I.C. Engines

Internal combustion engine

Internal combustion engines more popularly known as I.C. engine is a heat engine which converts the heat energy released by the combustion of fuel into mechanical work. Here the combustion of fuel takes place inside the engine cylinder.

The following are the most important ways of classification of I.C. engines:

1. According to the type of fuel used

a) Petrol engines.

b) Diesel engines.

c) Gas engines.

d) Bi-fuel engines.

2. According to the number of strokes per cycle

a) 2-stroke engine.

b) 4-stroke engine.

3. According to the method of ignition

a) Spark ignition engine (S.I. Engine).

b) Compression ignition engine (C.I. Engine).

4. According to the cycle of combustion

a) Otto cycle engine.

b) Diesel cycle engine.

c) Duel combustion engine.

5. According to the number of cylinders.

a) Single cylinder engine.

b) Multi cylinder engine.

6. According to the arrangement of cylinders

a) Vertical engine.

b) Horizontal engine.

c) V-engine.

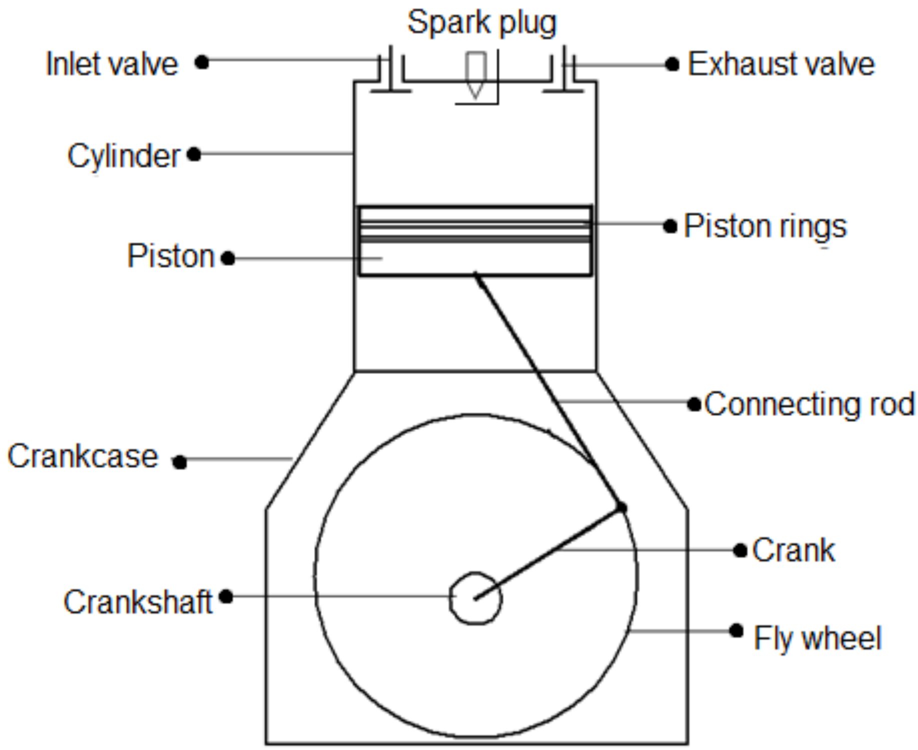
7. According to the method of cooling

a) Air cooled engine.

b) Water cooled engine.

Parts of I.C. Engine

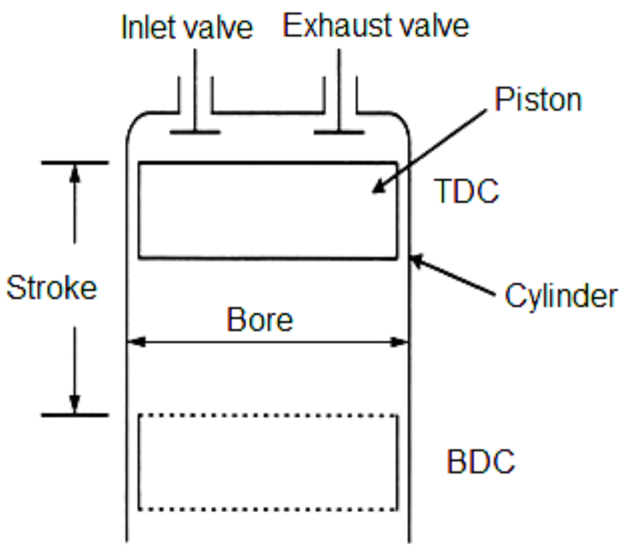
Various important parts of an I.C. Engine are shown the figure below.



1. **Cylinder:** It is the cylindrical vessel in which the fuel is burnt and the power is developed. It is considered as heart of the engine. The primary functions of cylinder are to contain the working fluid under pressure and to guide the piston while reciprocating inside the cylinder.
2. **Piston:** Piston is a close fitting hollow cylindrical plunger reciprocating in the cylinder. The power developed by the combustion of the fuel is transmitted by the piston to the crankshaft through connecting rod.
3. **Piston rings:** These are metallic rings inserted into the circumferential grooves provided at the top end of the piston. These rings maintain a gas tight joint between the piston and the cylinder while the piston is reciprocating in the cylinder. They also help in conducting the heat from the piston to the cylinder.
4. **Connecting rod:** It is a link that connects the piston and the crankshaft. Its function is to convert the reciprocating motion of the piston into rotary motion of the crankshaft.
5. **Crank & crankshaft:** The crank is a lever with one of its end connected to the connecting rod by a pin joint with other end connected rigidly to the crankshaft. The power required for any useful purpose is taken from the crankshaft.
6. **Crank case:** It encloses the crankshaft and serves as a sump for the lubricating oil.
7. **Valves:** The valves control the flow of air/fuel into the cylinder and exhaust gases from the engine cylinder. The valves are operated mechanically by cams. These valves are actuated by means of cams.

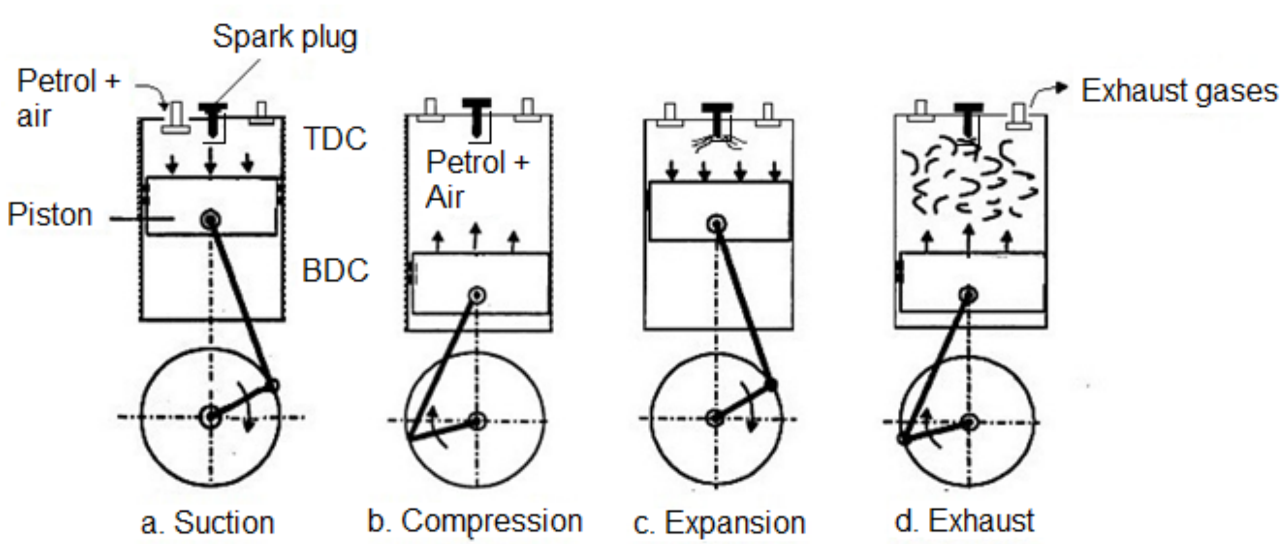
8. **Flywheel:** It is a heavy mass of rotating wheel mounted on the crankshaft and is used as an energy storing device. The flywheel stores energy received during the power stroke and supplies the same during other strokes.

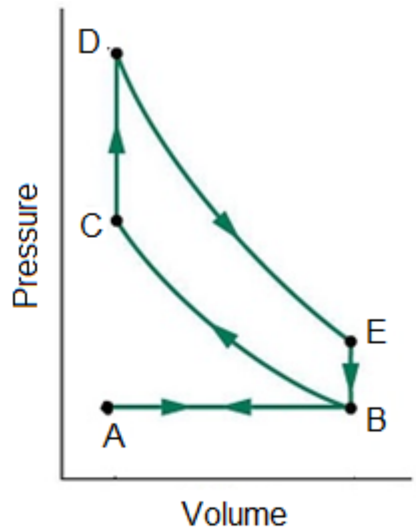
I.C. Engine terminology



1. **Top dead center (TDC):** The extreme position of the piston near to the cylinder head is called 'top dead center' or 'TDC'.
2. **Bottom dead center (BDC):** The extreme position of the piston nearer to the crankshaft is called 'bottom dead center' or 'BDC'.
3. **Bore:** The inside diameter of the cylinder is called 'bore'.
4. **Stroke:** It is the linear distance travelled by the piston from the TDC to BDC or BDC to TDC.

4 Stroke petrol engine





A 4-stroke petrol engine performs four different strokes to complete one cycle.

Suction stroke

1. At the beginning of the stroke, piston is in TDC and during the stroke, the piston moves from TDC to BDC.
2. The inlet valve opens and the exhaust valve will be closed. As the piston moves downwards, suction is created in the cylinder as a result, fresh air-petrol mixture (charge) is drawn into the cylinder through the inlet valve.
3. As the piston reaches BDC, the suction stroke completes and inlet valve closes. The suction stroke is represented by the line AB on P-V diagram.

Compression stroke

1. In this stroke the piston moves from BDC to TDC.
2. Both inlet and exhaust valves are closed. As the piston moves upwards, the air-petrol mixture in the cylinder is compressed.
3. The pressure and temperature of the mixture increases and this is shown by the curve BC on the P-V diagram.
4. When the piston reaches the TDC, the spark plug ignites the charge. The combustion of the fuel takes place at the constant volume and is shown by a line CD on the P-V diagram.

Expansion stroke/Power stroke

1. In this stroke both inlet and exhaust valves remain closed.
2. The combustion of fuel liberates gases and these gases start expanding. Due to expansion, the hot gases exert a large force on the piston and as a result the piston is pushed from TDC to BDC.

3. The power is transmitted down through the piston to the crank shaft through the connecting rod. This causes crankshaft to rotate at high speeds. Thus work is obtained in this stroke. Hence, this stroke is also called working stroke. This is shown by the curve DE on the P-V diagram.
4. As the piston reaches the BDC, the exhaust valve opens. A part of the burnt gases escape through the exhaust valve out of the cylinder due to their own expansion. This escape of gases occurs momentarily at constant volume which is shown by the curve EB on P-V diagram.

