system would be reduced to the raising of a weight
- The word ‘could be reduced to’ indicates that it is not necessary that weights should actually be raised in order to say that there is work interaction between the system and the surroundings.
- The system just sufficient to have an effect which is equivalent to the raising of weight.

<u>Sign Convention:</u>



- The work done by a system is considered as positive
- The work done on a system is considered negative

<u>Example of Work:</u>



- Consider a system consist of storage battery and motor
- Battery supplies electrical energy to motor which runs fan(surroundings)
- This clearly shows that the system(battery) has interaction with surroundings
- This the system is doing work on the surroundings(fan)
- But according to mechanics, there is no work done by the system since there is no force is acting through a distance

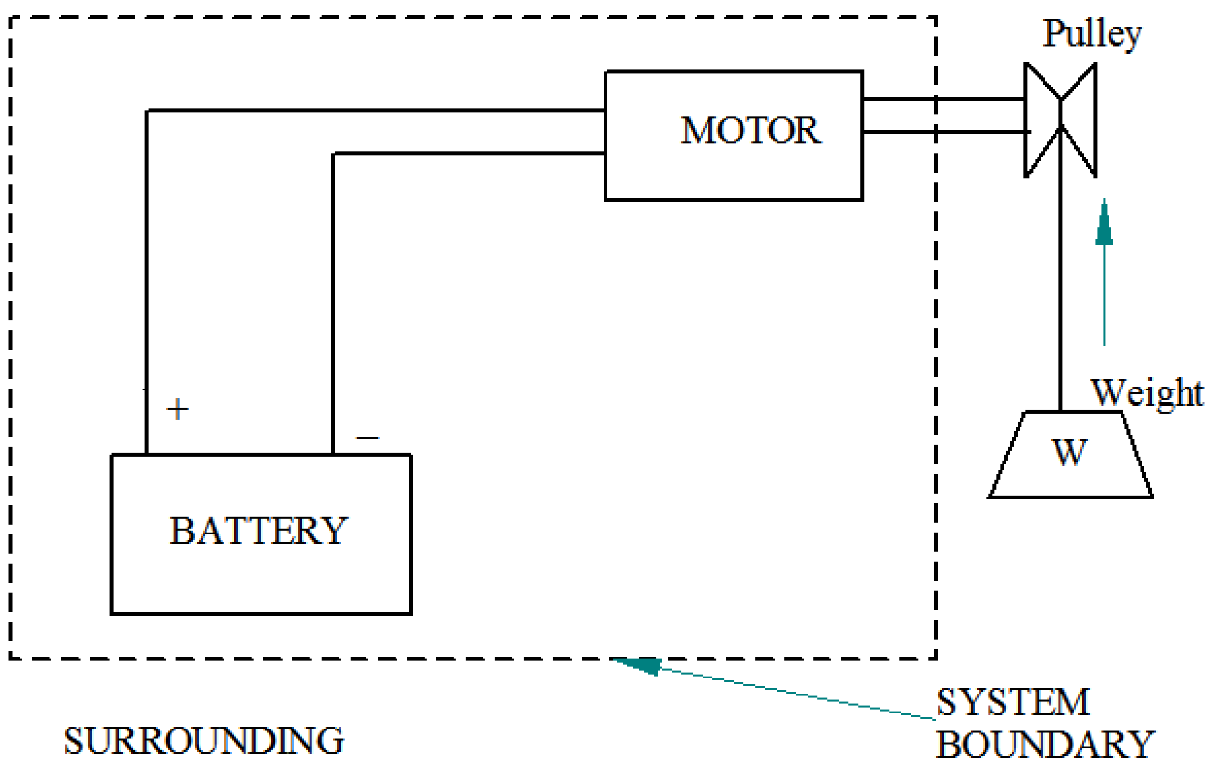


Fig: Thermodynamics definition of work

- Let the fan is replaced with a pulley and weight arrangement as shown in the fig
- According to thermodynamics definition , the work is said done by the system because the motor turns the pulley which raises the weight
- Thus, the sole effect external to the system can be reduced to raising of a weight
- Hence, thermodynamic work is done by the system

Expression for Work/Displacement Work:

- Consider a piston cylinder arrangement as given in the Figure 2.4.
- If the pressure of the fluid is greater than that of the surroundings, there will be an unbalanced force on the face of the piston.
- Hence, the piston will move towards right.

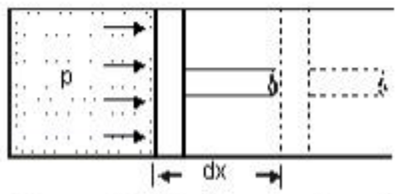


Figure 2.4 Displacement work

Let: F= Force acting on the piston

dX= Distance moved by the piston under the action of gas pressure

Force acting on the piston = Pressure×Area

W K T Work done =Force ×distance

Work done = P×A×dx

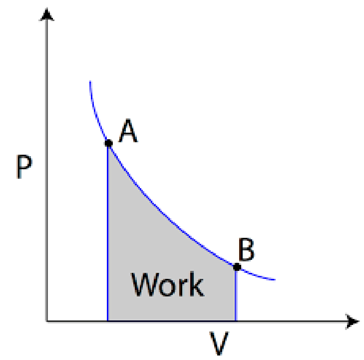
We know that area x length = volume A.dx=dV

Work done = P×dV

Where dV - change in volume.

- This work is known as displacement work or pdV work corresponding to the elemental displacement dx.
- To obtain the total work done in a process, this elemental work must be added from the initial state to the final state. Mathematically,
- That is

$$ {}_1W_2 = \int_1^2 pdV $$



- The, area under the P V curve representing the work done in the process

CONCEPT OF HEAT:

Thermodynamic Definition of Heat:

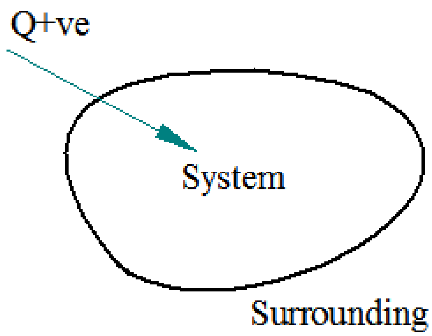
- It is the energy transfer from one system to another system by virtue(reason) of temperature difference
- It is represented by Q and it is expressed in joule(J) or kilo-joule(kJ 10^3J) MJ(10^6J)

Direction of Heat Transfer:

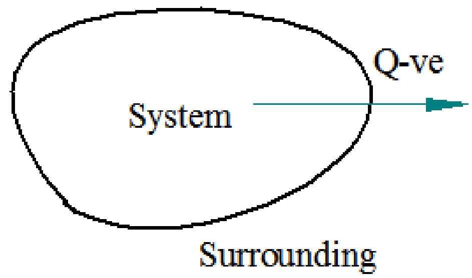
- Direction of heat transfer is from the high temperature to the lower temperature
- The driving force for heat transfer is temperature difference

Sign Convention:

- The symbol Q is used to represent heat transfer
- As a convention of sign, heat transferred to a system is considered as positive and heat transferred from a system is considered as negative



Q is Positive



Q is Negative

Relationship between Heat and Work

- Heat and work are related. Work can be completely converted into heat, but the reverse is not true: heat energy cannot be wholly transformed into work energy.
- For a closed system, the change in internal energy (ΔU) is related to heat (Q) and work (W) as follows: $\Delta U = Q + W$

EXPRESSION FOR HEAT TRANSFER:

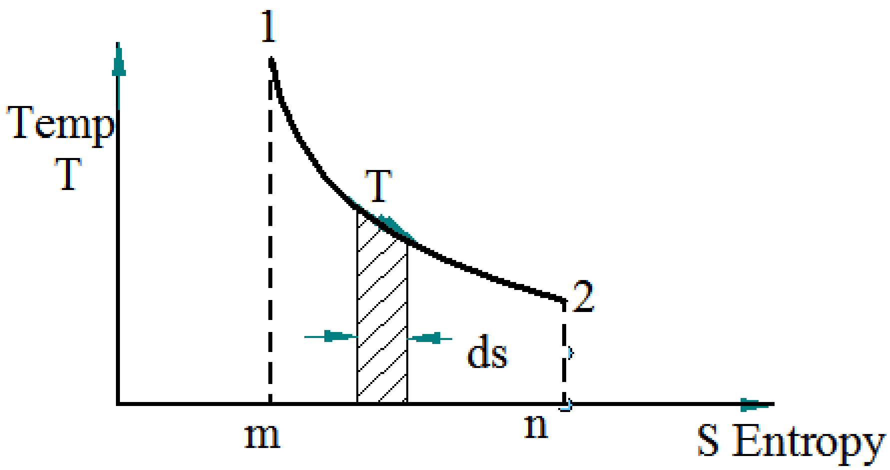


Fig: T-S Diagram

- Fig shows T-S diagram Entropy S is plotted along A axis and Temperature T is plotted along Y axis
- Heat transferred from state 1 to state 2 is calculated as follows

$$_1Q_2 = T.dS = \text{Area} = 1\text{-}2\text{-}n\text{-}m\text{-}1$$

COMPARISON BETWEEN WORK AND HEAT:

Similarities:

- Both are path functions
- Both are boundary phenomenon i.e., both are observed at the boundaries of the system as they cross them.
- Both represent transient phenomenon. The systems do not posses heat or work. These energy interactions occur only when a system undergoes change of state
- A system possesses energy, but not work or heat.
- Bothe are not properties of systems

Dissimilarities:

- Heat is energy interaction due to temperature difference only. Work is by reasons other than temperature difference.
- Heat is low grade energy whereas work is high grade energy.
- Heat transferred to a system is considered as positive and heat transferred from a system is considered as negative
- The work done by a system is considered as positive. The work done on a system is considered negative
- In a cyclic process, complete conversion of het to work is impossible but complete conversion of work to heat is possible

Note: Heat is the energy associated with the random motion of particles, while work is the energy of ordered motion in one direction

CONCEPT OF ENTROPY:

- Entropy is defined as the measure of disorder or randomness in a system.
- In general, greater disorder means greater entropy
- Adding heat increases the entropy (and disorder) of the system

  S (gases) > S (liquids) > S (solids)

Change in Entropy is defined as

$\Delta S = Q / T$

Where

Q is the energy transferred as heat to or from the system during the process,

T is the temperature of the system in kelvins

PRINCIPLE OF INCREASE OF ENTROPY:

The entropy of the universe increases because energy never flows uphill spontaneously.

Explanation:

Energy always flows downhill, and this causes an increase of entropy.

Consider the total energy q that is transferred from a hot region at temperature T1 to a cold region at temperature T2.

The entropy S_1 of the hot region is defined as

$$S_1 = \frac{q}{T_1}$$

The entropy S_2 of the cold region is

$$S_2 = \frac{q}{T_2}$$

Therefore, during the energy transfer, the change in entropy is

$$\Delta S = S_2 - S_1 = \frac{q}{T_2} - \frac{q}{T_1} = q\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Since $T_2 < T_1$, $\frac{1}{T_2} > \frac{1}{T_1}$, and ΔS is positive.

The total entropy of the system increases.

The total entropy of the universe is always increasing.

Note: In our solar system heat is generated everywhere including solar fusion and radiated heat from planets. dQ is therefore always a positive number. This is the reason that in our known universe, entropy s is always positive

THIRD LAW OF THERMODYNAMICS:

- The third law of thermodynamics states that **" The entropy of a perfect crystal at absolute zero temperature is exactly equal to zero."**
- **The Third law can be expressed as:**
- **LimT→0, S = 0**
- From the equation it clears that as the temperature of a system approaches absolute zero, its entropy becomes zero.

- That is The **third law of thermodynamics implies that the entropy of any solid compound or for crystalline substance is zero at absolute zero temperature**

Third Law of Thermodynamics Examples

- Consider H2O as an example to understand the concept of the third law of thermodynamics.
- Water exists in three different states:
- Gaseous state
- Liquid state
- Solid state

In Gaseous state

- In gaseous state, randomness is very high and hence the entropy is also high.

In Liquid state

- As the gas cools, it becomes liquid
- In liquid state, the randomness is reduced.
- This is because the movement between the molecules is reduced.
- Hence entropy of the molecules is reduced.

In Solid state

- When the water cools further, it becomes solid ice
- If the solid water reached absolute zero, all molecular motion would stop completely. At this point, the water would have no entropy (randomness) at all.

- In this state the moment between molecules is almost zero.
- This is because the molecules are packed very tightly in the solid state and hence the randomness is almost zero.

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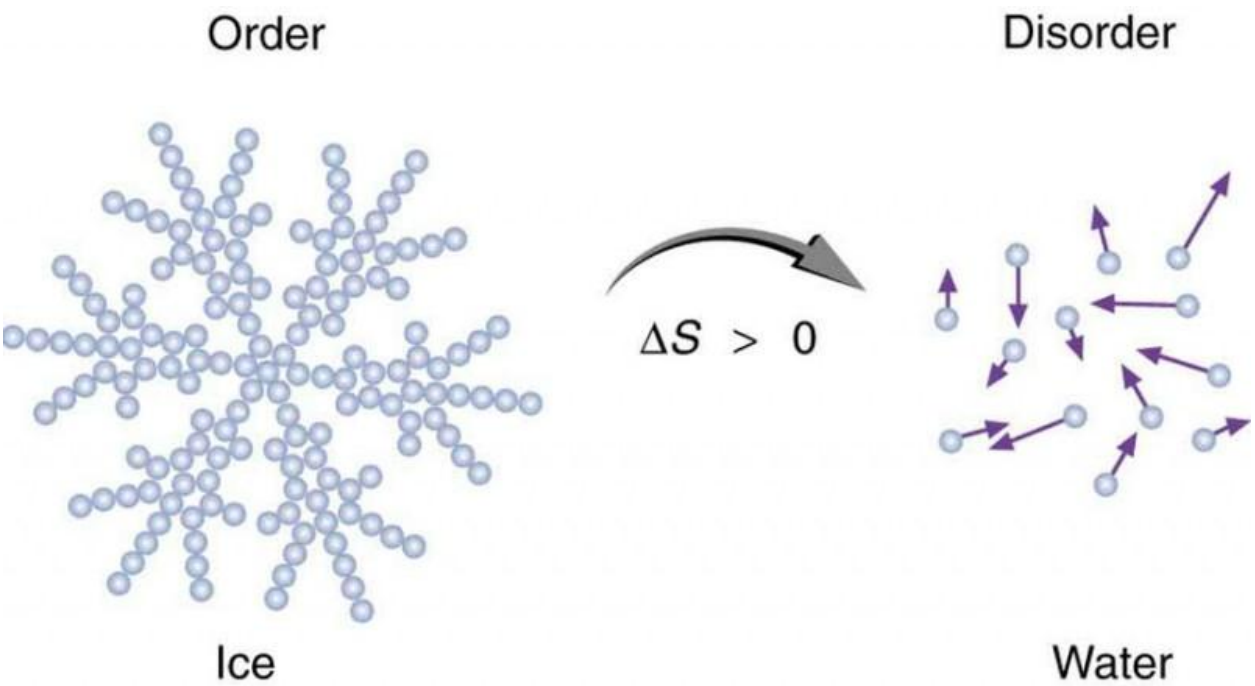

Fig: When ice melts, it becomes more disordered and less structured. The systematic arrangement of molecules in a crystal structure is replaced by a more random and less orderly movement of molecules without fixed locations or orientations. Its entropy increases because heat transfer occurs into it. Entropy is a measure of disorder

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MODULE-II: HYDRAULIC TURBINES, BOILERS AND PUMPS

Prime movers are the mechanical devices which convert the energy obtained by the natural resources into useful mechanical energy. Prime movers are classified into two types. They are

a. Thermal prime movers : Steam turbine, Gas turbine and Heat engine
b. Hydraulic prime movers : Water Turbines

WATER TURBINES:

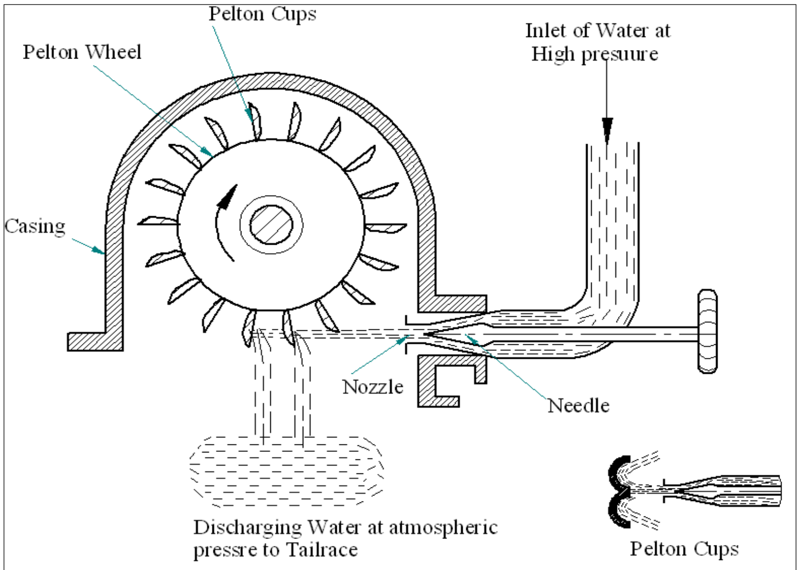
A Water turbine is defined as a prime mover in which the hydraulic energy of the water is transformed into mechanical energy in the form rotary motion.

Classification water turbines:

The water turbines are classified on the following criteria:

1. According to **hydraulic action** as
    a. Impulse turbine
    b. Reaction turbine
2. According to the **head of source of water** as
    a. High head turbine
    b. Medium head turbine
    c. Low head turbine
3. According to **direction of flow of water** as
    a. Tangential flow turbine
    b. Radial flow turbine
    c. Axial flow turbine
    d. Mixed flow turbine
4. According to the **position of shaft** as
    a. Horizontal shaft turbine
    b. Vertical shaft turbine
5. According to the **discharge of water** as
    a. High discharge turbine
    b. Low discharge turbine

Pelton Wheel:



2.10 Schematic representation of Pelton Turbine

Pelton wheel is a high head, tangential flow impulse turbine shown in fig 2.10. It consists of a rotor, on the periphery of which the double hemispherical buckets are evenly spaced and fitted. Water is transferred from a high head source through a penstock which is fitted with a nozzle. Through the nozzle, the water flows out as a high speed jet. The nozzle is provided with spear rod. A hand wheel is fitted to the spear rod so as to move the spear rod to and fro in order to get a desired size of jet of water. The jet of water at a high velocity impinges the buckets. As a result of impingement the runner rotates, supplying power to the shaft. After performing the work on the buckets the water discharges freely into the tail race.

Francis turbine:

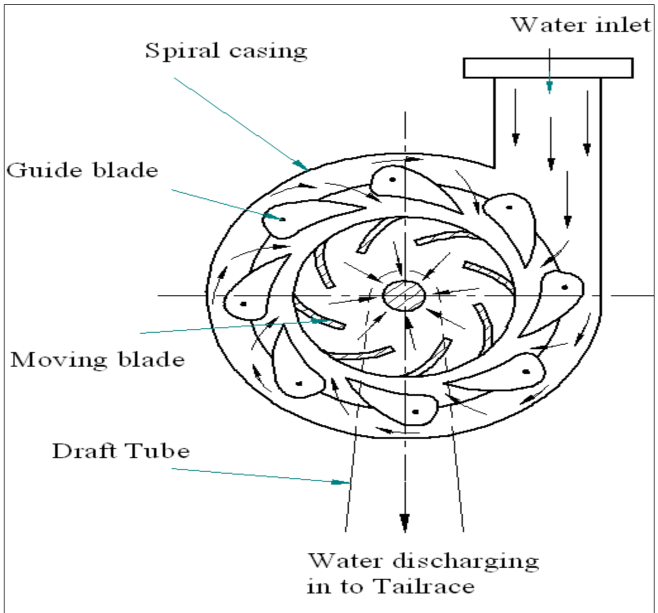
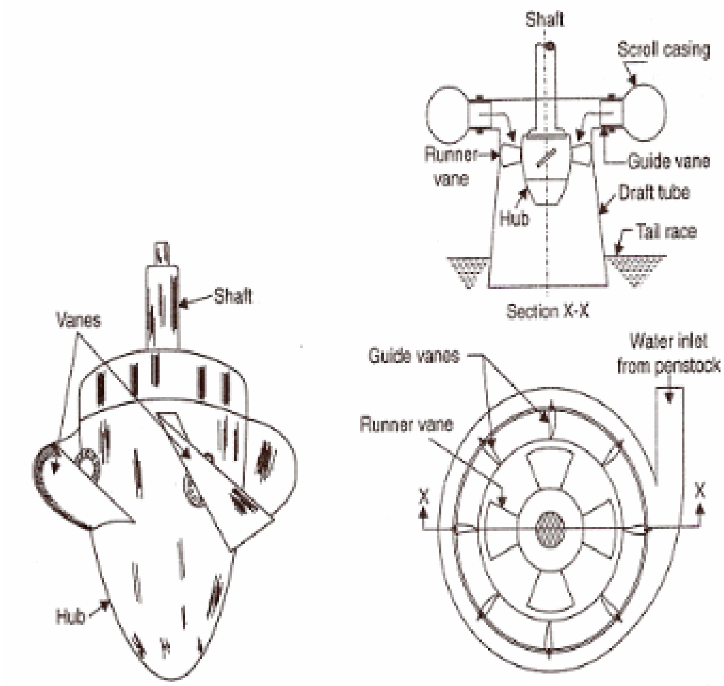


Fig2.11 Francis Turbine

Francis turbine shown in fig2.11 is a medium head, mixed flow reaction turbine. It consists of a spiral casing enclosing a number of stationary guide blades fixed all round the circumference of inner ring of moving vanes forming the runner which is keyed to the turbine shaft.

Water at high pressure enters through the inlet in the casing and flows radially inwards to the outer periphery of the runner through the guide blades. From the outer periphery of the runner the water flows inwards through the moving vanes and discharges at the centre of the runner at lower pressure. During its flow over the moving blades it imparts kinetic energy to the runner to set it into rotational motion. To enable the discharge of water at lower pressure, a diverging conical tube called draft tube is fitted at the centre of the runner. The other end of the draft tube is immersed in the discharging side of the water known as tail race.

Kaplan turbine:



Kaplan turbine shown in fig 2.12 is a low head, axial flow reaction turbine. It consists of a spiral casing, a ring of guide blades, a runner and a draft tube. The runner of a Kaplan turbine called boss or hub and it resembles the propeller of a ship. Hence the Kaplan is also sometimes called *propeller turbine*.

The water at high pressure enters the turbine casing through the inlet and flows over the guide blades. The water from the guide blades strikes the runner blades axially imparting the kinetic energy to set it into rotational motion. The specialty of this turbine is the runner vanes and their motion during the runner rotation. The specially designed vanes facilitate smooth flow of water to the tail race through a draft tube, while the runner is in motion.

Differences between impulse and reaction hydraulic turbines:

Sl No	Impulse turbine	Reaction turbine
1	The entire hydro energy is converted into kinetic energy	Only a part of the hydro energy is converted into kinetic energy and the rest remains as pressure head
2	Draft tube is not necessary	Draft tube is necessary
3	The water jet strikes a few buckets at a time with kinetic energy	The water is guided by the guide blades to flow over the blades with pressure energy
4	The pressure of the flowing water remains constant throughout	The pressure of the flowing water decreases after gliding over the blades
5	The runner need not run full	The runner should always run full and submerged in water
6	It is possible to regulate the flow without loss	It is not possible to regulate the flow without loss
7	Losses, if discharge is low	No losses even if the discharge is low

BOILERS:

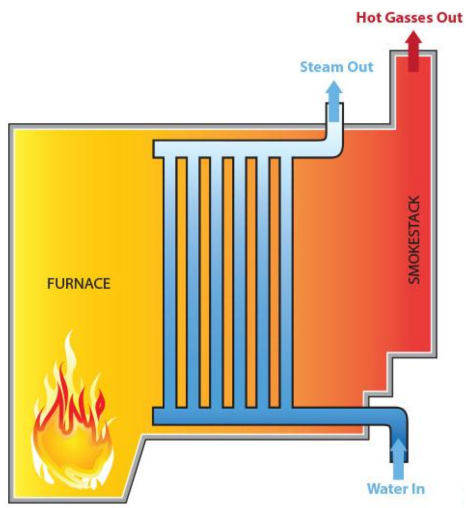
Boiler or steam generator is a device used to create steam by applying heat energy to water. Although the definitions are somewhat flexible, it can be said that older steam generators were commonly termed boilers and worked at low to medium pressure (6 to 2000kPa) but, at pressures above this, it is more usual to speak of a steam generator.

There are two general types of boilers: "fire-tube" and "water-tube".

Water-tube boilers:

A water tube boiler is such kind of boiler where the water is heated inside tubes and the hot gasses surround them. This is the basic definition of water tube boiler. Actually this boiler is just opposite of fire tube boiler where hot gasses are passed through tubes which are surrounded by water.

Examples: Bobcock & Wilcox boiler.



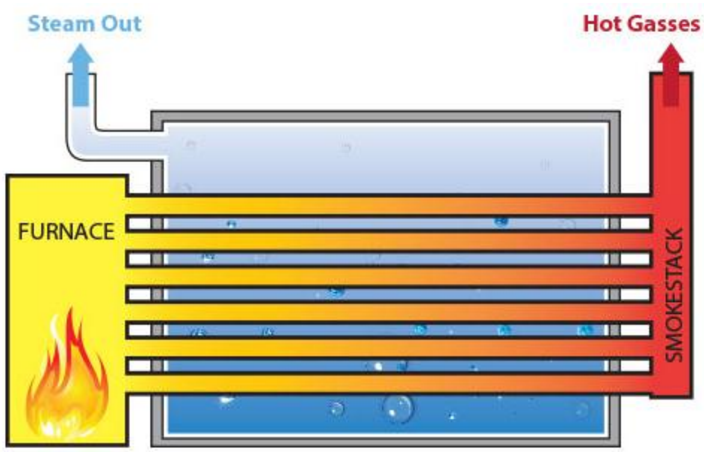
Advantages of Water Tube Boiler:

- Larger heating surface can be achieved by using more numbers of water tubes.
- Due to convectional flow, movement of water is much faster than that of fire tube boiler, hence rate of heat transfer is high which results into higher efficiency.
- Very high pressure in order of 140 kg/cm^2 can be obtained smoothly.

Fire-tube boilers:

A fire-tube boiler is a type of boiler in which hot gases from a fire pass through one or (many) more tubes running through a sealed container of water. The heat of the gases is transferred through the walls of the tubes by thermal conduction, heating the water and ultimately creating steam.

Examples: Vertical, Cochran, Lancashire and Locomotive boilers.



Lancashire boiler:

Lancashire boiler is a stationary, fire tube boiler which is constructed for normal working pressure up to 15 bar and 8500 kg of steam per hour. This boiler is widely used in sugar mills and chemical industries.

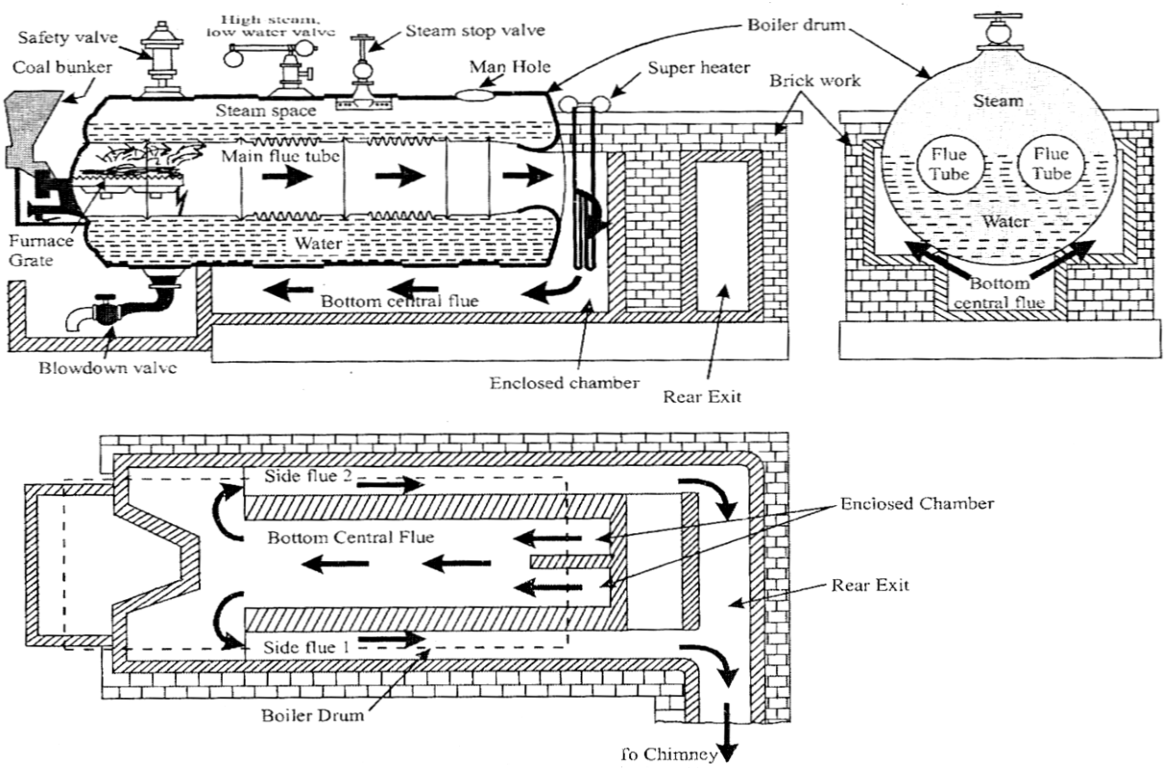


Figure 1.6

Construction:

The cylindrical shell is placed horizontally over brickwork and partly (3/4th) filled with water. The water level inside the boiler should be above the furnace tube which is constructed inside the drum as in figure 1.6

Two large tubes called furnace or flue tubes extend throughout the length of boiler drum. In each flue tubes two furnace greats are provided inside for burning fuel with ash pit at their rear end. The diameter of these flue tubes are made about 0.3 to 04 times of the boiler, in order to get in grates of sufficient area for burning. The brick work setting provides enclosed chamber for each of the flue tubes at the rear end of the boiler shell, which in turn connected to side channels

1 & 2 at their front end. The two side channels are connected to their rear end to a common rear passage which is connected to chimney.

Working:

The fuel is charged on grates and burned with a large quantity of air to produce hot gases. Initially the **first run** of hot gas passes inside the drum and from front end to rear end. During this heat transfer takes place from hot gas to water along the walls of the flue tubes.The hot gasses then emerge to rear enclosed chamber in the rear end, then pass downwards and unite. Now in **second run** hot gases pass from bottom portion of the boiler shell to bottom central channel. After second run hot gases divide at the front end of boiler shell and enters side channel 1 & 2 for third run. During the third run hot gasses pass through side channels to rear end of boiler and make their exit to chimney. During **third run** heat transfer takes place between hot gas and water through a portion of boiler shell exposed to side channel. Finally, steam accumulates in the boiler shell and can be taken out through stop valve.The boiler is mounted with essential mountings and accessories like stop valve, safety valve, blow off valve, pressure gauge, water gauge etc with **super heater** if required.

Babcock and Wilcox boiler:

Babcock and Wilcox boiler is a stationary, water tube, natural circulation boiler. It has a capacity to produce steam up to 40 bar and 4000 kg / hour. This type of boiler is used in thermal power plants, etc.

Construction and working:

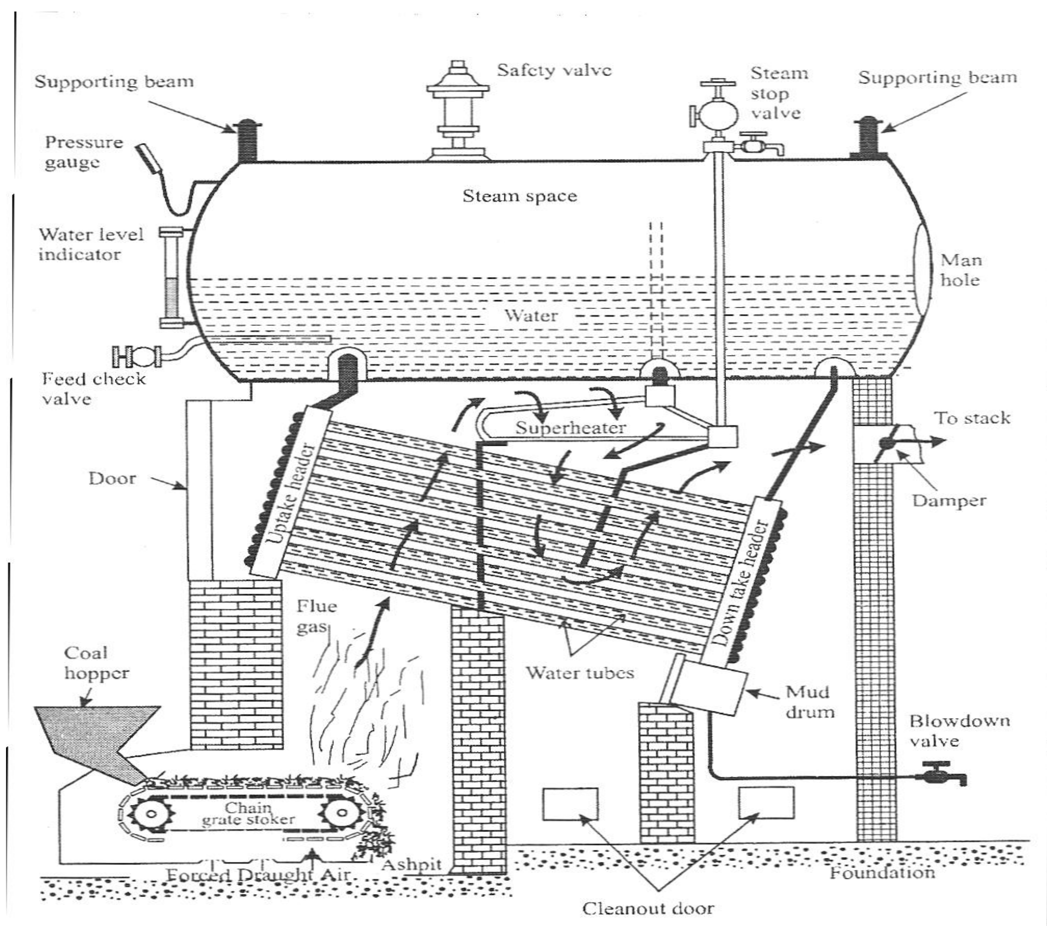
This boiler mainly consists of,

- Water tubes
- Water and steam drum
- Chain grate stoker
- Super heater
- Mud box

Water tubes: Water tubes are placed between the furnace at an inclined position which connect uptake and down take. The drum is connected at the front end to uptake and at backend to down take. The fire brick baffles make the hot gases to move in the upward direction then downward and again upward before leaving through chimney.

