PRINCETON INSTITUTE OF ENGINEERING & TECHNOLOGY FOR WOMEN
(Approved by AICTE, New Delhi & Affiliated to JNTU Hyderabad)
Chowdaryguda (V), Ghatkesar (M), Medchal-Malkajgiri(D).TS-500088
Phone: 9394544566 / 6305324412
e-mail: princeton.principal2020@gmail.com
JNTUH Code(6M) CIVIL-EEE-ECE-CSE-CSE(AI&ML)-CSE(DS)-CSE(CS) EAMCET Code-PETW

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Prepared By

Name : **A. NARESH BABU**

Designation : Assistant Professor

Department : Mechanical/Civil Engineering

MACHINE ELEMENTS (CAM AND FOLLOWER)

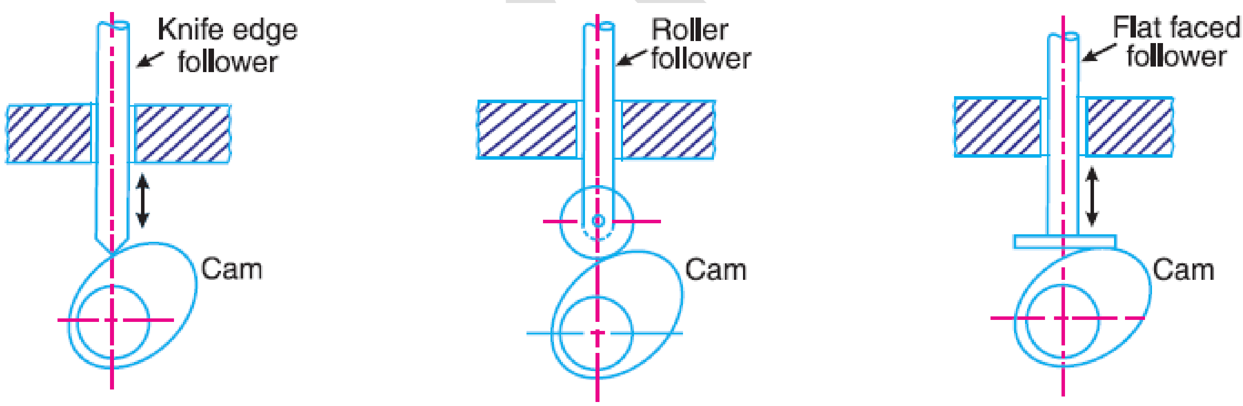
A cam is a rotating machine element which gives reciprocating or oscillating motion to another element known as follower. The cam and the follower have a line contact and constitute a higher pair. The cams are usually rotated at uniform speed by a shaft, but the follower motion is predetermined and will be according to the shape of the cam. The cam and follower is one of the simplest as well as one of the most important mechanisms found in modern machinery today. The cams are widely used for operating the inlet and exhaust valves of internal combustion engines, automatic attachment of machineries, paper cutting machines, spinning and weaving textile machineries, feed mechanism of automatic lathes etc.

Classification of Followers

The followers may be classified as discussed below:

1. According to the surface in contact. The followers, according to the surface in contact, are as follows:

(a) Knife edge follower. When the contacting end of the follower has a sharp knife edge, it is called a knife edge follower, as shown in Fig (a). The sliding motion takes place between the contacting surfaces (i.e. the knife edge and the cam surface). It is seldom used in practice because the small area of contacting surface results in excessive wear. In knife edge followers, a considerable side thrust exists between the follower and the guide.



(*a*) Cam with knife edge follower. (*b*) Cam with roller follower. (*c*) Cam with flat faced follower.

(b) Roller follower. When the contacting end of the follower is a roller, it is called a roller follower, as shown in Fig (b). Since the rolling motion takes place between the contacting surfaces (i.e. the roller and the cam), therefore the rate of wear is greatly reduced.

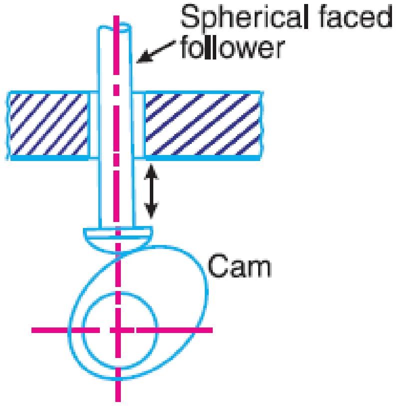
In roller followers also the side thrust exists between the follower and the guide. The roller followers are extensively used where more space is available such as in stationary gas and oil engines and aircraft engines.

(c) Flat faced or mushroom follower. When the contacting end of the follower is a perfectly flat face, it is called a flat-faced follower, as shown in Fig (c). It may be noted that the side thrust between the follower and the guide is much reduced in case of flat faced followers.

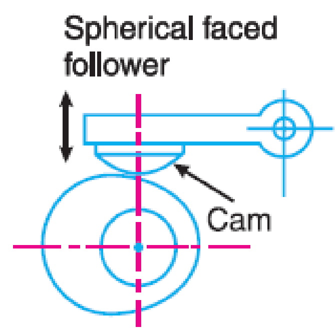
The only side thrust is due to friction between the contact surfaces of the follower and the cam. The relative motion between these surfaces is largely of sliding nature but wear may be reduced by off-setting the axis of the follower, as shown in Fig. 20.1 (f) so that when the cam rotates, the follower also rotates about its own axis. The flat faced followers are generally used where space is limited such as in cams which operate the valves of automobile engines.

Note: When the flat faced follower is circular, it is then called a mushroom follower.

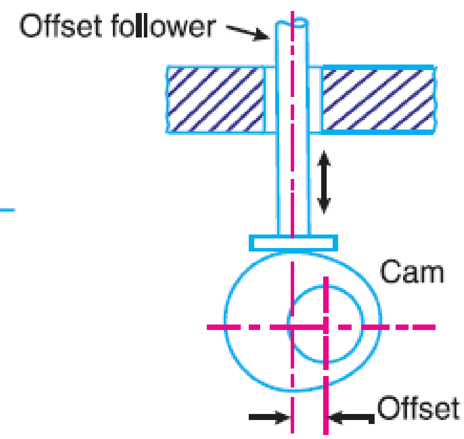
(d) Spherical faced follower. When the contacting end of the follower is of spherical shape, it is called a spherical faced follower, as shown in Fig. 20.1 (d). It may be noted that when a flat-faced follower is used in automobile engines, high surface stresses are produced. In order to minimize these stresses, the flat end of the follower is machined to a spherical shape.



(*d*) Cam with spherical faced follower.



(*e*) Cam with spherical faced follower.



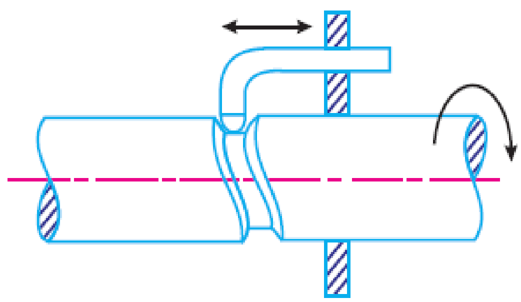
(*f*) Cam with offset follower.

2. According to the motion of the follower. The followers, according to its motion, are of the following two types:
(a) Reciprocating or translating follower. When the follower reciprocates in guides as the cam rotates uniformly, it is known as reciprocating or translating follower. The followers as shown in Fig (a) to (d) are all reciprocating or translating followers.
(b) Oscillating or rotating follower. When the uniform rotary motion of the cam is converted into predetermined oscillatory motion of the follower, it is called oscillating or rotating follower. The follower, as shown in Fig (e), is an oscillating or rotating follower.
3. According to the path of motion of the follower. The followers, according to its path of motion, are of the following two types:
(a) Radial follower. When the motion of the follower is along an axis passing through the centre of the cam, it is known as radial follower. The followers, as shown in Fig (a) to (e), are all radial followers.
(b) Off-set follower. When the motion of the follower is along an axis away from the axis of the cam centre, it is called off-set follower. The follower, as shown in Fig (f), is an off-set follower.

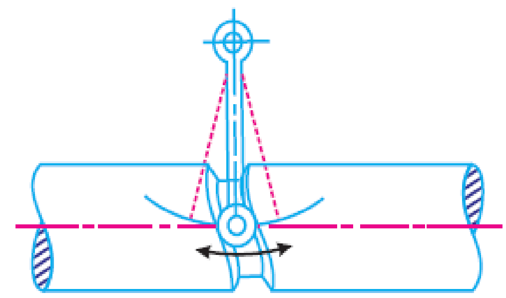
Note: In all cases, the follower must be constrained to follow the cam. This may be done by springs, gravity or hydraulic means. In some types of cams, the follower may ride in a groove.

Classification of Cams

Though the cams may be classified in many ways, yet the following two types are important from the subject point of view:



(a) Cylindrical cam with reciprocating follower.



(b) Cylindrical cam with oscillating follower.

1. Radial or disc cam. In radial cams, the follower reciprocates or oscillates in a direction perpendicular to the cam axis. The cams as shown in above Fig are all radial cams.
2. Cylindrical cam. In cylindrical cams, the follower reciprocates or oscillates in a direction parallel to the cam axis. The follower rides in a groove at its cylindrical surface. A cylindrical grooved cam with a reciprocating and an oscillating follower is shown in Fig. (a) and (b) respectively.

Note: In actual practice, radial cams are widely used. Therefore our discussion will be only confined to radial cams.

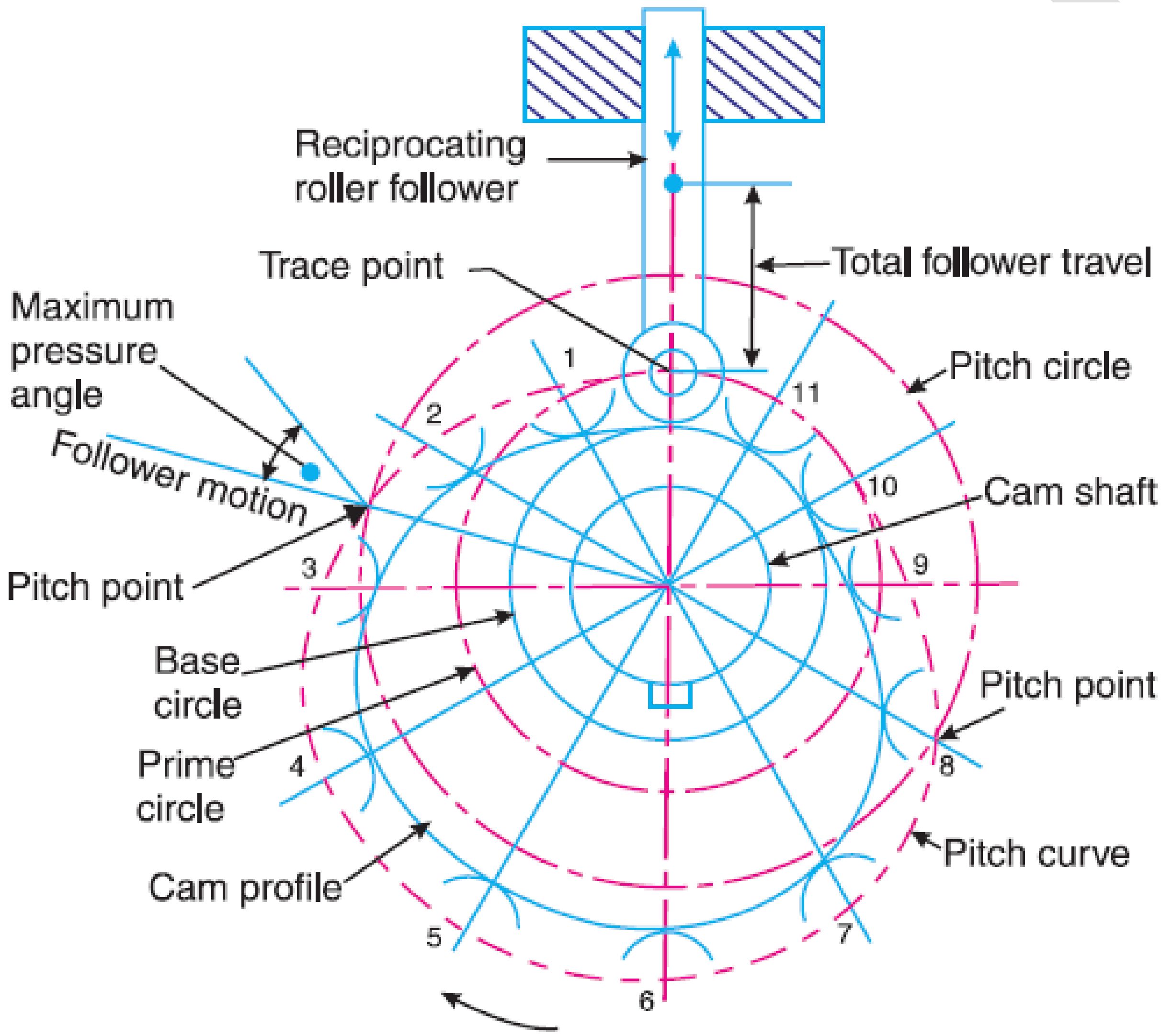
Terms Used in Radial Cams

Fig. shows a radial cam with reciprocating roller follower. The following terms are important in order to draw the cam profile.

1. Base circle. It is the smallest circle that can be drawn to the cam profile.
2. Trace point. It is a reference point on the follower and is used to generate the pitch curve. In case of knife edge follower, the knife edge represents the trace point and the pitch curve corresponds to the cam profile. In a roller follower, the centre of the roller represents the trace point.
3. Pressure angle. It is the angle between the direction of the follower motion and a normal to the pitch curve. This angle is very important in designing a cam profile. If the pressure angle is too large, a reciprocating follower will jam in its bearings.
4. Pitch point. It is a point on the pitch curve having the maximum pressure angle.
5. Pitch circle. It is a circle drawn from the centre of the cam through the pitch points.
6. Pitch curve. It is the curve generated by the trace point as the follower moves relative to the cam. For a knife edge follower, the pitch curve and the cam profile are same whereas for a roller follower, they are separated by the radius of the roller.

7. Prime circle. It is the smallest circle that can be drawn from the centre of the cam and tangent to the pitch curve. For a knife edge and a flat face follower, the prime circle and the base circle are identical. For a roller follower, the prime circle is larger than the base circle by the radius of the roller.

8. Lift or stroke. It is the maximum travel of the follower from its lowest position to the Top most position.



Terms used in radial cams.

Motion of the Follower

The follower, during its travel, may have one of the following motions.

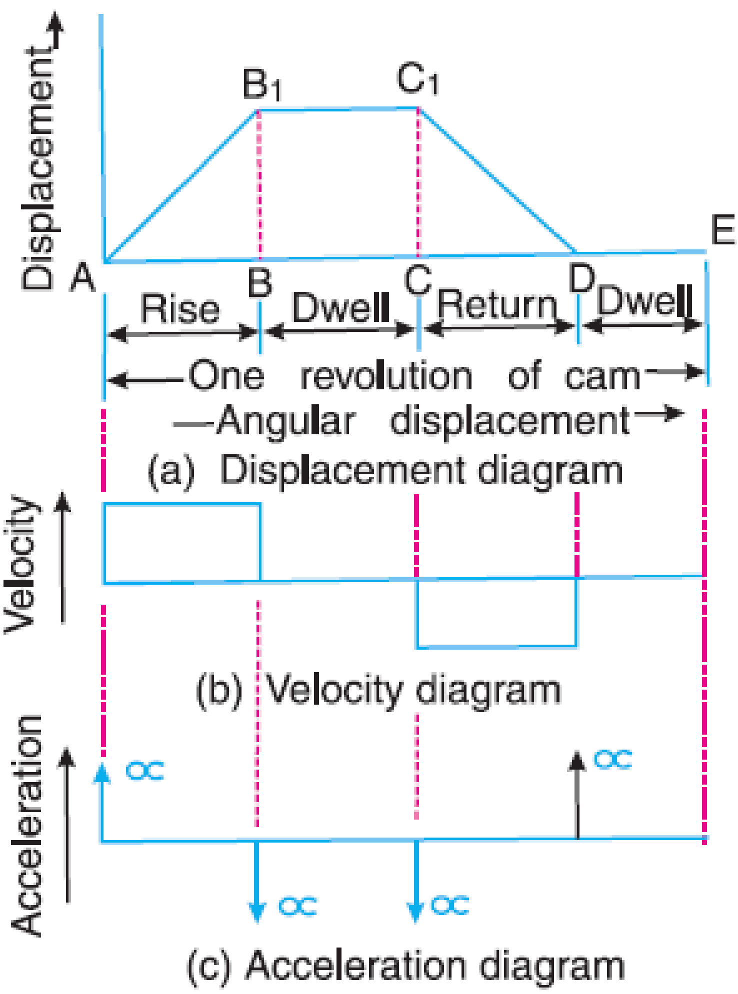
1. Uniform velocity,
2. Simple harmonic motion,
3. Uniform acceleration and retardation, and
4. Cycloidal motion.

Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Uniform Velocity

The displacement, velocity and acceleration diagrams when a knife-edged follower moves with uniform velocity are shown in below Fig (a), (b) and (c) respectively. The abscissa (base) represents the time (i.e. the number of seconds required for the cam to complete one revolution) or it may represent the angular displacement of the cam in degrees. The ordinate represents the displacement, or velocity or acceleration of the follower.

Since the follower moves with uniform velocity during its rise and return stroke, therefore the slope of the displacement curves must be constant. In other words, AB1 and C1D must be straight lines. A little consideration will show that the follower remains at rest during part of the cam rotation. The periods during which the follower remains at rest are known as dwell periods, as shown by lines B1C1 and DE in Fig (a). From Fig (c), we see that the acceleration or retardation of the follower at the beginning and at the end of each stroke is infinite. This is due to the fact that the follower is required to start from rest and has to gain a velocity within no time.

This is only possible if the acceleration or retardation at the beginning and at the end of each stroke is infinite. These conditions are however, impracticable.



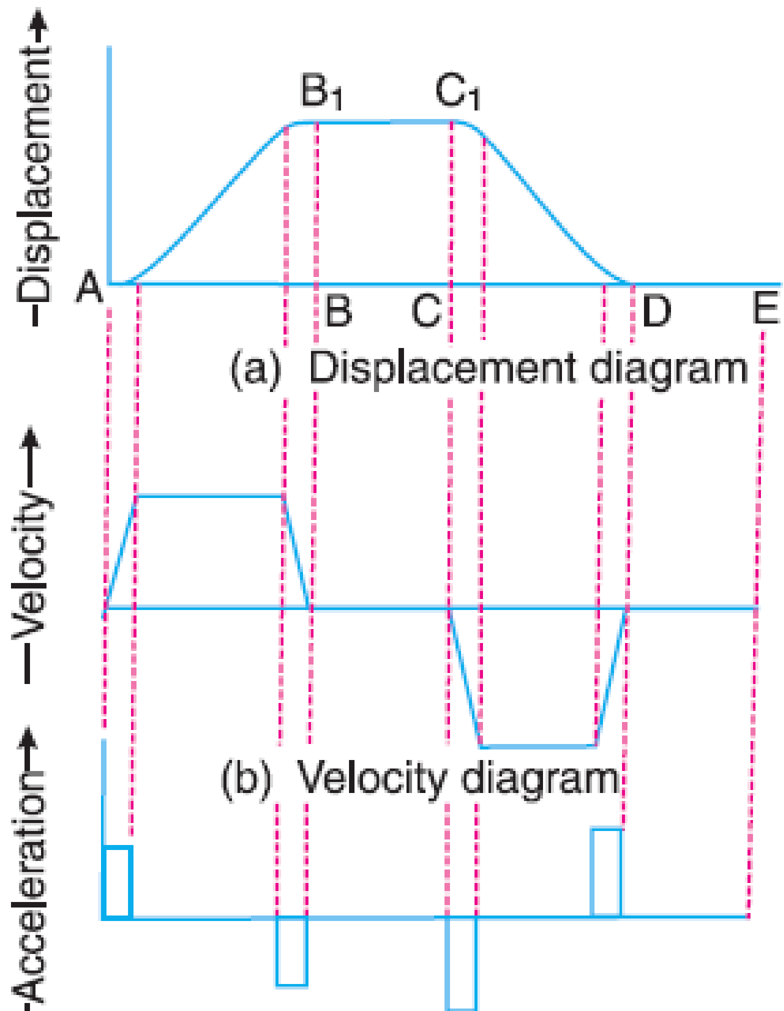
(a) Displacement diagram

(b) Velocity diagram

(c) Acceleration diagram

In order to have the acceleration and retardation within the finite limits, it is necessary to modify the conditions which govern the motion of the follower. This may be done by rounding off the sharp corners of the displacement diagram at the beginning and at the end of each stroke, as shown in Fig (*a*). By doing so, the velocity of the follower increases gradually to its maximum value at the beginning of each stroke and decreases gradually to zero at the end of each stroke as shown in Fig (*b*).

The modified displacement, velocity and acceleration diagrams are shown in Figure. The round corners of the displacement diagram are usually parabolic curves because the parabolic motion results in a very low acceleration of the follower for a given stroke and cam speed.



(a) Displacement diagram

(b) Velocity diagram

(c) Acceleration diagram

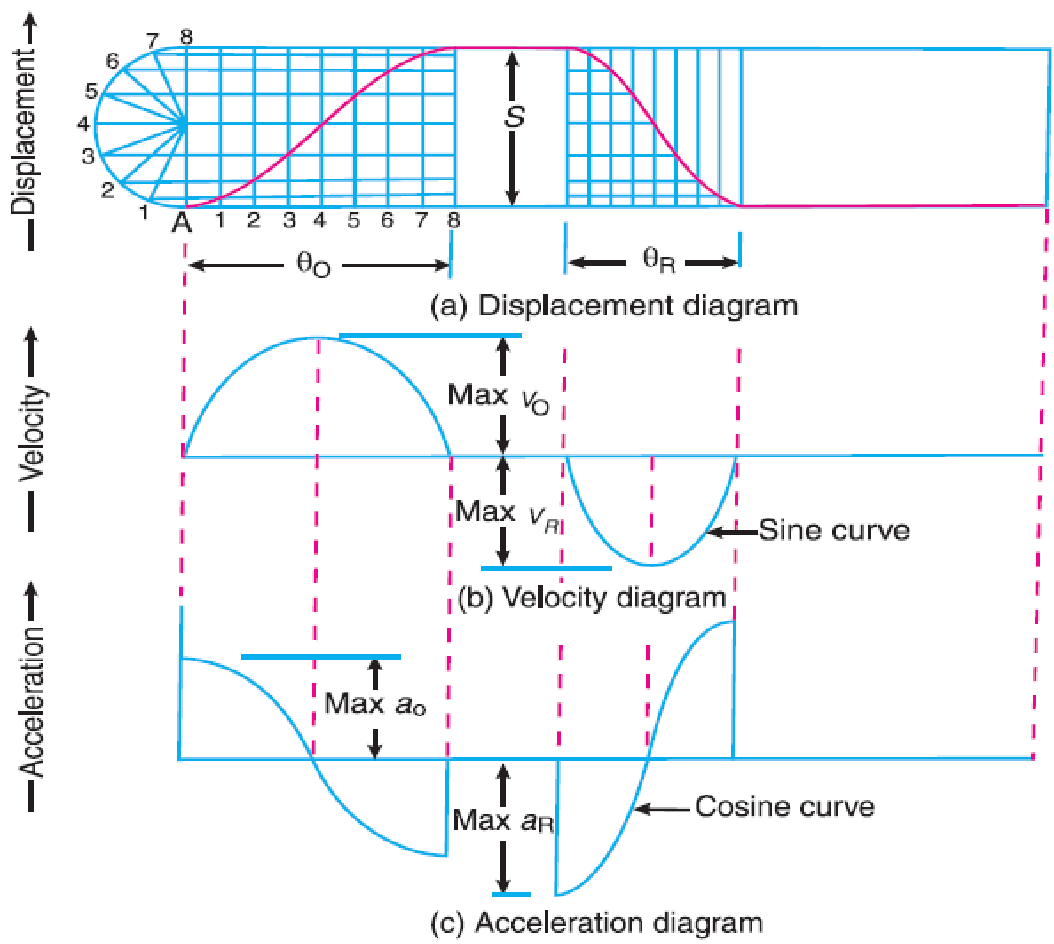
Modified displacement, velocity and acceleration diagrams when the follower moves with uniform velocity.

Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Simple Harmonic Motion

The displacement, velocity and acceleration diagrams when the follower moves with simple harmonic motion are shown in Fig (a), (b) and (c) respectively. The displacement diagram is drawn as follows:

1. Draw a semi-circle on the follower stroke as diameter.
2. Divide the semi-circle into any number of even equal parts (say eight).
3. Divide the angular displacements of the cam during out stroke and return stroke into the same number of equal parts.
4. The displacement diagram is obtained by projecting the points as shown in Fig (a).

The velocity and acceleration diagrams are shown in Fig (b) and (c) respectively. Since the follower moves with a simple harmonic motion, therefore velocity diagram consists of a sine curve and the acceleration diagram is a cosine curve. We see from Fig (b) that the velocity of the follower is zero at the beginning and at the end of its stroke and increases gradually to a maximum at mid-stroke. On the other hand, the acceleration of the follower is maximum at the beginning and at the ends of the stroke and diminishes to zero at mid-stroke.



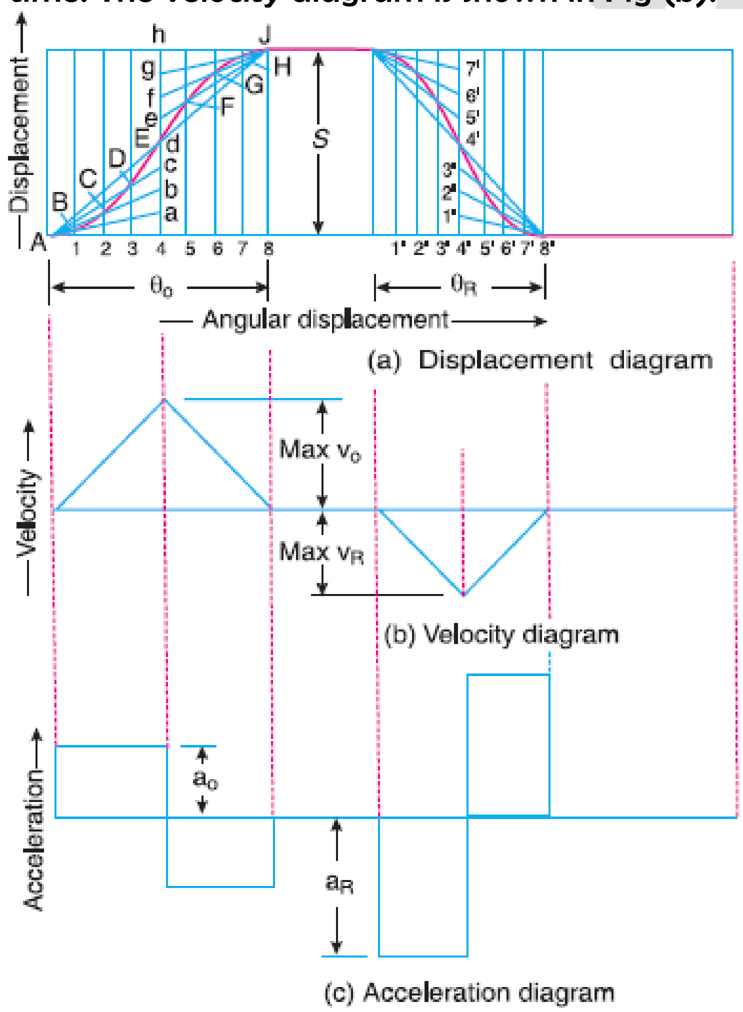
Displacement, velocity and acceleration diagrams when the follower moves with simple harmonic motion.

Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Uniform Acceleration and Retardation

The displacement, velocity and acceleration diagrams when the follower moves with uniform acceleration and retardation are shown in Fig (a), (b) and (c) respectively. We see that the displacement diagram consists of a parabolic curve and may be drawn as discussed below:

1. Divide the angular displacement of the cam during outstroke into any even number of equal parts (say eight) and draw vertical lines through these points as shown in Fig (a).
2. Divide the stroke of the follower (S) into the same number of equal even parts.
3. Join Aa to intersect the vertical line through point 1 at B. Similarly, obtain the other points C, D etc. as shown in Fig (a). Now join these points to obtain the parabolic curve for the out stroke of the follower.
4. In the similar way as discussed above, the displacement diagram for the follower during return stroke may be drawn.

Since the acceleration and retardation are uniform, therefore the velocity varies directly with the time. The velocity diagram is shown in Fig (b).



Displacement, velocity and acceleration diagrams when the follower moves with uniform acceleration and retardation.

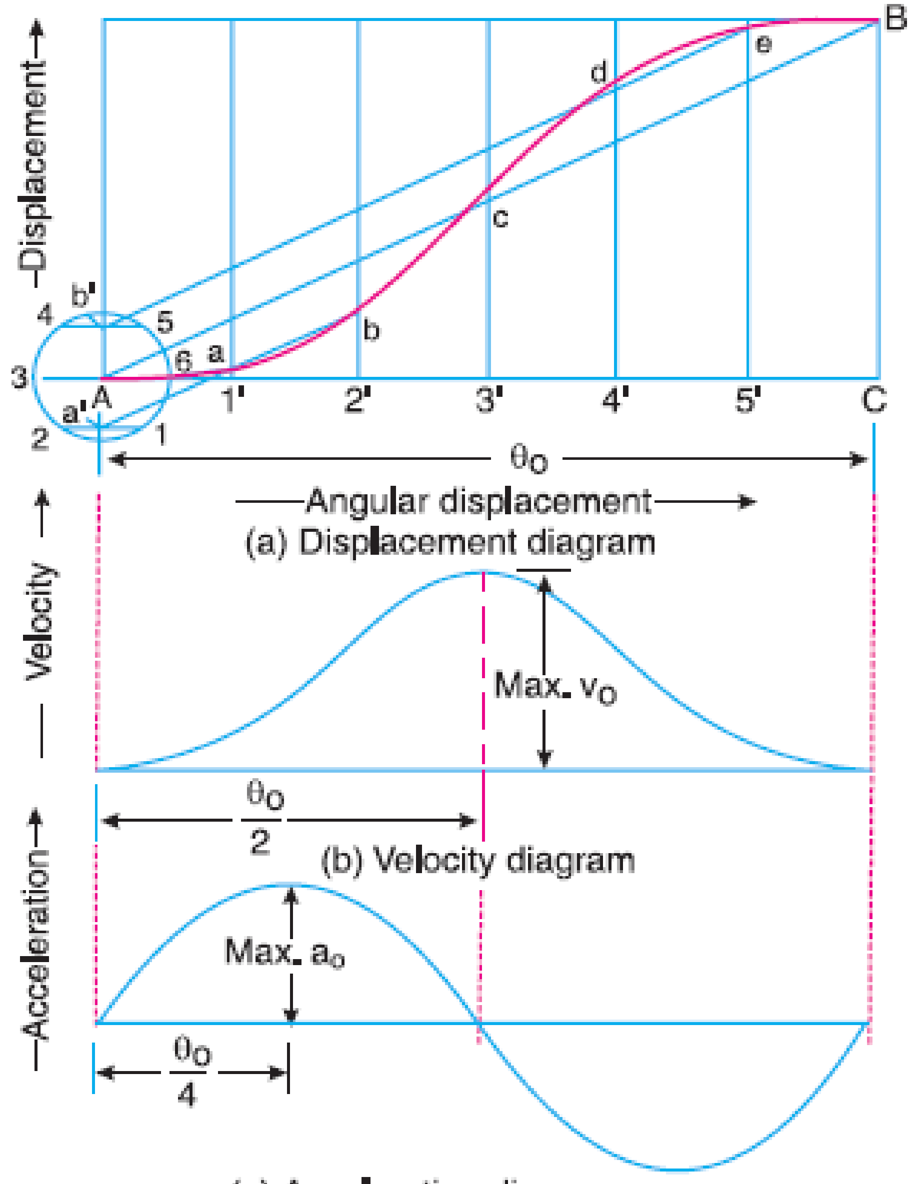
Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Cycloidal Motion

The displacement, velocity and acceleration diagrams when the follower moves with cycloidal motion are shown in Fig (*a*), (*b*) and (*c*) respectively. We know that cycloid is a curve traced by a point on a circle when the circle rolls without slipping on a straight line.

In case of cams, this straight line is a stroke of the follower which is translating and the circumference of the rolling circle is equal to the stroke (*S*) of the follower.

Therefore the radius of the rolling circle is $S / 2\pi$.

The displacement diagram is drawn as below:



(a) Displacement diagram

(b) Velocity diagram

(c) Acceleration diagram

Displacement, velocity and acceleration diagrams when the follower moves with cycloidal motion.

INTRODUCTION TO ENGINEERING MATERIALS

Classification of Engineering Materials

The engineering materials are mainly classified as:

1. Metals and their alloys, such as iron, steel, copper, aluminium, etc.
2. Non-metals, such as glass, rubber, plastic, etc.

The metals may be further classified as: (a) Ferrous metals and (b) Non-ferrous metals.

The word 'ferrous' is derived from a Latin word 'ferrum' which means iron.

The ferrous metals are those which have the iron as their main constituent, such as cast iron, wrought iron and steel.

The non-ferrous metals are those which have a metal other than iron as their main constituent, such as copper, aluminium, brass, tin, zinc, etc.

Selection of Materials for Engineering Purposes

The selection of a proper material, for engineering purposes, is one of the most difficult problems for the designer. The best material is one which serves the desired objective at the minimum cost. The following factors should be considered while selecting the material:

1. Availability of the materials,
2. Suitability of the materials for the working conditions in service, and
3. The cost of the materials.

The important properties, which determine the utility of the material, are physical, chemical and mechanical properties. We shall now discuss the physical and mechanical properties of the material in the following articles.

Physical Properties of Metals

The physical properties of the metals include luster, colour, size and shape, density, electric and thermal conductivity, and melting point. The following table shows the important physical properties of some pure metals.

Mechanical Properties of Metals

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness.

1. Strength. It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called *stress.
2. Stiffness. It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.
3. Elasticity. It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.
4. Plasticity. It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. Ductility. It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper, aluminium, nickel, zinc, tin and lead.
Note: The ductility of a material is commonly measured by means of percentage elongation and percentage reduction in area in a tensile test.
6. Brittleness. It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads snap off without giving any sensible elongation. Cast iron is a brittle material.
7. Malleability. It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are lead, soft steel, wrought iron, copper and aluminium.
8. Toughness. It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed up to the point of fracture. This property is desirable in parts subjected to shock and impact loads.
9. Machinability. It is the property of a material which refers to a relative case with which a material can be cut.

The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. It may be noted that brass can be easily machined than steel.
10. Resilience. It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.
11. Creep. When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called creep. This property is considered in designing internal combustion engines, boilers and turbines.
12. Fatigue. When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as *fatigue. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.
13. Hardness. It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal. The hardness is usually expressed in numbers which are dependent on the method of making the test.

The hardness of a metal may be determined by the following tests:
(a) Brinell hardness test, (b) Rockwell hardness test,
(c) Vickers hardness (also called Diamond Pyramid) test, and (d) Shore scleroscope.

Ferrous Metals:

We have already discussed that the ferrous metals are those which have iron as their main constituent. The ferrous metals commonly used in engineering practice are cast iron, wrought iron, steels and alloy steels. The principal raw material for all ferrous metals is pig iron which is obtained by smelting iron ore with coke and limestone, in the blast furnace. The principal iron ores with their metallic contents are shown in the following table:

Table Principal iron ores.

Iron ore	*Chemical formula*	*Colour*	*Iron content (%)*
Magnetite	Fe_2O_3	Black	72
Haematite	Fe_3O_4	Red	70
Limonite	$FeCO_3$	Brown	60–65
Siderite	$Fe_2O_3\ (H_2O)$	Brown	48

Cast Iron

The cast iron is obtained by re-melting pig iron with coke and limestone in a furnace known as cupola. It is primarily an alloy of iron and carbon. The carbon content in cast iron varies from 1.7 per cent to 4.5 percent. It also contains small amounts of silicon, manganese, phosphorous and sulphur. The carbon in a cast iron is present in either of the following two forms:

1. Free carbon or graphite, and 2. Combined carbon or cementite.

Since the cast iron is a brittle material, therefore, it cannot be used in those parts of machines which are subjected to shocks. The properties of cast iron which make it a valuable material for engineering purposes are its low cost, good casting characteristics, high compressive strength, wear resistance and excellent machinability. The compressive strength of cast iron is much greater than the tensile strength. Following are the values of ultimate strength of cast iron:

Tensile strength = 100 to 200 MPa
Compressive strength = 400 to 1000 MPa
Shear strength = 120 MPa
Note: $1 MPa = 1 MN/m^2 = 1 \times 10^6\ N/m^2 = 1\ N/mm^2$

Types of Cast Iron

The various types of cast iron in use are discussed as follows:

1. Grey cast iron. It is an ordinary commercial iron having the following compositions: Carbon = 3 to 3.5%; Silicon = 1 to 2.75%; Manganese = 0.40 to 1.0%; Phosphorous = 0.15 to 1%; Sulphur = 0.02 to 0.15%; and the remaining is iron.

The grey colour is due to the fact that the carbon is present in the form of free graphite. It has a low tensile strength, high compressive strength and no ductility. It can be easily machined.

A very good property of grey cast iron is that the free graphite in its structure acts as a lubricant. Due to this reason, it is very suitable for those parts where sliding action is desired. The grey iron castings are widely used for machine tool bodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agricultural implements.

Table Grey iron castings, as per IS : 210 – 1993.

IS Designation	*Tensile strength (MPa or N/mm^2)*	*Brinell hardness number (B.H.N.)*
FG 150	150	130 to 180
FG 200	200	160 to 220
FG 220	220	180 to 220
FG 260	260	180 to 230
FG 300	300	180 to 230
FG 350	350	207 to 241
FG 400	400	207 to 270

According to Indian standard specifications (IS: 210 – 1993), the grey cast iron is designated by the alphabets 'FG' followed by a figure indicating the minimum tensile strength in MPa or N/mm^2.

For example, 'FG 150' means grey cast iron with 150 MPa or N/mm^2 as minimum tensile strength. The seven recommended grades of grey cast iron with their tensile strength and Brinell hardness number (B.H.N) are given in above Table.

2. White cast iron. The white cast iron shows a white fracture and has the following approximate compositions:

Carbon = 1.75 to 2.3%; Silicon = 0.85 to 1.2%; Manganese = less than 0.4%; Phosphorus = less than 0.2%; Sulphur = less than 0.12%, and the remaining is iron.

3. Chilled cast iron. It is a white cast iron produced by quick cooling of molten iron. The quick cooling is generally called chilling and the cast iron so produced is called chilled cast iron. All castings are chilled at their outer skin by contact of the molten iron with the cool sand in the mould. But on most castings, this hardness penetrates to a very small depth (less than 1 mm). Sometimes, a casting is chilled intentionally and sometimes chilled becomes accidently to a considerable depth. The intentional chilling is carried out by putting inserts of iron or steel (chills) into the mould. When the molten metal comes into contact with the chill, its heat is readily conducted away and the hard surface is formed. Chills are used on any faces of a casting which are required to be hard to withstand wear and friction.

4. Mottled cast iron. It is a product in between grey and white cast iron in composition, colour and general properties. It is obtained in castings where certain wearing surfaces have been chilled.

5. Malleable cast iron. The malleable iron is a cast iron-carbon alloy which solidifies in the as-cast condition in a graphite free structure, i.e. total carbon content is present in its combined form as cementite (Fe3C).

6. Nodular or spheroidal graphite cast iron. The nodular or spheroidal graphite cast iron is also called ductile cast iron or high strength cast iron. This type of cast iron is obtained by adding small amounts of magnesium (0.1 to 0.8%) to the molten grey iron. The addition of magnesium causes the graphite to take form of small nodules or spheroids instead of the normal angular flakes.

It has high fluidity, castability, tensile strength, toughness, wear resistance, pressure tightness, weldability and machinability. It is generally used for castings requiring shock and impact resistance along with good machinability, such as hydraulic cylinders, cylinder heads, rolls for rolling mill and centrifugally cast products.

Alloy Cast Iron

The cast irons as discussed that it contain small percentages of other constituents like silicon, manganese, sulphur and phosphorus. These cast irons may be called as plain cast irons. The alloy cast iron is produced by adding alloying elements like nickel, chromium, molybdenum, copper and manganese in sufficient quantities. These alloying elements give more strength and result in improvement of properties.

The alloy cast iron has special properties like increased strength, high wear resistance, corrosion resistance or heat resistance. The alloy cast irons are extensively used for gears, automobile parts like cylinders, pistons, piston rings, crank cases, crankshafts, camshafts, sprockets, wheels, pulleys, brake drums and shoes, parts of crushing and grinding machinery etc.

Effect of Impurities on Cast Iron

We have discussed in the previous articles that the cast iron contains small percentages of silicon, sulphur, manganese and phosphorous. The effect of these impurities on the cast iron is as follows:

1. Silicon. It may be present in cast iron up to 4%. It provides the formation of free graphite which makes the iron soft and easily machinable. It also produces sound castings free from blow-holes, because of its high affinity for oxygen.
2. Sulphur. It makes the cast iron hard and brittle. Since too much sulphur gives unsound casting, therefore, it should be kept well below 0.1% for most foundry purposes.
3. Manganese. It makes the cast iron white and hard. It is often kept below 0.75%. It helps to exert a controlling influence over the harmful effect of sulphur.
4. Phosphorus. It aids fusibility and fluidity in cast iron, but induces brittleness. It is rarely allowed to exceed 1%. Phosphoric irons are useful for casting of intricate design and for many light engineering castings when cheapness is essential.

Wrought Iron

It is the purest iron which contains at least 99.5% iron but may contain up to 99.9% iron. The typical composition of a wrought iron is Carbon = 0.020%, Silicon = 0.120%, Sulphur = 0.018%, Phosphorus = 0.020%, Slag = 0.070%, and the remaining is iron.

The wrought iron is produced from pig iron by remelting it in the puddling furnace of reverberatory type. The molten metal free from impurities is removed from the furnace as a pasty mass of iron and slag. The balls of this pasty mass, each about 45 to 65 kg are formed. These balls are then mechanically worked both to squeeze out the slag and to form it into some commercial shape.

The wrought iron is a tough, malleable and ductile material. It cannot stand sudden and excessive shocks. Its ultimate tensile strength is 250 MPa to 500 MPa and the ultimate compressive strength is 300 MPa. It can be easily forged or welded. It is used for chains, crane hooks, railway couplings and water and steam pipes.

Steel

It is an alloy of iron and carbon, with carbon content up to a maximum of 1.5%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel. Other elements e.g. silicon, sulphur, phosphorus and manganese are also present to greater or lesser amount to impart certain desired properties to it.
Most of the steel produced now-a-days is plain carbon steel or simply carbon steel.
Carbon steel is defined as steel which has its properties mainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese.
The plain carbon steels varying from 0.06% carbon to 1.5% carbon are divided into the following types depending upon the carbon content.

1. Dead mild steel — up to 0.15% carbon
2. Low carbon or mild steel — 0.15% to 0.45% carbon
3. Medium carbon steel — 0.45% to 0.8% carbon
4. High carbon steel — 0.8% to 1.5% carbon

Effect of Impurities on Steel

The following are the effects of impurities like silicon, sulphur, manganese and phosphorus on steel.

1. Silicon. The amount of silicon in the finished steel usually ranges from 0.05 to 0.30%. Silicon is added in low carbon steels to prevent them from becoming porous. It removes the gases and oxides, prevent blow holes and thereby makes the steel tougher and harder.
2. Sulphur. It occurs in steel either as iron sulphide or manganese sulphide. Iron sulphide because of its low melting point produces red shortness, whereas manganese sulphide does not affect so much. Therefore, manganese sulphide is less objectionable in steel than iron sulphide.
3. Manganese. It serves as a valuable deoxidising and purifying agent in steel. Manganese also combines with sulphur and thereby decreases the harmful effect of this element remaining in the steel. When used in ordinary low carbon steels, manganese makes the metal ductile and of good bending qualities. In high speed steels, it is used to toughen the metal and to increase it's critical temperature.
4. Phosphorus. It makes the steel brittle. It also produces cold shortness in steel. In low carbon steels, it raises the yield point and improves the resistance to atmospheric corrosion. The sum of carbon and phosphorus usually does not exceed 0.25%.

Free Cutting Steels

The free cutting steels contain sulphur and phosphorus. These steels have higher sulphur content than other carbon steels. In general, the carbon content of such steels varies from 0.1 to 0.45 per cent and sulphur from 0.08 to 0.3 per cent. These steels are used where rapid machining is the prime requirement. It may be noted that the presence of sulphur and phosphorus causes long chips in machining to be easily broken and thus prevent clogging of machines.

Alloy Steel

Alloy steel may be defined as steel to which elements other than carbon are added in sufficient amount to produce an improvement in properties. The alloying is done for specific purposes to increase wearing resistance, corrosion resistance and to improve electrical and magnetic properties, which cannot be obtained in plain carbon steels. The chief alloying elements used in steel are nickel, chromium, molybdenum, cobalt, vanadium, manganese, silicon and tungsten. Each of these elements confers certain qualities upon the steel to which it is added. These elements may be used separately or in combination to produce the desired characteristic in steel.

Following are the effects of alloying elements on steel:

1. Nickel. It increases the strength and toughness of the steel. These steels contain 2 to 5% nickel and from 0.1 to 0.5% carbon. In this range, nickel contributes great strength and hardness with high elastic limit, good ductility and good resistance to corrosion. An alloy containing 25% nickel possesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning at high temperature. It has proved to be of advantage in the manufacture of boiler tubes, valves for use with superheated steam, valves for I.C. engines and spark plugs for petrol engines. A nickel steel alloy containing 36% of nickel is known as invar. It has nearly zero coefficient of expansion. So it is in great demand for measuring instruments and standards of lengths for everyday use.
2. Chromium. It is used in steels as an alloying element to combine hardness with high strength and high elastic limit. It also imparts corrosion-resisting properties to steel. The most common chrome steels contains from 0.5 to 2% chromium and 0.1 to 1.5% carbon. The chrome steel is used for balls, rollers and races for bearings. A nickel chrome steel containing 3.25% nickel, 1.5% chromium and 0.25% carbon is much used for armour plates. Chrome nickel steel is extensively used for motor car crankshafts, axles and gears requiring great strength and hardness.
3. Tungsten. It prohibits grain growth, increases the depth of hardening of quenched steel and confers the property of remaining hard even when heated to red colour. It is usually used in conjunction with other elements. Steel containing 3 to 18% tungsten and 0.2 to 1.5% carbon is used for cutting tools.

The principal uses of tungsten steels are for cutting tools, dies, valves, taps and permanent magnets.

4. Vanadium. It aids in obtaining a fine grain structure in tool steel. The addition of a very small amount of vanadium (less than 0.2%) produces a marked increase in tensile strength and elastic limit in low and medium carbon steels without a loss of ductility. The chrome-vanadium steel containing about 0.5 to 1.5% chromium 0.15 to 0.3% vanadium and 0.13 to 1.1% carbon have extremely good tensile strength, elastic limit, endurance limit and ductility. These steels are frequently used for parts such as springs, shafts, gears, pins and many drop forged parts.

5. Manganese. It improves the strength of the steel in both the hot rolled and heat treated condition. The manganese alloy steels containing over 1.5% manganese with a carbon range of 0.40 to 0.55% are used extensively in gears, axles, shafts and other parts where high strength combined with fair ductility is required. The principal use of manganese steel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.

6. Silicon. The silicon steels behave like nickel steels. These steels have a high elastic limit as compared to ordinary carbon steel. Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4% carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springs and corrosion resisting materials.

7. Cobalt. It gives red hardness by retention of hard carbides at high temperatures. It tends to decarburise steel during heat-treatment. It increases hardness and strength and also residual magnetism and coercive magnetic force in steel for magnets.

8. Molybdenum. A very small quantity (0.15 to 0.30%) of molybdenum is generally used with chromium and manganese (0.5 to 0.8%) to make molybdenum steel. These steels possess extra tensile strength and are used for air-plane fuselage and automobile parts. It can replace tungsten in high speed steels.

Stainless Steel

It is defined as that steel which when correctly heat treated and finished, resists oxidation and corrosive attack from most corrosive media.

The different types of stainless steels are discussed below:

1. Martensitic stainless steel. The chromium steels containing 12 to 14 per cent chromium and 0.12 to 0.35 per cent carbon are the first stainless steels developed. Since these steels possess Martensitic structure, therefore, they are called Martensitic stainless steels. These steels can be easily welded and machined. With increasing carbon, it is possible by hardening and tempering to obtain tensile strength in the range of 600 to 900 N/mm^2, combined with reasonable toughness and ductility.

In this condition, these steels find many useful general applications where mild corrosion resistance is required. Also, with the higher carbon range in the hardened and lightly tempered condition, tensile strength of about 1600 N/mm^2 may be developed with lowered ductility. After hardening and light tempering, these steels develop good cutting properties. Therefore, they are used for cutlery, springs, surgical and dental instruments.

2. Ferritic stainless steel. The steels containing greater amount of chromium (from 16 to 18 per cent) and about 0.12 per cent carbon are called ferritic stainless steels. These steels have better corrosion resistant property than Martensitic stainless steels. But, such steels have little capacity for hardening by heat treatment. However, in the softened condition, they possess good ductility and are mainly used as sheet or strip for cold forming and pressing operations for purposes where moderate corrosion resistance is required. They may be cold worked or hot worked. These steels have lower strength at elevated temperatures than Martensitic steels. However, resistance to scaling and corrosion at elevated temperatures are usually better.

3. Austenitic stainless steel. The steel containing high content of both chromium and nickel are called austenitic stainless steels. There are many variations in chemical composition of these steels, but the most widely used steel contain 18 per cent chromium and 8 per cent nickel with carbon content as low as possible. Such steel is commonly known as 18/8 steel. These steels are very tough and can be forged and rolled but offer great difficulty in machining. They can be easily welded, but after welding, it is susceptible to corrosive attack in an area adjacent to the weld. These steels are used in the manufacture of pump shafts, rail road car frames and sheathing, screws, nuts and bolts and small springs. Since 18/8 steel provide excellent resistance to attack by many chemicals, therefore, it is extensively used in chemical, food, paper making and dyeing industries.

Heat Resisting Steels

The steels which can resist creep and oxidation at high temperatures and retain sufficient strength are called heat resisting steels. A number of heat resisting steels have been developed as discussed below:

1. Low alloy steels. These steels contain 0.5 per cent molybdenum. The main application of these steels are for superheater tubes and pipes in steam plants, where service temperatures are in the range of 400°C to 500°C.

2. Valve steels. The chromium-silicon steels such as silchrome (0.4% C, 8% Cr, 3.5% Si) and Volmax (0.5% C, 8% Cr, 3.5% Si, and 0.5% Mo) are used for automobile valves. They possess good resistance to scaling at dull red heat, although their strength at elevated temperatures is relatively low. For aeroplane engines and marine diesel engine valves, 13/13/3 nickel-chromium-tungsten valve steel is usually used.

3. Plain chromium steel. The plain chromium steel consists of (a) Martensitic chromium steel with 12–13% Cr, and (b) Ferritic chromium steels with 18–30% Cr.

These steels are very good for oxidation resistance at high temperatures as compared to their strength which is not high at such conditions. The maximum operating temperature for Martensitic steels is about 750°C, whereas for ferritic steels it is about 1000 – 1150°C.

4. Austenitic chromium-nickel steels. These steels have good mechanical properties at high temperatures with good scaling resistance. These alloys contain a minimum of 18 per cent chromium and 8 per cent nickel stabilised with titanium or niobium. Other carbide forming elements such as molybdenum or tungsten may also be added in order to improve creep strength. Such alloys are suitable for use up to 1100°C and are used for gas turbine discs and blades.

High Speed Tool Steels

These steels are used for cutting metals at a much higher cutting speed than ordinary carbon tool steels. The carbon steel cutting tools do not retain their sharp cutting edges under heavier loads and higher speeds. This is due to the fact that at high speeds, sufficient heat may be developed during the cutting operation and causes the temperature of the cutting edge of the tool to reach a red heat. This temperature would soften the carbon tool steel and thus the tool will not work efficiently for a longer period.

The high speed steels have the valuable property of retaining their hardness even when heated to red heat. Most of the high speed steels contain tungsten as the chief alloying element, but other elements like cobalt, chromium, vanadium, etc. may be present in some proportion. Following are the different types of high speed steels:

1. 18-4-1 High speed steel. This steel, on an average, contains 18 per cent tungsten, 4 per cent chromium and 1 per cent vanadium. It is considered to be one of the best of all purpose tool steels. It is widely used for drills, lathe, planer and shaper tools, milling cutters, reamers, broaches, threading dies, punches, etc.

2. Molybdenum high speed steel. This steel, on an average, contains 6 per cent tungsten, 6 percent molybdenum, 4 per cent chromium and 2 per cent vanadium. It has excellent toughness and cutting ability. The molybdenum high speed steels are better and cheaper than other types of steels. It is particularly used for drilling and tapping operations.

3. Super high speed steel. This steel is also called cobalt high speed steel because cobalt is added from 2 to 15 per cent, in order to increase the cutting efficiency especially at high temperatures.

This steel, on an average, contains 20 per cent tungsten, 4 per cent chromium, 2 per cent vanadium and 12 per cent cobalt. Since the cost of this steel is more, therefore, it is principally used for heavy cutting operations which impose high pressure and temperatures on the tool.

Spring Steels

The most suitable material for springs are those which can store up the maximum amount of work or energy in a given weight or volume of spring material, without permanent deformation. These steels should have a high elastic limit as well as high deflection value. The spring steel, for aircraft and automobile purposes should possess maximum strength against fatigue effects and shocks.

The steels most commonly used for making springs are as follows:

1. High carbon steels. These steels contain 0.6 to 1.1 per cent carbon, 0.2 to 0.5 per cent silicon and 0.6 to 1 per cent manganese. These steels are heated to 780 – 850°C according to the composition and quenched in oil or water. It is then tempered at 200 - 500°C to suit the particular application. These steels are used for laminated springs for locomotives, carriages, wagons, and for heavy road vehicles. The higher carbon content oil hardening steels are used for volute, spiral and conical springs and for certain types of petrol engine inlet valve springs.
2. Chrome-vanadium steels. These are high quality spring steels and contain 0.45 to 0.55 per cent carbon, 0.9 to 1.2 per cent chromium, 0.15 to 0.20 per cent vanadium, 0.3 to 0.5 per cent silicon and 0.5 to 0.8 per cent manganese. These steels have high elastic limit, resistance to fatigue and impact stresses.

   Moreover, these steels can be machined without difficulty and can be given a smooth surface free from tool marks. These are hardened by oil quenching at 850 – 870°C and tempered at 470 – 510°C for vehicle and other spring purposes. These steels are used for motor car laminated and coil springs for suspension purposes, automobile and aircraft engine valve springs.
3. Silicon-manganese steels. These steels contain 1.8 to 2.0 per cent silicon, 0.5 to 0.6 per cent carbon and 0.8 to 1 per cent manganese. These steels have high fatigue strength, resistance and toughness. These are hardened by quenching in oil at 850 – 900°C and tempered at 475 – 525°C. These are the usual standard quality modern spring materials and are much used for many engineering purposes.

Heat Treatment of Steels

The term heat treatment may be defined as an operation or a combination of operations, involving the heating and cooling of a metal or an alloy in the solid state for the purpose of obtaining certain desirable conditions or properties without change in chemical composition. The aim of heat treatment is to achieve one or more of the following objects:

1. To increase the hardness of metals.
2. To relieve the stresses set up in the material after hot or cold working.
3. To improve machinability.

4. To soften the metal.
5. To modify the structure of the material to improve its electrical and magnetic properties.
6. To change the grain size.
7. To increase the qualities of a metal to provide better resistance to heat, corrosion and wear.

Following are the various heat treatment processes commonly employed in engineering practice:

1. Normalising. The main objects of normalising are:
1. To refine the grain structure of the steel to improve machinability, tensile strength and structure of weld.
2. To remove strains caused by cold working processes like hammering, rolling, bending, etc., which makes the metal brittle and unreliable.
3. To remove dislocations caused in the internal structure of the steel due to hot working.
4. To improve certain mechanical and electrical properties.

The process of normalising is frequently applied to castings and forgings, etc. The alloy steels may also be normalised but they should be held for two hours at a specified temperature and then cooling in the furnace.

Note:
(a) The upper critical temperature for steel depends upon its carbon content. It is 900°C for pure iron, 860°C for steels with 2.2% carbon, 723°C for steel with 0.8% carbon and 1130°C for steel with 1.8% carbon.
(b) Steel containing 0.8% carbon is known as eutectoid steel, steel containing less than 0.8% carbon is called hypoeutectoid steel and steel containing above 0.8% carbon is called hypereutectoid steel.

2. Annealing. The main objects of annealing are:
1. To soften the steel so that it may be easily machined or cold worked.
2. To refine the grain size and structure to improve mechanical properties like strength and ductility.
3. To relieve internal stresses which may have been caused by hot or cold working or by unequal contraction in casting.
4. To alter electrical, magnetic or other physical properties.
5. To remove gases trapped in the metal during initial casting.

The annealing process is of the following two types:
(a) Full annealing. The purpose of full annealing is to soften the metal to refine the grain structure, to relieve the stresses and to remove trapped gases in the metal.
The process consists of following temperatures:

(i) Heating the steel from 30 to 50°C above the upper critical temperature for hypoeutectoid steel and by the same temperature above the lower critical temperature i.e. 723°C for hypereutectoid steels.

(ii) Holding it at this temperature for some time to enable the internal changes to take place. The time allowed is approximately 3 to 4 minutes for each millimetre of thickness of the largest section, and

(iii) Cooling slowly in the furnace. The rate of cooling varies from 30 to 200°C per hour depending upon the composition of steel.

In order to avoid decarburisation of the steel during annealing, the steel is packed in a cast iron box containing a mixture of cast iron borings, charcoal, lime, sand or ground mica. The box along with its contents is allowed to cool slowly in the furnace after proper heating has been completed.

The following table shows the approximate temperatures for annealing depending upon the carbon contents in steel.

Table Annealing temperatures.

S.No.	Carbon content, per cent	Annealing temperature, °C
1.	Less than 0.12 (Dead mild steel)	875 – 925
2.	0.12 to 0.45 (Mild steel)	840 – 970
3.	0.45 to 0.50 (Medium carbon steel)	815 – 840
4.	0.50 to 0.80 (Medium carbon steel)	780 – 810
5.	0.80 to 1.50 (High carbon or tool steel)	760 – 780

(b) Process annealing. The process annealing is used for relieving the internal stresses previously set up in the metal and for increasing the machinability of the steel. In this process, steel is heated to a temperature below or close to the lower critical temperature, held at this temperature for some time and then cooled slowly. This causes complete recrystallisation in steels which have been severely cold worked and a new grain structure is formed. The process annealing is commonly used in the sheet and wire industries.

3. Spheroidising. It is another form of annealing in which cementite in the granular form is produced in the structure of steel. This is usually applied to high carbon tool steels which are difficult to machine. The operation consists of heating the steel to a temperature slightly above the lower critical temperature (730 to 770°C). It is held at this temperature for some time and then cooled slowly to a temperature of 600°C. The rate of cooling is from 25 to 30°C per hour.

The Spheroidising improves the machinability of steels, but lowers the hardness and tensile strength. These steels have better elongation properties than the normally annealed steel.

4. Hardening. The main objects of hardening are:

1. To increase the hardness of the metal so that it can resist wear.
2. To enable it to cut other metals i.e. to make it suitable for cutting tools.

The process of hardening consists of

(a) Heating the metal to a temperature from 30 to 50°C above the upper critical point for hypoeutectoid steels and by the same temperature above the lower critical point for hypereutectoid steels.

(b) Keeping the metal at this temperature for a considerable time, depending upon its thickness.

(c) Quenching (cooling suddenly) in a suitable cooling medium like water, oil or brine. It may be noted that the low carbon steels cannot be hardened appreciably, because of the presence of ferrite which is soft and is not changed by the treatment. As the carbon content goes on increasing, the possible obtainable hardness also increases.

Note:

1. The greater the rate of quenching, the harder is the resulting structure of steel.
2. For hardening alloy steels and high speed steels, they are heated from 1100°C to 1300°C followed by cooling in a current of air.

5. Tempering. The steel hardened by rapid quenching is very hard and brittle. It also contains internal stresses which are severe and unequally distributed to cause cracks or even rupture of hardened steel. The tempering (also known as drawing) is, therefore, done for the following reasons:

1. To reduce brittleness of the hardened steel and thus to increase ductility.
2. To remove the internal stresses caused by rapid cooling of steel.
3. To make steel tough to resist shock and fatigue.

The tempering process consists of reheating the hardened steel to some temperature below the lower critical temperature, followed by any desired rate of cooling. The exact tempering temperature depends upon the purpose for which the article or tool is to be used.

6. Surface hardening or case hardening. In many engineering applications, it is desirable that steel being used should have a hardened surface to resist wear and tear. At the same time, it should have soft and tough interior or core so that it is able to absorb any shocks, etc. This is achieved by hardening the surface layers of the article while the rest of it is left as such. This type of treatment is applied to gears, ball bearings, railway wheels, etc.

Following are the various surfaces or case hardening processes by means of which the surface layer is hardened:

1. Carburising, 2. Cyaniding 3. Nitriding, 4. Induction hardening and 5. Flame hardening

Non-ferrous Metals

We have already discussed that the non-ferrous metals are those which contain a metal other than iron as their chief constituent. The non-ferrous metals are usually employed in industry due to the following characteristics:

1. Ease of fabrication (casting, rolling, forging, welding and machining),
2. Resistance to corrosion,
3. Electrical and thermal conductivity, and
4. Weight.

The various non-ferrous metals used in engineering practice are aluminium, copper, lead, tin, zinc, nickel, etc. and their alloys. We shall now discuss these non-ferrous metals and their alloys in detail.

Aluminium

It is white metal produced by electrical processes from its oxide (alumina), which is prepared from clayey mineral called bauxite. It is a light metal having specific gravity 2.7 and melting point 658°C. The tensile strength of the metal varies from 90 MPa to 150 MPa.

In its pure state, the metal would be weak and soft for most purposes, but when mixed with small amounts of other alloys, it becomes hard and rigid. So, it may be blanked, formed, drawn, turned, cast, forged and die cast. Its good electrical conductivity is an important property and is widely used for overhead cables. The high resistance to corrosion and its non-toxicity makes it a useful metal for cooking utensils under ordinary condition and thin foils are used for wrapping food items. It is extensively used in aircraft and automobile components where saving of weight are an advantage.

Aluminium Alloys

The aluminium may be alloyed with one or more other elements like copper, magnesium, manganese, silicon and nickel. The addition of small quantities of alloying elements converts the soft and weak metal into hard and strong metal, while still retaining its light weight. The main aluminium alloys are discussed below:

1. Duralumin. It is an important and interesting wrought alloy. Its composition is as follows:

Copper = 3.5 – 4.5%; Manganese = 0.4 – 0.7%; Magnesium = 0.4 – 0.7%, and the remainder is aluminium. This alloy possesses maximum tensile strength (up to 400 MPa) after heat treatment and age hardening. After working, if the metal is allowed to age for 3 or 4 days, it will be hardened. This phenomenon is known as age hardening.

It is widely used in wrought conditions for forging, stamping, bars, sheets, tubes and rivets. It can be worked in hot condition at a temperature of 500°C. However, after forging and annealing, it can also be cold worked. Due to its high strength and light weight, this alloy may be used in automobile and aircraft components. It is also used in manufacturing connecting rods, bars, rivets, pulleys, etc.

2. Y-alloy. It is also called copper-aluminium alloy. The addition of copper to pure aluminium increases its strength and machinability.

The composition of this alloy is as follows:

Copper = 3.5 – 4.5%; Manganese = 1.2 – 1.7%; Nickel = 1.8 – 2.3%; Silicon, Magnesium, Iron = 0.6% each; and the remainder is aluminium.

This alloy is heat treated and age hardened like duralumin. The ageing process is carried out at room temperature for about five days.

It is mainly used for cast purposes, but it can also be used for forged components like duralumin. Since Y-alloy has better strength (than duralumin) at high temperature, therefore, it is much used in aircraft engines for cylinder heads and pistons.

3. Magnalium. It is made by melting the aluminium with 2 to 10% magnesium in a vacuum and then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres. It also contains about 1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraft and automobile components.

4. Hindalium. It is an alloy of aluminium and magnesium with a small quantity of chromium. It is the trade name of aluminium alloy produced by Hindustan Aluminium Corporation Ltd, Renukoot (U.P.). It is produced as a rolled product in 16 gauges, mainly for anodized utensil manufacture.

Copper

It is one of the most widely used non-ferrous metals in industry. It is a soft, malleable and ductile material with a reddish-brown appearance. Its specific gravity is 8.9 and melting point is 1083°C. The tensile strength varies from 150 MPa to 400 MPa under different conditions. It is a good conductor of electricity.