Exhaust stroke

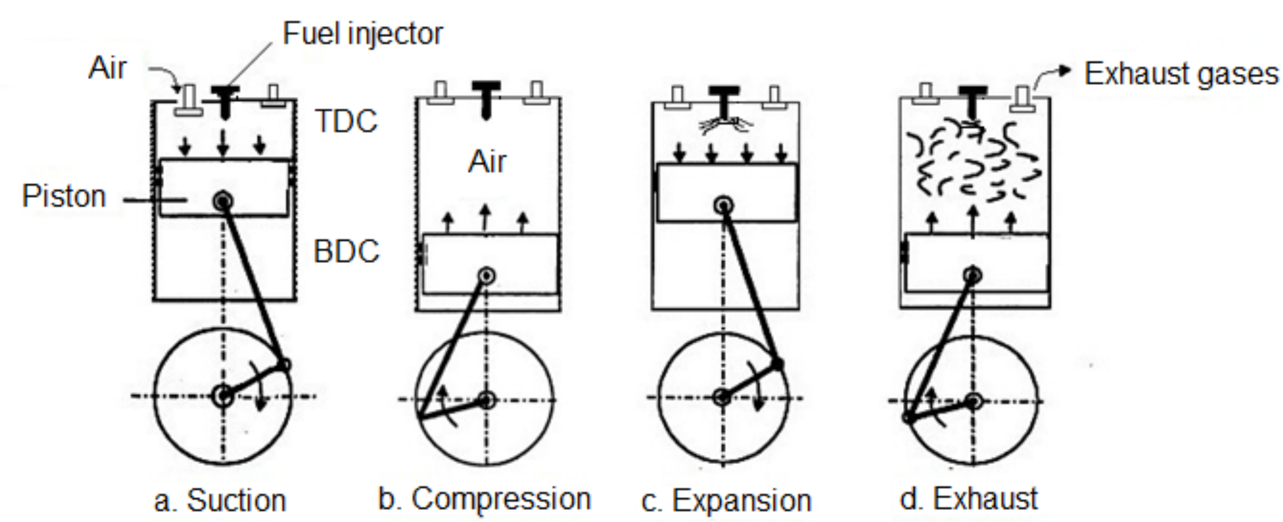
1. In this stroke the inlet valve is closed, and exhaust valve is opened.
2. The piston moves from BDC to TDC and forces the remaining burnt gases out of the cylinder to the atmosphere through the exhaust valve. This is shown by the line BA on P-V diagram.
3. When the piston reaches the TDC, the exhaust valve closes, and this completes the cycle.

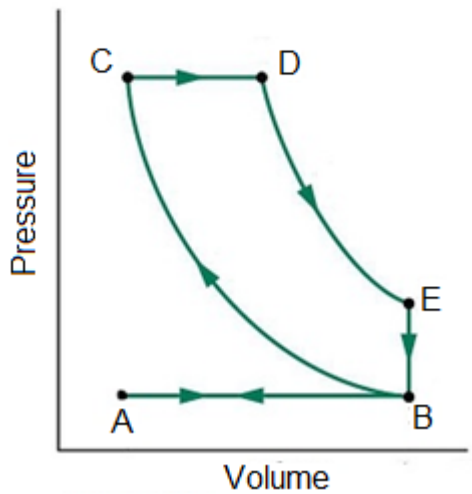
Each stroke is completed when the crankshaft rotates by 180°. Hence in 4-stroke engines, four different strokes are completed through 720° of the crankshaft rotation or 2 revolutions of the crankshaft based on the type of fuel used.

The working principle of a 4-Stroke Petrol engine is based on theoretical Otto cycle. Hence it is also known as Otto cycle engine.

And spark plug is used to ignite the air fuel mixture inside the engine cylinder, hence it is also known as spark ignition engine or S.I. engine.

4 stroke diesel engine





A 4-stroke diesel engine performs four different strokes to complete one cycle.

Suction stroke

1. At the beginning of the stroke piston is in TDC and during the stroke, piston moves from TDC to BDC.
2. The inlet valve opens and the exhaust valve will be closed.
3. The downward movement of the piston creates suction in the cylinder and as a result, fresh air is drawn into the cylinder through the inlet valve.
4. When the piston reaches the BDC, the suction stroke completes and this is represented by the line AB on P-V diagram.

Compression stroke

1. In this stroke piston moves from BDC to TDC. Both inlet and the exhaust valves are closed.
2. As the piston moves upwards, air in the cylinder is compressed to a high pressure and temperature. The compression process is shown by the curve BC in P-V diagram.
3. At the end of the stroke, the fuel (diesel) is sprayed into the cylinder by fuel injector.
4. As the fuel comes in contact with the hot compressed air, it gets ignited and undergoes combustion at constant pressure. This process is shown by the line CD on P-V diagram. At the point D fuel supply is cutoff.

Expansion stroke/Power stroke

1. In this stroke the piston moves from TDC to BDC. Both inlet and the exhaust valve remain closed.
2. As combustion of fuel takes place, the burnt gases expand and exert a large force on the piston. Due to this, piston is pushed from TDC to BDC. The power is transmitted down through the piston to the crank shaft through the connecting rod. This causes the crankshaft to rotate at high speeds. Thus, work is obtained in this stroke. This is shown by the curve DE on P-V diagram.

3. As the piston reaches the BDC, the exhaust valve opens. A part of the burnt gases escapes through the exhaust valve out of the cylinder due to their own expansion. This escape of gases occurs momentarily at constant volume which is shown by the curve EB on P-V diagram.

Exhaust stroke

1. The piston moves from BDC to TDC. The inlet valve is closed, and the exhaust valve is opened.
2. As the piston moves upward, it forces the remaining burnt gases out of the cylinder through the exhaust valve. This is shown by the line BA on P-V diagram.
3. When the piston reaches the TDC the exhaust valve closes. This completes one cycle.

Each stroke is completed when the crankshaft rotates by 180°. Hence in 4-stroke engines, four different strokes are completed through 720° of the crankshaft rotation or 2 revolutions of the crankshaft based on the type of fuel used.

The working principle of a 4-Stroke diesel engine is based on theoretical diesel cycle. Hence it is also known as diesel cycle engine.

And also the heat produced from the compression of the air is used to ignite the fuel when it is sprayed in the expansion stroke; hence it is also called compression ignition engine or C.I. engine.

TWO STROKE ENGINES

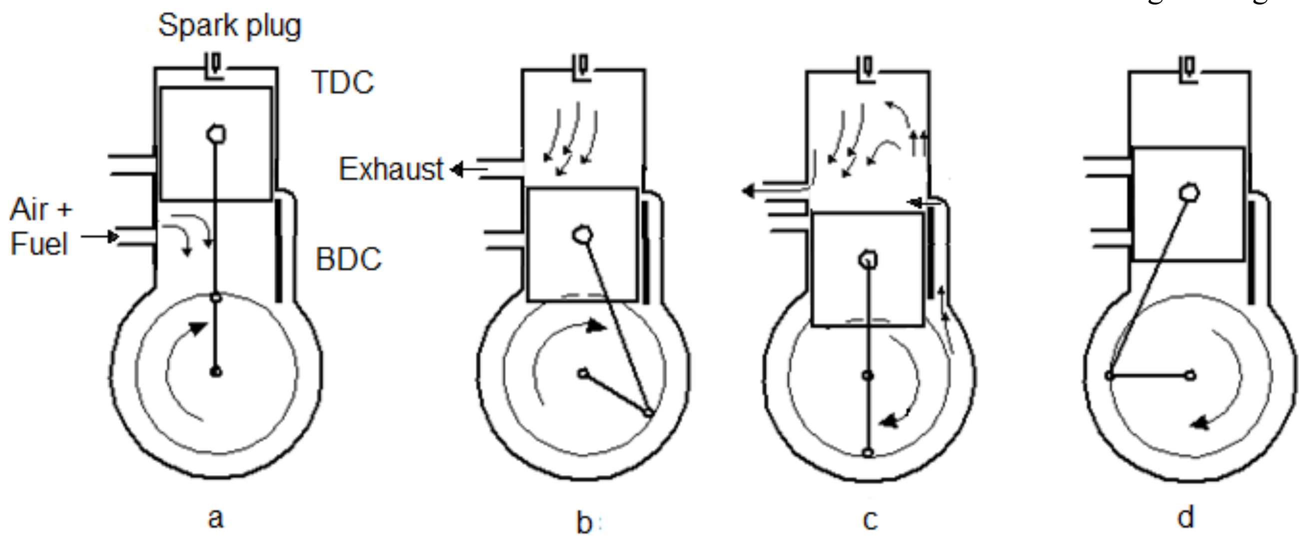
In a 2-stroke engine, ports are present in the cylinder in place of valves. The ports are the openings in the cylinder opened and closed by the movement of piston within the cylinder. There are three ports, namely

1. Inlet port: Through which admitting of charge into the crankcase takes place.
2. Transfer port: Through which the charge is transferred from the crankcase to the cylinder.
3. Exhaust port: Through which the burnt gases are discharged out of the cylinder.

In a 2 - stroke engine, piston performs two different strokes or crankshaft completes one revolution to complete all the operations of the working cycle.

In these engines there are no suction and exhaust strokes, instead they are performed while the compression and power strokes are in progress. Based on the type of fuel used, 2-stroke engines are classified as

2 stroke petrol engine



2-Stroke petrol engine works on the principle of theoretical Otto cycle. The two different strokes performed are first stroke (downward stroke) and second stroke (upward stroke).

First stroke

1. At the beginning of this stroke, the piston is in the TDC as shown in the figure (a). At this position, inlet port is opened, and hence fresh air petrol mixture enters the crank case.
2. The compressed air-petrol mixture present in the cylinder from the previous cycle is ignited by the spark generated by the spark plug. The combustion of fuel releases hot gases which increases the pressure in the cylinder. The high-pressure gases exert a pressure on the piston and hence the piston moves from TDC to BDC. Thus, piston performs power stroke. The power is transmitted from the piston to the crankshaft through the connecting rod. This causes the crankshaft to rotate at high speeds. Thus, work is obtained in this stroke.
3. As the piston moves downwards, it uncovers the exhaust port and hence burnt gases escape out of the cylinder as shown in the figure (b). And when the piston moves downwards the air fuel mixture in the crank case is compressed by the underside of the piston.
4. As piston moves still downwards, it opens the transfer port and the compressed charge from the crankcase rushes into the cylinder through the transfer port as shown in figure (c). The charge entering the cylinder drives away the remaining exhaust gases through the exhaust port.

<u>Second stroke</u>

1. At the beginning of the stroke, piston is in BDC, and it covers the inlet port as shown in the figure (c) and stops the flow of fresh charge into the crankcase.
2. During this stroke, piston moves towards TDC. As the piston moves upwards, it closes the transfer port, there by stopping the flow of fresh charge into the cylinder as shown in figure (d).

3. Further upward movement of the piston closes the exhaust port and actual compression of the charge begins. In the meantime, the inlet port is opened, and the upward movement of piston creates suction in the crankcase. Fresh charge enters the crankcase through the inlet port as shown in figure (a). The compression of the charge in the cylinder continues till the piston reaches the TDC. This completes the cycle.

Comparison between petrol and diesel engines

SI.	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
1.	Draws a mixture of petrol and air dur ing suction stroke .	Draws only air during suction stroke.
2.	The carburetor is employed to mix air and petrol in the required proportion and to supply it to the engine during	The injector is employed to inject the fuel at the end of compression stroke.
3.	Compression ratio ranges from 7: 1 to12: I	Compression ratio ranges from 18:1 to22:1
4.	The charge (Le petrol and air mixture) is ignited with the help of spark plug. This type of ignition is called spark ignition.	The ignition of the diesel is accomplished by the compressed air which will have been heated due to high compression ratio, to the temperature higher than the ignition temperature of the diesel. This type of ignition is called compression ignition.
5.	The combustion of fuel takes place approximately at constant volume.	The combustion of fuel takes place approximately at constant pressure.
6.	Works on theoretical Otto Cycle.	Works on theoretical Diesel Cycle.
7.	Power developed is less.	Power developed is more.
8.	Thermal efficiency is low.	Thermal efficiency is high.
	It is up to about 26%	It is up to about 40%.
9.	These are high speed engines	These are low speed engines.
10.	The maintenance cost is less.	The maintenance cost is more.
11.	The running cost is high because of the higher cost of petrol.	The running cost is low because of lower cost of diesel
12.	Lighter and cheaper because of low compression ratio	Heavier and costlier because of high compression ratio.