Water and steam drum: A horizontal drum is placed above the water tubes and is half filled with water and steam remains on other half. The portion of water tubes which is just above the furnace is heated more compared to others, the water density increases and rises to drum through the uptake where steam particles separate from water and collect over water surface. The water from drum comes down through down take into water tubes and move up again to drum through uptake, by this circulation of become continues.

Chain grate stoker: - The high capacity boilers are generally provided with chain grate stoker. It has slowly moving endless chain of grate bars and coal is feed at the front end of grate and burnt while moving on grate in furnace and residual ash will falls at other end.



Super heater: - Boilers are fitted with a set of super heater tubes which is placed just under the drum and above water tubes. Steam is taken from steam space of boiler through which tubes and super heated by receiving additional amount of heat by exiting hot gases. Super heated steam finally comes out of stop valve mounted over drum.

Boiler Mountings and Accessories:

Boiler Mountings:

The fittings and devices required for the steam boilers for their safe performance are called **Boiler Mountings**. Water level indicator and pressure gauge are the examples for boiler mountings.

(i) **Water level indicator** or **Water gauge**: Its function is to indicate the level of water inside the boiler shell.

(ii) **Safety valves**: Their function is to maintain safe pressure inside the boiler.

(iii) **Fusible plug**: Its function is to protect the boiler from explosion due to overheating caused on account of low water level.

(iv) **Pressure gauge**: Its function is to indicate the pressure of the steam inside the boiler.

(v) **Steam Stop valve** or **Junction valve**: Its function is to regulate the flow of steam from boiler to the engine whenever necessary and to shut-off the steam flow when not required.

Boiler Accessories:

The auxiliary plants required for the steam boilers to increase their efficiency are called **Boiler Accessories**. Super heater and air preheater are the examples for boiler accessories.

(i) **Super heater:** Its function is to absorb the heat from the hot flue gases and superheat the saturated steam without changing its pressure.

(ii) **Air Preheater:** Its function is to transfer heat from the flue gases to the air fed to the furnace for combustion purpose.

(iii) **Economizer:** Its function is to heat the feed water using exhaust flue gases.

(iv) **Feed water heater:** The function of feed water heater is to increase the temperature of the feed water before it enters the boiler.

(v) **Steam trap:** The function of steam trap is to automatically drain away the condensed steam from pipes, steam jackets and steam separators without allowing any steam to escape.

HYDRAULIC PUMPS:

- Pump is defined as a mechanical device that rotates or reciprocates to move fluid from one place to another.
- The function of a pump is to convert mechanical energy into hydraulic energy.
- Mechanical energy is delivered to the pump using an electric motor.
- When a hydraulic pump operates, it performs two functions.
- First, its mechanical action creates a vacuum at the pump inlet which allows atmospheric pressure to force liquid from the reservoir into the inlet line to the pump.
- Second, its mechanical action delivers this liquid to the pump outlet and forces it into the hydraulic system.

Need of a Pump

- Used to pump a liquid from lower pressure area to a High pressure area.
- To increase Flow rate.

Classification of Hydraluic Pumps

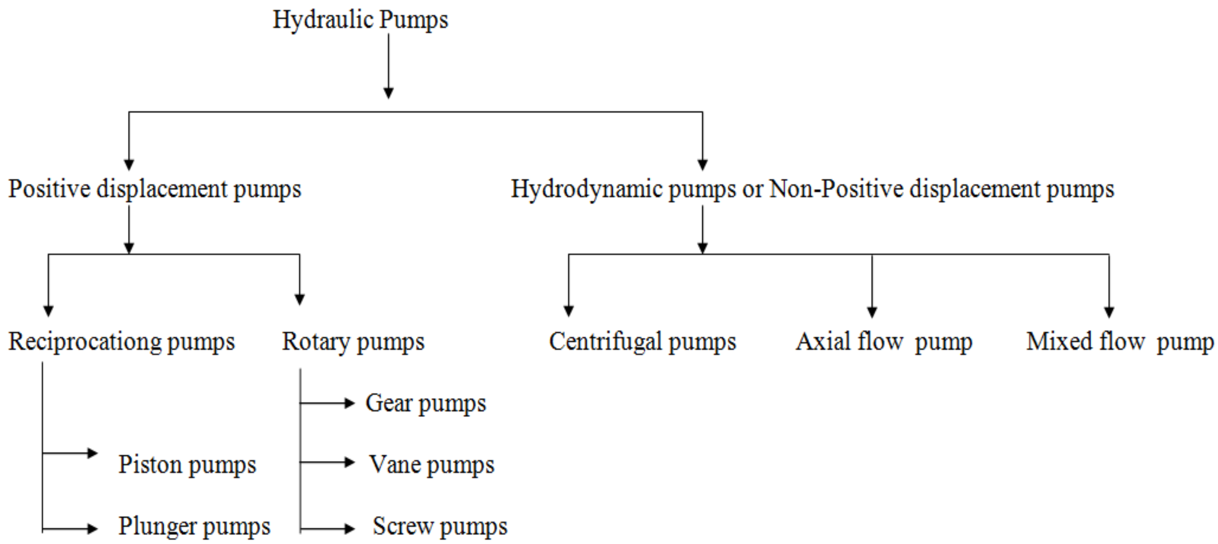


Fig: Classification of Hydraulic Pumps

1. **Positive Displacement pumps:**

- Positive displacement pumps supplies a fixed amount of fluid by using a reciprocating piston, or by rotating members
- Positive Displacement pumps apply pressure to the liquid by using a reciprocating piston, or by rotating members

Different Types of positive Displacement Pumps:

a. Reciprocating pump
b. Rotary pump

- Reciprocating pumps move the fluid using reciprocating pistons or plungers
- Rotary pumps move the fluid by using rotating elements like gears, screws, vanes or cam

2. **Hydrodynamic Pumps Or Non Positive displacement pumps:**

- These pumps are also called as Roto-dynamic pumps or Non positive displacement pumps

- In theses pumps dynamic force or centrifugal force causes the fluid movement from one place to another.

Different Types of Hydrodynamic Pumps:

a. Centrifugal pumps
b. Axial flow pumps
c. Mixed flow pumps

Let us discuss the working of Reciprocating pump and centrifugal pump

1. **RECIPROCATING PUMP:**

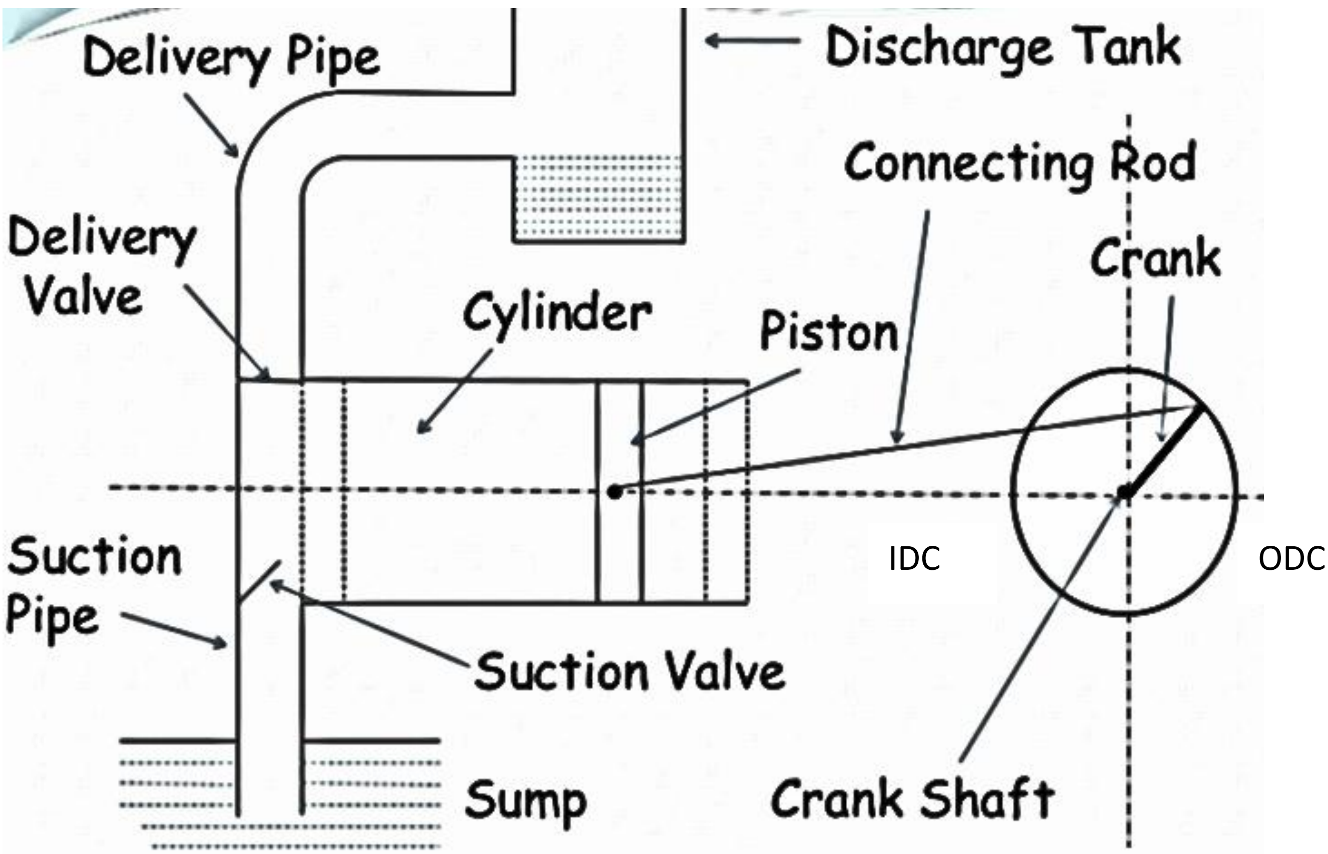


Fig: Reciprocating Pump

RECIPROCATING PUMP:

A pump which conveys the water from one place to another place with the help of linear motion of piston or plunger

Components of Reciprocating Pump

- Connecting Rod
- Piston
- Cylinder
- Suction Pipe
- Suction Valve
- Delivery Pipe
- Delivery Valve
- Sump

CONSTRUCTION OF RECIPROCATING PUMP:

Crank:

- It is mounted on the crank shaft.
- It is driven by either I.C. Engine or electric motor.

Connecting Rod:

- It connects the piston and the crank.
- It converts the rotary motion of crank into reciprocating motion of piston.

Piston

- It reciprocates inside the cylinder.
- It creates pressure difference inside the cylinder.

Suction Pipe:

- It conveys the water from sump to the cylinder

Delivery Pipe:

- It conveys the water from cylinder to the discharge tank.

Suction Valve

- Suction valve is non-return valve which means only one directional flow is possible in this type of valve.
- This is placed between suction pipe inlet and cylinder.
- During suction of liquid it is opened and during discharge it is closed.

Delivery Valve

- Delivery valve also non-return valve placed between cylinder and delivery pipe outlet.
- It is in closed position during suction and in opened position during discharging of liquid.

Sump:

- It is the reservoir of liquid from which water will be pumped.

<u>WORKING OF RECIPROCATING PUMP:</u>

1. **SUCTION STROKE:**

- When the crank rotates from I.D.C to O.D.C in clockwise direction, the piston moves from left to right side
- Hence vacuum is created inside the cylinder
- Because of vacuum, liquid will come from sump to the cylinder through suction valve
- When crank reaches O.D.C., the piston is on right most position and the cylinder is full of liquid.

2. **DELIVERY STROKE:**

- When the crank rotates from O.D.C to I.D.C in clockwise direction, the piston moves from right to left side
- Hence piston exerts pressure on the liquid.
- The pressurized water is then discharged to delivery tank through discharge pipe
- At the end of delivery stroke, the crank comes to I.D.C. Now the pump has completed one cycle.
- The same cycle repeated as the crank rotates

USES(APPLICATIONS) OF RECIPROCATING PUMP

- Reciprocating pump is mainly used for
- Oil drilling operations
- Pneumatic pressure systems
- Light oil pumping
- Feeding small boilers condensate return

2. CENTRIFUGAL PUMP:

Centrifugal pump: Centrifugal pump is a hydraulic machine which converts mechanical energy into hydraulic energy (i.e. pressure energy) by the use of centrifugal force

Main Parts of Centrifugal Pump:

The various main parts of a centrifugal pump are:

a. Impeller
b. Casing
c. Suction pipe with a foot valve and strainer
d. Delivery pipe

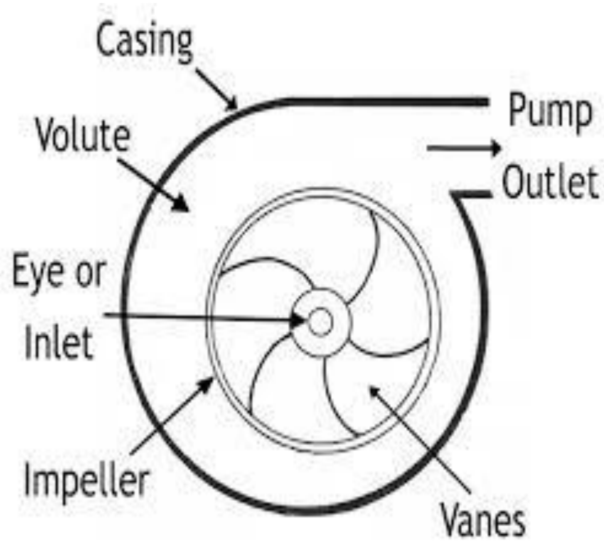


Fig: Centrifugal Pump

a. Impeller

- It is the heart of the pump. It consists of a number of curved blades
- It is fitted on a shaft. The shaft is connected to an external electric motor.
- The motor rotates the impeller with the help of the shaft

b. Casing

- The airtight chamber surrounding impeller is called casing.
- The area of the casing gradually increases towards the pump outlet
- Because of this design of Casing, the kinetic energy of the fluid is converted into pressure energy according to Bernoulli's Principal

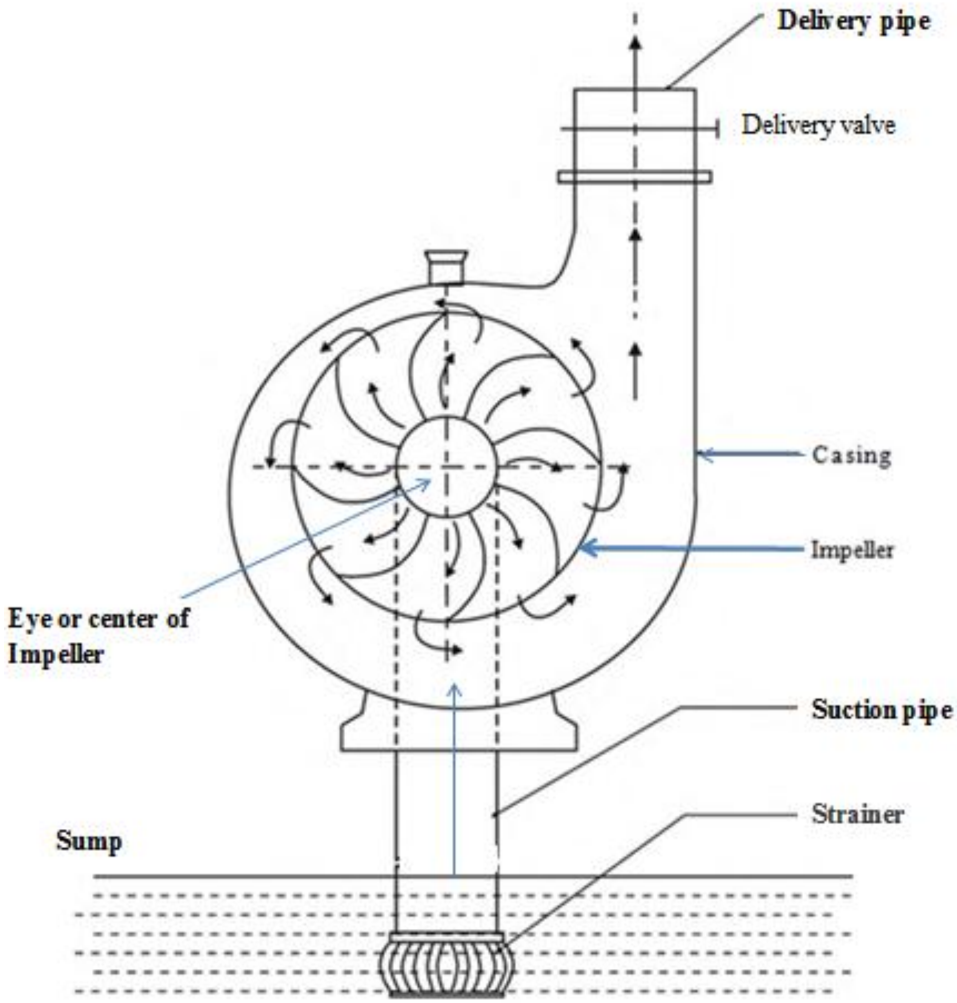
c. Suction Pipe:

- It conveys the water from sump to the pump

d. Delivery Pipe:

- It conveys the water from pump to the discharge tank or desired location

Working of Centrifugal pump:



Centrifugal Pump

Working of Centrifugal Pump:

- When the electric motor starts rotating, the impeller of pump also rotates
- The rotation of the impeller creates suction at the suction pipe.
- Due to suction created, water from sump enters to the pump through the centre, or eye of the impeller
- The impeller rotates at very high speedinside the casing
- Due to rotation of impeller, centrifugal force is developed

- This centrifugal-force, accelerates(increases velocity) the water radially outwards into pump casing
- The area of the casing gradually increases towards the pump outlet (As area increases, velocity decreases and pressure increases)
- Hence the velocity of the water keeps on decreasing and the pressure increases in the casing according to Bernoulli's Principal
- Now high pressure water goes to its desired location through delivery pipe.

Application of Centrifugal Pump

- The centrifugal pump is used in almost every field to raise the liquid from low level to high level.
- They are mostly used at home for filling water tanks, almost in every industry such as chemical, automobile, marine, manufacturing, for irrigation etc**.**

PRIMING OF PUMP

- Priming the pump means removing all the trapped air from the suction line of the pump and filling the pump with water before starting
- If air is not removed from the suction line of pump, then a small negative pressure is created at the suction pipe and it cannot suck the water from the water sump.
- So it is advised to fill the pump with water before starting it
- This is usually achieved by filling water through a connection which is close to the discharge side manually or through an automated system.
- After this the pump can be operated normally.

PUMP CAVITATION:

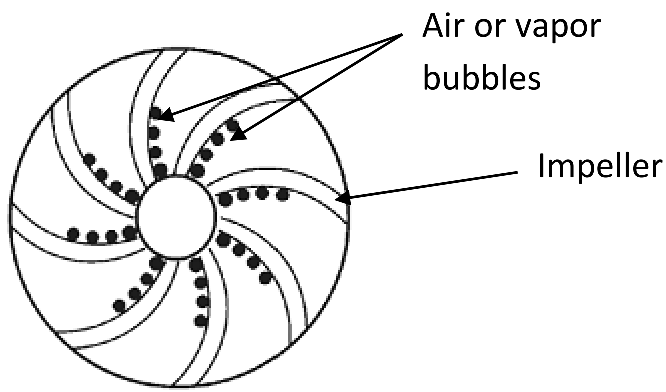


Fig: Pump cavitation

- Cavitation is the formation of air bubbles or vapor bubbles in water
- When the pressure of water at suction side is too low(less than vapor pressure), some of the water will vaporize, forming vapor bubbles in the water
- The vapor bubblesenter into the pump.
- As the pressure in the pump increases, the air bubbles(vapor bubbles) collapses or bursts and it creates a high energy shock wave inside the pump
- The shockwaves travel hit the impeller and causing mechanical damage, noise and vibration which can ultimately lead to pump failure
- Cavitation is a common problem for centrifugal pumps
- If you hear strange noises coming from thepump, there is a chance cavitation

Pump Cavitation can cause following problems:

- Failure of pump housing
- Destruction of impeller
- Excessive vibration
- Higher than necessary power consumption
- Fluctuation in discharge pressure
- Fluctuations in flow rate of water

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MODULE-III:REFRIGERATION AND AIR CONDITIONING AND IC ENGINES

REFRIGERATION:

Refrigeration may be defined as a method of reducing the temperature of a system below that of the surroundings & maintaining at that lower temperature by continuously abstracting the heat from it. The device is used to produce the refrigeration effect is known as refrigerator.

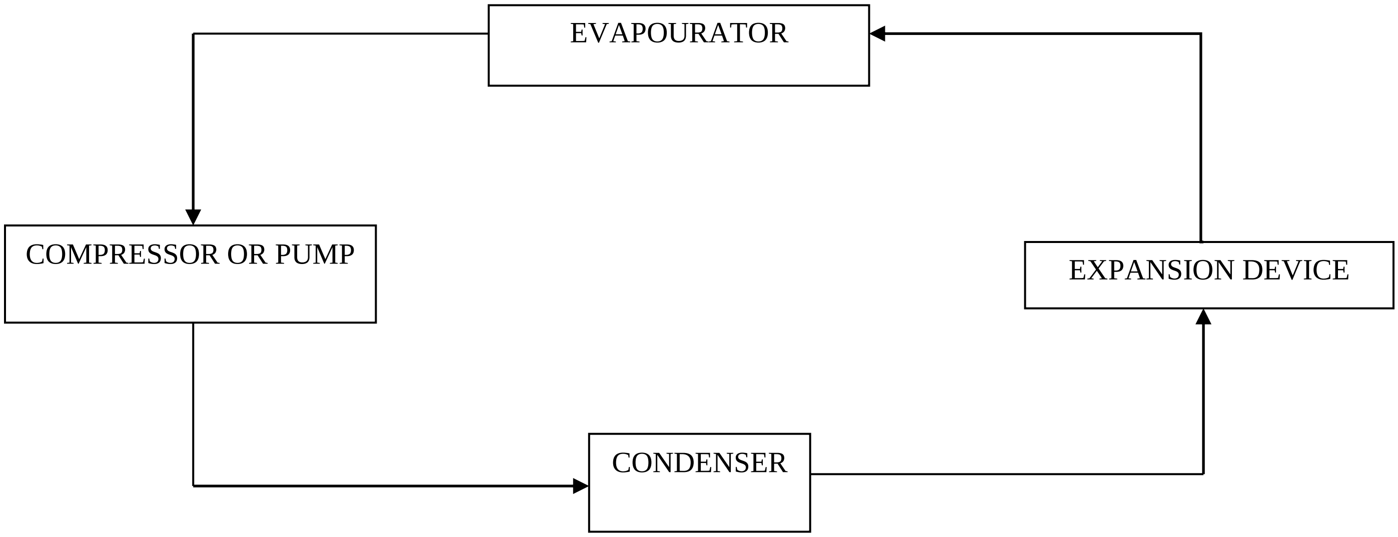
Concepts of refrigeration:

1. Heat is always transferring from body at a high temperature region to the body at a low temperature region.
2. Heat transfer is possible from a lower temperature system to higher temperature surroundings by some external means as per the 2^{nd} law of thermodynamics.
3. The working fluid changes from vapour phase to liquid phase after heat rejection and from liquid phase to vapour phase after heat absorption.
4. The change of phase of the working fluid from liquid phase to vapour phase results in cooling effect.

Principle of Refrigeration:

It is based on 2^{nd} law of thermo dynamics. As per Clausius Statement, heat cannot flow from a body at a lower temperature to a body at a higher temperature unless assisted by some external means. In refrigeration, heat is continuously removed from the system at a lower temperature and same heat is rejected to the surroundings at a higher temperature. This is done by using an external source like a compressor (or) a pump. Heat from a system at lower temperature is abstracted by using a working fluid/medium called refrigerant. The refrigerant rejects the heat to the high temperature surroundings. The refrigerant may be Freon, Ammonia, CO_2, SO_2, hydrocarbon refrigerant, methylene chloride, Ethylene, Ethane, Air, and Water.

Parts of a Refrigerator:



1. Compressor (or) Pump:

To compress and circulate the low temperature and low pressure working fluid into high temperature and high-pressure vapour. They are power absorbing mechanical devices and need input power. An electrical motor supplies power to these drives.

2. Condenser:

The high pressure, high temperature refrigerant entering from the compressor rejects its heat to the surrounding atmosphere in the condenser. It consists of a series of coils in the form of U – tubes. The latent heat of the refrigerant is given to the surrounding atmosphere, which results in change of phase of the refrigerant.

3. Expansion Value:

The high pressure and temperature liquid refrigerant expands in the expansion valve to low pressure & low temperature two-phase mixture. The temperature of the refrigerant drops in the expansion valve due to partial evaporation.

4. Evaporator:

It has cooling coils arranges in form of U – tubes. The function of the evaporator is to reduce the temperature of the refrigerator cabinet. The low temperature two phase mixture of refrigerant passing through the evaporator coils absorbs heat from the cabinet and changes into vapour phase.

Refrigeration Definitions:

1. Refrigeration Effect:

It is the amount of cooling produced by a refrigeration system.

It is defined as the rate at which the heat is removed from the space (or system) to be cooled in a cycle. It is also called *'capacity of refrigerator'*. It is expressed in ***kW or kJ/s.***

2. Ton of Refrigeration or Units of Refrigeration:

The unit of refrigeration is expressed in terms of 'ton of refrigeration'.

It is defined as the amount of heat absorbed in order to produce one ton of ice in 24 hours from water, whose initial temperature is 0°c.

In S.I. units the value of 1Ton of refrigeration =**210 kJ/min or 3.5 kW**

3. Ice Making Capacity:

Ice making capacity is the ability of a refrigerating system to make ice. In other words, it is the capacity of a refrigerating system to remove heat from water to make ice.

4. Co-efficient of Performance:

The performance of a refrigerator is measured by a factor known as Co-efficient Of Performance (COP). It is defined as the ratio or the amount of heat removed from a given space to the work supplied to achieve the heat removal.

$$COP = \frac{Heat\ extracted\ (absorbed)\ from\ the\ refrigerator}{Work\ supplied\ to\ the\ system}$$

or

$$COP = \frac{Heat\ absorbed}{Heat\ rejected - Heat\ absorbed} = \frac{Q}{W} = \frac{T_2}{T_1 - T_2}$$

Where, Q = heat removed in kJ/s and W = work supplied or work done in kJ/s

5. Relative COP:

It is defined as the ratio of actual COP to the theoretical COP of a refrigerator.

$$\text{Relative COP} = \frac{\text{Actual COP}}{\text{Theoretical COP}}$$

Properties of a good refrigerant:

1. It should have very low boiling point and very low freezing point.
2. It should have high enthalpy of evaporation and low specific volume.
3. It should have high latent heat of evaporation so that minimum amount of refrigerant can accomplish the work.
4. It should have low saturation pressure.
5. It should have good thermal conductivity for rapid heat transfer.
6. It should be non-toxic.
7. It should be non-inflammable.
8. It should be non-corrosive to the working parts.
9. It should be economical for both in initial cost and maintenance cost.
10. It should be chemically stable for temperature variations and neutral for lubricating oil.

List of Commonly Used Refrigerants:

The following represent some of the commonly used refrigerant**.**

No.	Refrigerant	Properties
1	**Ammonia (NH3)**	▪ It is the most widely used refrigerant in vapour absorption system. It has a normal boiling point temperature of -33.3°C. ▪ It is highly inflammable, irritating and corrosive. Hence, these food-destroying properties make it unsuitable for domestic refrigerator. ▪ But this refrigerant is used where its toxic nature is not considered seriously. It is used in large industries for cold storage, ice manufacturing plant packaging plants etc.
2	**Carbon dioxide (CO2)**	▪ It is non-toxic and non-flammable. ▪ Its normal boiling point is -77.6°C ▪ Due to its low specific volume the plant size is compact. ▪ It is used in ships where space consideration is more important.

3	**Sulphur dioxide ($S0_2$)**	▪ It is Colourless, suffocating and possesses irritating odour. ▪ It has a high boiling point of-10°C. ▪ This refrigerant was used in house hold refrigerator in olden days.
4	**Freon-12**	▪ It is non-flammable, non-explosive, non corrosive and odourless. ▪ Hence it is a widely accepted refrigerant for various applications. ▪ It has a boiling point of -29.8°C. ▪ It is used in small capacity equipment such as domestic refrigerators, water coolers, air-conditioner etc.
5	**Freon-22**	▪ It has a normal boiling point of -40.8°C that is about 10° less than that of Freon-l2. ▪ It is therefore, a comparatively high-pressure refrigerant. ▪ Freon-22 is employed for air-conditioners in large capacity plants, food freezing, freeze drying etc.

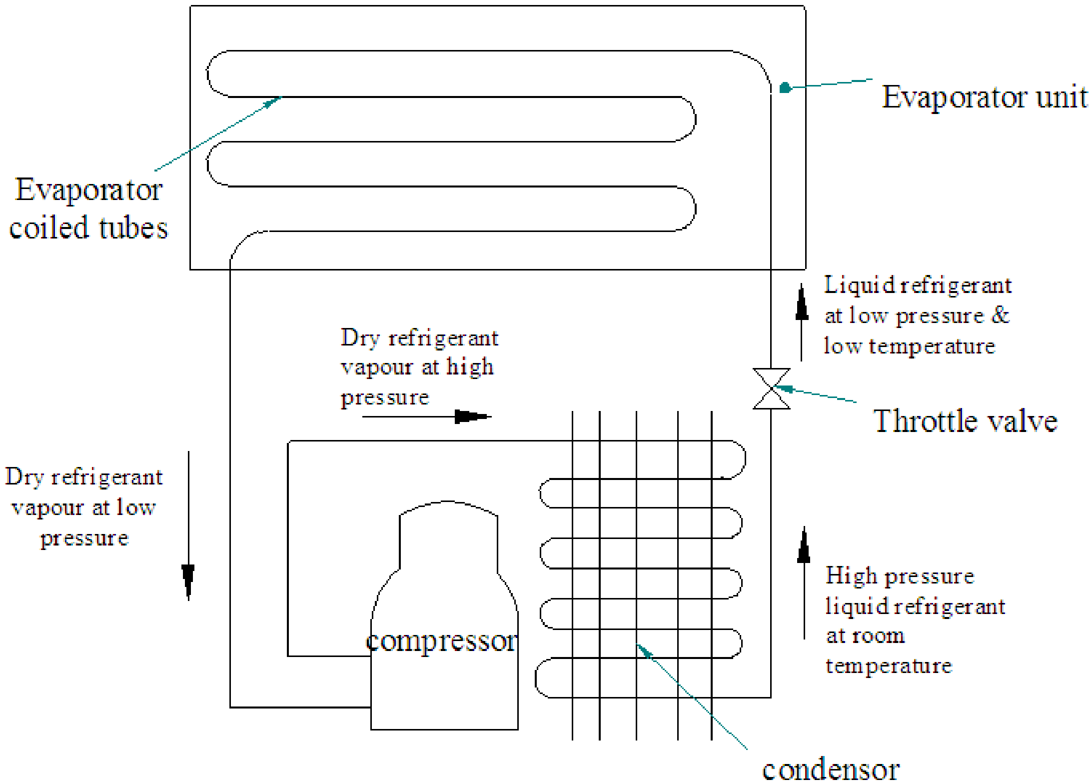
Refrigeration System:

There are three types of Mechanical Refrigerator systems. They are

1. Vapour Compression Refrigerator.
2. Vapour Absorption Refrigerator.

1. Vapour Compression Refrigerator:

➢ In Vapour Compression Refrigerator vapour refrigerant (Freon-12) is compressed as shown in the following figure.



From the fig, the arrangement consist of

1. *Evaporator*
2. *Compressor*
3. *Condenser and*
4. *An Expansion valve***.**

- The liquid refrigerant in the *evaporator* absorbs the latent heat from the system (cabinet/refrigerated space) which is to be cooled and undergoes a change of phase from liquid to vapour.
- The vapour refrigerant at low temperature and pressure is drawn into the *compressor* where it is compressed to a high pressure and temperature.
- The compressed vapour refrigerant then enters the *condenser*, where it is cooled and condensed to liquid phase by giving its latent heat to the surrounding medium (atmosphere or water).
- The high-pressure liquid refrigerant leaves the condenser and passes through the *expansion valve* where it is expanded to low pressure and temperature, which will be less than that of the temperature & pressure of the refrigerated space.