It is largely used in making electric cables and wires for electric machinery and appliances, in electrotyping and electroplating, in making coins and household utensils.

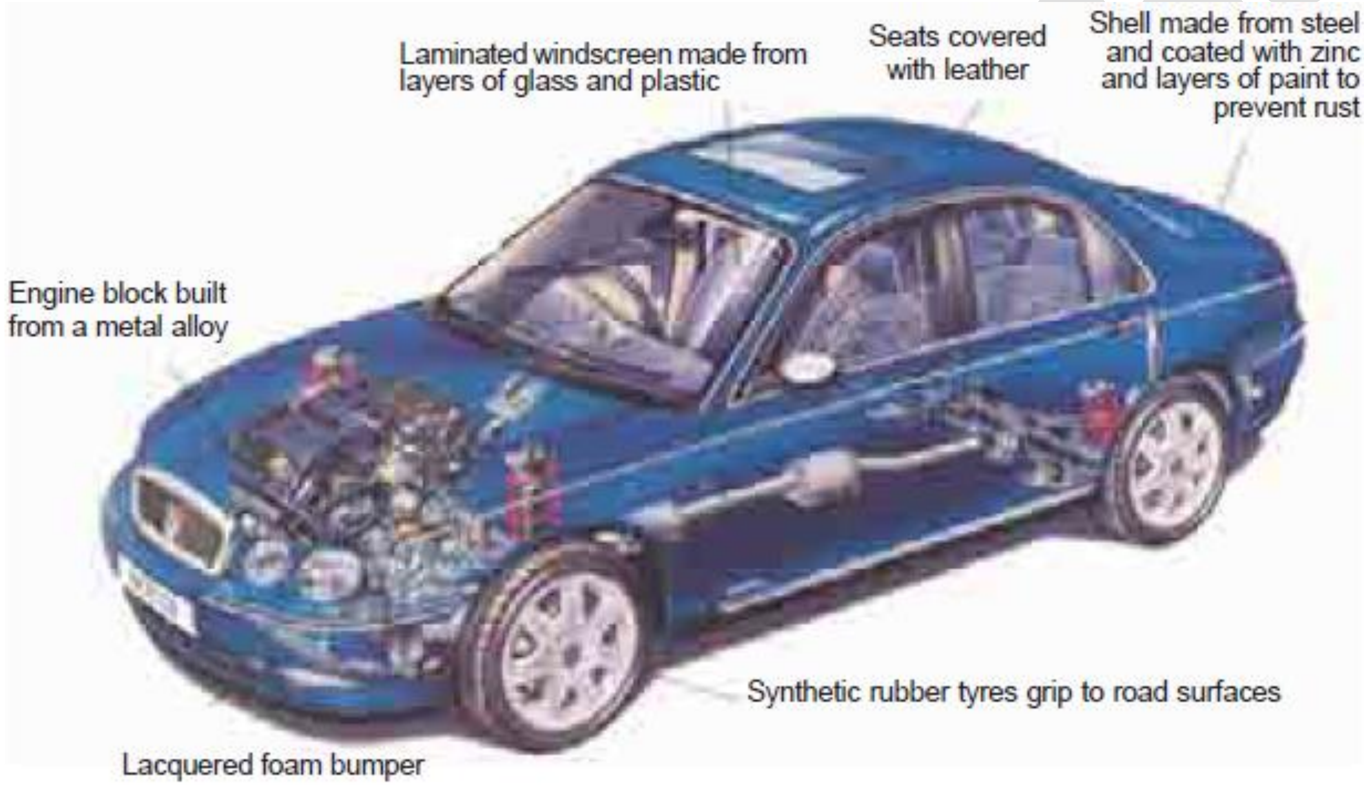
It may be cast, forged, rolled and drawn into wires. It is non-corrosive under ordinary conditions and resists weather very effectively. Copper in the form of tubes is used widely in mechanical engineering. It is also used for making ammunitions. It is used for making useful alloys with tin, zinc, nickel and aluminium.

Copper Alloys

The copper alloys are broadly classified into the following two groups:

1. Copper-zinc alloys (Brass). The most widely used copper-zinc alloy is brass. There are various types of brasses, depending upon the proportions of copper and zinc.

This is fundamentally a binary alloy of copper with zinc each 50%. By adding small quantities of other elements, the properties of brass may be greatly changed.
For example, the addition of lead (1 to 2%) improves the machining quality of brass. It has a greater strength than that of copper, but has a lower thermal and electrical conductivity. Brasses are very resistant to atmospheric corrosion and can be easily soldered. They can be easily fabricated by processes like spinning and can also be electroplated with metals like nickel and chromium. The following table shows the composition of various types of brasses according to Indian standards.



Materials are used to build a modern car.

2. Copper-tin alloys (Bronze). The alloys of copper and tin are usually termed as bronzes. The useful range of composition is 75 to 95% copper and 5 to 25% tin. The metal is comparatively hard, resists surface wear and can be shaped or rolled into wires, rods and sheets very easily. In corrosion resistant properties, bronzes are superior to brasses.
Some of the common types of bronzes are as follows:
(a) Phosphor bronze. When bronze contains phosphorus, it is called phosphor bronze.
Phosphorus increases the strength, ductility and soundness of castings. The tensile strength of this alloy when cast varies from 215 MPa to 280 MPa but increases up to 2300 MPa when rolled or drawn. This alloy possesses good wearing qualities and high elasticity. The metal is resistant to salt water corrosion. The composition of the metal varies according

to whether it is to be forged, wrought or made into castings. A common type of phosphor bronze has the following composition according to Indian standards:

Copper = 87–90%, Tin = 9–10%, and Phosphorus = 0.1–3%.

It is used for bearings, worm wheels, gears, nuts for machine lead screws, pump parts, linings and for many other purposes. It is also suitable for making springs.

(b) Silicon bronze. It contains 96% copper, 3% silicon and 1% manganese or zinc. It has good general corrosion resistance of copper combined with higher strength. It can be cast, rolled, stamped, forged and pressed either hot or cold and it can be welded by all the usual methods. It is widely used for boilers, tanks, stoves or where high strength and good corrosion resistance is required.

(c) Beryllium bronze. It is a copper base alloy containing about 97.75% copper and 2.25% beryllium. It has high yield point, high fatigue limit and excellent cold and hot corrosion resistance. It is particularly suitable material for springs, heavy duty electrical switches, cams and bushings. Since the wear resistance of beryllium copper is five times that of phosphor bronze, therefore, it may be used as a bearing metal in place of phosphor bronze. It has a film forming and a soft lubricating property, which makes it more suitable as a bearing metal.

(d) Manganese bronze. It is an alloy of copper, zinc and little percentage of manganese. The usual composition of this bronze is as follows:

Copper = 60%, Zinc = 35%, and Manganese = 5%

This metal is highly resistant to corrosion. It is harder and stronger than phosphor bronze. It is generally used for bushes, plungers, feed pumps, rods etc. Worm gears are frequently made from this bronze.

(e) Aluminium bronze. It is an alloy of copper and aluminium. The aluminium bronze with 6–8% aluminium has valuable cold working properties. The maximum tensile strength of this alloy is 450 MPa with 11% of aluminium. They are most suitable for making components exposed to severe corrosion conditions. When iron is added to these bronzes, the mechanical properties are improved by refining the grain size and improving the ductility.

Aluminium bronzes are widely used for making gears, propellers, condenser bolts, pump components, tubes, air pumps, slide valves and bushings, etc. Cams and rollers are also made from this alloy. The 6% aluminium alloy has a fine gold colour which is used for imitation jewellery and decorative purposes.

Gun Metal

It is an alloy of copper, tin and zinc. It usually contains 88% copper, 10% tin and 2% zinc. This metal is also known as Admiralty gun metal. The zinc is added to clean the metal and to increase its fluidity.

It is not suitable for being worked in the cold state but may be forged when at about 600°C. The metal is very strong and resistant to corrosion by water and atmosphere. Originally, it was made for casting guns. It is extensively used for casting boiler fittings, bushes, bearings, glands, etc.

Lead

It is a bluish grey metal having specific gravity 11.36 and melting point 326°C. It is so soft that it can be cut with a knife. It has no tenacity. It is extensively used for making solders, as a lining for acid tanks, cisterns, water pipes, and as coating for electrical cables.

The lead base alloys are employed where a cheap and corrosion resistant material is required. Alloy containing 83% lead, 15% antimony, 1.5% tin and 0.5% copper is used for large bearings subjected to light service.

Tin

It is brightly shining white metal. It is soft, malleable and ductile. It can be rolled into very thin sheets. It is used for making important alloys, fine solder, as a protective coating for iron and steel sheets and for making tin foil used as moisture proof packing.

A tin base alloy containing 88% tin, 8% antimony and 4% copper is called babbit metal. It is a soft material with a low coefficient of friction and has little strength. It is the most common bearing metal used with cast iron boxes where the bearings are subjected to high pressure and load.

Bearing Metals

The following are the widely used bearing metals:

1. Copper-base alloys 2. Lead-base alloys, 3. Tin-base alloys and 4. Cadmium-base alloys

The copper base alloys are the most important bearing alloys. These alloys are harder and stronger than the white metals (lead base and tin base alloys) and are used for bearings subjected to heavy pressures. These include brasses and bronzes which are discussed. The lead base and tin base alloys are discussed. The cadmium base alloys contain 95% cadmium and 5% silver. It is used for medium loaded bearings subjected to high temperature.

The selection of a particular type of bearing metal depends upon the conditions under which it is to be used. It involves factors relating to bearing pressures, rubbing speeds, temperatures, lubrication, etc. A bearing material should have the following properties:

1. It should have low coefficient of friction.
2. It should have good wearing qualities.
3. It should have ability to withstand bearing pressures.
4. It should have ability to operate satisfactorily with suitable lubrication means at the maximum rubbing speeds.
5. It should have a sufficient melting point.
6. It should have high thermal conductivity.

7. It should have good casting qualities.
8. It should have minimum shrinkage after casting.
9. It should have non-corrosive properties.
10. It should be economical in cost.

Zinc Base Alloys

The most of the die castings are produced from zinc base alloys. These alloys can be casted easily with a good finish at fairly low temperatures. They have also considerable strength and are low in cost. The usual alloying elements for zinc are aluminium, copper and magnesium and they are all held in close limits.

The composition of two standard die casting zinc alloys is as follows:

1. Aluminium 4.1%, copper 0.1%, magnesium 0.04% and the remainder is zinc.
2. Aluminium 4.1%, copper 1%, magnesium 0.04% and the remainder is zinc.

Aluminium improves the mechanical properties and also reduces the tendency of zinc to dissolve iron. Copper increases the tensile strength, hardness and ductility.

Magnesium has the beneficial effect of making the castings permanently stable. These alloys are widely used in the automotive industry and for other high production markets such as washing machines, oil burners, refrigerators, radios, photographs, television, business machines, etc.

Nickel Base Alloys

The nickel base alloys are widely used in engineering industry on account of their high mechanical strength properties, corrosion resistance, etc. The most important nickel base alloys are discussed below:

1. Monel metal. It is an important alloy of nickel and copper. It contains 68% nickel, 29% copper and 3% other constituents like iron, manganese, silicon and carbon. Its specific gravity is 8.87 and melting point 1360°C. It has a tensile strength from 390 MPa to 460 MPa. It resembles nickel in appearance and is strong, ductile and tough. It is superior to brass and bronze in corrosion resisting properties. It is used for making propellers, pump fittings, condenser tubes, steam turbine blades, sea water exposed parts, tanks and chemical and food handling plants.
2. Inconel. It consists of 80% nickel, 14% chromium, and 6% iron. Its specific gravity is 8.55 and melting point 1395°C. This alloy has excellent mechanical properties at ordinary and elevated temperatures. It can be cast, rolled and cold drawn. It is used for making springs which have to withstand high temperatures and are exposed to corrosive action. It is also used for exhaust manifolds of aircraft engines.
3. Nichrome. It consists of 65% nickel, 15% chromium and 20% iron. It has high heat and oxidation resistance. It is used in making electrical resistance wire for electric furnaces and heating elements.

4. Nimonic. It consists of 80% nickel and 20% chromium. It has high strength and ability to operate under intermittent heating and cooling conditions. It is widely used in gas turbine engines.

Non-metallic Materials

The non-metallic materials are used in engineering practice due to their low density, low cost, flexibility, resistant to heat and electricity. Though there are many non-metallic materials, yet the following are important from the subject point of view.

1. Plastics. The plastics are synthetic materials which are moulded into shape under pressure with or without the application of heat. These can also be cast, rolled, extruded, laminated and machined. Following are the two types of plastics:

(a) Thermosetting plastics, and (b) Thermoplastic.

The thermosetting plastics are those which are formed into shape under heat and pressure and results in a permanently hard product. The heat first softens the material, but as additional heat and pressure is applied, it becomes hard by a chemical change known as phenol-formaldehyde (Bakelite), phenol-furfural (Durite), urea-formaldehyde (Plaskon), etc.

The thermoplastic materials do not become hard with the application of heat and pressure and no chemical change occurs. They remain soft at elevated temperatures until they are hardened by cooling. These can be remelted repeatedly by successive application of heat. Some of the common thermoplastics are cellulose nitrate (Celluloid), polythene, polyvinyl acetate, polyvinyl chloride (P.V.C.), etc.

The plastics are extremely resistant to corrosion and have a high dimensional stability. They are mostly used in the manufacture of aeroplane and automobile parts. They are also used for making safety glasses, laminated gears, pulleys, self-lubricating bearing, etc. due to their resilience and strength.

2. Rubber. It is one of the most important natural plastics. It resists abrasion, heat, strong alkalis and fairly strong acids. Soft rubber is used for electrical insulations. It is also used for power transmission belting, being applied to woven cotton or cotton cords as a base. The hard rubber is used for piping and as lining for pickling tanks.

3. Leather. It is very flexible and can withstand considerable wear under suitable conditions. It is extensively used for power transmission belting and as a packing or as washers.

4. Ferrodo. It is a trade name given to asbestos lined with lead oxide. It is generally used as a friction lining for clutches and brakes.

Why Heat Treatment of Metals?

"Heat treating is a process where heat is applied to a material and then cooled to improve its performance, durability, and properties."

Generally, heat treatment of steel involves the heating and cooling of the material. The metal or alloy is heated to a specific temperature. Then, cooling occurs to harden the heated material. The process aims towards changing the microstructure of the metal also, it helps to bring out desired mechanical, chemical, and physical characteristics.

The alteration of these properties benefits the working life of the component involved. For example, there may be increased ductility, strength, surface hardness, or temperature resistance. Heat treatment is one of the essential aspects of the metal manufacturing process. This is because it helps to improve a metal part to withstand wear and tear better. Heat treatment of steel or metals plays important role in various manufacturing stages.

How Does Heat Treatment of Metals Work?

Although there are many types of heat treatment, they follow similar processes. The first step involves the heating of the metal or alloy to the required temperature. Sometimes, the temperature goes up to 2400°F. It is held at the temperature for a specified amount of time before cooling.

While the metal is hot, the microstructure changes. This is the physical structure of the metal. The change in the structure ultimately results in a change in the physical properties of the metal. The "soak time" is the amount of time used to heat the metal.

The soak time is a significant factor during the heat treatment process. A metal soaked for a more extended period will have more microstructure changes than that soaked for a shorter period. The cooling of the metal also plays a crucial role in the end result. The cooling process may be quick – quenching. In other cases, the cooling may be done slowly in a furnace.

The best type of cooling depends on the end result expected from the process. Therefore, it is important to consider these factors before starting the heat treatment of steel and metals.

Another factor also determines what properties of the metal change. This is the specific time for the heat treatment during a manufacturing process. Some metals may even require heating several times during manufacture. Therefore, it is important to understand the best ways to perform the operations correctly.

Benefits of Heat Treatment of Metals

Without the heat treatment of metals, there may be nothing like metal parts for devices and equipment. Even if they existed, they wouldn't function in the right manner. For example, non-ferrous metal parts would be too weak for several applications.

Strengthening of metal and alloys, like steel and aluminum, occurs through heat treatment. The applications of many of these metals are in airplanes, cars, computers, and others. These products rely on metals with highly increased strength. This is to ensure adequate safety and improved performance.

The major mechanical property that changed after heat treatment is the shear strength. Others include tensile strength and toughness. Heat-treated metals are usually stronger, ensuring durability. Therefore, there will be no need to replace expensive metal parts every now and then.

Using effectively heat-treated metal parts ensures the effective and cost-effective running of machines. Furthermore, the product will be a lot more efficient, even for the toughest applications. Also, there may be the need for extremely hard metals for some applications. The applications may be those requiring highly defined edges.

Heat treatment of the metals is one of the best ways to get the desired performance. It also helps to develop hard surfaces with ductile base materials. Asides from the application benefits, heat treatment is also beneficial to manufacturers.

A proper heat treatment process help relieves internal stresses. Consequently, this makes the metal easier to weld or machine. Processes such as hot forming may build stresses in steel materials over time. Therefore, these materials benefit greatly from heat treatments.

In a nutshell, the benefits of heat treatment of metals include:

- Increases strength, making the material ductile or more flexible.
- It introduces wear-resistant properties to the metal.
- Relieves stresses, making the part easier to machine or weld.
- It improves brittleness.
- Can improve the electrical and magnetic properties of a metal.

Stages of Heat Treatment

There are three stages of heat treatment:

- Heat the metal slowly to ensure that the metal maintains a uniform temperature
- Soak, or hold, the metal at a specific temperature for an allotted period of time
- Cool the metal to room temperature

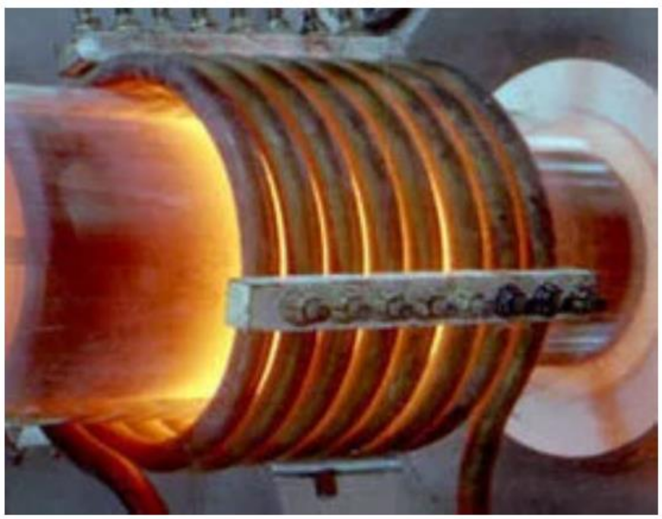
Types of Heat Treatment and Their Purposes in Machining:

As mentioned earlier, every heat treatment process involves heating and cooling. In this section, we'll discuss the four major heat treatment types. You will also understand their unique purposes in machining.

a) Hardening
b) Tempering
c) Annealing
d) Normalizing

Hardening

Hardening involves the heating of the metal material to a specific temperature. This temperature is the point at which the elements present in the metal go into the solution. The crystal lattice structure of the metal may have defects that present a source of plasticity. Heat treatment helps to address these defects.



It does so by bringing the metal into the solution of fine particles. This works to strengthen the metal material. Once there has been thorough heating of the metal to the required temperature, it is quenched as quickly as possible. Quenching helps the metal to trap particles in the solution. In some cases, technicians may add impurities to the alloy to further increase strength.

The purpose of hardening is to increase the strength of the metal. At the same time, it makes the metal more brittle while decreasing ductility. Therefore, it will help if you temper the metal after the hardening process.

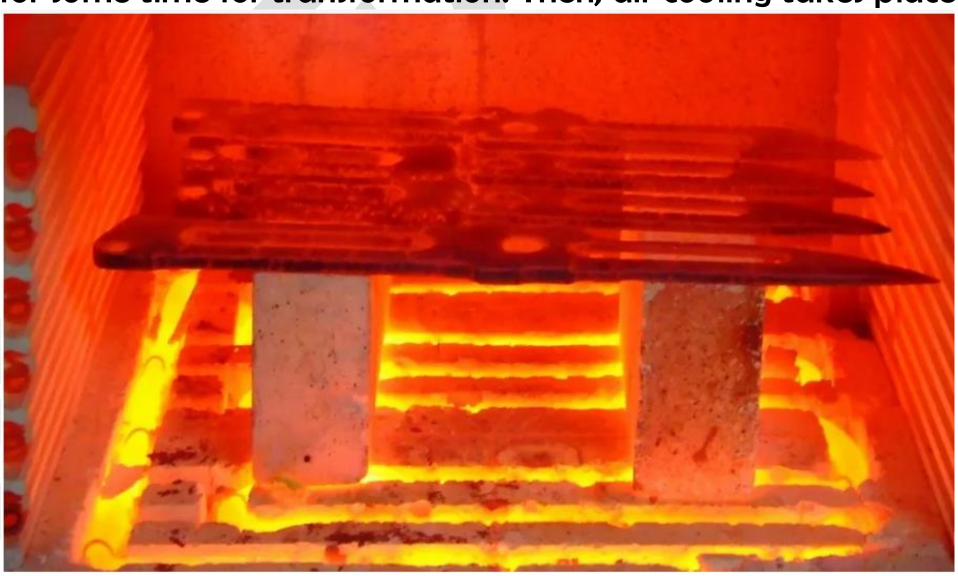
Tempering

This is another heat treatment process that helps to increase the resilience of steel. Iron-based alloys are usually hard but often too brittle for certain applications. Tempering helps to alter the hardness, brittleness, and ductility of the metal. This is in a bid to make the machining process easier.

In this case, heating occurs at a temperature below the critical point. Lower temperatures tend to reduce brittleness and maintain hardness. Tempering helps to reduce the hardness caused by hardening. This way, you can develop new physical properties for your metal. Therefore, tempering should often follow hardening during heat treatment.

Annealing

This process is suitable for metals like steel, aluminum, copper, silver, or brass. Annealing involves heating the metal to a specific temperature. Then, you hold the metal at that temperature for some time for transformation. Then, air cooling takes place.



The cooling may occur slowly or quickly for silver, copper, and brass. However, the cooling of steel has to be gradual for effective annealing. Annealing does the opposite of hardening. It decreases the metal's hardness while increasing its ductility. Thereby, it makes it easy to work on the metal. It is also a great way of fixing a weak metal. At the same time, it helps to relieve internal stresses in metals.

Normalizing

Normalizing is another form of annealing. In this case, the metal material is heated up to 200°F, which is higher than for annealing. The technician holds the metal at the critical temperature till transformation occurs. This heat treatment process requires air cooling after heating.

This process leads to smaller austenitic grains. Air cooling helps to produce Ferritic grains that are more refined. It works to remove any form of internal stress from metals. Internal stresses may lead to metal failure. Therefore, it is crucial to normalize the metal. Then, hardening can ensure the success of manufacturing processes.

Does the Heat Treatment of Metals Make Them Stronger?

Heating to a specific temperature range can give more pure and harder metal. Heat treatment usually creates stronger metals. However, it is also possible that some treatments may make the metal weaker.

What Happens During Heat Treatment of Metals?

An increase in the temperature of metal will increase its surface area, volume, and length. Therefore, heat treatment expands the metal (thermal expansion). The degree of expansion will depend on the type of metal in use.

At What Temperature Does Steel Become Weak?

Every steel material has its upper and lower limit for toughness. The temperature at which steel's toughness drops refers to the 'Ductile to Brittle Transition Temperature.' This is usually around 75°C for 0.01% carbon steel. The temperature differs for various types of steel materials.

Heat treatment applications

The most common application of heat treatment is in metallurgy. The following are some examples of the applications for heat-treated parts:

- Automobiles
- Aerospace
- Computers
- Metalworking
- Machinery
- Construction
- Others

The global automotive industry has been a large player in the market of heat-treated metals recently. In terms of materials, steel dominates the industry, but the forecast is for aluminium and other metals for manufacturing automobiles and aircraft to drive market growth. The global market for heat treatment has been evaluated at about $90.7 billion in 2016 and is estimated to expand yearly by 3.5% from 2017 to 2025.

Heat treating can change or improve the properties of a metal including:

- Strength
- Hardness
- Ductility
- Toughness
- Wear resistance
- Elasticity
- Magnetism

Heat treatment improves workability and machinability:

By removing internal stresses, heat treating increases manufacturability. For example, if a metal is too hard to bend or machine, it can be stress relieved or annealed to decrease the hardness. If a plastic deforms after machining, it can be annealed or stress relieved to keep it from deforming. Induction flame heat treating can soften just one area of a part, and the rest of the part is left unchanged.

Heat treatment improves wear resistance and durability:

Wear resistance of a part can be improved by heat treating through the process of hardening. Metals can be hardened on the surface or all around to make them stronger, more durable, tougher, and more resistant to wear.

Heat treatment improves strength and toughness:

Toughness and strength are a trade-off, as the strength is increased, the toughness may decrease causing brittleness. Heat treating can specifically affect tensile strength, yield strength, and fracture toughness. Case hardening increases strength, however the parts will need some tempering or drawn back to decrease brittleness. The amount of tempering is determined by the required ultimate strength desired in the material.

Heat treatment improves magnetic properties:

Most materials like 1008 or 316, tend to gain magnetism when they are work hardened. If a special annealing process is used, the magnetic permeability is reduced, which is especially important if the part is going to be used in an environment that is electronic.

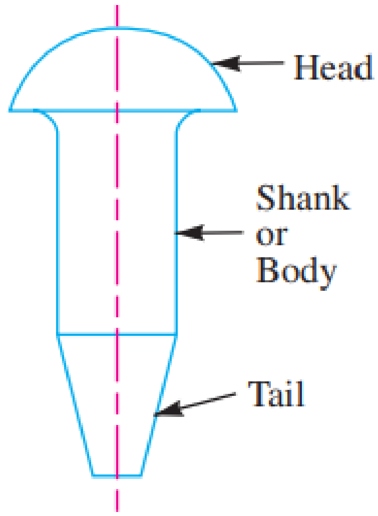
The Purpose of Heat Treating

Heat treating serves various purposes, which include:

- To improve the mechanical properties of a material that includes hardness, tensile strength, shock resistance, ductility, and resistance to corrosion.
- To improve machinability and reduce brittleness.
- For the relief of the internal stresses of the metal-induced during hot or cold working.
- To change the grain size or refine it.
- To increase the magnetic and electric properties.
- To increase the resistance to corrosion as well as resistance to wear.
- To improve the hardness of the surface of the material.
- To improve the limit of fatigue of medium and small-sized parts like gears, wrist pins, shafts etc.
- To give an appearance that is clean, bright and pleasing to the hardened surface.
- To obtain a tough core though case hardening.
- Heat treating improves the hardening properties of steel to allow it to cut other metals.
- To promote the uniformity of a structure.
- Soften a metal or plastic by the process of annealing
- Harden a metal through case hardening, hardening, Nitriding, carburizing
- Harden or soften just one area of a metal part through induction hardening
- Homogenize plastic parts that are injection molded through annealing
- Remove stress from extruded, formed, bent or cut material through stress relief
- Add resilience to a metal & Change the magnetic permeability.

RIVETED JOINTS

A rivet is a short cylindrical bar with a head integral to it. The cylindrical portion of the rivet is called shank or body and lower portion of shank is known as tail, as shown in below Figure.



The rivets are used to make permanent fastening between the plates such as in structural work, ship building, bridges, tanks and boiler shells. The riveted joints are widely used for joining light metals.

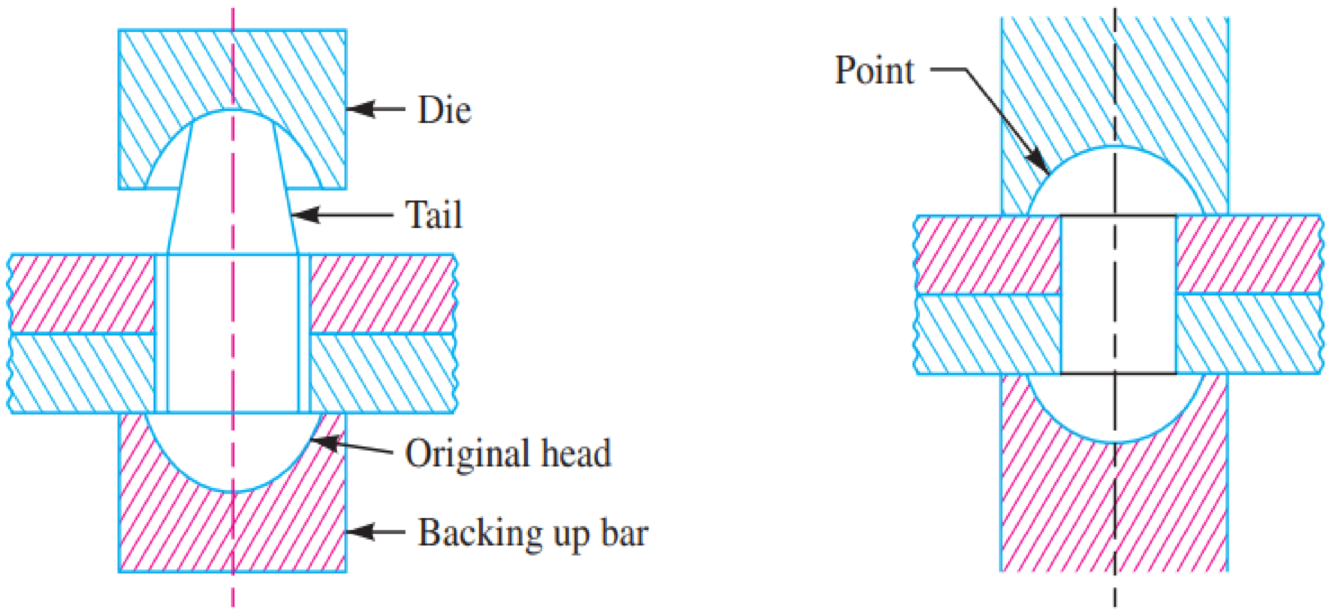
The fastenings (i.e. joints) may be classified into the following two groups:
1. Permanent fastenings, and
2. Temporary or detachable fastenings.

The **permanent fastenings** are those fastenings which cannot be disassembled without destroying the connecting components. The examples of permanent fastenings in order of strength are soldered, brazed, welded and riveted joints.
The **temporary or detachable fastenings** are those fastenings which can be disassembled without destroying the connecting components. The examples of temporary fastenings are screwed, keys, cotters, pins and splined joints.

Methods of Riveting:

The function of rivets in a joint is to make a connection that has strength and tightness. The strength is necessary to prevent failure of the joint. The tightness is necessary in order to contribute to strength and to prevent leakage as in a boiler or in a ship hull. When two plates are to be fastened together by a rivet as shown in below figure, the holes in the plates are punched and reamed or drilled. Punching is the cheapest method and is used for relatively thin plates and in structural work. Since punching injures the material around the hole, therefore drilling is used in most pressure-vessel work.

In structural and pressure vessel riveting, the diameter of the rivet hole is usually 1.5 mm larger than the nominal diameter of the rivet.



(*a*) Initial position. (*b*) Final position.

The plates are drilled together and then separated to remove any burrs or chips so as to have a tight flush joint between the plates. A cold rivet or a red hot rivet is introduced into the plates and the point (i.e. second head) is then formed. When a cold rivet is used, the process is known as cold riveting and when a hot rivet is used, the process is known as hot riveting. The cold riveting process is used for structural joints while hot riveting is used to make leak proof joints.

Note: A ship's body is a combination of riveted, screwed and welded joints

The riveting may be done by hand or by a riveting machine. In hand riveting, the original rivet head is backed up by a hammer or heavy bar and then the die or set, as shown in above Figure (a), is placed against the end to be headed and the blows are applied by a hammer. This causes the shank to expand thus filling the hole and the tail is converted into a point as shown in above Figure (b). As the rivet cools, it tends to contract. The lateral contraction will be slight, but there will be a longitudinal tension introduced in the rivet which holds the plates firmly together.

In machine riveting, the die is a part of the hammer which is operated by air, hydraulic or steam pressure.

Notes:

1. For steel rivets up to 12 mm diameter, the cold riveting process may be used while for larger diameter rivets, hot riveting process is used.
2. In case of long rivets, only the tail is heated and not the whole shank.

Material of Rivets

The material of the rivets must be tough and ductile. They are usually made of steel (low carbon steel or nickel steel), brass, aluminium or copper, but when strength and a fluid tight joint is the main consideration, then the steel rivets are used.

The rivets for general purposes shall be manufactured from steel conforming to the following Indian Standards:

(a) IS: 1148–1982 (Reaffirmed 1992) – Specification for hot rolled rivet bars (up to 40 mm diameter) for structural purposes; or

(b) IS: 1149–1982 (Reaffirmed 1992) – Specification for high tensile steel rivet bars for structural purposes.

The rivets for boiler work shall be manufactured from material conforming to IS: 1990 – 1973 (Reaffirmed 1992) – Specification for steel rivets and stay bars for boilers.

Note: The steel for boiler construction should conform to IS: 2100 – 1970 (Reaffirmed 1992) – Specification for steel billets, bars and sections for boilers.

Essential Qualities of a Rivet

According to Indian standard, IS: 2998 – 1982 (Reaffirmed 1992), the material of a rivet must have a tensile strength not less than 40 N/mm^2 and elongation not less than 26 percent. The material must be of such quality that when in cold condition, the shank shall be bent on itself through 180° without cracking and after being heated to 650°C and quenched; it must pass the same test. The rivet when hot must flatten without cracking to a diameter 2.5 times the diameter of shank.

Manufacture of Rivets

According to Indian standard specifications, the rivets may be made either by cold heading or by hot forging. If rivets are made by the cold heading process, they shall subsequently be adequately heat treated so that the stresses set up in the cold heading process are eliminated. If they are made by hot forging process, care shall be taken to see that the finished rivets cool gradually.

Types of Rivet Heads

According to Indian standard specifications, the rivet heads are classified into the following three types:

1. Rivet heads for general purposes (below 12 mm diameter) as shown in below Figure, according to IS: 2155 – 1982 (Reaffirmed 1996).
2. Rivet heads for general purposes (From 12 mm to 48 mm diameter) as shown in below Figure, according to IS: 1929 – 1982 (Reaffirmed 1996).
3. Rivet heads for boiler work (from 12 mm to 48 mm diameter, as shown in below Figure, according to IS: 1928 – 1961 (Reaffirmed 1996).

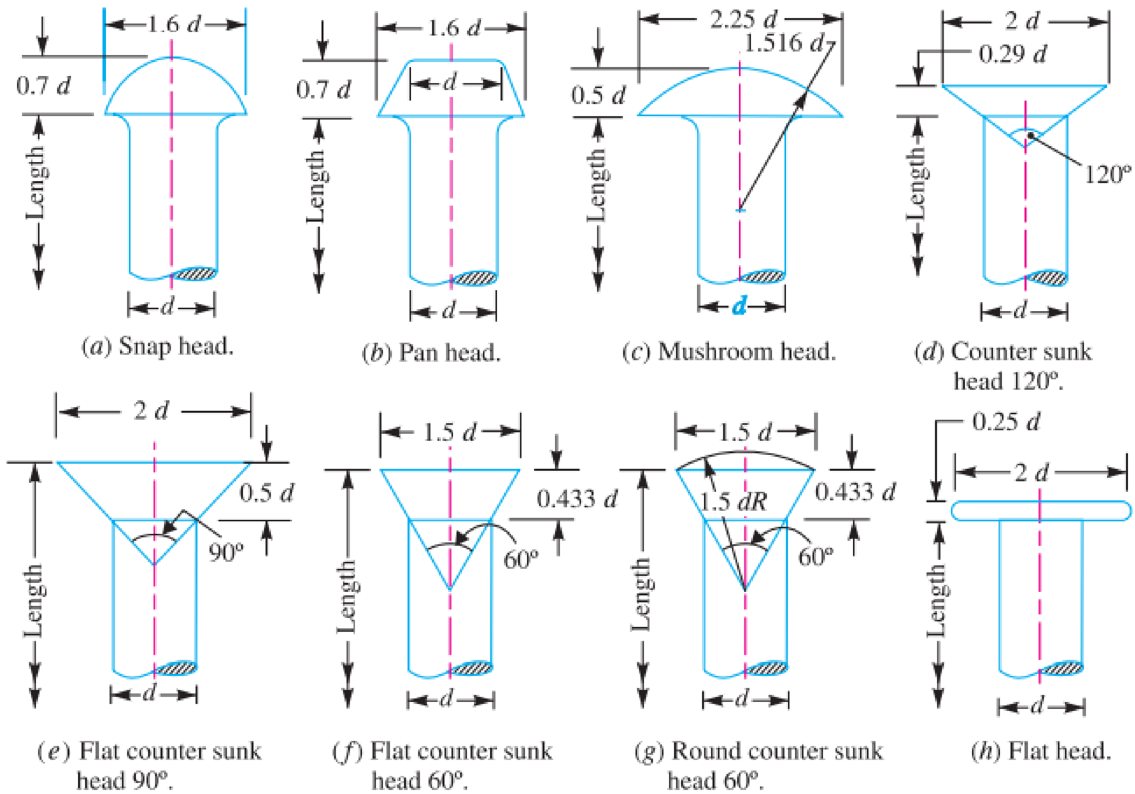


Fig. Rivet heads for general purposes (below 12 mm diameter).

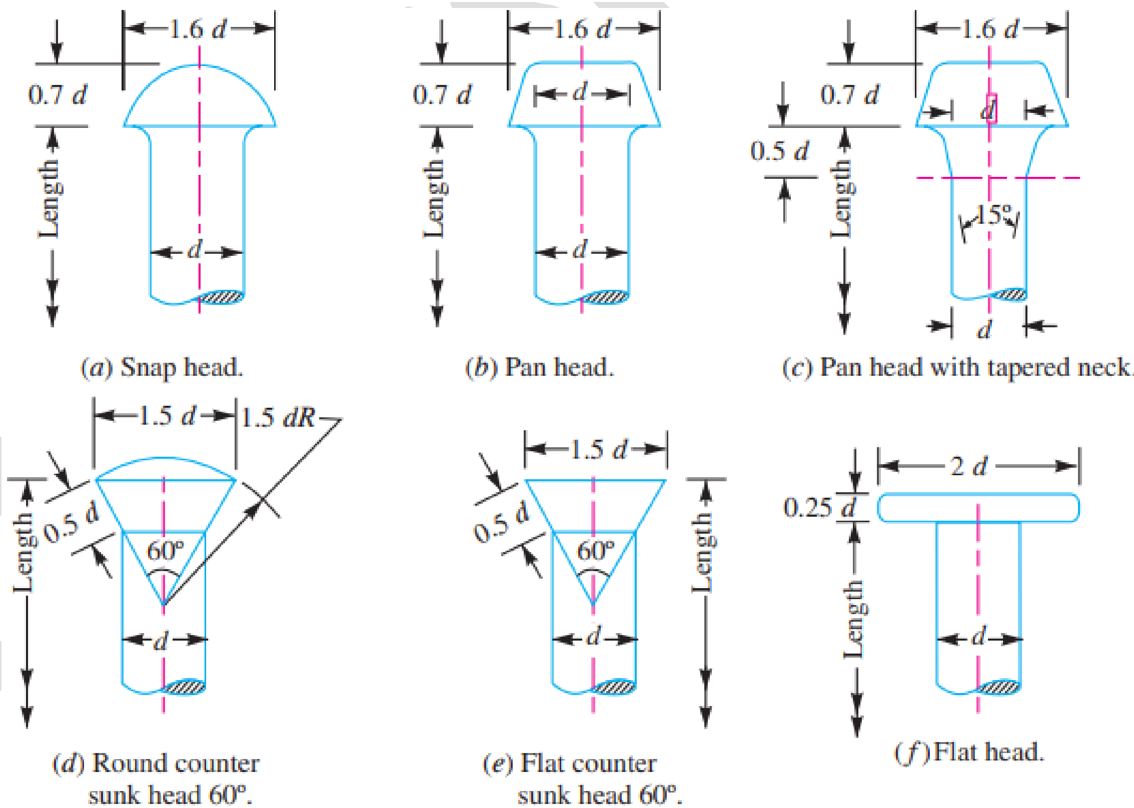


Fig. Rivet heads for general purposes (from 12 mm to 48 mm diameter)

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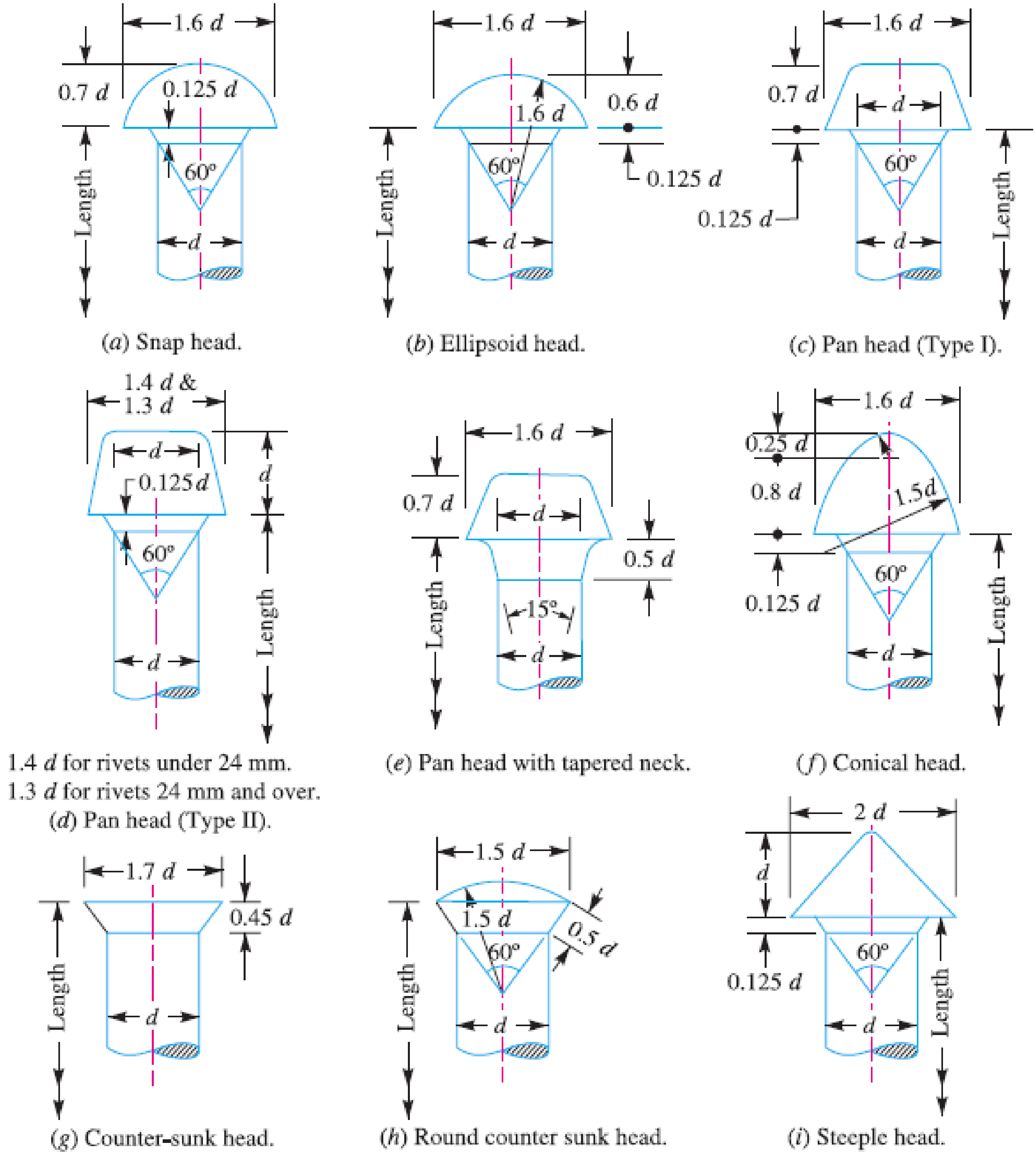


Fig. Rivet heads for boiler work.

The snap heads are usually employed for structural work and machine riveting.

The counter sunk heads are mainly used for ship building where flush surfaces are necessary.

The conical heads (also known as conoidal heads) are mainly used in case of hand hammering. The pan heads have maximum strength, but these are difficult to shape.

Types of Riveted Joints

Following are the two types of riveted joints, depending upon the way in which the plates are connected. 1. Lap joint, and 2. Butt joint.

Lap Joint: A lap joint is that in which one plate overlaps the other and the two plates are then riveted together.

Butt Joint: A butt joint is that in which the main plates are kept in alignment butting (i.e. touching) each other and a cover plate (i.e. strap) is placed either on one side or on both sides of the main plates. The cover plate is then riveted together with the main plates.

Butt joints are of the following two types:

1. Single strap butt joint, and
2. Double strap butt joint.

In a single strap butt joint, the edges of the main plates butt against each other and only one cover plate is placed on one side of the main plates and then riveted together.

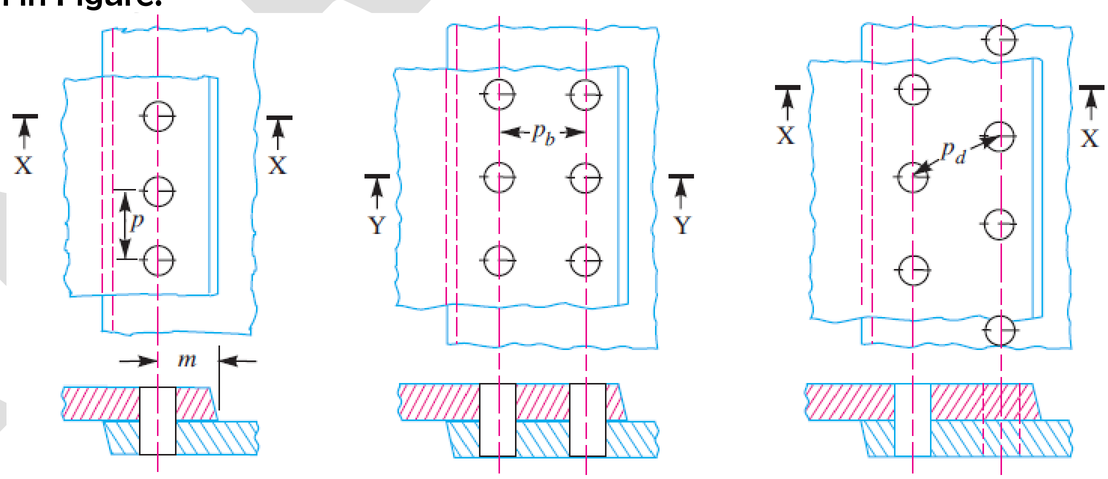
In a double strap butt joint, the edges of the main plates butt against each other and two cover plates are placed on both sides of the main plates and then riveted together.

In addition to the above, following are the types of riveted joints depending upon the number of rows of the rivets.

1. Single riveted joint, and
2. Double riveted joint.

A single riveted joint is that in which there is a single row of rivets in a lap joint as shown in below Figure (a) and there is a single row of rivets on each side in a butt joint as shown in below Figure.

A double riveted joint is that in which there are two rows of rivets in a lap joint as shown in below Figure (b) and (c) and there are two rows of rivets on each side in a butt joint as shown in Figure.



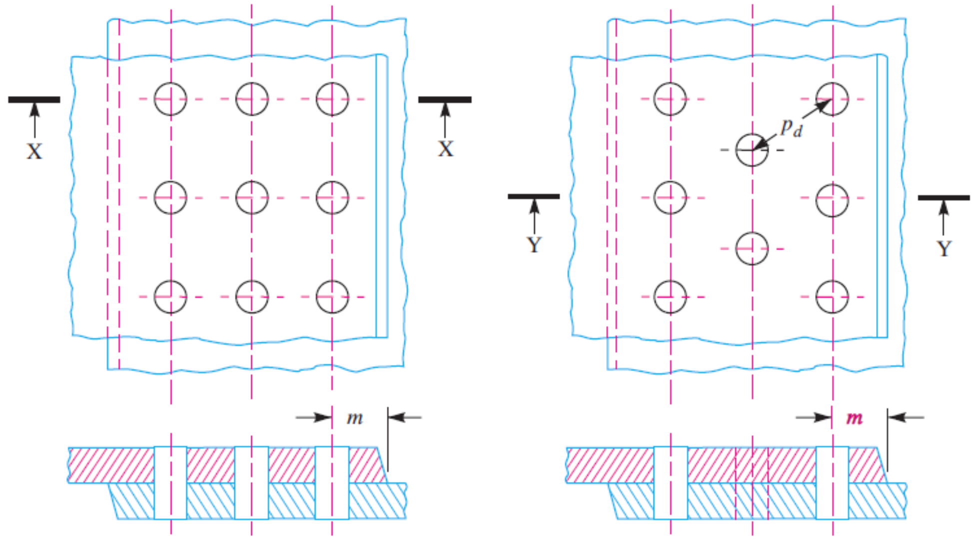
(a) Single riveted lap joint. (b) Double riveted lap joint (Chain riveting). (c) Double riveted lap joint (Zig-zag riveting).

Fig. Single and double riveted lap joints.

Similarly the joints may be triple riveted or quadruple riveted.

Notes: 1. When the rivets in the various rows are opposite to each other, as shown in Fig (b), then the joint is said to be chain riveted. On the other hand, if the rivets in the adjacent rows are staggered in such a way that every rivet is in the middle of the two rivets of the opposite row as shown in Fig (c), then the joint is said to be zigzag riveted.

2. Since the plates overlap in lap joints, therefore the force P, P acting on the plates [See Fig (a)] is not in the same straight line but they are at a distance equal to the thickness of the plate. These forces will form a couple which may bend the joint. Hence the lap joints may be used only where small loads are to be transmitted. On the other hand, the forces P, P in a butt joint [See Fig. (b)] act in the same straight line; therefore there will be no couple. Hence the butt joints are used where heavy loads are to be transmitted.



(*a*) Chain riveting. (*b*) Zig-zag riveting.

Fig. Triple riveted lap joint.

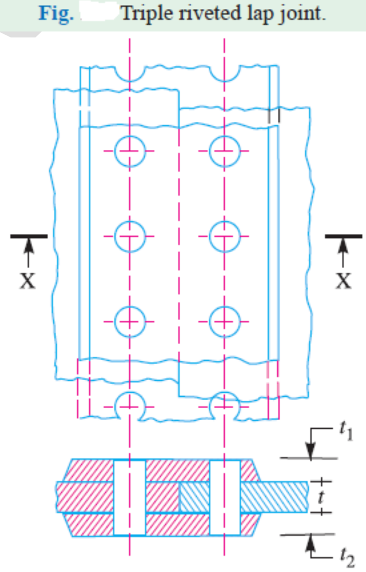
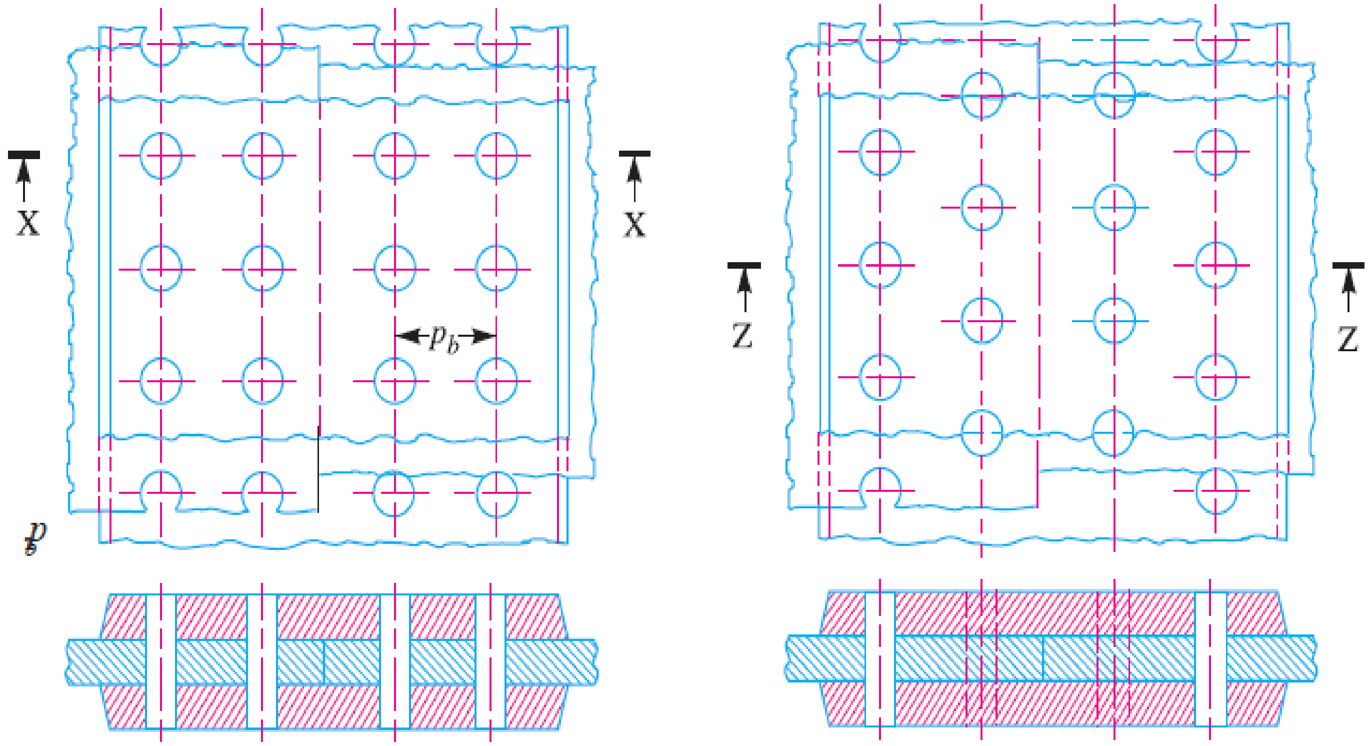


Fig. Single riveted double strap butt joint.



(*a*) Chain riveting. (*b*) Zig-zag riveting.

Fig. Double riveted double strap (equal) butt joints.

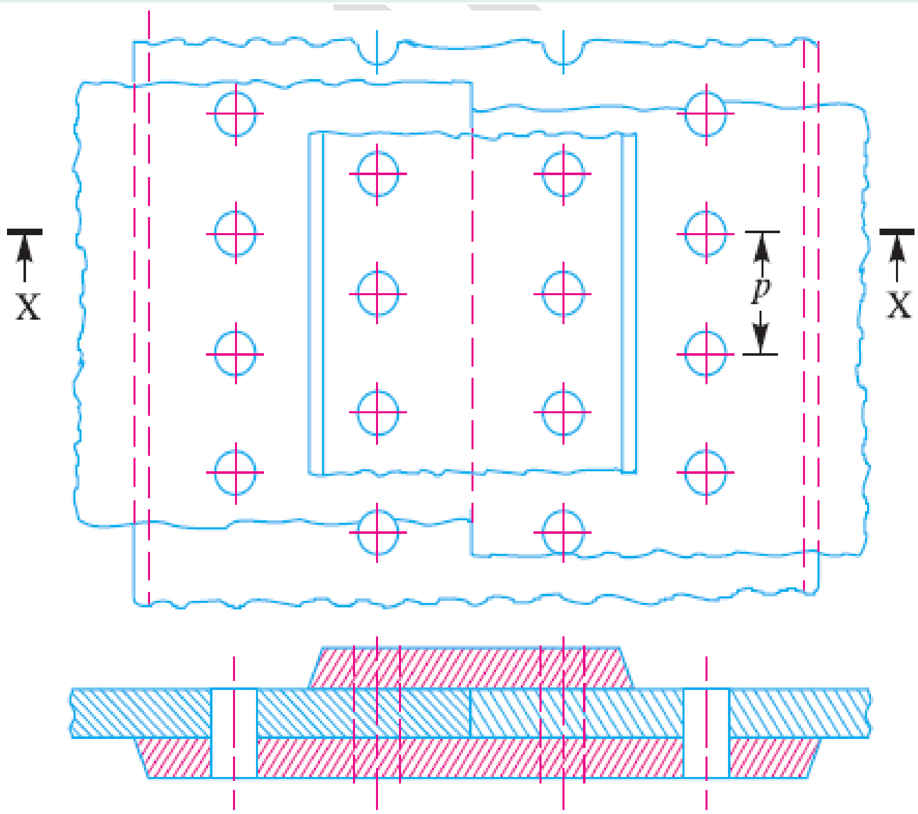


Fig. Double riveted double strap (unequal) butt joint with zig-zag riveting.

Important Terms Used in Riveted Joints

The following terms in connection with the riveted joints are important from the subject point of view:

1. Pitch. It is the distance from the centre of one rivet to the centre of the next rivet measured parallel to the seam as shown in Fig. It is usually denoted by p.
2. Back pitch. It is the perpendicular distance between the centre lines of the successive rows as shown in Fig. It is usually denoted by pb.
3. Diagonal pitch. It is the distance between the centres of the rivets in adjacent rows of zigzag riveted joint as shown in Fig. It is usually denoted by pd.
4. Margin or marginal pitch. It is the distance between the centre of rivet hole to the nearest edge of the plate as shown in Fig. It is usually denoted by m.

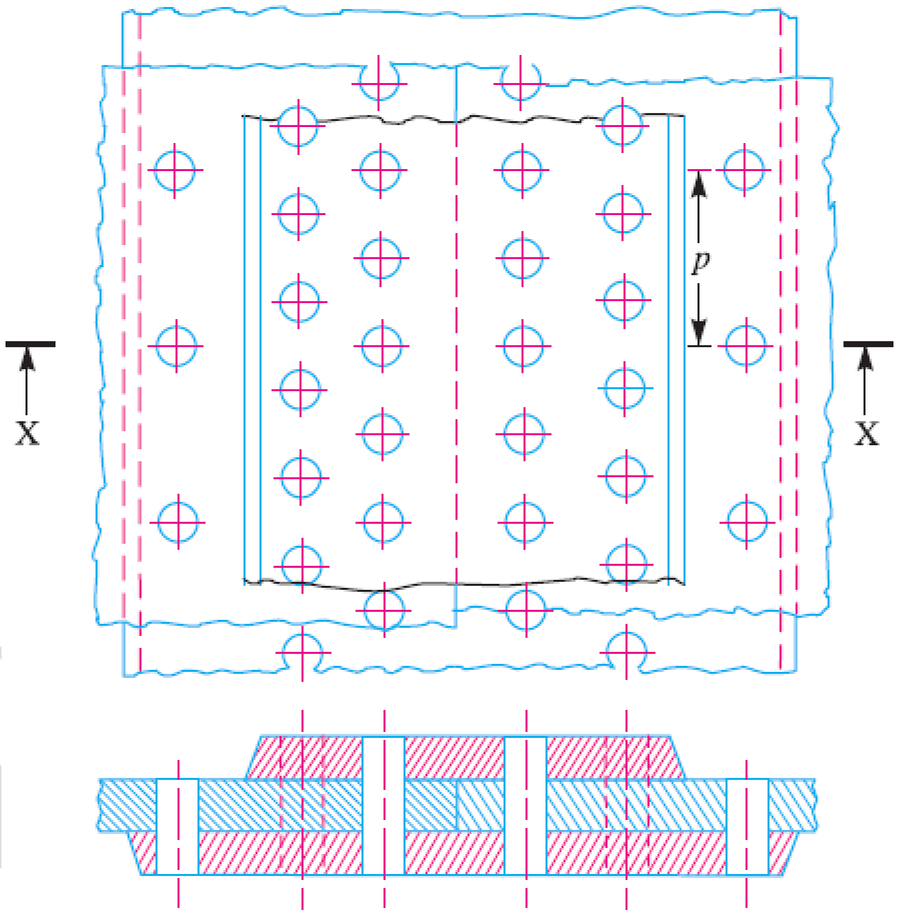


Fig. Triple riveted double strap (unequal) butt joint.

Caulking and Fullering

In order to make the joints leak proof or fluid tight in pressure vessels like steam boilers, air receivers and tanks etc. a process known as caulking is employed. In this process, a narrow blunt tool called caulking tool, about 5 mm thick and 38 mm in breadth, is used.

The edge of the tool is ground to an angle of 80°. The tool is moved after each blow along the edge of the plate, which is planed to a bevel of 75° to 80° to facilitate the forcing down of edge. It is seen that the tool burrs down the plate at A in Fig (a) forming a metal to metal joint.

In actual practice, both the edges at A and B are caulked. The head of the rivets as shown at C are also turned down with a caulking tool to make a joint steam tight. A great care is taken to prevent injury to the plate below the tool.

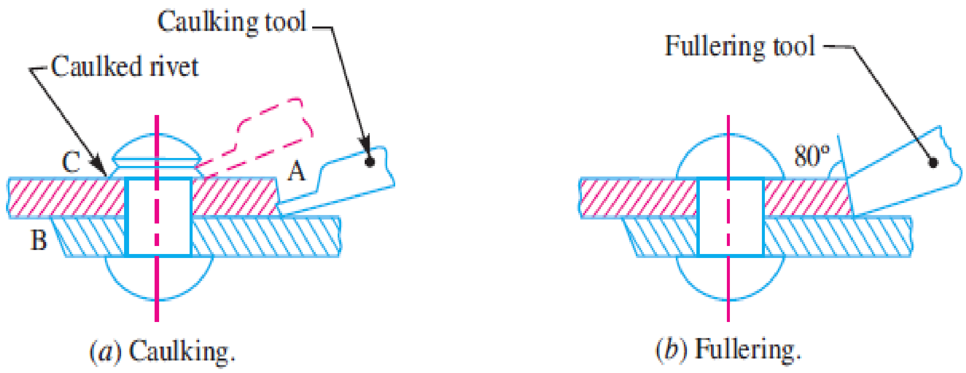


Fig. Caulking and fullering.

A more satisfactory way of making the joints staunch is known as Fullering which has largely superseded caulking. In this case, a Fullering tool with a thickness at the end equal to that of the plate is used in such a way that the greatest pressure due to the blows occur near the joint, giving a clean finish, with less risk of damaging the plate. A Fullering process is shown in Fig (b).

Failures of a Riveted Joint

A riveted joint may fail in the following ways:

1. Tearing of the plate at an edge. A joint may fail due to tearing of the plate at an edge as shown in Fig. This can be avoided by keeping the margin, m = 1.5d, where d is the diameter of the rivet hole.

2. Tearing of the plate across a row of rivets. Due to the tensile stresses in the main plates, the main plate or cover plates may tear off across a row of rivets as shown in Fig. 9.14. In such cases, we consider only one pitch length of the plate, since every rivet is responsible for that much length of the plate only.

The resistance offered by the plate against tearing is known as tearing resistance or tearing strength or tearing value of the plate.

Let p = Pitch of the rivets,

d = Diameter of the rivet hole,

t = Thickness of the plate, and

σ_t = Permissible tensile stress for the plate material.

We know that tearing area per pitch length,

$$A_t = (p - d)t$$

∴ Tearing resistance or pull required to tear off the plate per pitch length,

$$P_t = A_t.\sigma_t = (p - d)t.\sigma_t$$

When the tearing resistance (Pt) is greater than the applied load (P) per pitch length, then this type of failure will not occur.

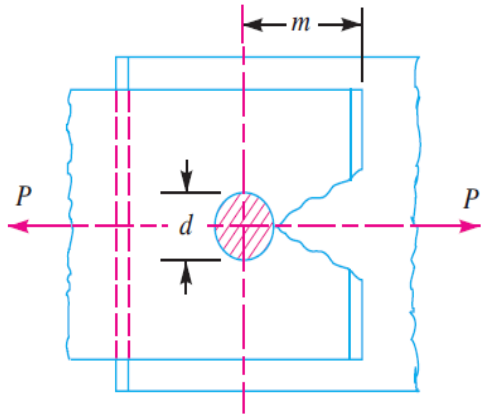


Fig. Tearing of the plate at an edge.

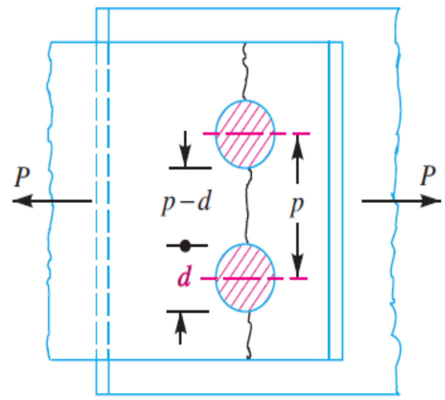


Fig. Tearing of the plate across the rows of rivets.

3. Shearing of the rivets. The plates which are connected by the rivets exert tensile stress on the rivets, and if the rivets are unable to resist the stress, they are sheared off as shown in Figure. It may be noted that the rivets are in single shear in a lap joint and in a single cover butt joint, as shown in Fig. But the rivets are in double shear in a double cover butt joint as shown in Fig. The resistance offered by a rivet to be sheared off is known as shearing resistance or shearing strength or shearing value of the rivet.

Let d = Diameter of the rivet hole,

τ = Safe permissible shear stress for the rivet material, and

n = Number of rivets per pitch length.