COMPARISON BETWEEN 2-STROKE AND 4-STROKE I.C. ENGINES.

SI. No.	2-Stroke Engine	4-Stroke Engine
1.	Requires two separate strokes to complete one cycle of operation.	Requires four separate strokes to complete one cycle of operation.
2.	Power is developed in every revolution of the crankshaft	Power is developed for every revolutions of the crankshaft.
3.	The inlet, transfer and exhaust ports are opened and closed by the movement of piston itself.	The inlet and exhaust are opened and closed by the valves.
4.	Turing moment is not uniform and hence requires a heavier flywheel.	Turing moment is uniform and hence Requires lighter flywheel.
5.	The charge is first admitted into the crankcase and then transferred to the engine cylinder.	The charge is directly admitted in to the engine cylinder during the suction stroke.
6.	For the same power developed the engine is heavy and bulky.	For the same power developed the Engine is light and compact.
7.	Thermal efficiency is low.	Thermal efficiency is high.
8.	Requires greater lubricant and coolant.	Requires lesser lubricant and coolant.
9.	Fuel consumption is more.	Fuel consumption is less.
10.	Initial cost is less.	Initial cost is more.

Brake Power: The power developed by the engine at the output shaft is called break power. Indicated power produced inside the IC engine cylinder will be transmitted through the piston connecting rod and crank. Therefore a certain fraction of the indicated power produced inside the cylinder will be lost due to friction of the moving parts of the engine. Therefore net power available at the crankshaft will be equal to the *difference between the Indicated power produced inside the engine cylinder and the power lost due to friction.* The net power available at the crankshaft is measured by applying the brake and is therefore called *brake power. The amount* of the power lost in friction is called *friction power.* The *friction power is the difference between the indicated power and the brake power.*

Friction Power = Indicated power - Brake Power

Brake power is calculated as follows:

W = Net load acting on the brake drum, kg

R = Radius of the brake drum, m

N = Revolutions per Minute of the crankshaft

T = Torque applied due to the net load W on the brake drum, N-m

= W*R kg-m

= 9.81*W*R N-m

Brake Power = $\frac{2\pi NT}{60000}$ kW

Mechanical Efficiency: It is the efficiency of the moving parts of the mechanism transmitting the indicated power to the crank shaft. Therefore it is *defined as the ratio of the brake power and the indicated power.* It is expressed in percentage.

Mechanical Efficiency = η_{mech} = BP / IP * 100

Thermal Efficiency: It is the efficiency of conversion of the heat energy produced by the actual combustion of the fuel into the power output of the engine. Therefore *it is defined as the ratio of the power developed by the engine to the heat supplied by the fuel in the same interval of time. It is expressed in percentage.*

$$Thermal\ Efficiency = \frac{\text{Power Output}}{\text{Heat Energy Supplied by the Fuel}} * 100$$

The power output to be used in the above equation may be *brake power* or *indicated power* accordingly the thermal efficiency is called *brake thermal efficiency* or *indicated thermal efficiency.*

The brake thermal efficiency is defined as the ratio of brake power to the heat supplied by the fuel. It is expressed in percentage.

$$Brake\ Thermal\ Efficiency = \frac{\text{Brake Power}}{\text{Heat Energy Supplied by the Fuel}} * 100$$

$$\eta_{bth} = \frac{BP}{m_f * CV} * 100$$

where m_f = mass of the fuel supplied kg/s

CV = Calorific Value of the fuel kJ/kg

The indicated thermal efficiency is defined as the ratio of indicated power to the heat supplied by the fuel. It is expressed in percentage.

$$Indicated\ Thermal\ Efficiency = \frac{\text{Indicated Power}}{\text{Heat Energy Supplied by the Fuel}} * 100$$

$$\eta_{bth} = \frac{IP}{m_f * CV} *100$$

Problem -1

A 4 cylinder I.C Engine running at 450 rpm has a bore diameter of 100 mm and stroke length 120 mm. The indicator diagram details are; area of the diagram 4cm2, length of the indicator diagram 6.5cm and the spring value of the spring used is 10 bar/cm. calculate the indicated power of the engine.

Solution

$$Indicated\ Power = \frac{100P_m LAN}{60 \times 2} kW$$

Mean Effective Pressure $P_m = \frac{sa}{l}$ N/m^2.

N= 450 rpm D= 100mm=0.1m a=4cm^2 L= 120 mm=0.12m l=6.5cm s= 10 bar/cm

$$A = \frac{\pi}{4} 0.1^2 = 0.0078m^2$$

P_m = 6.15 bar

IP = 2.17kW

Problem – 2

The following reading were taken on a for-stroke I.C Engine:

Diameter of the break drum =1.5m

Diameter of the rope = 10 mm

Load suspended on the brake drum = 100kg

Spring balance reading = 5kg

Crankshaft speed = 200 rpm

Determine the brake power of the engine.

Solution

Effective radius R = Radius of the brake drum + Radius of the rope

R =(1.5/2+ 0.01/2) m = 0.755 m

Net Load on the break drum W= (100-5) kg =95kg

$Torque = T = \frac{9.81}{1000} W\ R$ kNm = 0.7 kNm

$Break\ Power = \frac{2\pi\ N\ T}{60} kW$ = 14.66 kW

Problem – 3

A 4 stroke single cylinder I.C Engine of 250mm cylinder diameter and 400mm stroke runs at a piston speed of 8m/s. If the engine develops 50kW indicated power, find its mean effective pressure and the crankshaft speed.

Solution

D= 250 mm=0.25m, L= 400mm=0.4m, IP= 50kW, piston Speed =8m/s.

$$Indicated\ Power = \frac{100 P_m LAN}{60 \times 2} kW$$

Piston Speed = 2LN m/min.

8x60=2x0.4xN

N= 600 rpm

$$50 = \frac{100 \times P_{m\times} 0.4 \times \pi \times 0.25^2 \times N}{4 \times 60 \times 2}$$

P_m= 5.09 bar

Problem – 4

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

Solution

P_m=600 kN/m^2= 6 bar. Swept Volume LA = 6 litres = 6x10^{-3}m^3, N=1000rpm

$$Indicated\ Power = \frac{P_m LAN}{1000 \times 60 \times 2} kW$$

=24 kW

Problem – 5

A 4 cylinder 4 stroke engine running at 1000 rpm develops an indicated power of 15kW. The mean effective pressure is 5 x 105 N/m2. Find the diameter of the cylinder and the stroke of the piston when the ratio of diameter to stroke is 0.8.

Solution

IP = 15kW Pm = 5 x 10^5 N/m^2 = 5bar, N=1000rpm, D/L= 0.8

$$Indicated\ power\ developed/cylinder = \frac{Total\ Engine\ Power}{Number\ of\ cylinders} = \frac{15}{4} = 3.75kW$$

$$Indicated\ Power = \frac{100 P_m LAN}{60 \times 2} kW$$

$$3.75 = \frac{100 \times 5 \times 1.25D \times \pi D^2 \times 1000}{4 \times 60 \times 2}$$

D = 9.167 x 10^{-4} m^3= 0.09714m = 97.14mm

$$\frac{D}{L} = 0.8$$

L=121.42 mm

Problem – 6

The following data refers to a single cylinder 4 stroke petrol engine.

Cylinder diameter = 20cm

Stroke of the piston = 40cm

Engine speed = 400 rpm

Indicated mean effective pressure = 7 bar

Fuel consumption = 10 litres/hour

Calorific value of the fuel = 45000 kJ/kg

Specific gravity of the fuel =0.8

Find the indicated thermal efficiency.

Solution:

D= 0.2m, L=0.4m, N=400rpm, P_m=7bar.

$Indicated\ Power = \frac{100 P_m LAN}{60 \times 2} kW$

= 29.32kW

$$\eta_{I\ Thermal} = \frac{IP}{CV \times m} \times 100$$

$$\eta_{I\ Thermal} = \frac{29.32}{45000 \times \frac{10}{3600} \times 0.8} \times 100$$

$\eta_{I\ Thermal}$ = 29.32%

Problem – 7

The following observations were obtained during a trial on a four-stroke diesel engine.

Cylinder diameter = 25cm.

Stroke of the piston = 40cm.

Crankshaft speed = 250 rpm.

Brake load =70kg.

Break drum diameter = 2m.

Mean effective pressure = 6bar.

Diesel oil consumption =0.1 m^3/min.

Specific gravity of diesel =0.78.

Find:

1. Brake Power.
2. Indicated Power.
3. Friction Power.
4. Mechanical Efficiency.
5. Brake thermal Efficiency.
6. Indicated Thermal Efficiency.

- Solution

Brake Power:

W = 70kg, R=D/2 =2/2=1m, N= 250rpm

$Torque = T = \frac{9.81}{1000} W\ R$ kNm

= 0.686 kNm

$$Break\ Power = \frac{2\pi\ N\ T}{60} kW$$

BP= 17.95 kW

Indicated Power

P_m=6bar, L=0.4m, D= 0.4m, $A = \frac{\pi}{4} \times 0.4^2$,

N=250 rpm

$$Indicated\ Power = \frac{100 P_m LAN}{60\ \times\ 2} kW$$

IP = 24.54kW

3. Friction Power = Indicated Power – Brake Power

Friction Power = 24.54 – 17.95 = 6.59 kW

4. Mechanical Efficiency:

$$\eta_{Mech} = \frac{Break\ Power}{Indicated\ Power} \times 100$$

$\eta_{Mech} = \frac{17.95}{25.54} \times 100$ = 73.14%.

5. Brake Thermal Efficiency

$m = \frac{0.1 \times 0.78}{60}$, CV = 43900 kJ/kg

$$\eta_{B\ Thermal} = \frac{BP}{CV \times m} \times 100$$

= 31.45%.

6. Indicated Thermal Efficiency

$\eta_{I\ Thermal} = \frac{IP}{CV \times m} \times 100$ = 43%

Refrigeration & Air conditioning

Refrigeration is defined as a method of reducing the temperature of a system below that of the surroundings and maintaining it at the lower temperature by continuously abstracting heat from it. In a refrigerator, the working fluid that continuously extracts heat from within the refrigerator which is required to be cooled is called a **refrigerant**.

Refrigeration effect and Unit of refrigeration

In a refrigeration system, the rate at which the heat is absorbed in a cycle from the interior space to be cooled is called a refrigerating effect.

The unit of refrigeration is **ton.** It is also the capacity of refrigeration effect produced.

A ton of refrigeration is defined as the quantity of heat absorbed in order to form one ton of ice in 24 hours when the initial temperature of the water is 0°C.

One American ton (2000 pounds) is taken as the standard in refrigeration practice. But in S.I. system, 1 ton of refrigeration = 3.5 kW

Coefficient of performance

The performance of a refrigeration system is expressed by a factor known as the coeficient of peformance (COP). The COP of a refrigeration system is defined as the ratio of heat absorbed in a system to the work supplied.

If Q = Heat absorbed or removed, kW

& W = Work supplied to the motor, kW

COP = Q/W

Properties of a good refrigerant

Boiling point: An ideal refrigerant must have low boiling temperature at atmospheric pressure.

Freezing point: It must have a very low freezing point because the refrigerant should not freeze at low evaporator temperatures.

Thermal conductivity: It must have high thermal conductivity so that heat can be transferred to and from the refrigerant very easily.

Specific heat: A good refrigerant must have low specific heat when it is in liquid state and high specific heat when it is vapourised. The low specific heat of the refrigerant helps in more heat absorption in the evaporator and high specific heat of the vapour helps in easy condensing. Both these desirable properties will increase the refrigerating effect.

Specific volume: The specific volume of the refrigerant must be very low so that it occupies less volume upon vaporization.

Viscosity: The viscosity of a refrigerant at both the liquid and vapour states must be very low as it improves the heat transfer and reduces the pumping effort required.