- The low pressure-low temperature refrigerant again enters the *evaporator* where it absorbs the latent heat from the system and evaporates.
- The low pressure-low temperature vapour is drawn into the compressor and the cycle repeats.
- Thus heat is continuously extracted from the system, thereby keeping the system at the required lower temperature.

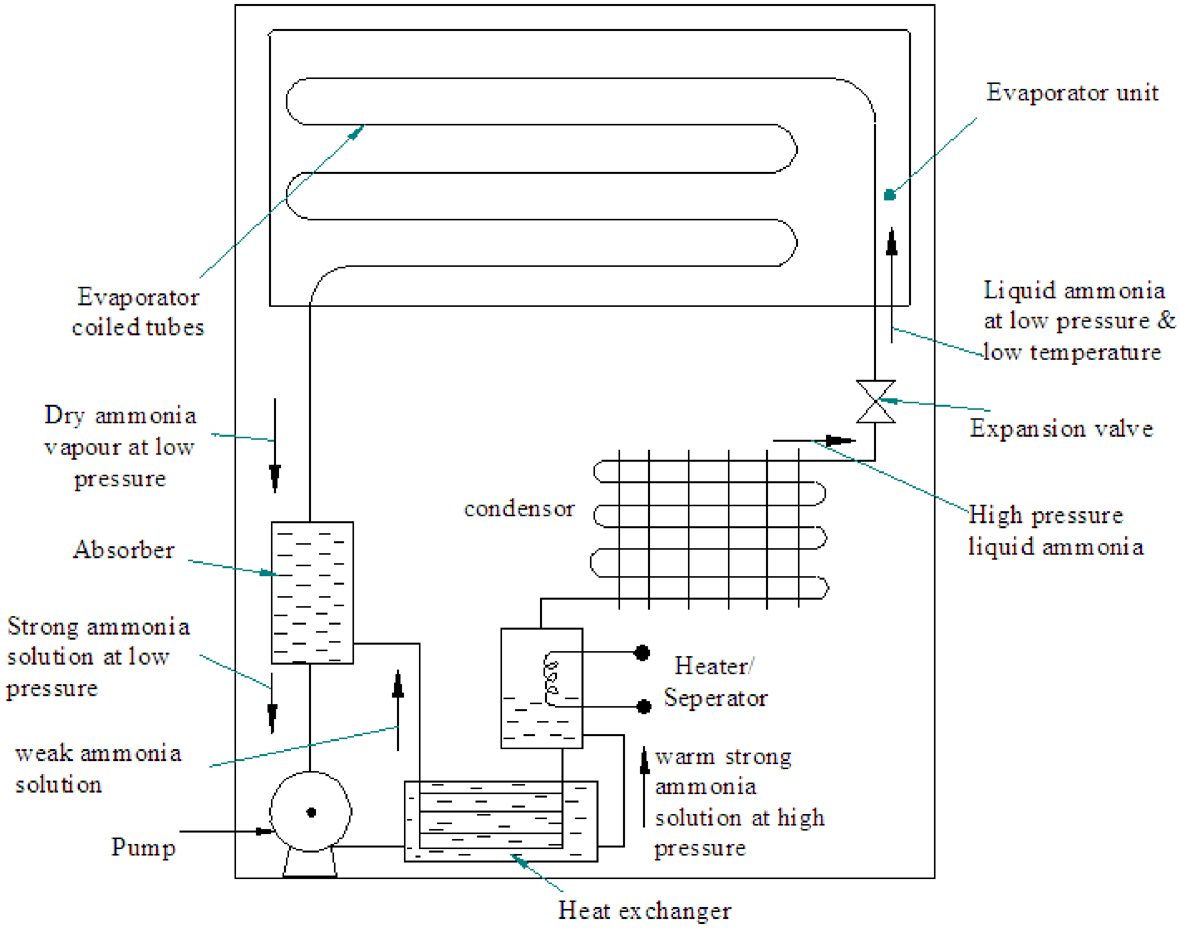
2. Vapour Absorption Refrigerator:

The compressor in the vapour compression refrigeration system consumes lot of energy. To avoid this, the vapour absorption refrigeration system has been developed. In this system, the compression process of vapour compression cycle is eliminated. Instead of that the three following process are introduced.

•Ammonia vapour is absorbed into water

•This mixture is pumped into a high pressure cycle

•This solution is heated to produce ammonia vapour.



The vapour absorption refrigeration system consists of Evaporator, Compressor, Condenser, an Expansion valve, Absorber, Circulating pump, Heat exchanger &Heater-Separator

- The liquid refrigerant (ammonia) in the evaporator absorbs the latent heat from the system (cabinet/refrigerated space) that is to be cooled and it undergoes a change of phase form liquid to vapour. The low pressure vapour refrigerant is then passed to the absorber.
- In the absorber, the low pressure vapour refrigerant (NH_3) is dissolved in the weak ammonia solution producing strong ammonia solution at low pressure.
- The strong ammonia solution is then pumped to a generator through the heat exchanger at high pressure.
- While passing through the heat exchanger, the strong ammonia solution is warmed up by the hot weak ammonia solution flowing from the generator to the absorber.

- This warm strong ammonia solution is heated by an external source in the generator, due to this heating, the weak ammonia solution in turn flows back to the heat exchanger & the high pressure ammonia vapour from the heater-separator passes to a condenser, where it is condensed to liquid phase.
- The high pressure liquid ammonia then passes through the expansion valve where it is expanded to low pressure and temperature.
- The low pressure-low temperature ammonia liquid again enters the evaporator where it absorbs the heat from the system and the cycle repeats.

Comparison between Vapour compression system & Vapour absorption system:

The following table illustrates comparison between Vapour compression system & Vapour absorption system:

Sl No.	Principle	Vapour compression system	Vapour absorption system
1	**Working method**	Refrigerant vapour is compressed	Refrigerant vapour is absorbed.
2	**Type of energy supplied**	Works solely on Mechanical energy	Works solely on Heat energy
3	**Mechanical work done**	More due the compressor used.	Less due the pump used.
4	**Refrigerant used**	Freon-12	Ammonia
5	**Capacity**	Limited to 1000 tons of refrigeration.	More than 1000 tons of refrigeration can be produced.
6	**Noise**	More due the compressor used.	Almost quiet in operation.
7	**Maintenance**	High due the compressor.	Less.
8	**Operating cost**	More	Less
9	**Leakage of Refrigerant**	Is a major problem	Almost no Leakage problem.
10	**COP**	Relatively higher but reduces at part loads.	Relatively lower but increases at part or full loads.

AIR CONDITIONING:

Air conditioning may be defined as the process of simultaneous control of temperature, humidity, cleanliness and air-motion of the confined space.

Principle of Air conditioning:

An Air conditioner is a machine which continuously draws the air from an indoor space (to be cooled) & cools it by refrigeration principles & discharge back into the same indoor space. Such continuous draw and re-circulation of cooled air keeps the indoor space at the required low temperature.

Applications of Air Conditioners:

Air conditioning provides comfort for human beings and also a controlled environment for industrial activities. Hence, applications of air conditioning can be broadly divided into

1. Comfort applications
2. Process applications.

1. Comfort applications:

Aim to provide an indoor environment that remains relatively constant in a range (preferred by humans) despite changes in external weather conditions or in internal heat loads, some of the applications are:

- In Residential buildings - single house and apartments.
- Institutional buildings - offices, hospitals, large complex buildings etc.
- Commercial buildings - shopping centers, malls etc.
- Transportation - in aircrafts, automobiles, ships etc.

2. Process applications:

Aim to provide a suitable environment for a process being carried out, regardless of internal heat loads and external weather conditions, some of the applications are

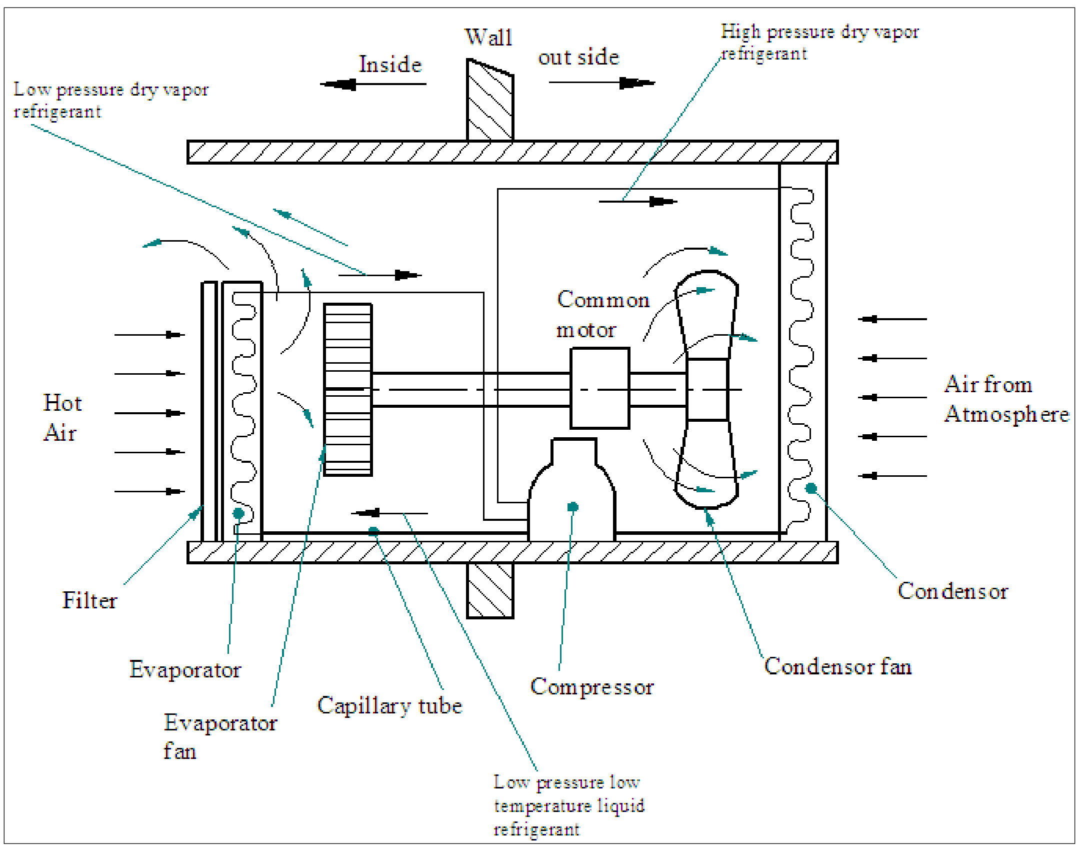
- Hospitals - in operation theatres (to reduce infection risk, to limit patient dehydration)
- Clean rooms - for production of integrated circuits,

- Pharmaceuticals and the like in which very high cleanliness and control of temperature and humidity are required.
- For breeding laboratory animals.
- Nuclear facilities
- Food cooking and processing areas
- Data processing centers etc.

Room air conditioner:

The Air conditioning system consist of

- A vapour compression refrigeration system
- An air filter &
- A double shaft motor that drives a fan at one end and a blower at the other end.
- The room side and the outdoor side of the unit are separated by an insulated partition wall within the casing.



Working:

- The blower sucks the warm air from the room through the air filter and the evaporator.
- The air from the interior passing over the evaporator coils is cooled by the refrigerant, which consequently evaporates by absorbing the heat from the air.
- The high temperature evaporated refrigerant from the evaporator is drawn by the suction of the compressor, which compresses it & delivers it to the condenser.
- The high-pressure-temperature refrigerant vapour now flows through the condenser coils.
- The condenser fan draws the atmospheric air from the exposed side-portions of the air conditioner which is projecting outside the building into the space behind it & discharges to pass through the center section of the condenser unit over the condenser coils.
- The high-pressure-temperature refrigerant passing inside the condenser coils condenses by giving off the heat to the atmospheric air.
- The cooled high pressure refrigerant from the condenser passes through the capillary tube, where it undergoes expansion & is again re-circulated to repeat the cycle continuously.

IC ENGINES:

Heat engines are thermal prime movers which converts the chemical energy contained in the fuel into heat energy by the combustion, further utilizes this heat energy to produce useful mechanical work. Heat engines are classified as

a) **Internal combustion Engine (IC Engine**): are those in which combustion of fuel takes place inside the engine cylinder. ***Example:*** *Petrol engines, Diesel engines, Gas engines, etc.*

b) **External combustion Engine (EC Engine):** are those in which combustion of fuel takes place outside the engine cylinder. ***Example:*** *Steam engines, Steam turbines.*

CLASSIFICATION OF I.C. ENGINES

I.C Engines can be classified into the following types:

(i)According to the type of fuel used

a) Petrol engines - fuel used in these engines is petrol.
b) Diesel engines - fuel used is Diesel.

(ii)According to the number of strokes

a) 4-strokeengine - the working cycle is completed in four different strokes.
b) 2-strokeengine - the working cycle is completed in two different strokes.

(iii) According to the method of ignition

a) Spark ignition engine (S.I engine) - Fuel is ignited by an electric spark.
b) Compression ignition engine (C.I. engine) – Ignition takes place due to high compression.

(iv) According to the cycle of combustion

a) Otto cycle engine – Combustion of fuel takes place at constant volume.
b) Diesel cycle engine - Combustion of fuel takes place at constant pressure.

(v) According to the number of cylinders

a) Single cylinder engine – These engines consist of only one cylinder.
b) Multi-cylinder engine - It consists of 2,3,4,6 or 8 cylinders.

(vi) According to the arrangement of cylinders

a) Inline or parallel engines - Cylinders are arranged in a line.
b) Radial engines – Cylinders are arranged radially.
c) V-engines – the arrangement of two cylinders are at an angle.
d) Opposed type engine - Cylinders are arranged opposite to each other.

(vii) According to the method of cooling

a) Air cooled engines – the cooling of the engine is done by air. Example: bike
b) Water cooled engines – the cooling of the engine is done by water, here a radiator is used for cooling purpose. Example: cars

IC ENGINE PARTS:

The following figure illustrate major parts of an IC Engine

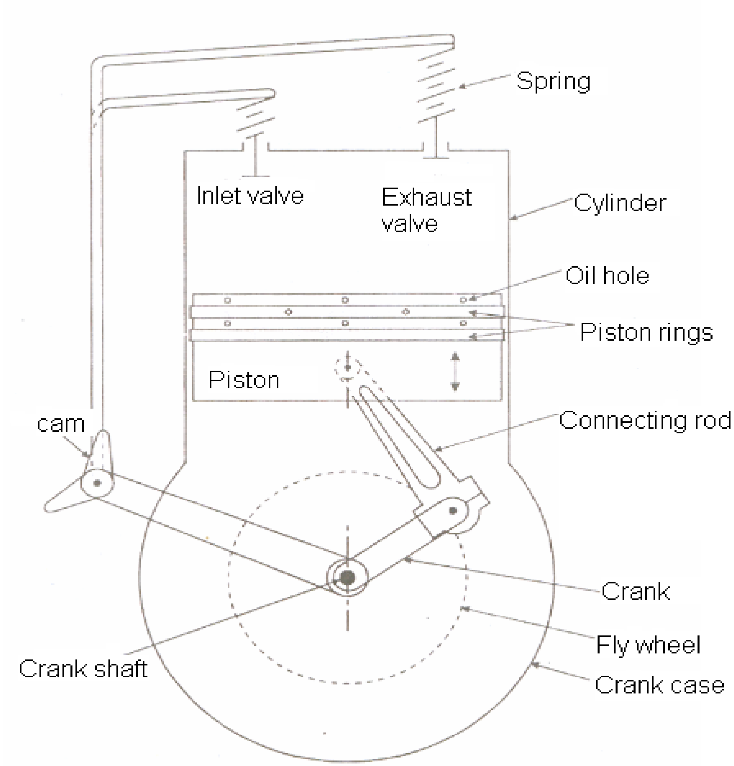


Fig: Parts of IC Engine

The parts of internal combustion engines are Cylinder, head, piston, piston rings (compression rings and oil control ring), connecting rod and crankshaft.

Functions of IC engine parts:

Cylinder (cylinder block): The cylinder is the main part of an engine. The combustion takes place in the combustion chamber and these gases exert pressure on the piston, due to high gas pressures the piston reciprocates in the cylinder block. The cylinder is designed to with stand high gas pressure. The temperature in the combustion chamber (cylinder block) will reach up to 2800^0 C. The cylinder has to be cooled properly either by air cooling or water cooling. In case of air cooled engines fins are provided around the cylinder block (Scooter and bikes) in water cooled engines water jackets are provided for the circulation of water to carry away the heat around the cylinder block. The cylinder block material is grey cast iron.

Cylinder head: The head is fitted on the top of the cylinder block and is provided with the inlet valve, exhaust valve and spark plug/fuel injector. There is a gasket is provided between cylinder and cylinder head in order to prevent the leakage of high pressure gases. The material used for cylinder head is grey cast iron and for gasket is copper and asbestos.

Piston: The piston is a cylindrical plug, which converts heat energy in to mechanical energy. A two stroke piston is fitted with only compression ring. In four-stroke engine both compression ring and oil control rings are fitted. The piston is connecting to the small end of the connecting rod. The piston is made of aluminium alloy. Functions of piston are

i) The piston will act as a seal

ii) To provide the passage for heat flow from piston to cylinder block through rings.

iii) It transmits the force of explosion to the crankshaft through connecting rod.

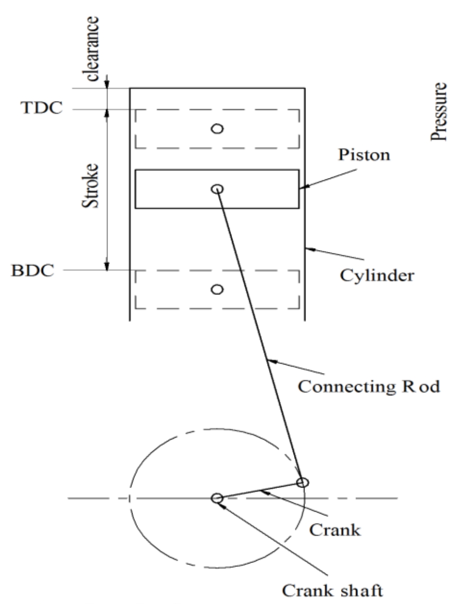
Connecting rod: The small end of the connecting rod is connected to the piston and the big end of the connecting rod is connecting to the crankshaft. The connecting rod converts the reciprocating motion of piston in to rotary motion of crankshaft. The connecting rod is made of I-beam cross section to provide maximum rigidity with minimum weight.

Crankshaft: The big end of the connecting rod is connected to the crankshaft. The power transmission starts from the crankshaft. The crankshaft is rigidly fixed in the crankcase. The other end of the crankshaft is connected to a clutch.

Crankcase: Crankcase is fitted at the bottom of the cylinder block. Two-stroke engine crankcase is properly sealed and made airtight. Four stroke engine crankcase will serve as a reservoir, filled with sufficient quantity of lubricating oil. This oil lubricates the main bearings of crankshaft, big end bearings of connecting rod, lubricates the cylinder liner, piston and piston rings.

<u>IC Engine Terminology</u>:

1) **Bore:** The nominal inside diameter of the engine cylinder is known as Bore.



2) **Stroke:** It is the linear distance, measured parallel to the axis of the cylinder, between extreme upper and lower positions of the piston.

3) **Top Dead Centre (TDC):** TDC in vertical engine is the extreme position of the piston nearer to the cylinder head. The cylinder volume is minimum at TDC. In case of horizontal engine this position is known as inner dead center (IDC).

4) **Bottom Dead Centre (BDC):** BDC in vertical engine is the extreme position of the piston towards the crank end. The cylinder volume will be maximum. In case of horizontal engine. This position is known as outer dead center (ODC).

5) **Clearance volume:** the volume contained in the cylinder above the top of the piston When the piston is at TDC is known as clearance volume and it is denoted by V_c

6) **Swept volume**: The volume swept by piston while traveling from TDC to BDC in known as swept volume and is denoted by V_s.

$V_s = (\pi D^2 / 4) L \quad m^3$

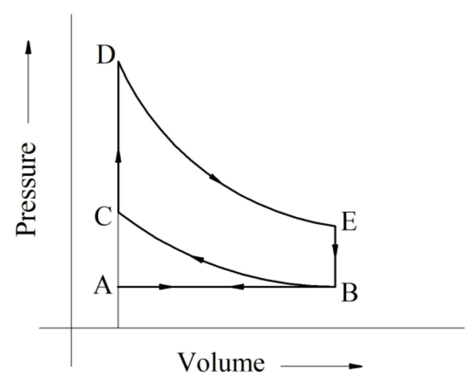
7) **Compression ratio**: It is the ratio of total volume of cylinder (V_s+V_c) to the clearance volume (V_c). It is denoted 'r'.

$$r = (V_s+V_c) / Vc$$

The compression ratio of petrol engine varies from 7:1 to 12:1.

The compression ratio of diesel engine varies from 16:1 to 22:1

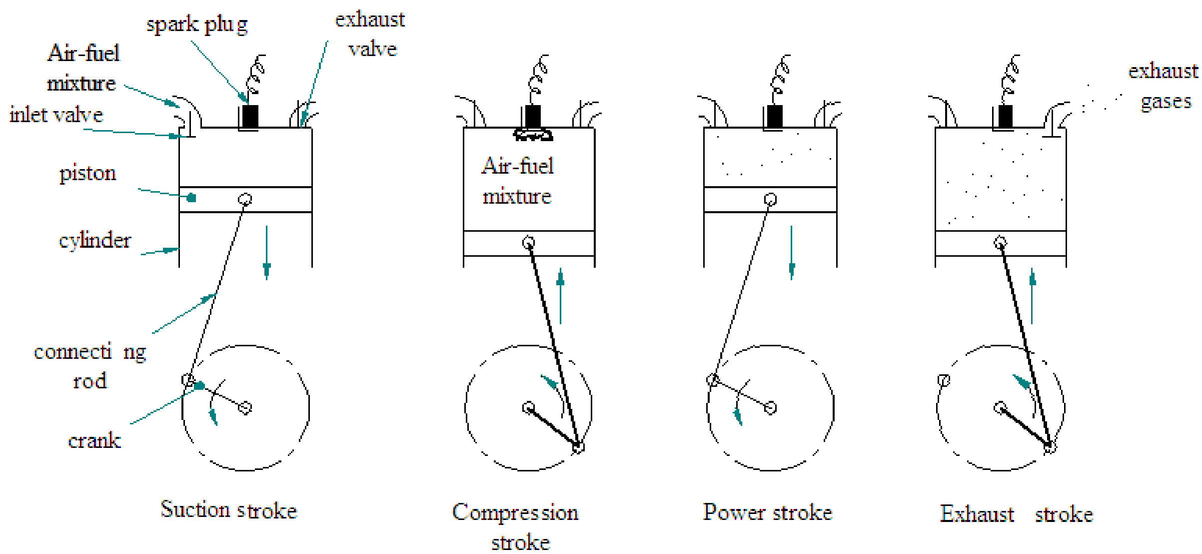
<u>4-Stroke Petrol Engine</u>:



The four-stroke petrol engine works on the principle of Otto (constant volume) cycle. As heat addition takes place at constant volume, this cycle is known as constant volume cycle. The parts of four-stroke petrol engine are cylinder, piston, head, crankcase, connecting rod, crankshaft, spark plug, and inlet and exhaust valve. The four-stroke petrol engine may be air-cooled or water-cooled. The piston performs four strokes to complete one cycle. The four different strokes are

i) Suction stroke ii) Compression stroke iii) Power or Expansion stroke iv) Exhaust stroke

Since the ignition in these engines is due to the spark of a spark plug, it is very commonly known as spark ignition engines (S.I Engines).



1. **Suction stroke**: The suction stroke is completed by rotating the crankshaft from 0^o to 180^o. During suction stroke the inlet valve opens and exhaust valve should kept in closed condition. When the piston starts moving from TDC to BDC, The volume above the piston increases, results in decrease in pressure (vacuum), This decrease in pressure draws the petrol and air mixture from the carburetor and delivered it to the cylinder, this process is continuous till the pressure inside the cylinder becomes equal to atmosphere. At the end of suction stroke the cylinder is completely filled with petrol and air mixture. At the end of suction stroke the inlet valve closes. The line AB in the PV diagram represents suction stroke (volume of mixture filled in the cylinder).

2. Compression stroke:

- During the compression stroke both inlet and exhaust valves are closed and the piston travels from the BDC to TDC & the crankshaft revolves further by half rotation, causing the compression of air and fuel mixture.
- This stroke is represented by a line **BC** on the (Pressure -Volume) P-V diagram.
- At the end of this stroke a spark is produced by a sparkplug, resulting in the combustion of the fuel and air & is represented by a line **CD** on P-V diagram.

3. Power stroke / Expansion stroke / Working stroke:

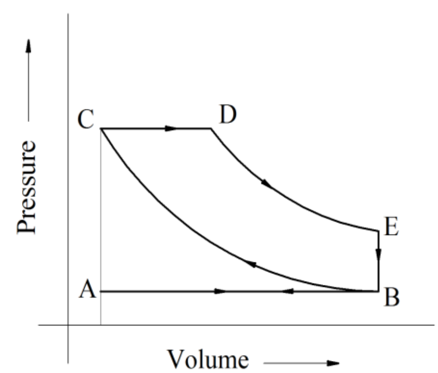
- In this stroke the piston travels from TDC to BDC with both the valves remain closed & the crankshaft revolves half rotation.
- The piston is forced due to the expansion of the burnt gases .This linear motion of the piston is transmitted to the crankshaft through the connecting rod to produce Mechanical power. This stroke is called as power stroke as the Mechanical power is produced during this stroke.
- It is represented by the curve **DE** on a P-V diagram.
- As the piston moves further, the pressure of the hot gases gradually decreases at constant volume as represented by the line **EB** in PV diagram.

4. Exhaust stroke:

- During Exhaust stroke the exhaust valve opens with inlet valve closed and the piston travels from BDC to TDC, causing the exhaust of burnt gases from the cylinder & the crankshaft revolves half rotation.
- This stroke is represented by a line **BA** on the (Pressure -Volume) P-V diagram.

4-Stroke Diesel Engine:

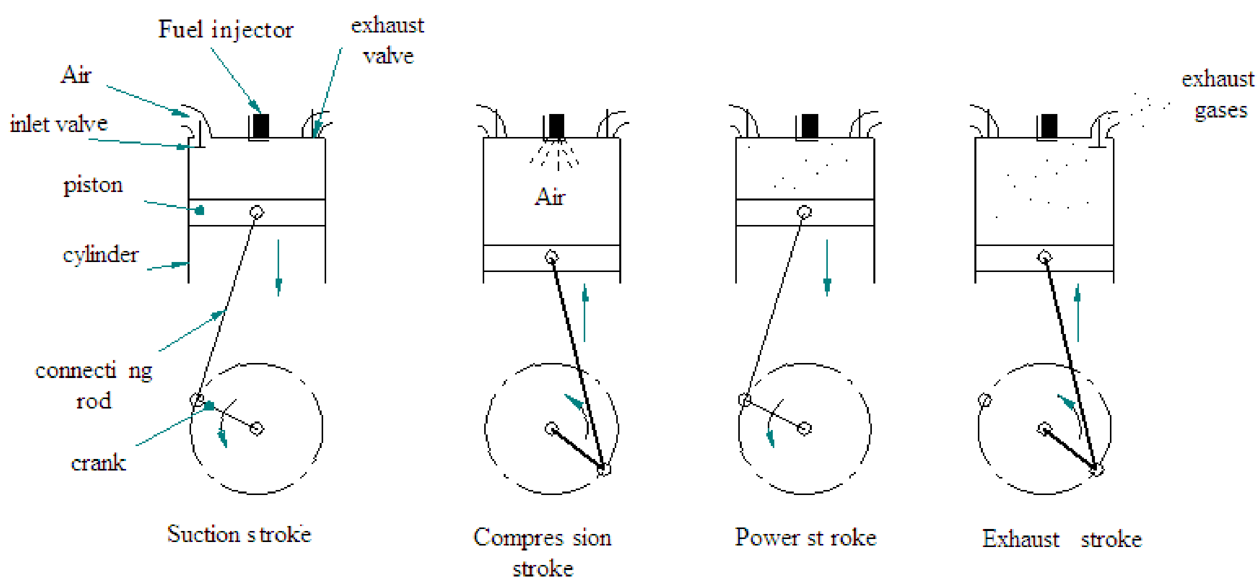
The working principle of a 4-stroke Diesel engine is based on Diesel cycle (constant pressure cycle). Hence, it is also called as constant pressure cycle engine. Since the ignition in these engines is due to high compression of air, it is very commonly known as Compression Ignition engines (C.I Engines).



The four strokes that are performed are,

1. Suction stroke
2. Compression stroke
3. Working stroke or Power stroke or Expansion stroke &
4. Exhaust stroke

The following figure represent working principle of 4-stroke Diesel engine with Theoretical Diesel-cycle.



1. Suction stroke:

- During suction stroke the inlet valve opens with outlet valve closed & the piston travels from (Top Dead Center) TDC to (Bottom Dead Center) BDC & the crankshaft revolves by half rotation, causing the suction of pure air.
- The energy required to perform this stroke is supplied by 'cranking' only during the first cycle at the time of starting, while running, the flywheel supplies the mechanical energy.
- This stroke is represented by a line **AB** on the (Pressure -Volume) P-V diagram.

2. Compression stroke:

- During the compression stroke both inlet and exhaust valves are closed and the piston travels from the BDC to TDC & the crankshaft revolves further by half rotation, causing the compression of air.
- This stroke is represented by a line **BC** on the (Pressure -Volume) P-V diagram.
- At the end of this stroke a metered quantity of fuel is injected through the fuel injector, the high temperature of the air ignites the fuel as soon as it is injected. This is called Auto-ignition or Self-ignition

3. Power stroke / Expansion stroke / Working stroke:

- In this stroke the piston travels from TDC to BDC with both the valves remain closed & the crankshaft revolves half rotation.
- The burnt gases released by the combustion of the fuel that is continuously injected into the cylinder, force the piston to perform earlier part of this stroke at constant pressure till the injection of the fuel is completed. This constant pressure expansion with simultaneous combustion is represented by the line **CD** on PV diagram.
- The piston is forced further during the remaining part of this stroke due to the expansion of the burnt gases .This linear motion of the piston is transmitted to the crankshaft through the connecting rod to produce Mechanical power. This stroke is called as power stroke as the Mechanical power is produced during this stroke.
- It is represented by the curve **DE** on a P-V diagram.
- As the piston moves further, the pressure of the hot gases gradually decreases at constant volume as represented by the line **EB** in PV diagram.

4. Exhaust stroke:

- During Exhaust stroke the exhaust valve opens with inlet valve closed and the piston travels from BDC to TDC, causing the exhaust of burnt gases from the cylinder & the crankshaft revolves half rotation.
- This stroke is represented by a line **BA** on the (Pressure -Volume) P-V diagram.

2-Stroke Petrol Engine:

One cycle is completed in 2 strokes of the piston in one revolution of the crankshaft. It has only ports at the cylinder walls and has no valves. These ports are covered and uncovered by the upward and downward movement of the piston

Scavenging: The exhaust gases are removed from the cylinder with the help of fresh compressed charge. This process of removing exhaust gases is called scavenging.

Deflector: In order To prevent the loss of incoming charge and helps for exhausting hot gases piston is provided with a deflector at its top. It is mainly used in scooters and motor cycles. It is having 3 ports.

1. Inlet Port: Through this inlet port only, Fresh charge from the carburetor is taken into the cylinder.
2. Transfer port: Through this Transfer port only, fresh charge entering into the cylinder from the crankcase.
3. Exhaust port: The Hot exhaust gases are pushed out from the combustion chamber. The cycle beginning at the point when the piston reaches TDC at the end of the compression stroke. When the piston is at TDC the exhaust and transfer ports are covered and inlet port is uncovered. When the piston is at BDC the exhaust and transfer ports are uncovered and inlet port is covered.

The following figure represent working principle of 2-stroke Petrol engine.

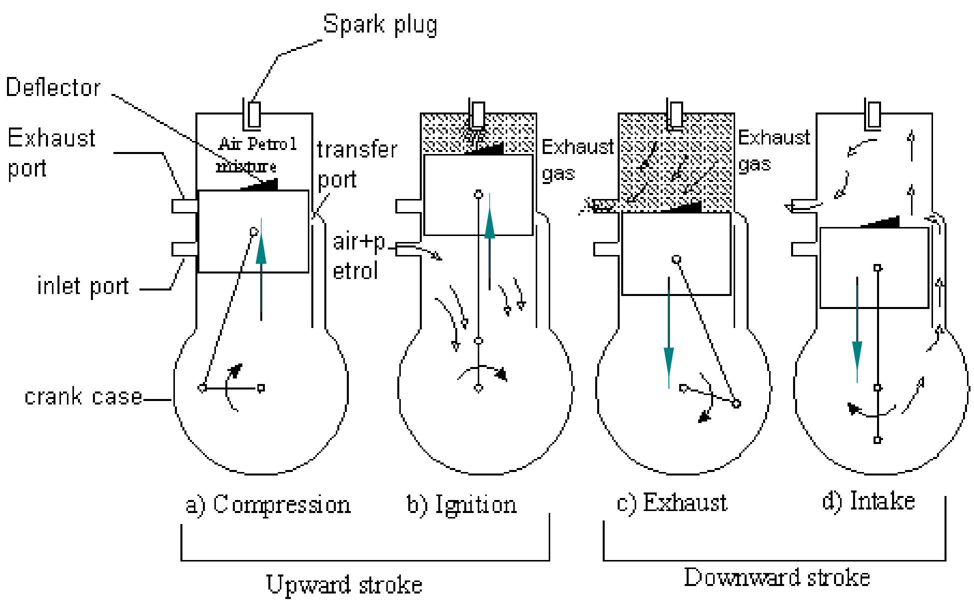


Fig: 2-Stroke Petrol Engine

A 2-stroke petrol engine works on the principle of Otto cycle & involves the following two strokes.