We know that shearing area,

$$A_s = \frac{\pi}{4} \times d^2 \qquad \text{...(In single shear)}$$

$$= 2 \times \frac{\pi}{4} \times d^2 \qquad \text{...(Theoretically, in double shear)}$$

$$= 1.875 \times \frac{\pi}{4} \times d^2 \qquad \text{...(In double shear, according to Indian Boiler Regulations)}$$

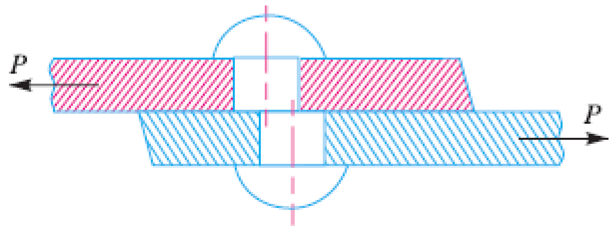
∴ Shearing resistance or pull required to shear off the rivet per pitch length,

$$P_s = n \times \frac{\pi}{4} \times d^2 \times \tau \qquad \text{...(In single shear)}$$

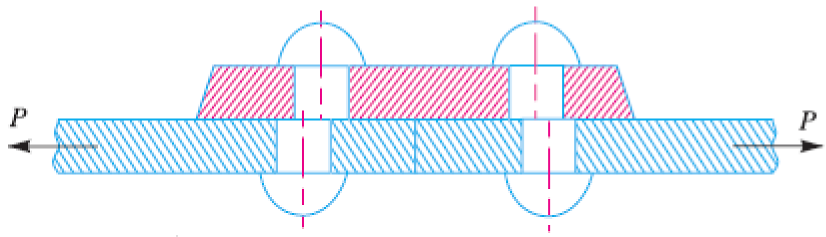
$$= n \times 2 \times \frac{\pi}{4} \times d^2 \times \tau \qquad \text{...(Theoretically, in double shear)}$$

$$= n \times 1.875 \times \frac{\pi}{4} \times d^2 \times \tau$$ ...(In double shear, according to Indian Boiler Regulations)

When the shearing resistance (P_s) is greater than the applied load (P) per pitch length, then this type of failure will occur.



(*a*) Shearing off a rivet in a lap joint.



(*b*) Shearing off a rivet in a single cover butt joint.

Fig. Shearing of rivets.

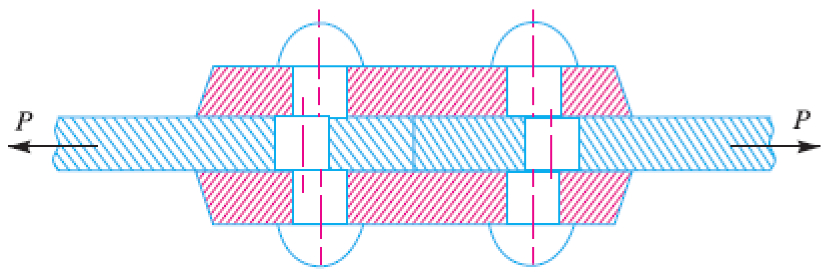


Fig. Shearing off a rivet in double cover butt joint.

4. Crushing of the plate or rivets. Sometimes, the rivets do not actually shear off under the tensile stress, but are crushed as shown in Fig. 9.17. Due to this, the rivet hole becomes of an oval shape and hence the joint becomes loose. The failure of rivets in such a manner is also known as bearing failure. The area which resists this action is the projected area of the hole or rivet on diametral plane.

The resistance offered by a rivet to be crushed is known as crushing resistance or crushing strength or bearing value of the rivet.

Let d = Diameter of the rivet hole,

t = Thickness of the plate,

σc = Safe permissible crushing stress for the rivet or plate material, and

n = Number of rivets per pitch length under crushing.

We know that crushing area per rivet (i.e. projected area per rivet),

$$A_c = d.t$$

∴ Total crushing area = n.d.t and

Crushing resistance or pull required to crush the rivet per pitch length,

$$P_c = n.d.t.\sigma_c$$

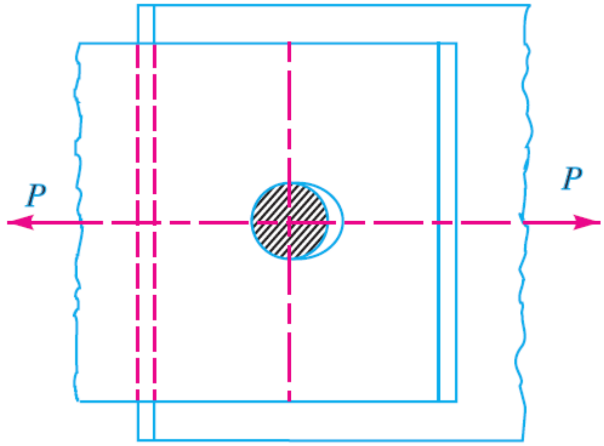


Fig. Crushing of a rivet.

When the crushing resistance (Pc) is greater than the applied load (P) per pitch length, then this type of failure will occur.

Note: The number of rivets under shear shall be equal to the number of rivets under crushing.

Strength of a Riveted Joint

The strength of a joint may be defined as the maximum force, which it can transmit, without causing it to fail. We have seen in that Pt, Ps and Pc are the pulls required to tear off the plate, shearing off the rivet and crushing off the rivet. A little consideration will show that if we go on increasing the pull on a riveted joint, it will fail when the least of these three pulls is reached, because a higher value of the other pulls will never reach since the joint has failed, either by tearing off the plate, shearing off the rivet or crushing off the rivet.

If the joint is continuous as in case of boilers, the strength is calculated per pitch length. But if the joint is small, the strength is calculated for the whole length of the plate.

Efficiency of a Riveted Joint

The efficiency of a riveted joint is defined as the ratio of the strength of riveted joint to the strength of the un-riveted or solid plate.

We have already discussed that strength of the riveted joint

= Least of Pt, Ps and Pc

Strength of the un-riveted or solid plate per pitch length,

$$P = p \times t \times \sigma t$$

∴ Efficiency of the riveted joint,

$$\eta = \frac{\text{Least of } P_t, P_s \text{ and } P_c}{p \times t \times \sigma_t}$$

where p = Pitch of the rivets,

t = Thickness of the plate, and

σ_t = Permissible tensile stress of the plate material.

Eccentric Loaded Riveted Joint

When the line of action of the load does not pass through the centroid of the rivet system and thus all rivets are not equally loaded, then the joint is said to be an *eccentric loaded riveted joint*, as shown in Fig. (*a*). The eccentric loading results in secondary shear caused by the tendency of force to twist the joint about the centre of gravity in addition to direct shear or primary shear.

Let P = Eccentric load on the joint, and

e = Eccentricity of the load *i.e.* the distance between the line of action of the load and the centroid of the rivet system *i.e.* G.

The following procedure is adopted for the design of an eccentrically loaded riveted joint.

1. First of all, find the centre of gravity G of the rivet system.

Let A = Cross-sectional area of each rivet,

x_1, x_2, x_3 etc. = Distances of rivets from OY, and

y_1, y_2, y_3 etc. = Distances of rivets from OX.

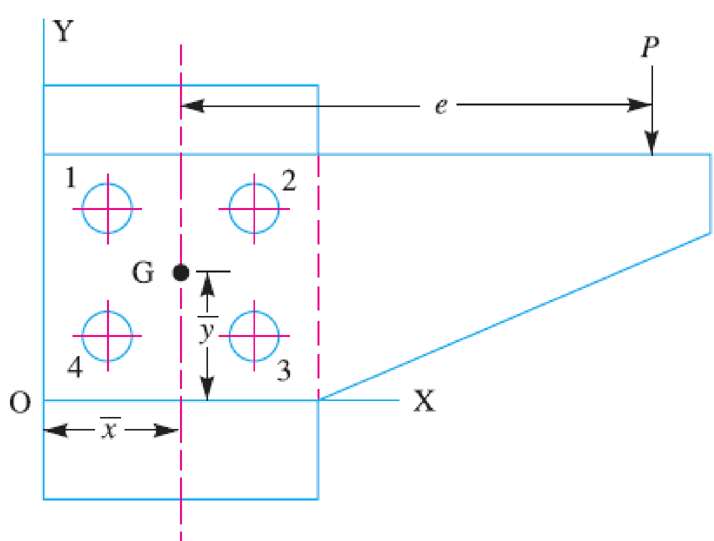
We know that

$$\bar{x} = \frac{A_1 x_1 + A_2 x_2 + A_3 x_3 + \ldots}{A_1 + A_2 + A_3 + \ldots} = \frac{A x_1 + A x_2 + A x_3 + \ldots}{n . A}$$

$$= \frac{x_1 + x_2 + x_3 + \ldots}{n} \quad \text{...(where } n = \text{Number of rivets)}$$

Similarly,

$$\bar{y} = \frac{y_1 + y_2 + y_3 + \ldots}{n}$$



(*a*)

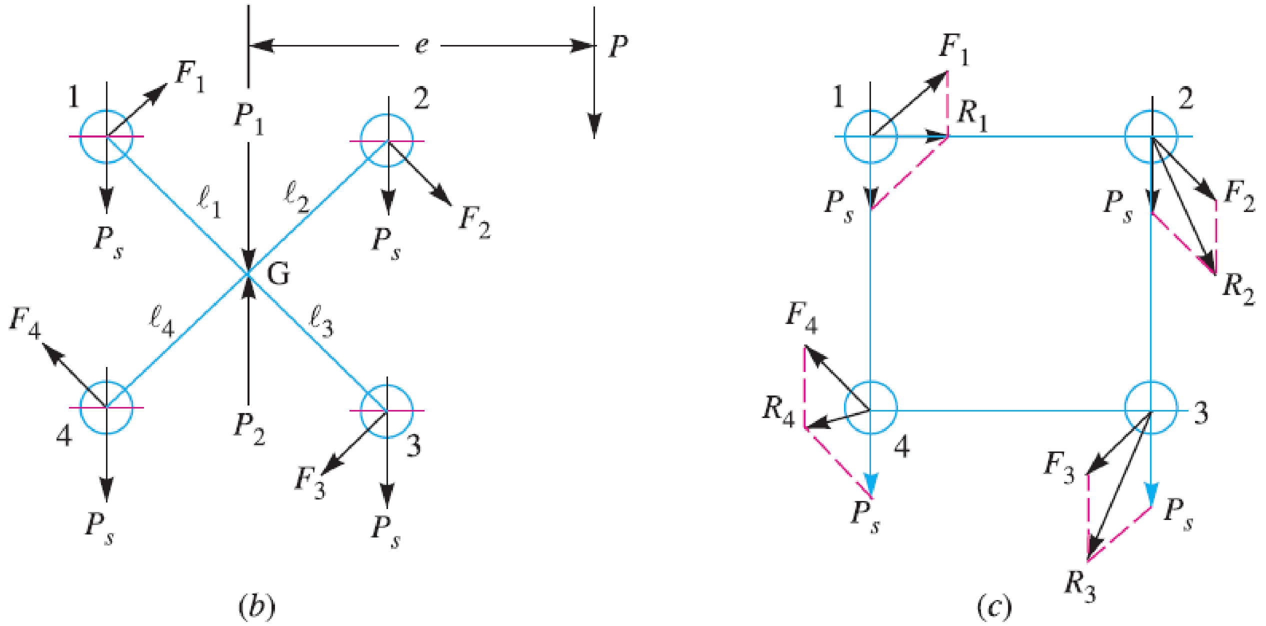


Fig. Eccentric loaded riveted joint.

2. Introduce two forces P_1 and P_2 at the centre of gravity '*G*' of the rivet system. These forces are equal and opposite to *P* as shown in Fig. 9.23 (*b*).

3. Assuming that all the rivets are of the same size, the effect of $P_1 = P$ is to produce direct shear load on each rivet of equal magnitude. Therefore, direct shear load on each rivet,

$$P_s = \frac{P}{n}, \text{ acting parallel to the load } P.$$

4. The effect of $P_2 = P$ is to produce a turning moment of magnitude $P \times e$ which tends to rotate the joint about the centre of gravity '*G*' of the rivet system in a clockwise direction. Due to the turning moment, secondary shear load on each rivet is produced. In order to find the secondary shear load, the following two assumptions are made :

(*a*) The secondary shear load is proportional to the radial distance of the rivet under consideration from the centre of gravity of the rivet system.

(*b*) The direction of secondary shear load is perpendicular to the line joining the centre of the rivet to the centre of gravity of the rivet system..

Let $F_1, F_2, F_3 \ldots$ = Secondary shear loads on the rivets 1, 2, 3...etc.

$l_1, l_2, l_3 \ldots$ = Radial distance of the rivets 1, 2, 3 ...etc. from the centre of gravity '*G*' of the rivet system.

$\therefore$ From assumption (*a*),

$$F_1 \propto l_1 \,;\; F_2 \propto l_2 \text{ and so on}$$

or

$$\frac{F_1}{l_1} = \frac{F_2}{l_2} = \frac{F_3}{l_3} = \ldots$$

$\therefore$

$$F_2 = F_1 \times \frac{l_2}{l_1}, \text{ and } F_3 = F_1 \times \frac{l_3}{l_1}$$

We know that the sum of the external turning moment due to the eccentric load and of internal resisting moment of the rivets must be equal to zero.

$$\therefore \quad P.e = F_1.l_1 + F_2.l_2 + F_3.l_3 + \ldots$$

$$= F_1.l_1 + F_1 \times \frac{l_2}{l_1} \times l_2 + F_1 \times \frac{l_3}{l_1} \times l_3 + \ldots$$

$$= \frac{F_1}{l_1}\left[(l_1)^2 + (l_2)^2 + (l_3)^2 + \ldots\right]$$

From the above expression, the value of F_1 may be calculated and hence F_2 and F_3 etc. are known. The direction of these forces are at right angles to the lines joining the centre of rivet to the centre of gravity of the rivet system, as shown in Fig. 9.23 (*b*), and should produce the moment in the same direction (*i.e.* clockwise or anticlockwise) about the centre of gravity, as the turning moment ($P \times e$).

5. The primary (or direct) and secondary shear load may be added vectorially to determine the resultant shear load (R) on each rivet as shown in Fig. 9.23 (*c*). It may also be obtained by using the relation

$$R = \sqrt{(P_s)^2 + F^2 + 2P_s \times F \times \cos\theta}$$

where θ = Angle between the primary or direct shear load (P_s) and secondary shear load (F).

When the secondary shear load on each rivet is equal, then the heavily loaded rivet will be one in which the included angle between the direct shear load and secondary shear load is minimum. The maximum loaded rivet becomes the critical one for determining the strength of the riveted joint. Knowing the permissible shear stress (τ), the diameter of the rivet hole may be obtained by using the relation,

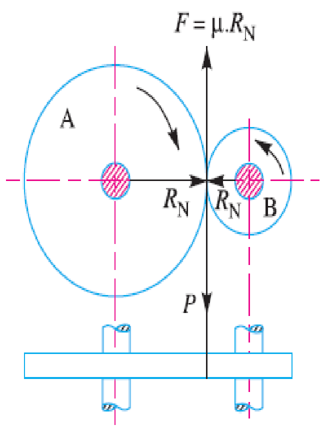
$$\text{Maximum resultant shear load } (R) = \frac{\pi}{4} \times d^2 \times \tau$$

SPUR GEARS

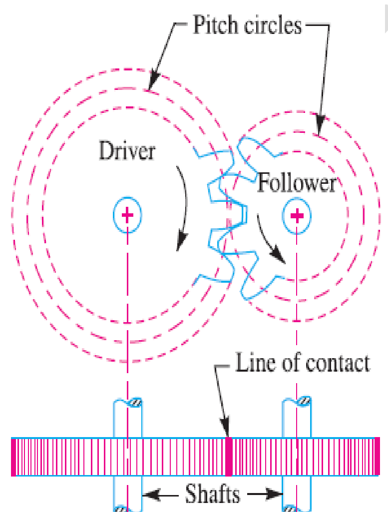
We have discussed earlier that the slipping of a belt or rope is a common phenomenon, in the transmission of motion or power between two shafts. The effect of slipping is to reduce the velocity ratio of the system. In precision machines, in which a definite velocity ratio is of importance (as in watch mechanism), the only positive drive is by gears or toothed wheels. A gear drive is also provided, when the distance between the driver and the follower is very small.

Friction Wheels

The motion and power transmitted by gears is kinematically equivalent to that transmitted by frictional wheels or discs. In order to understand how the motion can be transmitted by two toothed wheels, consider two plain circular wheels A and B mounted on shafts. The wheels have sufficient rough surfaces and press against each other as shown in Fig.



Friction Wheels



Gear or toothed Wheel

Let the wheel A is keyed to the rotating shaft and the wheel B to the shaft to be rotated. A little consideration will show that when the wheel A is rotated by a rotating shaft, it will rotate the wheel B in the opposite direction as shown in Fig. The wheel B will be rotated by the wheel A so long as the tangential force exerted by the wheel A does not exceed the maximum frictional resistance between the two wheels. But when the tangential force (P) exceeds the frictional resistance (F), slipping will take place between the two wheels.

In order to avoid the slipping, a number of projections (called teeth) as shown in Fig. are provided on the periphery of the wheel A which will fit into the corresponding recesses on the periphery of the wheel B. A friction wheel with the teeth cut on it is known as gear or toothed wheel. The usual connection to show the toothed wheels is by their pitch circles.

Note: Kinematically, the friction wheels running without slip and toothed gearing are identical. But due to the possibility of slipping of wheels, the friction wheels can only be used for transmission of small powers.

Advantages and Disadvantages of Gear Drives

The following are the advantages and disadvantages of the gear drive as compared to other drives, i.e. belt, rope and chain drives:

Advantages

1. It transmits exact velocity ratio.
2. It may be used to transmit large power.
3. It may be used for small centre distances of shafts.
4. It has high efficiency.
5. It has reliable service.
6. It has compact layout.

Disadvantages

1. Since the manufacture of gears requires special tools and equipment, therefore it is costlier than other drives.
2. The error in cutting teeth may cause vibrations and noise during operation.
3. It requires suitable lubricant and reliable method of applying it, for the proper operation of gear drives.

Classification of Gears

The gears or toothed wheels may be classified as follows:

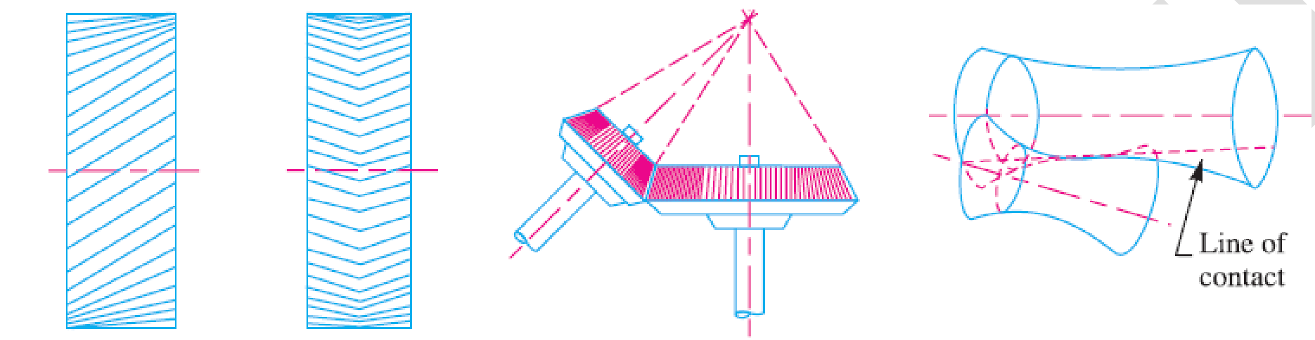
1. According to the position of axes of the shafts. The axes of the two shafts between which the motion is to be transmitted, may be (a) Parallel, (b) Intersecting, and (c) Non-intersecting and non-parallel.

The two parallel and co-planar shafts connected by the gears are shown in below Fig. These gears are called spur gears and the arrangement is known as spur gearing. These gears have teeth parallel to the axis of the wheel as shown in below Fig. Another name given to the spur gearing is helical gearing, in which the teeth are inclined to the axis. The single and double helical gears connecting parallel shafts are shown in below Fig (a) and (b) respectively.

The object of the double helical gear is to balance out the end thrusts that are induced in single helical gears when transmitting load. The double helical gears are known as herringbone gears. A pair of spur gears is kinematically equivalent to a pair of cylindrical discs, keyed to a parallel shaft having line contact.

The two non-parallel or intersecting, but coplanar shafts connected by gears is shown in Fig (c). These gears are called bevel gears and the arrangement is known as bevel gearing.

The bevel gears, like spur gears may also have their teeth inclined to the face of the bevel, in which case they are known as helical bevel gears.



(*a*) Single helical gear. (*b*) Double helical gear. (*c*) Bevel gear. (*d*) Spiral gear.

The two non-intersecting and non-parallel i.e. non-coplanar shafts connected by gears is shown in Fig (d).These gears are called skew bevel gears or spiral gears and the arrangement is known as skew bevel gearing or spiral gearing. This type of gearing also has a line contact, the rotation of which about the axes generates the two pitch surfaces known as hyperboloids.

Notes:

(i) When equal bevel gears (having equal teeth) connect two shafts whose axes are mutually perpendicular, then the bevel gears are known as mitres.

(ii) A hyperboloid is the solid formed by revolving a straight line about an axis (not in the same plane), such that every point on the line remains at a constant distance from the axis.

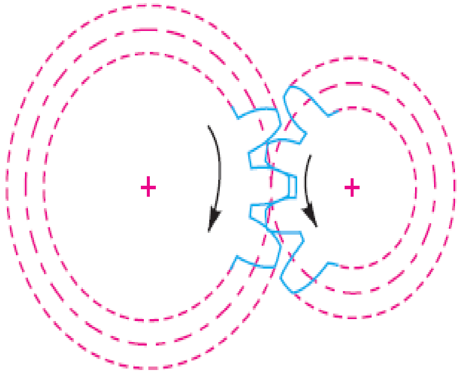
(iii) The worm gearing is essentially a form of spiral gearing in which the shafts are usually at right angles.

2. According to the peripheral velocity of the gears. The gears, according to the peripheral velocity of the gears, may be classified as:

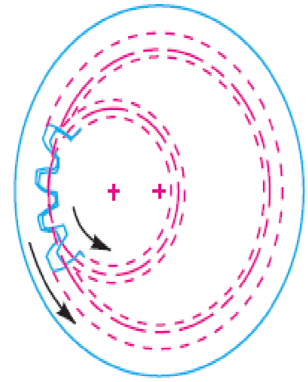
(a) Low velocity, (b) Medium velocity, and (c) High velocity.

The gears having velocity less than 3 m/s are termed as low velocity gears and gears having velocity between 3 and 15 m/s are known as medium velocity gears. If the velocity of gears is more than 15 m/s, then these are called high speed gears.

3. According to the type of gearing. The gears, according to the type of gearing, may be classified as: (a) External gearing, (b) Internal gearing, and (c) Rack and pinion.



(a) External gearing.



(b) Internal gearing.

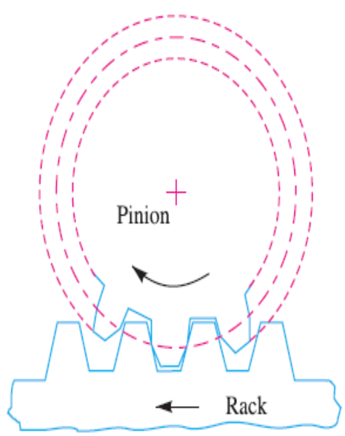
In external gearing, the gears of the two shafts mesh externally with each other as shown in Fig (a).The larger of these two wheels is called spur wheel or gear and the smaller wheel is called pinion. In an external gearing, the motion of the two wheels is always unlike, as shown in Fig (a).

In internal gearing, the gears of the two shafts mesh internally with each other as shown in Fig (b). The larger of these two wheels is called annular wheel and the smaller wheel is called pinion. In an internal gearing, the motion of the wheels is always like as shown in Fig (b).

Sometimes, the gear of a shaft meshes externally and internally with the gears in a straight line, as shown in Fig. Such a type of gear is called rack and pinion. The straight line gear is called rack and the circular wheel is called pinion. A little consideration will show that with the help of a rack and pinion, we can convert linear motion into rotary motion and vice-versa as shown in Fig.

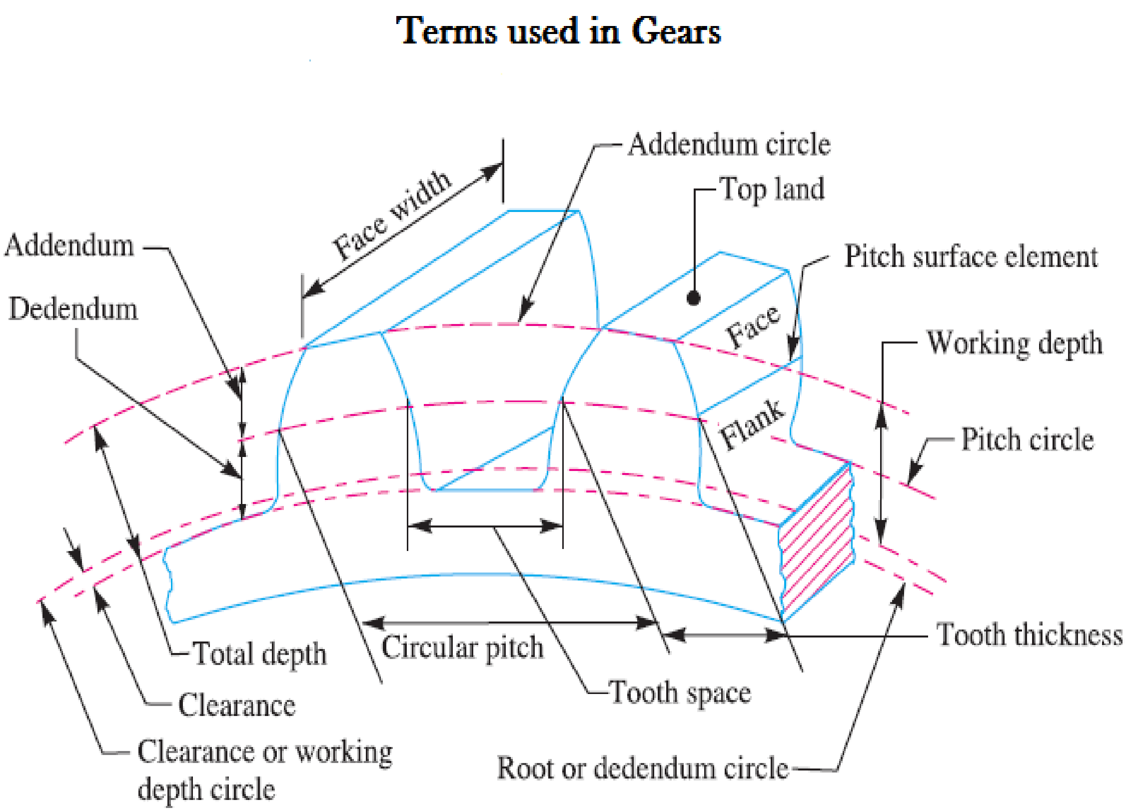
4. According to the position of teeth on the gear surface. The teeth on the gear surface may be (a) Straight, (b) Inclined, and (c) Curved.

We have discussed earlier that the spur gears have straight teeth whereas helical gears have their teeth inclined to the wheel rim. In case of spiral gears, the teeth are curved over the rim surface.



Terms used in Gears

The following terms, which will be mostly used in this chapter, should be clearly understood at this stage. These terms are illustrated in Fig.



1. Pitch circle. It is an imaginary circle which by pure rolling action, would give the same motion as the actual gear.
2. Pitch circle diameter. It is the diameter of the pitch circle. The size of the gear is usually specified by the pitch circle diameter. It is also called as pitch diameter.
3. Pitch point. It is a common point of contact between two pitch circles.
4. Pitch surface. It is the surface of the rolling discs which the meshing gears have replaced at the pitch circle.
5. Pressure angle or angle of obliquity. It is the angle between the common normal to two gear teeth at the point of contact and the common tangent at the pitch point. It is usually denoted by φ. The standard pressure angles are 14 1/2° and 20°.
6. Addendum. It is the radial distance of a tooth from the pitch circle to the top of the tooth.
7. Dedendum. It is the radial distance of a tooth from the pitch circle to the bottom of the tooth.
8. Addendum circle. It is the circle drawn through the top of the teeth and is concentric with the pitch circle.

9. Dedendum circle. It is the circle drawn through the bottom of the teeth. It is also called root circle.

Note: Root circle diameter = Pitch circle diameter × cos φ, where φ is the pressure angle.

10. Circular pitch. It is the distance measured on the circumference of the pitch circle from a point of one tooth to the corresponding point on the next tooth. It is usually denoted by pc.

Mathematically,

Circular pitch, pc = π D/T

Where D = Diameter of the pitch circle, and

T = Number of teeth on the wheel.

A little consideration will show that the two gears will mesh together correctly, if the two wheels have the same circular pitch.

Note: If D1 and D2 are the diameters of the two meshing gears having the teeth T1 and T2 respectively; then for them to mesh correctly,

$$p_c = \frac{\pi D_1}{T_1} = \frac{\pi D_2}{T_2} \quad \text{or} \quad \frac{D_1}{D_2} = \frac{T_1}{T_2}$$

Spur gears

11. Diametral pitch. It is the ratio of number of teeth to the pitch circle diameter in millimeters. It denoted by pd. mathematically,

$$p_d = \frac{T}{D} = \frac{\pi}{p_c}$$

Where T = Number of teeth, and
D = Pitch circle diameter.

12. Module. It is the ratio of the pitch circle diameter in millimeters to the number of teeth. It is usually denoted by m. mathematically,

Module, m = D / T

Note: The recommended series of modules in Indian Standard are 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40 and 50.

The modules 1.125, 1.375, 1.75, 2.25, 2.75, 3.5, 4.5,5.5, 7, 9, 11, 14, 18, 22, 28, 36 and 45 are of second choice.

13. Clearance. It is the radial distance from the top of the tooth to the bottom of the tooth, in a meshing gear. A circle passing through the top of the meshing gear is known as clearance circle.

14. Total depth. It is the radial distance between the addendum and the dedendum circle of a gear. It is equal to the sum of the addendum and dedendum.

15. Working depth. It is radial distance from the addendum circle to the clearance circle. It is equal to the sum of the addendum of the two meshing gears.

16. Tooth thickness. It is the width of the tooth measured along the pitch circle.

17. Tooth space. It is the width of space between the two adjacent teeth measured along the pitch circle.

18. Backlash. It is the difference between the tooth space and the tooth thickness, as measured on the pitch circle.

19. Face of the tooth. It is surface of the tooth above the pitch surface.

20. Top land. It is the surface of the top of the tooth.

21. Flank of the tooth. It is the surface of the tooth below the pitch surface.

22. Face width. It is the width of the gear tooth measured parallel to its axis.

23. Profile. It is the curve formed by the face and flank of the tooth.

24. Fillet radius. It is the radius that connects the root circle to the profile of the tooth.

25. Path of contact. It is the path traced by the point of contact of two teeth from the beginning to the end of engagement.

26. Length of the path of contact. It is the length of the common normal cut-off by the addendum circles of the wheel and pinion.

27. Arc of contact. It is the path traced by a point on the pitch circle from the beginning to the end of engagement of a given pair of teeth. The arc of contact consists of two parts, i.e.

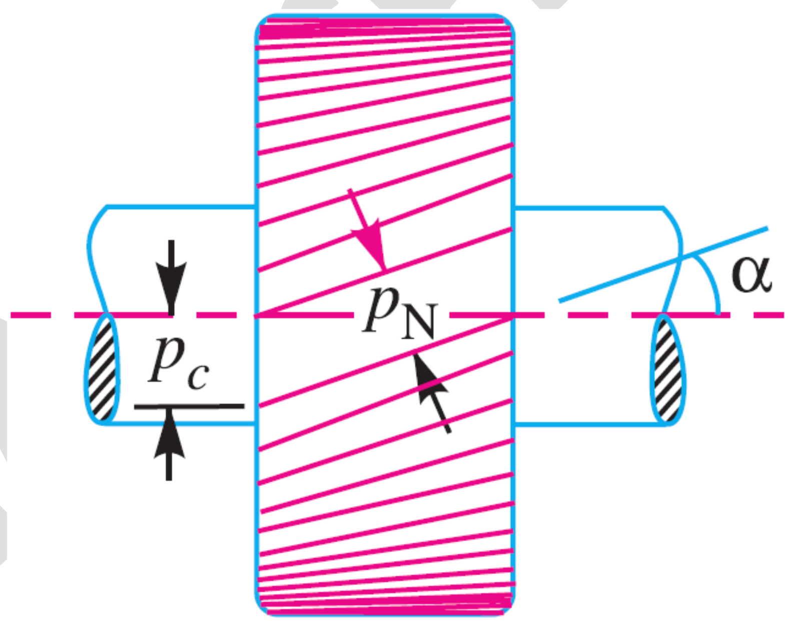
(a) Arc of approach. It is the portion of the path of contact from the beginning of the engagement to the pitch point.

(b) Arc of recess. It is the portion of the path of contact from the pitch point to the end of the engagement of a pair of teeth.

Note: The ratio of the length of arc of contact to the circular pitch is known as contact ratio i.e. number of pairs of teeth in contact.

HELICAL GEARS

A helical gear has teeth in form of helix around the gear. Two such gears may be used to connect two parallel shafts in place of spur gears. The helixes may be right handed on one gear and left handed on the other. The pitch surfaces are cylindrical as in spur gearing, but the teeth instead of being parallel to the axis, wind around the cylinders helically like screw threads. The teeth of helical gears with parallel axis have line contact, as in spur gearing. This provides gradual engagement and continuous contact of the engaging teeth. Hence helical gears give smooth drive with a high efficiency of transmission.



We have already discussed in that the helical gears may be of single helical type or double helical type. In case of single helical gears there is some axial thrust between the teeth, which is a disadvantage. In order to eliminate this axial thrust, double helical gears (i.e. herringbone gears) are used. It is equivalent to two single helical gears, in which equal and opposite thrusts are provided on each gear and the resulting axial thrust is zero.

Terms used in Helical Gears

The following terms in connection with helical gears, as shown in Fig are important from the subject point of view.

1. Helix angle. It is a constant angle made by the helices with the axis of rotation.
2. Axial pitch. It is the distance, parallel to the axis, between similar faces of adjacent teeth. It is the same as circular pitch and is therefore denoted by pc. The axial pitch may also be defined as the circular pitch in the plane of rotation or the diametral plane.
3. Normal pitch. It is the distance between similar faces of adjacent teeth along a helix on the pitch cylinders normal to the teeth. It is denoted by pN. The normal pitch may also be defined as the circular pitch in the normal plane which is a plane perpendicular to the teeth. Mathematically, normal pitch,

$$p_N = p_c \cos \alpha$$

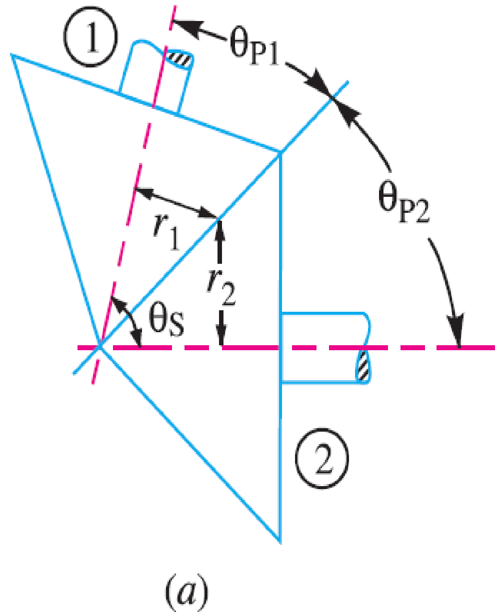
Note: If the gears are cut by standard hobs, then the pitch (or module) and the pressure angle of the hob will apply in the normal plane. On the other hand, if the gears are cut by the Fellows gear-shaper method, the pitch and pressure angle of the cutter will apply to the plane of rotation. The relation between the normal pressure angle (φN) in the normal plane and the pressure angle (φ) in the diametral plane (or plane of rotation) is given by

$$\tan \phi_N = \tan \phi \times \cos \alpha$$

BEVEL GEARS

The bevel gears are used for transmitting power at a constant velocity ratio between two shafts whose axes intersect at a certain angle. The pitch surfaces for the bevel gear are frustums of cones. The two pairs of cones in contact are shown in Fig. The elements of the cones, as shown in Fig (a), intersect at the point of intersection of the axis of rotation. Since the radii of both the gears are proportional to their distances from the apex, therefore the cones may roll together without sliding. In Fig (b), the elements of both cones do not intersect at the point of shaft intersection.

Consequently, there may be pure rolling at only one point of contact and there must be tangential sliding at all other points of contact. Therefore, these cones cannot be used as pitch surfaces because it is impossible to have positive driving and sliding in the same direction at the same time. We, thus, conclude that the elements of bevel gear pitch cones and shaft axes must intersect at the same point.

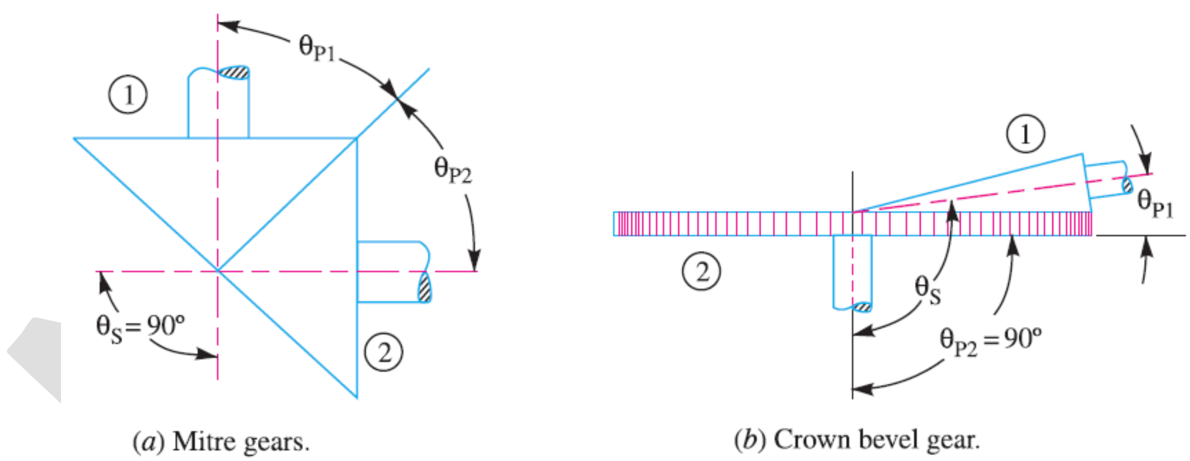


Classification of Bevel Gears

The bevel gears may be classified into the following types, depending upon the angles between the shafts and the pitch surfaces.

1. Mitre gears. When equal bevel gears (having equal teeth and equal pitch angles) connect two shafts whose axes intersect at right angle, as shown in Fig (a), then they are known as mitre gears.

2. Angular bevel gears. When the bevel gears connect two shafts whose axes intersect at an angle other than a right angle, then they are known as angular bevel gears.



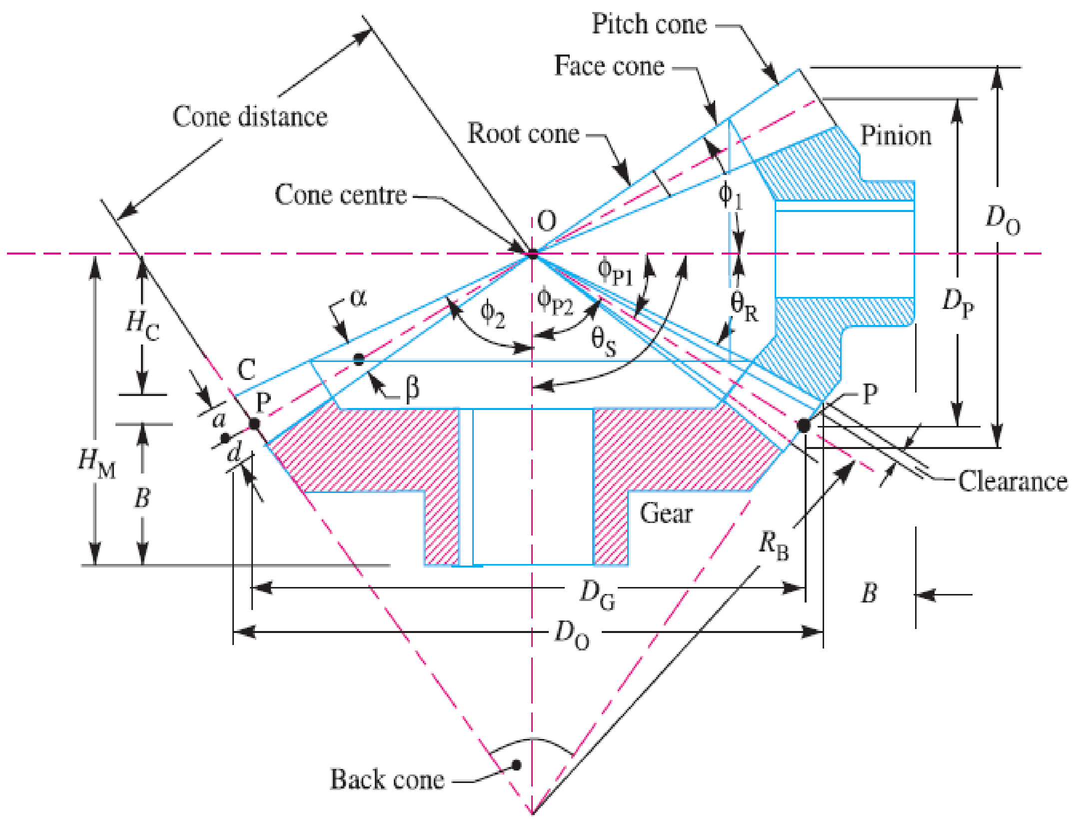
(a) Mitre gears. (b) Crown bevel gear.

3. Crown bevel gears. When the bevel gears connect two shafts whose axes intersect at an angle greater than a right angle and one of the bevel gears has a pitch angle of 90º, then it is known as a crown gear. The crown gear corresponds to a rack in spur gearing, as shown in Fig (b).

4. Internal bevel gears. When the teeth on the bevel gear are cut on the inside of the pitch cone, then they are known as internal bevel gears.

Note: The bevel gears may have straight or spiral teeth. It may be assumed, unless otherwise stated, that the bevel gear has straight teeth and the axes of the shafts intersect at right angle.

Terms used in Bevel Gears



A sectional view of two bevel gears in mesh is shown in Fig. The following terms in connection with bevel gears are important from the subject point of view:

1. Pitch cone. It is a cone containing the pitch elements of the teeth.

2. Cone centre. It is the apex of the pitch cone. It may be defined as that point where the axes of two mating gears intersect each other.

3. Pitch angle. It is the angle made by the pitch line with the axis of the shaft. It is denoted by 'θP'.

4. Cone distance. It is the length of the pitch cone element. It is also called as a pitch cone radius. It is denoted by 'OP'. Mathematically, cone distance or pitch cone radius,

$$OP = \frac{\text{Pitch radius}}{\sin \theta_P} = \frac{D_P/2}{\sin \theta_{P1}} = \frac{D_G/2}{\sin \theta_{P2}}$$

5. Addendum angle. It is the angle subtended by the addendum of the tooth at the cone centre. It is denoted by 'α'. Mathematically, addendum angle,

$$\alpha = \tan^{-1}\left(\frac{a}{OP}\right)$$

Where a = Addendum, and OP = Cone distance.

6. Dedendum angle. It is the angle subtended by the dedendum of the tooth at the cone centre. It is denoted by ‘β’. Mathematically, dedendum angle,

$$\beta = \tan^{-1}\left(\frac{d}{OP}\right)$$

Where d = Dedendum, and OP = Cone distance.

7. Face angle. It is the angle subtended by the face of the tooth at the cone centre. It is denoted by ‘φ’. The face angle is equal to the pitch angle plus addendum angle.

8. Root angle. It is the angle subtended by the root of the tooth at the cone centre. It is denoted by ‘θR’. It is equal to the pitch angle minus dedendum angle.

9. Back (or normal) cone. It is an imaginary cone, perpendicular to the pitch cone at the end of the tooth.

10. Back cone distance. It is the length of the back cone. It is denoted by ‘RB’. It is also called back cone radius.

11. Backing. It is the distance of the pitch point (P) from the back of the boss, parallel to the pitch point of the gear. It is denoted by ‘B’.

12. Crown height. It is the distance of the Crown Point (C) from the cone centre (O), parallel to the axis of the gear. It is denoted by ‘HC’.

13. Mounting height. It is the distance of the back of the boss from the cone centre. It is denoted by ‘HM’.

14. Pitch diameter. It is the diameter of the largest pitch circle.

15. Outside or addendum cone diameter. It is the maximum diameter of the teeth of the gear. It is equal to the diameter of the blank from which the gear can be cut. Mathematically, outside diameter,

$$D_O = D_P + 2\,a\cos\theta_P$$

D_P = Pitch circle diameter,

a = Addendum, and

θ_P = Pitch angle.

16. Inside or dedendum cone diameter. The inside or the dedendum cone diameter is given by

$$D_d = D_P - 2d\cos\theta_P$$

D_d = Inside diameter, and

d = Dedendum.

UNIT - II GEARS 2023

Types of Gears

Spur Gear

Helical Gear

Double Helical Gear (Herringbone Gear)

Spiral Bevel Gear

Miter Gear

Straight Bevel Gear

Internal Gear

Worm Gear

Rack and Pinion

Gear meshing

Gear Trains

Introduction:

Sometimes, two or more gears are made to mesh with each other to transmit power from one shaft to another. Such a combination is called ***gear train*** or ***train of toothed wheels.*** The nature of the train used depends upon the velocity ratio required and the relative position of the axes of shafts. A gear train may consist of spur, bevel or spiral gears.

Types of Gear Trains:

Following are the different types of gear trains, depending upon the arrangement of wheels:

1. Simple gear train,

2. Compound gear train,

3. Reverted gear train, and

4. Epicyclic gear train.

In the first three types of gear trains, the axes of the shafts over which the gears are mounted are fixed relative to each other. But in case of epicyclic gear trains, the axes of the shafts on which the gears are mounted may move relative to a fixed axis.

Simple Gear Train:

When there is only one gear on each shaft, as shown in Fig. 13.1, it is known as ***simple gear train.*** The gears are represented by their pitch circles. When the distance between the two shafts is small, the two gears 1 and 2 are made to mesh with each other to transmit motion from one shaft to the other, as shown in Fig. 13.1 (*a*). Since the gear 1 drives the gear 2, therefore gear 1 is called the ***driver*** and the gear 2 is called the ***driven*** or ***follower.*** It may be noted that the motion of the driven gear is opposite to the motion of driving gear.

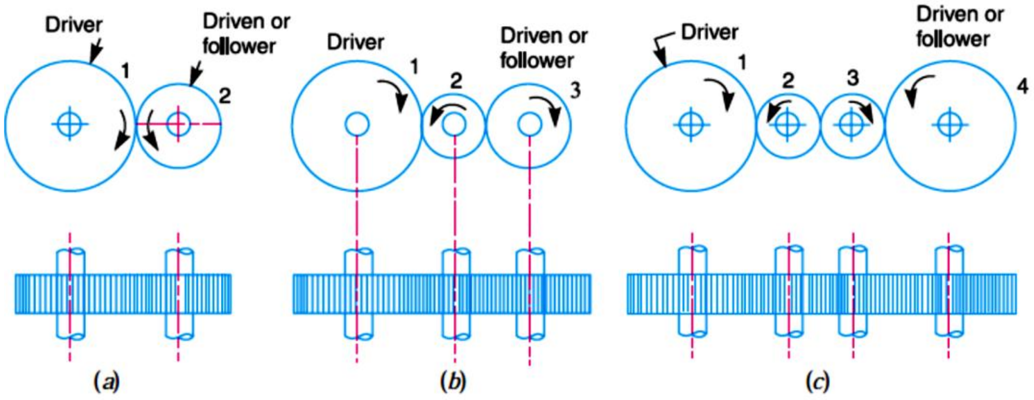


Fig. 13.1. Simple gear train.

Let N_1 = Speed of gear 1(or driver) in r.p.m.,

N_2 = Speed of gear 2 (or driven or follower) in r.p.m.,

T_1 = Number of teeth on gear 1, and

T_2 = Number of teeth on gear 2.

Since the speed ratio (or velocity ratio) of gear train is the ratio of the speed of the driver to the speed of the driven or follower and ratio of speeds of any pair of gears in mesh is the inverse of their number of teeth, therefore

$$\text{Speed ratio} = \frac{N_1}{N_2} = \frac{T_2}{T_1}$$

It may be noted that ratio of the speed of the driven or follower to the speed of the driver is known as ***train value*** of the gear train. Mathematically,

$$\text{Train value} = \frac{N_2}{N_1} = \frac{T_1}{T_2}$$

From above, we see that the train value is the reciprocal of speed ratio.

Sometimes, the distance between the two gears is large. The motion from one gear to another, in such a case, may be transmitted by either of the following two methods :

1. By providing the large sized gear, or

2. By providing one or more intermediate gears.

A little consideration will show that the former method (*i.e.* providing large sized gears) is very inconvenient and uneconomical method ; whereas the latter method (*i.e.* providing one or more intermediate gear) is very convenient and economical.

It may be noted that when the number of intermediate gears are ***odd,*** the motion of both the gears (*i.e.* driver and driven or follower) is ***like*** as shown in Fig. 13.1 (*b*).

But if the number of intermediate gears are ***even,*** the motion of the driven or follower will be in the opposite direction of the driver as shown in Fig. 13.1 (*c*).

Now consider a simple train of gears with one intermediate gear as shown in Fig. 13.1 (*b*).

Let N_1 = Speed of driver in r.p.m.,

N_2 = Speed of intermediate gear in r.p.m.,

N_3 = Speed of driven or follower in r.p.m.,

T_1 = Number of teeth on driver,

T_2 = Number of teeth on intermediate gear, and

T_3 = Number of teeth on driven or follower.

Since the driving gear 1 is in mesh with the intermediate gear 2, therefore speed ratio for these two gears is

$$\frac{N_1}{N_2} = \frac{T_2}{T_1} \quad \ldots\ldots\ldots\ldots(i)$$

Similarly, as the intermediate gear 2 is in mesh with the driven gear 3, therefore speed ratio for these two gears is

$$\frac{N_2}{N_3} = \frac{T_3}{T_2} \quad \ldots\ldots\ldots\ldots(ii)$$

The speed ratio of the gear train as shown in Fig. 13.1 (*b*) is obtained by multiplying the equations ***(i)*** and ***(ii).***

$$\frac{N_1}{N_2} \times \frac{N_2}{N_3} = \frac{T_2}{T_1} \times \frac{T_3}{T_2} \quad \text{or} \quad \frac{N_1}{N_3} = \frac{T_3}{T_1}$$

$$\textit{i.e Speed ratio} = \frac{\textit{Speed of driver}}{\textit{Speed of driven}} = \frac{\textit{No.of teeth on driven}}{\textit{No.of teeth on driver}}$$

$$and\ \ Train\ value = \frac{Speed\ of\ driven}{Speed\ of\ driver} = \frac{No.of\ teeth\ on\ driver}{No.of\ teeth\ on\ driven}$$

Similarly, it can be proved that the above equation holds good even if there are any number of intermediate gears. From above, we see that the speed ratio and the train value, in a simple train of gears, is independent of the size and number of intermediate gears. These intermediate gears are called ***idle gears,*** as they do not affect the speed ratio or train value of the system. The idle gears are used for the following two purposes:

1. To connect gears where a large centre distance is required, and

2. To obtain the desired direction of motion of the driven gear (*i.e.* clockwise or anticlockwise).

Compound Gear Train:

When there is more than one gear on a shaft, as shown in Fig. 13.2, it is called a ***compound train of gear.***

We have seen in previous section that the idle gears, in a simple train of gears do not affect the speed ratio of the system. But these gears are useful in bridging over the space between the driver and the driven. But whenever the distance between the driver and the driven or follower has to be bridged over by intermediate gears and at the same time a great (or much less) speed ratio is required, then the advantage of intermediate gears is intensified by providing compound gears on intermediate shafts. In this case, each intermediate shaft has two gears rigidly fixed to it so that they may have the same speed. One of these two gears meshes with the driver and the other with the driven or follower attached to the next shaft as shown in Fig.13.2.

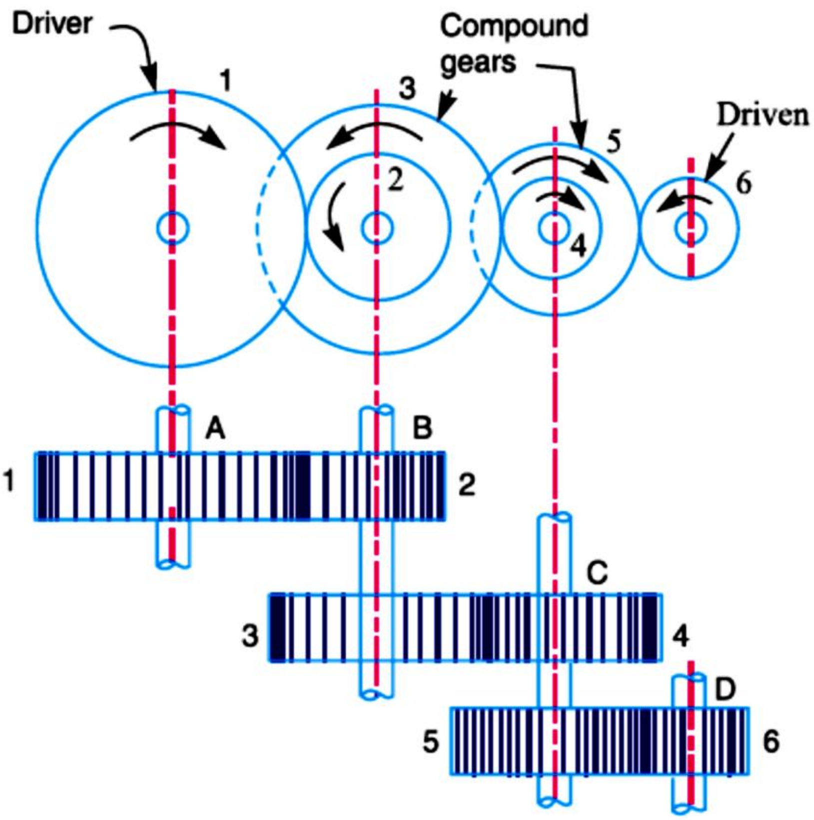


Fig. 13.2. Compound gear train.

In a compound train of gears, as shown in Fig. 13.2, the gear 1 is the driving gear mounted on shaft *A*, gears 2 and 3 are compound gears which are mounted on shaft *B*. The gears 4 and 5 are also compound gears which are mounted on shaft *C* and the gear 6 is the driven gear mounted on shaft *D*.

Let N_1 = Speed of driving gear 1,

T_1 = Number of teeth on driving gear 1,

N_2 ,N_3 ..., N_6 = Speed of respective gears in r.p.m., and

T_2 ,T_3..., T_6 = Number of teeth on respective gears.

Since gear 1 is in mesh with gear 2, therefore its speed ratio is

$$\frac{N_1}{N_2} = \frac{T_2}{T_1} \quad \ldots\ldots\ldots\ldots(i)$$

Similarly, for gears 3 and 4, speed ratio is

$$\frac{N_3}{N_4} = \frac{T_4}{T_3} \quad \ldots\ldots\ldots\ldots(ii)$$

and for gears 5 and 6, speed ratio is

$$\frac{N_5}{N_6} = \frac{T_6}{T_5} \quad \ldots\ldots\ldots\ldots(iii)$$

The speed ratio of compound gear train is obtained by multiplying the equations **(*i*), (*ii*)** and **(*iii*),**

$$\frac{N_1}{N_2} \times \frac{N_3}{N_4} \times \frac{N_5}{N_6} = \frac{T_2}{T_1} \times \frac{T_4}{T_3} \times \frac{T_6}{T_5}$$

Since gears 2 and 3 are mounted on one shaft *B*, therefore $N_2 = N_3$. Similarly gears 4 and 5 are mounted on shaft *C*, therefore $N_4 = N_5$.

$$\frac{N_1}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}$$

i.e

$$Speed\ ratio = \frac{Speed\ of\ the\ first\ driver}{Speed\ of\ \ last\ driven} = \frac{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivens}{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivers}$$

$$\mathbf{and}\ \ Train\ value = \frac{Speed\ of\ \ last\ driven}{Speed\ of\ the\ first\ driver} = \frac{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivers}{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivens}$$

The advantage of a compound train over a simple gear train is that a much larger speed reduction from the first shaft to the last shaft can be obtained with small gears. If a simple gear train is used to give a large speed reduction, the last gear has to be very large. Usually for a speed reduction in excess of 7 to 1, a simple train is not used and a compound train or worm gearing is employed.

Note: The gears which mesh must have the same circular pitch or module. Thus gears 1 and 2 must have the same module as they mesh together. Similarly gears 3 and 4, and gears 5 and 6 must have the same module.

Example: *The gearing of a machine tool is shown in Fig.* 13.3. *The motor shaft is connected to gear A and rotates at* 975 *r.p.m. The gear wheels B, C, D and E are fixed to parallel shafts rotating together. The final gear F is fixed on the output shaft. What is the speed of gear F? The numbers of teeth on each gear are as given below:*

Gear	***A***	***B***	***C***	***D***	***E***	***F***
No. of teeth	***20***	***50***	***25***	***75***	***26***	***65***

Solution: Given: N_A=975 r.p.m.; T_A=20; T_B=50; T_C=25; T_D=75; T_E=26; T_F=65

From Fig. 13.3, we see that gears *A*, *C* and *E* are drivers while the gears *B*, *D* and *F* are driven or followers. Let the gear *A* rotates in clockwise direction. Since the gears *B* and *C* are mounted on the same shaft, therefore it is a compound gear and the direction or rotation of both these gears is same (*i.e.* anticlockwise).

Similarly, the gears *D* and *E* are mounted on the same shaft, therefore it is also a compound gear and the direction of rotation of both these gears is same (*i.e.* clockwise). The gear *F* will rotate in anticlockwise direction.

Let N_F = Speed of gear *F*, *i.e.* last driven or follower.

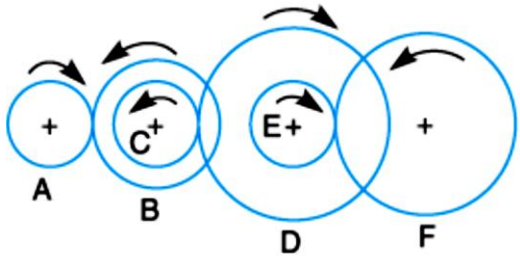


Fig. 13.3

We know that

$$\frac{Speed\ of\ the\ first\ driver}{Speed\ of\ \ last\ driven} = \frac{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivens}{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivers}$$

$$\frac{N_A}{N_F} = \frac{T_B \times T_D \times T_F}{T_A \times T_C \times T_E} = \frac{50 \times 75 \times 65}{20 \times 25 \times 26} = 18.75$$

$$\therefore N_F = \frac{N_A}{18.75} = \frac{975}{18.75} = 52\ r.p.m$$ **Ans.**

Design of Spur Gears:

Sometimes, the spur gears (*i.e.* driver and driven) are to be designed for the given velocity ratio and distance between the centers of their shafts.

Let x = Distance between the centers of two shafts,

N_1 = Speed of the driver,

T_1 = Number of teeth on the driver,

d_1 = Pitch circle diameter of the driver,

N_2 , T_2 and d_2 = Corresponding values for the driven or follower, and

p_c = Circular pitch.

We know that the distance between the centers of two shafts,

$$x = \frac{d_1 + d_2}{2} \quad \ldots\ldots\ldots\ldots(i)$$

and speed ratio or velocity ratio,

$$\frac{N_1}{N_2} = \frac{d_2}{d_1} = \frac{T_2}{T_1} \quad \ldots\ldots\ldots\ldots(ii)$$

From the above equations, we can conveniently find out the values of d_1 and d_2 (or T_1 and T_2) and the circular pitch (p_c). The values of T_1 and T_2, as obtained above, may or may not be whole numbers. But in a gear since the number of its teeth is always a whole number, therefore a slight alterations must be made in the values of x, *d*1 and d_2, so that the number of teeth in the two gears may be a complete number.

Example: *Two parallel shafts, about 600 mm apart are to be connected by spur gears. One shaft is to run at 360 r.p.m. and the other at 120 r.p.m. Design the gears, if the circular pitch is to be 25 mm.*

Solution. Given : x = 600 mm ; $N1$ = 360 r.p.m. ; $N2$ = 120 r.p.m. ; pc = 25 mm

Let d_1 = Pitch circle diameter of the first gear, and

d_2 = Pitch circle diameter of the second gear.

We know that speed ratio,

$$\frac{N_1}{N_2} = \frac{d_2}{d_1} = \frac{360}{120} = 3 \quad \text{or} \quad d_2 = 3d_1 \qquad \text{...}(i)$$

and centre distance between the shafts (x),

$$600 = 0.5(d_1 + d_2) \quad \text{or} \quad d_1 + d_2 = 1200 \qquad \text{...}(ii)$$

From equations ***(i)*** and ***(ii)***, we find that d_1 = 300 mm, and d_2 = 900 mm

∴ Number of teeth on the first gear,

$$T_1 = \frac{\pi \times d_1}{p_c} = \frac{\pi \times 300}{25} = 37.7$$

and number of teeth on the second gear,

$$T_2 = \frac{\pi \times d_2}{p_c} = \frac{\pi \times 900}{25} = 113.1$$

Since the numbers of teeth on both the gears are to be in complete numbers, therefore let us make the number of teeth on the first gear as 38. Therefore for a speed ratio of 3, the number of teeth on the second gear should be 38 × 3 = 114.

Now the exact pitch circle diameter of the first gear,

$$\acute{d}_1 = \frac{p_c \times T_1}{\pi} = \frac{25 \times 38}{\pi} = 302.36\, mm$$

and the exact pitch circle diameter of the second gear,

$$\acute{d}_2 = \frac{p_c \times T_2}{\pi} = \frac{25 \times 114}{\pi} = 907.1\, mm$$

∴ Exact distance between the two shafts,

$$\acute{x} = \frac{\acute{d}_1 + \acute{d}_2}{2} = \frac{302.36 + 907.1}{2} = 604.73\, mm$$

Hence the number of teeth on the first and second gear must be 38 and 114 and their pitch circle diameters must be 302.36 mm and 907.1 mm respectively. The exact distance between the two shafts must be 604.73 mm. **Ans.**

Reverted Gear Train:

When the axes of the first gear (*i.e.* first driver) and the last gear (*i.e.* last driven or follower) are co-axial, then the gear train is known as ***reverted gear*** **train** as shown in Fig. 13.4.

We see that gear 1 (*i.e.* first driver) drives the gear 2 (*i.e.* first driven or follower) in the opposite direction. Since the gears 2 and 3 are mounted on the same shaft, therefore they form a compound gear and the gear 3 will rotate in the same direction as that of gear 2. The gear 3 (which is now the second driver) drives the gear 4 (*i.e.* the last driven or follower) in the same direction as that of gear 1. Thus we see that in a reverted gear train, the motion of the first gear and the last gear is ***like.***

Let T_1 = Number of teeth on gear 1,

r_1 = Pitch circle radius of gear 1, and

N_1 = Speed of gear 1 in r.p.m.

Similarly,

T_2, T_3, T_4 = Number of teeth on respective gears,

r_2, r_3, r_4 = Pitch circle radii of respective gears, and

N_2, N_3, N_4 = Speed of respective gears in r.p.m.

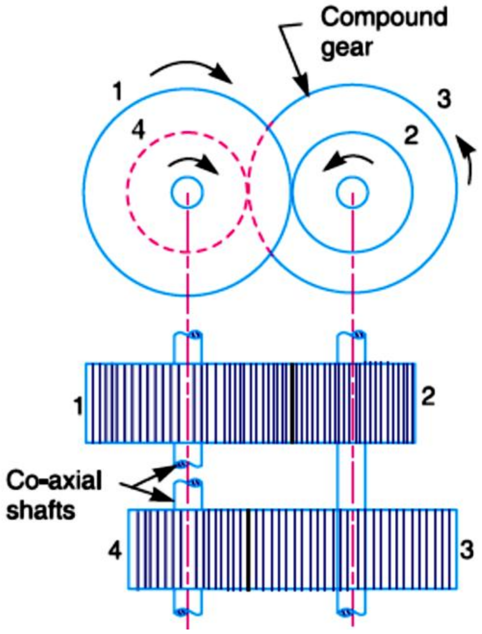


Fig. 13.4. Reverted gear train.

Since the distance between the centers of the shafts of gears 1 and 2 as well as gears 3 and 4 is same, therefore

$$r_1 + r_2 = r_3 + r_4 \qquad \text{...}(i)$$

Also, the circular pitch or module of all the gears is assumed to be same, therefore number of teeth on each gear is directly proportional to its circumference or radius.