Toxicity: A good refrigerant should be non-toxic. Any leakage of the toxic refrigerant increases suffocation and poisons the atmosphere or any food items stored.

Corrosiveness: A good refrigerant should be non-corrosive to prevent the corrosion of the metallic parts of the refrigerators.

Chemical stability: An ideal refrigerant must not decompose under operating conditions.

Coefficient of Performance (COP): The COP of a refrigerant must be high so that the energy spent in refrigeration will be less.

Odour: A good refrigerant must be odourless, otherwise food kept inside may lose their taste.

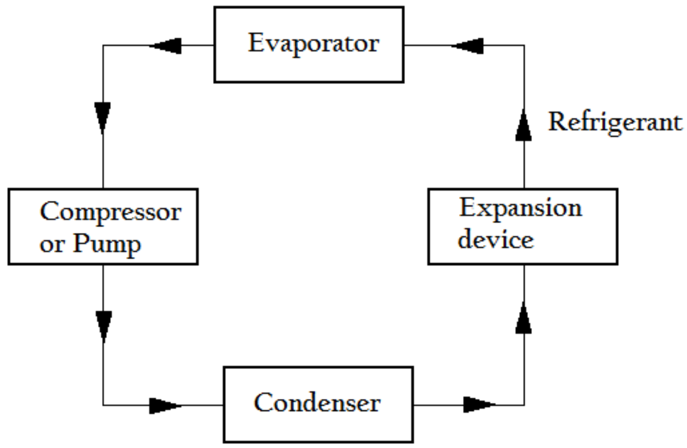
Leakage: The refrigerant must be such that any leakage can be detected by simple tests.

Commonly used refrigerants are:

1. **Ammonia –** It is used in ice plants and cold storage. Its melting point is and has low specific volume. It produces high refrigeration efects even in small refrigerators. It doesn't harm the ozone. But it is toxic, flammable, irritating and destroys the food due to which it cannot be used for domestic refrigeration.
2. **Carbon dioxide –** It is used in marine refrigerators. The effeciency of CO_2 is less, hence it is rarely used in domestic refrigerator. It is colourless, odourless, non toxic, non flammable and non corrosive.
3. **Sulphur dioxide –** Eariler sulphur dioxide was one of the most commonly used refrigerants in the refrigerators. But it was not used because its refrigeration effect was low and it had high specific volume due to which large capacity and high speed compressors were required. And also since it combines with water to form sulfuric acid which is corrosive.
4. **Methyl chloride –** Used in domestic and industrial refrigerators. Since it will burn under some conditions and is slightly toxic, it is not generally used.
5. **Freon –** Freon group of refrigerants is used almost universally in domestic refrigerators. These refrigerants are colourless, almost odourless, non toxic, non flammable, non explosive and non corrosive. **Freon-12** and **freon-22** are the two commonly used refrigerants in domestic refrigerator, water coolers, air conditioning plants, cold storage, food processing and storage etc. But it has been found that these refrigerants are major threat to ozone layer.

Parts of a refrigerator

To accomplish the task of producing the cooling effect, a refrigeraot must consist a eveporator, a condenser, a circulating device like pump or compressor and a expansion valve.



Evaporator: This is the main part of the refrigeration system where the liquid refrigerant is evaporated by absorbing the heat from refrigeration space which has to be cooled. It consists of metal tubes which surrounds the freezing and cooling compartments.

Circulating system: It consists of mechanical devices like pumps or compressors that are necessary to circulate the refrigerant to undergo the refrigeration cycle. They are generally driven by electric motors. The electrical energy input to the motor is the energy input to the refrigerator.

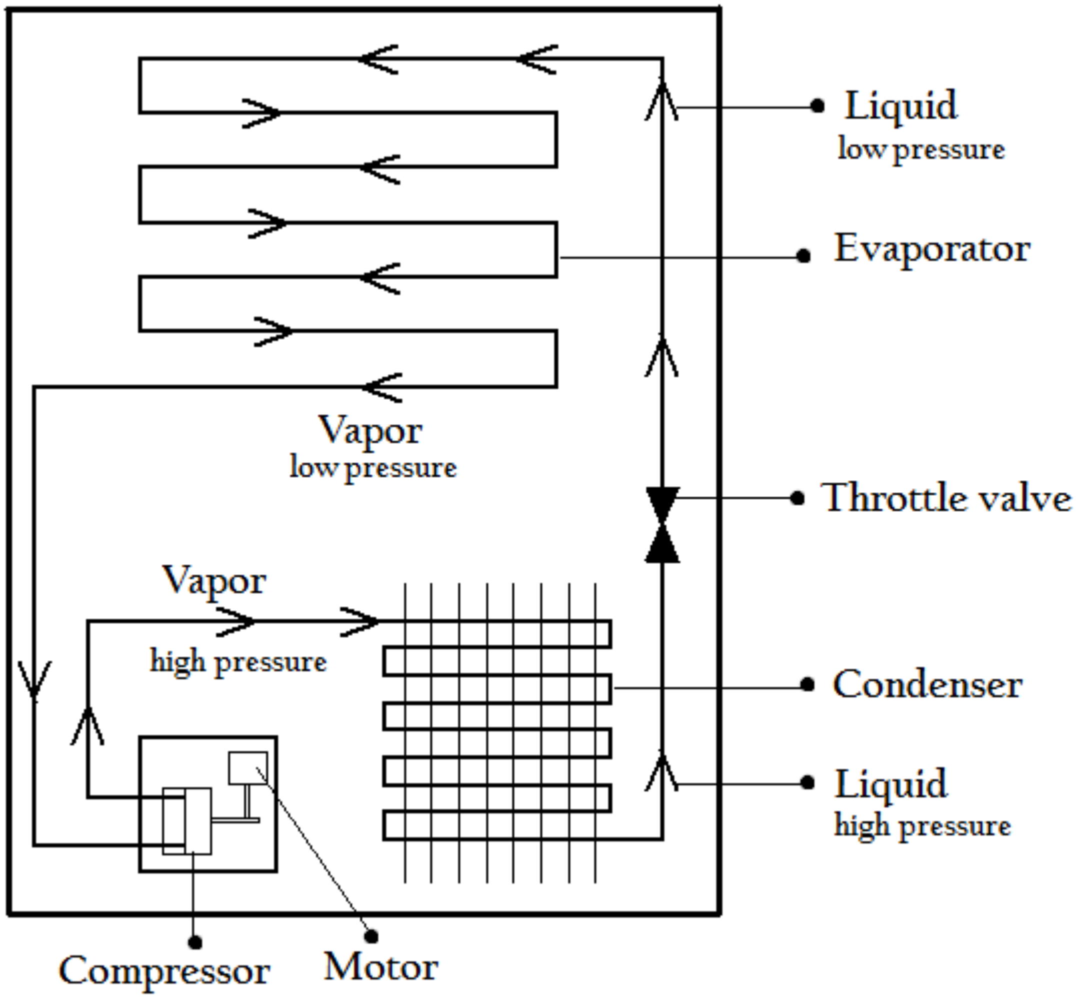
Condenser: It is a device where heat from the refrigerant is rejected at higher temperature to another medium, usually the atmospheric air. Here the refrigerant vapours gets converted into liquid by rejecting the heat that was absorbed in the refrigeration space and in the compressr

Expansion device: This device reduces the pressure and temperature of the liquid refrigerant before it passes to the evaporator.

Vapour compression refrigeration system

1. The system consists of evaporator, compressor, condenser and an throttle valve.
2. In this system, a liquid refrigerant alternatively undergoes a change of phase from vapour to liquid (condensation) and from liquid to vapour phase (evaporation) during the working cycle.
3. The liquid refrigerant in the evaporator absorbs the heat from the refrigeration space which is to be cooled and undergoes a change of phase form liquid to vapour.
4. This vapour at low temperature and pressure is drawn into the compressor where it is compressed to a high pressure and temperature. The compressed vapour then enters the condenser.
5. In the condenser the vapour refrigerant is cooled and condensed into liquid by giving its latent heat to the circulating cooling medium (air or water).
6. The high-pressure liquid refrigerant leaves the condenser and passes through the throttle valve where it is expanded to low pressure and temperature. The temperature of the refrigerant falls to a value less than that of the refrigerated space.

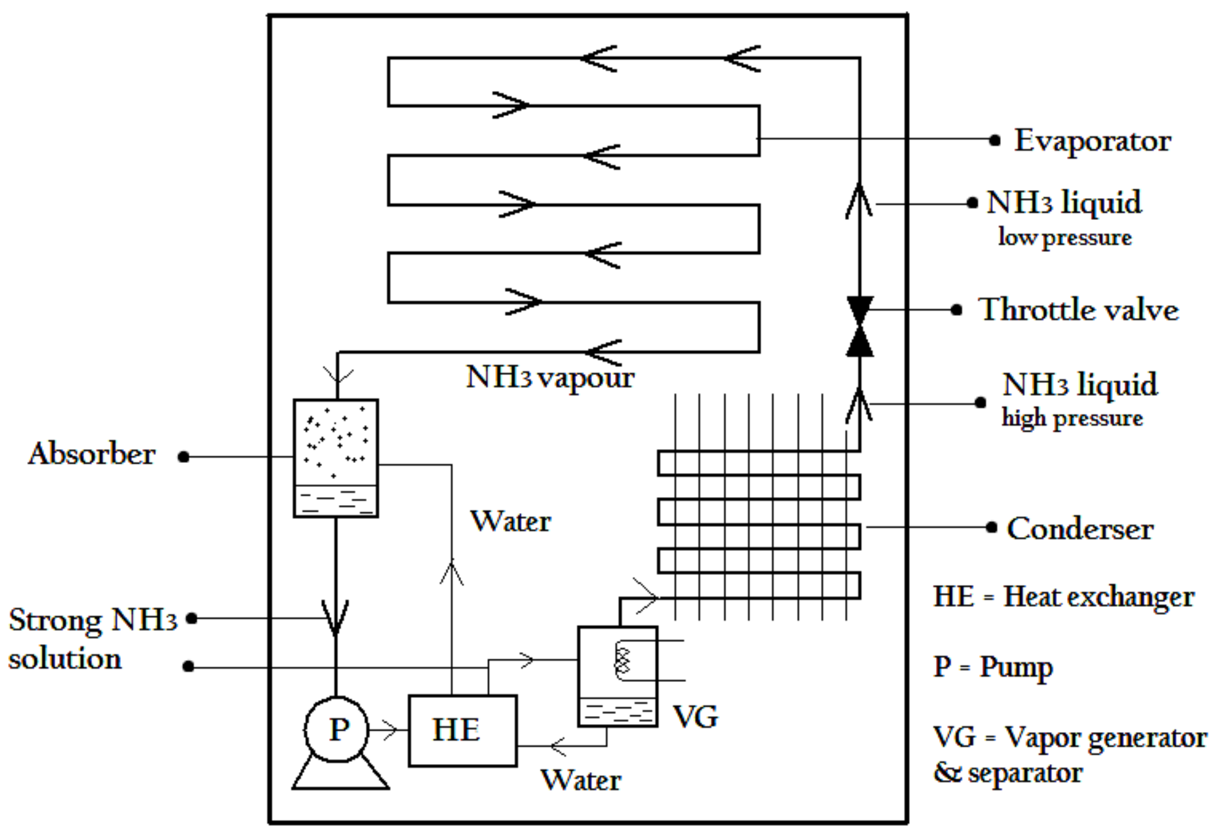
7. The low pressure-low temperature refrigerant again enters the evaporator where it absorbs the heat from the refrigeration space and evaporates. And the cycle repeats.