1. Upward stroke &
2. **Downward stroke**

1. Upward Stroke:

- During upward stroke the piston moves from BDC to TDC & the crankshaft revolves by half rotation, causing the compression of air and fuel mixture.
- Due to this upward movement of the piston, a partial vacuum is created in the crankcase & fresh air and fuel mixture is drawn from the inlet port to the crank case .As the piston moves upward, the exhaust port and the transfer port are covered by the piston.
- At the end of this upward stroke, the compressed charge is ignited in the combustion chamber by a spark plug.

2. Downward Stroke:

- During this stroke, as soon as the charge is ignited, the hot gases force the piston to move from TDC to BDC & the crankshaft revolves by half rotation.
- This linear motion of the piston is transmitted to the crankshaft through the connecting rod to produce Mechanical power.

- Further downward movement of the piston uncovers first the exhaust port & then the transfer port.
- The burnt gases escape through the exhaust port & the compressed charge from the crankcase flows into the cylinder through the transfer port. Here deflectors are used, so that the fresh air and fuel should not mix up with the burnt gases as shown in figure (d).

Comparison between Petrol Engine & Diesel Engine:

Sl No	**SI Engines** (Petrol engine)	**CI Engines** (Diesel engine)
1	Ignition of the fuel by spark plug	Ignition of the fuel by spraying fuel to compressed air at high temperature
2	Works on theoretical Otto cycle	Works on theoretical Diesel cycle
3	Fuel used is petrol	Fuel used is diesel
4	A mixture of air and petrol is drawn during suction stroke	Only air is drawn during suction stroke
5	Combustion is at constant volume	Combustion is at constant pressure
6	Low compression ratio ranging from 7:1 to 12:1	High compression ratio ranging from 16:1 to 22:1
7	Fuel cost is high	Fuel cost is low
8	Power output will be less	Power output will be more

Comparison between 2-stroke & 4-stroke IC Engine:

Sl No	Two-stroke Engines	Four-stroke Engines
1	One cycle is completed in two strokes of the piston	One cycle is completed in four strokes of the piston
2	Power is developed during each revolution of the crank	Power is developed during every alternate revolution of crank
3	Flywheel not essential but small flywheel can be provided for smooth operation	Flywheel is essential
4	Ports are used	Valves are used
5	Charge is admitted first into crank case and then to cylinder	Charge is admitted directly into cylinder
6	Construction is simple	Construction is complicated
7	Exhaust gases are driven out by the piston during the exhaust stroke	Exhaust gases are driven out by the incoming fresh charge

Performance parameters of IC engines:

i) **Mean effective pressure (p_m)**:

It is defined as the average pressure is acting on the piston during the entire expansion (power stroke) stroke.

p_m = Mean effective pressure **N / m²**

$$P_m = \frac{Net\ area\ of\ the\ indicator\ diagram \times spring\ cons\tan t}{Length\ of\ the\ indictor\ diagram}$$

$$P_m = \frac{a \times s}{l}$$

P_m is the hypothetical pressure acting on the piston throughout the power stroke.

ii) Indicated power (IP):

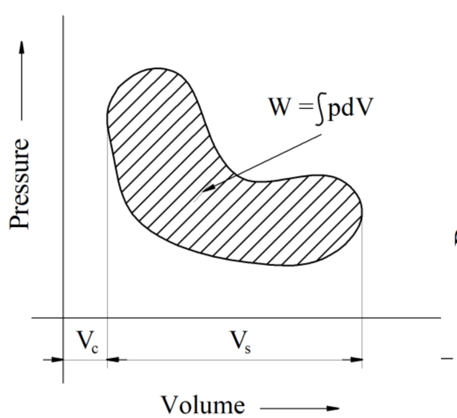
The power developed within the piston –cylinder arrangement by the combustion of fuel is known as the indicated power. The pressure acting on the piston varies throughout the working cycle. To record the variation of pressure for one cycle of operation, a device called piston indicator is mounted by drilling a small hole on the cylinder cover. It mainly consists of a small plunger and a cylinder. The plunger displacement is proportional to the pressure acting on it from inside against the spring force on the other side. The movement of the plunger transmitted to a stylus through linkages. The stylus traces out a graph on a recording drum, which rotates at a constant speed. The graph thus obtained is called the indicator diagram. The area of the indicator diagram is proportional to the work done in a cycle.

Mean effective pressure (p_m):

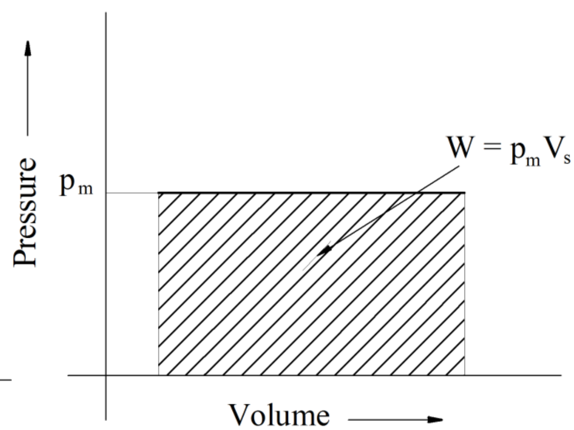
The work done on the piston for one cycle of operation is given by

$$W = \int pdV,$$

Where the integration is carried out for one cycle,



Indicator diagram.



Mean effective pressure.

The right hand side of the equation is nothing but the area within the loop on the pressure-volume diagram.

The mean effective pressure is defined as the equivalent constant pressure which has to be acting on the piston during the expansion stroke, to give the same work output as the varying pressure, in one cycle.

From the indicator diagram, the mean effective pressure can e calculated as,

$p_m = s.a/l.$

Where,

s = spring constant of the spring used in the piston indicator,

l = length of the indicator diagram,

a = area of the indicator diagram.

$$IP = \frac{p_m\, L\, A\, n}{60 \times 1000} \ \mathbf{kW}$$

Where,

p_m = mean effective pressure,

L = stroke length,

A = area of cross-section of the piston,

n = number of cycles per minute,

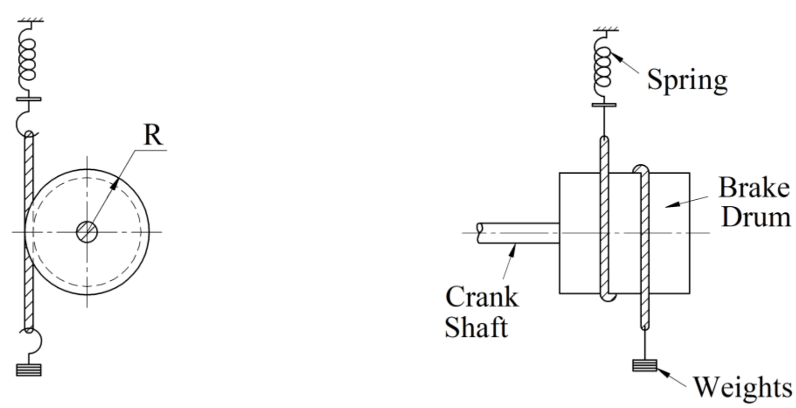
= N/2 for a four stroke engine,

= N for a two stroke engine.

N = crank shaft speed, rpm.

iii) Brake power (BP):

The power available at the crank shaft is always less than the power developed within the piston-cylinder arrangement because of frictional losses in the moving parts. The power actually available at the crank shaft is called the brake power. It can be measured using dynamometers. One such dynamometer is the brake-drum dynamometer.



It consists of a drum, which is mounted on the crankshaft. A rope is wound on the drum. One end of the rope is connected to a spring balance, and the other end, to a weight-loading device.

The torque on the brake drum is given by,

$T = (W - S) \times R$ Where, W = weight on the rope, N.

S = spring balance reading, N.

R = mean radius of brake drum, m.

Brake power is given by,

$$BP = \frac{2 \pi N T}{60 \times 1000} \ \mathbf{kW}$$

iv) Frictional power(FP):

The difference between indicated power and brake power is known as frictional power

$$FP = IP - BP \ \mathbf{kW}$$

v) Mechanical efficiency:

It is defined as the ratio of brake power to indicated power

$$\eta_{mech} = \frac{\text{Brake power}}{\text{Indicated power}}$$

vi) Thermal efficiency:

In IC engines, energy is supplied to the engine by burning fuel. But all of the energy that is supplied is not converted into useful mechanical work. Some of the energy supplied is lost through hot exhaust gases, some due to the cooling of the engine and some through radiation and convection heat losses. The fraction of the energy supplied that is available as useful work determines the thermal efficiency of the engine. The thermal efficiency can be calculated either for the indicated power, or for the brake power. Accordingly they are referred to as indicated thermal efficiency, and brake thermal efficiency.

Heat supplied to the engine per sec = mass of fuel burnt x calorific value.

$$\eta_{\text{indicated thermal}} = \frac{\text{Indicated power}}{m_f \times CV}$$

$$\eta_{\text{brake thermal}} = \frac{\text{Brake power}}{m_f \times CV}$$

Where,

m_f = Mass of fuel used in **kg / sec**.

CV = Calorific value of fuel **kJ / kg**

vii) Specific fuel consumption (SFC):

It is the mass of fuel supplied per hour in order to get unit power output.

$$SFC = \frac{m_f}{\text{Power}} \text{ kg/kW-hr}$$

SFC can be calculated on indicated power basis or on brake power basis.

Problems:

1. A single cylinder two stroke cycle I.C engine has a piston diameter of 105mm & stroke length 120mm. The mean effective pressure is 6bar .If the crankshaft speed is 1500rpm, calculate the indicated power of the engine.

2. A two stroke Diesel engine has a piston diameter of 200mm & a stroke of 300mm .It has mean pressure of 2.8 bar & a speed of 400rpm. The diameter of the brake drum is 1m & the effective brake load is 64kg. Find the indicated power, the brake power, the Mechanical efficiency of the engine & the average piston speed.

3. A four stroke I.C engine running at 450rpm has a bore diameter of 100mm & stroke length 120mm. The indicated diagram details are;

   Area of the diagram = 4cm^2

Length of indicator diagram = 6.5cm

Spring value of the spring used = 10bar/cm

Calculate the indicated power of the engine. Also find the average piston speed.

4. Find the indicated power of a four stroke petrol engine of swept volume of 6ltrs & running at 1000rpm. The mean effective pressure is 600 kN/m^2

5. The following readings were taken on a four stroke I.C engine

Diameter of the brakedrum = 1.5m

Spring balnce reading = 5kg

Diameter of the rope = 10mm

Crankshaft speed = 200rpm

Load suspended on the brakedrum = 100 kg.

Determine the brakepower of the engine?

6. The following data refers to a single cylinder four stroke petrol engine

Cylinder diameter = 20cm;

Stroke of piston = 40cm,

Engine speed = 400 rpm;

Indicated mean effective pressure = 7bar,

Fuel consumption = 10 liters/hr;

Calorific value of the fuel = 45000kj/kg, S

pecific gravity of the fuel = 0.8.

Find indicated thermal efficiency?

7. A four stroke petrol engine of 100mm bore & 150mm stroke consumes 1kg of fuel/hr. The mean effective pressure is 7bar & its indicated thermal efficiency is 30%. The calorific value of the fuel is $40x10^3$ kJ/kg. Find the crankshaft speed?

8. The following are the details of a 4-stroke petrol engine. (i) Diameter of brake drum=60.03cm, (ii) full brake load on drum=250N, (iii) brake drum speed = 450 rpm, (iv)

Calorific value of petrol = 40MJ/kg, (v) brake thermal efficiency=32%, (vi) mechanical efficiency=80%, specific gravity of petrol=0.82. Determine (i) brake power, (ii) indicated power, (iii) fuel consumption in liter per second, and (iv) indicated thermal efficiency.

9. The following observations were recorded during a test on a 4-stroke engine. Bore = 25cm, stroke=40cm, crank speed=250 rpm, net load on the brake drum=700N, diameter of brake drum=2m, indicated mean effective pressure=6bar, fuel consumption=0.0013kg/s, specific gravity of fuel=0.78, calorific value of fuel=43900kJ/kg. Determine (i) BP, (ii) IP, (iii) FP, and (iv) mechanical efficiency (v) indicated and brake thermal efficiency**.**

10. A petrol car which consists of four-cylinder engine develops Brake power of 30kW at 2500 rpm. The mean effective pressure on each piston is 8bar, and mechanical efficiency is 80%. Calculate the diameter and stroke of each cylinder, stroke to bore ratio is 1.5. Also calculate the fuel consumption if brake thermal efficiency is 28%. Consider the engine is 2-stroke engine and calorific value of petrol is 47300kJ/kg.

11. A 10 wheeler Truck when it is running with engine speed of 3700rpm it produces misfires. Which consists of 4-stroke 6 cylinders develops 50Kw of indicated power at mean effective pressure of 7 bars. The bore & stroke of the engine cylinder is 70mm & 100mm respectively. Find the average misfires per minute.

12. A Bajaj Pulsar 200CC bike when its engine running at 1000rpm it produces 60kW Brake power and also the following observations were recorded during the same speed and power.

The mean effective pressure=6bar,

Petrol consumption=0.0013kg/s,

Calorific value of petrol=47300kJ/kg.

Determine power developed inside the cylinder, mechanical efficiency, indicated and brake thermal efficiency**.**

****

MODULE-IV:ENGINEERING MATERIALS AND POWER TRANSMISSION

Common engineering materials that fall within the scope of material science and engineering maybe classified into one of the following seven groups:

1. Metals (ferrous and non-ferrous) and alloys
2. Ceramics
3. Polymeric (plastic) materials
4. Composites

1. Metals (ferrous and non-ferrous) and alloys:

All the elements are broadly divided into metals and non-metals according to their properties. Metals are element substances which readily give up electrons to form metallic bonds and conduct electricity.

Some of the important basic properties of metals are:

- Metals are usually good electrical and thermal conductors,
- At ordinary temperature metals are usually solid,
- To some extent metals are malleable and ductile,
- The freshly cut surfaces of metals are lustrous,
- When struck metal produce typical sound and
- Most of the metals form alloys.

When two or more pure metals are melted together to forma new metal whose properties are quite different from those of original metals, it is called an alloy.

Metallic materials possess specific properties like plasticity and strength. Few favorable characteristics of metallic materials are hardness, resistance to corrosion, good thermal and electrical conductivity, malleability, stiffness, the property of magnetism, etc. Metals may be magnetic, non-magnetic in nature.

I. FERROUS METALS:

Iron is the principal constituent of these ferrous metals. Ferrous alloys contain significant amount of non-ferrous metals. Ferrous alloys are extremely important for engineering purposes. On the basis of the percentage of carbon and their alloying elements present, these can be classified in to following groups:

Mild Steels (Low carbon steel):

The percentage of carbon in these materials range from 0.15% to 0.25%. These are moderately strong and have good weldability. The production cost of these materials is also low. Applications- Deep drawing parts, chain, wire, pipe etc.

Medium Carbon Steels:

These contains carbon between 0.3% to 0.6%. The strength of these materials is high but their weldability is comparatively less. Applications- Rolls, screws, axels, crank shafts etc.

High Carbon Steels:

These contain carbon varying from 0.65% to 1.5%. These materials get hard and tough by heat treatment and their weldability is poor. Applications- Rolling mills, rope wire, screw driver hammers etc.

Plain carbon steel:

The steel formed in which carbon content is up to 1.5%, silica up to 0.5%, and manganese up to 1.5% along with traces of other elements is called plain carbon steel.

In general the types of cast iron are (a) grey cast iron and (b) white cast iron

Cast Irons:

The carbon content in these substances varies between 2% to 4%. The cost of production of these substances is quite low and these are used as ferrous casting alloys. In general the types of cast iron are (i) grey cast iron and (ii) white cast iron

(i) Grey cast iron:

- Carbon here is mainly in the form of graphite. It contains 1.5 to 4.3% carbon and 0.3 to 5% silicon. This type of cast iron is inexpensive and has high compressive strength.

Applications: To make IC engine cylinder blocks, pump housings, valve bodies, fly wheels, machine tool base, etc.

(ii) White cast iron:

- In these cast irons carbon is present in the form of iron carbide is called as cementite which is hard and brittle. It contains 2.5% carbon, 0.8 to 1.2% silicon. These cast irons are difficult to machine and abrasion resistant.

Applications: Outer surface of car wheel, Rolls for crushing grains etc.

II. NON-FERROUS METALS:

These substances are composed of metals other than iron. However, thesemay contain iron in small proportion. Out of several non-ferrous metals only seven are available insufficient quantity reasonably at low cost and used as common engineering metals. These are aluminium, tin, copper, nickle, zinc and magnesium.

- **Aluminium:**

This is the white metal produced from Alumina. In its pure state it is weak and soft but addition of small amounts of Cu, Mn, Si and Magnesium makes it hard and strong.

Properties: - Good corrosion resistant, light weight, good thermal and electric conductor etc.

Applications: - Pistons, connecting rods power transmission lines, cooking utensils, aerospace and marine applications, etc.

- **Magnalium:**

- This is an aluminium alloy with 2 to 10 % magnesium. It also contains 1.75% Cu.

Properties: - Good damping properties, light weight, high thermal conductivity, low specific weight, non toxic, etc.

Applications: - Due to its light weight and good strength it is used for aircraft and automobile components.

- **Copper alloys:**

Copper is one of the most widely used non-ferrous metals in industry.

The following two important copper alloys are widely used in practice:

Brass (Cu-Zn alloy): It is fundamentally a binary alloy with Zn up to 50%. As Zn percentage increases, ductility increases up to ~37% of Zn beyond which the ductility falls. Lead or tin imparts other properties to brass. Lead gives good machining quality and tin imparts strength. Brass is highly corrosion resistant, easily machine able and therefore a good bearing material.

Bronze (Cu-Sn alloy): This is mainly a copper-tin alloy where tin may vary between 5 to 25 percentages. It provides hardness but tin content also oxidizes resulting in brittleness. Deoxidizers such as Zn may be added. Gun metal is one such alloy where 2% Zn is added as deoxidizing agent and typical compositions are 88% Cu, 10% Sn, 2% Zn. This is suitable for working in cold state. It was originally made for casting guns but used now for boiler fittings, bushes, glands and other such uses.

Properties: - It is soft, malleable and ductile and is a good conductor of heat and electricity.

Applications: - Electrical wires, circuits, plumbing fittings, refrigeration, air conditioning, water supply systems, cookware, doorknobs etc.

COMPOSITE MATERIALS:

In the present rapidly developing industrial era there is a need for the materials with specific requirement of properties and it is impossible for any single material to fulfill all the required properties, so the research and development of newer materials begun and the result is the composite material.

Composites can be defined in many ways, for simple understanding we can define it as a material which consists of two or more materials with significantly different properties in a microscopic level.The base material is called as matrix and constituent which is mixed to matrix is called reinforcement material. In some composites along with these matrix and reinforcement, fillers are also used in addition.

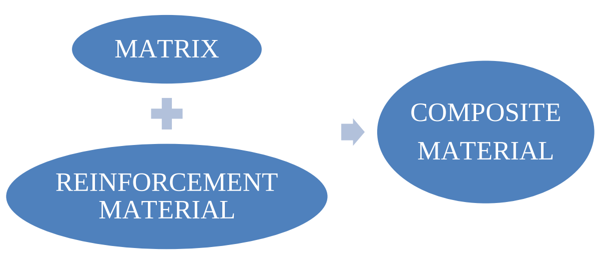


Figure 4.1 Composites

Composites play a most important role in many industrial applications. This is an evergreen field for researchers to research on new composite materials which will satisfy the need of various applications like structural, medical, house hold, industrial, construction, automobile, aerospace, marine, electrical, electronics and many more.

Composites are heterogeneous in microscopic level, but they are statically homogeneous at macroscopic level. Sometimes the properties obtained from composites formed may not be obtained from its constituents and sometimes we may not call only addition or mixing of two or more materials as composites as it must need to satisfy some conditions like,

- The mixture or addition of two or more materials should results in change of properties.
- The content of the reinforcement material should be more than 10% by volume.

Classifications of Composite Materials:

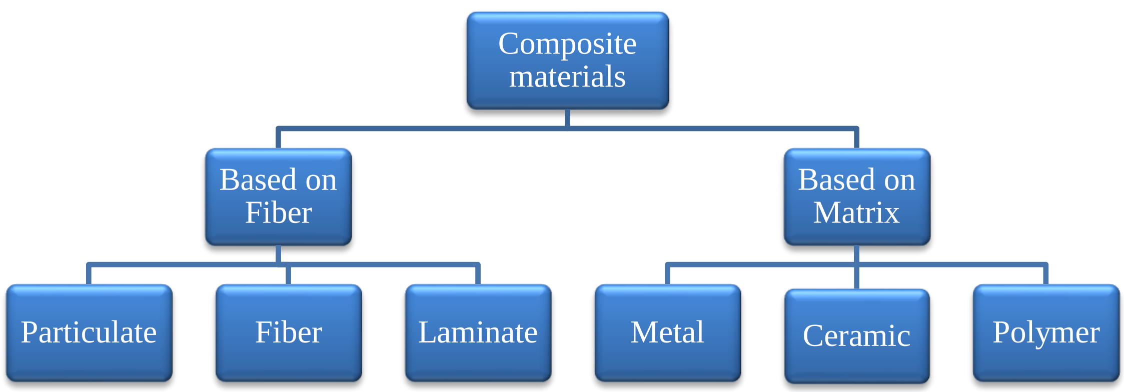


Figure 4.2 Classification of composites

Classification of composites based on reinforcement

1. Particulate reinforced composite.
2. Fiber reinforced composite.
3. Laminated reinforced composite.

Particulate reinforced composite:

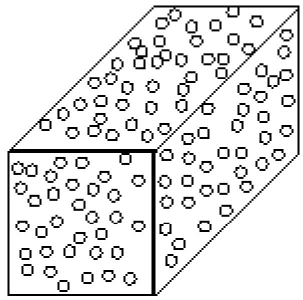
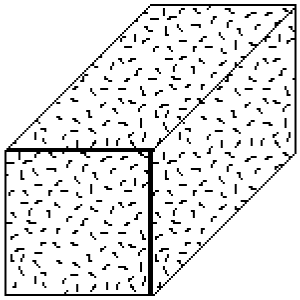
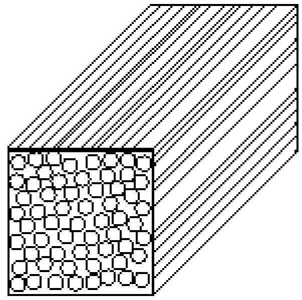


Figure 4.3 Particulate reinforced composite

Particulate composites are formed by immersing particles of different shapes like sphere, rod, bead, flake and some other shapes in matrix materials such as alloys, polymers and ceramics. They are usually isotropic due to random addition of particles. These composites have many advantageous like good strength, excellent working temperature, high resistance to oxidation, etc. General examples for these particulate composites include polymer composites reinforced with different fillers such as finely powdered glass, alumina particulates in rubber, silicon carbide particles in aluminum, polymers with fine rubber particles and concrete made up of cement, crushed stones and sand.

Fiber Reinforced composites:





Short fiber **Long fiber**

Figure 4.4 Short & Long fiber

Fiber composites consist of matrix reinforced by long and short fibers. Long fibers are generally continuous and short fibers are discontinuous fibers. There are lot of things to be taken care of when we manufacturing a fiber reinforced composite, which includes the dimension, position, quantity, properties and bonding of the fibers and matrix. Fibers are generally anisotropic these fibers may be unidirectional, cross woven or random. Generally long fibers are used most due to their load carrying capacity is very low at the ends compared to the other. So as the rods are long, the ends are less, and load carrying capacity is high. Examples of matrix materials include epoxy resins, metals like copper, aluminum, steel and ceramics like calcium-alumino silicate. And examples of fiber reinforced composites include glass fiber reinforced in epoxy, carbon fibers in polyester and banana fiber in polymers.

Laminated Reinforced composite:

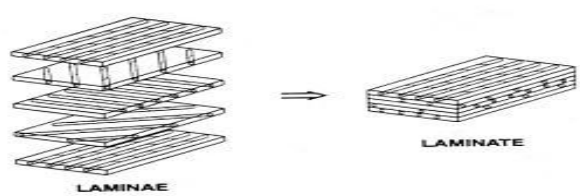


Figure 4.5 Laminated composite

Laminar composites may also called as platelet composites these are formed by two or more successive thin layers having different grain or fiber orientation held together by matrix binder. And laminated composites are more or less isotropic composite sheet that is weaker in any direction than it would be if the fibers were all placed in one direction. These have two of their measurements much bigger than the third. Examples include car bumper made of glass and epoxy laminates, plywood and some golf clubs use graphite and aramide fiber laminates. And also some metal laminates also used in pressure cookers, heating vessels, etc.

Classification based to type of matrix materials used:

1. Metal Matrix Composites (MMC).
2. Ceramic Matrix Composites (CMC).
3. Polymer Matrix Composites (PMC).

Metal Matrix Composites:

As the name only specifies metal matrix composites commonly called as MMCs uses metal as a matrix material. Matrix materials such as aluminum, magnesium, titanium, iron, tungsten and nickel are commonly used. And typical fibers used are carbon, silicon carbide and alumina. MMCs are better at higher temperatures than PMCs. They are mainly reinforced with metals and metal oxides to enhance thermal and mechanical properties to meet the needs of design. And to enhance the properties like strength and elastic stiffness, and control properties like thermal and electrical conductivity by adding silicon carbide fillers.

MMCs generally consist of bulky metals like steel and aluminum to increase their properties and advantages such as high specific strength and modulus by adding low density metal oxides like alumina and titanium dioxide. And graphite is used as reinforcing material to lower coefficients of thermal expansion. The applications of MMCs are in space vehicles, military, transportation, etc.

Ceramic matrix Composites:

Ceramic matrix composites as their name only say they use ceramic as matrix material. They are even called as CMCs. Ceramic composites are very hard in structures as they commonly reinforced by the materials like carbon and silicon carbide, cause of which they are brittle and have high service temperature. CMCs fracture toughness is very high because of reinforcement materials like silicon carbide. Ceramic composites are strong but they lack in ductility. CMCs are used in aerospace engine parts and outer protective shields due to their high strength and temperature resistance capacity.

3. Polymer Matrix Composites:

Polymer matrix composites also known as PMCs are most commonly used and advanced composite materials which consists of polymer like polyester, epoxy, urethane reinforced by fibers like glass fiber, carbon fiber, armide, boron fibers. Due to less cost, excellent strength to weight ratio and easy manufacturing techniques make PMCs find most important applications in many industries like aerospace structures, automobile parts, structural applications and many more. Now a day's polymer composites replaced many conventional materials and metals.

There are two basic categories of polymer matrices:

i) Thermo sets.

ii) Thermoplastics.

Roughly 95% of the composite market uses thermosetting plastics.

1. Thermosets

The materials which are once set or manufactured then cannot be molded back are called as thermo sets. The most commonly available thermo set resins are epoxy, polyester and polyvinyl Ester. They have a large grade of chemicals and verity of physical and mechanical properties. Thermosetting polymers are formed by chemical cross linking of the liquid resins to get into a hard tuff solid. Thermo sets are usually strong, and are very brittle when compared to thermo plastics. In general Thermo sets are thermally stable, dimensionally stable, they have good rigidity, light weight, and they are thermally and electrically insulating, and have high resistance to creep, they are deformed under load.

2. Thermoplastics

The materials which can be remolded even after setting or manufacturing just by applying heat are called as thermoplastics. Thermo plastics are not cross linked like thermosetting materials. Inbuilt characters of the monomers and their excellent molecular weight is responsible to get their strength and stiffness. The generally available thermoplastics are polyethylene, polystyrene, polyamides, nylon and polypropylene.

Applications of composite materials:

1. **Aerospace:**
    - Polymer composites are having 5 to 10 times higher specific strength than the aluminium alloys hence it is widely used in aircrafts.
    - Skeleton of the aircraft is built by using aluminium based MMC
    - The important parts like rudder, elevators, ailerons etc. are made of PMC
    - The salient features of the composites used in aerospace applications are:
        - High strength to weight ratio.
        - High stiffness to weight ratio.
        - Excellent fatigue performance.
        - Corrosion resistance.
        - Flexibility in design.
2. **Automobile:**
    - Steel and cast iron used in olden days are completely replaced by composites to reduce the weight and increase the fuel efficiency and speed.
    - Aluminium based MMC’s are used in engine blocks, piston, connecting rod, body of vehicle.
    - Fiber Reinforced Polymers(FRP) are widely used in Steering wheel, front and rear bumpers, doors, interiors etc.

JOINING PROCESSES:
SOLDERING, BRAZING & WELDING

INTRODUCTION

Some products cannot be manufactured as a single piece. The desired shape and size of such products can be obtained by joining two parts of same or different materials. These parts are manufactured individually and are joined together to obtain the desired product. For example, air craft and ship bodies, welded machine frames, furniture, computers, bridges and the transmission or electric towers etc., are all fabricated by joining several different parts.

Based on the type of joint produced joining processes can be classified as

1. Temporary Joint.
2. Permanent Joint.

If a product is in use for a long time and there is wear and tear, the parts need to be dismantled for maintenance, repair or replacement. A temporary joint can be easily dismantled separating the original parts without any damage to them. In case it is a permanent joint, an attempt to separate the parts already joined will result in the damage of the parts. In a permanent joint, the joint is made such that it has properties similar to the base metal of the two parts. The joined parts become one piece. These parts cannot be separated into their original shape, size and surface finish. Based on the process used for making the joint, the joining processes can be further classified as

1. Soldering.
2. Brazing.
3. Welding.
4. Mechanical Fasteners like bolts, nuts, rivets, screws etc.
5. Adhesive bonding.

Mechanical fasteners are most widely used for temporary joints. Joints obtained by bolts and screws are temporary in nature and can be dismantled easily whenever necessary. Rivets are semi-permanent fastening devices and the joint can be separated only by destroying the rivet without affecting the parent elements. Adhesive bonding has generally less strength than the mechanical fasteners. But adhesive bonding is used to join odd shaped parts or thin sheets which may not lend themselves to mechanical fastening. Brazing and soldering are considered to form permanent joints, but for repair or replacement these joints can be dismantled by heating. Welding is one of the most extensively used fabrication method. The joint strength obtained in welding is being equal to or some times more than that of the parent metal. Welding is not only used for making structures, but also for repair work such as the joining of broken castings. The choice of a particular joining process depends on several factors such as application, nature of loads or stresses, joint design, materials involved and size and shape of the components.

1. SOLDERING

Soldering is a method of joining similar or dissimilar metals by the application of heat and using a filler metal or alloy called solder, whose liquidus temperature is below 450^0 C. The molten filler metal is made to flow between the two closely placed adjacent surfaces by the capillary action.

Though soldering obtains a good joint between the two plates, the strength of the joint is limited by the strength of the filler metal used. Soldering is used for obtaining a leak proof joint or a low resistance electrical joint. The soldered joints are not suitable for high temperature applications because of the low melting temperatures of the filler metals used.

The purpose of using the flux is to prevent the formation of oxides on the metal surface when the same is heated. The fluxes are available in the form of powder, paste, liquid or in the form of core in the solder metal. It is necessary that the flux should remain in the liquid form at the soldering temperature and be reactive to be of proper use. The filler metals used are essentially alloys of lead and tin. The composition of solder used for different purposes are as given below

Soft solder	- lead 37%	tin 63%
Medium solder	- lead 50%	tin 50%
Plumber’s solder	- lead 70%	tin 30%
Electrician’s solder	- lead 58%	tin 42%

Soldering is classified into soft soldering and hard soldering.

Soft soldering is used extensively in sheet metal work for joining parts that are not exposed to the action of high temperatures and are not subjected to excessive loads and forces or vibrations. Soft soldering is also employed for joining wires and small parts. The solder is mostly composed of lead and tin. In soft soldering, Zinc chloride and ammonium chloride are the most common soldering fluxes used which are quick acting and produce efficient joints. But because of their corrosive nature the joint should thoroughly cleaned of the entire flux residue from the joint. These are to be used only for non-electrical soldering work. Rosin and rosin plus alcohol based fluxes are least active type and are generally used for electrical soldering work.

Hard soldering employs solder which melts at higher temperatures (350^0 C to 900^0 C) is stronger than used in soft soldering. Hard solder is an alloy of copper and zinc to which silver is added some times. German silver, used as a hard solder for steel is an alloy of copper, zinc and nickel.

Sequence of operations:

The following operations are required to be performed sequentially for making soldered joints.

1. Shaping and fitting of metal parts together: The two parts to be joined are shaped to fit closely so that the space between them is extremely small and filled completely with solder by capillary action. If a large gap is present, capillary action will not take place and the joint will not be strong.
2. Cleaning of surfaces: In order to obtain a sound joint, the surfaces to be soldered are cleaned to remove dirt grease or any other foreign material.
3. Application of flux: The flux is applied when the parts are ready for joining.
4. Application of heat and solder: The parts are held in a vice or with special work holding devices so that parts do not move while soldering.

Advantages:

- Simple and economical process.
- Relatively low temperature process, there is no metallurgical damage to base metal.
- The soft soldered joints can easily be dismantled by simple heating.

Disadvantage:

- The strength of joint relatively low.
- Flux must be thoroughly cleaned off after soldering, as it is often corrosive.