We know that circular pitch,

$$p_c = \frac{2\pi r}{T} = \pi m \qquad \text{or} \qquad r = \frac{m.T}{2}, \text{ where } m \text{ is the module.}$$

$$\therefore \qquad r_1 = \frac{m.T_1}{2} \; ; \; r_2 = \frac{m.T_2}{2} \; ; \; r_3 = \frac{m.T_3}{2} \; ; \; r_4 = \frac{m.T_4}{2}$$

Now from equation (*i*),

$$\frac{m.T_1}{2} + \frac{m.T_2}{2} = \frac{m.T_3}{2} + \frac{m.T_4}{2}$$

$$\therefore T_1 + T_2 = T_3 + T_4 \qquad \text{...}(ii)$$

$$Speed\ Ratio = \frac{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivens}{Product\ of\ the\ number\ of\ teeth\ on\ the\ drivers}$$

or

$$\frac{N_1}{N_4} = \frac{T_2 \times T_4}{T_1 \times T_3} \qquad \text{...}(iii)$$

From equations (*i*), (*ii*) and (*iii*), we can determine the number of teeth on each gear for the given centre distance, speed ratio and module only when the number of teeth on one gear is chosen arbitrarily. The reverted gear trains are used in automotive transmissions, lathe back gears, industrial speed reducers, and in clocks (where the minute and hour hand shafts are co-axial).

Example: *The speed ratio of the reverted gear train, as shown in Fig. 13.5, is to be 12. The module pitch of gears A and B is 3.125 mm and of gears C and D is 2.5 mm. Calculate the suitable numbers of teeth for the gears. No gear is to have less than 24 teeth.*

Solution: Given: Speed ratio, $N_A/N_D = 12$; $m_A = m_B = 3.125$ mm; $m_C = m_D = 2.5$ mm

Let N_A = Speed of gear A,

T_A = Number of teeth on gear A,

r_A = Pitch circle radius of gear A,

N_B, N_C, N_D = Speed of respective gears,

T_B, T_C, T_D = Number of teeth on respective gears, and

r_B, r_C, r_D = Pitch circle radii of respective gears.

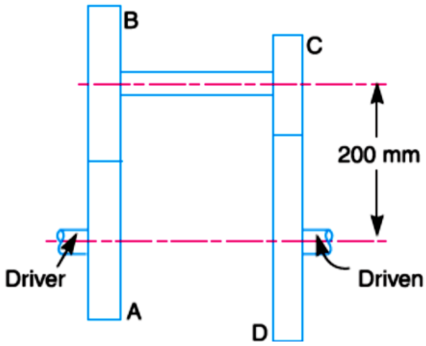


Fig. 13.5

Since the speed ratio between the gears A and B and between the gears C and D are to be same, therefore

$$Speed\ Ratio = \frac{Speed\ of\ the\ first\ driver}{Speed\ of\ last\ driven} = \frac{N_A}{N_D} = 12$$

Also $\frac{N_A}{N_D} = \frac{N_A}{N_B} \times \frac{N_C}{N_D}$ ...($N_B = N_C$, being on the same shaft)

For $\frac{N_A}{N_B}$ and $\frac{N_C}{N_D}$ to be same, each speed ratio should be $\sqrt{12}$ so that

$$\frac{N_A}{N_D} = \frac{N_A}{N_B} \times \frac{N_C}{N_D} = \sqrt{12} \times \sqrt{12} = 12$$

$$\frac{N_A}{N_B} = \frac{N_C}{N_D} = \sqrt{12}$$

Also the speed ratio of any pair of gears in mesh is the inverse of their number of teeth, therefore

$$\frac{T_B}{T_A} = \frac{T_D}{T_C} = \sqrt{12}$$

We know that the distance between the shafts $x = r_A + r_B = r_C + r_D = 200$ mm

or

$$\frac{m_A \times T_A}{2} + \frac{m_B \times T_B}{2} + \frac{m_C \times T_C}{2} + \frac{m_D \times T_D}{2} = 200 \qquad \ldots\ldots \left(\because r = \frac{m \times T}{2}\right)$$

$3.125\ (T_A + T_B) = 2.5\ (T_C + T_D) = 400$ ...($\because$ $m_A = m_B$, and $m_C = m_D$)

$\therefore\ T_A + T_B = 400 / 3.125 = 128$ ...***(ii)***

and $T_C + T_D = 400 / 2.5 = 160$ ...***(iii)***

From equation ***(i)***, $T_B = 3.464\ T_A$. Substituting this value of T_B in equation ***(ii)***,

$T_A + 3.464\ T_A = 128$ or $T_A = 128 / 4.464 = 28.67$ say 28 **Ans.**

and $T_B = 128 - 28 = 100$ **Ans.**

Again from equation ***(i)***, $T_D = 3.464\ T_C$. Substituting this value of T_D in equation ***(iii)***, $T_C + 3.464\ T_C = 160$ or $T_C = 160 / 4.464 = 35.84$ say 36 **Ans.**

and $T_D = 160 - 36 = 124$ **Ans.**

Note: ***The speed ratio of the reverted gear train with the calculated values of number of teeth on each gear is***

$$\frac{N_A}{N_D} = \frac{T_B}{T_A} \times \frac{T_D}{T_C} = \frac{100}{28} \times \frac{124}{36} = 12.3$$

Epicyclic Gear Train:

We have already discussed that in an epicyclic gear train, the axes of the shafts, over which the gears are mounted, may move relative to a fixed axis. A simple picyclic gear train is shown in Fig. 13.6, where a gear *A* and the arm *C* have a common axis at *O*1 about which they can rotate. The gear *B* meshes with gear *A* and has its axis on the arm at *O*2, about which the gear *B* can rotate. If the arm is fixed, the gear train is simple and gear *A* can drive gear *B* or ***vice- versa***, but if gear *A* is fixed and the arm is rotated about the axis of gear *A* (*i.e. O*1), then the gear *B* is forced to rotate ***upon*** and ***around*** gear *A*. Such a motion is called **epicyclic** and the gear trains arranged in such a manner that one or more of their members move upon and around another member is known as ***epicyclic gear trains*** (***epi.*** means upon and ***cyclic*** means around). The epicyclic gear trains may be ***simple*** or ***compound.***

The epicyclic gear trains are useful for transmitting high velocity ratios with gears of moderate size in a comparatively lesser space. The epicyclic gear trains are used in the back gear of lathe, differential gears of the automobiles, hoists, pulley blocks, wrist watches etc.

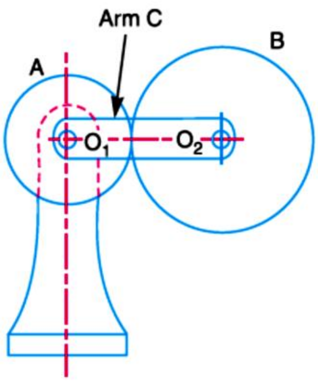


Fig. 13.6. Epicyclic gear train.

Velocity Ratios of Epicyclic Gear Train:

The following two methods may be used for finding out the velocity ratio of an epicyclic gear train. **1.** Tabular method, and **2.** Algebraic method.

These methods are discussed, in detail, as follows:

1. *Tabular method.* Consider an epicyclic gear train as shown in Fig. 13.6.

Let T_A = Number of teeth on gear *A*, and T_B = Number of teeth on gear *B*.

First of all, let us suppose that the arm is fixed. Therefore the axes of both the gears are also fixed relative to each other. When the gear *A* makes one revolution anticlockwise, the gear *B* will make T_A / T_B revolutions, clockwise. Assuming the anticlockwise rotation as positive and clockwise as negative, we may say that when gear *A* makes + 1 revolution, then the gear *B* will make ($-$ T_A / T_B) revolutions. This statement of relative motion is entered in the first row of the table (see Table 13.1).

Secondly, if the gear *A* makes + *x* revolutions, then the gear *B* will make ($- x \times T_A / T_B$) revolutions. This statement is entered in the second row of the table. In other words, multiply the each motion (entered in the first row) by *x*.

Thirdly, each element of an epicyclic train is given + *y* revolutions and entered in the third row. Finally, the motion of each element of the gear train is added up and entered in the fourth row.

Table 13.1. Table of motions.

		Revolutions of elements		
Step No.	Conditions of motion	Arm C	Gear A	Gear B
1.	Arm fixed-gear A rotates through + 1 revolution i.e. 1 rev. anticlockwise	0	+1	$-\frac{T_A}{T_B}$
2.	Arm fixed-gear A rotates through + x revolutions	0	+x	$-x\frac{T_A}{T_B}$
3.	Add + y revolutions to all elements	+ y	+ y	+ y
4.	Total motion	+ y	+x+y	$y-x\frac{T_A}{T_B}$

2. *Algebraic method*: This method will be discussed in separated chapter.

Example: *In an epicyclic gear train, an arm carries two gears A and B having 36 and 45 teeth respectively. If the arm rotates at 150 r.p.m. in the anticlockwise direction about the centre of the gear A which is fixed, determine the speed of gear B. If the gear A instead of being fixed, makes 300 r.p.m. in the clockwise direction, what will be the speed of gear B?*

Solution: Given: T_A = 36; T_B = 45; N_C = 150 r.p.m. (anticlockwise) .The gear train is shown in Fig. 13.7.

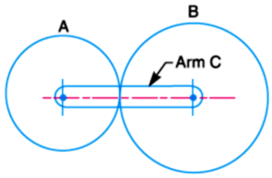


Fig. 13.7

First of all prepare the table of motions as given below:

Table 13.2. Table of motions.

		Revolutions of elements		
Step No.	Conditions of motion	Arm C	Gear A	Gear B
1.	Arm fixed-gear A rotates through + 1 revolution i.e. 1 rev. anticlockwise	0	+1	$-\frac{T_A}{T_B}$
2.	Arm fixed-gear A rotates through + x revolutions	0	+x	$-x\frac{T_A}{T_B}$
3.	Add + y revolutions to all elements	+ y	+ y	+ y
4.	Total motion	+ y	+x+y	$y-x\frac{T_A}{T_B}$

Speed of gear B when gear A is fixed

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CHAPTER

18

Flat Belt Drives

18.1 Introduction

The belts or *ropes are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds. The amount of power transmitted depends upon the following factors :

1. The velocity of the belt.
2. The tension under which the belt is placed on the pulleys.
3. The arc of contact between the belt and the smaller pulley.
4. The conditions under which the belt is used.

It may be noted that

(*a*) The shafts should be properly in line to insure uniform tension across the belt section.

(*b*) The pulleys should not be too close together, in order that the arc of contact on the smaller pulley may be as large as possible.

* Rope drives are discussed in Chapter 20.

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(*c*) The pulleys should not be so far apart as to cause the belt to weigh heavily on the shafts, thus increasing the friction load on the bearings.

(*d*) A long belt tends to swing from side to side, causing the belt to run out of the pulleys, which in turn develops crooked spots in the belt.

(*e*) The tight side of the belt should be at the bottom, so that whatever sag is present on the loose side will increase the arc of contact at the pulleys.

(*f*) In order to obtain good results with flat belts, the maximum distance between the shafts should not exceed 10 metres and the minimum should not be less than 3.5 times the diameter of the larger pulley.

18.2 Selection of a Belt Drive

Following are the various important factors upon which the selection of a belt drive depends:

1. Speed of the driving and driven shafts,
2. Speed reduction ratio,
3. Power to be transmitted,
4. Centre distance between the shafts,
5. Positive drive requirements,
6. Shafts layout,
7. Space available, and
8. Service conditions.

18.3 Types of Belt Drives

The belt drives are usually classified into the following three groups:

1. ***Light drives.*** These are used to transmit small powers at belt speeds upto about 10 m/s as in agricultural machines and small machine tools.

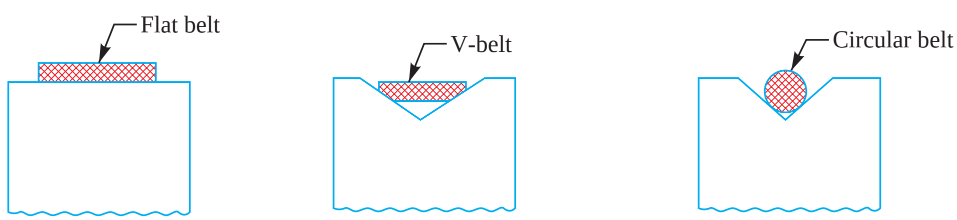
2. ***Medium drives.*** These are used to transmit medium powers at belt speeds over 10 m/s but up to 22 m/s, as in machine tools.

3. ***Heavy drives.*** These are used to transmit large powers at belt speeds above 22 m/s as in compressors and generators.

18.4 Types of Belts

Though there are many types of belts used these days, yet the following are important from the subject point of view:

1. ***Flat belt.*** The flat belt as shown in Fig. 18.1 (*a*), is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another when the two pulleys are not more than 8 metres apart.



(*a*) Flat belt. (*b*) V-belt. (*c*) Circular belt.

Fig. 18.1. Types of belts

2. ***V- belt.*** The V-belt as shown in Fig. 18.1 (*b*), is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are very near to each other.

3. ***Circular belt or rope.*** The circular belt or rope as shown in Fig. 18.1 (*c*) is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are more than 8 metres apart.

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If a huge amount of power is to be transmitted, then a single belt may not be sufficient. In such a case, wide pulleys (for V-belts or circular belts) with a number of grooves are used. Then a belt in each groove is provided to transmit the required amount of power from one pulley to another.

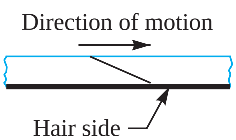
Note : The V-belt and rope drives are discussed in Chapter 20.

18.5 Material used for Belts

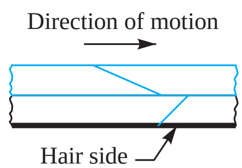
The material used for belts and ropes must be strong, flexible, and durable. It must have a high coefficient of friction. The belts, according to the material used, are classified as follows:

1. ***Leather belts.*** The most important material for flat belt is leather. The best leather belts are made from 1.2 metres to 1.5 metres long strips cut from either side of the back bone of the top grade steer hides. The hair side of the leather is smoother and harder than the flesh side, but the flesh side is stronger. The fibres on the hair side are perpendicular to the surface, while those on the flesh side are interwoven and parallel to the surface. Therefore for these reasons the hair side of a belt should be in contact with the pulley surface as shown in Fig. 18.2. This gives a more intimate contact between belt and pulley and places the greatest tensile strength of the belt section on the outside, where the tension is maximum as the belt passes over the pulley.

The leather may be either oak-tanned or mineral salt-tanned *e.g.* chrome-tanned. In order to increase the thickness of belt, the strips are cemented together. The belts are specified according to the number of layers *e.g.* single, double or triple ply and according to the thickness of hides used *e.g.* light, medium or heavy.



(*a*) Single layer belt.



(*b*) Double layer belt.

Fig. 18.2. Leather belts.

The leather belts must be periodically cleaned and dressed or treated with a compound or dressing containing neats foot or other suitable oils so that the belt will remain soft and flexible.

2. ***Cotton or fabric belts.*** Most of the fabric belts are made by folding convass or cotton duck to three or more layers (depending upon the thickness desired) and stitching together. These belts are woven also into a strip of the desired width and thickness. They are impregnated with some filler like linseed oil in order to make the belt water-proof and to prevent injury to the fibres. The cotton belts are cheaper and suitable in warm climates, in damp atmospheres and in exposed positions. Since the cotton belts require little attention, therefore these belts are mostly used in farm machinery, belt conveyor etc.

3. ***Rubber belt.*** The rubber belts are made of layers of fabric impregnated with rubber composition and have a thin layer of rubber on the faces. These belts are very flexible but are quickly destroyed if allowed to come into contact with heat, oil or grease. One of the principle advantage of these belts is that they may be easily made endless. These belts are found suitable for saw mills, paper mills where they are exposed to moisture.

4. ***Balata belts.*** These belts are similar to rubber belts except that balata gum is used in place of rubber. These belts are acid proof and water proof and it is not effected by animal oils or alkalies. The balata belts should not be at temperatures above 40°C because at this temperature the balata begins to soften and becomes sticky. The strength of balata belts is 25 per cent higher than rubber belts.

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18.6 Working Stresses in Belts

The ultimate strength of leather belt varies from 21 to 35 MPa and a factor of safety may be taken as 8 to 10. However, the wear life of a belt is more important than actual strength. It has been shown by experience that under average conditions an allowable stress of 2.8 MPa or less will give a reasonable belt life. An allowable stress of 1.75 MPa may be expected to give a belt life of about 15 years.

18.7 Density of Belt Materials

The density of various belt materials are given in the following table.

Table 18.1. Density of belt materials.

Material of belt	*Mass density in kg / m^3*
Leather	1000
Convass	1220
Rubber	1140
Balata	1110
Single woven belt	1170
Double woven belt	1250

18.8 Belt Speed

A little consideration will show that when the speed of belt increases, the centrifugal force also increases which tries to pull the belt away from the pulley. This will result in the decrease of power transmitted by the belt. It has been found that for the efficient transmission of power, the belt speed 20 m/s to 22.5 m/s may be used.

18.9 Coefficient of Friction Between Belt and Pulley

The coefficient of friction between the belt and the pulley depends upon the following factors:

1. The material of belt;
2. The material of pulley;
3. The slip of belt; and
4. The speed of belt.

Belts used to drive wheels

According to C.G. Barth, the coefficient of friction (μ) for oak tanned leather belts on cast iron pulley, at the point of slipping, is given by the following relation, *i.e.*

$$\mu = 0.54 - \frac{42.6}{152.6 + v}$$

where v = Speed of the belt in metres per minute.

The following table shows the values of coefficient of friction for various materials of belt and pulley.

Table 18.2. Coefficient of friction between belt and pulley.

Belt material	*Pulley material*						
	Cast iron, steel			*Wood*	*Compressed paper*	*Leather face*	*Rubber face*
	Dry	*Wet*	*Greasy*				
1. Leather oak tanned	0.25	0.2	0.15	0.3	0.33	0.38	0.40
2. Leather chrome tanned	0.35	0.32	0.22	0.4	0.45	0.48	0.50
3. Convass-stitched	0.20	0.15	0.12	0.23	0.25	0.27	0.30
4. Cotton woven	0.22	0.15	0.12	0.25	0.28	0.27	0.30
5. Rubber	0.30	0.18	—	0.32	0.35	0.40	0.42
6. Balata	0.32	0.20	—	0.35	0.38	0.40	0.42

18.10 Standard Belt Thicknesses and Widths

The standard flat belt thicknesses are 5, 6.5, 8, 10 and 12 mm. The preferred values of thicknesses are as follows:

(*a*) 5 mm for nominal belt widths of 35 to 63 mm,

(*b*) 6.5 mm for nominal belt widths of 50 to 140 mm,

(*c*) 8 mm for nominal belt widths of 90 to 224 mm,

(*d*) 10 mm for nominal belt widths of 125 to 400 mm, and

(*e*) 12 mm for nominal belt widths of 250 to 600 mm.

The standard values of nominal belt widths are in R10 series, starting from 25 mm upto 63 mm and in R 20 series starting from 71 mm up to 600 mm. Thus, the standard widths will be 25, 32, 40, 50, 63, 71, 80, 90, 100, 112, 125, 140, 160, 180, 200, 224, 250, 280, 315, 355, 400, 450, 500, 560 and 600 mm.

18.11 Belt Joints

When the endless belts are not available, then the belts are cut from big rolls and the ends are joined together by fasteners. The various types of joints are

1. Cemented joint, **2.** Laced joint, and **3.** Hinged joint.

The **cemented joint,** as shown in Fig. 18.3 (*a*), made by the manufacturer to form an endless belt, is preferred than other joints. The **laced joint** is formed by punching holes in line across the belt, leaving a margin between the edge and the holes. A raw hide strip is used for lacing the two ends together to form a joint. This type of joint is known as ***straight-stitch raw hide laced joint,*** as shown in Fig. 18.3 (*b*).

Metal laced joint as shown in Fig. 18.3 (*c*), is made like a staple connection. The points are driven through the flesh side of the belt and clinched on the inside.

Sometimes, **metal hinges** may be fastened to the belt ends and connected by a steel or fibre pin as shown in Fig. 18.3 (*d*).

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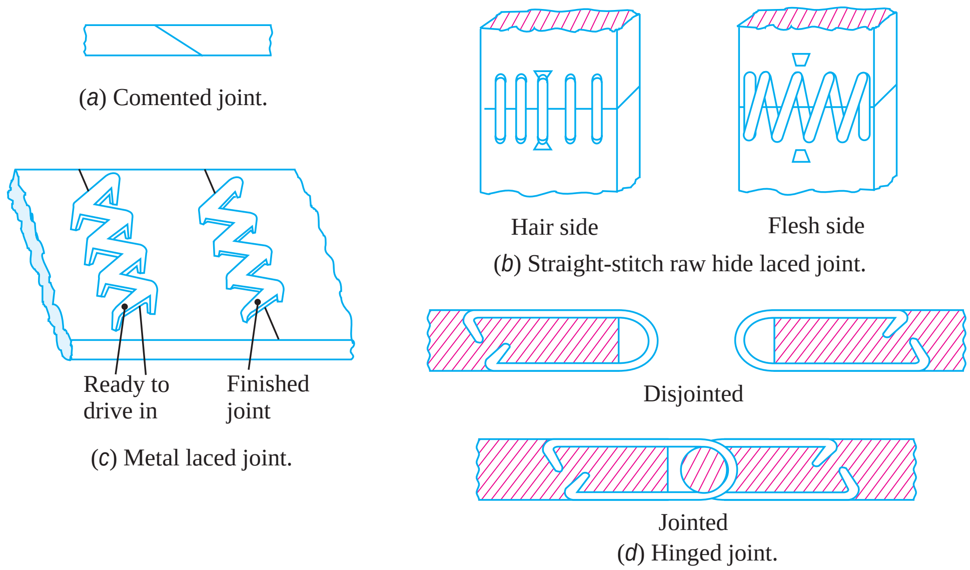

Fig. 18.3. Belt joints.

The following table shows the efficiencies of these joints.

Table 18.3. Efficiencies of belt joints.

Type of joint	*Efficiency* (%)	*Type of joint*	*Efficiency* (%)
1. Cemented, endless, cemented at factory	90 to 100	4. Wire laced by hand	70 to 80
2. Cemented in shop	80 to 90	5. Raw-hide laced	60 to 70
3. Wire laced by machine	75 to 85	6. Metal belt hooks	35 to 40

18.12 Types of Flat Belt Drives

The power from one pulley to another may be transmitted by any of the following types of belt drives.

Cross or twist belt drive

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1. *Open belt drive.* The open belt drive, as shown in Fig. 18.4, is used with shafts arranged parallel and rotating in the same direction. In this case, the driver *A* pulls the belt from one side (*i.e.* lower side *RQ*) and delivers it to the other side (*i.e.* upper side *LM*). Thus the tension in the lower side belt will be more than that in the upper side belt. The lower side belt (because of more tension) is known as ***tight side*** whereas the upper side belt (because of less tension) is known as ***slack side,*** as shown in Fig. 18.4.

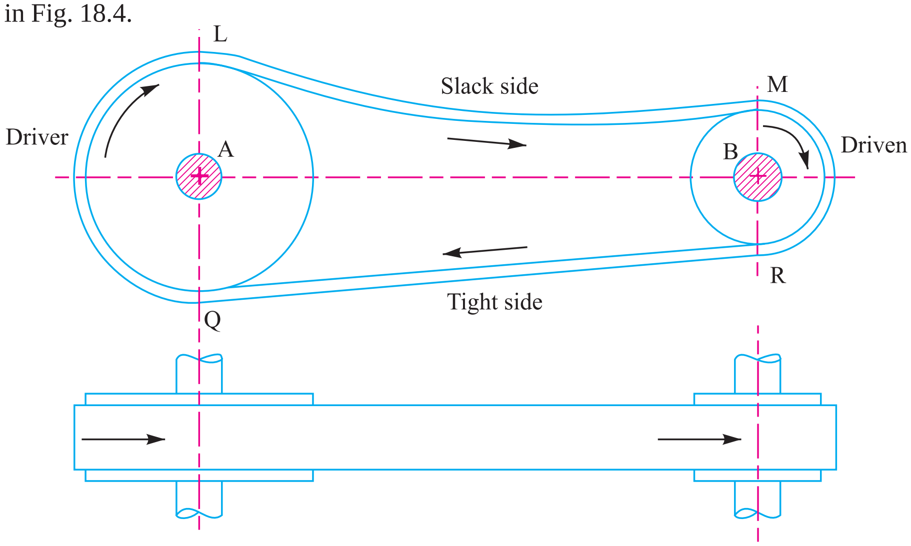


Fig. 18.4. Open belt drive.

2. *Crossed or twist belt drive.* The crossed or twist belt drive, as shown in Fig. 18.5, is used with shafts arranged parallel and rotating in the opposite directions. In this case, the driver pulls the belt from one side (*i.e. RQ*) and delivers it to the other side (*i.e. LM*). Thus, the tension in the belt *RQ* will be more than that in the belt *LM*. The belt *RQ* (because of more tension) is known as ***tight side,*** whereas the belt *LM* (because of less tension) is known as ***slack side,*** as shown in Fig. 18.5.

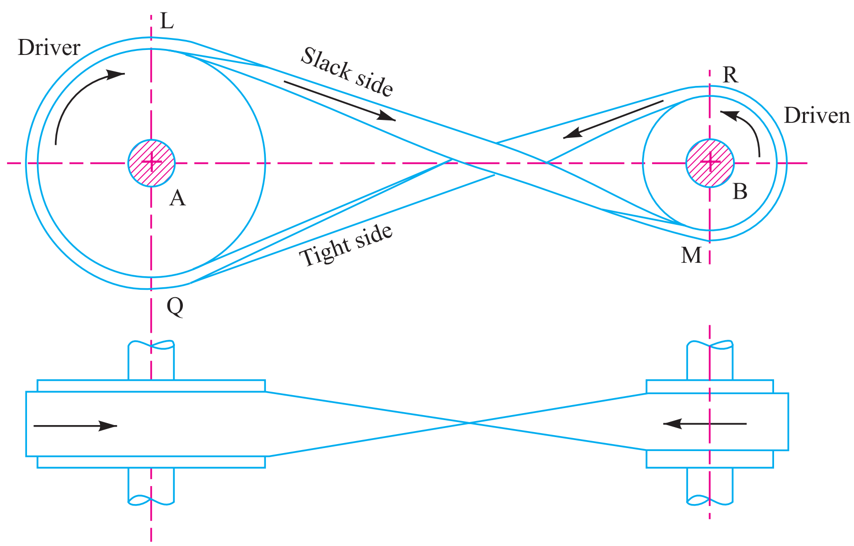
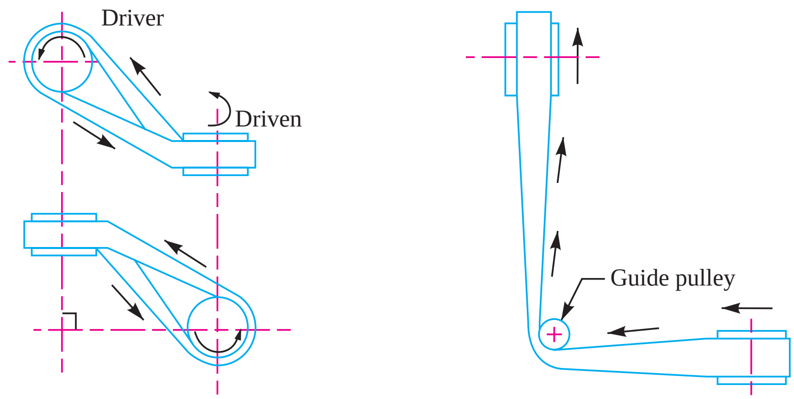


Fig. 18.5. Crossed or twist belt drive.

A little consideration will show that at a point where the belt crosses, it rubs against each other and there will be excessive wear and tear. In order to avoid this, the shafts should be placed at a maximum distance of 20 *b*, where *b* is the width of belt and the speed of the belt should be less than 15 m/s.

3. *Quarter turn belt drive.* The quarter turn belt drive (also known as ***right angle belt drive***) as shown in Fig. 18.6 (*a*), is used with shafts arranged at right angles and rotating in one definite direction. In order to prevent the belt from leaving the pulley, the width of the face of the pulley should be greater or equal to 1.4 *b*, where *b* is width of belt.

In case the pulleys cannot be arranged as shown in Fig. 18.6 (*a*) or when the reversible motion is desired, then a ***quarter turn belt drive with a guide pulley,*** as shown in Fig. 18.6 (*b*), may be used.

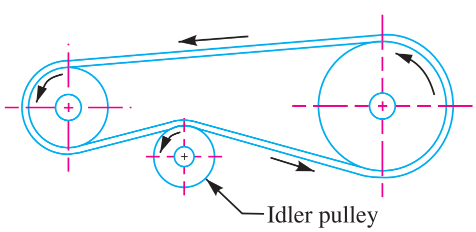


(*a*) Quarter turn belt drive.

(*b*) Quarter turn belt drive with guide pulley.

Fig. 18.6

4. *Belt drive with idler pulleys.* A belt drive with an idler pulley (also known as ***jockey pulley drive***) as shown in Fig. 18.7, is used with shafts arranged parallel and when an open belt drive can not be used due to small angle of contact on the smaller pulley. This type of drive is provided to obtain high velocity ratio and when the required belt tension can not be obtained by other means.



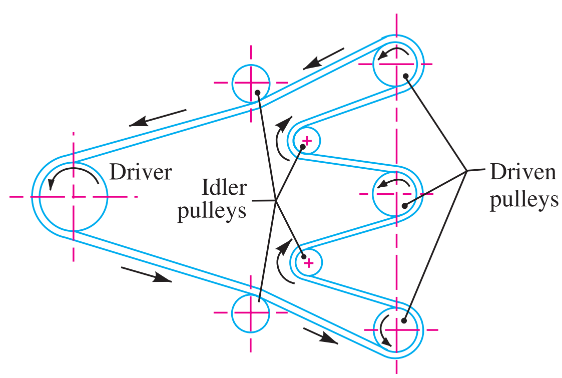


Fig. 18.7. Belt drive with single idler pulley.

Fig. 18.8. Belt drive with many idler pulleys.

When it is desired to transmit motion from one shaft to several shafts, all arranged in parallel, a belt drive with many idler pulleys, as shown in Fig. 18.8, may be employed.

5. *Compound belt drive.* A compound belt drive as shown in Fig. 18.9, is used when power is transmitted from one shaft to another through a number of pulleys.

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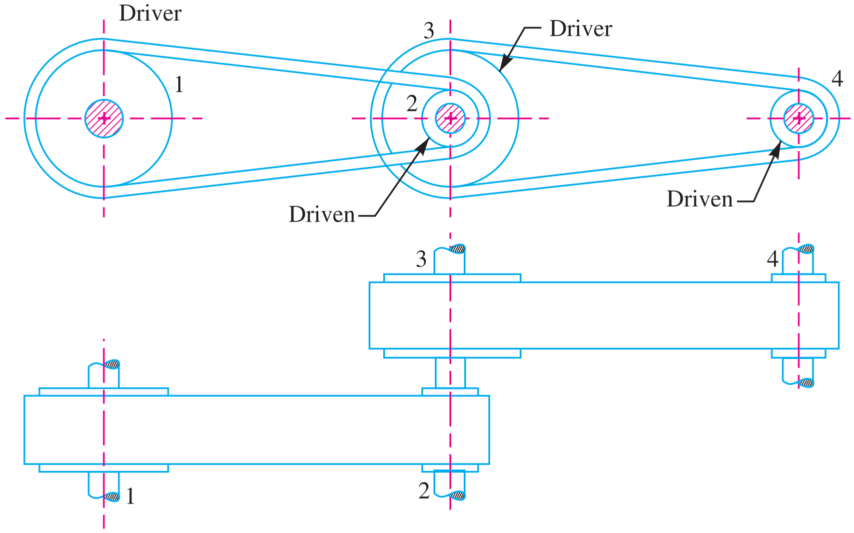

Fig. 18.9. Compound belt drive.

6. ***Stepped or cone pulley drive.*** A stepped or cone pulley drive, as shown in Fig. 18.10, is used for changing the speed of the driven shaft while the main or driving shaft runs at constant speed. This is accomplished by shifting the belt from one part of the steps to the other.

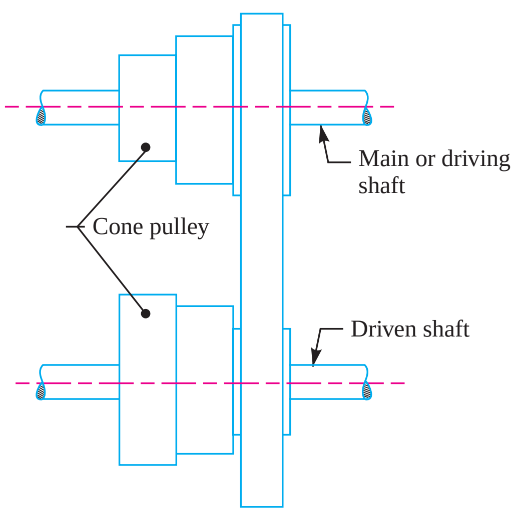

Fig. 18.10. Stepped or cone pulley drive.

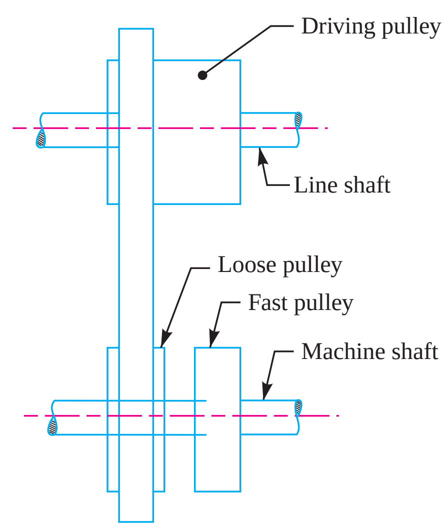

Fig. 18.11. Fast and loose pulley drive.

7. ***Fast and loose pulley drive.*** A fast and loose pulley drive, as shown in Fig. 18.11, is used when the driven or machine shaft is to be started or stopped whenever desired without interferring with the driving shaft. A pulley which is keyed to the machine shaft is called fast pulley and runs at the same speed as that of machine shaft. A loose pulley runs freely over the machine shaft and is incapable of transmitting any power. When the driven shaft is required to be stopped, the belt is pushed on to the loose pulley by means of sliding bar having belt forks.

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18.13 Velocity Ratio of a Belt Drive

It is the ratio between the velocities of the driver and the follower or driven. It may be expressed, mathematically, as discussed below:

Let d_1 = Diameter of the driver,

d_2 = Diameter of the follower,

N_1 = Speed of the driver in r.p.m.,

N_2 = Speed of the follower in r.p.m.,

∴ Length of the belt that passes over the driver, in one minute

$$= \pi\, d_1\, N_1$$

Similarly, length of the belt that passes over the follower, in one minute

$$= \pi\, d_2\, N_2$$

Since the length of belt that passes over the driver in one minute is equal to the length of belt that passes over the follower in one minute, therefore

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

and velocity ratio, $$\frac{N_2}{N_1} = \frac{d_1}{d_2}$$

When thickness of the belt (t) is considered, then velocity ratio,

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

Notes : 1. The velocity ratio of a belt drive may also be obtained as discussed below:

We know that the peripheral velocity of the belt on the driving pulley,

$$v_1 = \frac{\pi\, d_1\, N_1}{60} \text{ m/s}$$

and peripheral velocity of the belt on the driven pulley,

$$v_2 = \frac{\pi\, d_2\, N_2}{60} \text{ m/s}$$

When there is no slip, then $v_1 = v_2$.

$$\therefore \qquad \frac{\pi\, d_1\, N_1}{60} = \frac{\pi\, d_2\, N_2}{60} \quad \text{or} \quad \frac{N_2}{N_1} = \frac{d_1}{d_2}$$

2. In case of a compound belt drive as shown in Fig. 18.7, the velocity ratio is given by

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4} \quad \text{or} \quad \frac{\text{Speed of last driven}}{\text{Speed of first driver}} = \frac{\text{Product of diameters of drivers}}{\text{Product of diameters of drivens}}$$

18.14 Slip of the Belt

In the previous articles we have discussed the motion of belts and pulleys assuming a firm frictional grip between the belts and the pulleys. But sometimes, the frictional grip becomes insufficient. This may cause some forward motion of the driver without carrying the belt with it. This is called ***slip of the belt*** and is generally expressed as a percentage.

The result of the belt slipping is to reduce the velocity ratio of the system. As the slipping of the belt is a common phenomenon, thus the belt should never be used where a definite velocity ratio is of importance (as in the case of hour, minute and second arms in a watch).

Let s_1 % = Slip between the driver and the belt, and

s_2 % = Slip between the belt and follower,

$\therefore$ Velocity of the belt passing over the driver per second,

$$v = \frac{\pi\, d_1\, N_1}{60} - \frac{\pi\, d_1\, N_1}{60} \times \frac{s_1}{100}$$

$$= \frac{\pi\, d_1\, N_1}{60}\left(1 - \frac{s_1}{100}\right) \qquad ...(i)$$

and velocity of the belt passing over the follower per second

$$\frac{\pi\, d_2\, N_2}{60} = v - v\left(\frac{s_2}{100}\right) = v\left(1 - \frac{s_2}{100}\right)$$

Substituting the value of v from equation (*i*), we have

Belt slip indicator is used to indicate that the belt is slipping.

$$\frac{\pi\, d_2\, N_2}{60} = \frac{\pi\, d_1\, N_1}{60}\left(1 - \frac{s_1}{100}\right)\left(1 - \frac{s_2}{100}\right)$$

$$\therefore \quad \frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{s_1}{100} - \frac{s_2}{100}\right) \qquad ...\left(\text{Neglecting } \frac{s_1 \times s_2}{100 \times 100}\right)$$

$$= \frac{d_1}{d_2}\left[1 - \left(\frac{s_1 + s_2}{100}\right)\right] = \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$

...(where $s = s_1 + s_2$ *i.e.* total percentage of slip)

If thickness of the belt (t) is considered, then

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

18.15 Creep of Belt

When the belt passes from the slack side to the tight side, a certain portion of the belt extends and it contracts again when the belt passes from the tight side to the slack side. Due to these changes of length, there is a relative motion between the belt and the pulley surfaces. This relative motion is termed as ***creep.*** The total effect of creep is to reduce slightly the speed of the driven pulley or follower. Considering creep, the velocity ratio is given by

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \times \frac{E + \sqrt{\sigma_2}}{E + \sqrt{\sigma_1}}$$

where σ_1 and σ_2 = Stress in the belt on the tight and slack side respectively, and

E = Young's modulus for the material of the belt.

Note: Since the effect of creep is very small, therefore it is generally neglected.

Example 18.1. *An engine running at 150 r.p.m. drives a line shaft by means of a belt. The engine pulley is 750 mm diameter and the pulley on the line shaft is 450 mm. A 900 mm diameter pulley on the line shaft drives a 150 mm diameter pulley keyed to a dynamo shaft. Fine the speed of dynamo shaft, when 1. there is no slip, and 2. there is a slip of 2% at each drive.*

Solution. Given : N_1 = 150 r.p.m. ; d_1 = 750 mm ; d_2 = 450 mm ; d_3 = 900 mm ; d_4 = 150 mm ; $s_1 = s_2$ = 2%

The arrangement of belt drive is shown in Fig. 18.12.

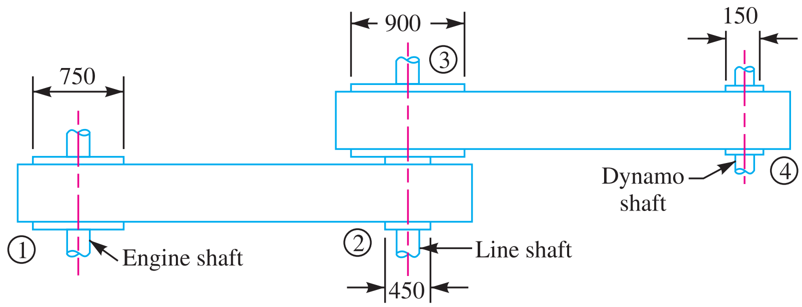
Let N_4 = Speed of the dynamo shaft.

1. When there is no slip

We know that

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4} \quad \text{or} \quad \frac{N_4}{150} = \frac{750 \times 900}{450 \times 150} = 10$$

∴ N_4 = 150 × 10 = 1500 r.p.m. **Ans.**



All dimensions in mm.

Fig. 18.12

2. When there is a slip of 2% at each drive

We know that

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4}\left(1 - \frac{s_1}{100}\right)\left(1 - \frac{s_2}{100}\right)$$

or
$$\frac{N_4}{150} = \frac{750 \times 900}{450 \times 150}\left(1 - \frac{2}{100}\right)\left(1 - \frac{2}{100}\right) = 9.6$$

∴ N_4 = 150 × 9.6 = 1440 r.p.m. **Ans.**

18.16 Length of an Open Belt Drive

We have discussed in Art. 18.12, that in an open belt drive, both the pulleys rotate in the same direction as shown in Fig. 18.13.

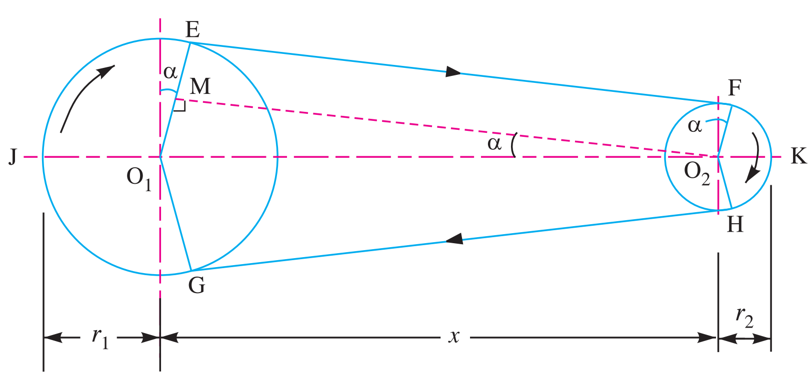


Fig. 18.13. Open belt drive.

Let r_1 and r_2 = Radii of the larger and smaller pulleys,

x = Distance between the centres of two pulleys (*i.e.* O_1O_2), and

L = Total length of the belt.

Let the belt leaves the larger pulley at E and G and the smaller pulley at F and H as shown in Fig. 18.13. Through O_2 draw O_2M parallel to FE.

From the geometry of the figure, we find that O_2M will be perpendicular to O_1E.

Let the angle $MO_2O_1 = \alpha$ radians.

We know that the length of the belt,

$$L = \text{Arc } GJE + EF + \text{Arc } FKH + HG$$
$$= 2\,(\text{Arc } JE + EF + \text{Arc } FK) \qquad \ldots(i)$$

From the geometry of the figure, we also find that

$$\sin\alpha = \frac{O_1M}{O_1O_2} = \frac{O_1E - EM}{O_1O_2} = \frac{r_1 - r_2}{x}$$

Since the angle α is very small, therefore putting

$$\sin\alpha = \alpha \text{ (in radians)} = \frac{r_1 - r_2}{x} \qquad \ldots(ii)$$

$$\therefore \qquad \text{Arc } JE = r_1\left(\frac{\pi}{2} + \alpha\right) \qquad \ldots(iii)$$

Similarly,

$$\text{arc } FK = r_2\left(\frac{\pi}{2} - \alpha\right) \qquad \ldots(iv)$$

and

$$EF = MO_2 = \sqrt{(O_1O_2)^2 - (O_1M)^2} = \sqrt{x^2 - (r_1 - r_2)^2}$$
$$= x\sqrt{1 - \left(\frac{r_1 - r_2}{x}\right)^2}$$

Expanding this equation by binomial theorem, we have

$$EF = x\left[1 - \frac{1}{2}\left(\frac{r_1 - r_2}{x}\right)^2 + \ldots\right] = x - \frac{(r_1 - r_2)^2}{2x} \qquad \ldots(v)$$

Substituting the values of arc JE from equation (*iii*), arc FK from equation (*iv*) and EF from equation (*v*) in equation (*i*), we get

$$L = 2\left[r_1\left(\frac{\pi}{2} + \alpha\right) + x - \frac{(r_1 - r_2)^2}{2x} + r_2\left(\frac{\pi}{2} - \alpha\right)\right]$$
$$= 2\left[r_1 \times \frac{\pi}{2} + r_1.\alpha + x - \frac{(r_1 - r_2)^2}{2x} + r_2 \times \frac{\pi}{2} - r_2.\alpha\right]$$
$$= 2\left[\frac{\pi}{2}(r_1 + r_2) + \alpha\,(r_1 - r_2) + x - \frac{(r_1 - r_2)^2}{2x}\right]$$
$$= \pi\,(r_1 + r_2) + 2\alpha\,(r_1 - r_2) + 2x - \frac{(r_1 - r_2)^2}{x}$$

Substituting the value of $\alpha = \dfrac{(r_1 - r_2)}{x}$ from equation (*ii*), we get

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

$$= \pi (r_1 + r_2) + 2x + \frac{(r_1 - r_2)^2}{x} \quad \text{... (in terms of pulley radii)}$$

$$= \frac{\pi}{2} (d_1 + d_2) + 2x + \frac{(d_1 - d_2)^2}{4x} \quad \text{... (in terms of pulley diameters)}$$

18.17 Length of a Cross Belt Drive

We have discussed in Art. 18.12 that in a cross belt drive, both the pulleys rotate in the opposite directions as shown in Fig. 18.14.

Let r_1 and r_2 = Radii of the larger and smaller pulleys,

x = Distance between the centres of two pulleys (*i.e.* O_1O_2), and

L = Total length of the belt.

Let the belt leaves the larger pulley at E and G and the smaller pulley at F and H as shown in Fig. 18.14.

Through O_2 draw O_2M parallel to FE.

From the geometry of the figure, we find that O_2M will be perpendicular to O_1E.

Let the angle $MO_2O_1 = \alpha$ radians.

We know that the length of the belt,

$$L = \text{Arc } GJE + EF + \text{Arc } FKH + HG$$

$$= 2 (\text{Arc } JE + FE + \text{Arc } FK) \quad \text{...}(i)$$

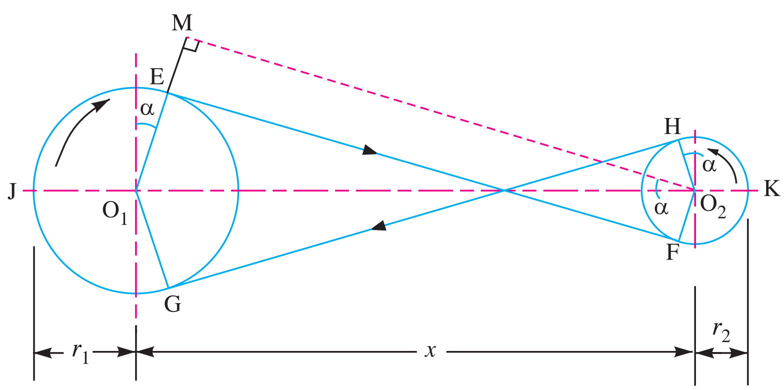


Fig. 18.14. Crossed belt drive.

From the geometry of the figure, we find that

$$\sin \alpha = \frac{O_1M}{O_1O_2} = \frac{O_1E + EM}{O_1O_2} = \frac{r_1 + r_2}{x}$$

Since the angle α is very small, therefore putting

$$\sin \alpha = \alpha \text{ (in radians)} = \frac{r_1 + r_2}{x} \quad \text{...}(ii)$$

$$\therefore \quad \text{Arc } JE = r_1 \left(\frac{\pi}{2} + \alpha \right) \quad \text{...}(iii)$$

Similarly, $$\text{arc } FK = r_2 \left(\frac{\pi}{2} + \alpha \right) \quad \text{...}(iv)$$

and
$$EF = MO_2 = \sqrt{(O_1O_2)^2 - (O_1M)^2} = \sqrt{x^2 - (r_1 + r_2)^2}$$
$$= x\sqrt{1 - \left(\frac{r_1 + r_2}{x}\right)^2}$$

Expanding this equation by binomial theorem, we have
$$EF = x\left[1 - \frac{1}{2}\left(\frac{r_1 + r_2}{x}\right)^2 + ...\right] = x - \frac{(r_1 + r_2)^2}{2x} \quad ...(v)$$

In the above conveyor belt is used to transport material as well as to drive the rollers

Substituting the values of arc *JE* from equation ***(iii)***, arc *FK* from equation ***(iv)*** and *EF* from equation ***(v)*** in equation ***(i)***, we get,
$$L = 2\left[r_1\left(\frac{\pi}{2} + \alpha\right) + x - \frac{(r_1 + r_2)^2}{2x} + r_2\left(\frac{\pi}{2} + \alpha\right)\right]$$
$$= 2\left[r_1 \times \frac{\pi}{2} + r_1.\alpha + x - \frac{(r_1 + r_2)^2}{2x} + r_2 \times \frac{\pi}{2} + r_2.\alpha\right]$$
$$= 2\left[\frac{\pi}{2}(r_1 + r_2) + \alpha(r_1 + r_2) + x - \frac{(r_1 + r_2)^2}{2x}\right]$$
$$= \pi(r_1 + r_2) + 2\alpha(r_1 + r_2) + 2x - \frac{(r_1 + r_2)^2}{x}$$

Substituting the value of $\alpha = \dfrac{(r_1 + r_2)}{x}$ from equation ***(ii)***, we get
$$L = \pi(r_1 + r_2) + 2 \times \frac{(r_1 + r_2)}{x}(r_1 + r_2) + 2x - \frac{(r_1 + r_2)^2}{x}$$
$$= \pi(r_1 + r_2) + \frac{2(r_1 + r_2)^2}{x} + 2x - \frac{(r_1 + r_2)^2}{x}$$

$$= \pi (r_1 + r_2) + 2x + \frac{(r_1 + r_2)^2}{x} \qquad \text{... (in terms of pulley radii)}$$

$$= \frac{\pi}{2} (d_1 + d_2) + 2x + \frac{(d_1 + d_2)^2}{4x} \qquad \text{... (in terms of pulley diameters)}$$

It may be noted that the above expression is a function of $(r_1 + r_2)$. It is thus obvious, that if sum of the radii of the two pulleys be constant, length of the belt required will also remain constant, provided the distance between centres of the pulleys remain unchanged.

18.18 Power Transmitted by a Belt

Fig. 18.15 shows the driving pulley (or driver) *A* and the driven pulley (or follower) *B*. As already discussed, the driving pulley pulls the belt from one side and delivers it to the other side. It is thus obvious that the tension on the former side (*i.e.* tight side) will be greater than the latter side (*i.e.* slack side) as shown in Fig. 18.15.

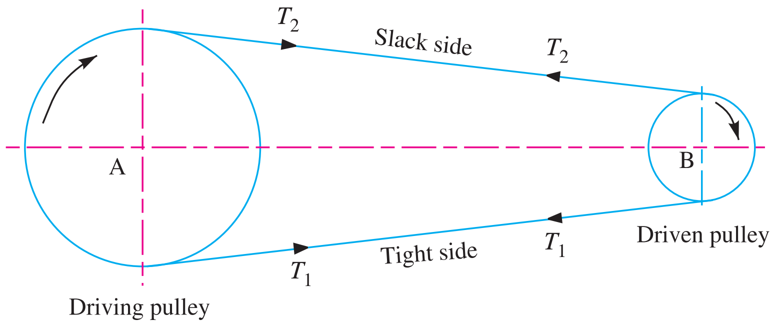


Fig. 18.15. Power transmitted by a belt.

Let T_1 and T_2 = Tensions in the tight side and slack side of the belt respectively in newtons,

r_1 and r_2 = Radii of the driving and driven pulleys respectively in metres,

and v = Velocity of the belt in m/s.

The effective turning (driving) force at the circumference of the driven pulley or follower is the difference between the two tensions (*i.e.* $T_1 - T_2$).

This massive shaft-like pulley drives the conveyor belt.

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CHAPTER

21

Chain Drives

21.1 Introduction

We have seen in previous chapters on belt and rope drives that slipping may occur. In order to avoid slipping, steel chains are used. The chains are made up of number of rigid links which are hinged together by pin joints in order to provide the necessary flexibility for wraping round the driving and driven wheels. These wheels have projecting teeth of special profile and fit into the corresponding recesses in the links of the chain as shown in Fig. 21.1. The toothed wheels are known as ****sprocket wheels or simply sprockets.*** The sprockets and the chain are thus constrained to move together without slipping and ensures perfect velocity ratio.

* These wheels resemble to spur gears.

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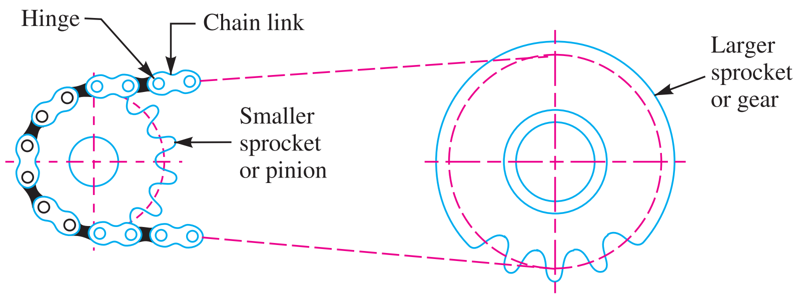


Fig. 21.1. Sprockets and chain.

The chains are mostly used to transmit motion and power from one shaft to another, when the centre distance between their shafts is short such as in bicycles, motor cycles, agricultural machinery, conveyors, rolling mills, road rollers etc. The chains may also be used for long centre distance of upto 8 metres. The chains are used for velocities up to 25 m / s and for power upto 110 kW. In some cases, higher power transmission is also possible.

21.2 Advantages and Disadvantages of Chain Drive over Belt or Rope Drive

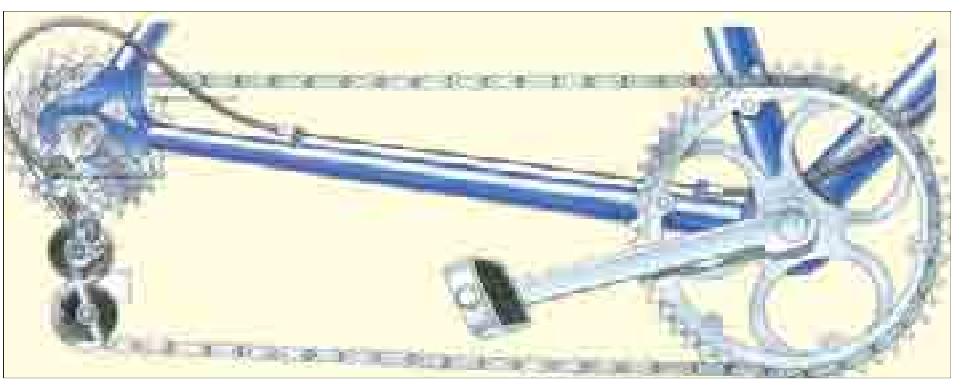
Following are the advantages and disadvantages of chain drive over belt or rope drive:

Advantages

1. As no slip takes place during chain drive, hence perfect velocity ratio is obtained.
2. Since the chains are made of metal, therefore they occupy less space in width than a belt or rope drive.
3. It may be used for both long as well as short distances.
4. It gives a high transmission efficiency (upto 98 percent).
5. It gives less load on the shafts.
6. It has the ability to transmit motion to several shafts by one chain only.
7. It transmits more power than belts.
8. It permits high speed ratio of 8 to 10 in one step.
9. It can be operated under adverse temperature and atmospheric conditions.

Disadvantages

1. The production cost of chains is relatively high.
2. The chain drive needs accurate mounting and careful maintenance, particularly lubrication and slack adjustment.
3. The chain drive has velocity fluctuations especially when unduly stretched.



Sports bicycle gear and chain drive mechanism

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21.3 Terms Used in Chain Drive

The following terms are frequently used in chain drive.

1. ***Pitch of chain.*** It is the distance between the hinge centre of a link and the corresponding hinge centre of the adjacent link, as shown in Fig. 21.2. It is usually denoted by *p*.

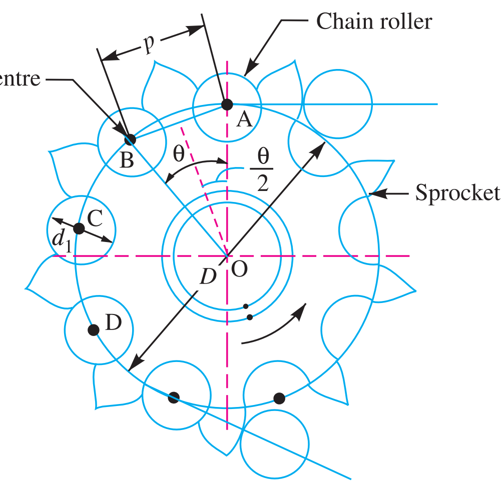

Fig. 21.2. Terms used in chain drive.

2. ***Pitch circle diameter of chain sprocket.*** It is the diameter of the circle on which the hinge centres of the chain lie, when the chain is wrapped round a sprocket as shown in Fig. 21.2. The points *A*, *B*, *C*, and *D* are the hinge centres of the chain and the circle drawn through these centres is called pitch circle and its diameter (*D*) is known as pitch circle diameter.

21.4 Relation Between Pitch and Pitch Circle Diameter

A chain wrapped round the sprocket is shown in Fig. 21.2. Since the links of the chain are rigid, therefore pitch of the chain does not lie on the arc of the pitch circle. The pitch length becomes a chord. Consider one pitch length *AB* of the chain subtending an angle θ at the centre of sprocket (or pitch circle),

Let D = Diameter of the pitch circle, and

T = Number of teeth on the sprocket.

From Fig. 21.2, we find that pitch of the chain,

$$p = AB = 2\,AO\sin\left(\frac{\theta}{2}\right) = 2 \times \left(\frac{D}{2}\right)\sin\left(\frac{\theta}{2}\right) = D\sin\left(\frac{\theta}{2}\right)$$

We know that $\theta = \dfrac{360^o}{T}$

$$\therefore \quad p = D\sin\left(\frac{360^o}{2\,T}\right) = D\sin\left(\frac{180^o}{T}\right)$$

or $$D = p\,\mathrm{cosec}\left(\frac{180^o}{T}\right)$$

The sprocket outside diameter (D_o), for satisfactory operation is given by

$$D_o = D + 0.8\,d_1$$

where d_1 = Diameter of the chain roller.

Note: The angle θ/2 through which the link swings as it enters contact is called **angle of articulation.**

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21.5 Velocity Ratio of Chain Drives

The velocity ratio of a chain drive is given by

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

where N_1 = Speed of rotation of smaller sprocket in r.p.m.,

N_2 = Speed of rotation of larger sprocket in r.p.m.,

T_1 = Number of teeth on the smaller sprocket, and

T_2 = Number of teeth on the larger sprocket.

The average velocity of the chain is given by

$$v = \frac{\pi\, D\, N}{60} = \frac{T\; p\; N}{60}$$

where D = Pitch circle diameter of the sprocket in metres, and

p = Pitch of the chain in metres.

21.6 Length of Chain and Centre Distance

An open chain drive system connecting the two sprockets is shown in Fig. 21.3.

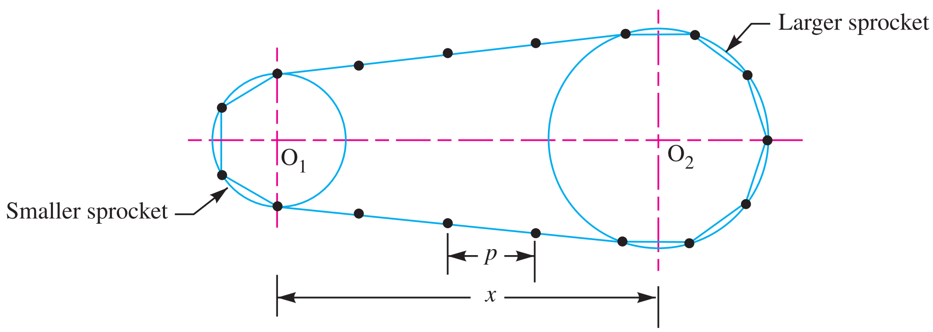


Fig. 21.3. Length of chain.

Let T_1 = Number of teeth on the smaller sprocket,

T_2 = Number of teeth on the larger sprocket,

p = Pitch of the chain, and

x = Centre distance.

The length of the chain (L) must be equal to the product of the number of chain links (K) and the pitch of the chain (p). Mathematically,

$$L = K.p$$

The number of chain links may be obtained from the following expression, *i.e.*

$$K = \frac{T_1 + T_2}{2} + \frac{2\,x}{p} + \left[\frac{T_2 - T_1}{2\,\pi}\right]^2 \frac{p}{x}$$

The value of K as obtained from the above expression must be approximated to the nearest even number.

The centre distance is given by

$$x = \frac{p}{4}\left[K - \frac{T_1 + T_2}{2} + \sqrt{\left(K - \frac{T_1 + T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2\,\pi}\right)^2}\,\right]$$

In order to accommodate initial sag in the chain, the value of the centre distance obtained from the above equation should be decreased by 2 to 5 mm.

Notes: 1. The minimum centre distance for the velocity transmission ratio of 3, may be taken as

$$x_{min} = \frac{d_1 + d_2}{2} + 30 \text{ to } 50 \text{ mm}$$

where d_1 and d_2 are the diameters of the pitch circles of the smaller and larger sprockets.

2. For best results, the minimum centre distance should be 30 to 50 times the pitch.

3. The minimum centre distance is selected depending upon the velocity ratio so that the arc of contact of the chain on the smaller sprocket is not less than 120º. It may be noted that larger angle of arc of contact ensures a more uniform distribution of load on the sprocket teeth and better conditions of engagement.

21.7 Classification of Chains

The chains, on the basis of their use, are classified into the following three groups:

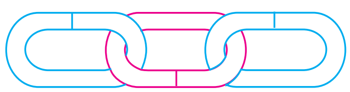
1. Hoisting and hauling (or crane) chains,
2. Conveyor (or tractive) chains, and
3. Power transmitting (or driving) chains.

These chains are discussed, in detail, in the following pages.

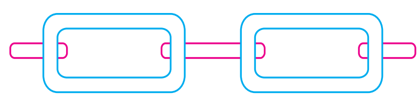
21.8 Hoisting and Hauling Chains

These chains are used for hoisting and hauling purposes and operate at a maximum velocity of 0.25 m / s. The hoisting and hauling chains are of the following two types:

1. *Chain with oval links*. The links of this type of chain are of oval shape, as shown in Fig. 21.4 (*a*). The joint of each link is welded. The sprockets which are used for this type of chain have receptacles to receive the links. Such type of chains are used only at low speeds such as in chain hoists and in anchors for marine works.



(*a*) Chain with oval links.



(*b*) Chain with square links.

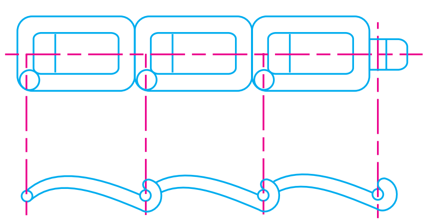
Fig. 21.4. Hoisting and hauling chains.

2. *Chain with square links*. The links of this type of chain are of square shape, as shown in Fig. 21.4 (*b*). Such type of chains are used in hoists, cranes, dredges. The manufacturing cost of this type of chain is less than that of chain with oval links, but in these chains, the kinking occurs easily on overloading.

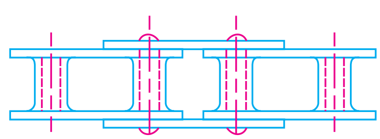
21.9 Conveyor Chains

These chains are used for elevating and conveying the materials continuously at a speed upto 2 m / s. The conveyor chains are of the following two types:

1. Detachable or hook joint type chain, as shown in Fig. 21.5 (*a*), and
2. Closed joint type chain, as shown in Fig. 21.5 (*b*).



(*a*) Detachable or hook joint type chain.



(*b*) Closed joint type chain.

Fig. 21.5. Conveyor chains.

The conveyor chains are usually made of malleable cast iron. These chains do not have smooth running qualities. The conveyor chains run at slow speeds of about 0.8 to 3 m / s.

21.10 Power Transmitting Chains

These chains are used for transmission of power, when the distance between the centres of shafts is short. These chains have provision for efficient lubrication. The power transmitting chains are of the following three types.

1. *Block or bush chain.* A block or bush chain is shown in Fig. 21.6. This type of chain was used in the early stages of development in the power transmission.

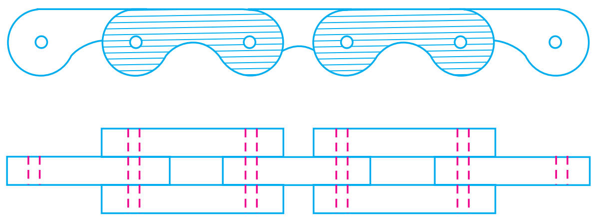


Fig. 21.6. Block or bush chain.