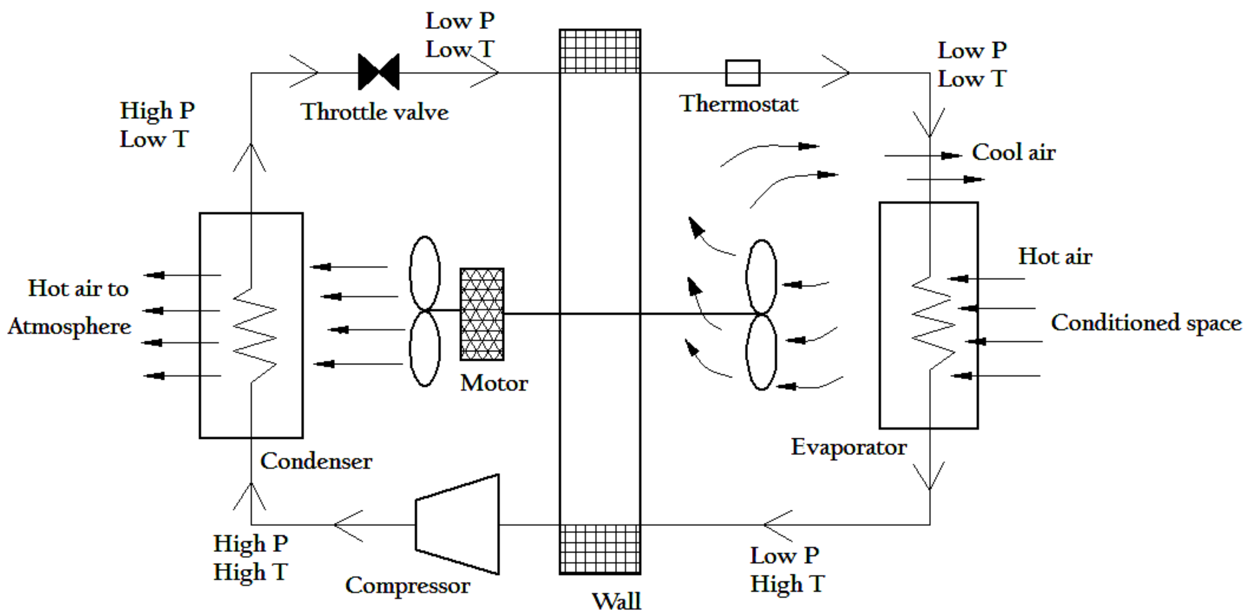
Vapour absorption refrigeration system

1. In this system, an absorbent like water is used to absorb large volumes of refrigerant vapours and form a solution. This solution when heated, gives out vapours of refrigerant which can be used in extraction of heat.
2. The liquid refrigerant enters the evaporator and absorbs the heat from the refrigeration space and gets converted to vapour.
3. This vapour is absorbed by an absorbent (water) in the absorber to form strong ammonia solution which is pumped to a vapour generator through a heat exchanger.
4. In the heat exchanger the strong ammonia solution is warmed up by the hot weak ammonia solution flowing from the vapour generator to the absorber.

5. In the vapour generator the strong ammonia solution is heated by external source. Due to heating, ammonia vapours gets seperated from the solution.
6. Any weak solution of ammonia which is left over in the vapour generator moves back to absorber and mixes up with the solution.
7. Next the ammonia vapour is condensed in a condenser, giving out heat to the surroundings and forming a liquid.
8. This cooled ammonia solution is passed through the throttling valve where the pressure and temperature of the refrigerant is reduced below the temperature to be maintained in the refrigerator.
9. The liquid refrigerant enters the evaporator and absorbs the heat from refrigeration space and gets converted to vapour. This cycle repeats.



Air conditioning



1. Air conditioning is defined as providing a comfortable indoor atmosphere by simultaneous control of temperature, humidity, air filtering, air purification and recirculation of the air.
2. The air conditioning system consists of a **compressor, condenser, evaporator, throttle valve, condenser and evaporator fans** driven by the same motor.
3. The evaporator fan and the evaporator coils of the unit always lie inside the building or space which is to be conditioned.
4. Condenser and the condenser fan of the unit projects outside the building or space to enable heat transfer with the atmosphere.
5. The low pressure-low temperature refrigerant enters the evaporator coils. The evaporator fan continuously draws hot air from the conditioned space and circulates it over the evaporator coils.
6. The hot air passing through the air filter comes in contact with cold evaporator coils and exchanges its heat. The cool fresh air enters the conditioned space.
7. The refrigerant vapours enter the compressor and gets compressed to a higher pressure and temperature.
8. The high pressure refrigerant leaving the compressor enters the condenser coils. The latent heat of the refrigerant vapour is given to the surrounding atmosphere.
9. Condensation takes place due to this heat transfer as the condenser fan draws air from outside the building and circulates it over the condenser coils.
10. The high pressure liquid refrigerant enters the throttle valve and expands in it. The pressure of the refrigerant reduces. This refrigerant moves to the evaporator coils and the cycle repeats.
11. Desired temperature inside the room can be adjusted by thermostatic control device.

POWER TRANSMISSION

The rotational motion can be transmitted from one mechanical element to the other with the help of certain systems known as transmission systems.

The methods of power transmission are

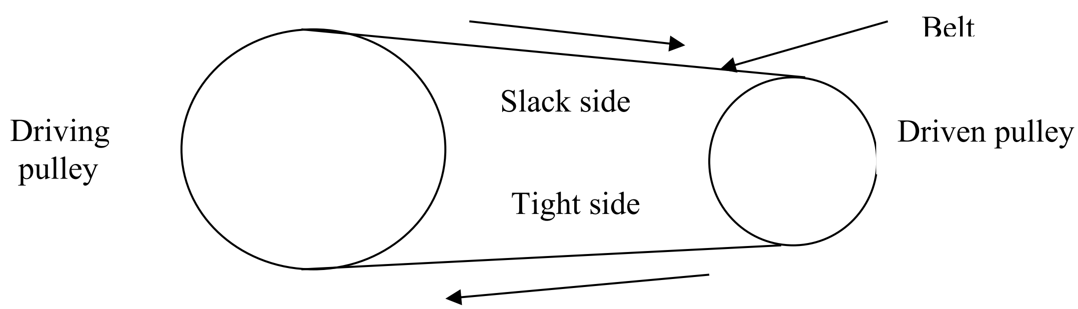
i. Belt drive.

ii. Gear drive.

iii. Rope drive.

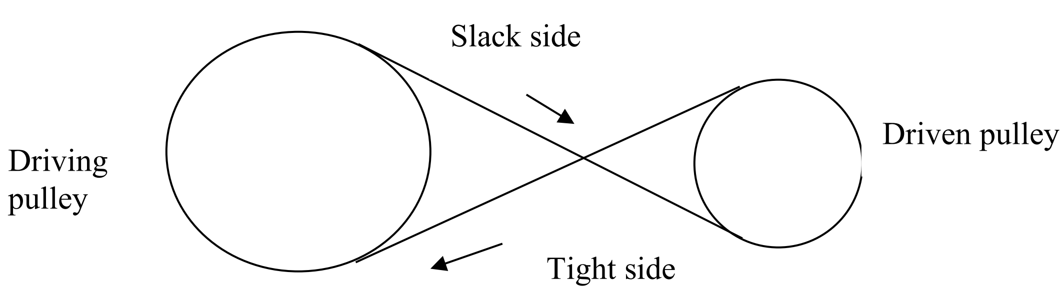
iv. Chain drive.

Open Belt Drive: This type of belt drive is employed when the two parallel shafts have to rotate in the same direction. When the shafts are placed far apart, the lower side of the belt should be the tight side and the upper side must be the slack side. This is because, when the upper side becomes the slack side, it will sag due to its own weight and thus increases the arc of contact which in turn increases the capacity of the drive.



Flat belt drives of the open system should always have their shaft axes either horizontal or inclined. They should never be vertical, for if so arranged the centrifugal force developed in the belt combined with the force of gravity causes the belt to stretch and tend to leave the rim of the pulleys, thereby losing contact with their rim surfaces.

Crossed Belt Drive:



This type of belt drive is employed when two parallel shafts have to rotate in the opposite direction. At the junction where the belt crosses, it rubs against itself 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.

Velocity Ratio of Belt Drive

The velocity ratio of a belt drive is defined as the ratio of the speed of the driven pulley to the speed of the driving pulley.

Let d_1 and d_2 be the diameters of the driving and the driven pulleys respectively, and let N_1 and N_2 be their speeds in revolutions per minute. If there is no relative slip between the pulleys and the portions of the belt which are in contact with them, the speed at every point on the belt will be same. Therefore the circumferential speeds of the driving and driven pulleys and the linear speed of the belt are equal.

$$\begin{bmatrix} Linear speed \\ of\ the belt \end{bmatrix} = \begin{bmatrix} Circumferential\ speed \\ of\ the driving\ pulley \end{bmatrix} = \begin{bmatrix} Circumferential\ speed \\ of\ driven\ pulley \end{bmatrix}$$

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

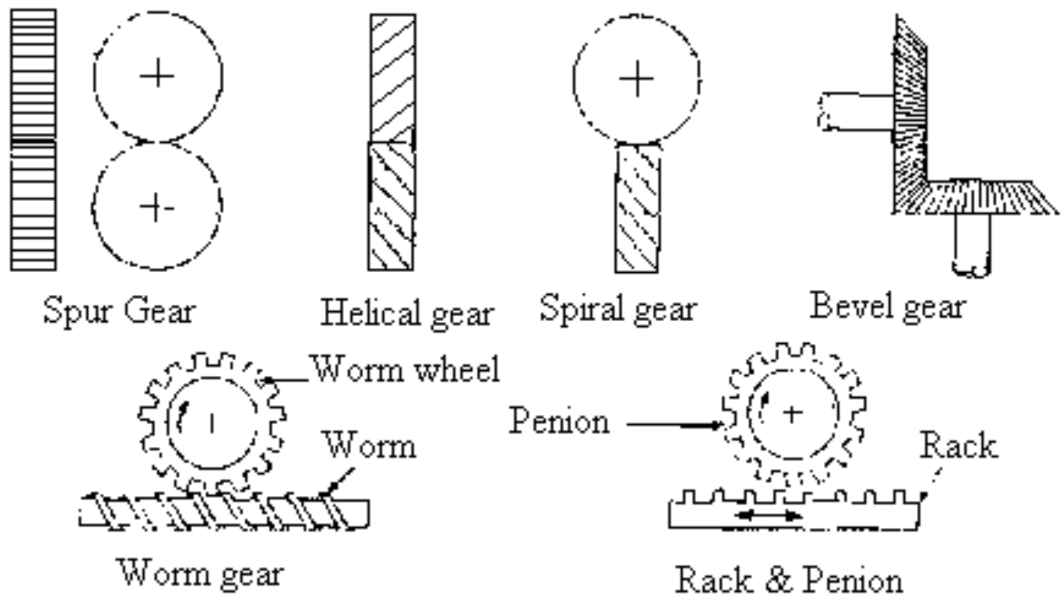
$$= d_1 N_1 \qquad\qquad = d_2 N_2$$

Velocity Ratio $= N_2 / N_1 = d_1 / d_2$

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

Types gears

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 Gears**

When the axes of the driving and driven shafts are parallel and co-planar as shown in Fig. 8.10, and the teeth of the gear wheels are parallel to the axes, the gears are called spur gears. The contact between the mating gears will be along a line, hence spur gears can transmit higher power. Because of the instantaneous line contact when the teeth mesh, noise will be very high. They are widely used in machine tools, automobile gear boxes and in all general cases of power transmission where gear drives are preferred.

2. **Helical Gears**

Helical gears are similar to the spur gears except that the teeth are cut in the form of the helix around the gear as shown in Fig. 8.11. Helical gears are used for transmitting power between two parallel shafts and also between nonparallel, non-intersecting shafts. The contact between the mating gears will be along a curvilinear path. Helical gears are preferred to spur gears when smooth and quiet running at higher speeds is necessary. The main disadvantage of the helical gears is that it produces end thrusts on the driving and driven shafts. Generally, they are used in automobile power transmission.