2. BRAZING

Brazing is a process of making joints where in coalescence is produced by heating to suitable temperatures above 500^0 C and by using a non-ferrous filler metal having a melting point (up to 900^0 C) below that of the base metal, the filler metal being distributed between the closely fitted surfaces of the joint by capillary action. Brazing gives a much stronger joint than soldering.

The principal difference is the use of a harder filler material commercially known as spelter. Filler metals used in this process may be divided into copper base alloys and silver base alloys. The spelter is usually an alloy of copper, zinc and tin. Both similar and dissimilar metals can be joined. The flux along with spelter (filler metal) is applied to remove oxides from the surfaces. Borax is the most widely used flux. It will dissolve the oxides of most of the common metals. Other fluxes used are mixtures of borax, boric acid, fluorides and chlorides.

Advantages:

- Dissimilar metals, such as stainless steel to cast iron can be joined by brazing. Almost all metals can be joined by brazing except aluminium and magnesium which cannot easily be joined by brazing.
- Because of the lower temperatures used there is less problems due to heat.
- The joint can be quickly finished without much skill.
- Because of the simplicity of the process it is often an economical joining method with reasonable joint strength.
- The brazed joints are reasonably stronger, depending on the strength of the filler metal used.

Disadvantages:

- Flux material required to prevent the corrosion.
- Large section cannot be joined.
- Fluxes and filler materials may toxic.

Applications of Brazing:

Brazing has been used to manufacture a wide variety of products such as Honey comb sandwich panels for aircraft missiles, motor cycle frames, air plane propellers, Hydraulic fitting, refrigerator evaporators, manufacture of cutting tools etc.,

The use of pressure-vacuum brazing has found wide spread acceptance in the general application of brazing joint in nuclear, aerospace engineering.

3. WELDING

Welding is a process of metallurgically joining two pieces of metals by the application of heat with or without the application of pressure and addition of filler metal. The joint formed is a permanent joint. Modern methods of welding may be classified under two broad headings.

a. Plastic welding process
b. Fusion welding process

In plastic welding process the pieces of metal to be joined are heated to a plastic state and then forced together by external pressure. This procedure is used in forge welding, resistance welding, spot welding in which pressure is required.

In the fusion welding, the material at the joint is heated to a molten state and allowed to solidify. This includes gas welding arc welding and Thermit welding.

The surfaces of the metal which are to be joined by any of the welding processes must be sufficiently clean to permit clean metallic surfaces to come in to contact. In some operations, materials known as fluxes are applied to the parts being welded to dissolve the oxides or to prevent the formation of oxides. Fluxes are different for different metals. For ferrous materials borax, sodium carbonate etc, have been found to give excellent results.

Types of Joints:

The welding joints are classified as Butt, Lap, Tee, Corner joints and edge joints. The choice of the type of joint is governed by the kind of metal to be welded, its thickness and technique of welding. Figure 4.6 shows the different types of joints used in welding.

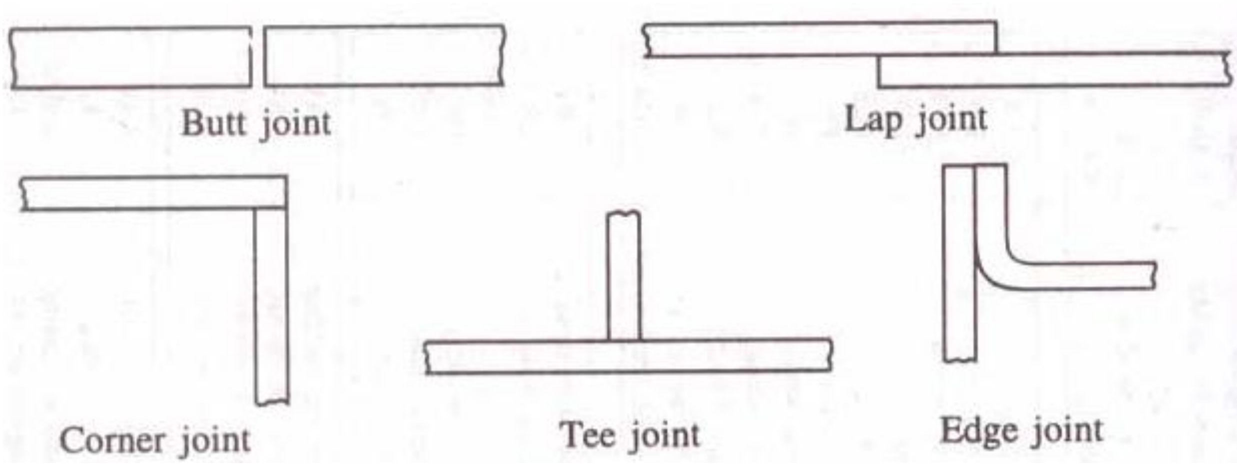
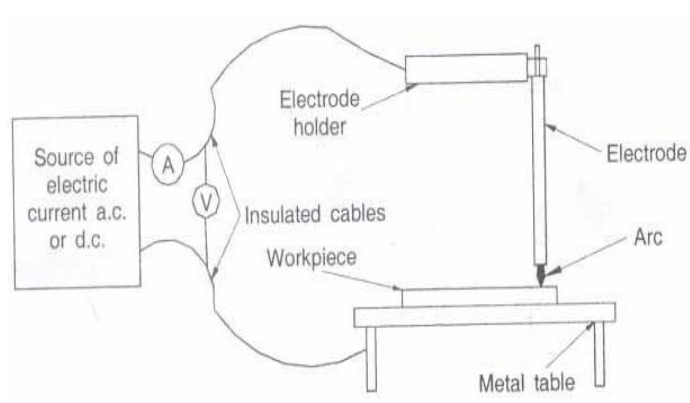


Figure 4.6: Different Types of Joints

3.1. ARC WELDING:

Arc welding is a method of joining metals with heat produced by an electrical arc. In this process the heat necessary to melt the edges of the metal to be joined is obtained from an electric are struck between the electrode (filler rod) and the work, producing a temperature of 4000^0C, in the welding zone. The heat of the arc melts the base metal or edges of the parts fusing them together. Filler metal, usually added melts and mixes with molten base metal to form the weld metal. The weld metal cools and solidifies to form the weld. In most cases, the composition of the filler material, known as welding rod, needed to provide extra metal to the weld, is same as that of the material being welded.



A typical arc welding setup is shown in Figure 4.7.

1. An arc welding circuit consists of a power supply to furnish electric power.
2. An electrode to conduct the electricity to the arc.
3. Cables which connect the power supply to the electrode and workpiece to complete the welding circuit.
4. The arc itself provides the heat for welding.

5. The workpiece to weld is kept on a metallic table. **Figure 4.7: Arc Welding Setup**

The arc must be shielded because; as it hardens the molten metal combines with oxygen and nitrogen to form impurities that weaken the weld. Shielding can be obtained by adding a paste, powder or fibrous flux to the arc. The electrodes are usually coated with a flux. This coating forms a gaseous cloud that shields the molten metal from the atmosphere. The coating also forms a protective slag. The slag floats on the molten pool and hardens as the weld cools. This keeps impurities out of the weld. The process is shown in Figure 4.8.

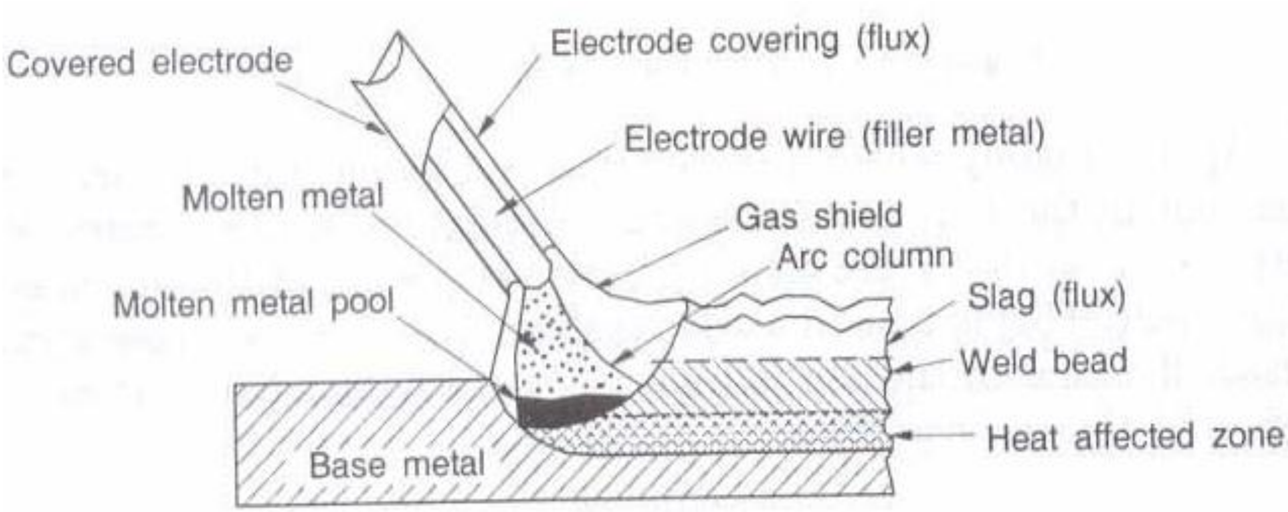


Figure 4.8: Arc Welding Process

Advantages:

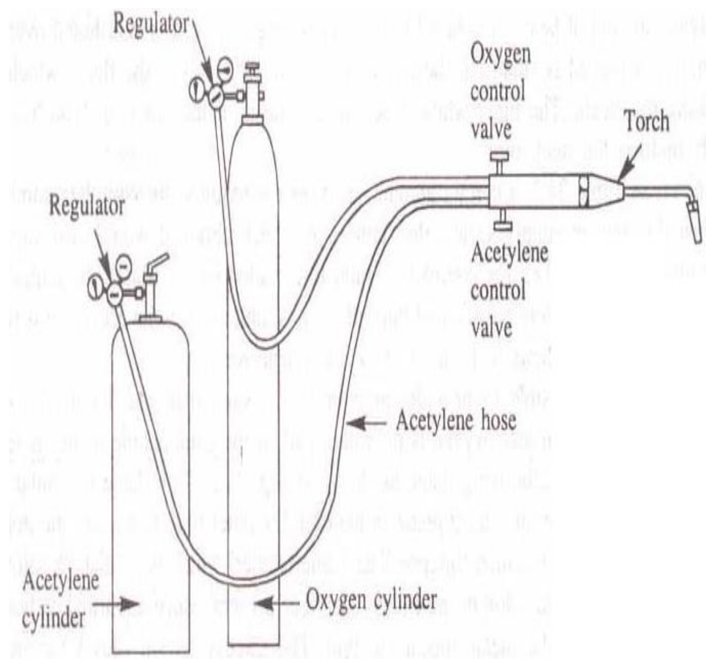
1. As a manual process it is applicable to an infinite variety of work and can be executed in any position.
2. There is less buckling and warping of the work.
3. It produces strong sound and ductile welds.
4. Satisfactory welds can be produced in heavy as well as in light sections.
5. Low cost process.
6. Excellent joint properties can be obtained in mild, low alloy and stainless steels, nickel and copper-base alloys.
7. Low accuracy in setting up required.

Disadvantages:

1. Basically a manual process requiring adequate operator skill for good results.
2. Electrodes require frequent changing.
3. Multi run welds necessary on thick plate-slag chipping necessary after each run.
4. The principal disadvantage has been the high heat of the metal arc which makes it unsuitable for use on materials less than 1.55 mm thick.
5. High initial cost of welding equipment.

3.2. GAS WELDING

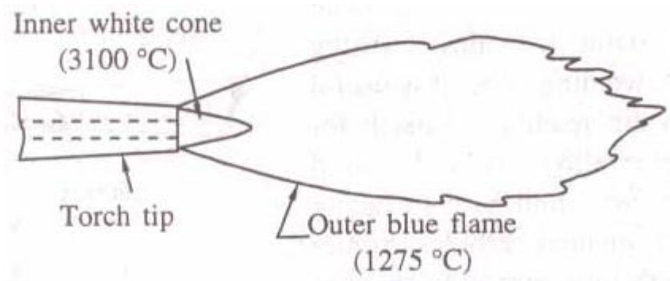
Gas welding is a fusion welding process, in which a flame produced by the combustion of gases is employed to melt the metal. The molten metal is allowed to flow together thus forming a solid continuous joint upon cooling. By burning pure oxygen in combination with other gases, in special torches, a flame upto 3300^0 C can be attained. The gas is purchased in cylinder and connected through resulting valves and pressure gauges into flexible hoses attached to the nozzle. A typical arrangement is shown in Figure 4.



The oxy-acetylene flame is used to pre heat the parts to be welded around the joint and also to melt the filler metal. A jet of oxy acetylene flame issuing from the nozzle of a burner is played on the junction of the two pieces to be welded. At the same time a filler rod is held in the zone of jet and its melt is deposited on the fused junction. A weld is obtained after the molten metal solidifies. The coating on the filler rod acts as a flux to keep the joint clean. The filler metal or filler rod used must combine with the parts being joined. The melting point of the filler metal must be the same or lower than the melting point of the metal being joined.

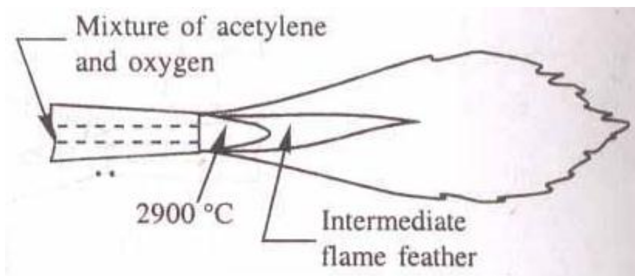
Neutral Flame:

The correct adjustment of the flame is very important for reliable works. When oxygen and acetylene are supplied to the torch in nearly equal volumes, a neutral flame is produced having a maximum temperature of 3200^0C. This neutral flame is desired for most welding operations. Neutral flame has little effect on the base metal and sound welds are produced when compared to other flames. Figure 5 shows neutral flame.



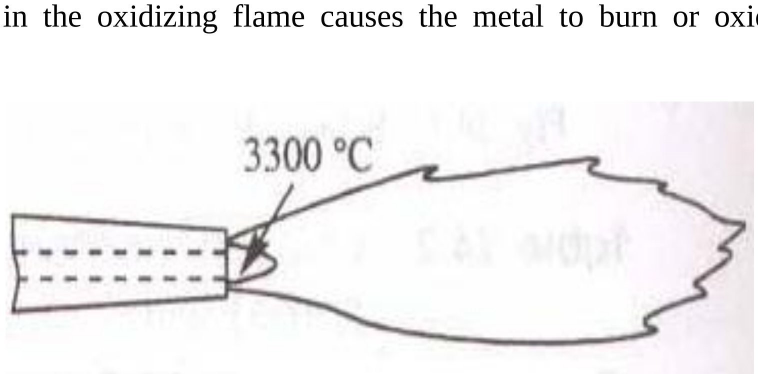
Carbonizing Flame:

In a carbonizing flame or reducing flame excess of acetylene is present. The temperature of this flame is low. The excess unburnt carbon is absorbed in ferrous metals, making the weld hard and brittle. In between the outer blue flame and inner white cone, an intermediate flame feather exists, which is reddish in colour. The length of the flame feather is an indication of the excess acetylene present. Figure 6 shows a carbonizing flame. Carbonizing flame is used for welding high carbon steels and cast iron, alloy steel and for hard facing.



Oxidizing Flame:

In an oxidizing flame excess of oxygen is present. The flame is similar to the neutral flame with the exception that the inner white cone is some what small, giving rise to higher tip temperatures. Excess of oxygen in the oxidizing flame causes the metal to burn or oxidize quickly. Oxidizing flame is useful for welding some nonferrous alloys such as copper and zinc base alloys. The Figure 7 shows the oxidizing flame.



Advantages:

1. The equipment is in expensive in complicated and it is easily portable.
2. Useful for welding light metals such as automobile bodies and repair works.
3. A large variety of material can be welded.
4. Welds can be produced at reasonable cost.
5. Compared to electric arc welding this provides greater flexibility with respect to heat impact and cooling rates.

Disadvantages:

1. Gas welding equipment must always be handled carefully as in certain circumstances acetylene is explosive (when a flame is applied under pressure) as oxygen when used in an oily atmosphere (such as an olds dirty garage floor pit).
2. A high temperature flame from a hand held torch is dangerous when handled carelessly.
3. It is much slower than electric arc welding and does not concentrate the heat close to the weld. Thus, the heat treated area is larger, which causes more distortion.
4. Highly skilled operators are required to produce a good weld.
5. If electric arc welding is available gas welding is seldom used for work over 3.2mm thick.
6. The process is not satisfactory for heavy section.

POWER TRANSMISSION

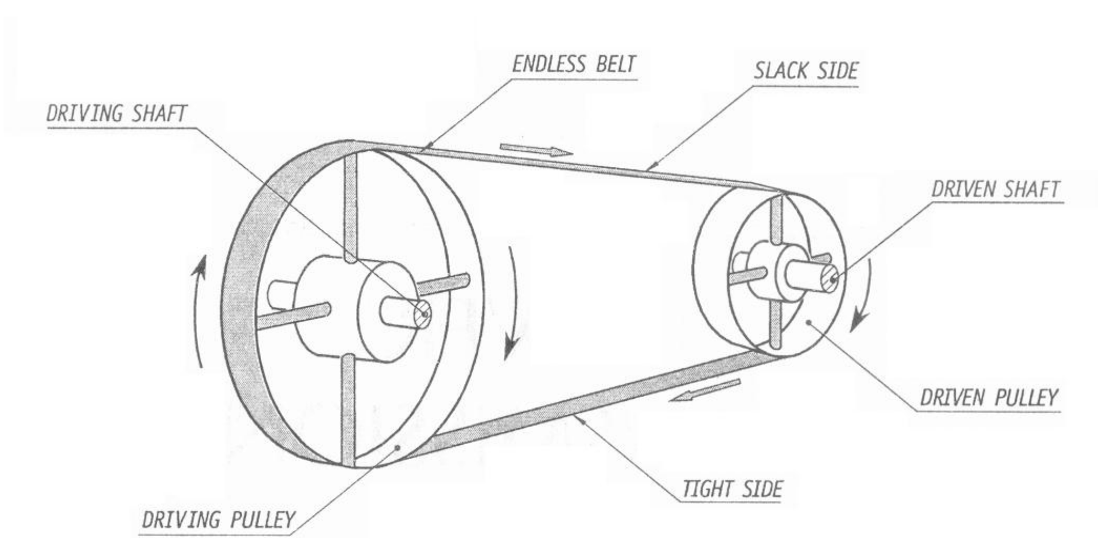
A source of power is very essential for running various machines. A system which transmits power or motion from one system to another system is called transmission system. The method of transmitting power from a source by using transmission systems is known as power transmission.

A system which drives (supplies Power) is known as driving system or the driver. The system which is driven (receives Power) by the driver is known as driven system or the driven.

Classification:- Depending on the distance between the driver and the driven and depending on the speed and power to be transmitted. The Power Transmission systems are classified as

1. Rope Drives.
2. Chain Drives.
3. Belt Drives.
4. Rear Drives.

Belt Drives:- Belt Drive is one of the most common and effective means of transmitting power or motion from one shaft to the other by means of a thin inextensible belt running over two pulleys. A pulley is a circular disc having a hole at the center so as to accommodate a shaft in it as shown in figure.



The pulley mounted on the driving shaft is called driver, where as the pulley mounted on the driven shaft is called the driven or the follower. The belt passing over the pulley is kept in tension so as to avoid slip over the pulley. This helps in transmitting power effectively from one shaft to anther. Due to difference in tensions of the belt, the driven pulley rotates along with the driver pulley. The portion of the belt having less tension is called slack side, where as the portion of the belt having more tension is called tight side.

The tension is dependent on the direction of rotation of the driver pulley. If the direction of rotation of the driver pulley is clock wise, then the lower side of the belt will be tight side and the upper side will be slack side.

Materials used for belts:- The materials used for belts must be strong, flexible and durable. It should have a high coefficient of friction. The different materials used in manufacturing of belt are Leather, Rubber, Cotton or Fabric and Balata.

Leather belts may be used in both dry and wet conditions. Rubber belts are used when the belts are exposed to damp conditions. Fabric or Cotton belts are used when atmospheric conditions affect the leather or rubber belt. Balata bets are the widely used types of belts.

Types of Belt Drives:- Based on the cross section, the belt drives are classified as

1. Flat Belt Drives.
2. V-Belt Drives.

1. Flat Belt Drives:- Flat Belts are used to transmit power between two shafts when the center distance between the shaft is large. Flat Belts are usually endless and the belt runs over the pulley.

Advantages

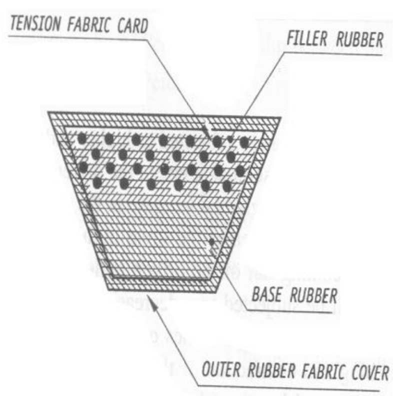
- It is used when the center distance between the two shafts is more.
- The speeds can be varied by varying the diameters of the pulleys.
- Low installation and operating costs.
- It is highly flexible to over loads with longer life and can be subject to rough operation.

Dis-Advantages

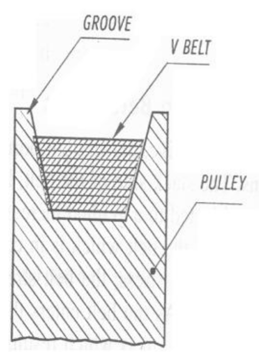
- They are not efficient when the center distance between the two shafts is small.
- The slip between the belt and pulleys causes the driven pulley to rotate at lesser speed. This reduces the power transmission.
- They are used for transmitting only between parallel shafts.
- Exact velocity ratio cannot be maintained.

2. V – Belt Drive:- V – Belts are used to transmit power between two shafts when the center distance between the shaft is small. V – Belts are usually endless and trapezoidal in cross section as shown in figure. The belts are made of fabric and cord (that carry load) molded in rubber and covered with fabric and rubber.

In case of flat belt drive, the belt runs over the pulley where as in V – Belt Drive, the rim of the pulley is grooved so as to accommodate the V – Belt as shown in figure. The effect of the groove is to increase the grip of the V – Belt on the pulley, there by reducing the chances of slipping.



Section of V-Belt



V-Belt in Groove

Advantages

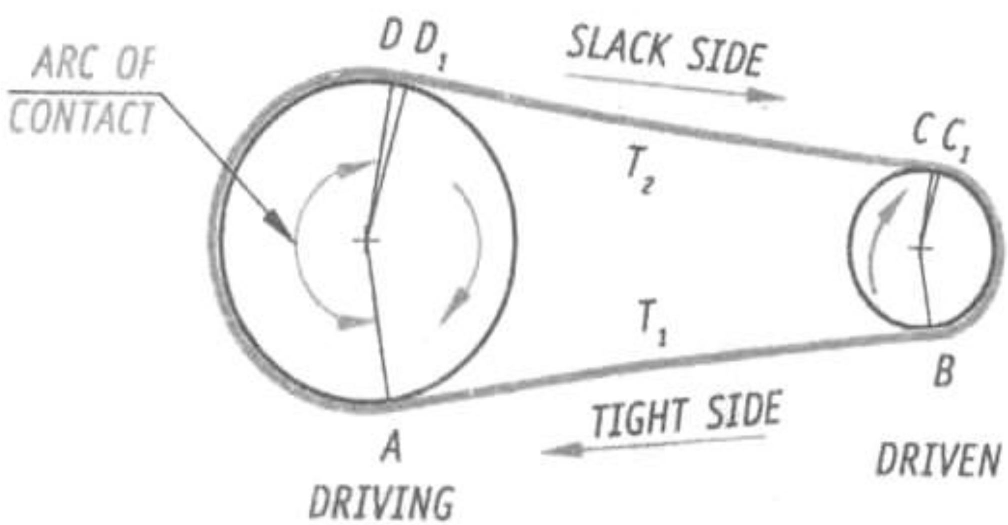
- They can transmit higher power.
- They can be used for small center distances.
- There is no slipping of the belt from the pulley.
- They can be used to get high velocity ratio.
- It is possible to operate with the shaft axes in any positions.

Dis-Advantages

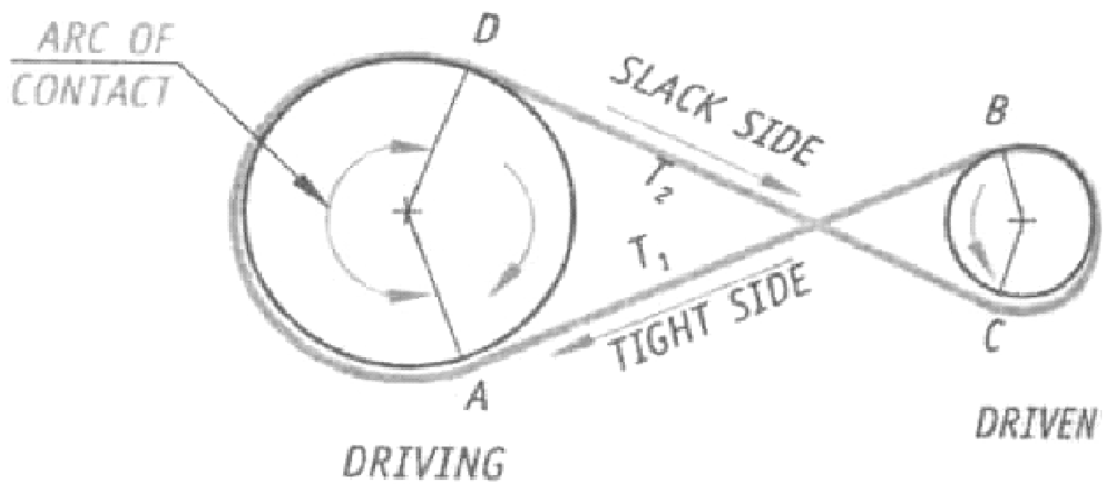
- It cannot be used for large center distance.
- They have shorter life span due to continuous rubbing of the belt in the groove.
- Their construction is not simple.
- Their cost is high.

1. Open Belt Drive.
2. Cross Belt Drive.

1. Open Belt Drive:- Open Belt Drives are used to connect two shafts that are parallel and rotating in the same direction as shown in figure. Generally lower side of belt should be tight side and upper side of belt should be slack side. Due to the lesser tension on the slack side, the belt sags due to its own weight, hence increasing the arc of contact and transmission capacity.

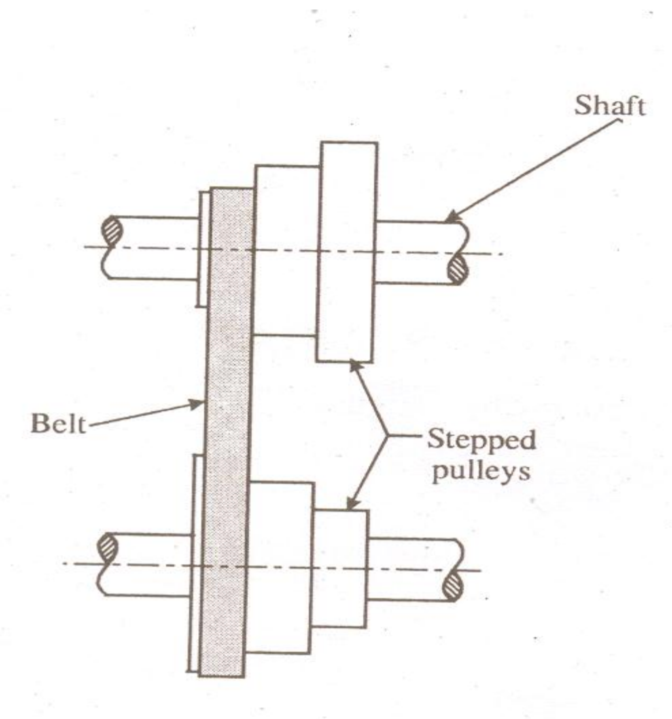


2. Cross Belt Drive:- Cross Belt Drives are used to connect two shafts that are parallel and rotating in the opposite direction as shown in figure. At the junction where belt crosses, it rubs against it self and wears off. To avoid excessive wear, the shafts must be placed at a maximum distance from each other and operated at very low speeds.

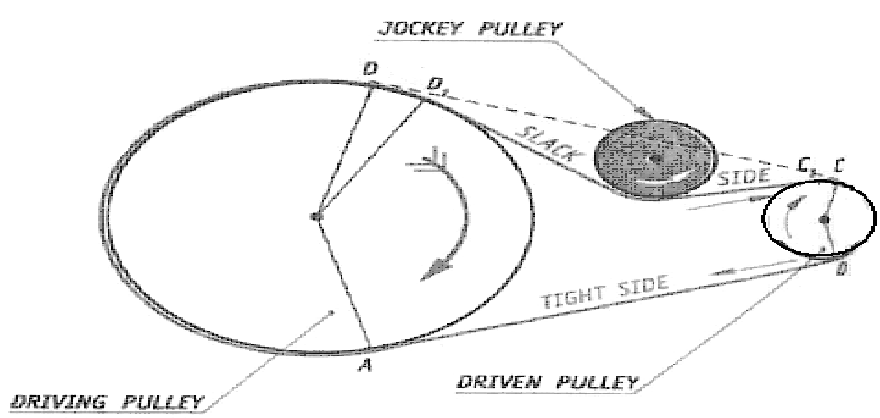


Types of Pulleys:- Pulleys are used to transmit power from one shaft to another shaft using belts or ropes. They are made of cast iron, steel etc. Some important types of pulleys are

1. Stepped Cone Pulley:- A Stepped Cone Pulley having several steps of varying diameters mounted on two parallel shafts such that the smallest step of one pulley is opposite to the largest step of the other as shown in figure. A belt runs over them. These pulleys are used when the speed of driven shaft is to be changed very frequently, by shifting the belt from one pair of pulleys to the other.

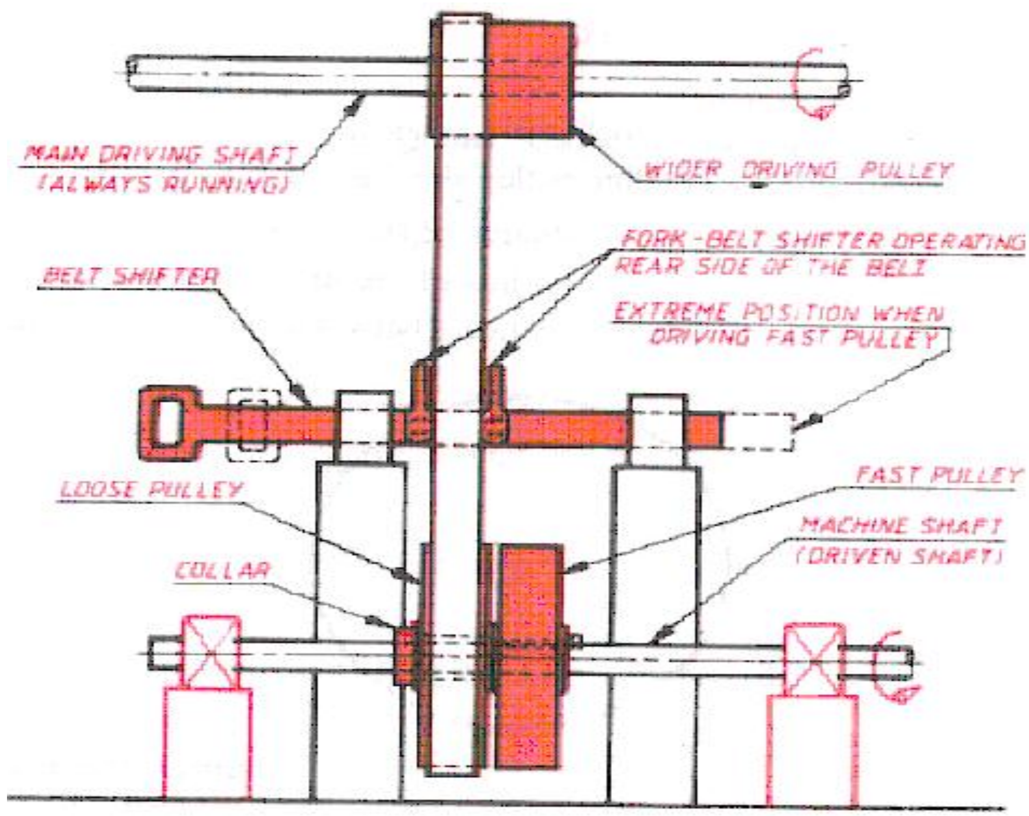


2. Idler (Jockey or Rider) Pulley:- In an open belt drive arrangement, if the center distance is small or if driven pulley is very small then the arc of contact of the belt with the driven pulley will be very small, which reduces the tensions in the belt. An Idler Pulley called Jockey Pulley is place on the slack side of the belt as shown in figure, which increases the arc of contact and thus the tensions which results in increased power transmission.



3. Fast and Loose Pulley:- When a number of machines obtain the drive from a main driving shaft, often it may required to rum some of the machines to be stopped and started intermittently without stopping and starting the main driving shaft every time. This can be accomplished by mounting two pulleys known as Fast and Loose Pulleys as shown in figure.

A Loose Pulley is free to rotate where as the Fast Pulley is rigidly secured to the shaft. This pair is mounted on a counter shaft placed above or near the machine to be operated. The counter shaft rotates when the driving belt from the main shaft is engaged on the Fast Pulley. This belt can be shifted from the Fast Pulley on to the Loose Pulley using a belt shifter, when the belt from the main shaft is engaged on the Loose Pulley the counter shaft rotating.