It produces noise when approaching or leaving the teeth of the sprocket because of rubbing between the teeth and the links. Such type of chains are used to some extent as conveyor chain at small speed.

2. *Bush roller chain.* A bush roller chain as shown in Fig. 21.7, consists of outer plates or pin link plates, inner plates or roller link plates, pins, bushes and rollers. A pin passes through the bush which is secured in the holes of the roller between the two sides of the chain. The rollers are free to rotate on the bush which protect the sprocket wheel teeth against wear. The pins, bushes and rollers are made of alloy steel.

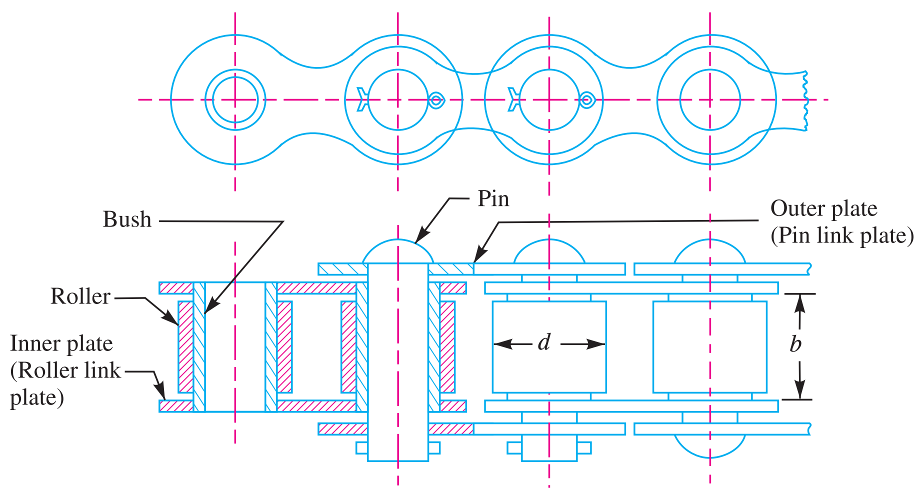


Fig. 21.7. Bush roller chain.

A bush roller chain is extremely strong and simple in construction. It gives good service under severe conditions. There is a little noise with this chain which is due to impact of the rollers on the sprocket wheel teeth. This chain may be used where there is a little lubrication. When one of these chains elongates slightly due to wear and stretching of the parts, then the extended chain is of greater pitch than the pitch of the sprocket wheel teeth. The rollers then fit unequally into the cavities of the wheel. The result is that the total load falls on one teeth or on a few teeth. The stretching of the parts increase wear of the surfaces of the roller and of the sprocket wheel teeth.

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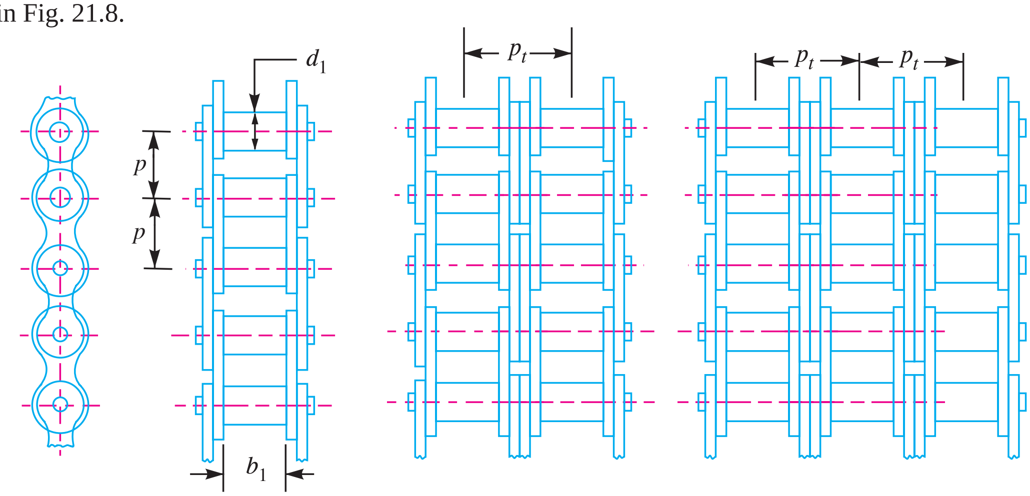
Rear wheel chain drive of a motorcycle

The roller chains are standardised and manufactured on the basis of pitch. These chains are available in single-row or multi-row roller chains such as simple, duplex or triplex strands, as shown in Fig. 21.8.



Simplex chain. Duplex chain. Triplex chain.

Fig. 21.8. Types of roller chain.

3. *Silent chain.* A silent chain (also known as ***inverted tooth chain***) is shown in Fig. 21.9.

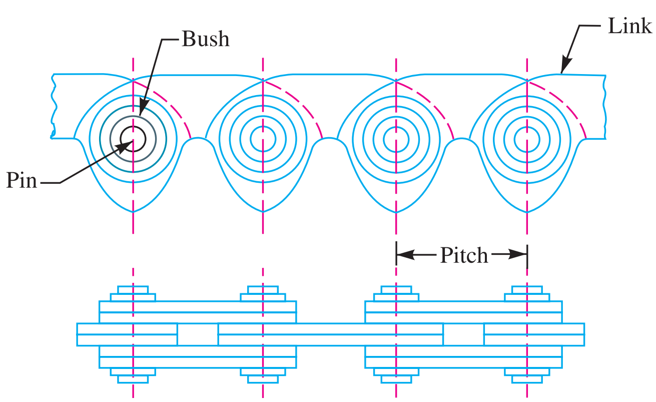


Fig. 21.9. Silent chain.

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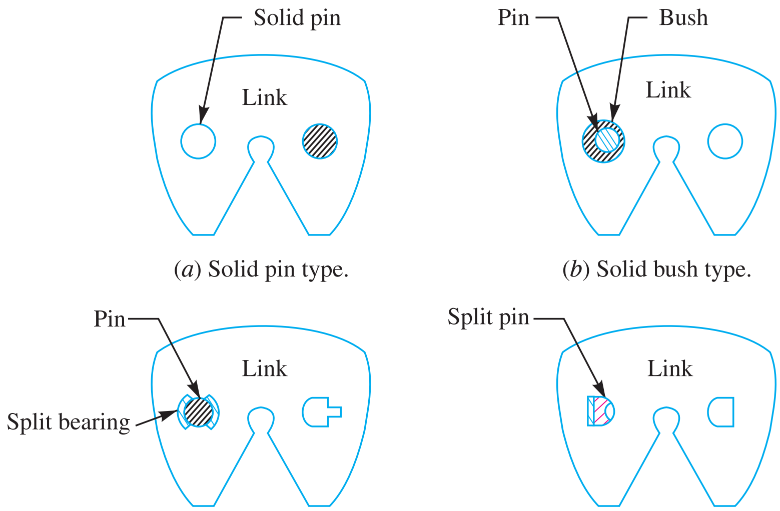
It is designed to eliminate the evil effects caused by stretching and to produce noiseless running. When the chain stretches and the pitch of the chain increases, the links ride on the teeth of the sprocket wheel at a slightly increased radius. This automatically corrects the small change in the pitch. There is no relative sliding between the teeth of the inverted tooth chain and the sprocket wheel teeth. When properly lubricated, this chain gives durable service and runs very smoothly and quietly.

The various types of joints used in a silent chain are shown in Fig. 21.10.



(*a*) Solid pin type. (*b*) Solid bush type. (*c*) Split bush type. (*d*) Rocket pin type.

Fig. 21.10. Silent chain joints.

21.11 Characteristics of Roller Chains

According to Indian Standards (IS: 2403 —1991), the various characteristics such as pitch, roller diameter, width between inner plates, transverse pitch and breaking load for the roller chains are given in the following table.

Table 21.1. Characteristics of roller chains according to IS: 2403 — 1991.

ISO Chain number	*Pitch (p) mm*	*Roller diameter (d_1) mm Maximum*	*Width between inner plates (b_1) mm Maximum*	*Transverse pitch (p_1) mm*	*Breaking load (kN) Minimum*		
					Simple	*Duplex*	*Triplex*
05 B	8.00	5.00	3.00	5.64	4.4	7.8	11.1
06 B	9.525	6.35	5.72	10.24	8.9	16.9	24.9
08 B	12.70	8.51	7.75	13.92	17.8	31.1	44.5
10 B	15.875	10.16	9.65	16.59	22.2	44.5	66.7
12 B	19.05	12.07	11.68	19.46	28.9	57.8	86.7
16 B	25.4	15.88	17.02	31.88	42.3	84.5	126.8
20 B	31.75	19.05	19.56	36.45	64.5	129	193.5
24 B	38.10	25.40	25.40	48.36	97.9	195.7	293.6
28 B	44.45	27.94	30.99	59.56	129	258	387
32 B	50.80	29.21	30.99	68.55	169	338	507.10
40 B	63.50	39.37	38.10	72.29	262.4	524.9	787.3
48 B	76.20	48.26	45.72	91.21	400.3	800.7	1201

Top

Material handling equipment (MHE)

Material handling equipment (MHE) is mechanical equipment used for the movement, storage, control, and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption, and disposal. The different types of handling equipment can be classified into four major categories: transport equipment, positioning equipment, unit load formation equipment, and storage equipment.

Conveyors:

Short definition is simply, that convey material. Conveyors are mechanical devices or assemblies used to move items or packages with minimal effort. They usually consist of frames that support rollers, wheels, or belts and may be motor powered or manual devices. Belt conveyors convey material with the help of belt.

The belt of the conveyor may be of textile, strip steel, woven mesh steel wire.

1. Conveyors with textile belt
2. Conveyors with metal belt
3. Chain driven and rope driven belt conveyors

Types of belt conveyors:

(i). According to the design

a. Stationary conveyors

b. Portable & mobile conveyors

(ii). According to the purpose

c. General purpose conveyor

d. Special purpose conveyor

Special purpose belts are used to convey hot loads or for operation at ambient temperature over +60°C and -25°C and also for the transport of material chemically injurious to the fabric or rubber cover of the belt. Special purpose belts include heat resistant, frost resistant, and uninflammable and other types.

Belt conveyor System consists of an endless belt on which various materials such as sand, cement, concrete, earth, etc., are carried. The size, grade and type of belt to be selected depend up on the type of materials to be transported. There are two pulleys on either sides of belt at its extreme ends which rotates the belt. There are numerous carrier shafts under the belt in the upper side of the conveyor to support the belt against the weight of the material. At the lower side, there are idler shaft which are less in number than carries shaft.

According to their path of motion belt conveyors are classified as:

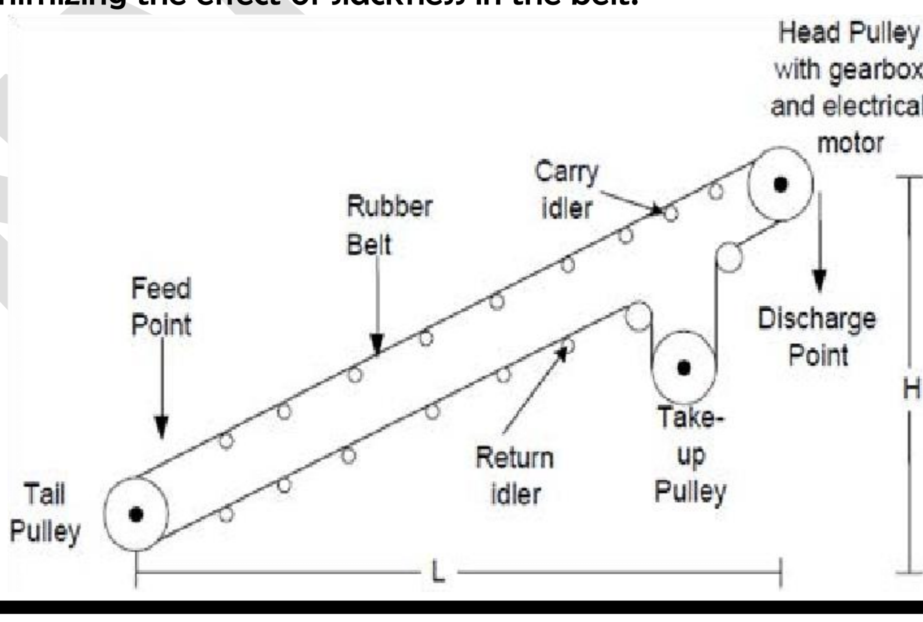
1) Horizontal
2) Inclined
3) Combined
   - Inclined horizontal
   - Horizontal inclined
   - Horizontal inclined horizontal
   - Inclined horizontal inclined

Parts of belt conveyors:

1. Belts
2. Idlers
3. Centering device
4. Take ups
5. Drive units
6. Loading & discharging
7. Belt Cleaner
8. Automated hold back brakes
9. Conveyor frame

Working Steps:

The Working principle of a belt conveyor is mainly due to friction. A motor and gear box is used to rotate the pulleys which produce friction in between the belt and pulley. Due to the frictional force, the belt is rotated from one pulley to another, overcoming the load and drag force. Two drums/pulleys on which the belt runs are mounted on two shafts. These, shaft continuously rotate with the pulleys in same direction (i.e., direction in which the material is to be transported). The weight of material being conveyed acts on the belt and the carrier shaft which uniformly distributes the load. The idler shafts are used for minimizing the effect of slackness in the belt.



The weight of material being conveyed acts on the belt and the carrier shaft which uniformly distributes the load. The idler shafts are used for minimizing the effect of slackness in the belt.

The belt conveyors are commonly used for short distance transportation of large quantity of materials. It can also be used for longer distances provided it justifies the initial cost of the system. For longer distance, the length of belt and number of carrier shaft has to be increased.

Application of belt conveyors:

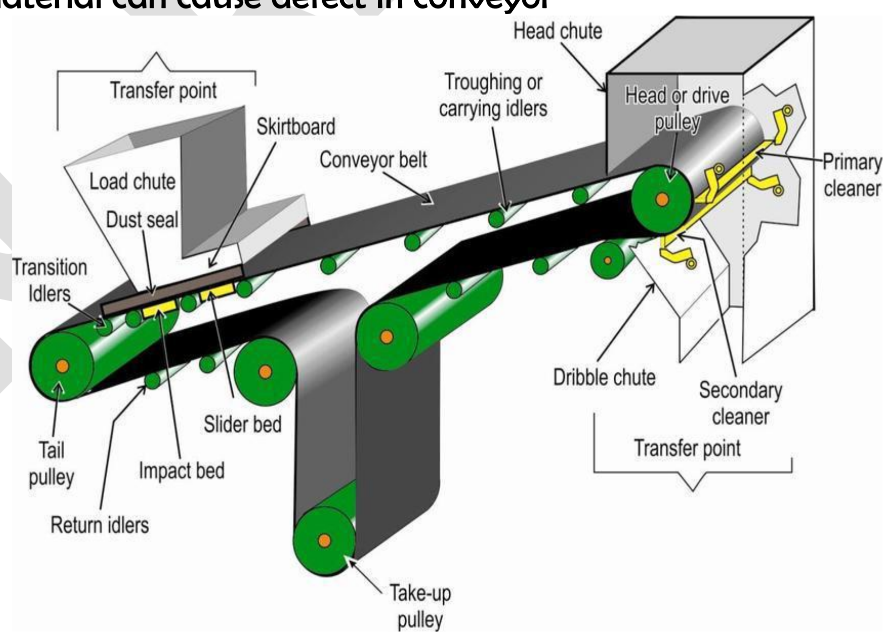
1. Convey great variety of unit loads & bulk loads
2. Foundry shop to convey mold or sand
3. Deliver fuel in power plant
4. Distribution of molding sand
5. Coal or ores mining
6. Cement & food industries
7. Carry articles of light weight in line production from one operation to another.

Advantages of belt conveyors:

1. High capacity 500-5000 m3 /hour or more
2. Ability to transport loads for long distance (500-1000m or up)
3. Simplicity in design
4. Comparatively low in own weight
5. Reliable source
6. Convenient operation
7. Less skill required to operate

Disadvantages of belt conveyors:

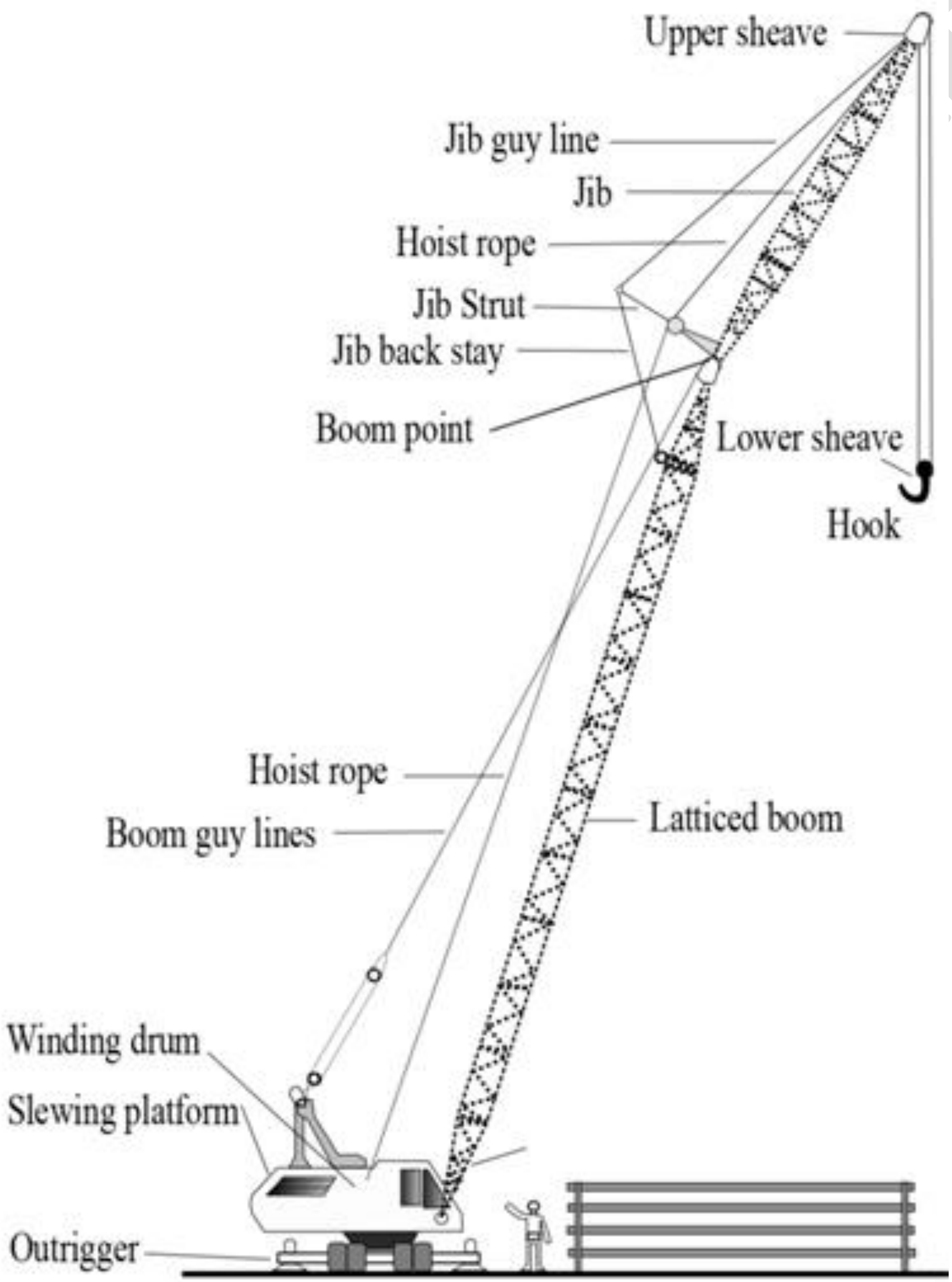
1. Not suitable for hot ashes & slag.
2. Not suitable granular, powder
3. Abrasive material can cause defect in conveyor



UNIT-II MATERIAL HANDLING

CRANES

A crane is a type of machine, generally equipped with a hoist rope, wire ropes or chains, and sheaves, that can be used both to lift and lower materials and to move them horizontally. It is mainly used for lifting heavy things and transporting them to other places. The device uses one or more simple machines to create mechanical advantage and thus move loads beyond the normal capability of a human. Cranes are commonly employed in transportation for the loading and unloading of freight, in construction for the movement of materials, and in manufacturing for the assembling of heavy equipment.



Cranes play a really vital part in our modern day infrastructure development. Heavy construction and manufacturing will not be same as it was now without cranes.

A crane is a heavy and powerful derrick or tower like machine which is used to lift heavy materials. It uses cables and pulleys in life the heavy objects.

These cranes are generally temporary structure built on the ground, which can be removed after the construction work is completed. Otherwise, cranes are built in a custom designed vehicle. It can be operated by either form a cab which can travel along the crane or from a separate control room.

Crane rental is used in the heavy construction of buildings and manufacturing of heavy industrial products. It also used in logistics and transport industry, which handles heavy products.

Based on the usage and requirement cranes are classified into many types.

Types of Cranes

Different types of cranes are as follows.

1. Telescopic Crane.
2. Mobile Cranes.
3. Truck Mounted Crane.
4. Tower Crane.
5. Rough Terrain Crane.
6. Overhead Crane.
7. Bridge Crane.
8. Crawler Crane.
9. Aerial Crane.
10. Hydraulic Crane.
11. Carry Deck Crane.
12. Floating Crane.
13. Bulk-handling Crane.
14. Hammerhead Crane.
15. Stacker Crane.
16. Railroad Crane.
17. Harbor Cranes.
18. Level Luffing Crane.

1. Telescopic Crane

The telescopic crane consists of a large boom where some numbers of tubes have been fitted inside with each other. It increases their height with the help of tubes throughout the hydraulic system. They are specially used to transport goods from one place to another.

When it comes to transferring the object into a high place, Telescopic cranes would be the best. Since they could adjust their heights in line with the place. They may also be used in rescue operations.

2. Mobile Cranes

Mobile cranes are generally found on vehicles, but cranes used for construction work are adapted to move on the tractor, and several cranes may be attached to barges when used for construction work on waterway bridges.

The lifting arm is usually articulated to allow lifting and reduction as required. Generally, this is achieved through a system of cables or hydraulic mechanisms, and the whole mobile structure may be coupled to a support to provide more stability during its operation.

3. Truck Mounted Crane

Truck-mounted cranes are made up of both parts of the carrier, along with the boom (arm). Due to their unique build, they are ready to travel easily on the road without a unique setup or transportation equipment.

Truck-mounted cranes are outfitted with counterweights and outriggers for insertion, allowing them to move slowly while carrying a large load.

Different versions of this truck-mounted crane exist; for example, special truck-mounted cranes are used for the inspection, maintenance, and building of bridges.

4. Tower Crane / Construction Crane

Commonly utilized in the construction of tall buildings, tower cranes offer you amazing lifting capabilities. |Because of their size, tower cranes are equipped with an operating cab that controls the whole crane.

Tower cranes have their jib extending horizontally from the mast (tower part), which itself rests on a concrete base. A Luffing jib can move up and down, while the fixed jib has an operating dolly that moves materials horizontally.

The engine (known as a slewing unit) that controls the rotation of the crane sits on the top of the mast. As a result of their size, tower cranes are built together with the building, growing alongside it; once the building is done, the process is reversed.

Using its height, ability to lift heavy materials, and various features, tower cranes are an essential tool when constructing a tall building.

5. Rough Terrain Crane

A rough terrain crane is a crane that's mounted in an undercarriage with four rubber wheels, designed for operations off-road.

The outriggers extend vertically and horizontally to level and stabilize the crane when hoisting. These types of cranes are single-engine machines in which the same engine can be used for powering the undercarriage as it is for powering the crane.

These cranes are ideal for construction sites that have uneven, dirt, and rocky terrain. The mobility and ability of this crane to travel around the site make it an effect support crane for lighter hoists on the highway, infrastructure, and construction projects.

6. Overhead Crane

These types of cranes can also be known as suspended cranes. They are usually used at a factory, and some are able to lift very heavy loads.

The hoist of the crane is set onto a trolley that can move in one direction along a beam, sometimes both beams.

They move at angles to the direction across the ground or elevated level tracks. The tracks are usually mounted across the side of an assembly area.

7. Bridge Crane

The bridge crane also called an overhead crane is generally found in industrial environments.

Its name comes from the fact that it resembles a bridge supported by both steel beams, which straddle the workload, together with the hoist travelling along the bridge part of the crane.

There are both subtypes of overhead cranes: gantry and jib cranes.

Gantry

A variant of this overhead crane is the gantry crane, although sometimes both terms are used interchangeably. The most critical difference between a bridge and gantry crane is that the gantry crane is supported by both a-frame steel legs and is normally built on a track. Gantry cranes are generally seen at shipping docks and ports, lifting cargo off ships.

Jib Crane

Jib cranes are just another version of the bridge crane. These kinds of cranes are permanently installed within a workstation and usually utilized for repetitive tasks. The jib, or arm, is usually mounted on either a wall or floor-mounted pillar using a moveable hoist and might have some additional movement.

8. Crawler Crane

Crawler crane moves itself with the help of tracks that are also known as crawlers. It has many disadvantages and advantages depending on its use. Their main advantage is that it may move mostly on any surface of the earth; it may even move on soft soils because of its crawlers. Because it transfers its load to a great area. That is why it may be used at unprepared sites without worrying about anything. And their main disadvantage is that it is very heavy and move on tracks. That is why it can't be moved easily from one site to another and will cost more money. However, it can be moved by trucks easily and without costing much money.

9. Aerial Crane

These types of cranes can also be known as Sky Cranes. They looked like helicopters and used to carry large loads. They're used mostly because places where reaching by land is difficult. And as all of you know that Helicopters fly, that means they're capable of reaching any place. They generally lift loads to high rise buildings. They could lift anything in their capacity from boats, cars to pre-made swimming pools. They may also be used for rescue purposes in disaster.

10. Hydraulic Crane

Hydraulic cranes could be simple in design but can perform difficult tasks that would otherwise seem impossible. In a matter of minutes, these machines are capable of assembling beams on the roads, lifting heavy equipment in factories, as well as building houses.

11. Carry Deck Crane

Carry deck cranes are a relatively new type of crane which evolved from the older pick and carry model, which was first introduced in the 1980s. They are small, four-wheeled, can rotate a full 360 degrees, and are more portable than other types of cranes. Carry deck cranes are easy to set up, and their small size easily allows them to navigate around open and restricted spaces, making them a staple on many job sites.

12. Floating Crane

Also called a crane vessel or crane boat, these floating cranes are used for projects in the sea, like ports or oil rigs.

These cranes have a rich history they've been used since the middle Ages as well as with the help of continuous technological advancements, have helped many generations of people.

As of today, there are several types of floating cranes as well, like the sheer leg and semi-submersible. Nevertheless, the only difference floating cranes have from another common type is that they're used in the sea.

13. Bulk-handling Crane

Bulk-handling cranes are utilized to carry large volumes of heavy materials, such as coal or minerals. Instead of a hook at the end, bulk-handling cranes have a specialized hook that uses a grabbing mechanism along with a bucket to grab, hold, and lift materials.

14. Hammerhead Crane

Hammerhead cranes are a few of the most commonly utilized in construction projects. This crane has a horizontal, swiveling lever resting on a fixed tower.

The trolley is held at the forward part of the arm and can be counterbalanced with the part of the arm, which extends backwards.

Hammerhead cranes also offer a feature called racking, which allows the trolley to move forward and back horizontally along the crane arm. These cranes can be extremely heavy and are assembled on the job site.

15. Stacker Crane

Stacker cranes are automated machines using a forklift-like mechanism and are primarily designed for warehouse storage.

Normally, stacker cranes are used in places with special working conditions, such as extremely cold temperatures, making it unnecessary for a human worker to endure extreme working conditions.

16. Railroad Crane

These kinds of cranes move on the railway track. Rail Road Cranes are utilized for the construction of railway lines, maintenance, and for their repairing. They cannot travel on roads or another place except railway tracks because of the flanged wheels.

17. Harbor Cranes

This crane use for harbor area. So, called Harbor cranes, this crane use loading and unloading of ships.

18. Level Luffing Cranes

This crane features a special mechanism where the crane hook was made to stay at a constant level. Because of this, up and down motions of the jib arm is only going to move the hook towards, or away from, the base of the crane.

Advantage of this type of motion is that the crane could be set to operate at a fixed level relative to the ground, where such action is required to handle load materials with precision as may be often be required, for instance, during shipbuilding.

Sr.No.	Types of Cranes	Use of Cranes
1	Telescopic Crane	Highly adaptable for a variety of mobile situations
2	Mobile Crane	Lift heavy objects and move them short distances
3	Truck Mounted Crane	Mainly for loading and moving equipment on job site
4	Tower Crane	Building large structures
5	Rough Terrain Crane	Pick and carry operations on rough terrain
6	Overhead Crane	Extremely heavy or bulky loads through the overhead space in a facility
7	Bridge Crane	Typically used for industrial environments
8	Crawler Crane	Jobs with soft/uneven terrain
9	Aerial Crane	Places where it's hard to be reached by land cranes
10	Hydraulic Crane	A hydraulic crane is a type of heavy-duty equipment used for lifting and hoisting.
11	Carry Deck Crane	Loading and moving materials on job sites
12	Floating Crane	Projects on the sea, like ports or oil rigs
13	Bulk-handling Crane	Lifting and moving bulk cargo, like coal or scrap metal
14	Hammerhead Crane	One of the most commonly used crane types
15	Stacker Crane	Retrieval of cargo in warehouse storage
16	Railroad Crane	A railroad for one of three primary purposes: freight handling in goods yards, permanent way (PW) maintenance, and accident recovery work
17	Harbor Crane	Unloading small loads (balls, crates, etc.) from ships at the Port of Barcelona
18	Level Luffing Crane	Large project and industrial equipment installing field where large lifting capacity, high perching accuracy and high safety are required for lifting large members and equipment component

7 TYPES OF CRANES USED IN CONSTRUCTION WORKS

1. Telescopic Crane
2. Mobile Cranes
3. Truck Mounted Crane
4. Tower Crane
5. Rough Terrain Crane
6. Overhead Crane
7. Loader Crane

Civil engineering uses many different types of cranes during a project. They can be used to move heavy equipment or machinery. Many types of cranes can quickly and easily move equipment into trenches or down steep hills. They can move large pipes from one place to another.

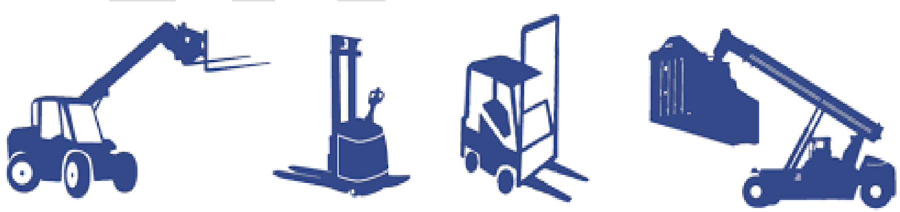
Cranes are beneficial in the construction process for buildings, bridges and overpasses. They are an indispensable asset to the construction and engineering fields.

Cranes have become a common sight on any work sight that involves heavy lifting or the lifting on materials onto higher areas. So using proper type of crane is important in construction works.

INDUSTRIAL TRUCKS

Industrial trucks are used to move materials over variable paths, with no restrictions on the area covered by the movement. The major types of industrial trucks are:

1. Hand truck
   a. Two-wheeled hand truck
   b. Dolly
   c. Floor hand truck
2. Pallet jack
   a. Manual pallet jack
   b. Powered pallet jack
3. Walkie stacker
   a. Manual walkie stacker
   b. Powered walkie stacker
4. Pallet truck
5. Platform truck
   a. Walkie platform truck
   b. Rider platform truck
6. Counterbalanced lift truck
   a. Sit-down counterbalanced lift truck
   b. Stand-up counterbalanced lift truck
7. Narrow-aisle straddle truck
8. Narrow-aisle reach truck
9. Turret truck
   a. Operator-down turret truck
   b. Operator-up turret truck
10. Order picker
11. Side loader
12. Tractor-trailer
13. Personnel and burden carrier
14. Automatic guided vehicle (AGV)
    a. Tow AGV
    b. Unit load AGV
    c. Assembly AGV
    d. Light load AGV
    e. Fork AGV



Uses of Industrial trucks:

- Used to move materials over variable (horizontal) paths with no restrictions on the area covered (i.e., unrestricted area)
- Provide vertical movement if the truck has lifting capabilities,
- Used when there is insufficient (or intermittent) flow volume such that the use of a conveyor cannot be justified,
- Provide more flexibility in movement than conveyors and cranes,
- Not licensed to travel on public roads—"commercial trucks" are licensed to travel on public roads.

Powered industrial trucks & Non-Powered industrial trucks:

Truck is a material handling equipment used to move parts and other materials from one place to another.

Industrial Trucks are categorized in to two types: They are:-

1) Powered Trucks 2) Non-Powered Trucks

1) Powered Trucks: These are self propelled trucks which are used to move loads from one place to other. Often these are used in warehouses and factories.

These are mainly classified in to three types:

a) Walkie Trucks b) Fork Lift rider trucks and c) Towing Tractors

a) Walkie Trucks: These trucks are battery powered trucks. The arrangement consists of forks which are inserted in a pallet. The steering lever is used to control the direction of vehicle which is supported by a driven unit. In this type of truck, worker cannot ride on the vehicle. The speed of these trucks is 5 KM/Hr which is equal to walking speed of human being.

Applications: It is used to carry loads to narrow spaces

b) Fork Lift rider trucks

These tucks are widely used than warlike trucks because the worker can sit and ride the vehicle in appropriate way. These are used to carry heavy loads ranging up to 450 kg-4500 kg. These trucks are driven by (Internal combustion). Engines or electric motors using batteries. The material can be transported to larger distances. These trucks are available in all sizes from 1-30 tonnes.

Applications:

These are most common type of truck used for handling most form of materials.

They are used as general purpose machines and are employed in trade and industry.

c) Towing Tractors

These trucks are modified form of trucks which consists of a trailing cart used for moving large amount of materials to distribution areas.

Applications:

These are used in both indoor and outdoor operations.

These are used at airports to transport goods.

2) Non-Powered Trucks

These are commonly known as hand trucks, because these trucks are moved manually by human workers.

These are mainly classified in to three types:

a) Two wheeled trucks

b) Dollies trucks

c) Pallet trucks

a) Two wheeled trucks

These trucks consist of more than one wheel, which are used to transport limited materials or parts. Rate of delivery is low. Cost of the truck is less compared to other trucks.

Applications:

These are used in industries to lift materials or components which are light in weight.

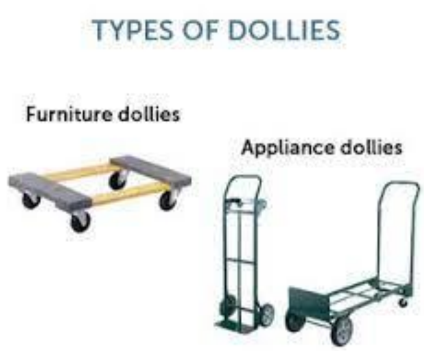
Used as sky caps at Airport.

b) Dollies trucks

These are called as multiwheeled hand trucks. The frames of dolly trucks are available in different sizes with various wheel configurations.

Applications:

Used to transport uniform objects.



c) Pallet trucks

It consists of pull lever, pallet and two forks. The two forks can be inserted into a pallet whenever required. The lever mechanism is actuated to lift the pallet from ground. When the load is placed on pallet the worker needs to pull the truck to its destination point.

Applications:

Used as baggage carts by porters in railway stations and bus stands etc.

Bulldozers

Bulldozer, also called Dozer, powerful machine for pushing earth or rocks, used in road building, farming, construction, and wrecking; it consists of a heavy, broad steel blade or plate mounted on the front of a tractor. Bulldozers are strong machines that mainly assist with pushing, digging, excavating, and levelling materials like soil and debris at a work site. They come with large, heavy blades in the front that push material. Some come with other modifications like rippers in the rear to help break down tough ground.

Three Main Types Bulldozer Types

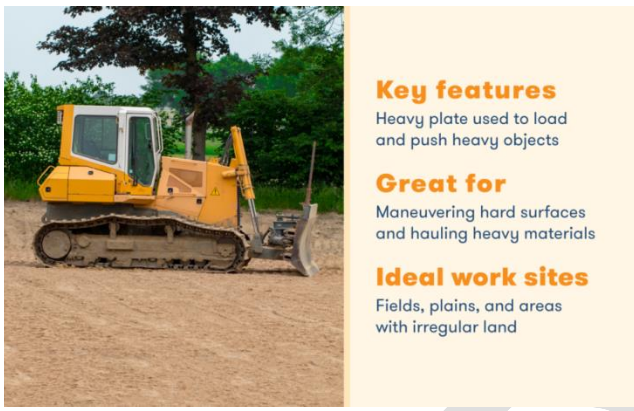
1) Crawler Bulldozer, 2) Wheel Bulldozer and 3) Mini Bulldozer

1) Crawler Bulldozer

A crawler is sometimes referred to as a track bulldozer and looks most similar to a tractor. This heavyweight is great for moving heavy materials from one area to another. This bulldozer is ideal for traversing dense and irregular terrain since the tracks give it great traction. Larger crawlers have rippers that assist with crushing and clearing dense terrain.

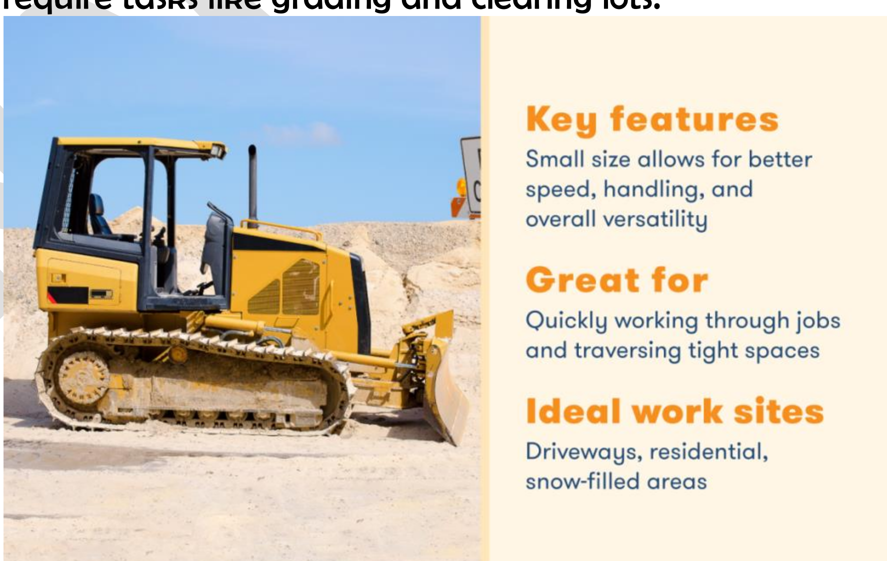
2) Wheel Bulldozer

This machine is sometimes referred to as a tire bulldozer and is normally larger than a crawler. A wheel dozer is more maneuverable than a crawler since its tires offer better overall handling. It also has completely articulated hydraulic steering and moves on a smaller axis. This machine is also ideal to use for soft or sensitive ground since the tires are gentler than tracks.



3) Mini Bulldozer

This smaller bulldozer is also known as a compact bulldozer. A mini dozer is great for projects that require more maneuverability and versatility than larger machinery. Thanks to its small size, a compact bulldozer can perform well in different types of projects that require tasks like grading and clearing lots.



BULLDOZER PARTS

A ripper is the extended attachment located at the rear of the bulldozer that resembles a claw. Rippers are used to break up land to allow agriculture to grow or break down rock and earth to be moved. You can find both single-shank rippers and multi-shank rippers depending on your project needs.

A bulldozer's final drives are likely the most used and most replaced part on a bulldozer. Modern final drives distribute the load over multiple gear teeth and lift the drive motor away from suspension.

The bulldozer's cab is an important part of this machine since it's where the operator controls this machine. There are different features for some cabs that increase both its level of comfort and safety. You should check to see if your cab reduces sound and absorbs impact while you're moving around the work site. These are crucial since operators can spend hours at a time inside the cab.

Tracks and tires greatly impact a bulldozer's mobility. Tracks are great for navigating hard, uneven terrain while tires are better suited for soft ground. You may also want to consider tires if you're working in a sensitive area that you don't want to damage.

Bulldozers generally require high-powered engines since they move lots of heavy materials around the work site. There are different types of engines that fulfill different needs. For example, some newer engines produce fewer emissions compared to older engines to comply with certain EPA requirements.

The push frame is essential when positioning materials for different tasks. This bulldozer part is responsible for moving the blade. The blade is the heavy metal plate located at the front of the bulldozer that is used to push and dig through materials. Like we mentioned earlier, different types of blades are better suited for specific projects.

ENERGY: POWER GENERATION

An **engine** or **motor** is a machine designed to convert one or more forms of energy into mechanical energy.

For Example:-

Heat Engine and Electric Motor

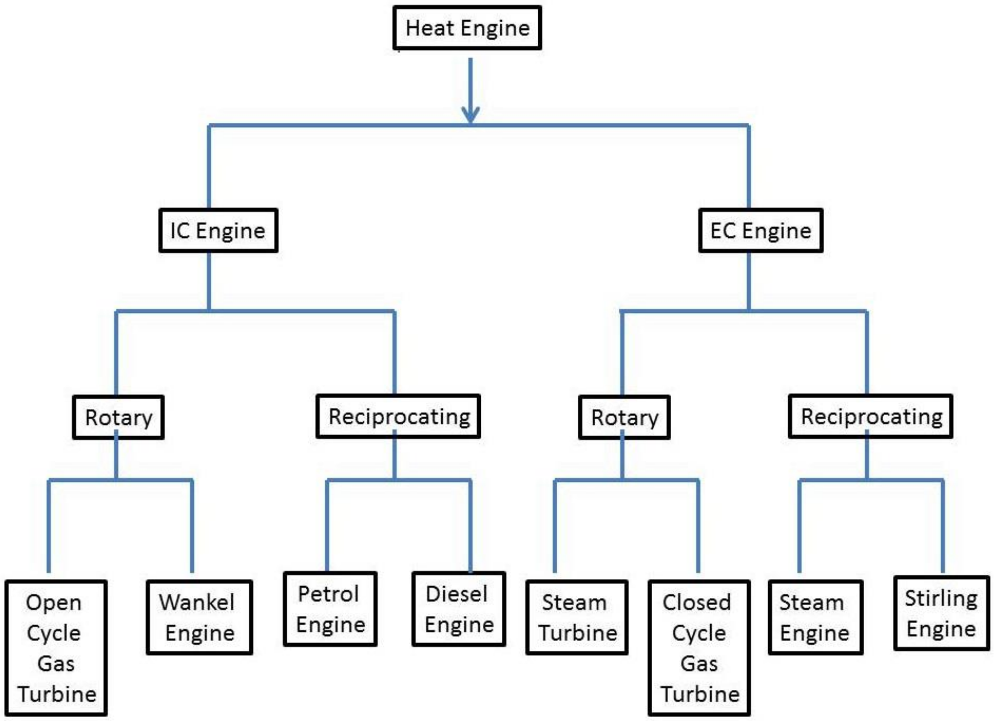
Heat Engine: A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work.

Electric Motor: An Electric Motor is a device which transforms the electrical energy into Mechanical Energy.

HEAT ENGINE:

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. It is classified into two types:-

(a) External combustion engine (b) Internal combustion engine



Combustion in Engines can take place externally as well as internally.

External combustion engine:

An **external combustion engine (EC engine)** is a reciprocating engine in which an **external heat source** is used to heat the (internal) working fluid through a heat exchanger or engine walls. As the fluid gets heat, it expands, generates power, and moves the vehicle.

In simple words, an **engine** in which the combustion of the **working fuel** occurs outside the **working cylinder** is called an **external combustion engine**.

"Don't waste your time in anger, regrets, worries, and grudges. Life is too short to be unhappy."

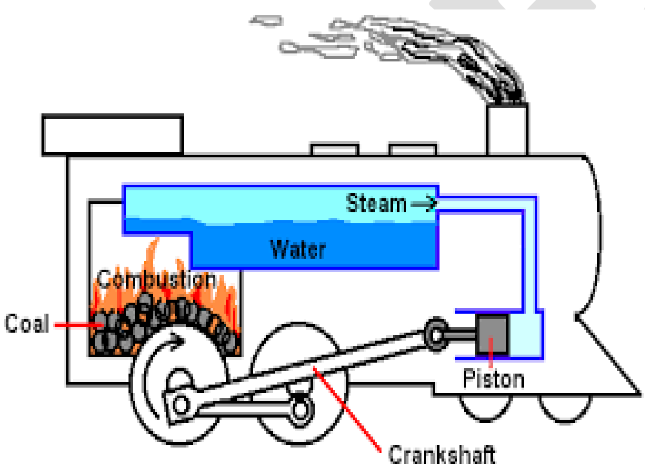
These types of engines use gas, steam, or liquid as a working fluid. In this engine, a fuel-air mixture is filled into the external combustion chamber. As the fuel-air mixture burns, a large amount of heat generates.

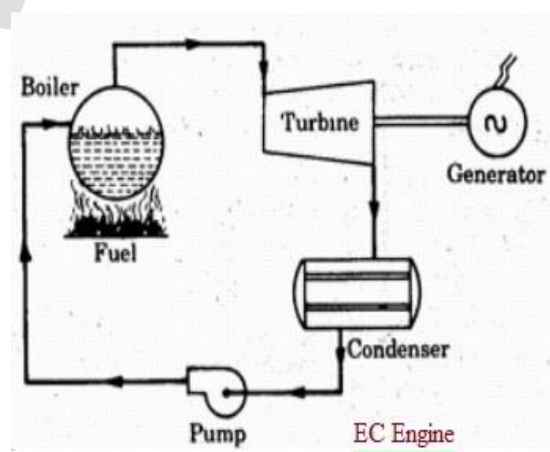
A heat exchanger or engine wall is used to transfer the produced heat from the external combustion chamber to the internal working fluid. When the internal fluid heats up, it expands and acts on the engine mechanisms, resulting in movement and available work.

A steam engine is a most common example of an external combustion engine. In this engine, as the steam enters the engine, it expends, rotates the piston, and converts thermal energy into mechanical power. In the case of a steam engine, the steam is generated outside the engine (i.e., boiler). Therefore, it is called an EC engine.

In the present time, the EC engines don't use in transportation applications due to the inefficiency of mobile design but are still used in power plants. These types of engines are most commonly used in hydroelectric power plants.

Coal-fired power plants work in a similar way: Coal is shipped from mines to power plants and burned in boilers. The pipes use to supply water to the boiler. As the water enters the boiler, the burning coal heats up the water and convert it into steam, which drives the turbine to produce electricity.





Working of External Combustion Engine:-

An external combustion engine is a type of engine in which an external heat source uses to burn the internal working fluid. The Stirling engine and steam engine are the most common types of EC engine.

An EC engine works in the following way:

1. First of all, the burning fluid (such as coal) is supplied to the external heat source (such as a boiler).

2. The water supply from the reservoir to the boiler.
3. As the water enters the boiler, the coal ignites and supplies heat to the water.
4. As the water temperature increases, it converts into steam.
5. After the water conversion into steam, steam passes through a compressor which compresses the steam and increases steam pressure.
6. When highly compressed steam reaches the engine cylinder, it expands and forces the piston to move forward and backward.
7. A crankshaft is connected to the piston. The piston delivers its motion to the crankshaft.
8. The crankshaft transforms the piston motion into rotatory motion and rotates the flywheel.
9. As the flywheel rotates, it further delivers power to the vehicle tires and helps to move the vehicle.

Parts and Function of External Combustion Engine:-

The external combustion engine has the below given major parts:

1. Cylinder
2. Piston
3. Flywheel
4. Connecting rod
5. Crankshaft
6. External heat source
7. Camshaft

1) Cylinder

The working cylinder is a part of the EC engine in which the working fuel(i.e., gas) is trapped. As it gets heat from the external heat source, it heats the working fluid, burns the fluid, and generates useful work.

2) Piston

This reciprocating component of the external combustion engine reciprocates inside the working cylinder. When the working fuel ignites in the cylinder, the generated power reciprocates the piston forward and backward. This motion of the piston further rotates the crankshaft.

3) Crankshaft

As the crankshaft gets reciprocating motion by the piston, it converts this motion into rotary motion and rotates the flywheel.

4) Flywheel

When the flywheel gets power by the crankshaft, it converts received rotary motion into mechanical power and moves the vehicle wheels.

5) Camshaft

The main function of the camshaft is to control the opening and closing of the inlet and outlet valves. This part of the engine ensures a proper opening and closing of the inlet and outlet valves and ensures a proper supply of fuel.

Advantages of External Combustion Engine:-

1. These engines have the capability to use all types of fuels.
2. The external combustion engines generate very low noise.
3. They have a low emission rate.
4. They are best suitable for high power generation applications.

Disadvantages of External Combustion Engine:-

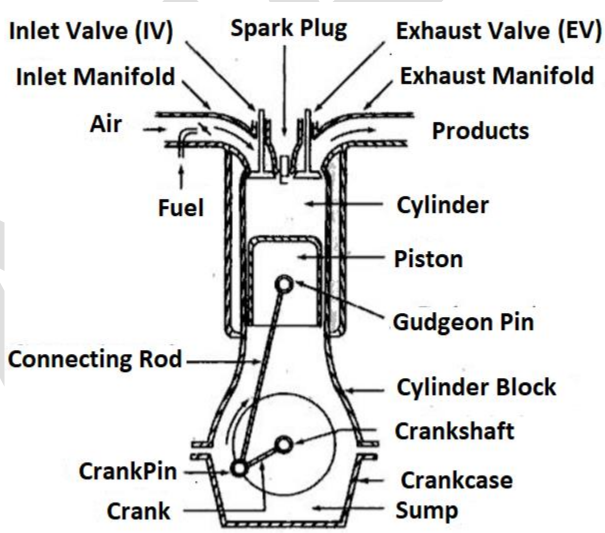
1. They are not ideal for low power generation applications.
2. They have working fluid leakage issues.
3. The EC engine has more size than the IC engine.
4. They consume more lubricate than the IC engines.
5. These engines have a high operational temperature. Therefore, they need more care and high construction material.

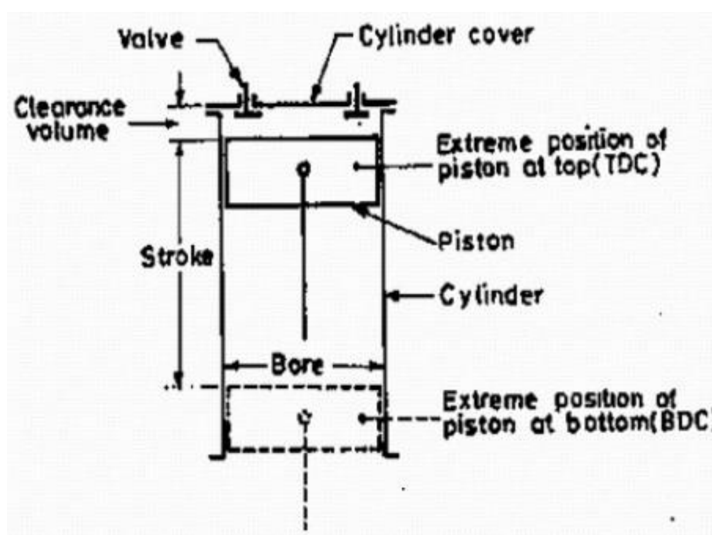
Applications of External Combustion Engine:-

1. The external combustion engines are used in Marine and Locomotive.
2. Use in the experimental space vehicles
3. Use in Power plants and Large Marine

Internal combustion engine:

In this engine, the combustion of air and fuels take place inside the cylinder and are used as the direct motive force.





UNIT - III ENERGY POWER 2023

It can be classified into the following types:
1. According to the basic engine design:-
(a) Reciprocating engine (Use of cylinder piston arrangement),
(b) Rotary engine (Use of turbine)

2. According to the type of fuel used:-
(a) Petrol engine,
(b) Diesel engine,
(c) Gas engine (CNG, LPG),
(d) Alcohol engine (ethanol, methanol etc)

3. According to the number of strokes per cycle:-
(a) Four stroke and
(b) Two stroke engine

4. According to the method of igniting the fuel:-
(a) Spark ignition engine,
(b) Compression ignition engine and
(c) Hot spot ignition engine

5. According to the working cycle:-
(a) Otto cycle (constant volume cycle) engine,
(b) Diesel cycle (constant pressure cycle) engine,
(c) Dual combustion cycle (semi diesel cycle) engine.

6. According to the fuel supply and mixture preparation:-
(a) Carburetted type (fuel supplied through the carburettor),
(b) Injection type (fuel injected into inlet ports or inlet manifold, fuel injected into the cylinder just before ignition).

7. According to the number of cylinder:-
(a) Single cylinder and
(b) Multi-cylinder engine

8. Method of cooling:-
Water cooled or air cooled

9. Speed of the engine:-
Slow speed, medium speed and high speed engine

10. Cylinder arrangement:-
Vertical, horizontal, inline, V-type, radial, opposed cylinder or piston engines.

11. Valve or port design and location:-
Overhead (I head), side valve (L head); in two stroke engines: cross scavenging, loop scavenging, uniflow scavenging.

12. Method governing:-
Hit and miss governed engines, quantitatively governed engines and qualitatively governed engine.

13. Application:-
Automotive engines for land transport, marine engines for propulsion of ships, aircraft engines for aircraft propulsion, industrial engines, prime movers for electrical Generators.

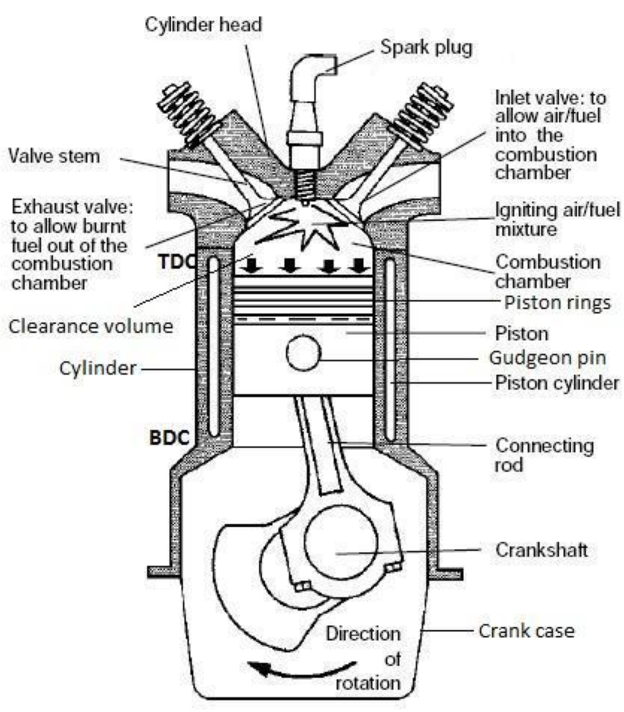
Main components of reciprocating IC engines:

Cylinder: It is the main part of the engine inside which piston reciprocates to and fro. It should have high strength to withstand high pressure above 50 bar and temperature above 2000 oC. The ordinary engine is made of cast iron and heavy duty engines are made of steel alloys or aluminum alloys. In the multi-cylinder engine, the cylinders are cast in one block known as cylinder block.

Cylinder head: The top end of the cylinder is covered by cylinder head over which inlet and exhaust valve, spark plug or injectors are mounted. A copper or asbestos gasket is provided between the engine cylinder and cylinder head to make an air tight joint.

Piston: Transmit the force exerted by the burning of charge to the connecting rod. Usually made of aluminium alloy which has good heat conducting property and greater strength at higher temperature.

Figure shows the different components of IC engine:-



Piston rings: These are housed in the circumferential grooves provided on the outer surface of the piston and made of steel alloys which retain elastic properties even at high temperature.

2 types of rings- compression and oil rings. Compression ring is upper ring of the piston which provides air tight seal to prevent leakage of the burnt gases into the lower portion. Oil ring is lower ring which provides effective seal to prevent leakage of the oil into the engine cylinder.

Connecting rod: It converts reciprocating motion of the piston into circular motion of the crank shaft, in the working stroke. The smaller end of the connecting rod is connected with the piston by gudgeon pin and bigger end of the connecting rod is connected with the crank with crank pin. The special steel alloys or aluminium alloys are used for the manufacture of connecting rod.

Crankshaft: It converts the reciprocating motion of the piston into the rotary motion with the help of connecting rod. The special steel alloys are used for the manufacturing of the crankshaft. It consists of eccentric portion called crank.

Crank case: It houses cylinder and crankshaft of the IC engine and also serves as sump for the lubricating oil.

Flywheel: It is big wheel mounted on the crankshaft, whose function is to maintain its speed constant. It is done by storing excess energy during the power stroke, which is returned during other stroke.

Terminology used in IC engine:

1. Cylinder bore (D): The nominal inner diameter of the working cylinder.
2. Piston area (A): The area of circle of diameter equal to the cylinder bore.
3. Stroke (L): The nominal distance through which a working piston moves between two successive reversals of its direction of motion.
4. Dead centre: The position of the working piston and the moving parts which are mechanically connected to it at the moment when the direction of the piston motion is reversed (at either end point of the stroke).
   (a) Bottom dead centre (BDC): Dead centre when the piston is nearest to the crankshaft.
   (b) Top dead centre (TDC): Dead centre when the position is farthest from the crankshaft.
5. Displacement volume or swept volume (Vs): The nominal volume generated by the working piston when travelling from the one dead centre to next one and given as,

$$V_s = A \times L$$

6. Clearance volume (Vc): the nominal volume of the space on the combustion side of the piston at the top dead centre.
7. Cylinder volume (V): Total volume of the cylinder.

$$V = V_s + V_c$$

8. Compression ratio (r): $r = V_s / V_c$

Advantages of internal combustion engines

1. Size of engine is very less compared to external combustion engines
2. Power to weight ratio is high
3. Very suitable for small power requirement applications
4. Usually more portable than their counterpart external combustion engines
5. Safer to operate
6. Starting time is very less
7. High efficiency than external combustion engine
8. No chances of leakage of working fluids
9. Requires less maintenance
10. Lubricant consumption is less as compared to external combustion engines
11. In case of reciprocating internal combustion overall working temperature is low because peak temperature is reached for only small period of time (only at detonation of fuel).

Disadvantages of internal combustion engines

1. Variety of fuels that can be used is limited to very fine quality gaseous and liquid fuel
2. Fuel used is very costly like gasoline or diesel
3. Engine emissions are generally high compared to external combustion engine
4. Not suitable of large scale power generation
5. In case of reciprocating internal combustion noise is generated due to detonation of fuel

Types and applications of internal combustion engines

1. Gasoline Engines: They are used for Automotive, Marine, Aircraft purposes.
2. Gas Engines: They are used for Industrial Power purposes
3. Diesel Engines: They are used for Automotive, Railways, Power, Marine purposes.
4. Gas Turbines: They are used for Power, Aircraft, Industrial, Marine purposes.

Four stroke engine:

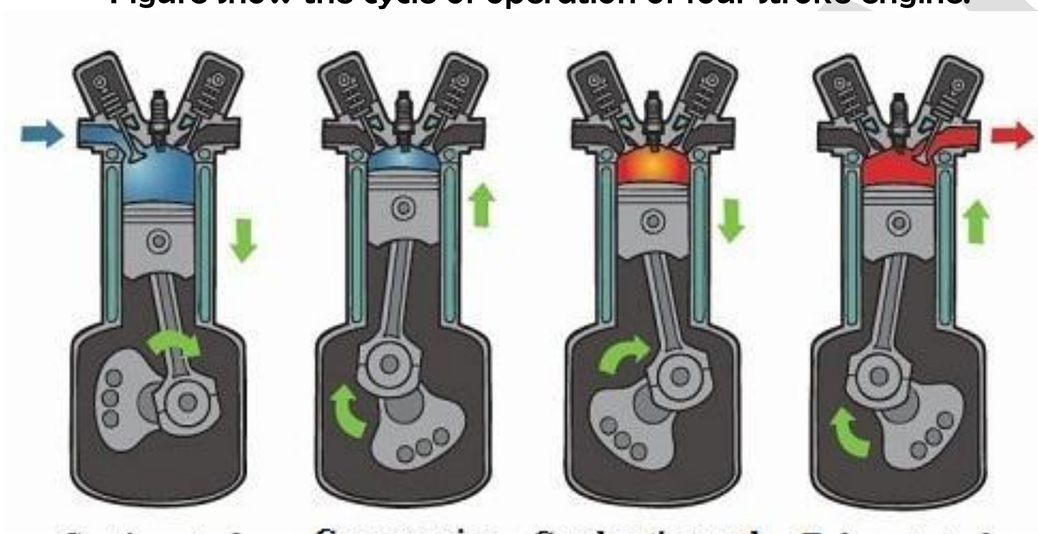
Cycle of operation completed in four strokes of the piston or two revolution of the piston. (i) Suction stroke (suction valve open, exhaust valve closed)-charge consisting of fresh air mixed with the fuel is drawn into the cylinder due to the vacuum pressure created by the movement of the piston from TDC to BDC.

(ii) Compression stroke (both valves closed)-fresh charge is compressed into clearance volume by the return stroke of the piston and ignited by the spark for combustion. Hence pressure and temperature is increased due to the combustion of fuel

(iii) Expansion stroke (both valves closed)-high pressure of the burnt gases force the piston towards BDC and hence power is obtained at the crankshaft.

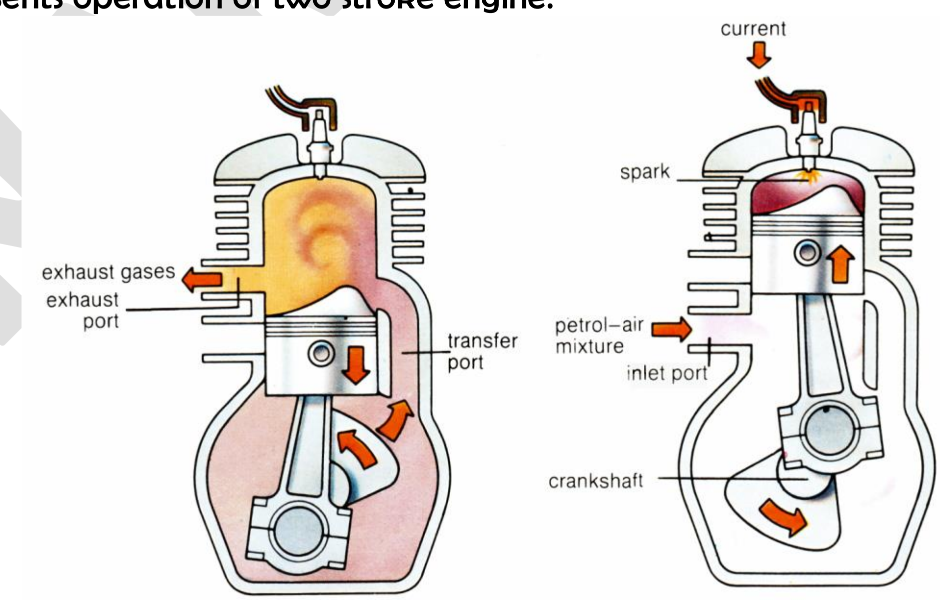
(iv) Exhaust stroke (exhaust valve open, suction valve closed)- burned gases expel out due to the movement of piston from BDC to TDC.

Figure show the cycle of operation of four stroke engine.



Two stroke engine:

Figure represents operation of two stroke engine:-



Cycle of operation in two stroke engine

-No piston stroke for suction and exhaust operations
-Suction is accomplished by air compressed in crankcase or by a blower
-Induction of compressed air removes the products of combustion through exhaust ports
-Transfer port is there to supply the fresh charge into combustion chamber

Comparison between external combustion engine and internal combustion engine:

External Combustion Engine	Internal Combustion Engine
In an EC engine, the burning process of the working fuel occurs outside the working cylinder.	In an IC engine, the burning process of the working fuel occurs inside the cylinder.
They have a large size.	They have small sizes.
The external combustion engine needs large installation space.	The internal combustion engine requires low installation space than the EC engine.
These engines have high weight.	They are light.
They are difficult to start.	They are very easy to start.
This engine requires more time for the initial start.	It starts very quickly.
The efficiency of the external combustion engine is between **15% to 25%.**	The efficiency of the IC engine is between **35% to 45%.**

External Combustion Engine	Internal Combustion Engine
It has a high capital cost.	It has a low capital cost.
The EC engine has low thermal efficiency.	The IC engine has high thermal efficiency.
The fuel used for EC engines has a low cost.	The fuel used for IC engines has high costs.
It is less efficient than an IC engine.	It is the most efficient engine.