4. Bevel gears

When the axes of the two shafts are inclined to one another, and intersect when produced, bevel gears shown in Fig. are used. Teeth of the bevel gears are cut on the conical surfaces. The most common examples of power transmission by bevel gears are those in which the axes of the two shafts are at right angles to each other. When two bevel gears have their axes at right angles and are of equal sizes, they are called miter gears.

5. Worm and Worm Wheel

Worm gears are used to transmit power between the driving and driven shafts having their axes at right angles and non-coplanar. A worm drive consists of a worm (essentially a screw) which may have one or more number of helical threads of trapezoidal shape cut on it and a worm wheel - a gear wheel with the tooth profile consisting of a small segment of a helix which engages with the worm. Worm gears are suitable for transmission of power when a high velocity ratio as high as 60:1 is required. They are generally employed in machine tools, like lathe, milling, drilling machines etc, to get large speed reduction. Another important characteristic of the worm and worm wheel drive is that it offers self-locking facility between the driven and the driving units when the direction of the drive is reversed.

7. **Rack and Pinion**

When a rotary motion is to be converted into a linear motion, rack and pinion arrangement is used. Rack is a rectangular bar with a series of straight teeth cut on it. Theoretically rack is considered to be a spur gear of infinite diameter. Rack and pinion arrangement, find their application in machine tools, such as, lathe, drilling, planning machines, and on some steep rail tracks, where the teeth of the locomotive wheel mesh with a rack embedded in the ground, offering the locomotive improved traction.

Advantages and Disadvantages of Gear Drives

1. They are positive non-slip drives.
2. Most convenient for very small center distances.
3. By using different types of gears, it will be possible to transmit the power when the axes of the shafts are not only parallel, but even when nonparallel, intersecting, non-intersecting and co-planar or non-coplanar.
4. The velocity ratio will remain constant throughout.
5. They can be employed conveniently for low, medium, and high-power transmission.
6. Any velocity ratio as high as, even up to 60:1 can be obtained.
7. They have very high transmission efficiency.
8. Gears can be cast in a wide range of both metallic and non-metallic materials.
9. If required gears may be cast integral with the shafts.
10. Gears are employed for wide range of applications like in watches, precision measuring instruments, machine tools, gear boxes fitted in automobiles, aero engines, etc.

Disadvantages

1. They are not suitable for shafts of very large center distances.
2. They always require some kind of lubrication.
3. At very high speeds noise and vibrations will be more.
4. They are not economical because of the increased cost of production of precision gears.

5. Use of large number of gear wheels in gear trains increases the weight of the machine.

Velocity ratio of Gear drive

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 d_1 and d_2 be the pitch circle diameters of the driving and driven gear respectively. Let T_1 and T_2 be the number of teeth on the driving and driven gears respectively. Let N_1 and N_2 be their speeds in revolutions per minute.

Since there is no slip between the pitch cylinders of the two gear wheels, the linear speed of the two pitch cylinders must be equal.

$$\begin{bmatrix} \textit{Linear speed of the pitch} \\ \textit{cylinder representing the Driving gear} \end{bmatrix} = \begin{bmatrix} \textit{Linear speed of the pitch} \\ \textit{cylinder representing driven gear} \end{bmatrix}$$

$$\pi\, d_1 N_1 = \pi\, d_2 N_2$$

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The circular pitch for both the meshing gears remains same.

i.e. $$p_c = \frac{\pi\, d_1}{T_1} = \frac{\pi\, d_2}{T_2}$$

i.e., $$\frac{d_1}{d_2} = \frac{T_1}{T_2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From equation (1) and (2)

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

Velocity ratio of the worm and worm wheel is expressed as:

$$\boxed{\text{Velocity ratio} = \frac{\text{Speed of the Worm}}{\text{Speed of the Worm Wheel}} = \frac{\text{Number of Teeth on Worm Wheel}}{\text{Number of Threads on the Worm}}}$$

Gear train

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 gear train may be spur , bevel or helical etc.

The different types of gear trains are:

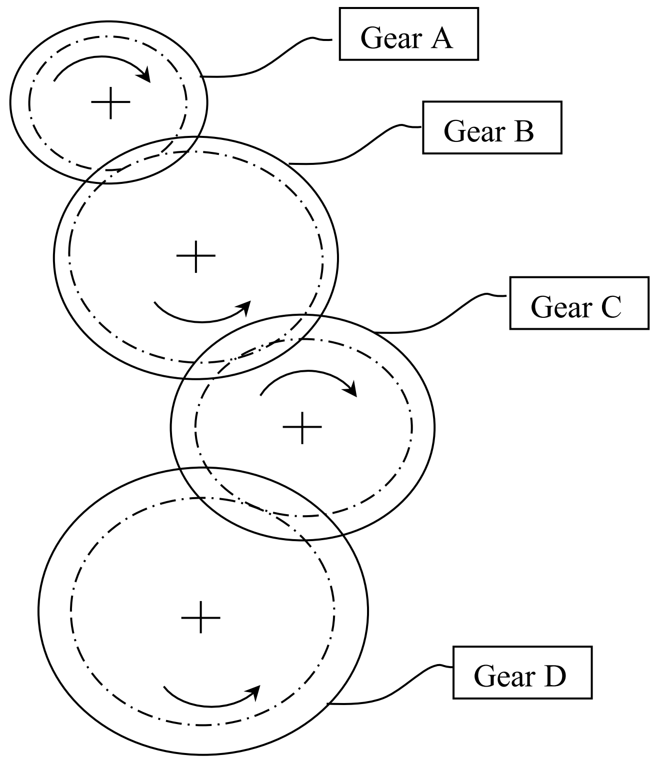
1. Simple gear train.

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

Simple gear train

In a simple gear train a series of gear wheels are mounted on different shafts between the driving and driven shafts each gear carrying only one gear as shown in fig. 8.6. A is the driving gear, B and C are intermediate gears and D is the driven gear.

Let N_A, N_B, N_C, N_D be the speed in RPM T_A,T_B, T_C, T_D be the number of teeth of gears A, B,C and D respectively.



Simple gear train

i. A drives B

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

ii. B drives C

$$\frac{N_C}{N_B} = \frac{T_B}{T_C}$$

iii. C drives D

$$\frac{N_D}{N_C} = \frac{T_C}{T_D}$$

Velocity ratio between the driving and driven Gears is given by,

$$\text{Velocity Ratio} = \frac{N_D}{N_A}$$

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

Substituting from (i), (ii) and (iii)

$$\text{Velocity Ratio} = \frac{N_D}{N_A}$$

$$= \frac{T_A}{T_B} \cdot \frac{T_B}{T_C} \cdot \frac{T_C}{T_D}$$

$$\text{Velocity Ratio } \frac{N_D}{N_A} = \frac{T_A}{T_D}$$

Compound gear train

A compound gear train is one in which each shaft carries two or more gears and keyed to it. Fig.8.7 represents a compound gear train in which gears Band C constitute a compound gear.

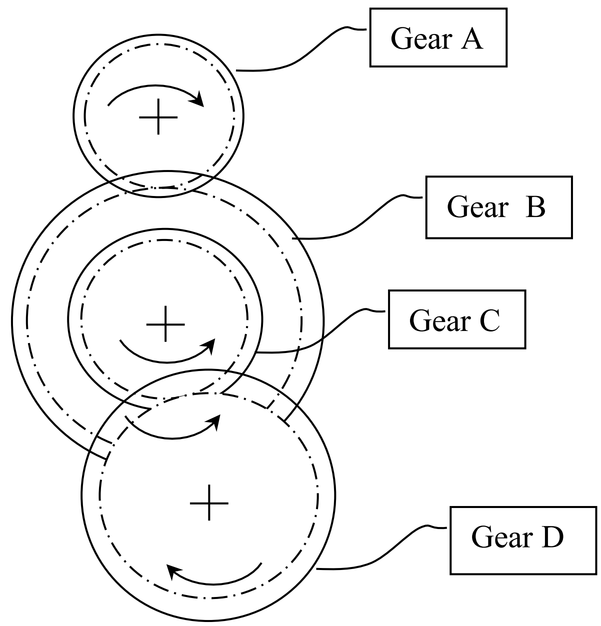
Gear A drives B, $\frac{N_B}{N_A} = \frac{T_A}{T_B}$ ....(1)

Since gears B and C are keyed to the same shaft, both of them rotate at the same speed

i.e, $N_B = N_C$ but $T_B \neq T_C$

Gear C drives D

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



Compound gear train

Velocity ratio between driving and driven gear

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

Substituting from (1) and (2)

$$\textbf{Velocity ratio} = \frac{N_D}{N_A} = \frac{T_C}{T_D} \cdot \frac{T_A}{T_B}$$

Problems

1. Power is to be transmitted from the shaft to another by means of a belt drive. The diameter of the larger pulley is 600 mm and the diameter of the smaller pulley is 300 mm. the distance between the center of the two pulley's is 3 meter. If the axes of the two shafts are in the same plane and parallel to each other, find the length of the belt required for, i.Open Belt Drive and ii. Crossed Belt Drive

Given: $d_1 = 600\ mm = 0.6\ m$

$d_2 = 300\ mm = 0.3\ m$

$c = 3\ m$

(i) Length of open belt required is given by

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

$$L = 2 \times 3 + \pi(0.3 + 0.15) + \frac{(0.3 - 0.15)^2}{3}$$

$L = 7.42\ m$

(i) Length of cross belt required is given by

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

$$L = 2 \times 3 + \pi(0.3 + 0.15) + \frac{(0.3 + 0.15)^2}{3}$$

$L = 7.48\ m$

2. Shaft running at 100 rpm is to drive a parallel shaft at 150 rpm. The pulley on the driving shaft is 35 cm in diameter. Find the diameter of the driven pulley. calculate the linear velocity of the belt and also the velocity ratio.

Given: $N_1 = 100\ rpm$

$N_2 = 150\ rpm$

$d_1 = 35\ cm = 0.35\ m$

Diameter of driven pulley d_2 is given by

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

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

$d_2 = 0.233\ m$

Velocity ratio is $\frac{N_2}{N_1} = 1.5$

Linear velocity of belt is $\pi d_1\ N_1 = 110\ \frac{m}{s}$

3. The sum of the diameters of 2 pulleys A and B is connected by a belt is 900 mm. If they runs at 700 and 1400 rpm respectively. Determine the diameter of each pulley.

Given: $d_A + d_B = 900\ mm$

$d_A + d_B = 0.9 - - - - - - - - (i)$

$N_A = 700\ rpm\ , N_B = 1400\ rpm$

$$\frac{N_B}{N_A} = \frac{d_A}{d_B} = 2 - - - - - - -(ii)$$

From equation (i) $d_B \left(\frac{d_A}{d_B} + 1\right) = 0.9$

$$d_B = \frac{0.9}{3} = 0.3\ m$$

$d_A = 0.6\ m$

4. In a crossed belt drive the difference in tensions between the tight and slack sides of the belt is 1000 N. Find the tension on the slack and tight sides. If the angle of contact is 160° and its coefficient of friction is 0.3.

Given: $T_1 - T_2 = 1000 - - - - - (i)$

$\theta = 160°$

$$\theta = 160\ \times \frac{\pi}{180} = 2.793\ radians$$

$\mu = 0.3$

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

$T_1 = 2.311\ T_2$

From equation (i)

$2.311\, T_2 - T_2 = 1000$

$T_2 = 762.77\ N$

$T_1 = 237.22\ N$

5. In a belt drive, the angle of lap on the driven pulley is 160° and coefficient of friction between the pulley and belt material is 0.28. If the width of the belt it is 200 mm and the maximum tension in the belt is not to exceed 50 N/mm width, find the initial tension in the belt drive.