Fast and Loose Pulleys

Velocity Ratio of Belt Drives:- It is defined as the ratio of speed of driven pulley (Follower) to the speed of the driving pulley (Driver).

Let d_1 Diameter of driving pulley (Driver)

d_2 Diameter of driven pulley (Follower)

N_1 Speed of driving pulley

N_2 Speed of driven pulley

Assuming that there is no slip between the belt and pulley, the linear speed at every point on the belt must be same

Linear Speed of Belt = Surface Speed of Driver = Surface Speed of Driver

Hence $\Pi d_1 N_1 = \Pi d_2 N_2$ $d_1 N_1 = d_2 N_2$

Therefore

$$\text{Velocity Ratio} = V = \frac{N_2}{N_1} = \frac{d_1}{d_2}$$

Thus,

$$\text{Velocity Ratio} = \frac{\text{Speed of driven pulley}}{\text{Speed of driver pulley}} = \frac{\text{Diameter of driver pulley}}{\text{Diameter of driven pulley}}$$

Effect of Thickness of Belt on Velocity Ratio:- If we consider the thickness of belt 't', the Velocity Ratio equation is modified as follows

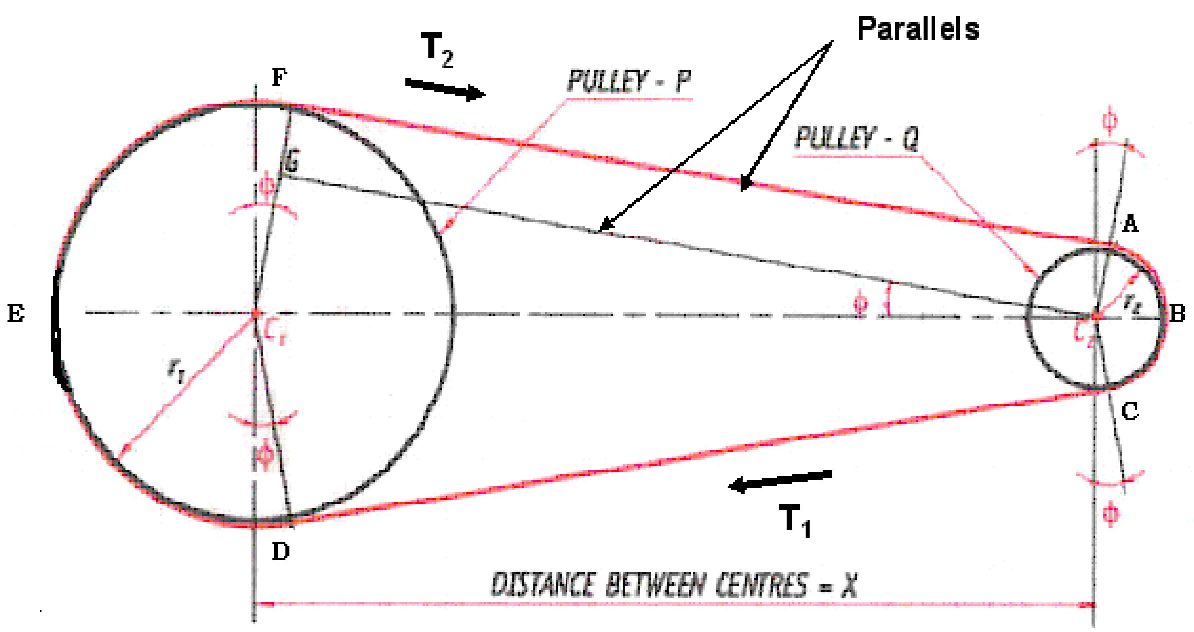
Linear Speed of Belt= Mean Surface Speed of driver= Mean Surface Speed of driven

Hence $\Pi(d_1+t)N_1 = \Pi(d_2+t)N_2$ $(d_1+t)N_1 = (d_2+t)N_2$

Therefore

$$\text{Velocity Ratio} = V = \frac{N_2}{N_1} = \frac{(d_1 + t)}{(d_2 + t)}$$

Length of a Open Belt Drive System



Consider two pulleys connected by a flat belt (Open Belt Drive) as shown in figure.

Let C_1 and C_2 be the centers lf larger and smaller pulley respectively.

Draw a line C_2G parallel to line FA.

Draw lines C_1F, C_1D and C_2A, C_2C

Let r1 → Radius of larger Pulley.

r2 → Radius of smaller Pulley.

X → Distance between centers of the two Pulleys.

L → Length of the Belt.

As shown in figure the arc of contact of larger pulley is DEF and the arc of contact of smaller pulley is ABC

Therefore Length of Open Belt Drive is given by

L= Arc length DEF + Length FA + Arc length ABC + Length CD

As Length FA = Length CD

L= Arc length DEF + 2 x Length FA + Arc length ABC

Length of Arc is given by

l= Arc radius x Included angle l=rxθ

L= $r_1[\pi + 2\phi] + 2 \times X \cos\phi + r_2[\pi - 2\phi]$

L= $\pi r_1 + r_1 2\phi + 2X\cos\phi + r_2\pi - r_2 2\phi$

L= $\pi(r_1 + r_2) + 2\phi(r_1 - r_2) + 2X\cos\phi$ ----------- (1)

From triangle GC_2C_1 $\sin\phi = \frac{r_1 - r_2}{X}$

$\sin^{-1}\left(\frac{r_1 - r_2}{X}\right) = \frac{r_1 - r_2}{X}$ ------------(2) because ϕ is very small

Now $\cos\phi = \sqrt{1-\sin^2\phi}$

Using Binominal Theorem and ignoring the higher order powers

$$\cos\phi = 1 - \frac{1}{2}\sin^2\phi = 1 - \frac{1}{2}\left[\frac{r_1 - r_2}{X}\right]^2$$ ---------------(3)

Substuting equation (2) and (3) in equation (1)

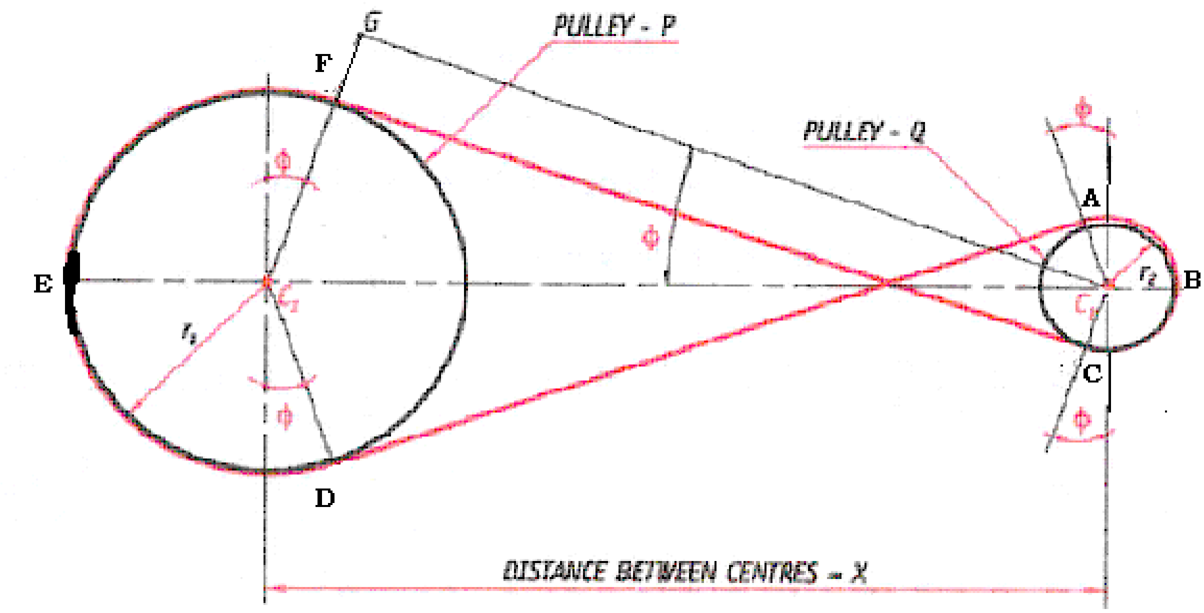
$$L = \pi(r_1 + r_2) + 2\frac{(r_1 - r_2)}{X} \times (r_1 - r_2) + 2X\left[1 - \frac{1}{2}\left(\frac{r_1 - r_2}{X}\right)^2\right]$$

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

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

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

Length of a Cross Belt Drive System



Consider two pulleys connected by a flat belt (Cross Belt Drive) as shown in figure.

Let C_1 and C_2 be the centers lf larger and smaller pulley respectively.

Draw a line C_2G parallel to line FC.

Draw lines C_1F, C_1D and C_2A, C_2C

Let r1 → Radius of larger Pulley.

r2 → Radius of smaller Pulley.

X → Distance between centers of the two Pulleys.

L → Length of the Belt.

As shown in figure the arc of contact of larger pulley is DEF and the arc of contact of smaller pulley is ABC

Therefore Length of Cross Belt Drive is given by

L= Arc length DEF + Length FC + Arc length ABC + Length AD

As Length FC = Length AD

L= Arc length DEF + 2 x Length FC + Arc length ABC

Length of Arc is given by

l= Arc radius x Included angle l=rxθ

L= $r_1[\pi + 2\phi] + 2 \times X \cos\phi + r_2[\pi + 2\phi]$

L= $\pi r_1 + r_1 2\phi + 2X\cos\phi + r_2\pi + r_2 2\phi$

L= $(\pi + 2\phi)(r_1 + r_2) + 2X\cos\phi$ ----------- (1)

From triangle GC_2C_1 $\sin\phi = \frac{r_1 + r_2}{X}$

$\sin^{-1}\left(\frac{r_1 + r_2}{X}\right) = \frac{r_1 + r_2}{X}$ ------------(2) because ϕ is very small

Now $\cos\phi = \sqrt{1 - \sin^2\phi}$

Using Binominal Theorem and ignoring the higher order powers

$$\cos\phi = 1 - \frac{1}{2}\sin^2\phi = 1 - \frac{1}{2}\left[\frac{r_1 + r_2}{X}\right]^2 \quad \text{---------------(3)}$$

Substuting equation (2) and (3) in equation (1)

$$L= \left[\pi + 2\frac{(r_1 + r_2)}{X}\right](r_1 + r_2) + 2X\left[1 - \frac{1}{2}\left(\frac{r_1 + r_2}{X}\right)^2\right]$$

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

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

$$\boxed{L= \pi(r_1 + r_2) + \frac{(r_1 + r_2)^2}{X} + 2X}$$

Power Transmitted by a Belt Drive

Let $T_1 \rightarrow$ Tension in tight side of the Belt in N.

$T_2 \rightarrow$ Tension in slack side of the Belt in N.

$d_1 \rightarrow$ Diameter of Driver pulley in mt.

$d_2 \rightarrow$ Diameter of Driven pulley in mt.

The effective turning force acting on the circumference of the follower is the difference in tensions on the tight side (T_1) and slack side (T_2) of the belt.

Therefore Driving force is given by

F= $(T_1 - T_2)$ N   F= $\frac{(T_1 - T_2)}{1000}$ KN

W.K.T Power P= $F \times V$ Where V → Velocity of Belt in mt/sec

Therefore

$$P = \frac{(T_1 - T_2)V}{60 \times 1000} \text{ KW}$$

Where V= $\pi d_1 N_1 = \pi d_2 N_2$ mt/min

Initial Tensions in Belt:- When the belt is wound around the two Pulleys the two ends of the belt are joined together tightly and are fixed over the pulleys so as to maintain a tight grip between the belt and the pulley.

Thus even when the pulleys are stationary the belt is subjected to some tensions and this tension is called initial belt tension. It is denoted by T_0 and is expressed as

$$T_0 = \frac{T_1 + T_2}{2}$$

Where $T_1 \rightarrow$ Tension in tight side of the Belt.

$T_2 \rightarrow$ Tension in slack side of the Belt.

Ratio of Tensions in Flat Belt Drive

The ratio of tensions is given by

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

Where $T_1 \rightarrow$ Tension in tight side of the Belt.

$T_2 \rightarrow$ Tension in slack side of the Belt.

$\mu \rightarrow$ Angle of contact between Belt and Pulley.

$\vartheta \rightarrow$ Co-efficient of Friction.

Slip in Belt Drives:- The common phenomenon encountered in belt drive is the slipping of belt. The power transmitted from one shaft to the other depends on the frictional grip between the belt and the pulley rim. There is always some amount of slip between the belt and the pulley rim.

The reasons for slipping of belt are

- When the difference in tensions is more than the frictional force.
- When the pulley surface is too smooth.
- When frictional force becomes lesser due to excessive belt stretching.

The effect of slip

- Reduce the velocity ratio.
- Reduce the capacity of belt to transmit power.
- Also causes damage to the belt.

Slip may be defined as the relative motion between the pulley and the belt passing over it. It is generally expressed as a percentage.

When the slip is considered the velocity ratio is given by

$$\text{Velocity Ratio} = \frac{N_2}{N_1} = \frac{d_1}{d_2}\left[\frac{100 - S}{100}\right]$$

Where S → Percentage Slip.

$S = S_1 + S_2$

S_1→ Percentage slip between driver pulley and Belt.

S_2→ Percentage slip between driven pulley and Belt.

If the thickness of belt is taken in to consideration

$$\text{Velocity Ratio} = \frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}\left[\frac{100 - S}{100}\right]$$

Creep in Belt Drive:- As the material of belt is elastic, length of the belt elongates more on tight side than on slack side resulting in uneven stretching. As the slack side of the belt with lower tension enters the driven pulley, the portion of the belt in contact with the driven pulley increases the stress in the belt, which results in elongation of the belt. On the other hand, when the tight side of the belt enters the driving pulley, the portion of the belt in contact with the driving pulley decreases the stress in the belt and hence the belt contracts. Due to this uneven tension and contraction of the belt a relative motion between the belt and the pulley surface exists. This relative motion between the belt and the pulley surface to uneven stretching of the belt is known as creep. Creep in belt is unjustified as it results in loss of power and reduced velocity ratio.

GEAR DRIVES:

A wheel provided with teeth is called Gear.

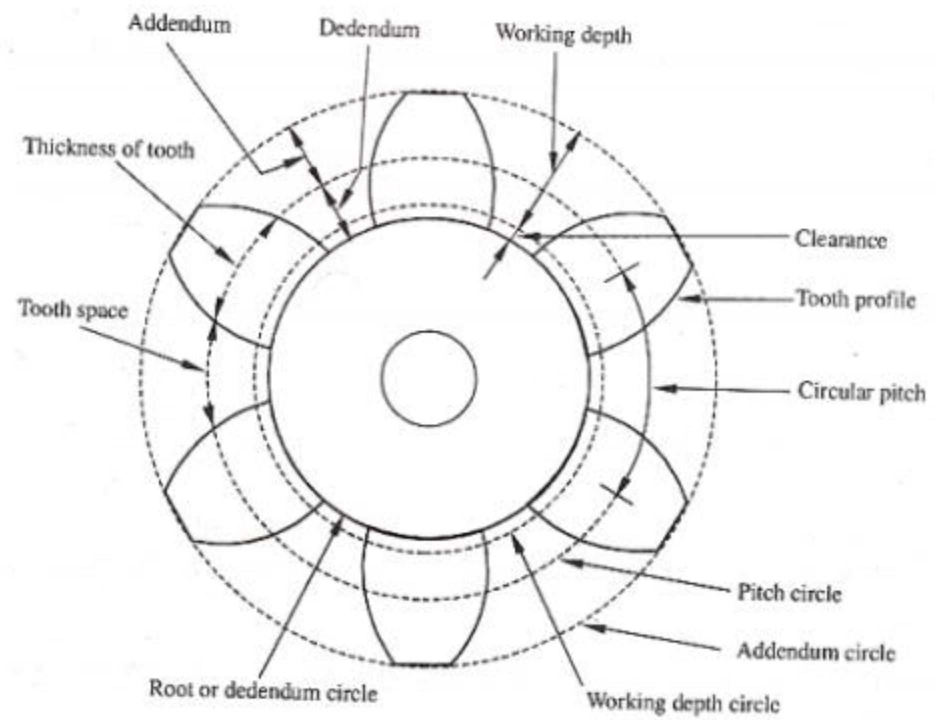
Gears are used to transmit power or motion from one shaft to another

Types of Gears:- Gear drives transmit power form one shaft to another shaft, when their axes are parallel or intersecting and neither parallel nor intersecting. There are various types of gears and the selection of a particular type of gear depends on the application. Gears are commonly classified based on the position of axis of the shaft on which the gear is mounted, they are

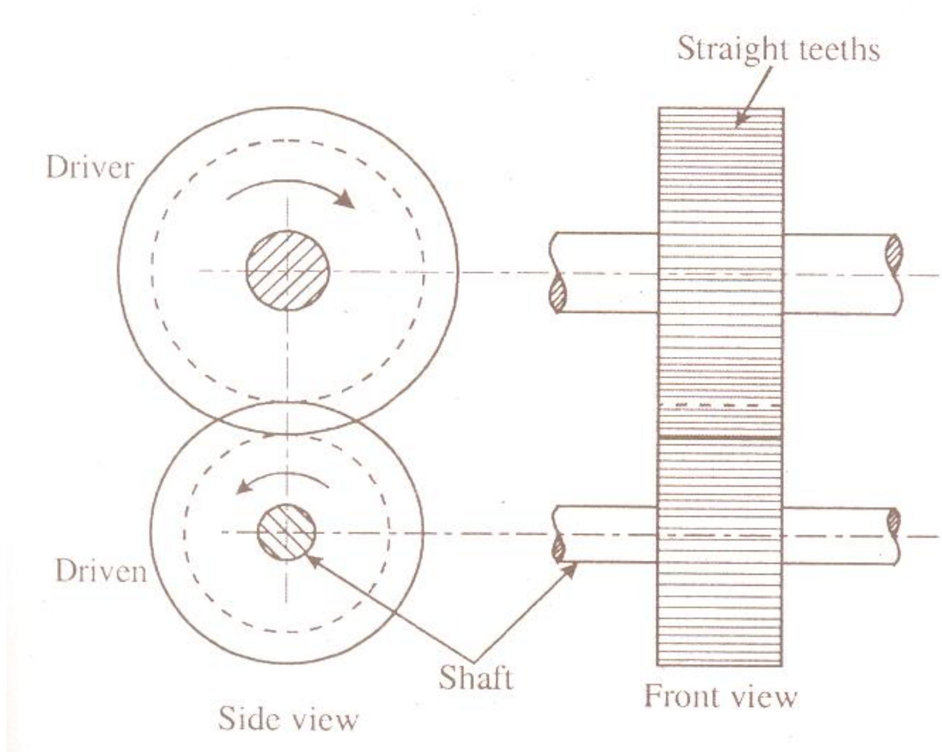
1. Spur Gears - For parallel axes shafts.
2. Helical Gears - For both parallel and non-parallel and non-intersecting axes shafts.
3. Spiral Gears - For non-parallel and non- intersecting axes shafts.
4. Bevel Gears - For intersecting axes shafts.
5. Worm Gears - For non-parallel and non-co-planar axes shafts.
6. Rack and Pinion - For converting rotary motion into linear motion.

1. **Spur Gear:-** Spur Gears are the simplest and the most commonly used gears designed to transmit motion between two parallel shafts as shown in figure. The axis of the two shafts i.e. the driving

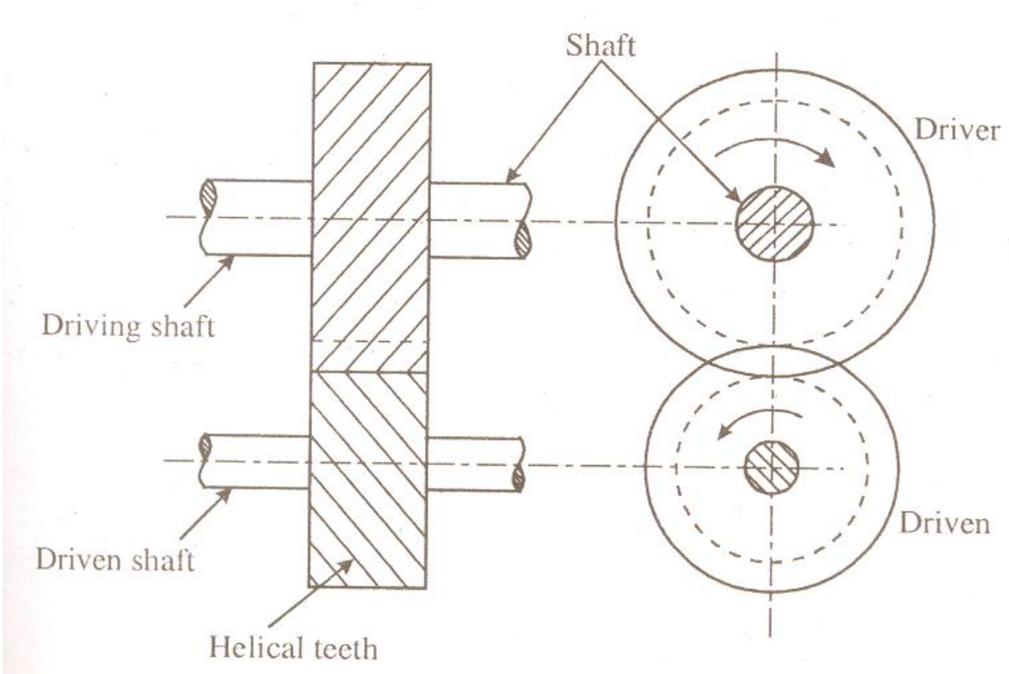
shaft and the driven shafts are parallel to each other. The teeth are cut straight on the periphery of the wheel and they are parallel to the axis of the wheel. Spur Gears are used in machine tools, gear boxes, alarm clock and watches etc



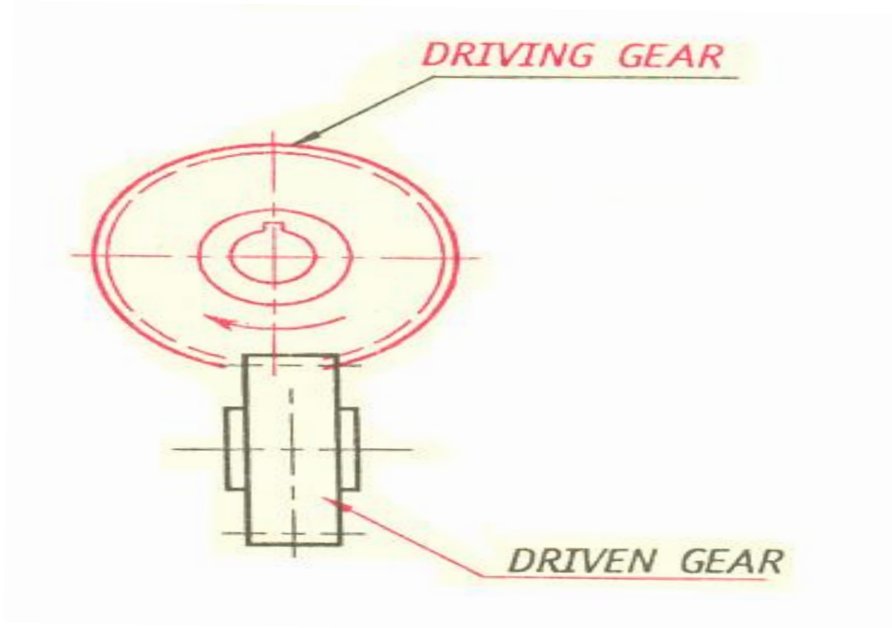
2.



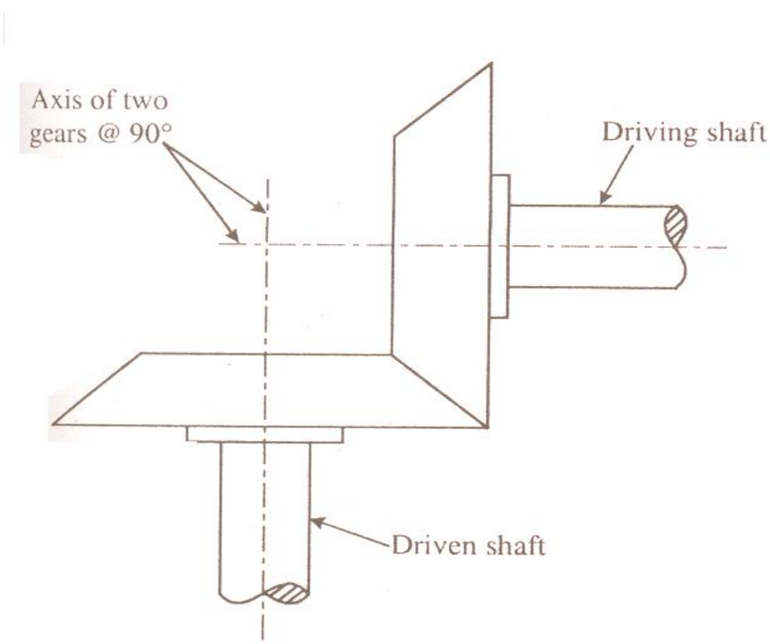
2. Helical Gears:- Helical Gears used to transmit power between two parallel or non-parallel but non-intersecting shafts as shown in figure. In Helical Gears, the teeth are curved each being helical in shape and hence the name helical gears. When two teeth on a helical gear engage, the contact starts at one end of the teeth and gradually spreads as the gears rotate until the two teeth are in full engagement. This gradual engagement makes helical gears run much more smoothly and quietly than spur gears. They are used in automobiles.



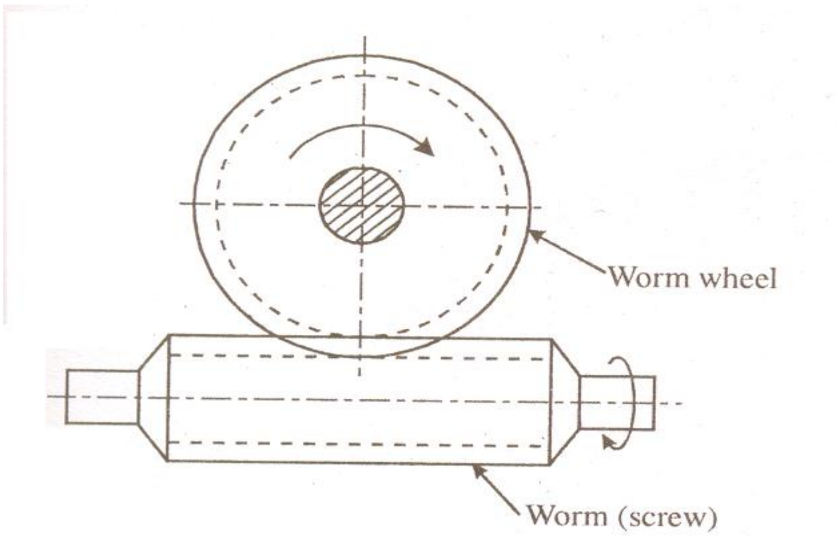
3. Spiral Gear:- Spiral Gears are used to connect non-parallel and non-intersecting shafts as shown in figure. The gears are cylindrical in shape and teeth have point contact. Hence they are used to transmit small power.



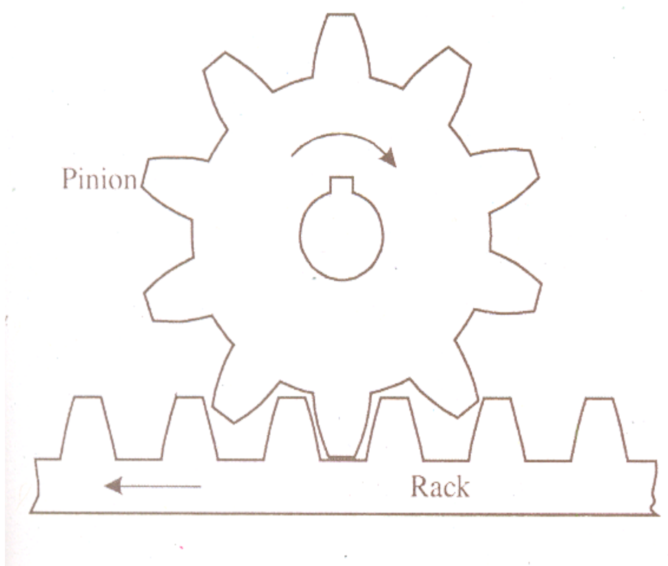
4. Bevel Gear:- Bevel gears are used for transmitting power between two intersecting shafts as shown in figure. They are usually mounted on shafts that are 90^0 apart, but can be designed to work at other angles also. The teeth are cut on the outside of the conical surface and vary in cross-section throughout their length. Since the diameter of the cone is more on its base, the teeth will be thicker at the base. The teeth on Bevel gears can be straight, spiral. When two bevel gears have their axes at right angles and are of equal sizes, they are called miter gears.



5. Worm Gear (Worm & Worm Wheel):- Worm gears are used to transmit power between two shafts having their axis at right angles and non-intersecting as shown in figure. Worm gear is a type of screw gearing that consists of a screw meshing with a helical gear. The screw is called Worm and the gear wheel meshing with the wheel is called Worm Gear or Worm Wheel. Here the contact between the teeth is line contact, they are used in machine tools. The worm and worm wheel cannot be rotated in the reverse direction.



6. Rack & Pinion:- Rack is a gear having teeth cut along a straight line, while a Pinion is a gear with teeth cut along its periphery as shown in figure. With the help of Rack and Pinion, rotary motion can be converted in to linear motion.



Advantages of Gear Drives

- They can be used to transmit power between parallel, non-parallel, intersecting and non-intersecting shafts.
- They are positive drives without slip and have higher transmission efficiency.
- They are well suited for small center distances.
- The velocity ratio of gear drives remains constant throughout.
- The drive has higher velocity ratio.
- They can be used for low, medium or high power transmission.

Dis-Advantages of Gear Drives

- They are not suitable for longer center distances.
- They always require some kind of lubrication.
- At very high speeds noise and vibration will be more.
- Cost for production of gears is high.
- Damage to the single teeth affects the whole arrangement.

Comparison between Belt Drives and Gear Drives

Belt Drive	Gear Drive
1. They are non-positive drives, as there is a reduction in power transmission due to slip.	1. They are positive drives.
2. Efficient when the center distance between the two shafts is more.	2. Efficient when the center distance between two shafts is very small.
3. Used to transmit power between parallel shafts.	3. Used to transmit power between parallel, non-parallel, intersecting and non-intersecting shafts.
4. Due to slip exact velocity ratio cannot be maintained.	4. Due to absence of slip, constant velocity ratio can be maintained.
5. Only moderate power can be transmitted.	5. Can be used for low, medium or high power transmission.
6. Power transmission efficiency is low.	6. Power transmission efficiency is more.
7. Lubrication is not required.	7. Requires some kind of lubrication.

Velocity Ration of Gear Drives:- The velocity ratio of a gear drive is defined as the ratio of the speed of the driven gear to the speed of the driving gear.

Let

d1 = pitch circle diameter of the driver gear

d2 = pitch circle diameter of the driven gear

T1 = Number of teeth on the driver gear

T2 = Number of teeth on the driven gear.

N1 =speed of the driver gear in rpm

N2 = speed of the driven gear in rpm

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

Hence $\pi d_1N_1 = \pi d_2N_2$

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad \text{………………} (1)$$

The circular pitch for both the mating gears remain same

Hence $p_c = \frac{\pi d_1}{T_1} = \frac{\pi d_2}{T_2}$ $\qquad \frac{d_1}{T_1} = \frac{d_2}{T_2}$ ……………… (2)

Substituting equation (2) in (1)

$$\text{Velocity Ratio of a Gear Drive} = \frac{N_2}{N_1} = \frac{d_1}{d_2} = \frac{T_1}{T_2}$$

Velocity Ration of Worm Gear:- A Worm gear consists of a screw called Worm and a wheel called worm wheel.

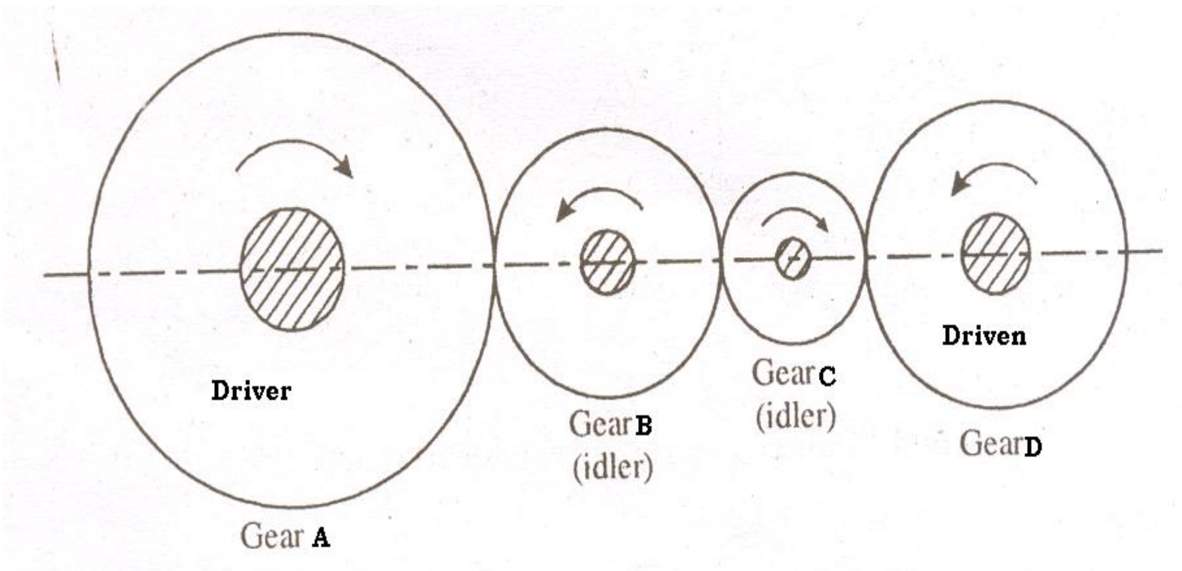
$$\text{Velocity ratio} = \frac{\text{Speed of the worm}}{\text{Speed of the worm wheel}} = \frac{\text{Number of teeth on worm wheel}}{\text{Number of teeth on the}}$$

Gear Trains:- A gear train is an arrangement of number of successively meshing gear wheels through which the power can be transmitted between the driving and driven shafts. The gear wheels used in a gear train may be Spur or Helical or Bevel etc. the velocity ratio between the driving and the driven shafts depends on the type of combination of gear wheels arranged in a gear train.