Comparison between SI engine and CI engine:

SI ENGINE	CI ENGINE
Working cycle is Otto cycle.	Working cycle is diesel cycle.
Petrol or gasoline or high octane fuel is used.	Diesel or high cetane fuel is used.
High self-ignition temperature.	Low self-ignition temperature.
Fuel and air introduced as a gaseous mixture in the suction stroke.	Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke.
Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced.	Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump.
Use of spark plug for ignition system	Self-ignition by the compression of air which increased the temperature required for combustion
Compression ratio is 6 to 10.5	Compression ratio is 14 to 22
Higher maximum RPM due to lower weight	Lower maximum RPM
Maximum efficiency lower due to lower compression ratio	Higher maximum efficiency due to higher compression ratio
Lighter	Heavier due to higher pressures

Comparison between **Four-stroke engine** and **Two-stroke engine**:

Four-stroke engine	**Two-stroke engine**
Four stroke of the piston and two revolution of crankshaft	Two stroke of the piston and one revolution of crankshaft
One power stroke in every two revolution of crankshaft	One power stroke in each revolution of crankshaft
Heavier flywheel due to non-uniform turning movement	Lighter flywheel due to more uniform turning movement
Power produce is less	Theoretically power produce is twice than the four stroke engine for same size
Heavy and bulky	Light and compact
Lesser cooling and lubrication requirements	Greater cooling and lubrication requirements
Lesser rate of wear and tear	Higher rate of wear and tear
Contains valve and valve mechanism	Contains ports arrangement
Higher initial cost	Cheaper initial cost
Volumetric efficiency is more due to greater time of induction	Volumetric efficiency less due to lesser time of induction
Thermal efficiency is high and also part load efficiency better	Thermal efficiency is low, part load efficiency lesser
It is used where efficiency is important.	It is used where low cost, compactness and light weight are important
Examples:- cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc.	Examples:- lawn mowers, scooters, motor cycles, mopeds, propulsion ship etc.

Refrigeration

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

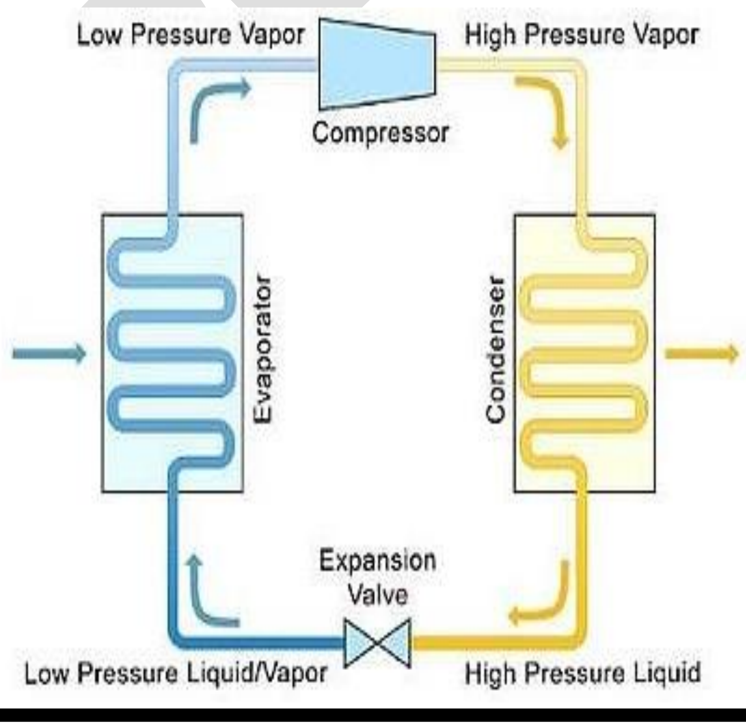
The aim is to cool some product or space to the required temperature.

In simple, refrigeration means the cooling of or removal of heat from a system. The equipment employed to maintain the system at a low temperature is termed as refrigerating system and the system which is kept at lower temperature is called refrigerated system.

In simple terms, a refrigeration cycle's mission is heat absorption and heat rejection. As any HVAC instructor will tell you (emphatically), *you can't make cold,* you can just remove heat. The refrigeration cycle, sometimes called a heat pump cycle, is a means of routing heat away from the area you want to cool. This is accomplished by manipulating the pressure of the working refrigerant (air, water, synthetic refrigerants, etc.) through a cycle of compression and expansion.

Four fundamental elements of a basic cycle are as follows:

- The compressor
- The condenser
- The expansion device
- The evaporator



The compressor

Compression is the first step in the refrigeration cycle, and a compressor is the piece of equipment that increases the pressure of the working gas. Refrigerant enters the compressor as low-pressure, low-temperature gas, and leaves the compressor as a high-pressure, high-temperature gas.

Compressor

Condenser

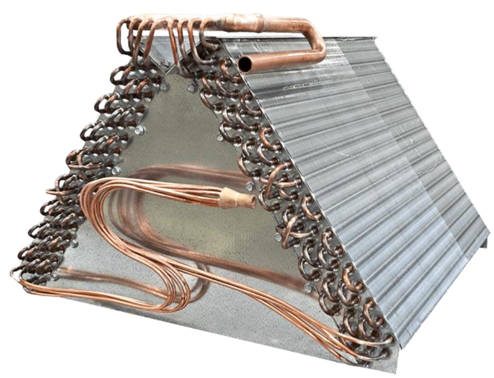
The condenser

A refrigerator's condenser is part of the system that removes heat from its interior. Combined with the evaporator unit within the fridge, the condenser removes heat from inside the refrigerator and transfers it to the outside of the unit.

The Expansion valve

Expansion valves are devices used to control the refrigerant flow in a refrigeration system. They help to facilitate the change of higher pressure of liquid refrigerant in the condensing unit to lower pressure gas refrigerant in the evaporator.

Expansion valve



Evaporator

The evaporator

The basic function of an evaporator in the refrigerator system is to remove the heat from the water, air, and other substances present in the refrigerator. The evaporators of refrigerator systems act as a heat exchanger which helps in transferring the heat from the substance and make it cool.

Applications (refrigeration):-

1. Ice making
2. Transportation of foods above and below freezing
3. Industrial air-conditioning
4. Comfort air-conditioning
5. Chemical and related industries
6. Medical and surgical aids
7. Processing food products and beverages
8. Oil refining and synthetic rubber manufacturing
9. Manufacturing and treatment of metals
10. Freezing food products
11. In submarine ships, aircrafts, and rockets, refrigeration have widespread applications.
12. Comfort air conditioning of hotels, residential buildings, hospitals, offices etc can be achieved.
13. Blood and human tissues can be preserved.
14. Concrete used for dams can be cooled easily.
15. It is applied in the processing of photographic materials.
16. Miscellaneous applications:
    (*i*) Extremely low temperatures
    (*ii*) Plumbing
    (*iii*) Building construction etc.

Mechanical Refrigeration Systems:-

The various refrigeration systems may be enumerated as below:

1. Ice refrigeration
2. Air refrigeration system
3. Vapour compression refrigeration system
4. Vapour absorption refrigeration system
5. Special refrigeration systems
    (*i*) Adsorption refrigeration system
    (*ii*) Cascade refrigeration system
    (*iii*) Mixed refrigeration system
    (*iv*) Vortex tube refrigeration system
    (*v*) Thermoelectric refrigeration
    (*vi*) Steam jet refrigeration system.

UNIT OF REFRIGERATION IN TERMS OF TON OF REFRIGERATION:

The Unit of refrigeration is "TON of Refrigeration". It is denoted by letter "TR". One TON of refrigeration is defined as "the amount of cooling effect produced by uniform melting of one ton of ice from and at 0°C in 24 Hours".

OR

One TON of refrigeration is defined as "the amount of heat removed to produce one TON of ice at 0°C in 24 Hours".

OR

One TON of refrigeration is defined as heat removal from ice at the rate of 210 kJ/min.

The Capacity of refrigerating machine is expressed in terms of TON of refrigeration.

Explanation:

One Ton of ice = 1000 kg
Latent heat of fusion of ice = 336 kj/kg
Time = 24*60 = 1440 minutes
Heat required for melting one ton of ice from and at 0ºC in 24 Hours:
Q = mL = 1000 * 336 = 336000 kJ/day
A Ton of refrigeration = 1 TR = 336000 kJ/day.
TR = (336000)/ (24*60) = 233 kJ/min
In all practical refrigeration applications
One TON of refrigeration is taken as 210 kJ/min
1 TR = 210 kJ/min
1 TR = 210/60 = 3.5 kJ/sec = 3.5 kW

Remember:

1. A Machine is capable of removing heat at the rate of 210 kJ/min is rated as one ton machine.
2. A one ton machine produces cooling effect in the given space at the rate of 210 kJ/min.
3. A 5 ton refrigerating machine is capable of producing cooling effect of 5*210 = 1050 kJ/min.

COEFFICIENT OF PERFORMANCE (COP):

The effectiveness (efficiency) of a refrigerating machine is expressed by energy ratio in the form of coefficient of performance. It is abbreviated ac COP.

Coefficient of performance of a refrigerating machine is defined as the ratio of the refrigeration effect produced to the work supplied.

COP = (refrigeration effect)/(Work supplied) = N/W

COP is the ratio between two energies and hence has no units. Its value may be less than or greater than one depending up on the type of application.

The COP calculated from taking actual values during a test is known as Actual COP.

The COP obtained from applying thermodynamics laws is known as Theoretical COP.

The ratio between actual COP and Theoretical COP is termed as Relative COP.

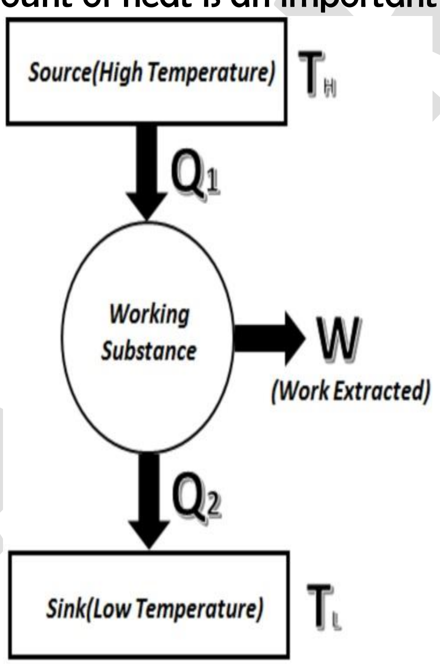
Relative COP = (Actual COP)/ (Theoretical COP)

Difference between a Heat Engine, Refrigerator and Heat Pump:-

OR

COP or Efficiency of a Heat Engine, Refrigerator and Heat Pump:-

Heat Engine: A heat engine is a system that converts Thermal energy into Mechanical Energy. In a heat engine, the heat supplied to the engine is converted into useful work. Q1 is the heat supplied to the engine and Q2 is the heat rejected from the heat engine. In Heat engine how much work is extracted from a given amount of heat is an important quantity.



$$Q_1 = W + Q_2 \quad \Rightarrow \quad W = Q_1 - Q_2$$

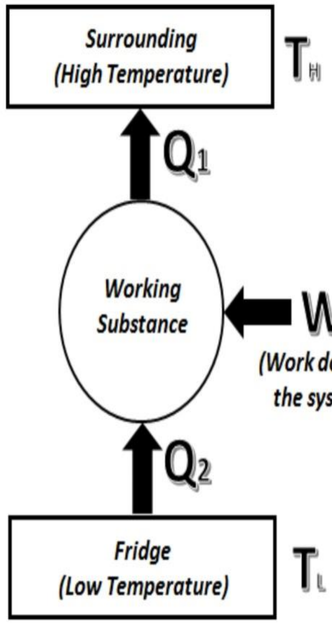
$$\text{Efficiency } (\eta) = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

or

$$\eta = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$$

For Heat Engine, $W < Q_1 \Rightarrow \eta < 1$

Refrigerator: A refrigerator is a reversed heat engine, where heat is pumped from low temperature (cold body--> Q2) to high temperature (hot body-->Q1). In refrigerator how much heat is extracted from lower temperature is an important quantity.



$Q_1 = W + Q_2 \Rightarrow W = Q_1 - Q_2$

Efficiency(**Coefficient of Performance**)

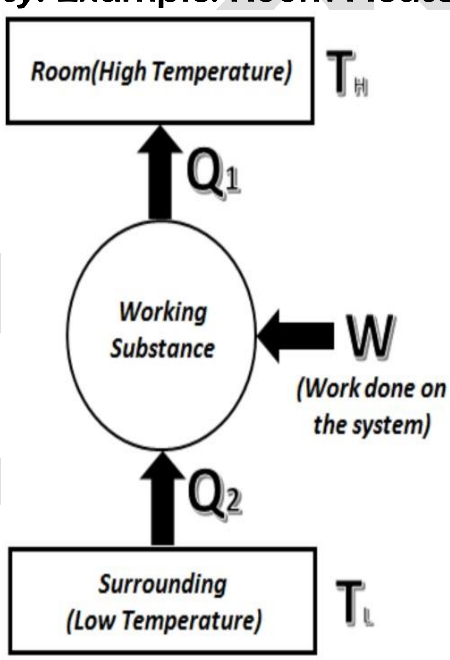
$$(\eta) = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

or $$= \frac{T_L}{T_H - T_L}$$

Important: For refrigerator $T_H > T_L$

$\Rightarrow \eta > 1$, if $T_H \leq 2T_L$

Heat Pump: Heat Pump is a device that transfers heat from a cold body (Q2) to a hot body (Q1) by using mechanical/electrical energy, as in a refrigerator. Heat Pumps may be used either to heat or cool. In heat pump how much heat is rejected at higher temperature is an important quantity. Example: Room Heater.



$Q_1 = W + Q_2 \Rightarrow W = Q_1 - Q_2$

Efficiency(**Coefficient of Performance**)

$$(\eta) = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2}$$

or $$\eta = \frac{T_H}{T_H - T_L}$$

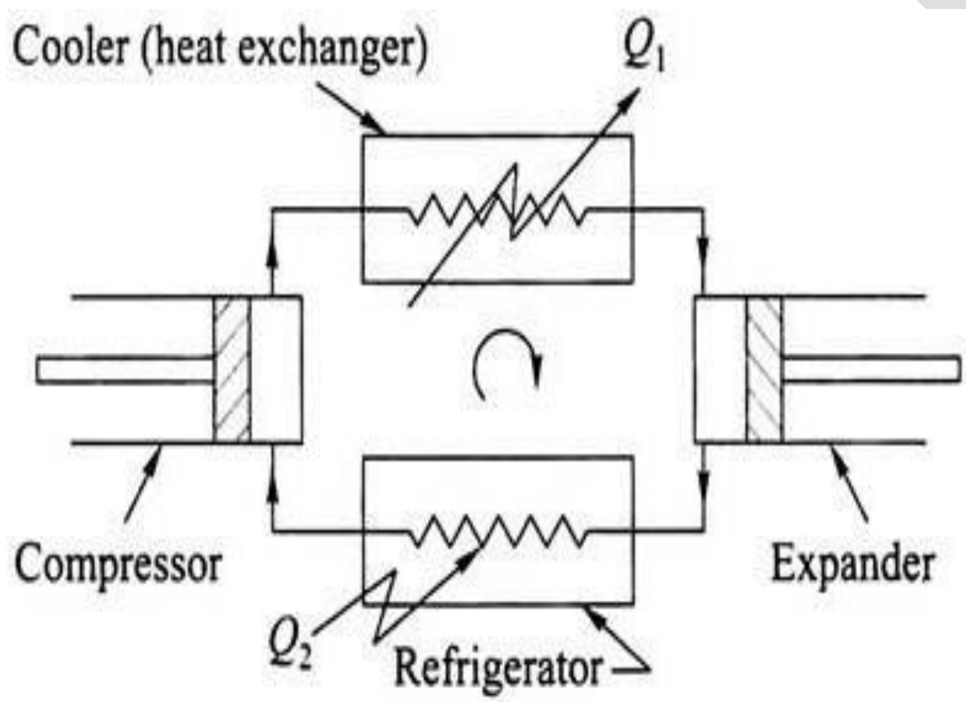
For Heat Pump, $Q_1 > W \Rightarrow \eta > 1$

AIR REFRIGERATION SYSTEM:-

Air Refrigeration system working on Bell-Coleman cycle.

The air cycle refrigeration system uses air as working fluid/refrigerant. This system is working on reversed Brayton cycle. Gas cycle refrigeration systems find applications in air craft cabin cooling and also in the liquefaction of various gases.

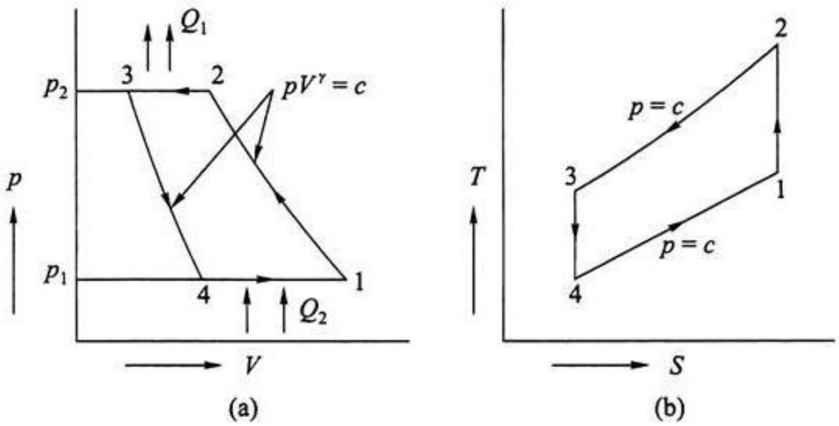
Figure shows a simple diagram of an air cycle refrigeration system known as Bell-Coleman cycle.



Following are the components of an air cycle refrigeration system:

(a) Compressor
(b) Cooler (heat exchanger)
(c) Expander
(d) Refrigerator

In this system, cooling effect is produced in the refrigerator. The system has very low COP. In spite of the fact that this system has low COP, this is still popular in aircraft cooling system. In this system, work obtained by the expander is used for the operation of the compressor. This is why less work is required for the operation of the system. Figures (a) and (b) show p-V and T-S plot for the cycle.



Bell–Coleman cycle on (a) p–V and (b) T–S plot

The various processes are:

Process 1-2: Air drawn from the refrigerator at (1) is supplied to the compressor where it is compressed isentropically by Process (1-2).

Process 2-3: High-temperature and high-pressure compressed air is supplied to the cooler where it gets cooled at constant pressure up to (3).

Process 3-4: The air at (3) is expanded by isentropic process up to (4).

Process 4-1: The cooled air is supplied to the refrigerator to produce cold effect. The air gets heated at constant pressure process during (4-1).

Considering m kg of air, heat absorbed in refrigerator, $Q2 = mCp\ (T1 – T4)$

Heat rejected in cooler, $Q1 = mCp\ (T2 – T3)$

Work required for the operation = $Q1 – Q2 = [mCp\ (T2 - T3) – mCp\ (T1 – T4)]$

$$\text{COP} = \frac{\text{Heat absorbed in refrigerator}}{\text{Work required}}$$

$$= \frac{mc_p(T_1 - T_4)}{[mc_p(T_2 - T_3) - mc_p(T_1 - T_4)]}$$

$$= \frac{1}{\left(\dfrac{T_2 - T_3}{T_1 - T_4}\right) - 1} \qquad 1$$

Considering Process (1–2),

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} = (P_r)^{\left(\frac{\gamma-1}{\gamma}\right)}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} = (P_r)^{\left(\frac{\gamma-1}{\gamma}\right)}$$

Hence, $\frac{T_2}{T_1} = \frac{T_3}{T_4}$

or $\frac{T_2}{T_3} = \frac{T_1}{T_4}$

$$\frac{T_2}{T_3} - 1 = \frac{T_1}{T_4} - 1$$

$$\frac{T_2 - T_3}{T_1 - T_4} = \frac{T_3}{T_4}$$

Equation **1** becomes

$$\text{COP} = \frac{1}{\left(\frac{T_3}{T_4}\right) - 1} = \frac{T_4}{T_3 - T_4}$$

Merits and Demerits of Air Cycle Refrigeration:

Merits:

(a) Air is non-flammable, so there is no chance of fire hazards.

(b) Air is cheaply and easily available as compared to other refrigerants.

(c) The weight of air refrigeration system per ton of refrigeration is much less as compared to other systems. Because of this reason, this system is employed in aircraft applications. Weight is an important consideration in aircrafts.

Demerits:

(a) The COP of the system is very low as compared to other systems.

(b) The amount of air required to be circulated for producing cold effect is more as compared to other refrigerants used in other systems. In this system, heat is carried by air in the form of sensible heats.

Vapour Compression Refrigeration Cycle

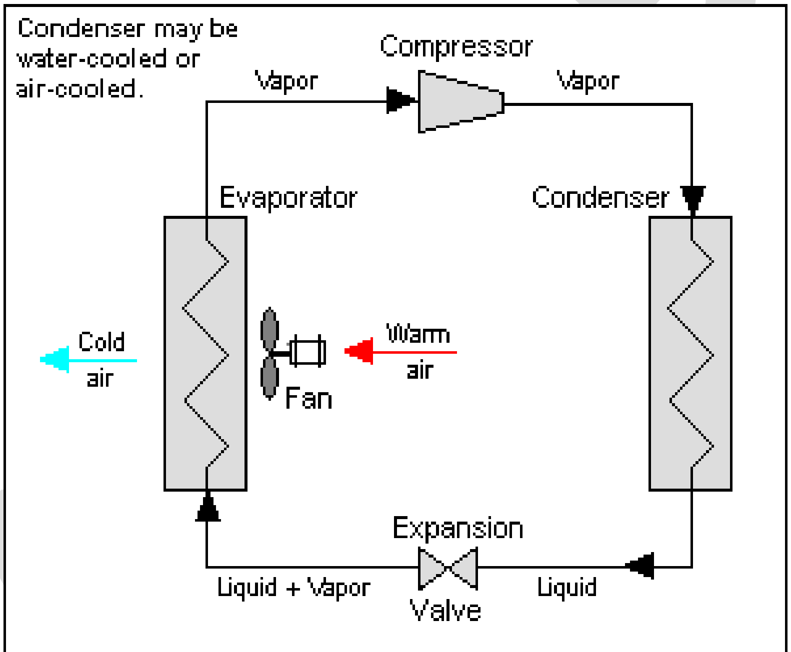
Vapour Compression Refrigeration Cycle is the most widely used refrigeration system. In this system, the working fluid is a vapor. It readily evaporates and condenses or changes alternatively between the vapor and liquid phase without leaving the refrigerating plant.

During evaporation, it absorbs heat from the cold body and this heat is used as its latent heat for converting it from liquid to vapour whereas in Condensing or cooling, it rejects heat to external bodies, thus creating a cooling effect in the working fluid.

Components of Vapour Compression Refrigeration System:

The figure above consists of the following five essential parts, those are:

1. Compressor 2. Condenser 3. Receiver 4. Expansion Valve 5. Evaporator



TYPICAL SINGLE-STAGE VAPOR COMPRESSION REFRIGERATION

Working of Vapor Compression Refrigeration System:

The working of Vapor Compression Refrigeration System can be completed under 4 processes and are as follows.

Compression Process: The vapour at low temperature and low pressure enter the compressor where it is compressed isentropically and subsequently, its temperature and pressure considerably increase.

Condensation Process: This vapour after leaving the compressor enters into the condenser, where it is condensed into high-pressure liquid and is collected in a receiver tank.

Expansion Process: From the receiver tank, it passes through the expansion valve, where it is throttled down to low pressure and temperature.

Vaporization Process: After finding its way through an expansion valve, it finally passes onto the evaporator, where it extracts heat from the surroundings or circulating fluid and vaporizes to lower pressure vapour.

If expansion takes place without throttling, temperature level drops to a very low level due to which it should undergo sensible heat and latent heat in order to reach the evaporation stage.

Note:

- Work is done by the compressor.
- The heat extracted from the evaporator is the difference of heat entering the evaporator and heat leaving the evaporator.

Types of Vapor Compression Cycles:

The types of Vapor Compression Cycles which are important from the subject point of view are as follows.

1. Cycle with superheated vapor after compression
2. Cycle with superheated vapor before compression
3. Cycle with wet vapor after compression
4. Cycle with dry saturated vapor after compression
5. Cycle with under cooling or sub cooling of the refrigerant

Advantages:

- The temperature at the evaporator section can be controlled employing regulation of expansion valve.
- It exhibits high Coefficient of Performance.
- The running cost is low because the volume circulation of the refrigerant is low in the system.

Disadvantages:

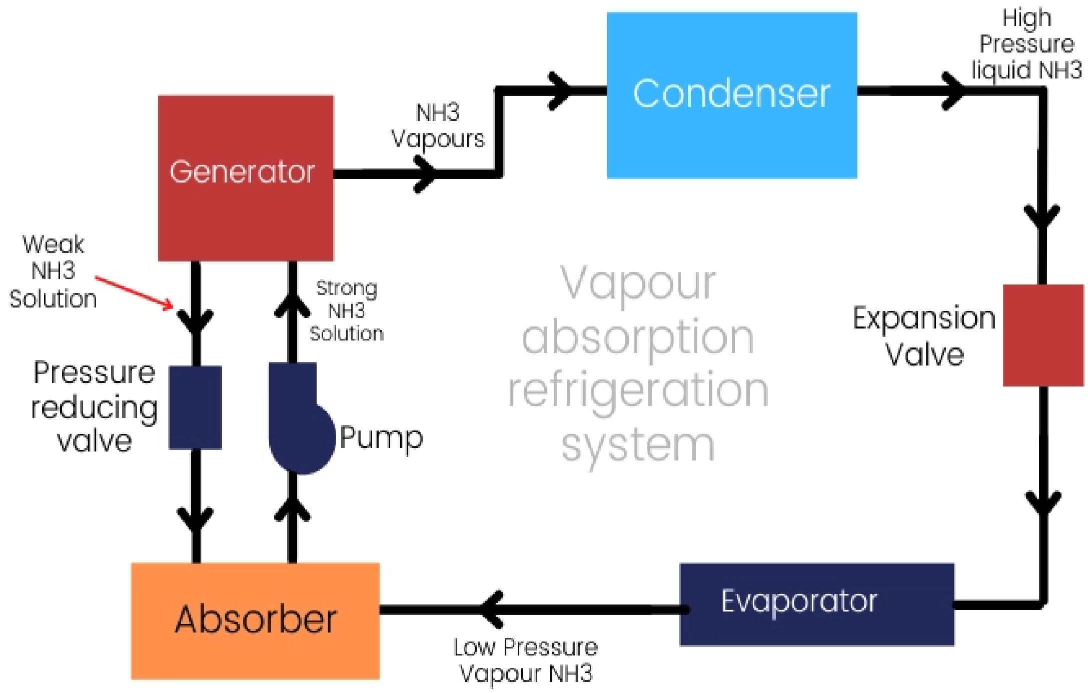
- Make sure that there should be no leakage of refrigerant from the pipes/hose.
- Refrigerant can affect the atmosphere.
- The cost of the system is high.

Applications:

- It is used in domestic refrigeration for keeping the food.
- It is helpful in food processing and cold storages.
- It is useful in Industrial refrigeration for chemical processing, heating and cooling.
- It is useful in Cryogenic refrigeration, Medical refrigeration, Transport refrigeration and Electronic cooling.

Vapour Absorption Refrigeration System

Compared to the Vapour compression system, in the vapour absorption system compressor is replaced by Generator, Absorber & Pump. In this System, Ammonia (NH3) is used as Refrigerant & Water + Ammonia is used as Absorbent.



It consists Of Condenser, Generator, Absorber, Expansion Valve, and Pressure Reducing Valve & Pump.

A) ABSORBER: From Evaporator, Vapour NH3 Enters into Absorber. An absorber is already filled with Absorbent (water+NH3). Absorbent Absorbs the NH3 Vapours and Strong NH3 Solution is Forms. During Absorption of NH3, Heat is generated.
If Temperature inside the Absorber Increases, Water will lose Absorbing Capacity so a Strong NH3 Solution will Not Form.
Hence Cooling is Available at Absorber.

B) Pump: It is used to suck the Strong NH3 Solution from Absorber & Deliver to Generator.

C) Generator: It is used to Heat the NH3 Solution with the help of heating Coils. From Pump, Strong NH3 Enters into the Generator. This NH3 Heated by Generator, Hence High-Pressure NH3 Vapours is Form.

From Generator High-Pressure NH3 Vapours Goes to Condenser & Remaining Weak Solution From Generator Returns to Absorber through Pressure Reducing Valve (PRV).
If this Weak Solution Goes to Condenser, It may damage the system.

D) Pressure reducing valve (PRV): It is used to reduce Pressure of Weak NH3 Solution. It is located Between the Generator & Absorber.

E) Condenser: From Evaporator, NH3 Vapours Enter into the Condenser. Condensation Is Heat Removal Process. Hence in Condenser heat is remove from NH3 Vapours with the help of a Cooling Medium. After Condenser, High-Pressure Liquid NH3 Goes to Expansion Valve.

F) Expansion valve: Expansion Valve is located between the condenser & evaporator. After the condenser, high-pressure liquid NH3 Enters into Expansion Valve. Expansion Valve Converts the High-Pressure Liquid NH3 to Low-Pressure Vapour NH3 by Expansion. After Expansion Valve, Liquid NH3 Goes to Evaporator.

G) Evaporator: After Expansion Valve, Low-Pressure NH3 Vapours Enters into the Evaporator. Evaporator Absorbs the Heat from Enclosed Room (to be cooled) with the help of NH3.
After Evaporator, Vapour NH3 Goes to Absorber.

Working:

1) When Vapour NH3 from Evaporator Enters into the Absorber, It gets Absorbed by Absorbent (water + NH3) and Strong NH3 Solution Forms.

2) The Strong NH3 Solution from Absorber Suck by Pump & Deliver to Generator.

3) When Strong NH3 Solution enters into Generator, Generator heats the NH3 Solution with the help of Heating Coils.

4) From Generator High-Pressure Vapour NH3 Forms which is Flows through Condenser. The Weak Solution Remains in Generator is Returns to Absorber through Pressure Reducing Valve.

5) When High-Pressure Vapour NH3 enters into Condenser, Condenser Removes the heat from Vapour NH3 with the help of Cooling Medium.

6) After Condenser, High-Pressure Liquid NH3 enters into the Expansion Valve, where it expands and Converted into Low-Pressure Vapour NH3.

7) After Expansion Valve, Vapour NH3 Enters into the Evaporator, Where It Absorbs heat from Enclosed Room (to be cooled).

8) After Evaporator, Vapour NH3 again enters into the Absorber.

Hence In this way Cycle Continues and provides Cooling to Enclosed Room.

Advantages:

1. Less wear and tear due to less number of moving parts.
2. No compressor or any reciprocating component is required.
3. Use of low grade energy (heat energy) to change the condition of refrigerant leaving the Evaporator.
4. No refrigerant leakage problem.
5. Less noisy, because the system has only one moving part (i.e., pump).
6. Exhaust stream may be used as a source of heat energy in the generator.
7. System can be used in remote places, where availability of electricity is a problem.
8. Easy to control.
9. Load variations don't affect the performance of system.
10. Less overall cost & more life.
11. Environment friendly.

Disadvantages:

1. Lower COP
2. It takes more time to produce the same refrigerating effect, as compared to VCC.
3. Bulky in Size.
4. Costly pump is required.
5. If kerosene is used for supplying heat energy to the generator ,it gives out bad smell.

Modes & Mechanisms of Heat Transfer

The heat transfer is defined as the transmission of heat energy from one region to another region as a result of temperature gradient. In actual practice, the heat transfer always takes place from the region of high temperature to the region of low temperature.

Modes of Heat Transfer

The transfer of heat energy from one region to another region takes place by the following three modes:-

1. Conduction (Energy transfer in a solid)
2. Convection (Energy transfer in a fluid)
3. Radiation (Does not need a material to travel through)

Conduction:

When the heat transfers from one part of the substance to another part without the movement in the molecules of the substance, it is called the conduction mode of heat transfer.

In this mode, the rate of heat transfer, i.e., the rate of conduction of heat along the substance depends upon the temperature gradient.

The rate of heat transfer through conduction is governed by Fourier's law of heat conduction.

$$Q = - KA\ (dT/dx)$$

Where, 'Q' is the heat flow rate by conduction
'K' is the thermal conductivity of body material
'A' is the cross-sectional area normal to the direction of heat flow and
'dT/dx' is the temperature gradient of the section.

Following are the examples of conduction:

- Ironing of clothes is an example of conduction where the heat is conducted from the iron to the clothes.
- Heat is transferred from hands to ice cube resulting in the melting of an ice cube when held in hands.
- Heat conduction through the sand at the beaches. This can be experienced during summers. Sand is a good conductor of heat.

Convection

When the transfer of heat takes place from one part to another part of the substance or fluid due to the actual motion of the molecules, it is called the convection mode of heat transfer. In this method, the rate of heat transfer depends mainly upon the difference in the fluid density at different temperature.

The transfer of heat energy from *immersion water heater* to water is an example of convection mode of heat transfer. The amount of heat absorbed by water from the heater through convection partly depends upon the temperature of the heating element and partly upon the position of the heater.

The rate of convective heat transfer is governed by Newton's law of cooling.

$$Q = hA(T_s - T_\infty)$$

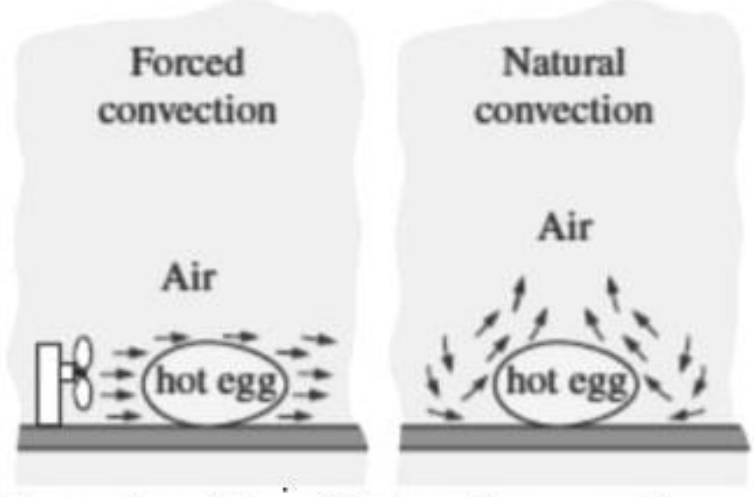
Where,

Where 'T_s' is the surface temperature
'T_∞' is the outside temperature
'h' is the coefficient of convection.

Types of Convection:

Forced Convection- Convection is called forced convection if the fluid is forced to flow over the surface by external means such as a fan, pump, or the wind.

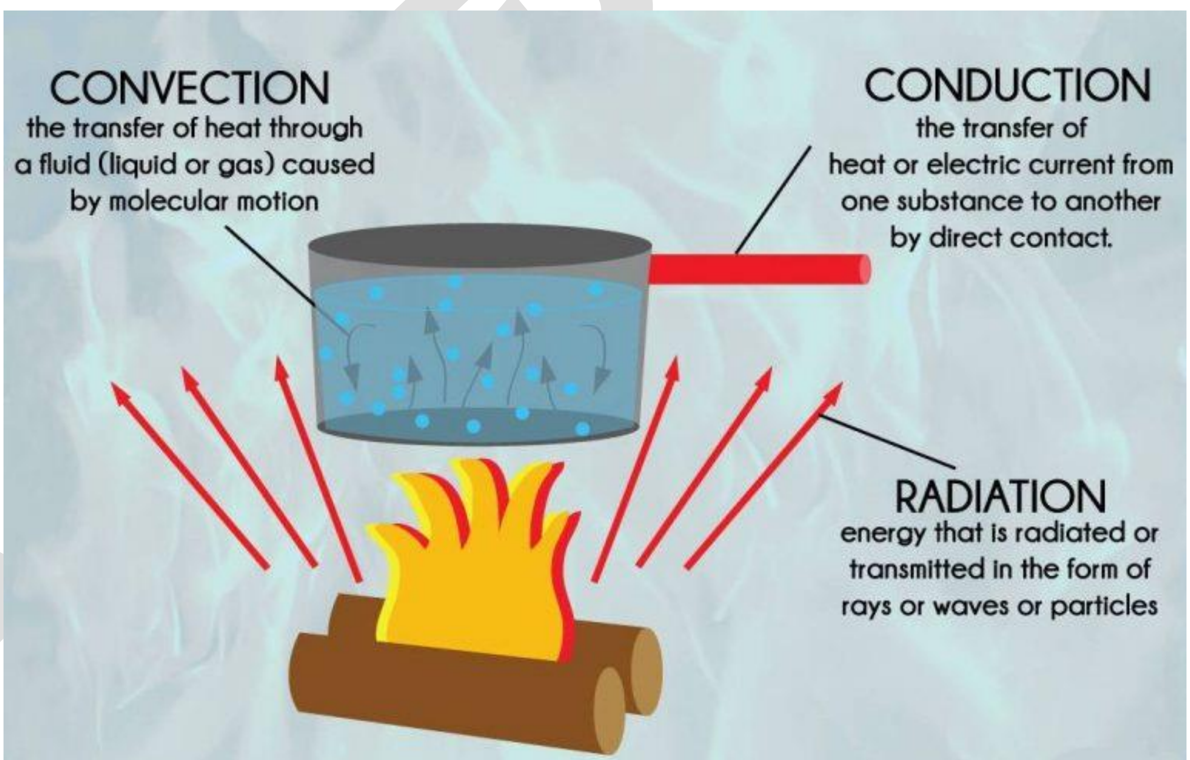
Natural or Free Convection- In contrast, convection is called natural (or free) convection if the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid.



Forced and Free (Natural) convection

Examples of convection include:

- Boiling of water, that is molecules that are denser move at the bottom while the molecules which are less dense move upwards resulting in the circular motion of the molecules so that water gets heated.
- Warm water around the equator moves towards the poles while cooler water at the poles moves towards the equator.
- Blood circulation in warm-blooded animals takes place with the help of convection, thereby regulating the body temperature.



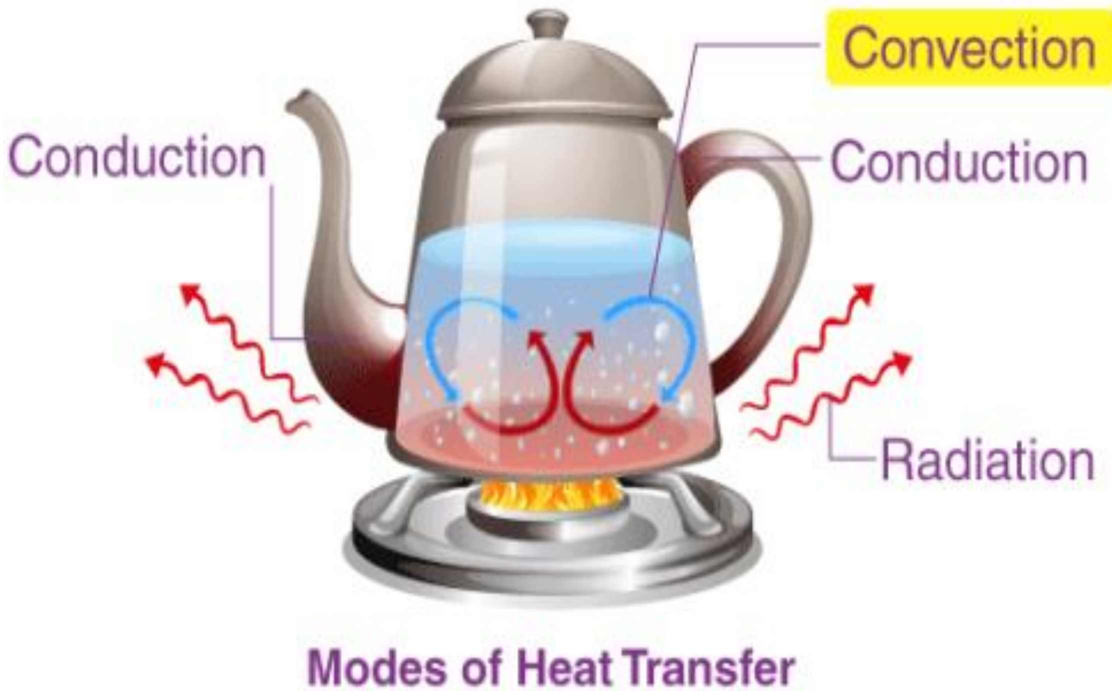
Radiation

When the heat transfer takes place from the source of heat to the substance to be heated without direct contact between them, it is called the radiation mode of heat transfer. The heat transfer through the radiation depends upon the surface. The transfer of heat in case of *solar heater*is an example of radiation mode of heat transfer.

The rate of heat radiation that can be emitted by a surface at a thermodynamic temperature is based on Stefan-Boltzmann's law.

$$Q = \sigma.T^4$$

Where 'T' is the absolute temperature of the surface
'σ' is the Stefan-Boltzmann constant.

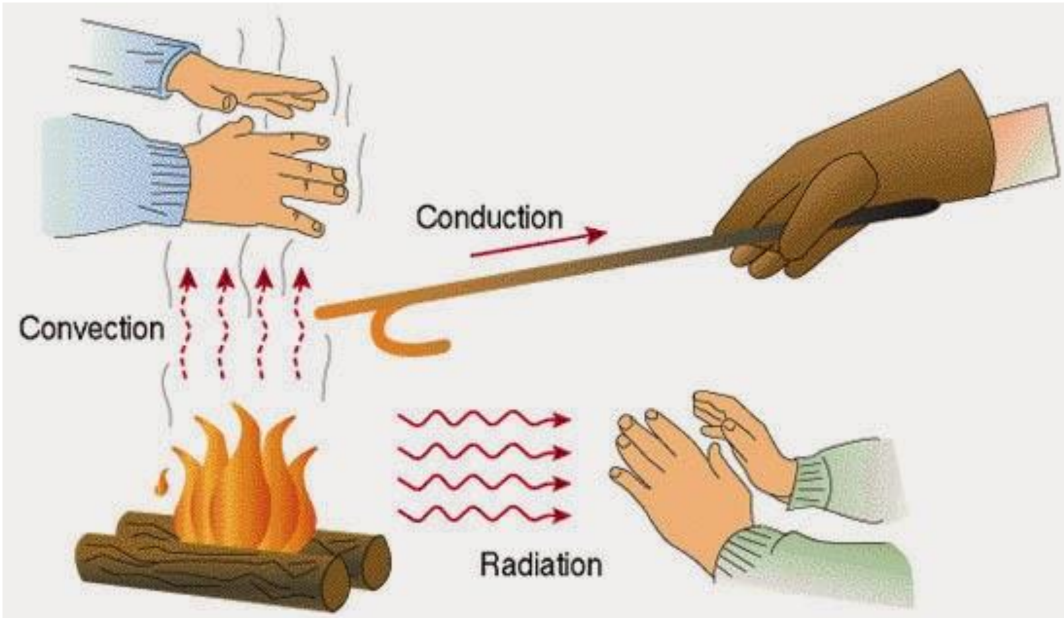


Following are the examples of radiation:

- Microwave radiation emitted in the oven is an example of radiation.
- UV rays coming from the sun is an example of radiation.
- The release of alpha particles during the decaying of Uranium-238 into Thorium-234 is an example of radiation.

Unit of Heat Transfer:-

SI system - Joule, MKS system - cal, Rate of transfer of heat – KW



Comparison between conduction and convection are as follows:-

1	It is the mode of heat transfer from one part of substance to another part of same substance or one substance to another without displacement of molecules or due to the vibrations of molecules.	It is the mode of heat transfer from one part of a substance to another part of same substance or one substance to another with a displacement of molecules or due to the fluid flowing.
2	It is the mode of heat transfer in which fluid particles do not mix with each other.	It is the mode of heat transfer in which fluid particles mix with each other.
3	It occurs in solid.	It occurs in liquid and gases.
4	It governs by Fourier's law of heat conduction.	It governs by Newton's law of convection heat transfer.
5	Example: Heat flow from one end to other end of metal rod.	Example: Heat flow from boiler shell to water.

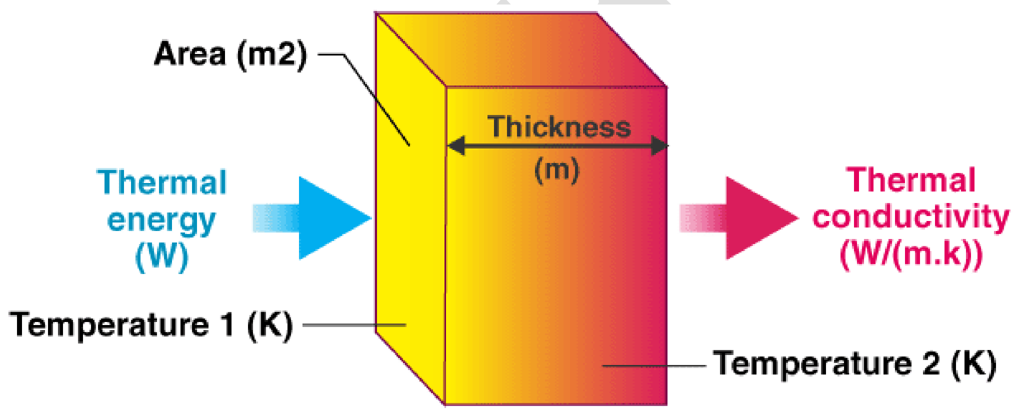
What is Thermal Conductivity?

Thermal conductivity refers to the ability of a given material to conduct/transfer heat. It is generally denoted by the symbol 'k' but can also be denoted by 'λ' and 'κ'. The reciprocal of this quantity is known as thermal resistivity. Materials with high thermal conductivity are used in heat sinks whereas materials with low values of λ are used as thermal insulators.

Fourier's law of thermal conduction (also known as the law of heat conduction) states that the rate at which heat is transferred through a material is proportional to the negative of the temperature gradient and is also proportional to the area through which the heat flows. The differential form of this law can be expressed through the following equation:

$$q = -k.\nabla T$$

Where ∇T refers to the temperature gradient, q denotes the thermal flux or heat flux, and k refers to the thermal conductivity of the material in question.



An illustration describing the thermal conductivity of a material in terms of the flow of heat through it is provided above. In this example, Temperature1 is greater than Temperature2. Therefore, the thermal conductivity can be obtained via the following equation:

$$\text{Heat Flux} = -k * (\text{Temperature2} - \text{Temperature1})/\text{Thickness}$$

Formula

Every substance has its own capacity to conduct heat. The thermal conductivity of a material is described by the following formula:

$$K = (QL)/(A\Delta T)$$

Where,

K is the thermal conductivity in W/m.K
Q is the amount of heat transferred through the material in Joules/second or Watts
L is the distance between the two isothermal planes
A is the area of the surface in square meters
ΔT is the difference in temperature in Kelvin

Measurement

There exist several methods of measuring the thermal conductivities of materials. These methods are broadly classified into two types of techniques – transient and steady-state techniques.

SI Unit

Thermal conductivity is expressed in terms of the following dimensions: Temperature, Length, Mass, and Time.
The SI unit of this quantity is watts per meter-Kelvin or Wm-1K-1.
It is generally expressed in terms of power/(length * temperature).
These units describe the rate of conduction of heat through a material of unit thickness and for each Kelvin of temperature difference.

Thermal Conductivity (k)

- The thermal conductivity of a material can be defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference.
- The thermal conductivity of a material is a measure of the ability of the material to conduct heat.
- A high value for thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or insulator.
- Note that materials such as copper and silver that are good electrical conductors are also good heat conductors, and have high values of thermal conductivity.
- Materials such as rubber, wood, and Styrofoam are poor conductors of heat and have low conductivity values.

Applications of heat transfer:

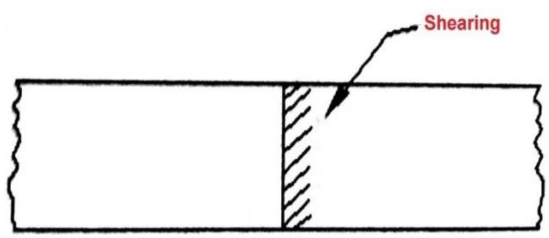
1) Fins provided on the motorcycle engine.
2) Cooling jackets provided in cylinder blocks
3) Radiators
4) Heat carried away by exhaust gases
5) Heat transfer from sun rays into the cabin/car.

Sheet metal operations:

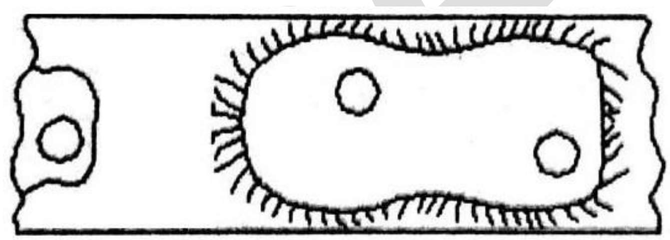
1. Shearing Operations 2. Blanking Operations 3. Punching Operations
4. Piercing Operations 5. Trimming Operations 6. Drawing Operations
7. Embossing Operations 8. Bending Operations 9. Squeezing Operations

1. Shearing

It is a cut in a straight line across a strip, sheet or bar. It leaves a lean edge on the piece of metal is sheared or cut. In this operation, a sheet metal workpiece is placed or kept between two dies from one end. And, the punch is hit at the other end of the sheet, producing a shearing effect.



Shearing Operation



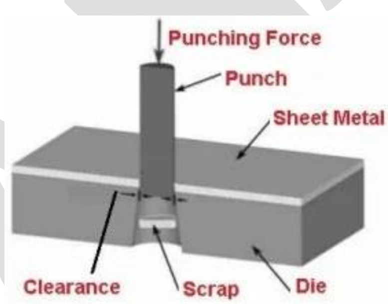
Blanking Operation

2. Blanking

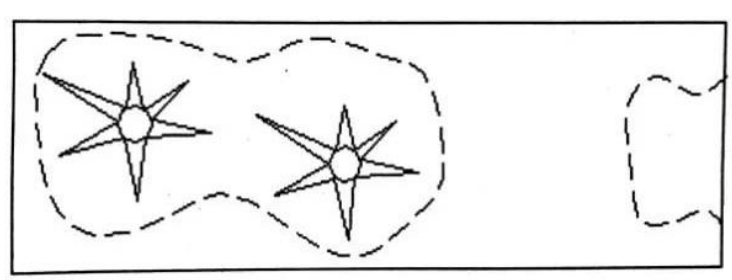
It is an operation of cutting a whole piece from sheet metal. In which enough scrap is left all around as shown in fig. A punch and die is applied for this type of sheet metal operation.

3. Punching

It is an operation of producing circular holes on a sheet of metal by a punch and die. This is the exact opposite of blanking but the operation is nearly the same. A Punch and die are further used here such as blanking operations.



Punching Operation



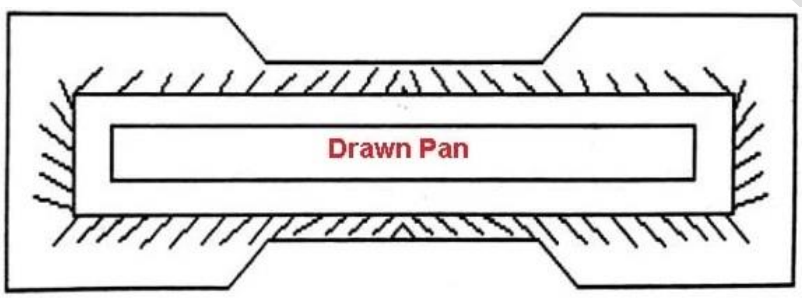
Piercing Operation

4. Piercing

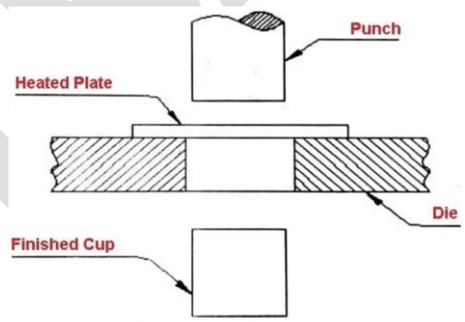
Piercing is the process in which desired shape holes are produced in a piece of sheet metal without eliminating any material from the sheet or removing a very small amount of material as shown in the figure. Both punch and die are also applied in this operation. The punch used in the piercing operation is usually bullet-shaped.

5. Trimming

The trimming operation is also known as shaving operation. It is a finishing operation by removing the burrs from the cut edges is taken out in order to make edges smooth and also provide dimensional accuracy.



Trimming Operation



Drawing Operation

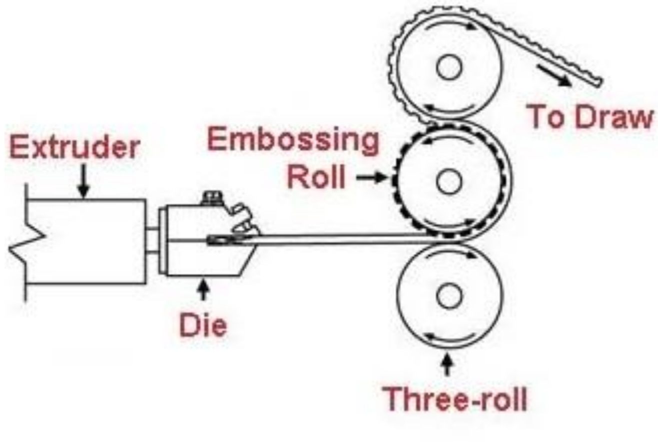
6. Drawing

It is an operation of producing thin-walled hallows or vessel shaped parts from sheet metal. It can be divided into two categories:

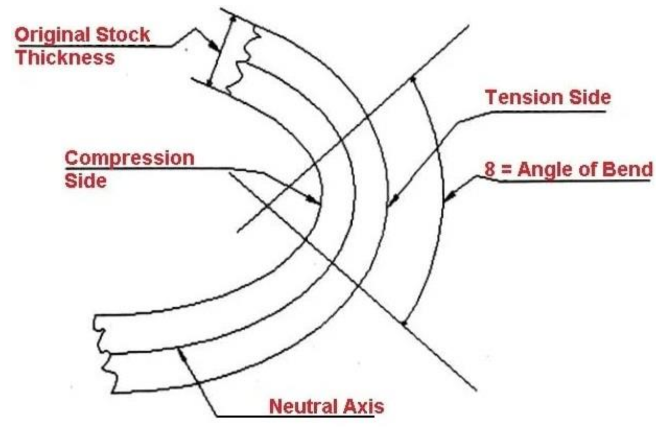
1. Deep drawing: The length of depth of the object to be drawn is deeper than its width.
2. Shallow drawing: The length of the object to be drawn is less than its width. The examples of drawing are pans, tubes and cams.

7. Embossing

It is the metalworking operation which is used to create raised surfaces or lettering in sheet metal. There is no change in metal thickness during this operation.



Embossing Operation



Bending Operation

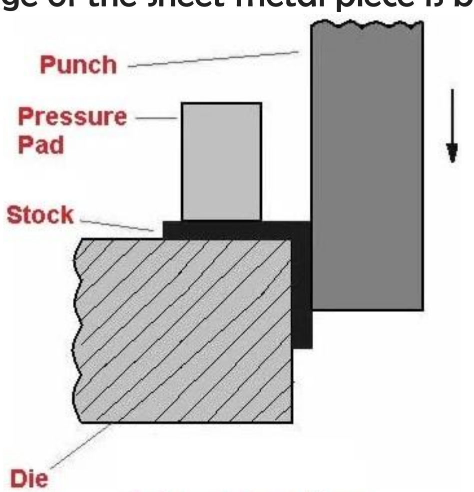
8. Bending

It occurs when forces are applied to localized areas. Here the metal flow is uniform along the bend axis with the inner surface in compression and outer surface in tension.

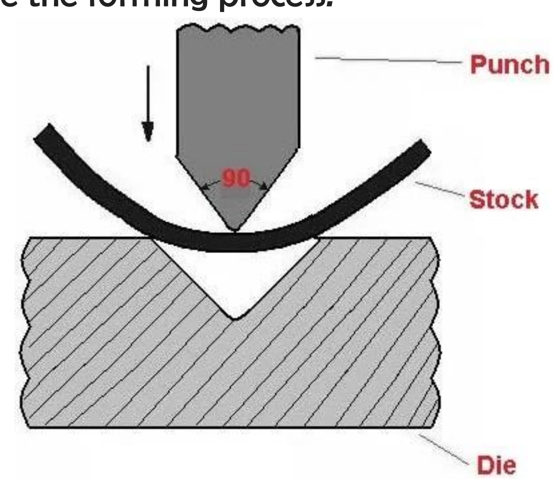
Types of bending

1. Edge bending 2. V-bending 3. U-bending 4. Offset bending 5. Channel bending

1. Edge Bending: It is a type of bending operation, In which a piece of sheet metal is fixed or held between two dies from one end, as shown in the fig. Then the other end is forced to strike upon the punch which is free or unfixed. Thus, the free or unfixed edge of the sheet metal piece is bent to make the forming process.



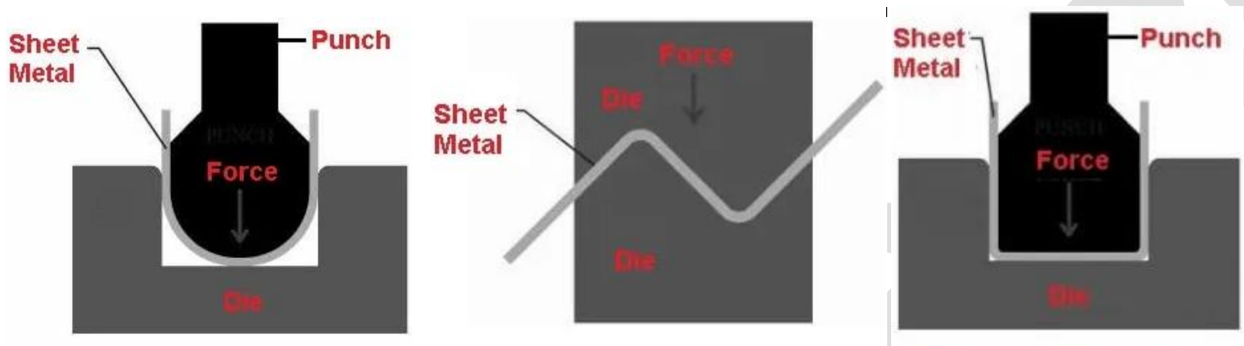
Edge Bending



V-Bending

2. V-bending: In this type of bending operation, when a piece of sheet metal is pressed between the die and the punch; it is formed into a V-shape in the die.

3. U-bending: In this type of a bending operation, in which when the punch is pressed by a force to move into the die, the sheet metal piece gets formed into a U-shape.



U-Bending   Offset Bending   Channel Bending

4. Offset Bending: It is a type of bending operation, in which a piece of sheet metal is formed into an offset shape with the help of a punch and die.

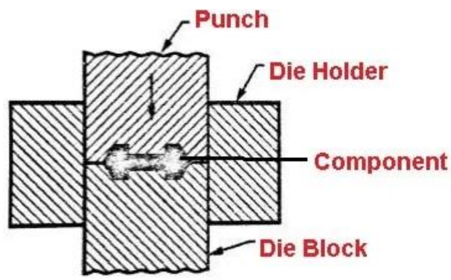
5. Channel Bending: In this type of a bending operation, in which when a force is used to the punch to move into the die, the sheet metal piece, in between the punch and die, gets the shape according to the shape of the die and punch i.e. a channel shape.

9. Squeezing

It is a quick and widely used way of forming ductile metals. It has different operations such as sizing, coining, riveting etc.

1. Sizing: Sizing operation is a squeezing operation that reduces the thickness of the metal. The sizing is done in an open die and only the surface where the die and work piece touch will be sized.

2. Coining: It is a process of pressing metal in a die so that it flows into the die space. For example medals, Coins, and Jewellery.



Coining Operation

The sheet metal operation depending on the type of stress-induced:

Sl.No.	Stress Induced	Operations
1	Shear	Shearing, Blanking, Piercing and Trimming
2	Tension	Stretch forming
3	Compression	Coining and Sizing etc
4	Tension and Compression	Drawing, Bending, Forming etc

Applications:-

1. Automotive Manufacturing
2. Aerospace Engineering
3. Ship building
4. Construction &
5. Press working
6. Sheet metal work is used for making hoppers, funnels, various ducts, chimneys, ventilating pipes, machine tool guides, boiler etc.

Advantages:-

1. Strength and Durability
2. Malleability
3. Replaceability
4. Sustainability
5. Cost-Effectiveness

Sheet metal work definition: SMW is working on the metal of 16 gauges to 30 gauges, with hand tools and simple machines into different forms by cutting, forming into shape and joining. SMW is one of the major applications in engineering industry. It has its own significances as useful trade in engineering work.

WELDING

Welding is a fabrication process whereby two or more parts are fused together by means of heat, pressure or both forming a join as the parts cool. Welding is usually used on metals and thermoplastics but can also be used on wood.
The completed welded joint may be referred to as a weldment.
The parts that are joined are known as a parent material. The material added to help form the join is called filler or consumable. The form of these materials may see them referred to as parent plate or pipe, filler wire, consumable electrode (for arc welding), etc.
Welding process are classified as

1. Gas welding:-	2. Arc welding:-	3. Resistance welding:-
-Air acetylene welding	-Carbon arc welding	-Spot welding
-Oxy acetylene welding	-Shielded metal work welding	-Seam welding
-Oxy hydrogen welding	-Flux cored arc welding	-Percussion welding
-Pressure gas welding	-Submerged arc welding	-Flash butt welding
	-TIG(GTAW) welding	-Resistance butt welding
	-MIG(GMAW) welding	
	-Plasma arc welding	
	-Electro slag welding or electro gas welding	
4. Solid state welding:	5. Thermo chemical welding:	6.Radiant energy welding:
-Cold welding	-Thermit welding	-Electron beam welding
-Diffusion welding	-Atomic hydrogen welding.	-Laser beam welding
-Explosive welding		
-Friction welding		
-Hot pressure welding		
-Ultrasonic welding		

According to modern method the welding may be classified as
I. Pressure welding (plastic welding)
II. Non pressure welding (fusion welding)

Pressure welding: In pressure welding the piece of metal to be joined are heated to a plastic state and then force together by external pressure. Ex:-Resistance welding, hot pressure welding, Diffusion welding.
Non pressure welding: In non pressure welding the material at the joint is heated to the molten state and allowed to solidify. Ex:-Gas welding, Arc welding.

Welding Tools:-

1. Spanner 2. Hammer 3. Pliers 4. Chisel 5. Tongs 6. Cylinder key 7. Wire brush
8. Clamps 9. Angular grinder 10. Spark lighter 11. Try square 12. Tip cleaner
13. Files 14. Centre punch 15. Scale and weld-gauge 16. Steel tape

Spanner: Spanners are generally used for tightening or loosening various fasteners. These are designed with drop-forge steel or carbon steel. But in welding, a double-ended spanner is used for tightening and opening the nuts of the welding apparatus and job.

Hammer: Welding hammers are essential tools used for chipping to remove slab-coating from the weld area. It is used for shaping the job. Normally a 500 grams hammer is used for the purpose. There are three types of hammers – ball pane, cross pane, and straight one. For large-sized jobs, a Sledgehammer may be used.

Pliers: Welding pliers are specially designed to effectively remove welding spatter. The multiple jaws of the piler are used to pull the wire and install the tips and nozzles.

Chisel: Normally, chisels are used to cut flat, round, or angled iron and cut sheets of thick metal. They are also used to remove unnecessary metal from a work surface by cutting it into small pieces. But in welding, it is used for cutting the jobs and for cleaning the slag, spatter, and surplus metal from the job after welding.

Tongs: Tongs are hand tools used by blacksmiths to lift and hold hot weld pieces of metal. They are usually made of wrought iron or steel and are better than pliers or vice grips. These are available in different sizes and shapes which are intended to hold the job while welding.

Cylinder Key: It is used for opening and tightening the spindle valve of the gas cylinder.

Wire Brush: It is used for cleaning the welding surface before and after welding. It consists of steel wires and is made of stainless steel. Keep in mind that in welding, always use a brush with stainless steel bristles and a chipping hammer made of stainless steel.

Clamps: Welding clamps are sheets of metal that temporarily hold two parts of material tightly together. Welding clamps permit you to securely hold your workpiece, so the operator will produce a tighter joint. This makes it easy to run the arc and join the pieces together without worrying about moving sheets. These types of clamps are generally available in varieties of sizes and shapes.




Angular Grinder: Angular grinders are commonly seen in metal fabrication and some metal shops. They are types of handheld power tools attached to consumable stone discs or blades. These discs spin at high speed to grind, cut or give a smooth finishing touch to weld metal.

Spark Lighter: It consists of a shape edges stone piece that produces a spark when it is rubbed with a hatched cast-iron wheel. It is used for lighting the gas released from the welding torch.

Try Square: It is an L-shaped measuring instrument. Its blade is usually graduated in centimeters and the same is used for job measurement purposes. It is also used for checking the right angles of a rectangular job.

Tip Cleaner: There is a fine hole in the nozzle. The hole may get dirty and even closed during use. A nozzle edges tip cleaner is used for cleaning the hole, see in the figure. A tip cleaner may also be used for removing slag from the job after welding is done.



Files: These are similar to angular grinders, used to remove rough edges and burrs from the metal you cut. The file tools are available in various shapes and sizes which are used for work finishing purposes. Metal files are also commonly used for all kinds of other metal projects.