Given:

$\theta = 160°$

$$\theta = 160\ \times \frac{\pi}{180} = 2.793\, radians$$

$\mu = 0.28$

Maximum tension in the belt for a width of 200 mm is $T_1 = 50\ \times 200 = 10000\ N$

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

$$\frac{10000}{T_2} = e^{0.28\ \times 2.793}$$

$T_2 = 4574.77\ N$

Initial tension in the belt is $T_0 = \frac{T_1+T_2}{2} = 7287.387\ N$

6. The driven pulley of 400 mm diameter of a belt drive runs at 200 rpm. The angle of lap is 165° and coefficient of friction between the belt material and the pulley is 0.25. Find the power transmitted if the initial tension is not to exceed 10 kN.

Given:

$d_2 = 400\ mm = 0.4\ m$

$N_2 = 200\ rpm$

$\theta = 165°$

$$\theta = 165\ \times \frac{\pi}{180} = 2.879\, radians$$

$\mu = 0.25$

$$T_0 = \frac{T_1 + T_2}{2} = 10000\ N - - - - - - - - (i)$$

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

$$\frac{T_1}{T_2} = e^{0.25\ \times 2.879}$$

$T_1 = 2.053\ T_2$

Substitute $T_1 = 2.053\ T_2$ in equation (i)

$$\frac{2.053\ T_2\ + T_2}{2} = 10000$$

$T_2 = 6550.93\ N$

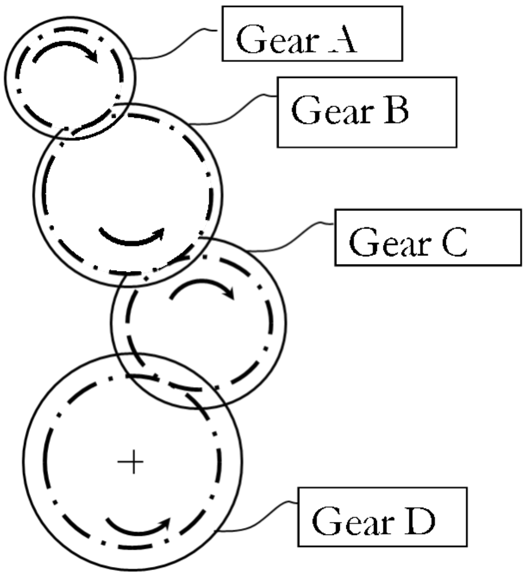
$T_1 = 13449.06\ N$

7. A simple gear train is made up of four gears A, B, C &D having 20,40,60 and 70 teeth respectively. If gear A is the main driver and rotating at 500 rpm clockwise calculate the following:

i. Speeds of intermediate gears, ii. direction of the last follower iii. Train value

Given: $T_A = 20\,, T_B = 40\,, T_C = 60\,, T_D = 70$

$N_A = 500\, rpm\ in\ clockwise\ direction$



(i) Gear A drives gear B

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

$N_B = 250\, rpm\ anti-clockwise$

Gear B drives gear C

$$\frac{N_C}{N_B} = \frac{T_B}{T_C}$$

$N_C = 166.67\, rpm\ clockwise$

ii) Gear C drives gear D

$$\frac{N_D}{N_C} = \frac{T_C}{T_D}$$

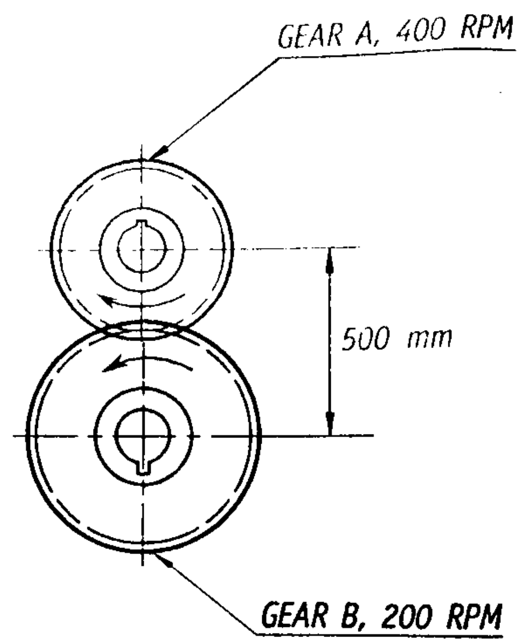
$N_D = 142.86\, rpm\ anti-clockwise$

(iii) Train value

Velocity ratio = $\frac{N_A}{N_D} = \frac{T_D}{T_A} = 3.5$

$$Train\ value = \frac{1}{velocity\ ratio} = 0.285$$

8. Two spur gears A and B connect two parallel shafts that are 500 mm apart. Gear A runs at 400 rpm and gear B at 200 rpm. If the circular pitch is given to be 30 mm calculate the number of teeth on gears A and B.



Solution:

N_A= 400 rpm, N_B = 200 rpm, p_C =30 mm T_A=? T_B =?

Let d_A & d_B represent the diameters of gear A & B.

Velocity ratio = $\frac{N_A}{N_B} = \frac{d_B}{d_A}$ $\quad \frac{400}{200} = \frac{d_B}{d_A}$ $\quad d_B = 2d_A$……..Eq-1

Center distance $500 = \frac{1}{2}(d_A + d_B)$

$d_A + d_B = 1000$……..Eq-2

Solving Eq-1 & Eq-2 we get

d_A= 333.34 mm d_B= 666.66mm

Number of teeth of gear A = $T_A = \frac{\pi d_A}{p_C} = \frac{\pi \times 333.34}{30}$ =35.

Speed ratio = $\frac{N_A}{N_B} = \frac{T_B}{T_A}$

Number of teeth of gear B = $T_B = \frac{N_A}{N_B} \times T_A = \frac{400}{200} \times 35 = 70$

SOLDERING, BRAZING AND WELDING

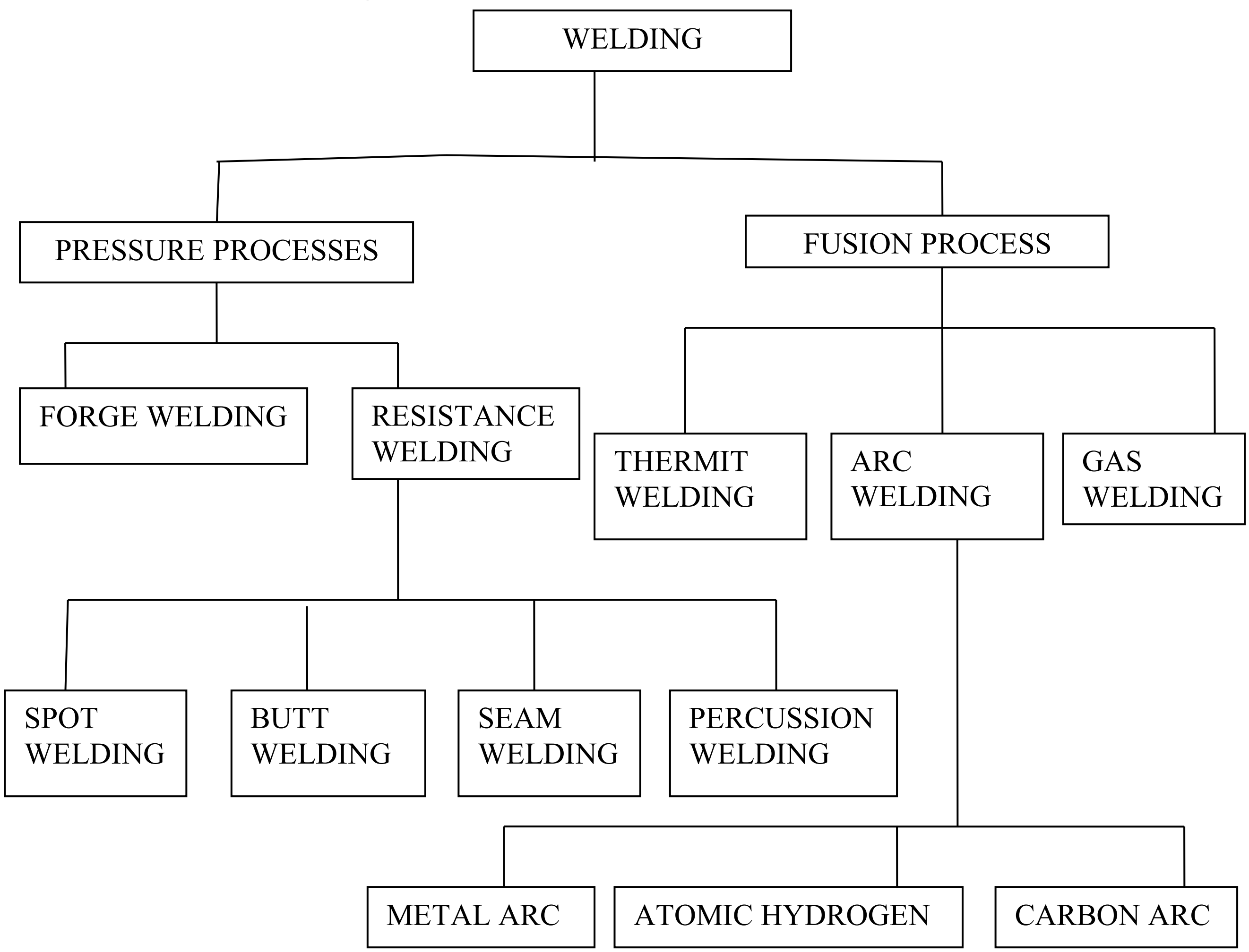
Welding and its principle

Welding may be defined as the metallurgical joining of two metal pieces together to produce essentially a single piece of metal. Welding is extensively used in the fabrication work in which metal plates, rolled steel sections, castings of ferrous materials are joined together. It is also used for repairing broken, worn-out, or defective metal parts.

Principle of Welding

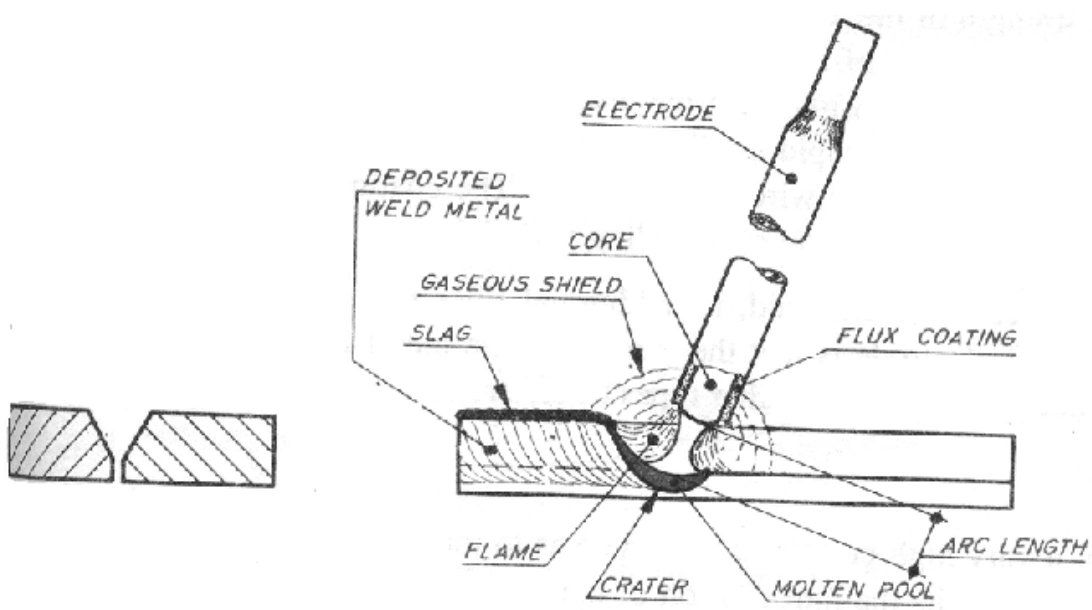
A *welding* is a metallurgical process in which the junction of the two parts to be joined are heated and then fused together with or without the application of pressure to produce a continuity of the homogenous material of the same composition and the characteristics of the parts which are being joined.