The different types of gear trains are

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

1. Simple Gear Train:- In a simple gear train, a series of gear wheels are mounted on different shafts between the driver and driven shafts, each gear carrying only one gear as shown in figure. A is a driving gear, D is a driven gear and B & C are the intermediate gears also called as Idler gears, because the velocity ration depends only upon the number on teeth on the driver and driven gear, but they change the direction of rotation of driven gear.



When the number of Idler gears are even, the driver and driven gears rotates in opposite direction. When the number of Idler gears are odd, the driver and driven gears rotates in same direction.

Let

N_A, N_B, N_C and N_D be the speed of Gear A, B, C & D respectively.

T_A, T_B, T_C and T_D be the number of teeth in Gear A, B, C & D respectively.

1. Gear A drives B

$$\frac{N_B}{N_A} = \frac{T_A}{T_B} \quad \text{………….. (1)}$$

2. Gear B drives C

$$\frac{N_C}{N_B} = \frac{T_B}{T_C} \quad \text{……………(2)}$$

3. Gear C drives D

$$\frac{N_D}{N_C} = \frac{T_C}{T_D} \quad \text{……………(3)}$$

The Velocity Ration between the driving and driven gear is given by,

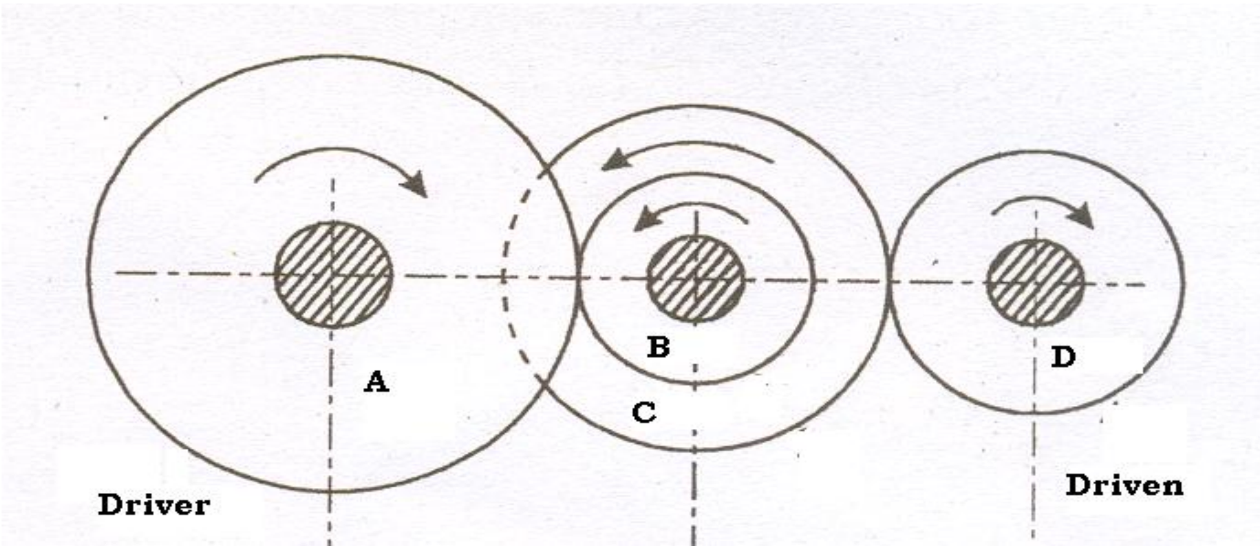
$$\frac{N_D}{N_A} = \frac{N_D}{N_C} \times \frac{N_C}{N_B} \times \frac{N_B}{N_A}$$

Substituting equation (1), (2) and (3)

$$\frac{N_D}{N_A} = \frac{T_A}{T_B} \times \frac{T_B}{T_C} \times \frac{T_C}{T_D}$$

Velocity Ratio of Simple Gear Train = $\frac{N_D}{N_A} = \frac{T_A}{T_D}$

2. Compound Gear Train:- In a Compound Gear Train, the intermediate shaft carries two gears which are keyed to it. When velocity ratio is very high, a simple gear train becomes practically impossible in such cases a compound gear train is used.



As shown in figure, A is the driving gear, D is the driven gear and B & C keyed to an intermediate shaft and are called compound gears. Since gear B & C are mounted on the same shaft, they rotate at the same speed and direction.

Let

N_A, N_B, N_C and N_D be the speed of Gear A, B, C & D respectively.

T_A, T_B, T_C and T_D be the number of teeth in Gear A, B, C & D respectively.

1. Gear A drives B

$$\frac{N_B}{N_A} = \frac{T_A}{T_B} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

2. Since the gears B and C keyed to the same shaft, both of them rotate at the same speed i.e. N_B=N_C but T_B=T_C

3. Gear C drives D

$$\frac{N_D}{N_C} = \frac{T_C}{T_D} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

The Velocity Ration between the driving and driven gear is given by,

$$\frac{N_D}{N_A} = \frac{N_D}{N_C} \times \frac{N_C}{N_A}$$

Substituting equation (1) and (2)

$$\frac{N_D}{N_A} = \frac{T_A}{T_B} \times \frac{T_C}{T_D}$$

Velocity Ratio of Compound Gear Train = $\frac{N_D}{N_A} = \frac{T_A}{T_B} \times \frac{T_C}{T_D}$

****

MODULE V: MACHINE TOOLS, CNC AND ROBOTICS

Cutting tools:- Tools which are used to separate/remove material stock from the work piece are known as cutting tools. Ex hack saw, chisel etc.

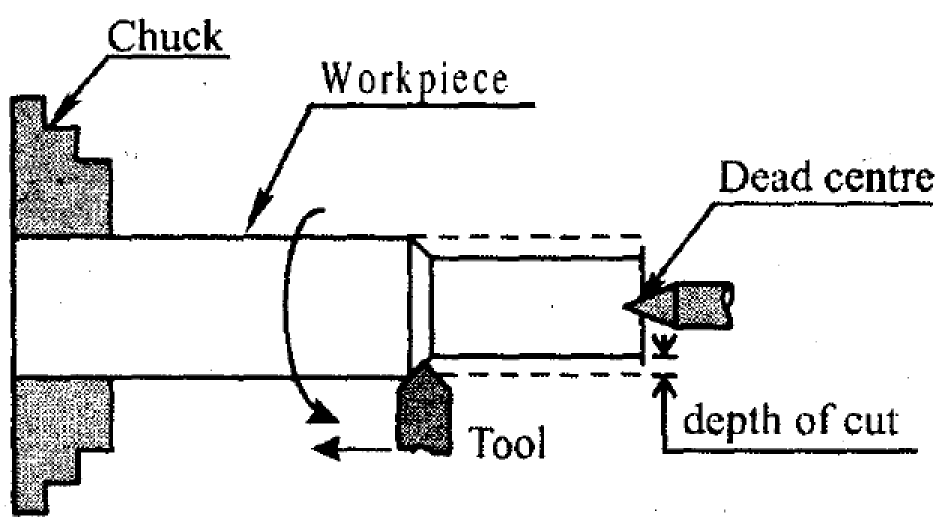
Machine tools: - Machine tools are power driven cutting tools or machines which enable the removal of excess stock of material from the work piece.

Relative Motion: - change in position of a object (fixed/moving) with respect to the other object (fixed/moving)is called as relative motion.

Lathe:-

- Lathe is one of the most widely used machine tools in metal cutting work.
- Lathe is usually used for machining (metal removal) the job which is rotated and a cutting tool is fed to cause the cutting action.
- Lathe is generally used for machining cylindrical jobs.

Working principle of Lathe



The work piece is hold firmly in the work holding device called the chuck and is supported by the dead center as shown in the fig.above

The chuck is rotated at a particular speed by some mechanisms; the cutting tool is moved against the rotating work piece to facilitate the removal of material.

Schematic diagram of Lathe Machine.

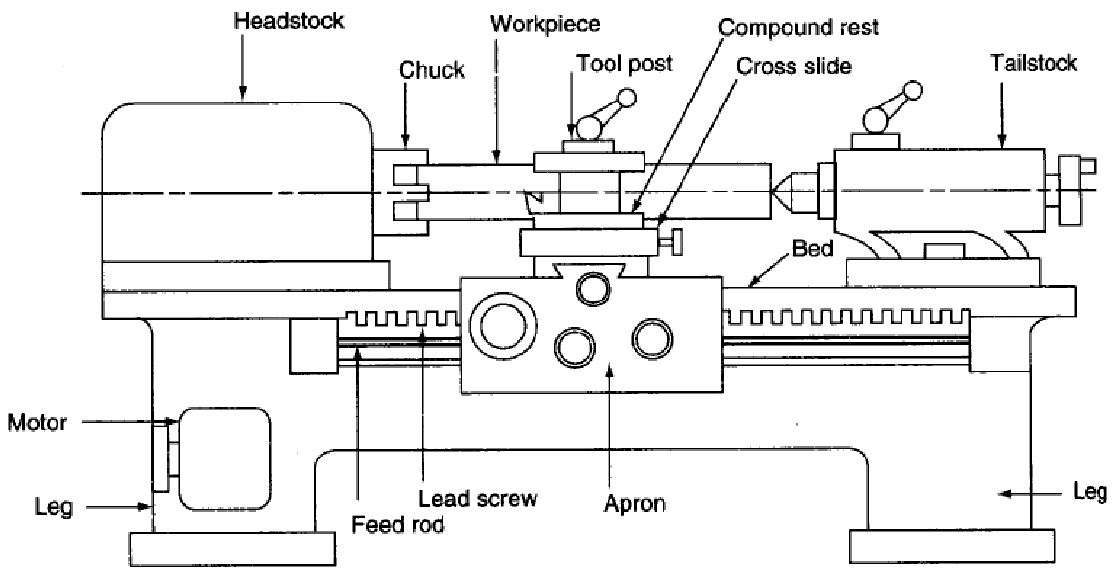


Figure 1 Lathe machine.

1. Bed: The lathe bed provides a heavy rigid frame on which all the main components like headstock, tail stock and carriage are mounted. It comprises inner and outer guide rails that are precision machined. bed is made out of cast iron alloy.

2. Headstock: It is mounted in a fixed position at the left end on the bed. It carries a hollow spindle which can rotate at different speeds.

The spindle carries a work-holding device which in turn rotates the job to be machined. The spindle speed is controlled by a stepped cone pulley and back

gear arrangement both of which are housed inside the headstock.

3. Tailstock: It is mounted at the left end on the bed and can slide towards the headstock. It can be fixed at any position on the bed to suit the length of the work to hold a lathe center, drill bit or other such tool. The tailstock is used for drilling,reaming, tapping, threading and centering parts.

4. Carriage: It moves on the guide ways of the lathe bed. A cutting tool is fixed in the tool post, the movement of which is guided by the carriage. The carriage is equipped with levers, clutches and gears that control its movement either by hand or by power feed. It carries the following

units.

• **Saddle:** It is the main part or the base of the carriage which slides along the bed ways. It supports cross-slide, compound rest and tool post. Generally, it uses a hand wheel to move along the bed but it can also be power operated through the apron mechanism.

• **Cross slide:** It is mounted on the saddle and slides in a direction perpendicular to the axis of the spindle

• **Compound rest:** It is mounted on the top of the cross-slide. It can swivel to any desired

angle in a horizontal plane. It is operated by a handwheel through the compound *rest.*

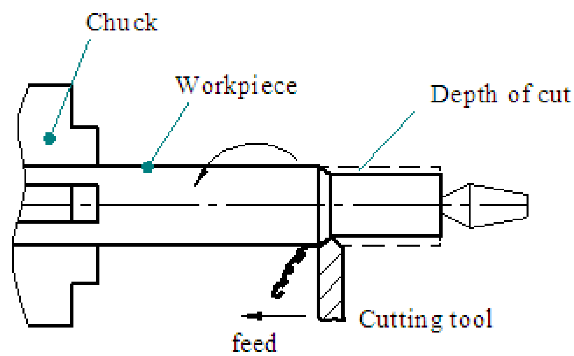
.Tool post: It is fixed on top of the compound rest and mounts the tool holder, in which the cutting tools are clamped.

. Apron is attached to the front of the carriage and bears the mechanism which controls the movement of the carriage and the cross slide.

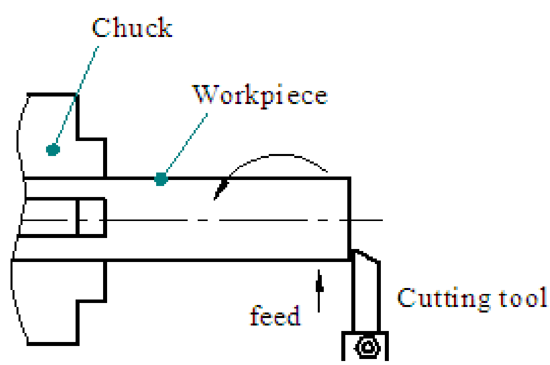
. Legs: *The whole machine is supported on two legs made out of cast iron. The leg on left side houses the electric motor and the headstock, the right side leg houses tailstock and other parts.*

Lathe Operations

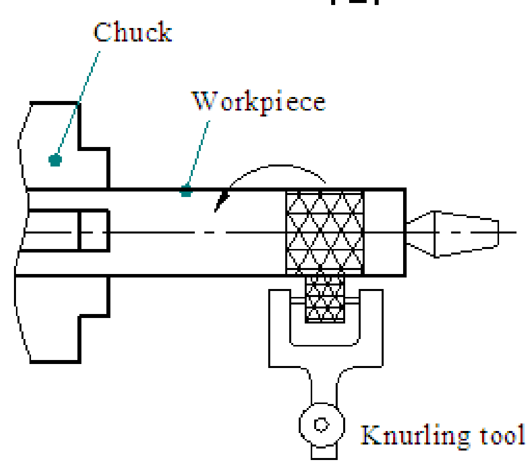
- **Plain or Cylindrical turning operation:** Cylindrical turning is a lathe operation used to remove excess material from the work piece and to produce a cylindrical surface of desired dimension. Using the cross slide, the cutting tool is first adjusted for the desired depth of cut. As the work piece revolves the tool is fed against the work piece in a direction parallel to the axis of the spindle as shown in the figure



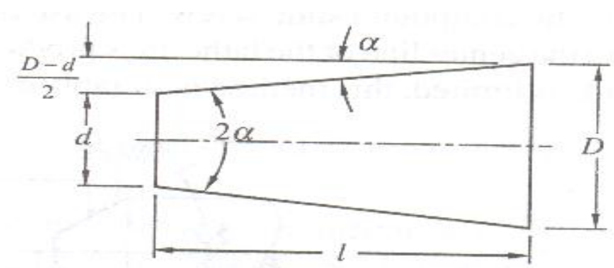
- **Facing operation:**
  Facing is the operation used to produce a flat surface normal to the rotational axis of the spindle. During facing, the carriage is locked to the lathe bed to prevent its movement. Using the cross slide, the tool is fed at right angles to the axis of the work piece as shown in figure.



- **Knurling:**
  Knurling is the process of embossing a diamond shaped pattern on the surface of the work piece by the use of revolving hardened steel wheels pressed against the work. A knurling tool held in the tool post as shown in the figure is used for this operation. Knurling is done to provide grip on handles, screw heads and other cylindrical parts to be gripped by hand.



- **Taper turning:**
  A rod is said to be tapered when it increases or decreases in diameter at uniform rate as shown in the figure 5.8. A cone is an example of a taper. Taper turning is the process of producing a conical surface from a cylindrical work piece. If D is the larger diameter, and d is the smaller diameter and l is the length or distance between the two diameters, then the taper can be expressed as



$$\text{Taper or Conicity, } T = \frac{D - d}{l}$$

and half the taper angle can be expressed as

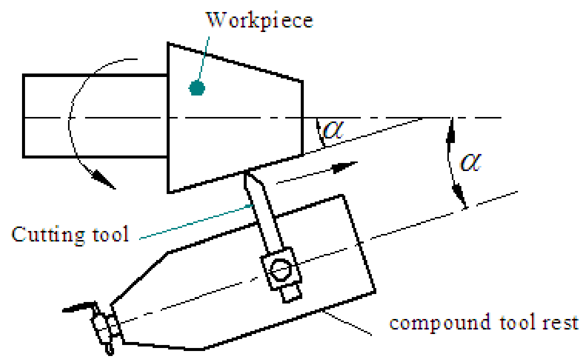
$$\text{Half the taper angle, } \alpha = \tan^{-1} \frac{D - d}{2l}$$

Taper turning can be carried out by any one of the following methods:

(i) By using a form tool
(ii) By swiveling the compound rest
(iii) By offsetting the tailstock
(iv) By using taper turning attachment

(i) Taper turning by swiveling of compound rest:

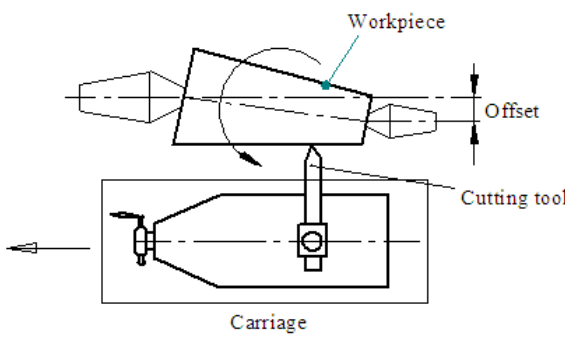
A taper can be produced with the use of compound rest as shown in the figure. The tool mounted on the compound rest is attached to a circular base graduated in degrees, which may be swivelled and clamped at any desired angle. This angle must be one half the taper angle, required on the component. The tool is fed by hand by rotating the compound slide screw.



The use of the compound slide permits movement of the tool at an angle to the centre line of the lathe, thus producing the taper. Since the linear movement of a compound rest slide is limited, this method is suitable only for tapers no longer than this movement.

(ii) Taper turning by tailstock offset method:

In the tailstock offset method as shown in the figure, the centre line of the workpiece be offset from the axis of the lathe and the tool is fed parallel to the axis of the lathe. This is achieved by moving the tailstock towards or away from the operator by means of set over screw. The amount of set over offset 'x' can be determined from the following formula.



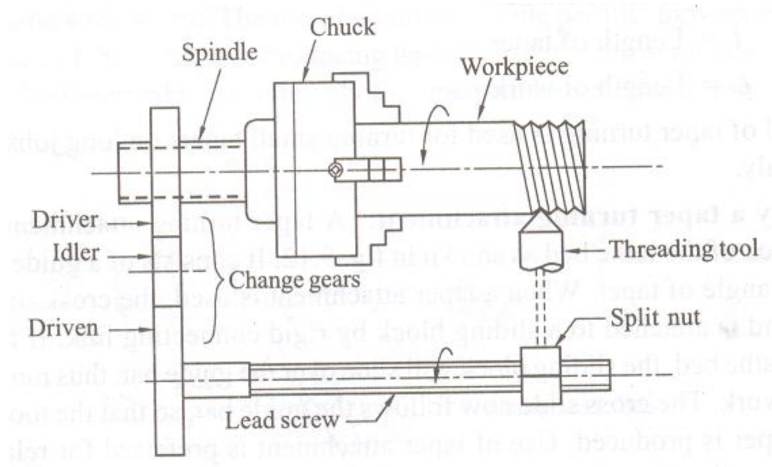
Offset $x = \frac{(D - d)\, L}{2l}$

Where
D = Larger diameter
d = Smaller diameter
l = Length of the taper
L = Length of the work

This method of taper turning is used for turning small tapers on long jobs and is confined to external tapers only.

- **Thread Cutting:**

The principle of thread cutting on a lathe is to produce a helical groove on a revolving cylindrical surface by feeding the tool longitudinally as shown in the figure.



A single point cutting tool of the desired profile is mounted on the tool post. To make a cut, the carriage is connected to the rotating lead screw. Since the lead screw is geared to the spindle, the carriage will move a predetermined distance per revolution of the workpiece. This distance is equal to the lead of the desired thread. The depth of cut is adjusted with compound rest hand wheel and graduated dial. Successive cuts are continued until the thread reaches its correct depth.

Specification of Lathe:

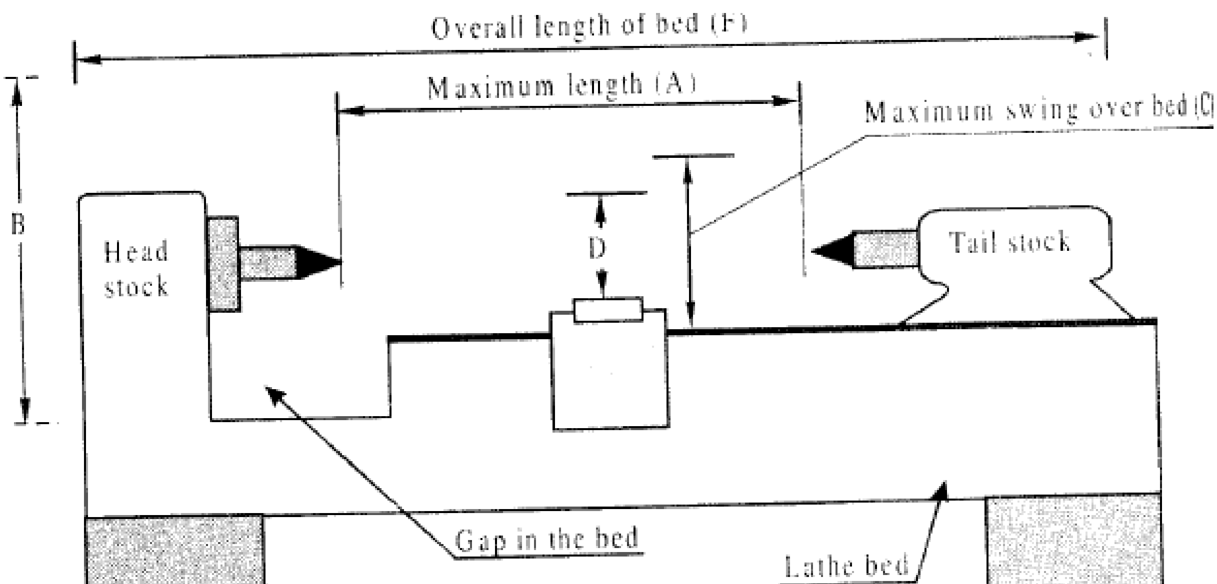


Fig. 5.2 : Specification of lathe

A lathe is mainly specified by the maximum size of the work that it can handle.

Other important specifications include the following

1.The largest diameter of the workpiece, commonly called the swing.

2. The maximum distance between headstock and tailsstock centers.

3. power of the main drive, that is, motor;

4. range of spindle speeds;

5. range of feeds;

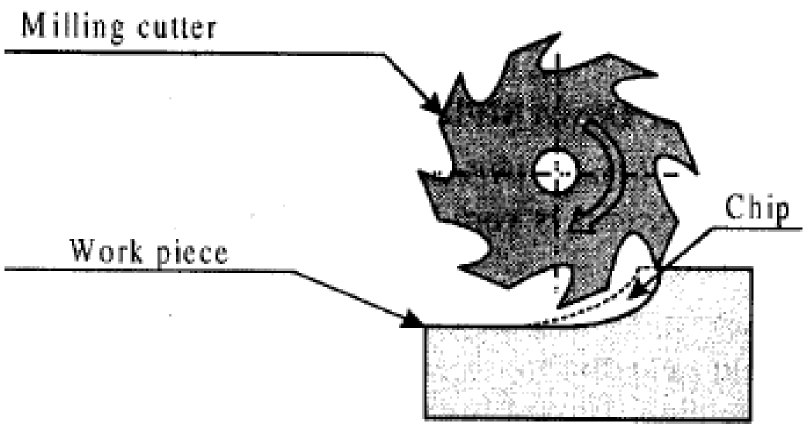
6. space occupied by the machine

MILLING MACHINES.

Milling is a machining process in which the metal cutting takes place with the help of a rotating multi-point cutter called milling cutter. Here the job is held stationary and fed against a rotating tool. The cutter has multiple cutting edges and it rotates at high speed. The machining takes place at a much faster rate and generally a good surface finish is obtained.

The machine tools employed for various milling operations are called milling machines. Milling machines are quite versatile and can do several operations like making flat surfaces, grooving, thread and gear cutting.

Working Principle of Milling Machine



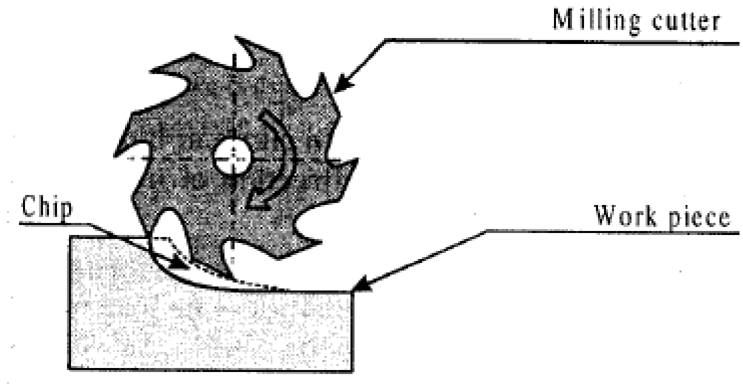
The milling cutter is attached to a horizontal rotating shaft known as arbor. The work piece which clamped on the table is fed in the direction opposite to the milling cutter(up milling) or in the same direction of the milling cutter (down milling) The metal is removed by advancing the workpiece during each revolution of the rotating cutter in the form of chips. The milling operation is extensively used in machining flat surfaces contoured surfaces external & internal threads, helical surfaces of various cross sections.

Depending upon relative feed direction of worktable and rotation of cutter two different methods of milling is possible

1. Conventional milling or Up milling

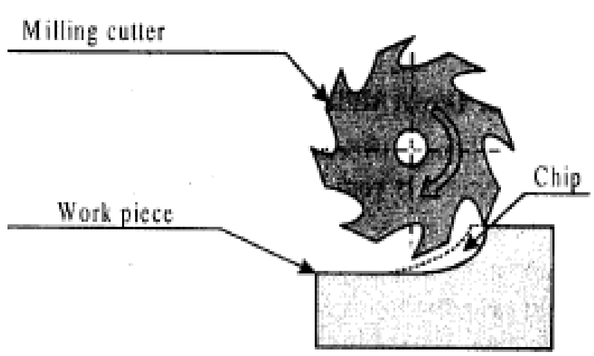
2. Climb milling or Down milling

1. Conventional milling or Up milling



The milling cutter is attached to a horizontal rotating shaft known as arbor. The work piece which clamped on the table is fed in the opposite direction of the milling cutter. The metal is removed by advancing the workpiece during each revolution of the rotating cutter in the form of chips. In up-milling, the chip thickness varies from a minimum at the tooth entrance to a maximum at the tooth exit. The forces produced by the cutting tool tend lift the work piece up from the table. Hence conventional milling process requires heavy work holding devices. Up milling leads to poor surface finish, due to vibrations developed by cutting forces of the cutter.

Down Milling



In down milling, the metal is removed by the rotating cutter fed in the direction of movement of the workpiece In down milling, the chip thickness varies from a maximum near the tooth entrance to a minimum near the tooth exit. Thus the cutting tooth is subjected to a maximum load from the very beginning. The cutting forces in down milling tend to act downwards, forcing the workpiece into the fixture or the vice. Hence the down milling process doesn't require heavier work holding devices This type of milling produces higher surface finish compared to up milling.

Classification of Milling Machines

On the basis of the type of construction the milling machines may be classified as:

1. Column and Knee-Type Milling Machine: It is a general-purpose milling machine. The worktable is mounted on a knee which slides in the guide ways of the column.

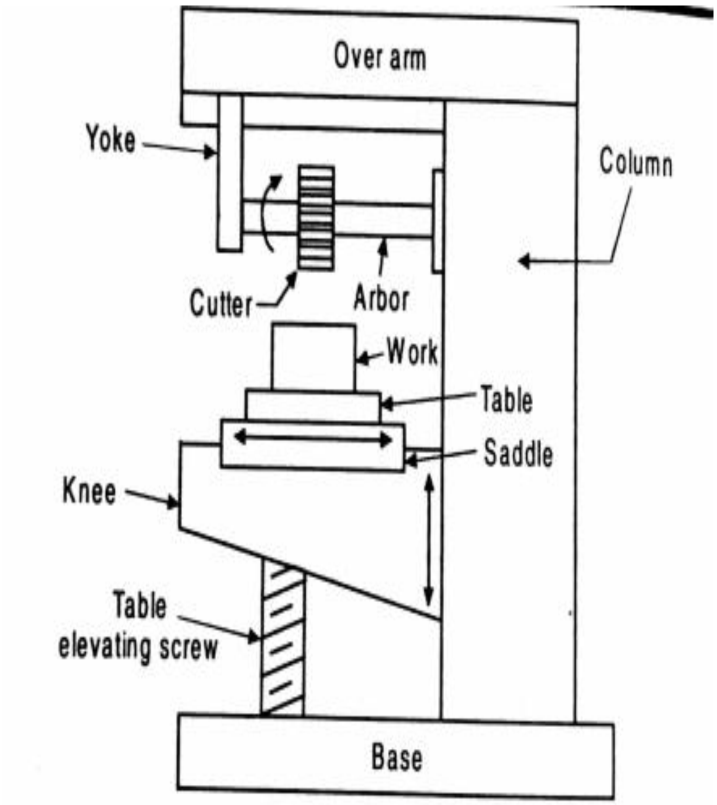
2. Vertical Milling Machine: The spindle of this machine is held in the vertical position. Universal Milling Machine: This a kind of horizontal milling machine in which the table can be swiveled on a horizontal plane.

3. Bed-Type Milling Machine: This is used as a production machine.

4. CNC Milling Machines: They are computer numerical controlled, here all the movements of tool and work are controlled by the computer program entered by the operator/ engineer.

5. Special-Purpose Milling Machines: They are manufactured for performing some specific type of machining operation.

1. Column and Knee-Type (Horizontal) Milling Machine:



It is a general-purpose milling machine. The worktable is mounted on a knee which slides in the guide ways of the column. It can be adjusted to a desired height. Figure above shows the block diagram of a column and knee-type milling machine with horizontal arbor.

Following are its principal parts:

• Column with base: It is the main structural body of the milling machine to support other parts.

• Arbor: It holds and provides rotary motion to the cutter.

• Ram: It is also known as over arm. It supports the arbor and can be adjusted to accommodate different arbor lengths.

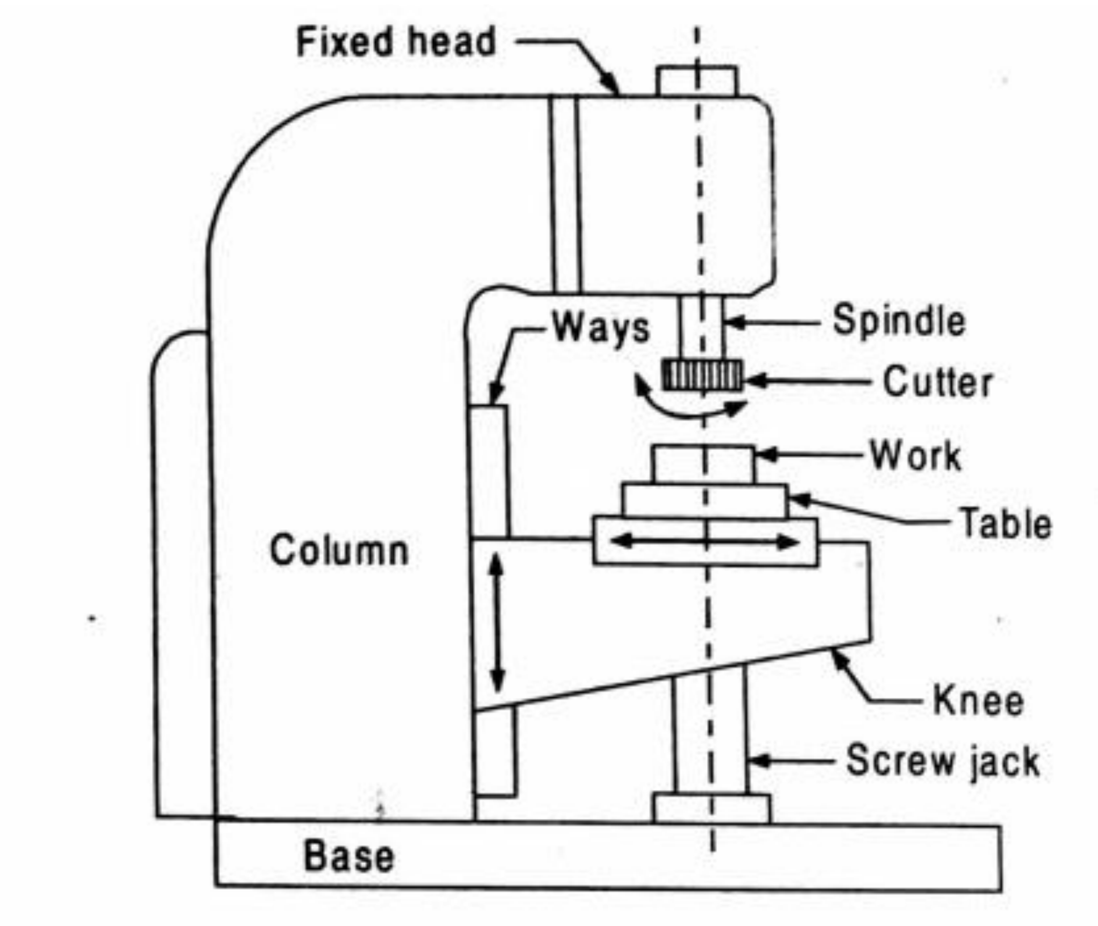
• Machine table: The job and its holding devices are mounted on the machine table. It can move longitudinally to provide the feed motions to the job.