Centre Punch: The punch tools are often used to mark holes that must be drilled in secondary operations, or as gauging marks for bend lines, shearing, spot weld locations. It is used for marking on a job piece before cutting the same into a desired shape.

Scale and Weld-gauge: Scale is used for measuring the size of a job and the weld-gauge is used for measuring the depth of the weld.

Steel Tape: Long jobs are measured by steel tape. It is marked in inches and centimeters and it is housed in a steel or plastic case. The spring for the assembly helps in the quick and automatic collection of the tape.

Welding Equipments:

1. Gas cylinder 2. Gas regulator 3. Hose-pipe 4.Welding goggles 5. Welding Helmet 6. Handy gloves 7. Anvil 8.Cylinder trolly 9. Apron 10.Welding torch

Gas Cylinder: Welding gas cylinders are made with thick steel sheets as they have to bear high gas pressure. Manufacturers supply gas-filled cylinders to the users. Generally, oxygen and acetylene gas cylinders are used for gas welding purposes. The two gases are supplied in separate cylinders.

1. Oxygen Cylinder 2. Acetylene Cylinder

Gas Regulator: For the welding process, the oxygen and acetylene gases reach the welding torch through gas regulators. There are two main functions of a gas regulator:

1. To maintain necessary gas pressure during the course of welding.
2. To supply the gas to the welding torch at a low pressure. The regulator's body is generally made of brass metal.

Hose Pipe: The hosepipe is the medium through which gas is supplied from the regulator to the welding torch. Separate hose pipes are used for oxygen and acetylene gases. These are made of good quality rubber and are fitted with the help of clamps in their respective regulators and welding torches. Typically, a black or blue pipe is used for oxygen gas while a red pipe is used for acetylene gas.

Welding Goggles: Goggles are used for the protection of eyes against any possible bad effect of the gas flame. Green or blue glasses are used in the goggles which are capable to protect the eyes from ultraviolet and infra-red radiation of the high-temperature gas flame.

Welding Helmet: It is an essential type of welding equipment that is considered the most important piece of personal protective equipment that a welder should have. This helmet not only protects the eyes and skin from serious sparks, but also from potentially vision-damaging ultraviolet and infrared rays released by arcs.

Handy Gloves: Welding gloves are tools that protect a welder's hands from the dangers of welding. Leather or asbestos gloves are used for the protection of hands against any possible burn during welding.
These gloves allow the operator to be protected from electric shock, extreme heat, and ultraviolet and infrared radiation, and also provide abrasion resistance and increased grip.

Anvil: An anvil is consisting of a strong metal (usually forged or cast steel) with a flattened top surface upon which another object strikes. An anvil is used for hammering a hot job as required. It is made of steel so as to have sufficient toughness, see in the figure. The anvil is used as a forging tool in most cases.

Cylinder Trolly: A cylinder trolly is very helpful for conveying the two gas cylinders from one place to another for gas welding purposes.

Apron: A leather apron is very useful equipment for protecting a welder's clothing against sparks and red-hot particles. It is usually tied to the chest portion of the body.

Welding Torch: It is also known as a blow-pipe. The instrument is meant for producing the oxygen-acetylene flame. It is provided with two gas adjusting knobs (one for each gas). The desired type of flame can be produced by adjusting the two knobs. Two hose pipes are clamped on the two inlets of the instrument.
Gases are mixed in the mixing chambers and then the mixture comes out of the welding torch through its nozzle or tip where it is converted into flame with the help of a spark lighter. The nozzle or tip is made to bear the high temperatures.
Nozzle's size depends on the size of its hole and they are replaceable. The size is marked on the nozzle which indicates the thickness of the metallic sheets to be welded with that nozzle.

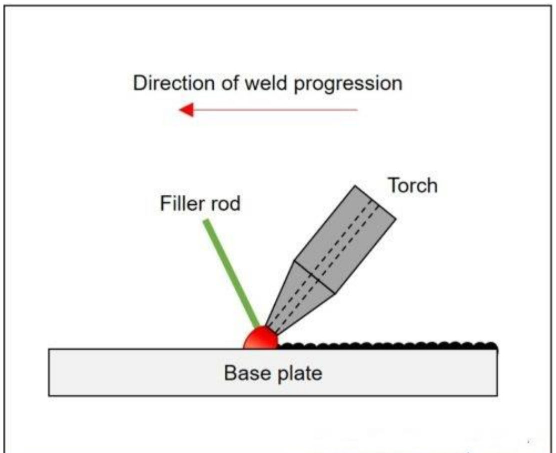
WELDING TECHNIQUES:

1. Leftward Welding 2. Rightward welding

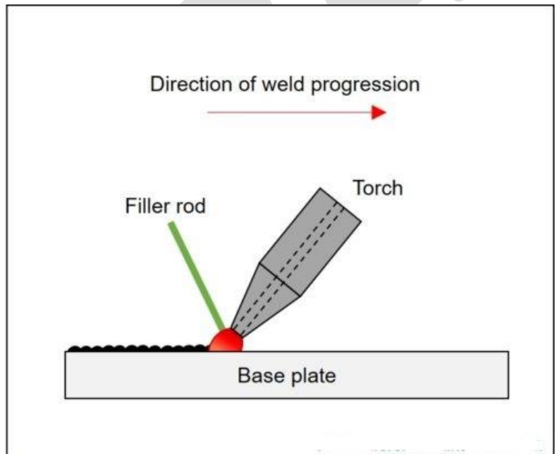
Leftward Welding is used on steel for flanged edge welds, for unbevelled plates up to 5.0mm (3/16in). It is also the method usually adopted for cast iron and non-ferrous metals. Welding is started at the right-hand end of the joint and proceeds towards the left.
The blowpipe is given a forward motion with a slight sideways movement to maintain melting of the edges of both plates at the desired rate and the welding rod is moved progressively along the weld seam – see fig. The sideways motion of the blowpipe should be restricted to a minimum.

Rightward welding is recommended for steel plate over 5.0mm (3/16in) thick. Plates from 5.0mm to 8.0mm (3/16in to 5/16in) need not be bevelled; over 8.0mm (5/16in) the edges are bevelled to 30o to give an included angle of 60o for the welding V. Suitable for horizontal/vertical position.

The weld is started at the left-hand end and moves towards the right with the blowpipe flame preceding the filler rod in the direction of travel. The rod is given a circular forward motion and the blowpipe is moved steadily along the weld seam – See Fig. This is faster than leftward welding and consumes less gas; the V angle is smaller, less filler rod is used and there is less distortion. The all-position rightward technique is a modification of the above and is particularly suitable for mild steel plate and pipe in the vertical and overhead position.



Forehand Welding Technique



Backhand Welding Technique

WELDING POSITIONS:

All welding can be classified according to the position of the workpiece or the position of the welded joint on the plates or sections being welded.

The American Welding Society has defined the four basic welding positions as shown below.

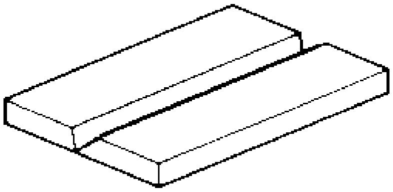
- Flat position
- Horizontal position
- Verticle position
- Overhead position

In plate welding, we have four different positions namely;

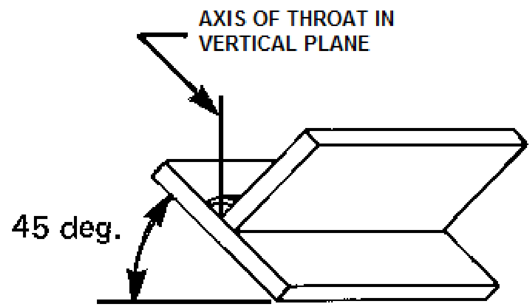
1. Flat position (1G or 1F)
2. Horizontal Position (2G or 2F)
3. Vertical Position (3G or 3F)
4. Overhead Position (4G or 4F)

Note: *1. G Designates groove welding (V-groove, J-groove, U-groove etc.)*
2. F Designates fillet welds ("T" – Joint, Lap Joint etc.)

FLAT WELDING POSITION (1G OR 1F):



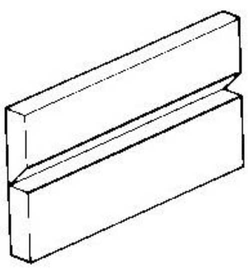
1G



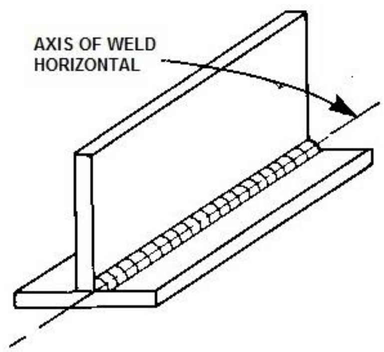
1F

In flat welding the welders head remains above the test coupon.

HORIZONTAL WELDING POSITION (2G OR 2F)



2G

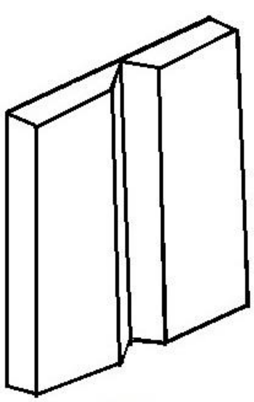


2F

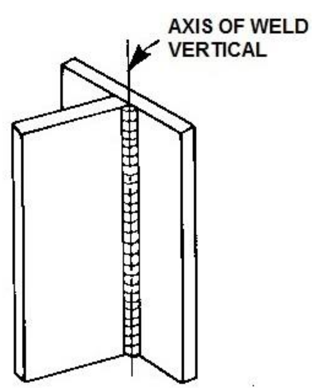
In horizontal weld position, movement of electrode shall be in **horizontal plane.** We have two different welding techniques in horizontal welding, these are;

1. Rightward technique
2. Leftward Technique

VERTICAL WELDING POSITION (3G OR 3F)



3G

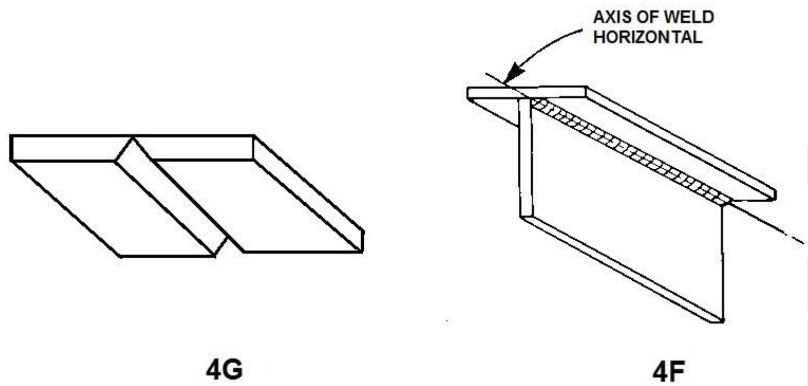


3F

In vertical weld position, movement of electrode shall be in **vertical plane.** We have two different welding methods in vertical welding, these are;

1. Uphill
2. Downhill

OVERHEAD WELDING POSITION (4G OR 4F)



Overhead position is one of the most difficult positions because welder has to work against the gravity. In overhead welding, the test coupon (or workpiece) remains above the head of the welder.

Weld Defect:

Welding Defects can be defined as the irregularities formed in the given weld metal due to wrong welding process or incorrect welding patterns, etc.

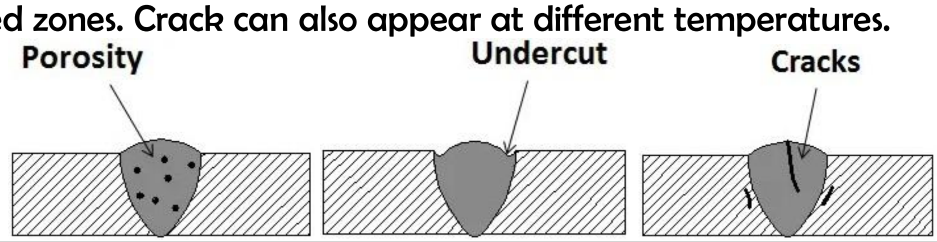
Types of Weld Defects:

1. Porosity and Blowholes 2. Undercut 3. Weld crack 4. Incomplete fusion 5. Incomplete penetration 6. Spatter 7. Overlap 8. Crater 9. Necklace cracking 10.Distortion 11. Hot Tear 12.Mechanical damage 13. Misalignment 14. Excess reinforcement 15.Lamellar tearing 16. Whiskers Slag inclusion

1. Porosity: Porosity in the condition in which the gas or small bubbles gets trapped in the welded zone.

2. Undercut: When the base of metal melts away from the weld zone, then a groove is formed in the shape of a notch, then this type of defect is known as Undercut. It reduces the fatigue strength of the joint.

3. Weld Crack: This is the most unwanted defect of all the other welding defects. Welding cracks can be present at the surface, inside of the weld material or at the heat affected zones. Crack can also appear at different temperatures.

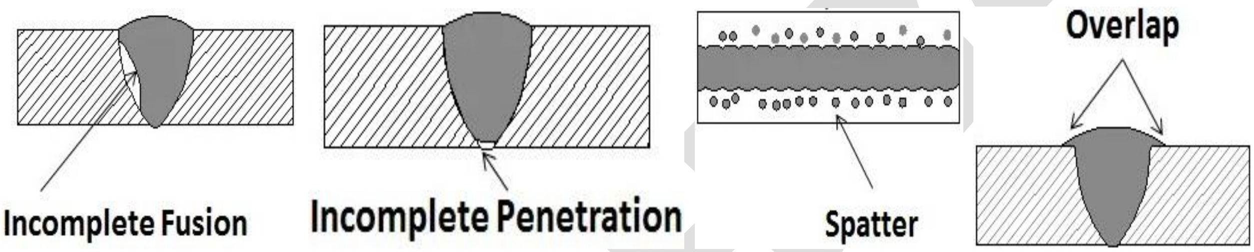


4. Incomplete Fusion: Incomplete fusion occurs when the welder does not accurately weld the material and the metal pre solidifies which leads to a gap which is not filled with the molten metal.

5. Incompletely Filled Groove or Incomplete Penetration: These defects occur only in the butt welds where the groove of the metal is not filled completely. It is also called as incomplete penetration defect.

6. Spatter: When some metal drops are expelled from the weld and remain stuck to the surface, then this defect is known as Spatter.

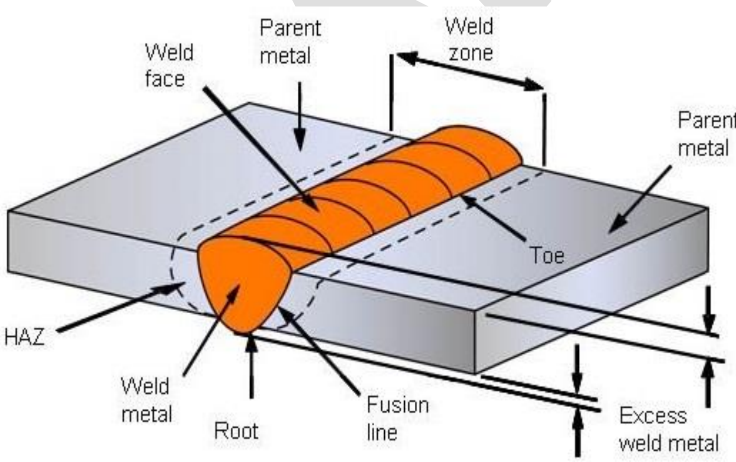
7. Overlap: When the weld face extends beyond the weld toe, then this defect occurs. In this condition the weld metal rolls and forms an angle less than 90 degrees.



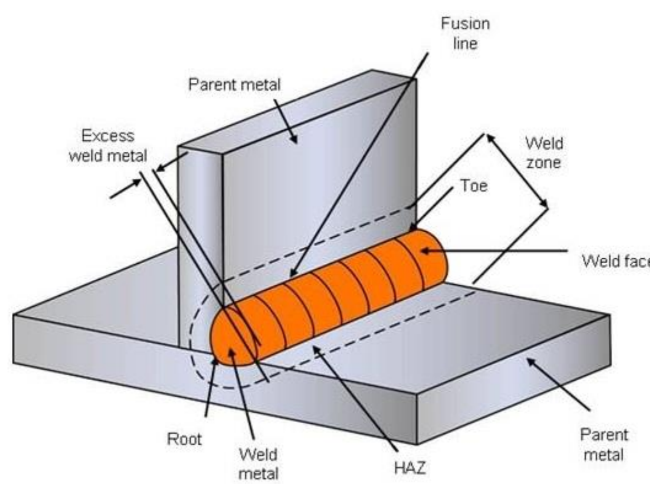
8. Crater: It occurs when the crater is not filled before the arc is broken, which causes the outer edges to cool faster than the crater. This causes a stress and then crack is formed.

9. Necklace Cracking: It occurs in the use of electron beam welding where the weld does not penetrate properly. Therefore, the molten metal does not flow into the cavity and results in a cracking known as "Necklace Cracking".

Features of Completed Welds:



Butt weld



Fillet weld

Parent Metal
Metal to be joined or surfaced by welding, braze welding or brazing.

Filler Metal
Metal added during welding, braze welding, brazing or surfacing.

Weld Metal
All metal melted during the making of a weld and retained in the weld.

Heat Affected Zone (HAZ)
The part of the parent metal metallurgically affected by the weld or thermal cutting heat, but not melted.

Fusion Line
Boundary between the weld metal and the HAZ in a fusion weld. This is a non-standard term for weld junction.

Weld Zone
Zone containing the weld metal and the HAZ.

Weld Face
The surface of a fusion weld exposed on the side from which the weld has been made.

Weld Root
Zone on the side of the first run furthest from the welder.

Weld Toe
Boundary between a weld face and the parent metal or between runs. This is a very important feature of a weld since toes are points of high stress concentration and often they are initiation points for different types of cracks (e.g., fatigue cracks, cold cracks).

In order to reduce the stress concentration, toes must blend smoothly into the parent metal surface.

Advantages

- Welding establishes strong, durable, and permanent joint links.
- It is a simple process that results in a great finish.
- The technique, when used with filler material, produces a stronger weld than the base material.
- It can be performed at any place
- It is an economical and affordable process

- It is used in various sectors like construction, automobile, and many more industries.

Disadvantages

- It is hazardous when performed under the safety and security guidelines.
- It is a difficult task to dismantle the joined material through welding.
- Requires skilled labor and electric supply.

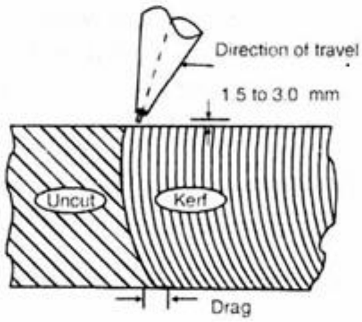
Applications of Welding:

1. Shipbuilding
2. Automotive industries
3. Construction industries
4. Mechanical industries
5. Used for most types of sheet metal welding
6. Fabrication of pressure vessels and steel structures
7. Automotive industry and home improvement industry
8. Aerospace and aircraft construction
9. Auto body repairs
10. Manufacturing plants
11. Industrial piping
12. Railroads
13. Maintenance and repair
14. Fabrication of sheet metal
15. Automobile and aircraft industries
16. Joining ferrous and non-ferrous metals
17. Joining thin metals.

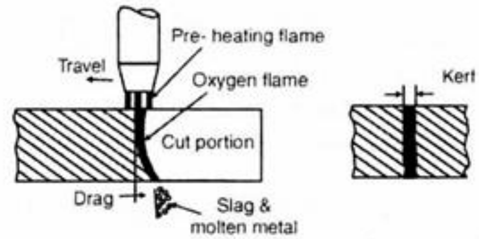
GAS CUTTING: Gas cutting is the cutting of a preheated metal by a jet of oxygen.

Process of Gas Cutting:

Apart from using hacksaw, power saw, chisels, etc. for metal cutting operation, gas or oxygen cutting is extensively used now-a-days in industry.



(a) Positioning of cutting torch in oxy- fuel gas cutting.



(b) Gas Flame Cutting.

Equipments for Gas-Cutting:
1. Gas cutting torch.
2. Pressure regulators.
3. Gas cylinders.
4. Hose and hose fittings.
5. Goggles and glasses.
6. Gloves and apron.
7. Spark lighter and spanners.
8. Cylinder valves.
9. Chipping hammer and wire brush.

Brazing: Brazing is a metal-joining process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, with the filler metal having a lower melting point than the adjoining metal.

OR

Brazing is a welding process that is used to join two pieces of base metal using melted filler which flows across the joint.

When the filler metal cools, it creates a solid weld between the two pieces of metal. The process of brazing is similar in nature to that of soldering, and brazing forms a very strong welded joint which tends to be stronger than either of the base metals on their own. Brazing allows welders to create a strong weld and does not cause the base metals to melt or lose their shape while the process is being completed. The process of brazing is commonly used when the welder needs to create a joint that is invisible to the naked eye, yet strong enough to hold up in a variety of temperatures. Joints that are created using the brazing technique are often pliable and can withstand jolts and twisting.

Soldering: Soldering is a joining process used to join different types of metals together by melting solder. Solder is metal alloys usually made of tin and lead which is melted using a hot iron. The iron is heated to temperatures above 600 degrees Fahrenheit which then cools to create a strong electrical bond. As well as creating strong electrical joints solder can also be removed using a desoldering tool.

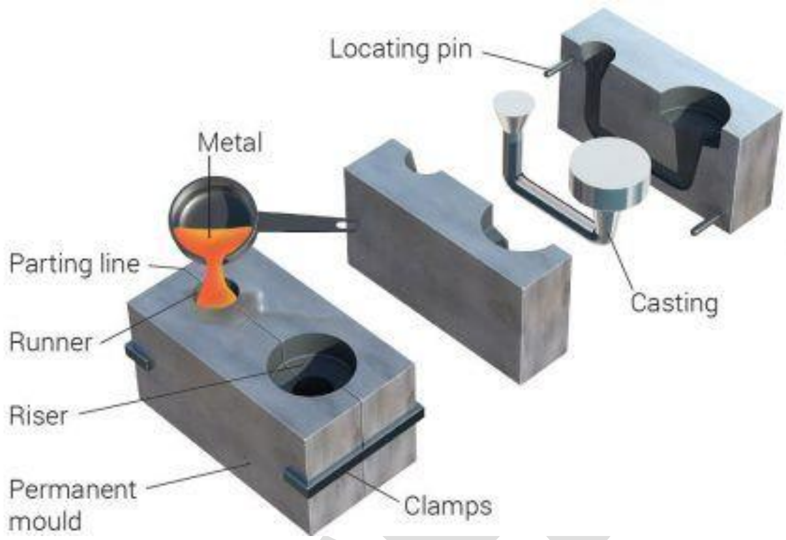
The only difference between brazing and soldering is the temperature at which each process takes place. Soldering takes place at a temperature below 840°F (450°C), and brazing occurs at a temperature above 840°F (450°C).

Comparison of Welding, Soldering and Brazing

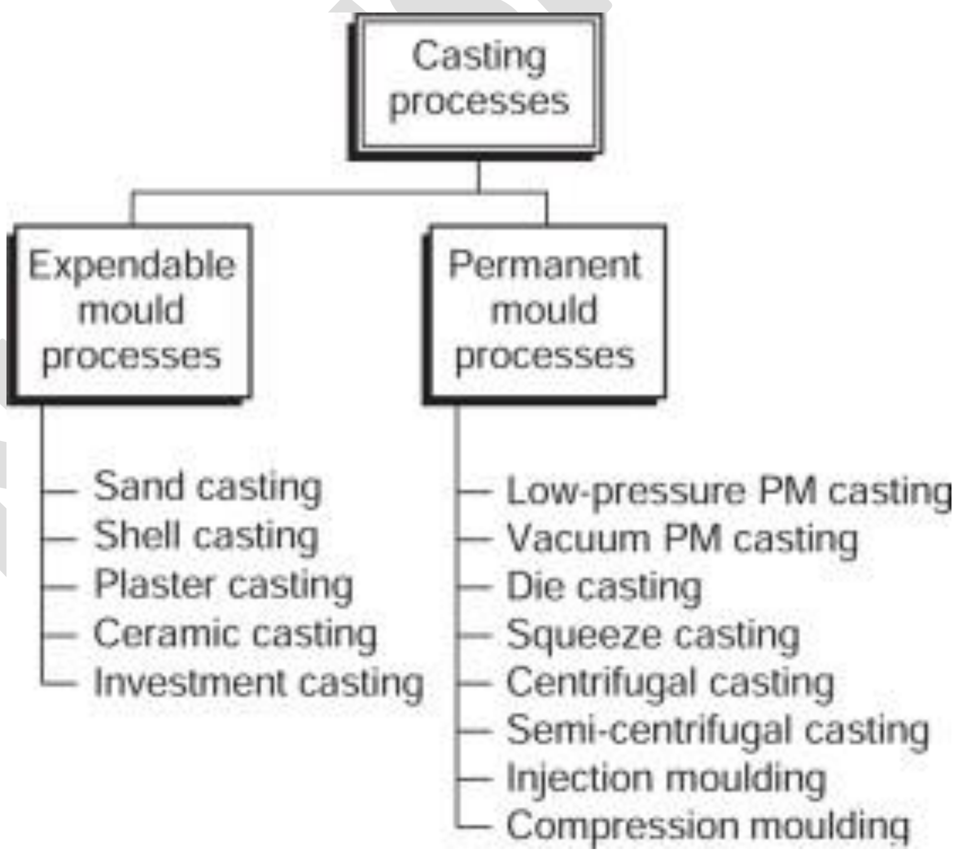
Sl.No.	Welding	Soldering	Brazing
1	These are the strongest joints that can bear the load. The strength of the welded joint can exceed the strength of the base metal.	These are the weakest joint of the three. Not to bear the weight. Generally, use to make electrical contacts.	These are stronger than soldering but also weaker than welding. It can be used to bear some load.
2	The temperature of the desired welding zone is up to 3800°C.	Temperature required up to 450°C.	It may go up to 600°C in brazing.
3	The workpiece needs to be heated to their melting point to join.	Workpieces do not need to be heated.	The workpiece is heated but below the melting point.
4	The mechanical properties of the base metal may vary in the joint space due to heating and cooling.	There is no change in mechanical properties after joining.	The mechanical properties of the joint may change, but it is almost negligible.
5	Involving heat consumption, high-level skills are required.	The costs involved and the skill requirement is very low.	The costs involved and the skills needed are between the two others.
6	Heat treatment is usually required to eliminate the unwanted effects of welding.	No heat treatment is required.	No heat treatment is required after brazing.
7	Since it is performed at high temperature, it is not necessary to preheat the work before welding.	Preheating the workpiece before soldering is good for making good quality joints.	Preheating is beneficial for forming a solid joint because brazing is done at relatively low temperatures.

CASTING:

CASTING: Casting is a manufacturing process in which a liquid material is usually poured into a mold that contains a cavity of the desired shape and then allowed to solidify. The solidified part is also known as the casting, which is ejected or broken from the mold to complete the process.



TYPES OF CASTING PROCESSES:

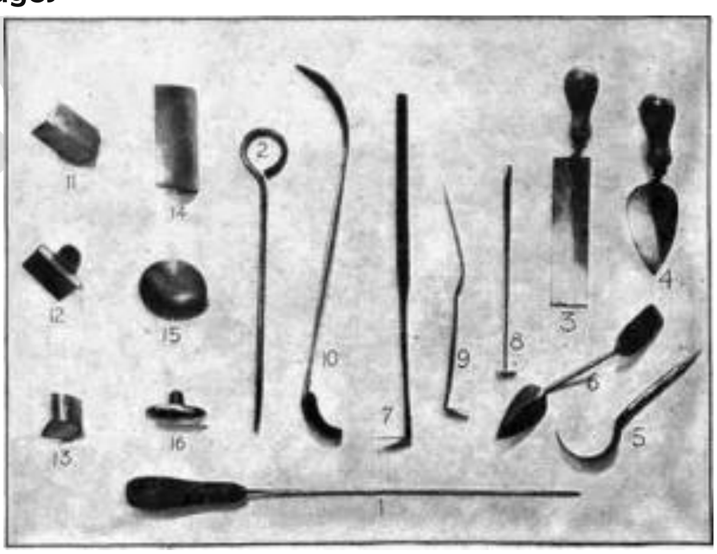


ADVANTAGES & DISADVANTAGES OF CASTING PROCESSES:

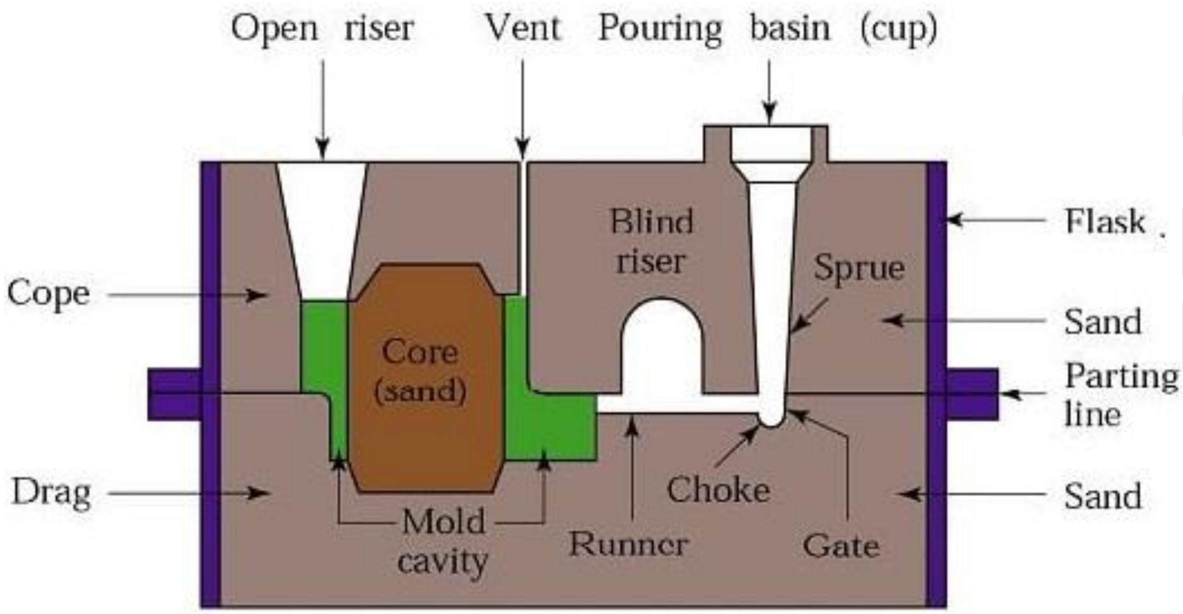
	Process	Advantages	Disadvantages	Examples
1.	Sand	Wide range of metals, sizes, shapes, low cost	poor finish, wide tolerance	engine blocks, cylinder heads
2.	Shell mould	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
3.	Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
4.	Plaster mould	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
5.	Ceramic mould	complex shapes, high accuracy, good finish	small sizes	impellers, injection mould tooling
6.	Investment	complex shapes, excellent finish	small parts, expensive	jewelry
7.	Permanent mould	good finish, low porosity, high production rate	Costly mould, simpler shapes only	gears, gear housings
8.	Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	precision gears, camera bodies, car wheels
9.	Centrifugal	Large cylindrical parts, good quality	Expensive, limited shapes	pipes, boilers, flywheels

Different types of Casting tools and equipments:

1. Hand riddle **2.** Shovel **3.** Rammer 4. Sprue pin 5. Strike of bar 6. Mallet 7. Draw spike 8. Vent rod 9. Lifter 10. Travels 11. Slicslick 12. Smoother **13.**Swabs 14. Spirit level 15. Gate cutter 16. Daggers **17.** Bellows 18. Clamp 19. cutters 20. wedges



Basic Terminologies of Casting Process:



- **Flask:** A metal or wood frame in which mold is formed.
- **Cope:** The upper half of the flask is called cope.
- **Drag:** The lower half of the flask is called drag.
- **Core:** Core is used to create an internal hollow cavity in the final product.
- **Vents:** These are the places created in the mold to carry off-gases produced when the molten metal comes in contact with the sand.
- **Mold cavity:** This is the hollow space in the mold where the metal part is formed.
- **Riser:** It is the reservoir of molten metal that supplies additional metal in case of any reduction.
- **Runner:** It is the passage from where the molten metal can be regulated before reaching the mold cavity.
- **Pouring Cup:** It is the cup or basin from where molten metal is poured in the metal.
- **Pattern:** It is the duplicate of the shape needed to form.
- **Sprue:** It is the cavity through which molten metal flows downward.
- **Parting Line:** This is the line that separates the cope and drag.

Advantages of Casting

1. Molten metal can flow into any small section in the mould cavity; hence any intricate shape can be produced.
2. Practically any material can be cast.
3. The tools required are very simple and inexpensive.
4. Due to the same cooling rate from all directions, uniform mechanical properties can be obtained.
5. The deposition of the air is absent.
6. The Casting metals of the centrifugal casting process are strong.
7. The hollow sections can be produced with the help of centrifugal casting.
8. Investment Casting Process can be used to produce *intricate shapes*.
9. The removal of patterns is *easy*.
10. Investment Casting can produce a number of products in one go.

Limitations

1. With a normal sand-casting process, the dimensional accuracies and surface finish is poor.
2. Defects are inevitable.
3. Sand casting is labour intensive.

Applications

1) Slush Casting Process is used to produce **Gold Jewellery**.
2) It is used to manufacture the **lamp's components** and hallow parts.
3) Slush Casting is mainly used to manufacture **brass materials** items.
4) Investment Casting Process is used to manufacture **intricate shapes** like Pistons, Valves, etc.
5) This type of casting is used to manufacture **non-symmetrical shapes**.
6) Investment Casting is used to manufacture the **Jet Engine Blades** and **Rotors**.
7) It is used to manufacture the components that involve in the **beverage machines**.
8) Centrifugal Casting Process is used to produce **composite pipes**.
9) Centrifugal Casting is used to manufacture **ceramic** and even **cast-iron pipes** too.

MACHINE TOOLS

Introduction to M/C Tools: Machine tools are generally the power driven metal cutting or metal farming machines used to alter/change the workpiece to the required shape and size by:

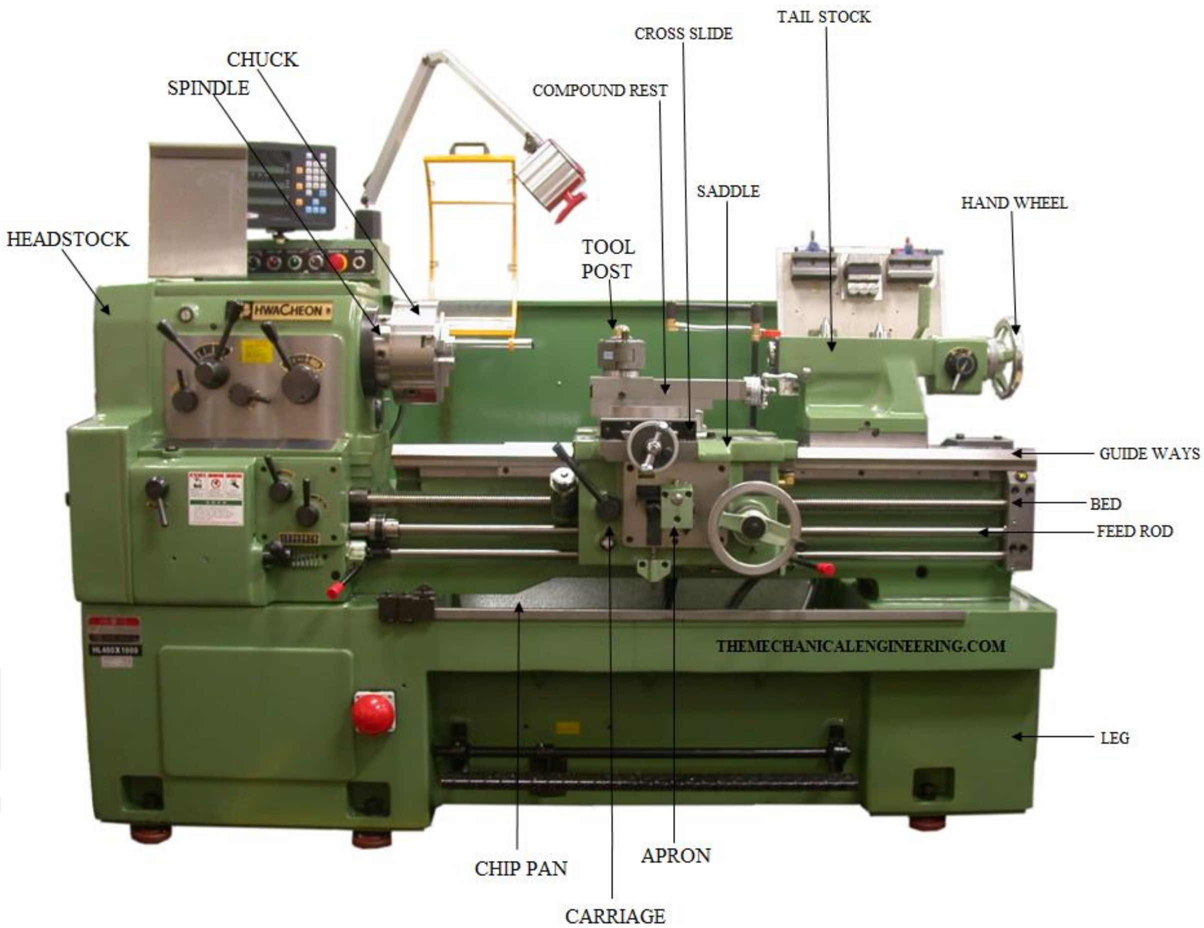
1. Cutting away the unwanted sections
2. Pressing, drawing, punching or shearing
3. Controlled electrical machinery process

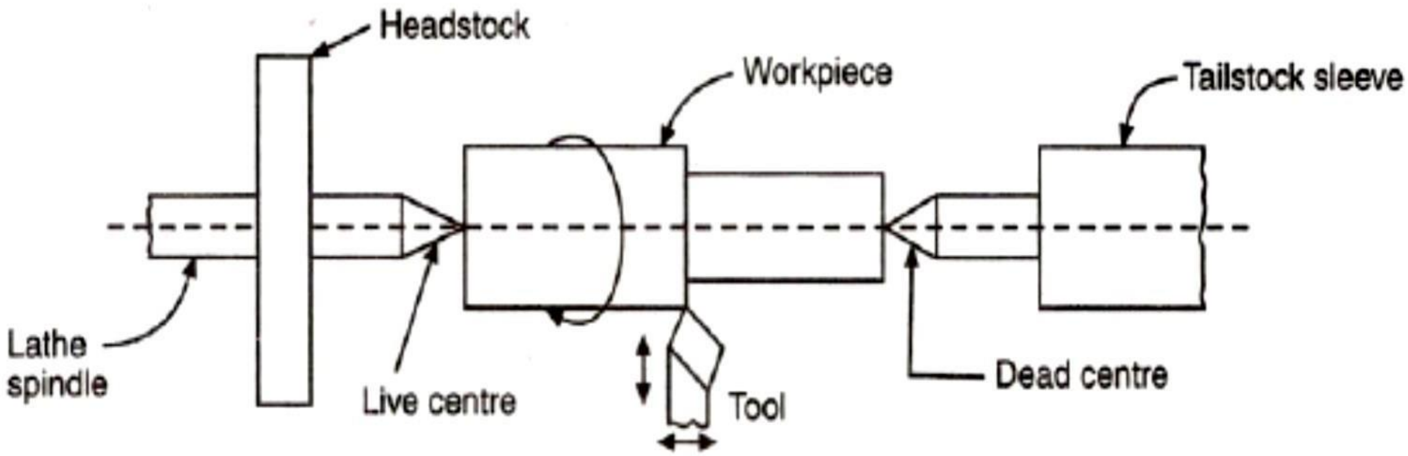
LATHE MACHINE

The *Lathe* was invented by Jacques de Vaucanson around 1751. The Lathe Machine is an ancient tool. Lathe Machine is a Production Machine tool. Lathe Machine is one of the oldest machine tools in the production machine. This Machine is also known as the "mother of all machines".

Definition: A lathe machine is a machine tool that removes the undesired material from a rotating workpiece in the form of chips with the help of a tool that is traversed across the work and can be feed deep into the work.

It one of the most versatile machine that it can produce another lathe and widely used machine tools all over the world.





Lathe Machine Parts

The Lathe Machine consists of following Main Parts:

1. Bed
2. Headstock
3. Tail stock
4. Carriage
5. Saddle
6. Cross Slide
7. Compound rest
8. Tool Post
9. Apron
10. Chuck
11. Feed rod
12. Lead Screw
13. Spindle

Lathe Machine Working Principle:

A Lathe works on the principle of rotating the workpiece and a fixed cutting tool.

The workpiece is held between two rigid and strong supports called a center or in a chuck or in faceplate which revolves. Lathe removes the undesired material from a rotating workpiece in the form of chips with the help of a tool that is transverse across the work and can be fed deep in the work.

The main function of the lathe is to remove the metal from a job to give it the required shape and size. The normal cutting operations are performed with the cutting tool fed either parallel or at right angles to the axis of the work. The cutting tool can be fed at an angle relative to the axis of the work for machining tapers and angles.

Lathe Machine Types:

There are 10 different types of Lathe Machine and those are:

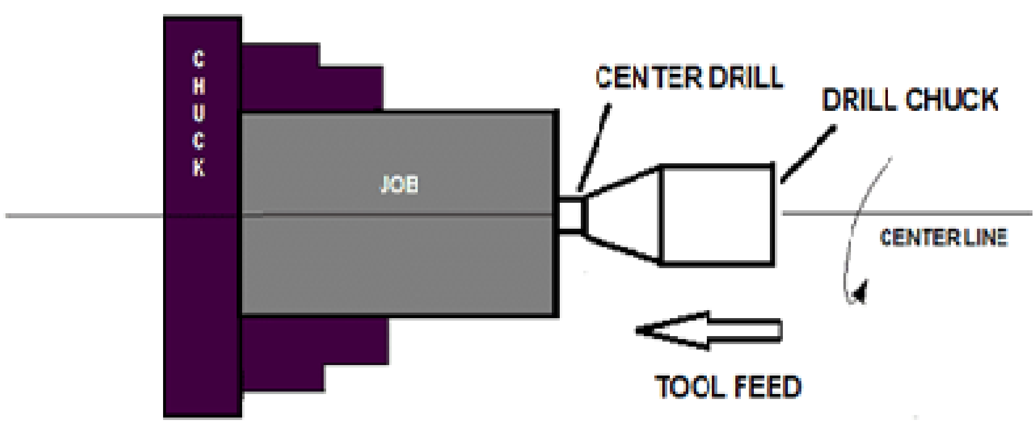
- Engine Lathe or Center Lathe
- Speed Lathe
- Turret lathe
- Capstan Lathe
- Tool room Lathe
- Bench Lathe
- Gap bed lathe
- Hollow spindle Lathe
- Vertical Turret Lathe
- CNC Lathe Machine

Different Operation Performed on lathe Machine:

The following different types of Lathe Machine Operation are:

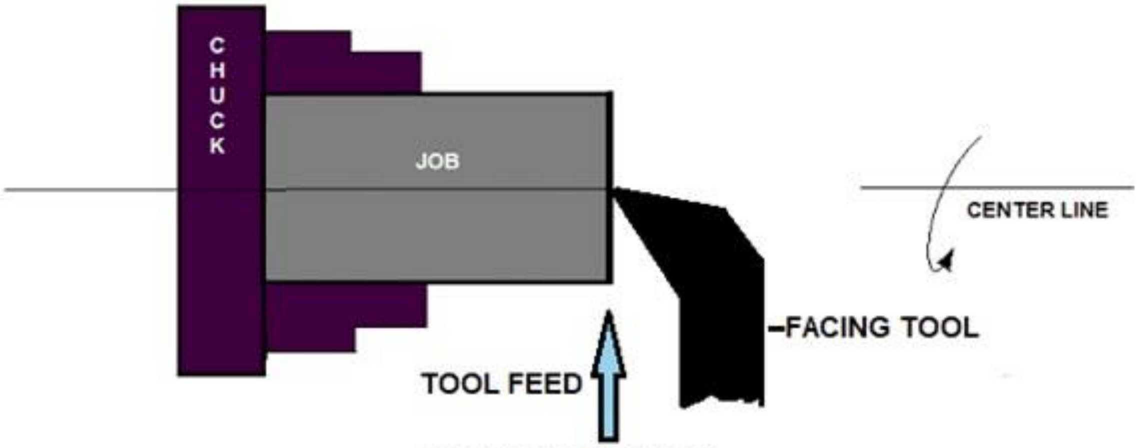
1) Centering Operation
2) Facing Operation
3) Turning Operation
4) Chamfering Operation
5) Knurling Operation
6) Thread Cutting Operation
7) Drilling Operation
8) Boring Operation
9) Reaming Operation
10) Spinning Operation
11) Tapping Operation
12) Parting Off Operation

Centering operation in the lathe: We use this operation for producing a conical hole in the face of the job to make the bearing support of the lathe center when the job is to hold between two centers. (Head- stock and Tail-stock).



CENTERING OPERATION

Facing operation in the lathe: Facing operation is for making the ends of the job to produce a smooth flat surface with the axis of operation or a certain length of a job.



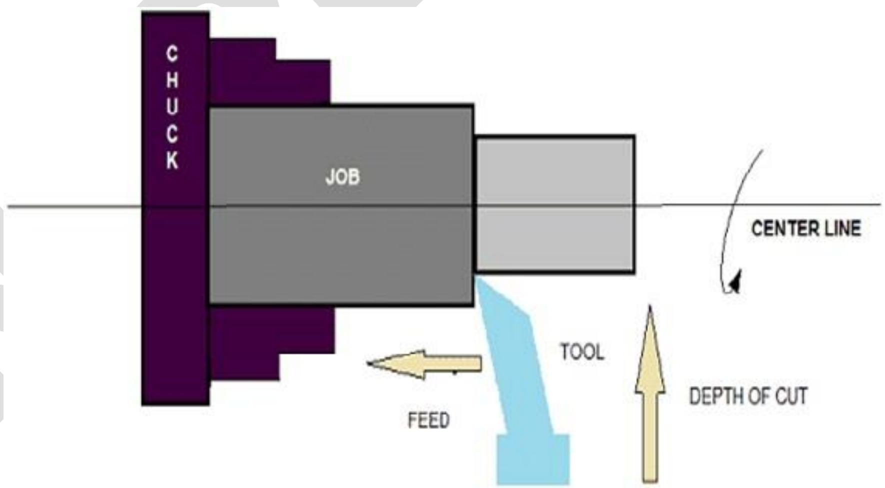
FACING OPERATION

Turning Operation in the lathe: The Operation by which we remove the excess material from the workpiece to produce a cone shaped or a cylindrical surface

There are several types of turning operations, those are:

1. Straight turning
2. Shoulder turning
3. Rough turning
4. Finish turning
5. Taper turning
6. Eccentric turning

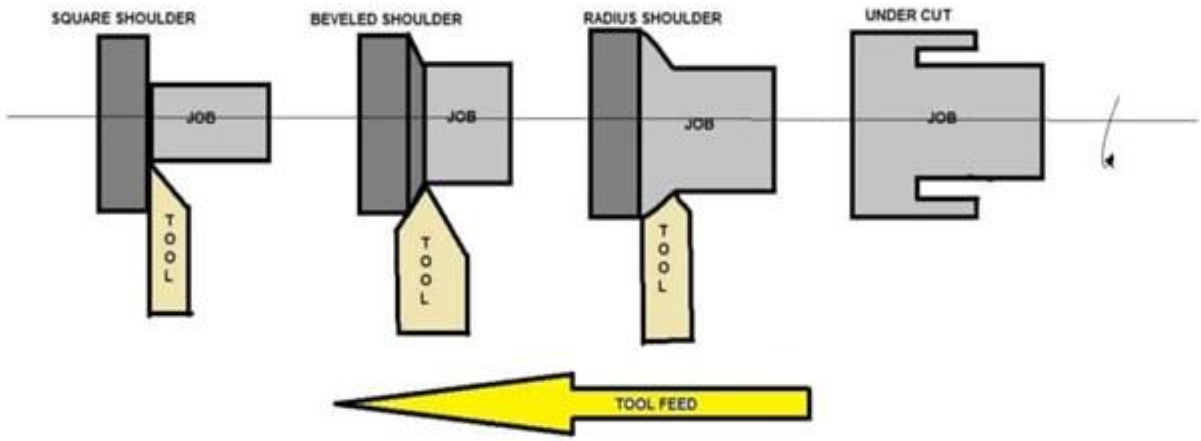
Straight turning: This operation is done to produce a cylindrical surface by removing excess material from the workpiece.



STRAIGHT TURNING OPERATION

Shoulder turning: A shoulder turning is called which has a different diameter to form a step from one diameter to another. There are four kinds of the shoulder.

1. Square
2. Bevelled
3. Radius
4. Undercut



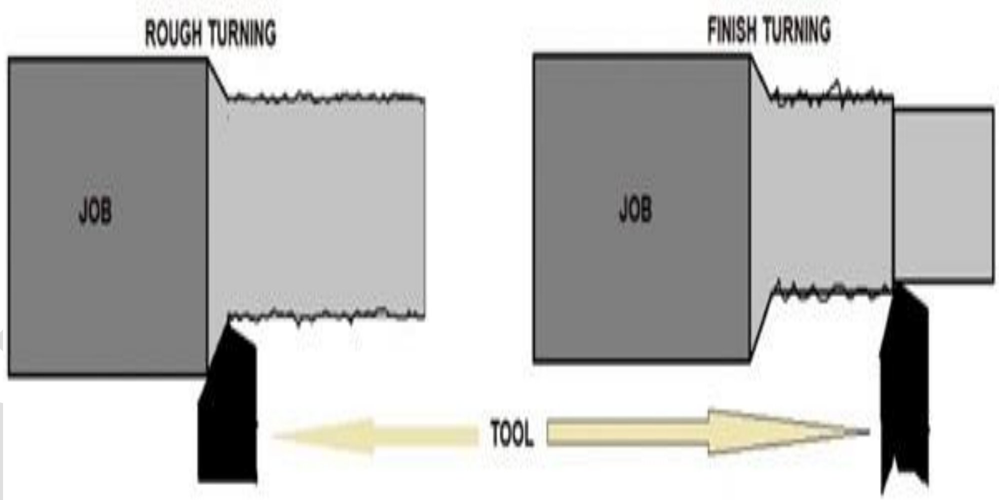
SHOULDER TURNING

Rough Turning: It is a process of removal of excess material from the workpiece in minimum time by applying a high rate of feed and heavy depth of cut.

The depth of cut is around 2 to 5mm and the rate of feed is 0.3 to 1.5mm/revolution.

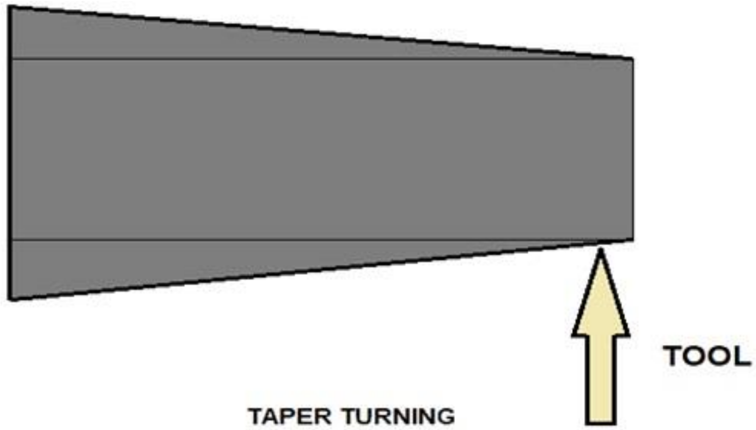
Finish turning: The finish turning operation needs high cutting speed, minimum feed and a very small depth of cut to generate the smooth surface.

In finish turning the depth of cut is around 0.5 to 1mm and the rate of feed is 0.1 to 0.3 mm/revolution.

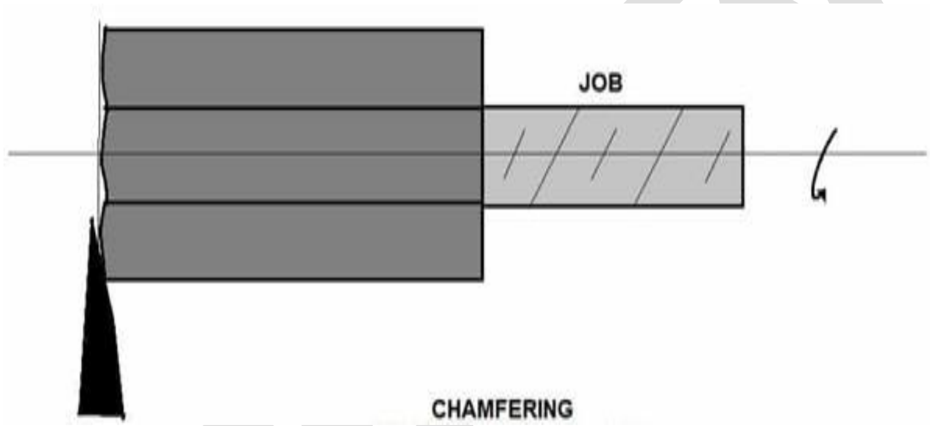


ROUGH TURNING & FINISH TURNING

Taper Turning: A Taper is defined as a uniform decrease or increase in the diameter of the workpiece along with its length. The operation by which a conical surface of the gradual reduction in diameter from a cylindrical workpiece is produced is called taper turning.

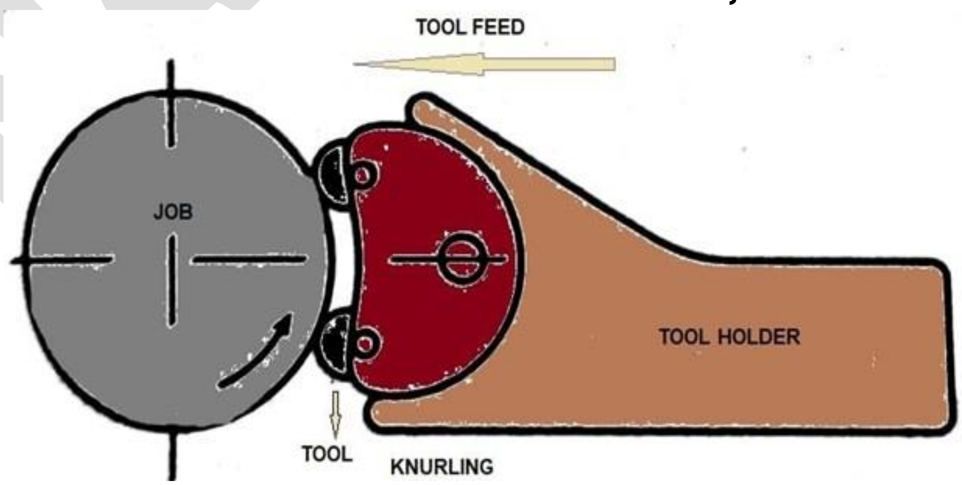


Chamfering operation: Chamfering is used for beveling the end of a job to remove burrs, to look better, to make a passage of the nut into the bolt. This operation is done after thread cutting, knurling, rough turning.

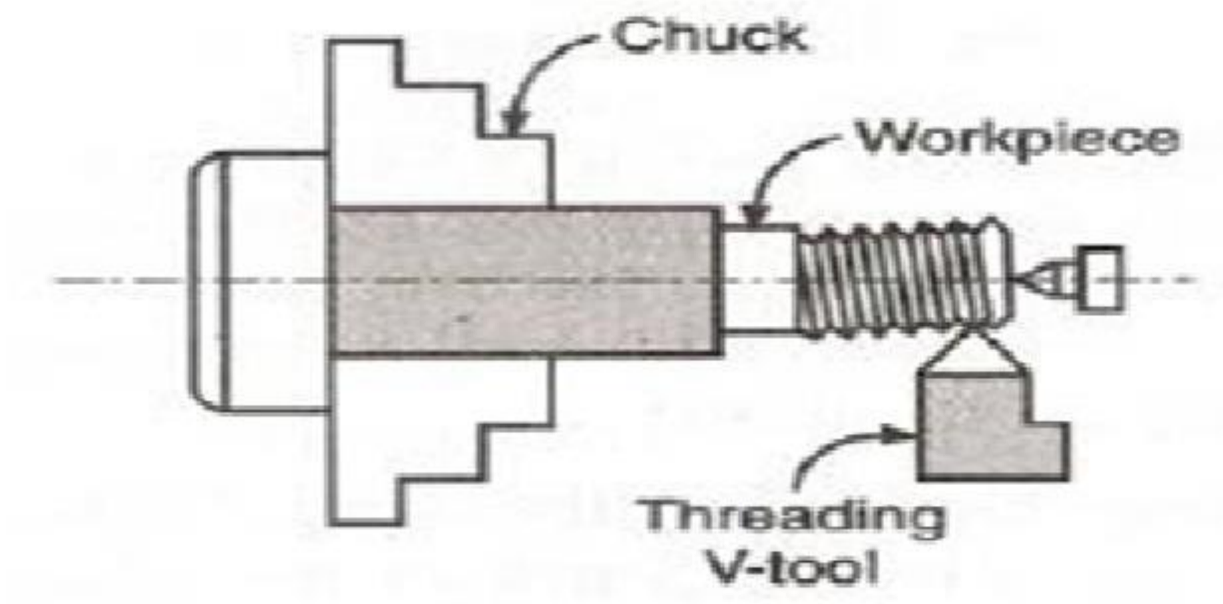


Knurling operation: It is the process of producing a rough surface on the workpiece to provide effective gripping.

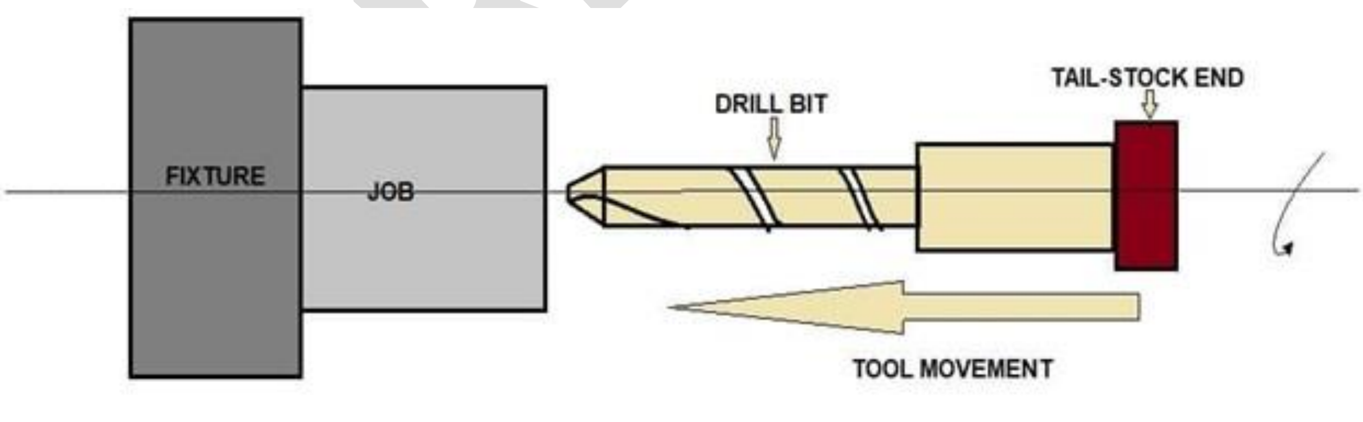
Knurling tool is held rigidly on the tool post and pressed against the rotating job so that leaving the exact facsimile of the tool on the surface of the job.



Thread Cutting Operation: It is the operation that is produced to a helical groove on a cylindrical or conical surface by feeding the tool longitudinally when the job revolved between the two centers.

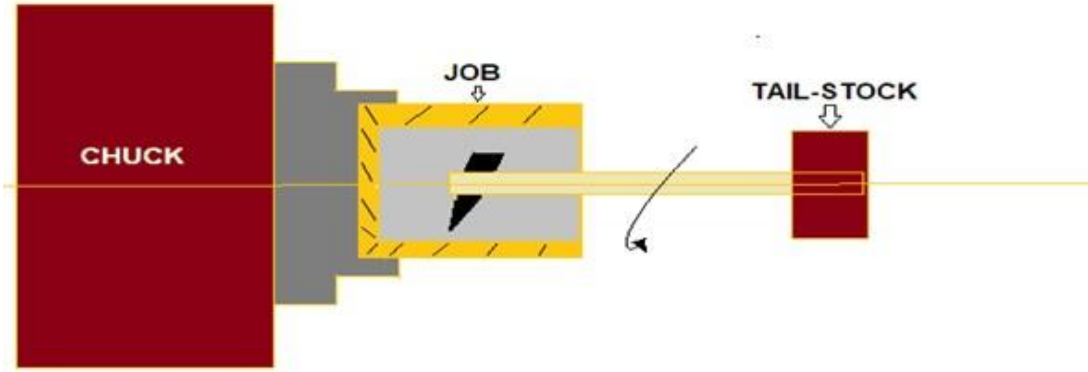


Drilling operation: Drilling is an operation by which we can make holes in a job.
In this operation, the job is rotated at the turning speed on the lathe axis and the drilling tool fitted on the tail-stock spindle. And the tail-stock is moved towards the job by hand feed.



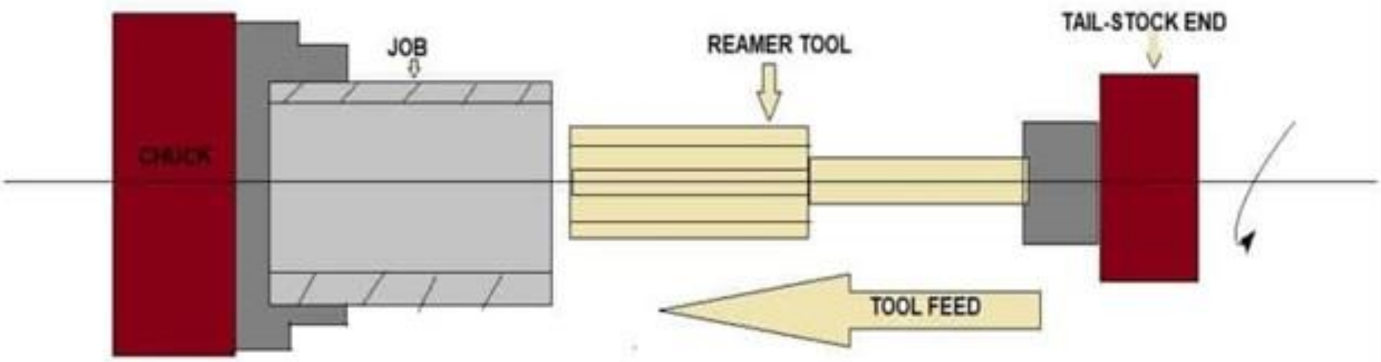
DRILLING

Boring Operation: In this operation, we can enlarge the diameter of the existing hole on a job by turning inside with some farm tool knows as boring tool. The boring tool is also fitted on tail-stock.



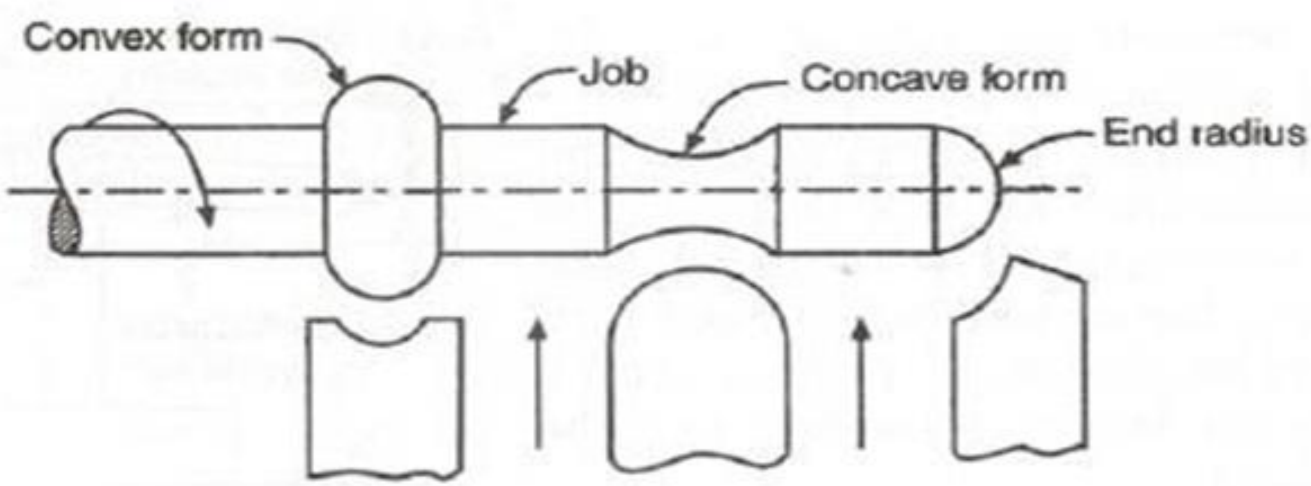
BORING OPERATION

Reaming Operation: Reaming is the operation for sizing or finishing a drilled hole to the required size by tool called a reamer. This tool is fitted to Tail-Stock.