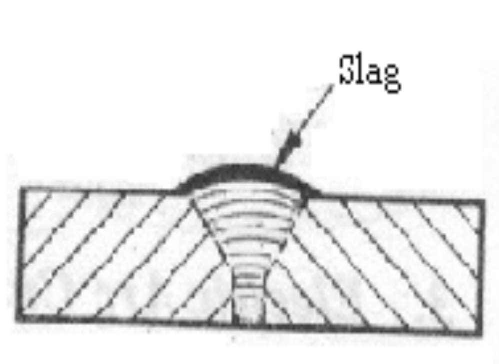
Classifications of welding



Principle of arc welding

The principle of arc welding is as follows. When two conductors of an electic circuit are touched together momentarily and then instantaneously separated slightly, assuming that there is sufficient voltage in the circuit to maintain the flow of current, an electric arc is formed. Concentrated heat is produced throughout the length of the arc at a temperature of about 5000 to 6000°c. In arc welding, usually the parts to be welded are wired as one pole of the circuit, and the electrode held by the operator forms the other pole. When the arc is produced, the intense heat quickly melts the workpiece metal which is directly under the arc, forming a nall molten metal pool. At the same time the tip of the electrode at the arc also melts, this molten metal of the electrode is carried over by the arc to the molten metal pool of the workpiece. The molten metal in the pool is agitated by the action of the arc, thoroughly mixing the base and the filler metal. A solid joint will be formed when the molten metal cools and solidifies. The flux coating over the electrode produces an inert gaseous shield surrounding the arc and protects the molten metal from oxidizing by coming in contact with the atmosphere. Fig(6.1) illustrates the arc welding process. Both alternating current (A.C) and direct current (D.C) are used for arc welding. Whenever A.C. supply is not available, D.C generators are used for D.C arc welding. For AC arc welding a step down transformer is used. The transformer receives the A.C. supply between 200 and 440 volts and transforms it to the required low voltage in the range of 80 to 100 volts. A high current of l00A to 400 A will be suitable for general arc welding work.





Plates after welding

In D.C welding, the workpiece is connected to the positive pole of a D.C generator and the electrode to the negative pol*e* in order to melt greater mass of metal in the base material. This kind of setup is said to have" straight polarity". When the less heat is required at the base material, the polarity is reversed. Because of this option of selection of polarity depending upon the type of the job, in D.C. welding it is possible to melt many metals which require more heat to melt.

In AC. arc welding, there is no choice of polarity since they change in every cycle. As the A.C. current acquires zero values twice in every cycle, at these moments the potential difference is also zero and hence higher voltage is required to maintain the arc.

Types of welding electrodes

- WELDING ELECTRODES
  - Consumable electrodes
    - Bare
    - Coated
  - Non-consumable electrodes

Consumable electrodes also melts along with the workpieces and fills the joint. They are made of various metals depending upon their purpose and the chemical composition of the workpieces. The consumable electrodes either will be *bare or coated.* When the bare electrodes are used, the globules of the molten metal while passing from the electrodes absorb oxygen and nitrogen from the atmospheric air to form non-metallic constituents which gets trapped in the solidifying weldmetal and thereby, decreasing the strength of the joint. The coated electrodes facilitate ;

I. the protection of molten metal form oxygen and nitrogen of the air by providing a gas shield around the arc and the molten pool of metal;
II. to establish and maintain the arc throughout welding;
III. the formation of slag over the joint thus protects from rapid cooling; and
IV. the addition of alloying element. The electrodes are made of either soft steel wire or alloy steel. The coating is usually composed of chalk, ferro manganese, starch, kaolin, alloying and binding materials.

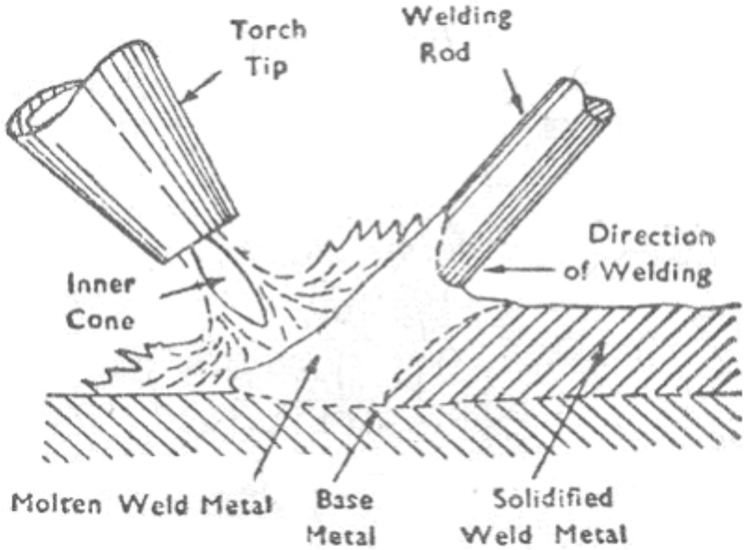
When non-consumable *electrodes* are used, an additional filler material is also required. The advantages of using this type of electrode is that the amount of the metal deposited by the filler rod can be controlled which is not possible in the other types of electrodes.

Principle of gas welding

Gas welding is accomplished by melting the edges or surfaces to be joined by gas flame and allowing the molten metal to flow together, thus forming a solid continuous joint upon cooling. This process is particularly suitable for joining metal sheets and plates having a thickness of 20 to 50 mm. With material thicker than 15mm additional metal called filler metal is added to the weld in the form of welding rod.

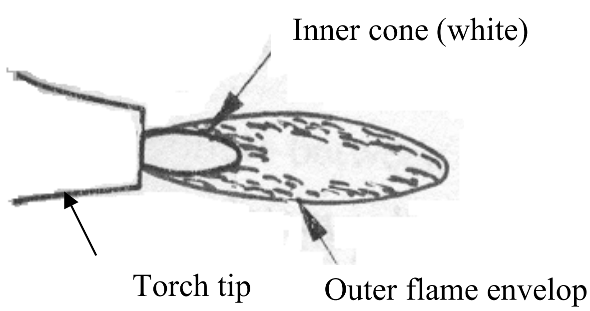
Various gas combination can be used for producing a hot flame for welding metals. Common mixtures of gases are oxygen and acetylene, oxygen and hydrogen, oxygen and other fuel gas, and air and acetylene. The oxygen-acetylene mixture is used to a much greater extent than the other and has a prominent place in the welding industry. The temperature of the oxy-acetylene flame in its hottest region is about 3200^0C, whereas the temperature obtained in oxy-hydrogen flame is about $1{,}900^0$C.

The oxy-acetylene gas equipment consists of *two* large steel cylinders. One containing oxygen at high pressure, and the other dissolved acetylene also at high pressure, rubber tubes, pressure regulators and blow torch. The oxygen and the acetylene are supplied to the blow torch separately, where both of them get mixed and comes out through the nozzle of the blow torch.

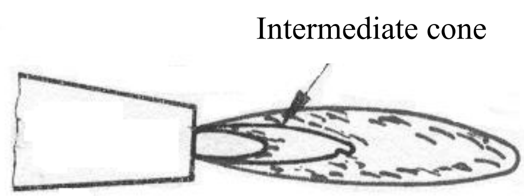


Types of gas welding flames

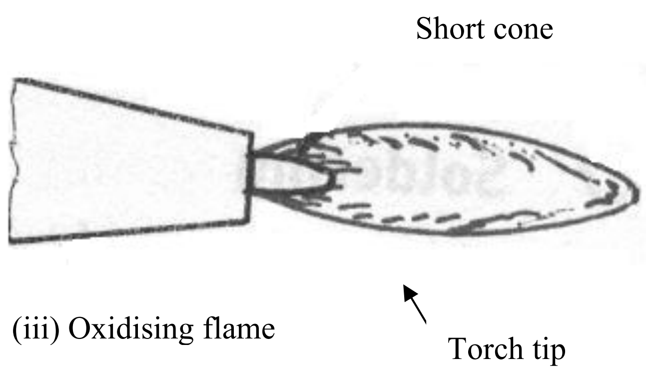
For the complete combustion of the acetylene, 2.5 volumes of oxygen are required for 1 volume of acetylene. In practice, however, ratio of the parts of oxygen to the parts of the acetylene, referred as gas ratio varies from 0.95 to 1.5. Depending on the gas ratio*, neutral, oxidizing and* carburising or reducing flame can *be* obtained.



(i) Neutral Flame



(ii) Carburizing flame



(iii) Oxidising flame

A natural flame is obtained by supplying equal volumes of oxygen and acetylene. The natural flame consists of an inner small whitish cone surrounded by a sharply defined blue flame. Most of the oxy-acetylene welding is done with the use of the natural flame.

A carburizing or a reducing flame is obtained by supplying an excess acetylene in the gas ratio between 0.95 to 1. It has three cones an inner white cone, surrounded by an intermediate whitish cone known as " intermediate flame feather" and a bluish envelop flame. This flame is generally used due to its reducing nature, for welding alloy steels, castiron and aluminium to protect from the oxidizable elements.

The oxidizing flame is obtained when there is an excess oxygen, having gas ratio as high as 1.15 to 1.5. In appearance it resembles a natural flame with exception that the inner white cone flame is some what shorter. This is used for oxy-acetylene cutting and not suitable for welding, since weld metal will be oxidized.

Soldering

Soldering is a method of uniting two thin metal pieces using a dissimilar metal or an alloy by the application of heat.

There are two types of solders soft solder (alloy of lead and tin) and hard solder (copper+tin+silver). The melting temperature of soft solder is 150-350^{0}C and that of hard solder is 600-900^{0}C. Zinc chloride is the most commonly used flux for the soft soldering

To clean the joint surfaces and to prevent the oxidation, suitable flux is used.

Brazing

Brazing is a method of joining two similar or dissimilar metals using a special fusible alloy. It produces joints stronger than soldering. During brazing, the base metal of the two pieces to be joined is not melted. The filler metal must have the ability to wet the surfaces of the base metal to which it is applied. Some diffusion or alloying of the filler metal with the 'base metal takes place even though the base metal does not reach its melting temperature. The materials used in brazing are copper base and silver base alloys.

Before brazing, the surfaces of the parts are cleaned removing oxides and grease. After cleaning, a flux is applied at the place of the joint. Common borax and mixtures of borax and boric acid have been used as flux. After the flux is applied, the joint and the filler material are heated by an oxy-accetylence welding torch to the temperatures above the melting temperature of the filler material. The molten filler material flows by capillary action into the joint space and after cooling produces a strong joint.

6.10 Distinguish between soldering, brazing and welding.

Sl.no	Brazing	Soldering
1	Melting point of the filler material is above 450^0C.	Melting point of the filler material is below 450^0C.
2	Dissimilar metals can be joined easily.	Only similar metals can be joined .
3	Good surface finish.	Does not yield a good surface finish
4	Stronger joints	Less stronger joints
5	The strength of the brazed joints is a function of the attraction forces between the molecules of the brazing materials.	The solder act as a metal solvent by melting small amounts of the base metal, and these form a chemical bond with one of the solder constituents. Thus the strength of the joint is the function of the alloy formed.

6.11 Comparison of Soldering, brazing and welding.

Sl.no	Soldering, Brazing	Welding
1	There is no direct melting of the base metals being joined	There is a direct melting of the base metals being joined
2	Useful for joining dissimilar metals	Useful for joining similar metals
3	Brazing alloy and the solder have low melting points than the metals to be joined.	Welding alloy have high melting points than the metals to be joined.
4	Filler materials are solder and brazing alloy	Welding rod is used as filler material.