• Power drive with gear boxes: It provides power and motions to the tool and work.

• Bed: It moves vertically upward and downward and accommodates the various drive mechanisms.

- ***Working***
  - Work piece is mounted directly on table using machine vice.
  - Cutter of required shape and size are mounted over the arbor which is driven by spindle.
  - Feed in all 3 axes can be given by using knee elevating handle, cross slide handle, table movement handle.

Vertical Milling Machine



In vertical milling machine, the axis of the spindle is perpendicular to the work table.The work piece can be moved both in vertical and horizontal plane.The spindle head can be moved up and down over the guide ways. The saddle is mounted on a knee which can be moved up and down over the guide ways provided on the column face. The worktable mounted on the saddle can be moved longitudinally over the guide ways provided on the top of the saddle. The machine is used to machine grooves, slots and flat surfaces.

- Base and column – base is the foundation for the machine and column is the vertical part houses motor, transmission system.
- Spindle head – mounted on front face of the column at the top. It has a vertical spindle run by motor to which milling tool is fitted to end.

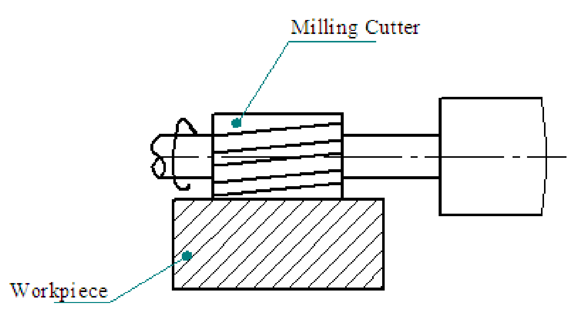
Working

- *Work piece is mounted on table and cutter is mounted on vertical spindle.*
- *Feed is given by movement of knee, saddle and table and also vertical movement of tool.*

Milling Operations Various milling operations can be performed on a milling machine to produce flat, vertical, inclined surfaces, grooves, slots, keyways, gear teeth etc. Some of the most commonly operations are, plain or slab milling, angular milling, face milling, form milling, slot milling, and straddle milling.

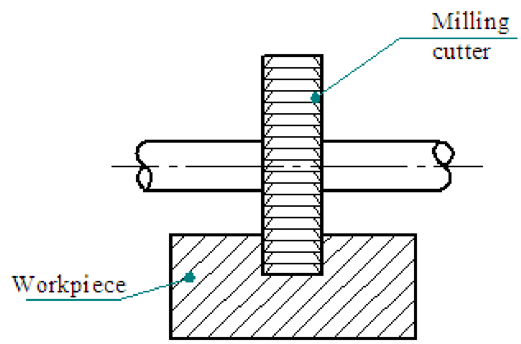
- **Plain milling:**

Slab milling or **plain milling** is a method of producing flat surfaces parallel to the cutter axis as shown in the figure. The cutter used in this operation is called plain milling cutter or slab milling cutter. It has straight or helical teeth cut on the periphery of a cylindrical surface. This operation is performed on a horizontal milling machine.



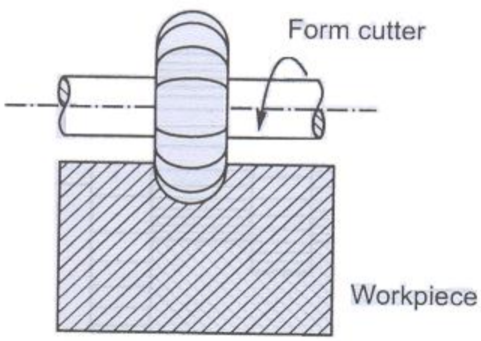
➢ **Slot milling**:

It is process to produce desired slots, grooves and key ways using suitable cutters. Figure illustrates groove milling operation using a side milling cutter, which has teeth on its periphery and also on one or both of its sides. Similarly open slots and closed slots can be cut by using plain milling cutters and end milling cutters respectively. T-slots and dove tail slots are cut by using special cutters.



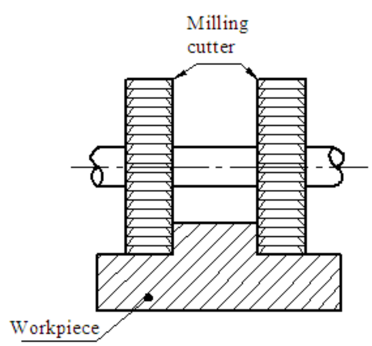
➢ **Form milling:**

Form milling is an operation of generating specific forms such as semicircular grooves, hemispherical cavities, concave or convex slots, etc on work pieces. This is carried out by using a form milling cutter or an end milling cutter with the specific form on it. This process is illustrated in the figure.



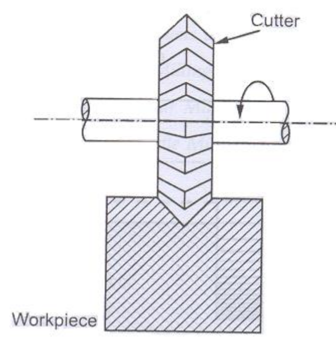
➢ **Straddle milling:**

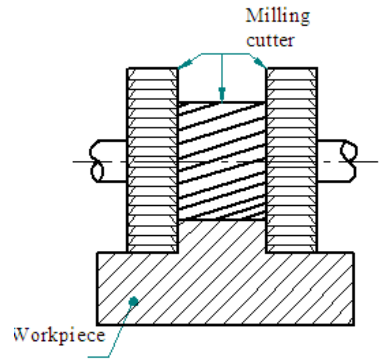
It is a process of producing two parallel vertical surfaces in a single cut. Straddle milling is accomplished by mounting two side milling cutters on the same arbor, set apart at an exact spacing using suitable collars. This operation is illustrated in figure.



➢ **Angular milling:**

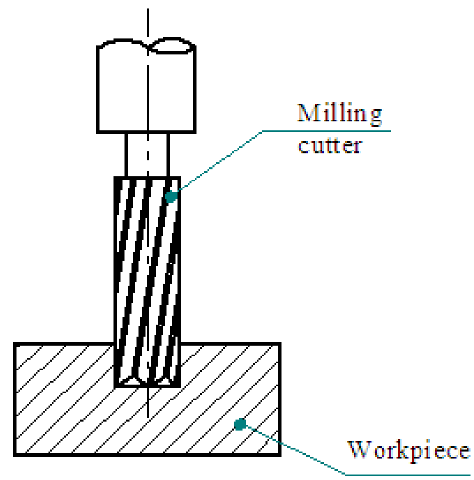
It is a process of producing V-grooves of desired angle. It is accomplished by using a single or double angle cutter. A single angle cutter consists of teeth inclined to the axis on one conical surface and is used for cutting chambers. A double angle cutter consists of teeth on two conical surfaces and is used for V-grooves as shown in the figure.





- **Gang milling:**

  It is a process of machining several surfaces of a work piece simultaneously at one pass of it. Two or more cutters are used on the same arbor to produce the desired shape as shown in the figure. It saves machining time to a great extent.



- **End milling:**

  It is an operation of producing narrow slots, grooves and key ways using and end mill. The milling cutter may be attached to the vertical spindle for milling the slot as shown in the figure. The depth of cut is given by raising the machine table.

ROBOTICS:

Robots are devices that are programmed to move parts, or to do work with a tool. Robotics is a multidisciplinary engineering field dedicated to the development of autonomous devices, including manipulators and mobile vehicles.

An industrial robot is a general purpose, programmable machine possessing certain anthropomorphic characteristics. The most typical anthropomorphic or human like, characteristics of a robot is its arm. This arm, together with the robots capacity to be programmed, make it ideally suited to a variety of production tasks, including machine loading, spot welding, spray painting and assembly. The robot can be programmed to perform sequence of mechanical motions, and it can repeat that motion sequence over the over until programmed to perform some other job.

An industrial robot is a general purpose programmable machine that possesses certain anthropomorphic features

• The most apparent anthropomorphic feature of an industrial robot is its mechanical arm, or manipulator

• Robots can perform a variety of tasks such as loading and unloading machine tools, spot welding automobile bodies, and spray painting

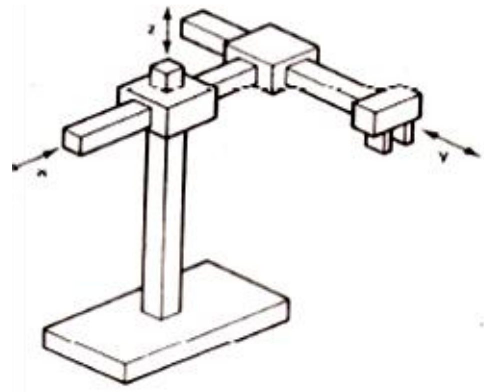
• Robots are typically used as substitutes for human workers in these tasks

Robot Physical Configuration

Industrial robots come in a variety of shapes and sizes. They are capable of various arm manipulations and they possess different motion systems.

Classification based on Physical configurations

1. Cartesian configuration: A robot which is constructed around this configuration consists of three orthogonal slides, as shown in fig. the three slides are parallel to the x, y, and z axes of the Cartesian coordinate system. By appropriate movements of these slides, the robot is capable of moving its arm at any point within its three dimensional rectangular spaced work space.



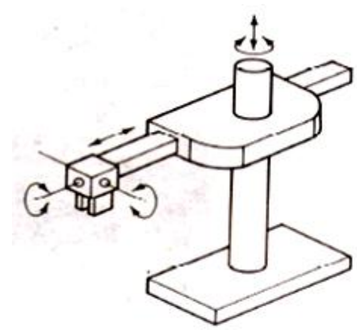
Advantages:

- High resolution and accuracy.
- No counterbalance problem.
- 3 linear axes

Disadvantages:

- Large structural framework.
- Complex mechanical design for linear sliding motions.
- Confinement of the workspace (limited).

2. Cylindrical configuration: in this configuration, the robot body is a vertical column that swivels about a vertical axis. The arm consists of several orthogonal slides which allow the arm to be moved up or down and in and out with respect to the body. This is illustrated schematically in figure.

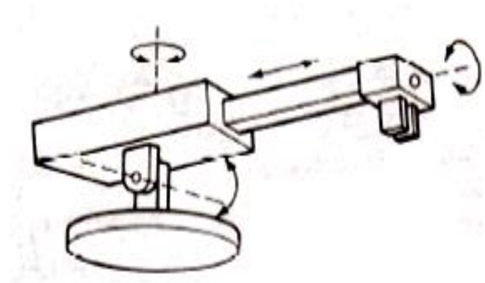


Advantages:

- Almost no counterbalance problem.
- Mechanical design is less complex than Cartesian robots.
- 2 linear axes +1 rotating can reach all around itself.

Disadvantages:

- Large structural framework.
- Lower accuracy compared with the Cartesian robots.
- Restriction of the workspace



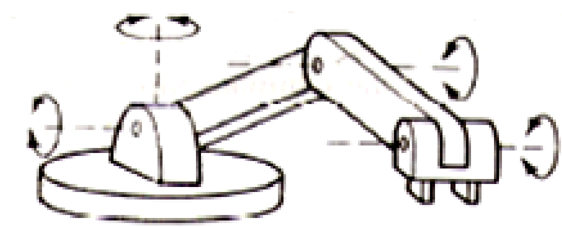
3. Polar/Spherical configuration: this configuration also goes by the name "spherical coordinate" because the workspace within which it can move its arm is a partial sphere as shown in figure. The robot has a rotary base and a pivot that can be used to raise and lower a telescoping arm.

Advantages:

- Low weight and minimal structural complexity.
- Short joint travel for many motions.
- Good accuracy and resolution.
- 1 linear + 2 rotational axes

Disadvantages:

- Large variable torque on second joint creating counterbalance problem.
- Position error is large due to rotary joints.



4. Jointed-arm/Revolve configuration: is combination of cylindrical and articulated configurations. This is similar in appearance to the human arm, as shown in fig. the arm consists of several straight members connected by joints which are analogous to the human shoulder, elbow, and wrist. The robot arm is mounted to a base which can be rotated to provide the robot with the capacity to work within a quasi-spherical space.

Advantages:

- Flexibility to reach over or under an object.
- Good workspace.
- 3 rotational axes can reach above or below obstacles.

Disadvantages:

- Counterbalance problem.
- Poor resolution and accuracy due to rotary joints.
- High moment of inertia and dynamic instability (i.e. vibrations).

ROBOT APPLICATIONS

Need to replace human by robots:

- Work environment hazardous for human beings
- Repetitive tasks
- Boring and unpleasant tasks
- Multi shift operations
- Infrequent changeovers
- Performing at a steady pace
- Operating for long hours without rest
- Responding in automated operations
- Minimizing variation

Industrial Robot Applications:

Industrial Robot Applications can be divided into:

1. Material-handling applications:
    - Involve the movement of material or parts from one location to another.
    - It includes part placement, palletizing and/or de-palletizing, machine loading and unloading.
2. Processing Operations:
    - Requires the robot to manipulate a special process tool as the end effectors.
    - The application include spot welding, arc welding, riveting, spray painting, machining, metal cutting, debarring, polishing.
3. Assembly Applications:
    - Involve part-handling manipulations of a special tools and other automatic tasks and operations.
4. Inspection Operations:
    - Require the robot to position a work part to an inspection device.
    - Involve the robot to manipulate a device or sensor to perform the inspection.

Material Handling Applications

1. Part Placement:

- The basic operation in this category is the relatively simple pick-and-place operation.
- This application needs a low-technology robot of the cylindrical coordinate type.
- Only two, three, or four joints are required for most of the applications.
- Pneumatically powered robots are often utilized.

2. Palletizing and/or Depalletizing
   - The applications require robot to stack parts one on top of the other, that is to palletize them, or to unstack parts by removing from the top one by one, that is depalletize them.
   - Example: process of taking parts from the assembly line and stacking them on a pallet or vice versa.
3. Machine loading and/or unloading:
   - Robot transfers parts into and/or from a production machine.
   - There are three possible cases:
     - ➢ Machine loading in which the robot loads parts into a production machine, but the parts are unloaded by some other means. Example: a press working operation, where the robot feeds sheet blanks into the press, but the finished parts drop out of the press by gravity.
     - ➢ Machine loading in which the raw materials are fed into the machine without robot assistance. The robot unloads the part from the machine assisted by vision or no vision. Example: bin picking, die casting, and plastic moulding.
     - ➢ Machine loading and unloading that involves both loading and unloading of the work parts by the robot. The robot loads a raw work part into the process ad unloads a finished part. Example: Machine operation difficulties
   - Difference in cycle time between the robot and the production machine. The cycle time of the machine may be relatively long compared to the robot's cycle time.
4. Stacking and insertion operation:
   - In the stacking process the robot places flat parts on top of each other, where the vertical location of the drop-off position is continuously changing with cycle time.
   - In the insertion process robot inserts parts into the compartments of a divided carton.

   The robot must have following features to facilitate material handling:

   - ➢ The manipulator must be able to lift the parts safely.
   - ➢ The robot must have the reach needed.

- The robot must have cylindrical coordinate type.
- The robot's controller must have a large enough memory to store all the programmed points so that the robot can move from one location to another.
- The robot must have the speed necessary for meeting the transfer cycle of the operation.

Processing operations:

• Robot performs a processing procedure on the part.

• The robot is equipped with some type of process tooling as its end effector.

• Manipulates the tooling relative to the working part during the cycle.

• Industrial robot applications in the processing operations include:

- Spot welding
- Continuous arc welding
- Spray painting
- Metal cutting and deburring operations
- Various machining operations like drilling, grinding, laser and water jet cutting, and riveting.
- Rotating and spindle operations
- Adhesives and sealant dispensing

Assembly operations:

Batch assembly: As many as one million products might be assembled.

The assembly operation has long production runs.

Low-volume: In this a sample run of ten thousand or less products might be made.

The assembly robot cell should be a modular cell.

One of the well suited areas for robotics assembly is the insertion of odd electronic components.

Inspection operation:

- Some inspection operation requires parts to be manipulated and other applications require that an inspection tool be manipulated.
- Inspection work requires high precision and patience, and human judgment is often needed to determine whether a product is within quality specifications or not.
- Inspection tasks that are performed by industrial robots can usually be divided into the following three techniques:

- By using a feeler gauge or a linear displacement transducer known as a linear variable differential transformer (LVDT), the part being measured will come in physical contact with the instrument or by means of air pressure, which will cause it to ride above the surface being measured.
- By utilizing robotic vision, matrix video cameras are used to obtain an image of the area of interest, which is digitized and compared to a similar image with specified tolerance.
- By involving the use of optics and light, usually a laser or infrared source is used to illustrate the area of interest.

- The robot may be in active or passive role.
- In active role robot is responsible for determining whether the part is good or bad.

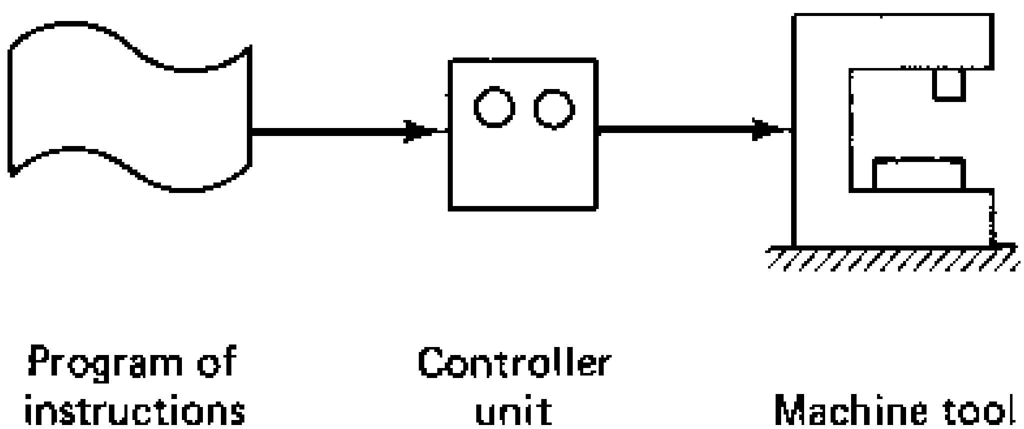
NUMERICAL CONTROL:

Numerical control can be defined as a form of programmable automation in which process is controlled by numbers, letters and symbols. In NC, the numbers form a programme of instructions designed for a particular work part or job. This capability to change a program for each new job gives NC its flexibility.

Basic components of NC system

An operational numerical control system consists of the following three basic components:

1. Program of instructions.
2. Controller unit.
3. Machine tool or processing equipment.



Program of Instruction:

The program of instructions is the detailed step by step set of instructions which tell the machine what to do. It is coded in numerical or symbolic form on some type of input medium that can be interpreted by the controller unit. The most common one is the 1-inch-wide punched tape. Over the years, other forms of input media have been used, including punched cards, magnetic tape, and even 35mm motion picture film. There are two other methods of input to the NC system which should be mentioned. The first is by manual entry of instructional data to the controller unit. This is time consuming and is rarely used except as an auxiliary means of control or when one or a very limited no. of parts to be made. The second method of input is by means of a direct link with the computer. This is called direct numerical control, or DNC.

Controller Unit:

The second basic component of NC system is the controller unit. This consists of electronics and hardware that read and interpret the program of instructions and convert it to mechanical actions of the machine tool. The typical elements of the controller unit include the tape reader, a data buffer, signal output channels to the machine tool, and the sequence controls to coordinate the overall operation of the foregoing elements. The tape reader is an electrical-mechanical device for the winding and reading the punched tape containing the program of instructions. The signal output channels are connected to the servomotors and other controls in machine tools.

Most N.C. tools today are provided with positive feedback controls for this purpose and are referred as **closed loop systems.** However there has been growth in the **open loop systems** which do not make use of feedback signals to the controller unit. The advocates of the open loop concept claim that the reliability of the system is great enough that the feedback controls are not needed.

Machine Tool:

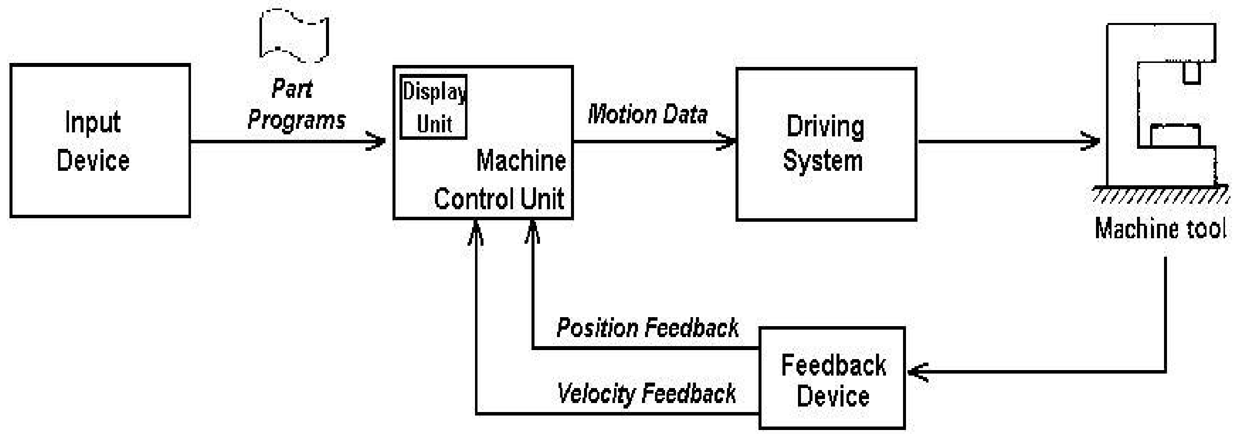
The third basic component of an NC system is the machine tool or other controlled process. It is part of the NC system which performs useful work. In the most common example of an NC system, one designed to perform machining operations, the machine tool consists of the worktable and spindle as well as the motors and controls necessary to drive them. It also includes the cutting tools, work fixtures and other auxiliary equipment needed in machining operation.

Extensions of NC

Numerical control has caused a virtual revolution in the discrete metal parts manufacturing industry. The success of NC has led to number of extensions of Numeric Control concepts and technology. Four of the important developments are the following:

- Direct numerical control (DNC).
- Computer numerical control (CNC).
- Adaptive Control.
- Industrial robots.

Computer Numerical Control (CNC)



CNC is a NC system that utilizes a dedicated, stored program computer to perform some or all of the basic numerical control functions. As of this writing the typical CNC system uses a minicomputer as the controller unit. It is expected that in future generations of computer numerical control, microcomputers will become predominant. Because a digital computer is used in both CNC and DNC there is often confusion surrounding the two systems, Figure below shows the general configuration of CNC

Main differences are:

1. DNC computers distribute instructional data to and collect from a large number of machines. CNC computers control only one machine or a small number of machines.
2. DNC computers occupy a location that is typically remote from the machines under their control. CNC computers are located very near their machine tools.
3. DNC software is developed not only to control individual pieces of production technology, but also to serve as part of management information system in the manufacturing sector of the firm. CNC software is developed to augment the capabilities of a particular machine tool.
4. Except for the fact that a digital computer is used, CNC machines are similar and the part programs are entered in a similar manner. Punched tapes are still the common device for entering the part program into the system

CONTROL SYSTEM

According to the type of control systems used, CNC systems can be classified as:

1. Open loop system

2. Closed loop system.

1. Open loop system:

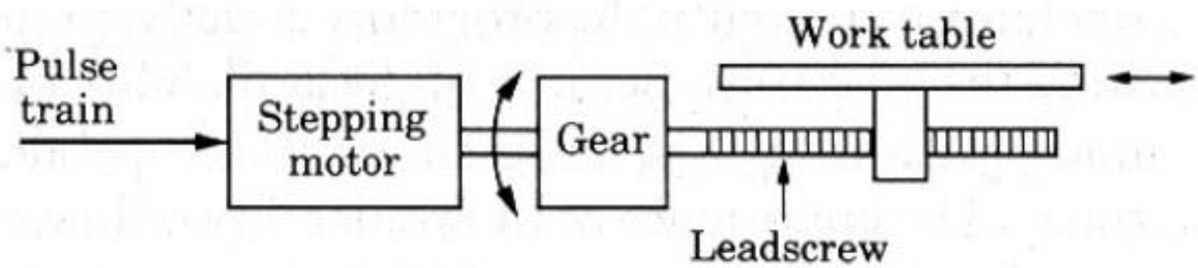


Fig: Open Loop Control system

- Figure shows an open loop control system
- The system does not use feedback signals to indicate the table position to the controller unit.
- An open-loop system uses stepping motors.
- The stepping motor is driven by a series of electrical pulses generated by the MCU
- The stepper motor drives the lead screw which gives movement to the table
- The system does not use feedback signals and hence in this system it is not possible to monitor table position
- Hence inaccuracy may takes place in this system

2. **Closed loop control system:**

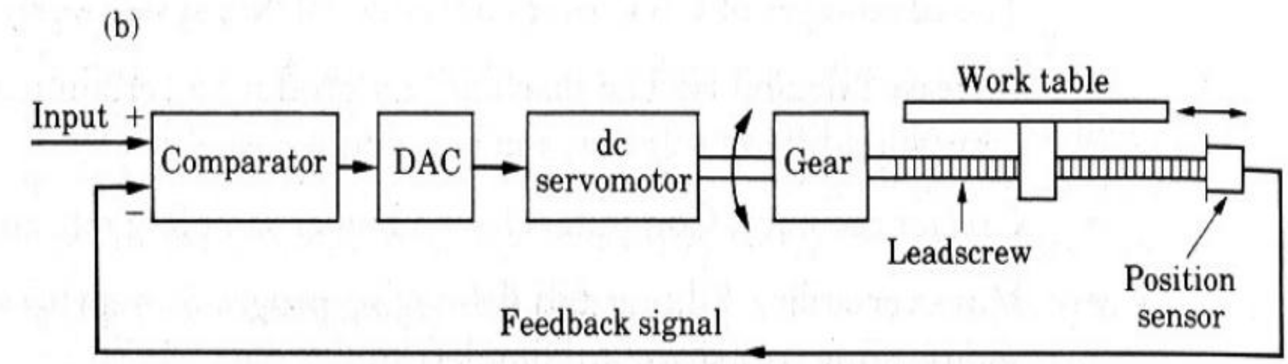


Fig: Closed loop control system

- Fig shows closed loop control system
- The system uses feedback signals to indicate the table position to the controller unit.
- Closed-loop systems uses DC servo motors , Sensors, comparator and DC servomotor
- Sensor, which is used to monitor the output
- Sensor which measure the table position and sends to comparator
- Comparator which compares the input signal with feedback signal
- If there is an error, the system monitors DC motor
- The system uses feedback signals and hence in this system it is possible to monitor table position
- Hence accurate machining takes place in this system

ADVANTAGES OF CNC MACHINE TOOLS

1. Complex Machining Operations can be performed easily.
2. High accuracy and surface finish
3. High production rate.
4. It can be run for 24 hours a day and 365 days a year
5. Reduced man power and errors
6. Reduced scraps

DISADVANTAGES OR LIMITATIONS OF NC/ CNC MACHINE TOOLS

1. The cost of the CNC machine is very high
2. High Maintenance Cost
3. High Tooling Cost
4. It requires highly skilled programmer
5. Need for Conditional Environment (A/C rooms)
6. CNC technology can cause unemployment.

APPLICATIONS OF CNC MACHINE TOOLS

CNC machines are used when

1. Parts with complicated shapes
2. Parts requiring high accuracy and precision
3. Parts needed in a hurry
4. When parts are too small or too big

CNC machines are used in

1. Automotive industry
2. Machining industry
3. Aerospace industry
4. Electrical industry

COMMONLY USED CNC MACHINES IN INDUSTRIES ARE :

1. CNC Lathe machine
2. CNC Milling machine
3. CNC Drilling machine
4. CNC Grinding machine
5. CNC Laser cutting machine
6. CNC Water jet cutting machine
7. CNC Electro discharge machine

DIFFERENCE BETWEEN NC AND CNC MACHINES

NC MACHINES	CNC MACHINES
▪ NC stands for Numerical Control	▪ CNC stands for Computer Numerical Control
▪ Part program cannot be edited or modified	▪ Part program can be edited or modified
▪ Less storage capacity	▪ High Storage capacity
▪ Hard-wired controller is used as MCU	▪ Micro or minicomputer is used as the MCU
▪ Part program is entered using punched tape	▪ Part program is entered using alphanumeric keyboards.
▪ NC machine cost is less	▪ CNC machine cost is high

CNC MACHINING CENTERS:

- CNC machining center can be defined as a sophisticated CNC machine tool
- CNC machining center performs multiple machining operations like drilling, milling and lathe operations by using a variety of tools with Automatic Tool Changer (ATC) unit

CNC machining centers are usually designed with features to reduce non productive time.

The features are:

- ATC (Automatic Tool Changer)
- Automatic work part positioner
- APC (Automatic Pallet Changer)
- CNC Servo System
- Feedback System

CLASSIFICATION OF CNC MACHINING CENTRES:

Machining centres are classified according to the spindle configuration as:

a. Horizontal machining centres:
b. Vertical machining centres
c. Universal centres

a. Horizontal machining centres:

- As the name says this machining centre has horizontal spindle on which tool is mounted
- Horizontal Machining centers are used rectangular /cube shaped work piece that requires tool access from sides
- This machine centers consists of 4 axis
- Ex: CNC Turning centres

b. Vertical machining centres

- As the name says this machining centre has vertical spindle on which tool is mounted
- Vertical Machining centers typically used for flat work that requires tool access from top
- This machine centers consists of 3
- **Ex: CNC Milling centres**

c. Universal Machining Centre

- This machine centers consists of 5 or more axis so that all the five sides of a components can be machined in a single set up.
-
- In this machine the spindle axis can be tilted to any angle between horizontal and vertical
- It is very flexible machine tool than horizontal and vertical milling centres

CNC TURNING CENTERS:

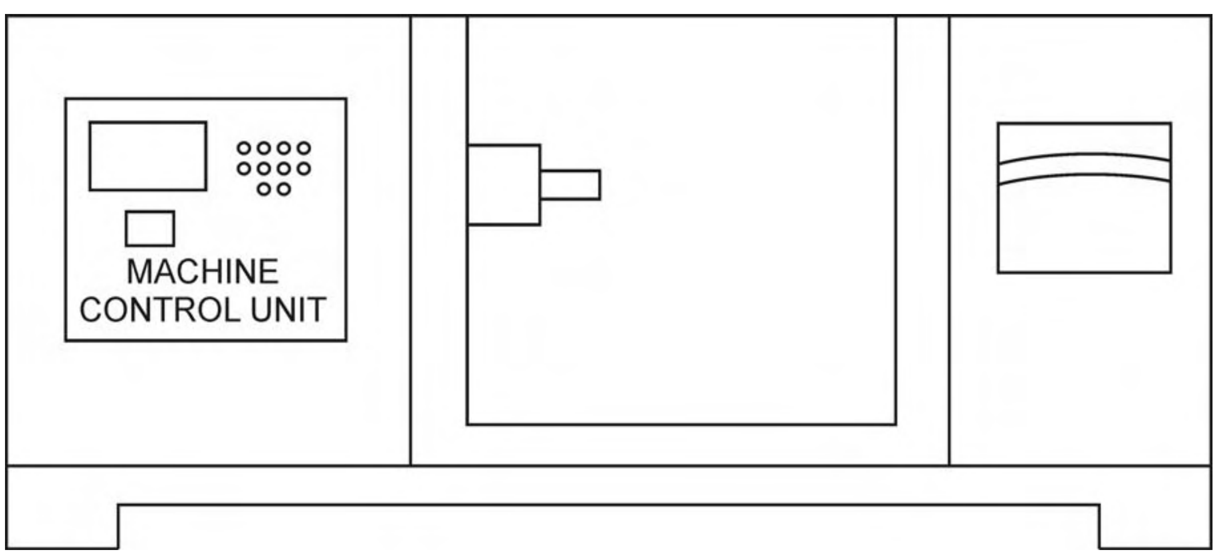


Fig: CNC Turning Centers

- CNC lathes are widely used in making components with axi-symmetric geometry.
- These are generally machined with 2-axis control. [X and Z axes]

- Some CNC lathes have an additional Y-axis.
- AC servomotors drive the X and Z axis
- Sliding doors with bulletproof glass windows are provided for safety and visibility of the machining zone
- Hydraulic chucks are provided for clamping the workpieces.
- Tools are mounted in indexable turrets which can hold 8, 12 or 16 tools.

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THE END