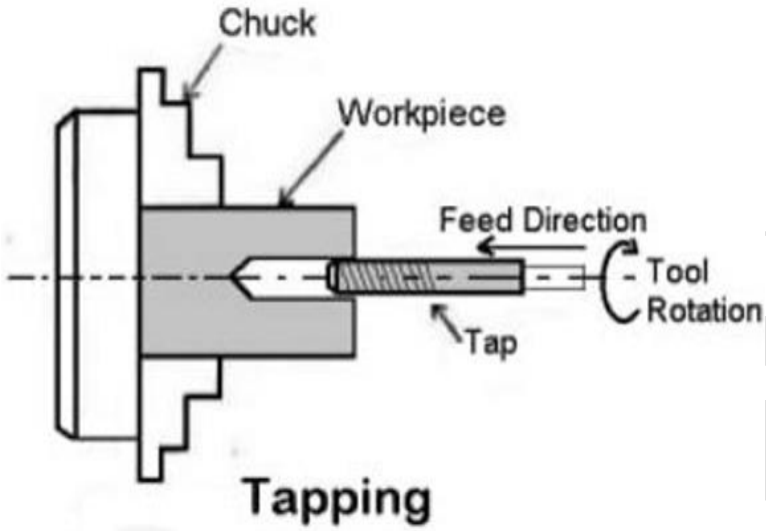


REAMING OPERATION

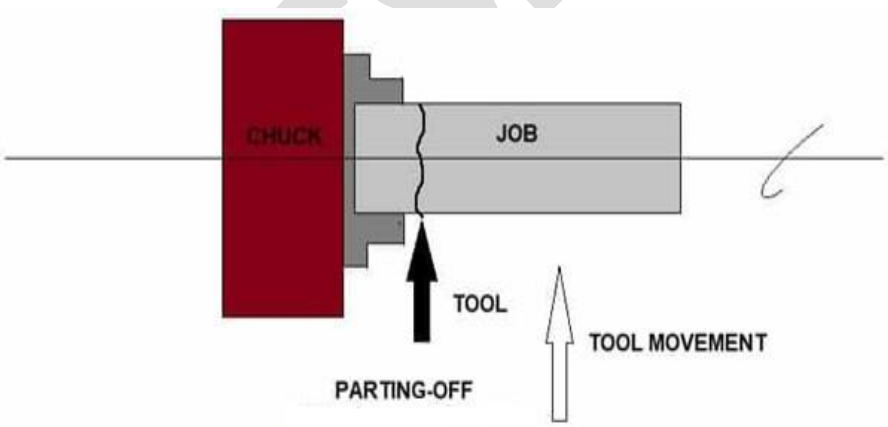
Spinning Operation: In this operation the job of this sheet metal is held between the former and the tail-stock centers rotate at high speed with the former. The long round nose forming tool rigidly fixed on special tool post presses the job on the periphery of the former. So the job is taken exactly the shape of the former. This is a chipless machining process.



Tapping operation: We use this operation for creating internal threads within a hole by means of a tool called tap.

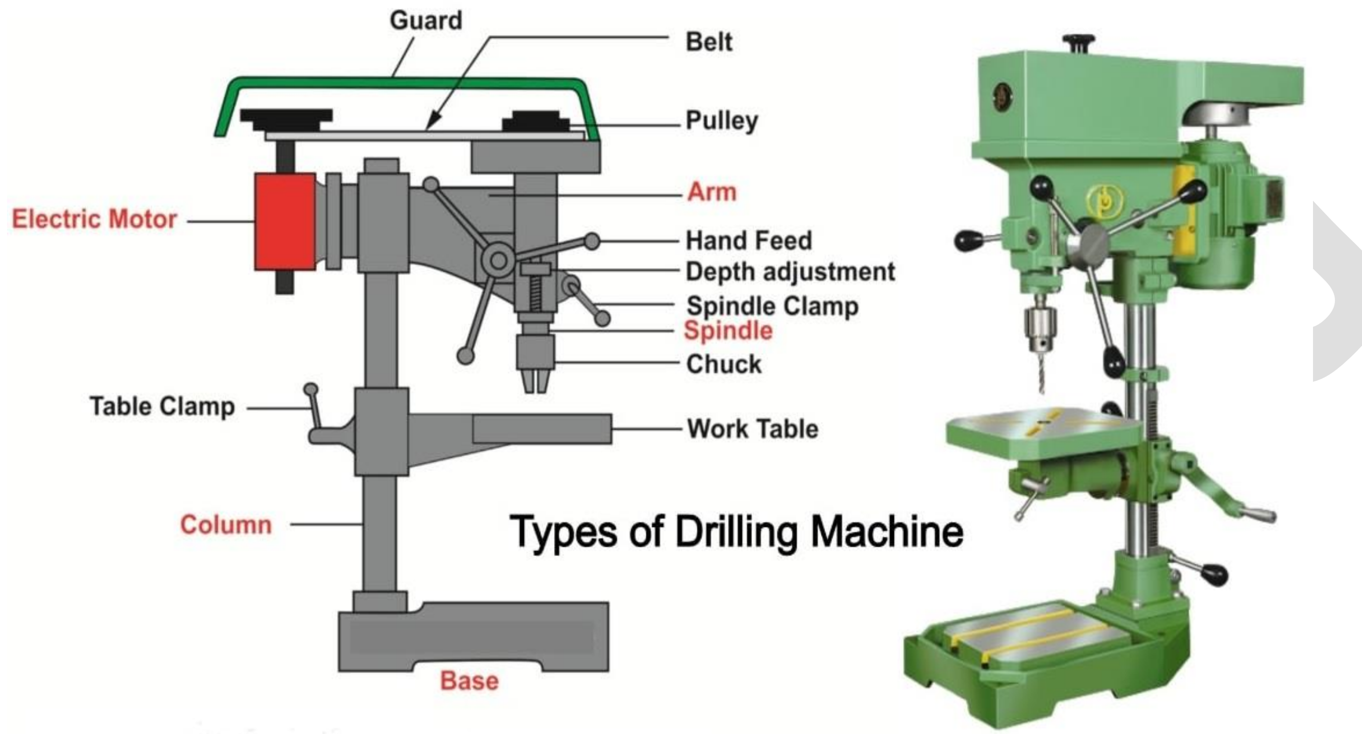


Parting-off operation: It is the operation of cutting off a bar type job after complete the machining process. In this operation a bar type job is held on a chuck, rotates at turning speed, a parting off tool is fed into the job slowly until the tool reaches the center of the job.



DRILLING MACHINE

Introduction: Drilling machine is one of the most important machine tools in a workshop. It was designed to produce a cylindrical hole of required diameter and depth on metal workpiece. Though holes can be made by different machine tools in a shop, drilling machine is designed specifically to perform the operation of drilling and similar operations. Drilling can be done easily at a low cost in a shorter period of time in a drilling machine.



Definition: Drilling can be called as the operation of producing a cylindrical hole of required diameter and depth by removing metal by the rotating edges of a drill. The cutting tool known as drill is fitted into the spindle of the drilling machine. A mark of indentation is made at the required location with a centre punch. The rotating drill is pressed at the location and is fed into the work. The hole can be made upto a required depth.

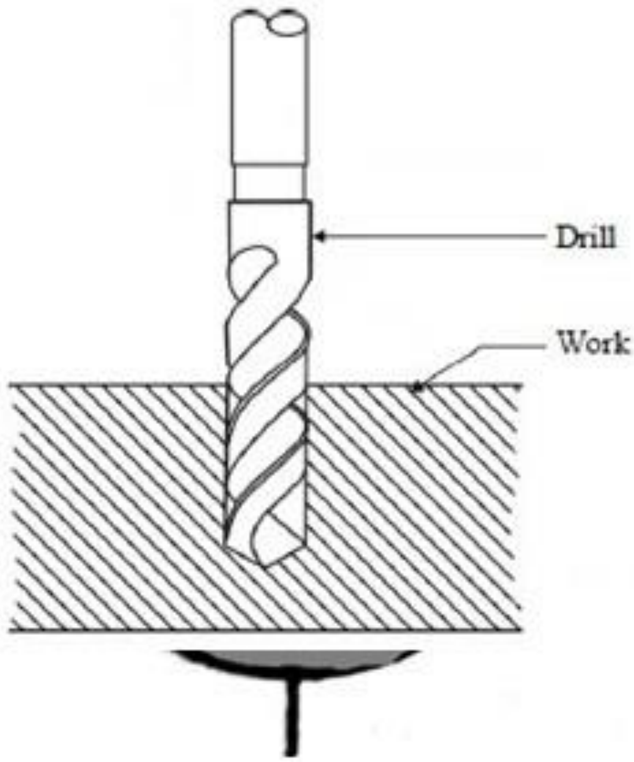
Different types of drilling machines	Work holding devices
1. Portable drilling M/C (or) Hand drilling M/C	1. Drill vise
2. Sensitive drilling M/C (or) Bench drilling M/C	2. 'T' - bolts and clamps
3. Upright drilling M/C	3. Step block
4. Radial drilling M/C	4. V - block
5. Gang drilling M/C	5. Angle plate
6. Multiple spindle drilling M/C	6. Drill jigs
7. Deep hole Drilling M/C	
Tool holding devices	**Tools used in a drilling machine**
1. By directly fitting in the spindle	1. Drill
2. By a sleeve	2. Reamer
3. By a socket	3. Counter bore
4. By a chuck	4. Countersink
5. Tapping attachment	5. Tap

Drilling machine operations

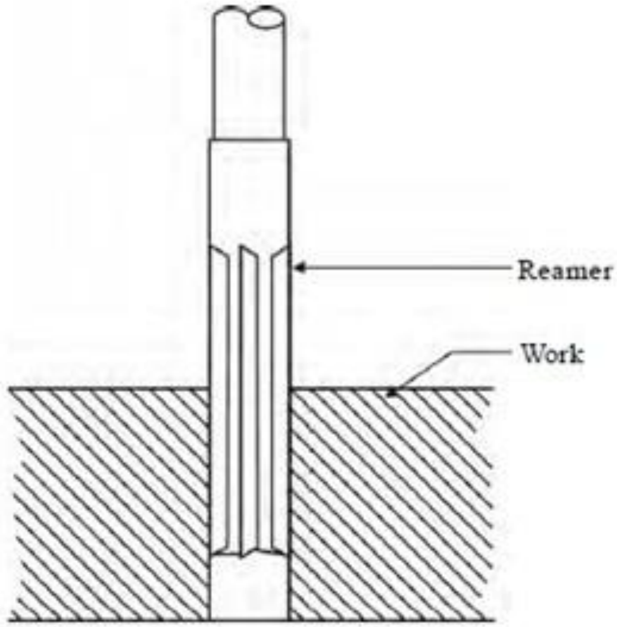
Though drilling is the primary operation performed in a drilling machine, a number of similar operations are also performed on holes using different tools. The different operations that can be performed in a drilling machine are:

1. Drilling
2. Reaming
3. Boring
4. Counter boring
5. Countersinking
6. Spot facing
7. Tapping
8. Trepanning

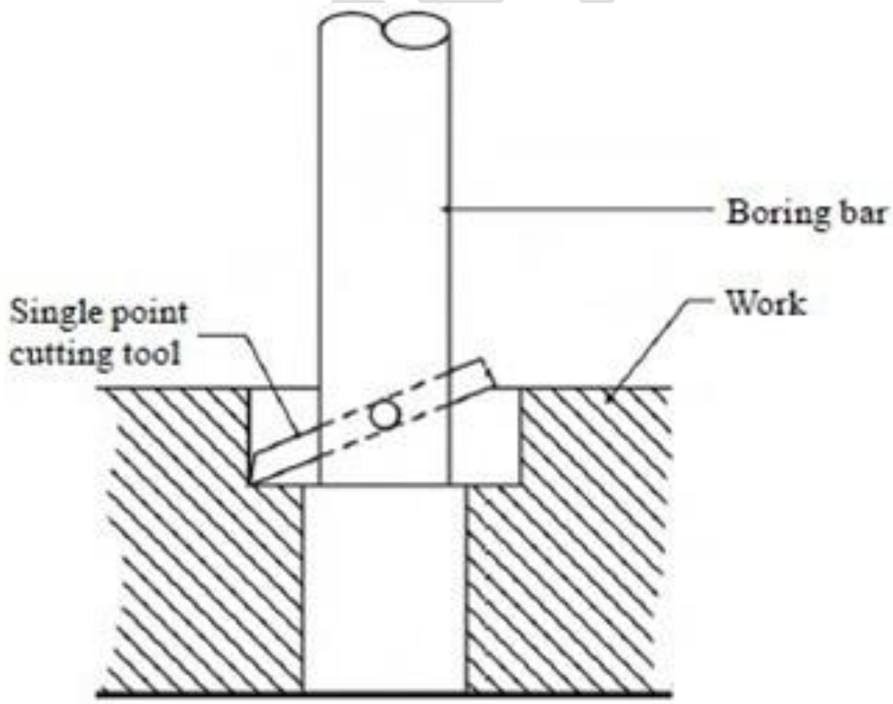
1. Drilling: Drilling is the operation of producing a hole by removing metal from a solid mass by the rotating edge of a cutting tool known as drill.



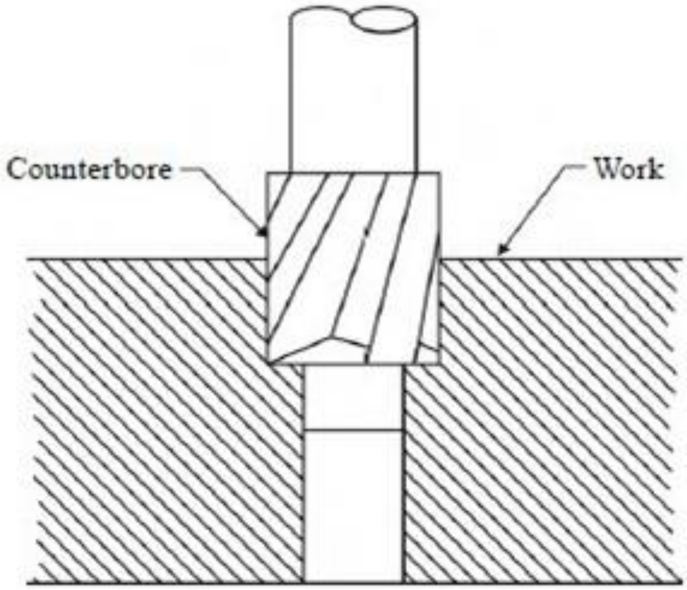
2. Reaming: The holes that are produced by drilling are rarely straight and cylindrical in form. To produce accurate and smooth holes, the drilled holes are reamed by a tool called reamer. The reamer is a cutting tool having several cutting edges in straight or helix shape.



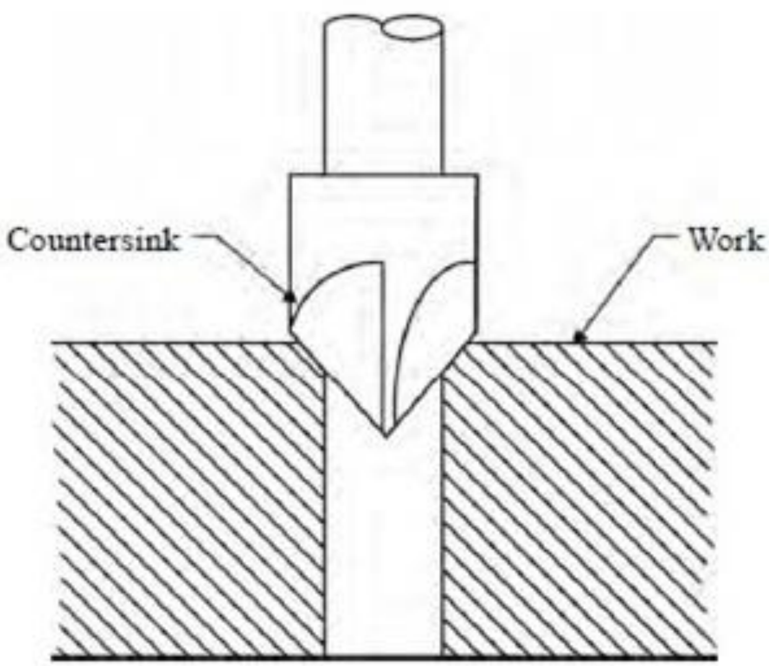
3. Boring: Boring is the operation of truing and enlarging a previously drilled hole by means of a single point cutting tool. Boring is done on drilling machine to perform the following tasks on a hole already drilled.



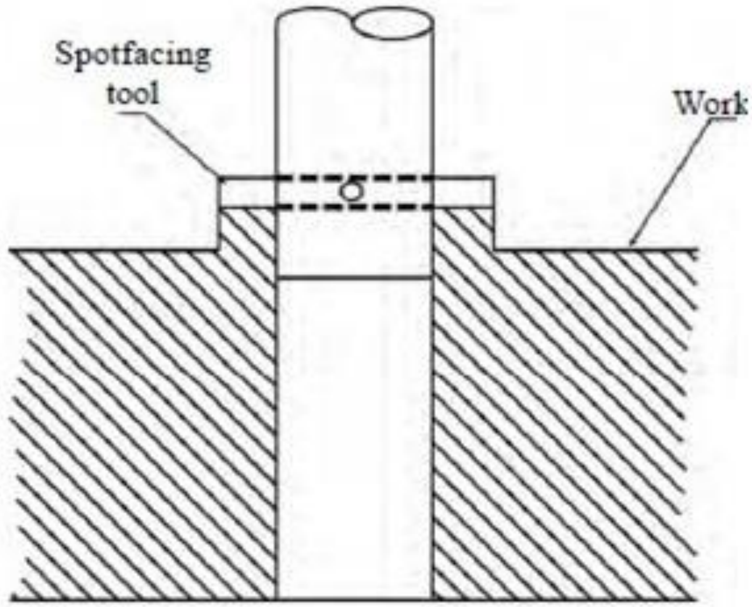
4. Counter Boring: Counter boring is the operation of enlarging one end of an existing hole concentric with the original hole with square bottom. It is done to accommodate the heads of bolts, studs and pins. The cutting edges of the counter-bore (tool used for counter boring) may have straight or spiral teeth.



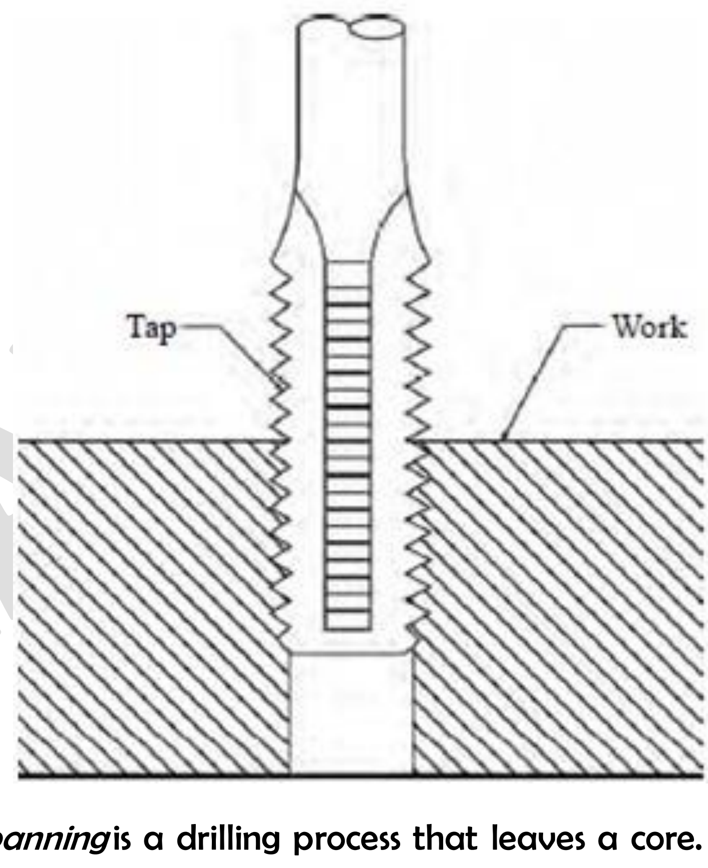
5. Countersinking: Counter sinking is the operation of making a cone shaped enlargement at the end of a hole to provide recess for a flat head screw or a countersunk rivet. The counter-sunks (tools used for counter sinking) carry included angles of 60°, 82° or 90° and the cutting edges of the tool are formed at the conical surface.



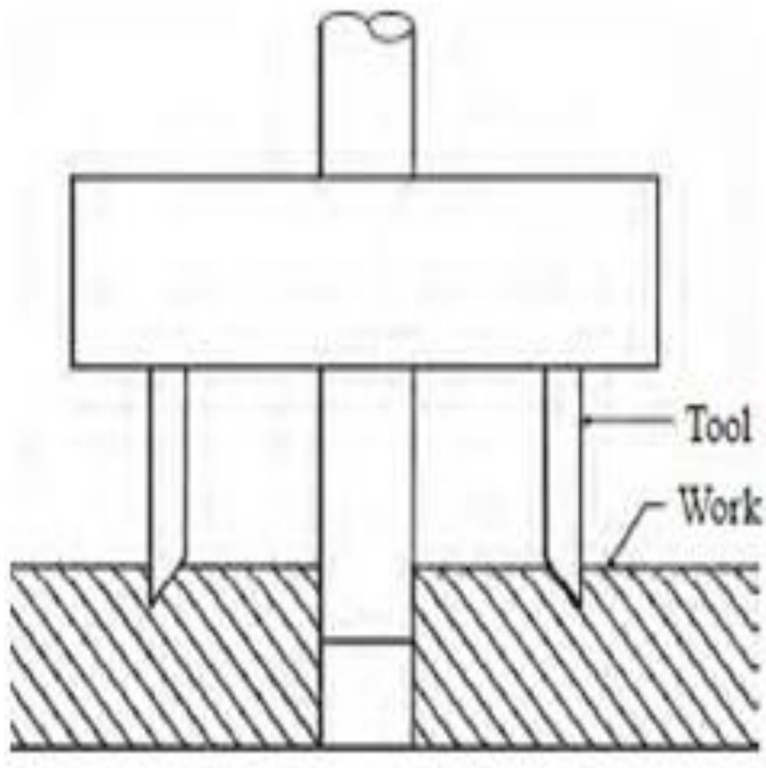
6. Spot facing: Spot facing is the operation of smoothing and squaring the surface around and at the end of a hole so as to provide a smooth seat for a nut or for the head of a cap screw. Spot facing is generally done on castings and forgings.



7. Tapping: Tapping is the operation for making internal threads in a hole by means of a tool called tap. The tap is essentially a bolt with threads cut on it.



8. Trepanning: *Trepanning* is a drilling process that leaves a core. Trepanning is a <u>deep hole drilling process</u> that has broad application over many industries. In many cases, trepanning is meant to be a roughing operation to be honed for finish or machined further. In other cases, the trepanned hole is fit for use 'as-drilled'.



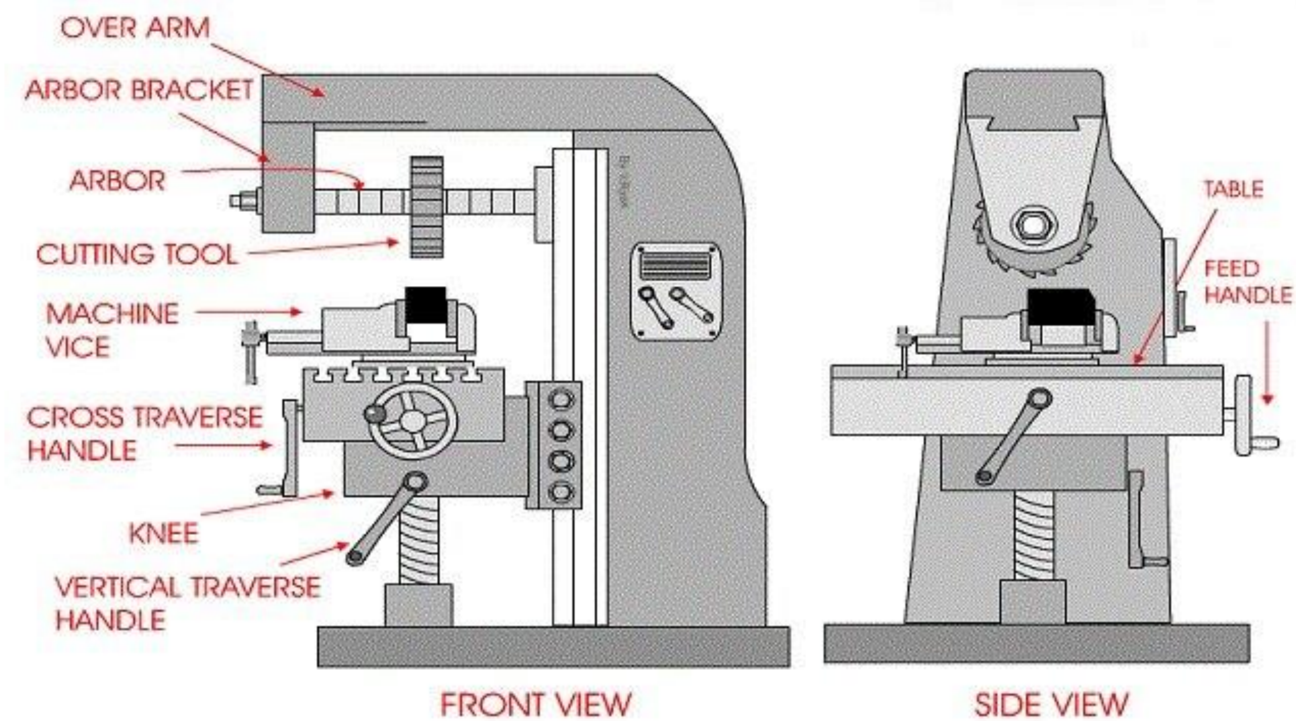
MILLING MACHINE

Introduction: The milling machine is believed to come into existence in 17 the century. It was used by the clockmakers at that time. Then in the 18th century in the United States, a machine was used which was similar to the lathe machine but in this machine, the cutting tool is used to rotate and the workpiece uses to remain stationary.

This was the better-developed form of the Milling machine. Inventor name: Eli Whitney invented the Milling machine in the year 1818. During that time, it was used for the making of gun parts. Now, these machines can perform multiple operations. Gradually with time now we have the most advanced form of the Milling machine which is the CNC Milling Machine. It is very accurate and has a high production speed.

Definition: The milling machine is a type of in which a cutter having multiple cutting edges is used to remove the material from the workpiece by feeding the work past a rotating multipoint cutter. The metal removal rate is higher very high as the cutter has a high speed and many cutting edges.

It is the most important machine in the tool room as nearly all the operations can be performed on it with high accuracy. MRR (Material Removal Rate) can be further increased by increasing the number of teeth on the cutter. This machine tool makes up about 85 percent of all material removal processes.



Milling Machine Application or Uses:

Milling Machine is used for Machining flat surfaces, Slotting, Contoured surfaces.
It is also useful for making Complex and irregular areas, Revolution surface, Gear cutting, Machining external and internal threads.
Machining helical surfaces of various cross-sections and many more

Milling Machine Parts:

The Milling Machine consists of Base, Column, Knee, Saddle, Table, Over-Arm, Spindle or Arbor, Arbor supports, Ram, and Milling Head.

Milling Machine Working Principle:

- ✓ Milling machine employed in the metal removing operation in which the work is rigidly clamped on the table of the machine and the revolving cutter which has multiple teeth is mounted on the arbor.
- ✓ The cutter revolves at high speed and the work is fed slowly past the cutter.
- ✓ The work can be fed in a vertical, longitudinal, or cross direction depending upon the type of milling machine being used.
- ✓ As the work proceeds, the cutter-teeth remove the metal from the surface of the job (workpiece) to produce the desired shape.

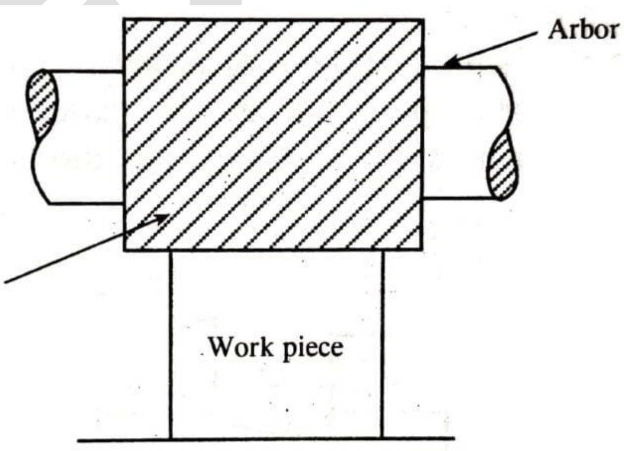
Milling Machine Operations:

1) Plain or Slab Milling Operation
2) UP and DOWN Milling Operation
3) Face Milling Operation
4) End Milling Operation
5) Gang Milling Operation
6) Straddle Milling Operation
7) Groove Milling Operation
8) Gear Milling Operation
9) Side Milling Operation and
10) T-Slot Milling Operation

The milling machine does not give a continuous cut like in the case of the Lathe Machine.

1. Plain Milling or Slab Milling Operation:

Plain or slab milling is a process in which the plain, horizontal or flat surfaces are produced, which is parallel to the axis of the rotation of the cutter. A peripheral mill cuter is used for performing the slab milling operation.



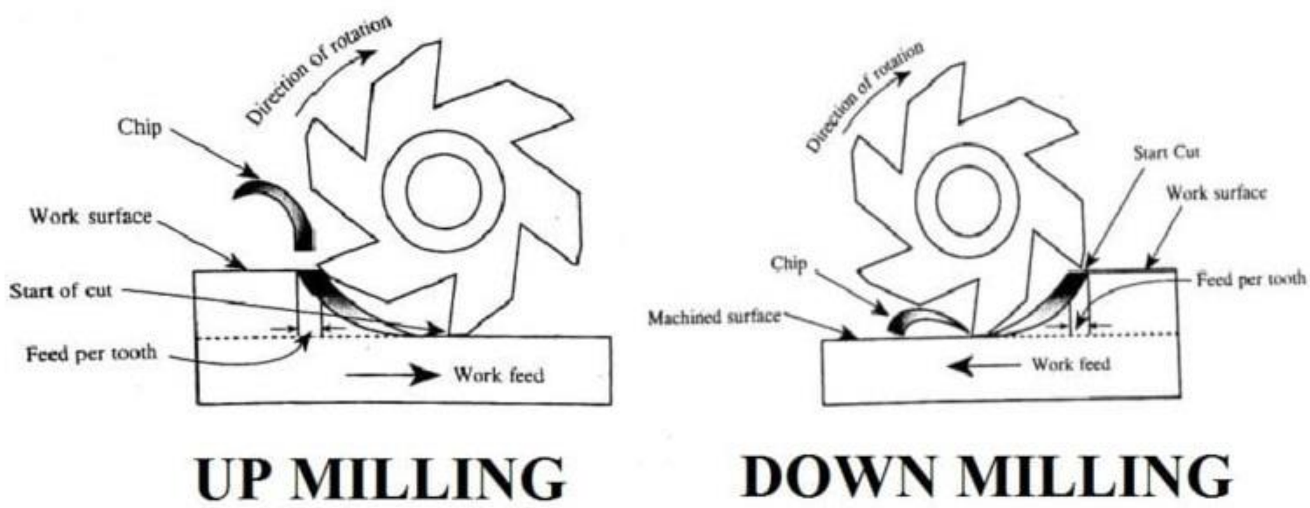
Plain milling

2. Up Milling and Down Milling:

Up milling is a method of milling operation in which the cutter and the workpiece both move in the opposite direction.

Down Milling is a method of milling operation in which the direction of the rotation of the cutter coincides with the direction of the work feed.

Difference Between UP and DOWN Milling?



Chip Thickness will be minimum in the beginning and maximum at the end in the case of up-milling. Whereas, the chip thickness will be greater at the beginning and lesser at the end in the case of down-milling

Tool Life will is more in the case of down-milling as compared with the up-milling.

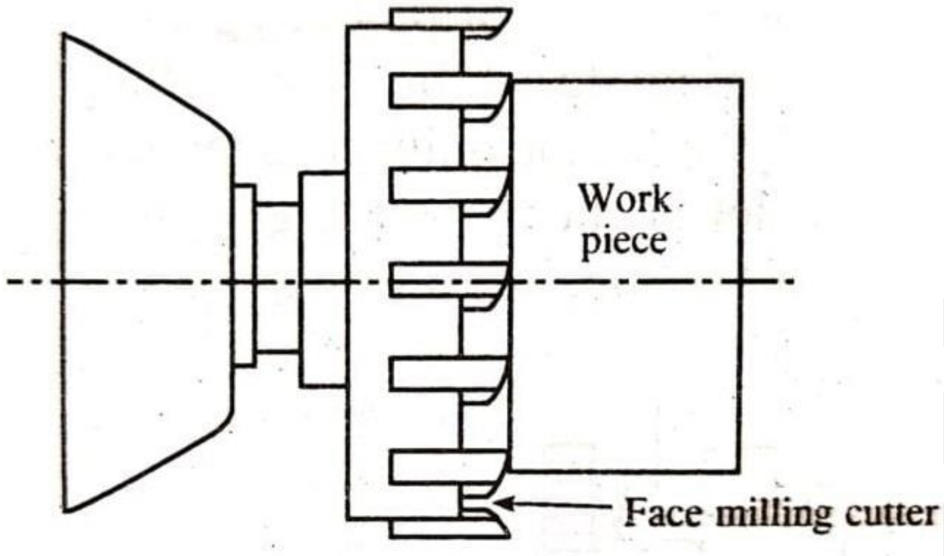
The surface finish will be more in the case of the down-milling as compared with the up-milling method due to which down-milling method is used for the finishing operations in the industries.

Accuracy will be more in the case of up-milling as compared with the down-milling process since in up-milling the workpiece is pulled against the table so the fasteners will be under tension and we know that under tension the backlash error will not have any effect which ultimately results in the better accuracy in up-milling

3. Face Milling Operation:

It is a type of milling operation in which the layer of material is removed from the face of the material. **The end milling cutter is preferred for performing face milling operations.**

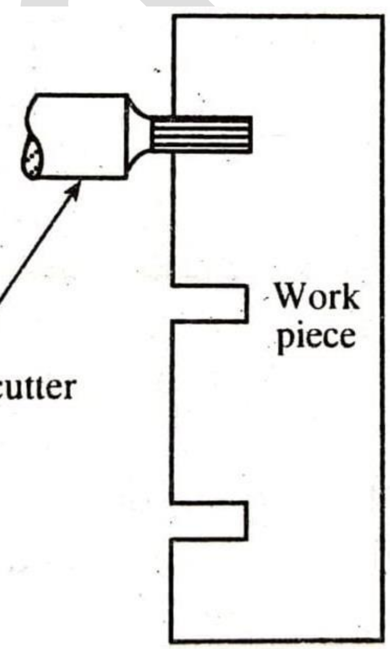
In Face Milling operation the teeth for cutting are present on both the periphery and the face of the cutter. The axis of rotation of the cutter is perpendicular to the work surface. In face milling most of the cutting is done by the periphery portions of the teeth, the face portion provides finishing the action.



Face milling

4. End Milling Operation:

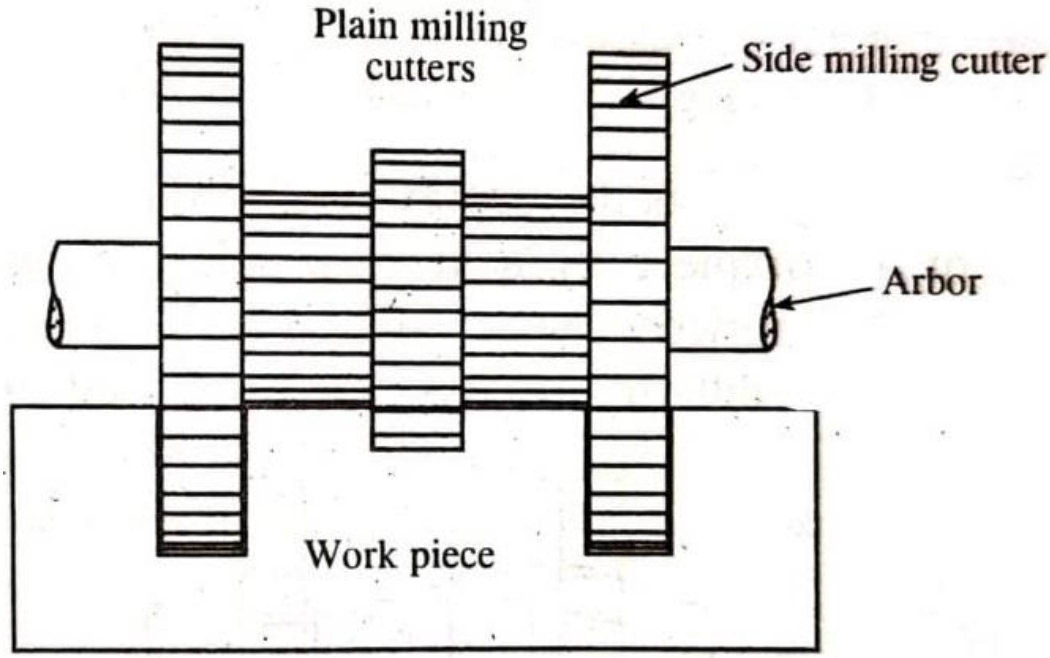
This type of operation is the combination of the slab milling and face-milling operation used for creating slots in the workpiece and is mostly used for handling the complicated profile.



End milling

5. Gang Milling Operation:

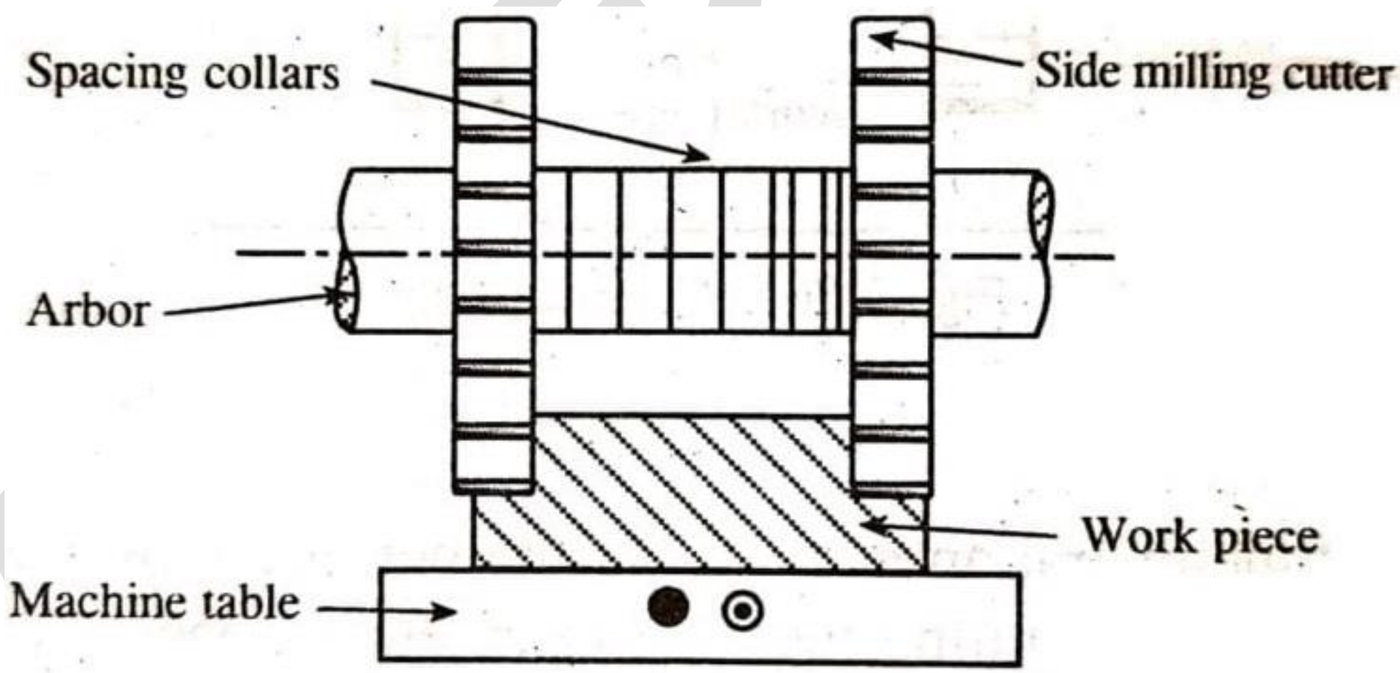
This is a type of milling operation in which multiple cutters are being mounted on the same arbor to produce the desired shape on the workpiece.



Gang milling

6. Straddle Milling Operation:

The straddle is the type of milling process in which milling is performed on two surfaces simultaneously. T-slot milling is a unique example of straddle Milling.



Straddle milling

Advantages of Milling Machine:

High speed: In Milling, the rate of metal removal is very high as the cutter rotates at a high speed and has multiple cutting edges.

Better surface finish: The surface finish of the materials machined on the milling machine is better because of the multi-cutting edges.

Increased Productivity: CNC Milling Machines are the machines in which the milling operation is being controlled by software. It has increased the overall production with better finish and accuracy.

High Accuracy: In the milling machine, the products machined are of high accuracy, especially in the case of the most advanced form of milling machine which is the CNC Machine.

Huge Application: The indexing head makes it suitable for so many applications as the exact rotation of the job is possible by the use of it. Milling can be used for machining flat surfaces, irregular surfaces, contoured surfaces, slotting, gear cutting, and many more.

Milling Machine disadvantages with remedies:

High Flank wear: It has a high flank wear rate which can be prevented by reducing speed and increasing the feed rate. Further to avoid it one should use harder carbide with proper geometry and sharpened cutting edges.

High crater wear: High crater wear is found which can be tackled by reducing speed and using harder carbide.

Breaking of carbide: Sometimes the production process gets hindered because of the breaking of the carbide. The remedy for this problem can be the use of tougher carbide, and rigidity of the cutter, machine, and arbor should be ensured.

High Chatter: This happens due to poor rigidity of cutter, machine, loose arbor, and improper geometry. This situation can be improved by increasing feed, reducing speed, and using unequal pitch cutters.

Chip clogging: The milling machine also suffers from the problem of chip clogging which can be reduced by using reducing the number of teeth on the cutter and increasing speed and chip pockets.

GRINDING MACHINE

Introduction: A **grinding** is metal cutting operation which is performed by means of a rotating abrasive wheel that acts as a tool. These are mostly used to finish work pieces which must show a high surface quality, accuracy of shape and dimension.

Mostly, it is finishing operation because it removes material in very small size of chips **0.25 – 0.5 mm.** There accuracy in dimensions is in the order of **0.000025 mm.**

Grinding is also done to machine materials which are too hard for other machining strategies that use cutting tools.

Definition: A **grinding machine** is machine tool which is used for removing of rough surface of a workpiece with the help of rotating abrasive wheel that acts as a tool.

Or

An operation in which, removing of rough surface and making smooth surface are done, is known as **Grinding or Grinding Machine.**

Or

A grinding machine or grinder is an industrial power tool that uses an abrasive wheel for cutting or removing the material.

Working of Grinding Machine:

- In a **grinding machine**, there is an electric motor which supplies the motion power to the grinding wheel with the help of a belt and pulley.

- So when we start the electric motor the motor rotates at a certain rpm (150-15000 RPM, it may change according to the types of grinding machine) with the help of v-belt and cone pulley the grinding wheel also starts rotating and we perform the operation.
- It works to the action of rubbing or friction between the abrasive particles and workpiece material.
- Due to this, workpiece is fed against the rotating abrasive wheel to remove material in the form of very small size of chips.

Parts of Grinding Machine

Parts of Grinding Machine

1. Wheel
2. Wheel Head
3. Base
4. Saddle
5. Table
6. Headstock
7. Tail Stock
8. Cross -feed

Different types of Grinding Machines:

Rough Grinders:

- Floor or bench grinders
- Portable grinders
- Abrasive belt grinders
- Swing Frame grinders

Precision Grinders:

- Surface Grinders
- Cylindrical Grinders (Plain, Universal, and Centerless grinders)
- Tool and Cutter Grinders
- Internal Grinders (Chucking, Planetary, and Centerless grinders)
- Special Grinding machine

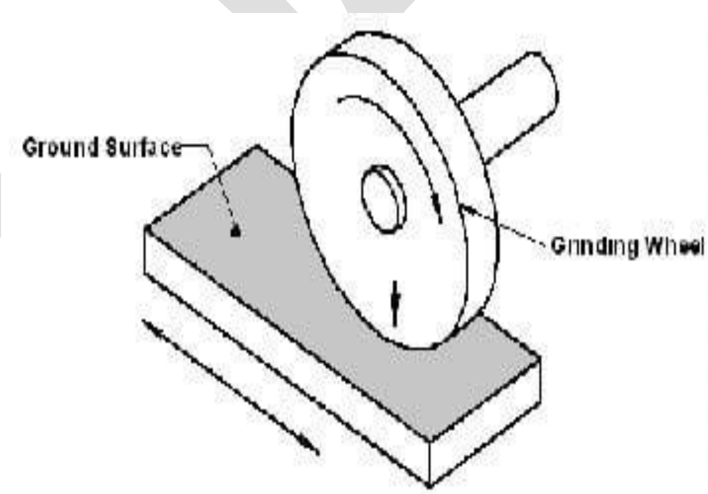
Grinding Machine Operations:

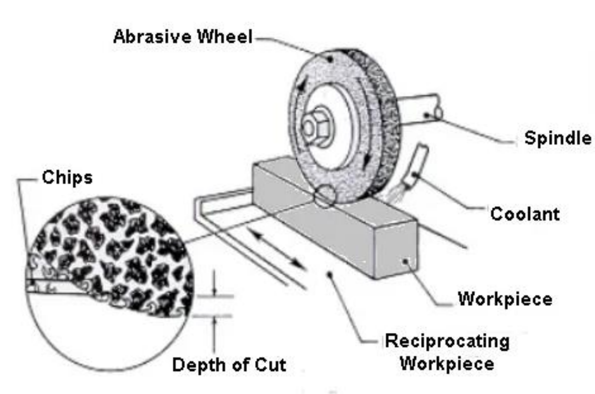
1) Surface Grinding Operation
2) Cylindrical Grinding Operation
3) Thread grinding Operation
4) Internal and External Grinding
5) Centerless Grinding
6) Form Grinding Operation
7) Wet and Dry Grinding Operation

Surface Grinding Operation:

Surface grinding involves grinding flat surfaces and is one of the most common grinding operations. Typically the workpiece is secured on a magnetic Chuck attached to the worktable of the grinder. Nonmagnetic materials generally are needed by vises special fixtures, vacuum Chuck's.

A straight wheel is mounted on the horizontal spindle of the grinder. Transverse grinding occurs as the table reciprocating. Longitudinally and feels latterly after each stroke. In plunge grinding the wheel is moved radially into the workpiece as it is when grinding a groove.



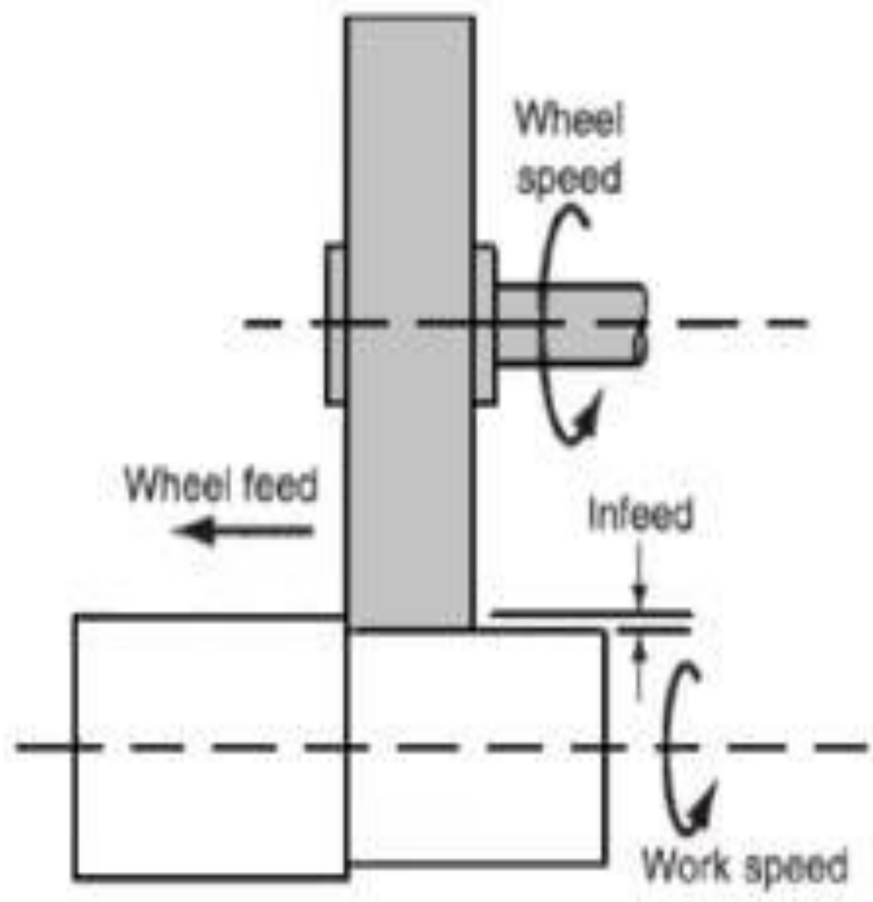


SURFACE GRINDING

Cylindrical Grinding Operation:

The rotating cylindrical workpiece reciprocates laterally along its axis in a grinder used for the large and long workpiece. The grinding wheel reciprocate called a roll grinder cylindrical grinders are identified by the maximum diameter and length of the workpiece that can be ground similar to engine lathes.

In universal grinders, both the workpiece and the wheel axes can be moved and swiveled around a horizontal plane permitting the grinding of tapers and other shapes. This typical applications include crankshaft bearing spindles pins, bearing rings and rolls for rolling mills.



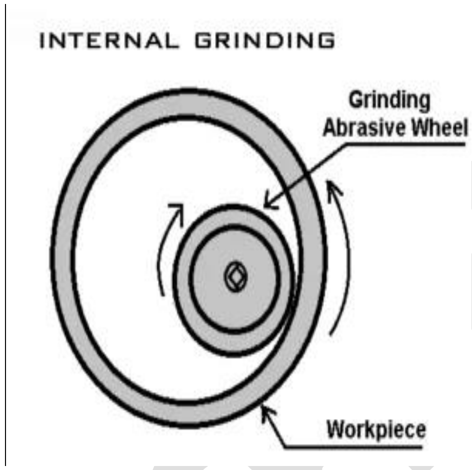
Thread grinding Operation:

It is done on cylindrical grinders with specially dressed wheels matching the shape of the thread as well as using a Centerless grinder. Although costly thread produced by grinding is the most accurate of any manufacturing process and has a very fine surface finish.

Internal and External Grinding:

In an internal grinding, a small wheel is used to grind the inside diameter of the part, such as bushings and bearing races. The workpiece is held in a Rotating Chuck. The headstock of internal grinders can be swiveled on a horizontal plane to grind tapered holes. Whereas

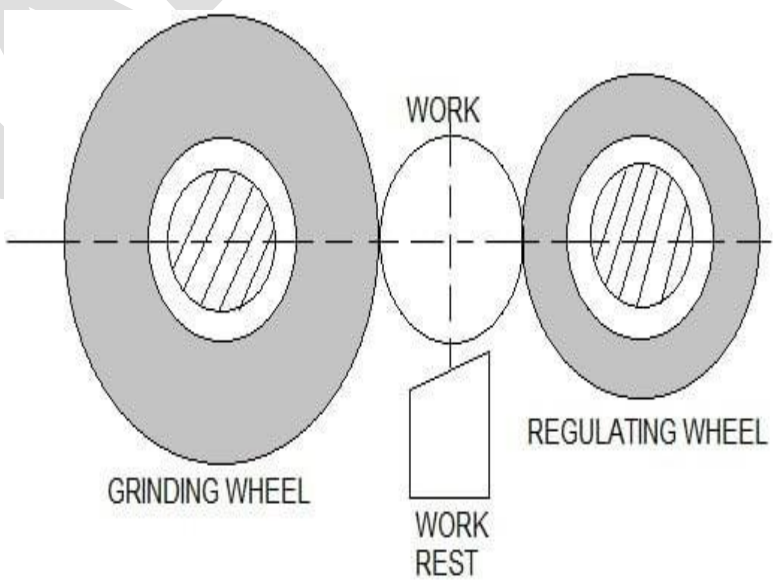
In an external grinding, a small wheel is used to grind the outside diameter of the part, such as bushings and bearing races. The workpiece is held in a Rotating Chuck.



Centerless Grinding Operation:

In this operation there are two wheels are fitted parallel with a 5-10 degree angle and this angle is provided to get a longitudinal motion of the workpiece.

Here the work piece is supported blade, not by centers or chucks. A cylindrical rod is placed between the two-wheel due to the tilted angle the workpiece is automatically passed through the wheels, and we got a smooth surface.



Wet and Dry Grinding Operation:

Here In Wet, we sprayed coolant generally water or any other coolant to cool the surface so that the longevity of the grinding wheel increases and also we get a fine surface finish.

But In case of Dry Grinding operation Here In Wet, we do not use any coolant to cool the surface.

Grinding Machine Advantages:

The following **advantages of Grinding Machine** are:

- With the help of this machine, we can obtain a good surface finish on the workpiece.
- Grinding can machine hard material.
- The surface smoothness is good and it can be obtained from this machine.
- The work operation can be done at maximum temperature also.
- In a grinding machine, the abrasive particles are self-sharpened action.
- The semi-skilled operation can work on this machine. The work can be performed easily.
- The machine productivity is good.
- One major advantage of this machine is the manual and automatic operation can be performed.

Grinding Machine Disadvantages:

The following **disadvantages of Grinding Machine** are:

- The Grinding Machine is a little costly. The cost of this machine is more than 2.5 lacks.
- Unlike another machine (Lathe Machine) the material removal rate is not fast.
- It takes more time for removing the material.
- Once the grinding operation starts the wheel cannot rotates in the reverse direction and the wheel is constantly degrading and it requires much spindle power.

Grinding Machine Application:

The following **applications of Grinding Machine are**:

- The Grinding Machine is used in various industries for grinding. The first and foremost industry where this machine is used in Manufacturing Industry.
- The Grinding Machine is used for finishing the cylindrical and flat surfaces. In other words, we can say it is used for grinding various materials.

ABRASIVES WHEELS & ITS PROPERTIES

The grinding process is capable of producing very accurate sizes, equally accurate geometry like flatness or circle and extremely good surface finish. It is capable of machining hardness high-speed steel, which cannot be done by other machining processes.

Abrasives wheels are the impure form of aluminium oxide. A grinding wheel or bonded abrasive is made up of thousands of tiny abrasive particles insert in matric calls as 'bond'.

In bonded abrasives, porosity is essential to provide clearance for the chips being produced and to provide cooling; otherwise chips would interfere with the griding process.

Hardness Comparison of Abrasive Material

An abrasive is a second hardest material, compared to diamond.

- ✓ Aluminium oxide (hardness of 2000-3000)
- ✓ Silicon carbide (hardness of 2100-3000). These are the perfect examples of conventional abrasives.
- ✓ The cubic boron nitrite (hardness of 4000-5000)
- ✓ Diamond (hardness of 7000-8000) comes under the category of super abrasives.
- ✓ In addition to hardness, an important characteristic called friability. Friability is the ability of abrasive grains to fracture (break) into small pieces. High friability indicates low strength or low fracture resistance of the abrasive.

For example, aluminium oxide has a lower friability than silicon carbide and has fewer tendencies to a piece. Bonded abrasive are marked with a standardization system of letters and numbers, indicating the type of abrasive, grain size, grade, structure, and bond type.

Life of Grinding Wheel:

When a grinding wheel is applied to the workpiece, the sharp edges of the abrasive grains which are cutting, will, in the end, lose their cutting effect and become dull.
At that stage, the abrasive grains should either split or form new edges or it should break away from the wheel exposing the next layer of grains to do work.

If the dulled grains stay in the wheel, they simply keep on rubbing on work without actually cutting. **This defect is known as 'glazing'.** If on the other hand, the abrasive grains break away from the wheel or split prematurely, before becoming dull, **it causes a reduction in life of the grinding wheel.**

Selection of Abrasives in Grinding

- Emery and corundum are no longer used in modern grinding wheels.
- Instead, artificially manufactured abrasives are used due to their high purity. And they include silicon carbide and aluminium oxide.
-

1. Silicon carbide

- Silicon carbide is greenish-black in colour.
- It is harder and more brittle than alumina. For this reason, it is used for grinding materials of low grinding resistance like cast iron, brass, and copper.
- The code for silicon carbide is C.

2. Aluminium oxide

- It is reddish-brown in colour.
- Aluminium oxide abrasive is more suitable for grinding most steels because of its greater toughness to cope with increased grinding resistance offered.
- Aluminium oxide wheels it is A.

The abrasive, the performance of grinding wheels also depends on many other factors. It is important that a suitable grinding wheel is selected for particular applications.

Selection of Grinding Wheels:

It means choosing the most appropriate wheel for a particular grinding machine operation. Wheel selection would depend on what abrasive is required and characteristic of the wheels and also on operating conditions like a wheel and work speed, type and conditions of machines used.

Thumb rule is to use a hard wheel for soft material and soft wheel for hard material. A hard wheel retains the abrasives as they do not get dulled easily on soft materials.

Bond and Types of bond:

Bond refers to the substance of which the matrix of the grinding wheel is made. The following bonds are generally used in the manufacture of grinding wheels. The bond hardness or grade is usually represented by the letters of the English alphabet.

A represents the very soft grade, while Z is very hard M and N represent medium grade hardness.

1. Vitrified Bond
2. Silicated Bond
3. Shellac Bond
4. Rubber Bond
5. Resinoid Bond

1. Vitrified Bond

- It is denoted by letter V.
- About 80% of the wheels used in the industry are of this bond.
- It is also called as ceramic bond.
- They are strong, stiff, porous, and resistant to oils, acids, and water. They are brittle and lack resistance to mechanical and thermal shock.

2. Silicate Bond

- It is denoted by letter S.
- Silicate of soda (commonly known as water glass) is the main component of this bond.

3. Shellac Bond

- It is denoted by letter E.
- Shellac (a naturally available material) is the main component of the bond.

4. Rubber Bond

- It is denoted by letter R.
- This process consists of mixing crude rubber, sulfur, and the abrasive grains together, rolling the mixture into sheets, cutting out circles and heating them under pressure to vulcanize the rubber.
- The wheels can be made like this and can be used as saws for cutting-off operations.

5. Resinoid Bond

- It is denoted by letter B.
- Resoniod bonding materials are thermosetting resins, and the bond is an organic compound, so the wheels with resinoid bonds are also called as organic wheels.
- Some of these wheels are made from bakelite and other resinous material.

Wheel Grit, Grade and Structure:

1. Grit

Grit indicates the size of the abrasive grain. It is indicated by a number. Higher the number, smaller the size of grains. Abrasives finer than 200, are called "flours" designated as F, FF, and FFF.

The finer abrasive used as jewelers
For the fine finish of ground surface, smaller grit size abrasive wheels are used. But their metal cutting capacity is limited.
Large size abrasive wheels, finish is rough but metal removal rate is higher.

2. Grade

The degree of hardness possessed by the bond is called the grade of the wheel and indicates the strength of the grip with which the abrasive grains are held in the bond.

It indicates the type and the amount of bond in the wheel. It is also referred to as the hardness of a bonded abrasive. A hard wheel has a stronger bond and a larger amount of bonding material between the grains than a soft wheel.

3. Structure

Structure of a bonded abrasive is a measure of the porosity (spacing between the grains). The structure of the bond material in a wheel varies from about 10% to 30% of its total volume. Structure of the bond depends upon this percentage.

If the abrasive grains are too strictly packed, the percentage of bond material will be on the lower side this is called a closed structure. If the abrasive grains are less strictly packed in the same volume, the wheels are called an open structure.

The structure is indicated by a number varying from 1 (very closed structure) to 15 (very open structure. On every grinding machine wheel, the manufactures are limit to give the following information. in specified sequence about the,

- Abrasive used (A or C)
- Grit number (ex: 46)
- Grade (A to Z)
- Structure (1 to 5)
- Bond type (by letters)

THANKS TO ALL

Code No: 154AF **R18**

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
B. Tech II Year II Semester Examinations, August/September - 2021
BASIC MECHANICAL ENGINEERING FOR CIVIL ENGINEERS
(Civil Engineering)

Time: 3 Hours **Max. Marks: 75**

Answer any five questions
All questions carry equal marks

\- - -

1. In detailed explain about different types of heat treatment processes with suitable example. [15]

2. In brief explain about different types of Belt conveyors with neat diagrams. [15]

3. Explain the working of 4-stroke compression ignition engine with a neat sketch. [15]

4. With a neat diagram explain about the gas welding process. [15]

5. Explain the working and constructional details of a simple lathe machine. [15]

6. Describe different welding methods with the help of figures. [15]

7. Explain the step-by-step procedure to calculate COP of a refrigeration system. [15]

8.a) Discuss about different methods of failure of riveted joints.
b) Explain about efficiency of riveted joints and eccentrically loaded riveted joints. [7+8]

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R18

Code No: 154AF

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
B. Tech II Year II Semester Examinations, November/December - 2020
BASIC MECHANICAL ENGINEERING FOR CIVIL ENGINEERS
(Civil Engineering)

Time: 2 hours **Max. Marks: 75**

Answer any Five Questions
All Questions Carry Equal Marks
\- - -

1. Explain different profiles of cam and followers with neat sketches. [15]

2. Explain the function of riveted joint and different types of riveted joints. [15]

3. Draw the line diagrams of different gear trains and explain their working. [15]

4. With the help of schematic diagram, explain the working details of belt conveyors and cranes. [15]

5. Draw the line diagram and explain the working of Air refrigeration system. [15]

6. Write the three basic equations of heat transfer modes and explain the composite wall and other applications of heat transfer. [15]

7. What are the welding methods available? Explain the working of them with line diagrams. [15]

8. What are the techniques adopted for the grinding operation? What are the materials used in preparing the grinding wheel? [15]

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THANKS TO ALL

BY

NARESH BABU A

(7)

R18

Code No: 154AF

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
B. Tech II Year II Semester Examinations, April/May - 2023
BASIC MECHANICAL ENGINEERING FOR CIVIL ENGINEERS
(Civil Engineering)

Time: 3 Hours **Max. Marks: 75**

Note: i) Question paper consists of Part A, Part B.
ii) Part A is compulsory, which carries 25 marks. In Part A, Answer all questions.
iii) In Part B. Answer any one question from each unit. Each question carries 10 marks and may have a, b as sub questions.

PART – A

(25 Marks)

1.a) Explain the advantages of cam in terms of applications. [2]
b) Explain the significance of Heat treatment. [3]
c) Compare the belt drive with other conveyor systems. [2]
d) Explain the limitations of gears and their applications. [3]
e) Explain the effect of refrigerants on air craft refrigeration system. [2]
f) What are the desirable properties of a good refrigerant? [3]
g) Explain the salient features of Brazing. [2]
h) Describe the working of different casting methods. [3]
i) Explain the need and significance of a lathe machine. [2]
j) What are the different operations can be performed on milling machine? [3]

PART – B

(50 Marks)

2.a) Explain the concept and types of composite materials and their advantages.
b) With the help of line diagrams, explain different types of eccentrically loaded riveted joints. [5+5]

OR

3.a) What are the different types of ceramic metals and explain the advantages of the same.
b) Derive the equation for the strength of the riveted joint. [5+5]

4.a) Explain the concept and types of gear trains and their advantages.
b) With the help of line diagrams, explain different types of Helical and Bevel gears. [5+5]

OR

5.a) What are the different types of industrial trucks and explain their applications.
b) Explain the differences between the cranes and bull dozers with line diagrams. [5+5]

6.a) Explain the two and four stroke internal combustion engines working elaborately and give applications also.
b) Explain the working of air refrigeration system and explain how to calculate the COP. [5+5]

OR

7. Explain how the heat transfer will take place in solids, liquids and vacuum and also derive the basic equations of each and give the applications. [10]

8.a) Draw the line diagrams and explain the different tools and accessories used in sheet metal work.

b) Compare and contrast the operations of brazing and soldering. [5+5]

OR

9.a) Explain the working principle with line diagram of gas cutting and advantages of the same.

b) What is meant by casting, explain its working and how it is different from other methods and give the applications? [5+5]

10. Draw the line diagram and explain the working details of a radial drilling machine. [10]

OR

11. Explain the basic principle of milling machine and with the help of a neat diagram explain the working of a milling machine. [10]

---ooOoo---