Metal Joining processes:

Soldering: Types of Solder, Types of Flux used, methods of soldering

Brazing: methods of brazing, Filler metals, Types of Flux, advantages of brazing over soldering.

Welding: Classification, Arc welding, oxy Acetylene Welding

Transmission of power & Lubrication and bearings

Belt drives: Flat belt drive, open and cross belt, velocity ratio, slip, creep. Length of belt, Stepped pulley, Idler pulley, problems on velocity ratio.

Gear Drives: Classification of gears according to shaft position, Terminology of application. Problems on simple ad compound gear trains.

Bearing and Lubrication:

Bearings: Solid, Bushed, pedestal, Pivot Collar, Ball and Roller bearings, merits and demerits.

Lubrication: Types of Lubricants, properties of lubricant, Lubricators (Drop Feed, Wick, Ring and Splash)

Welding

- ***Welding*** is a process of joining two pieces of metal by the application of heat with or without the application of pressure and filler material.
- Welding produces a ***permanent joint.***
- Welding is used in joining pressure vessels, tanks, bridges, railways, machine frames & brackets, building the body of automobiles, aircrafts & ships etc.

Welding process may be broadly classified as;

1. ***Plastic welding*** or ***Pressure welding***
2. ***Fusion welding*** or ***Non Pressure welding***

Plastic Welding (or) Pressure welding:

In this type of welding, the metal pieces to be joined are heated to a plastic state and then joined together by the application of pressure without the addition of filler material.

Ex: Forge welding, Resistance welding.

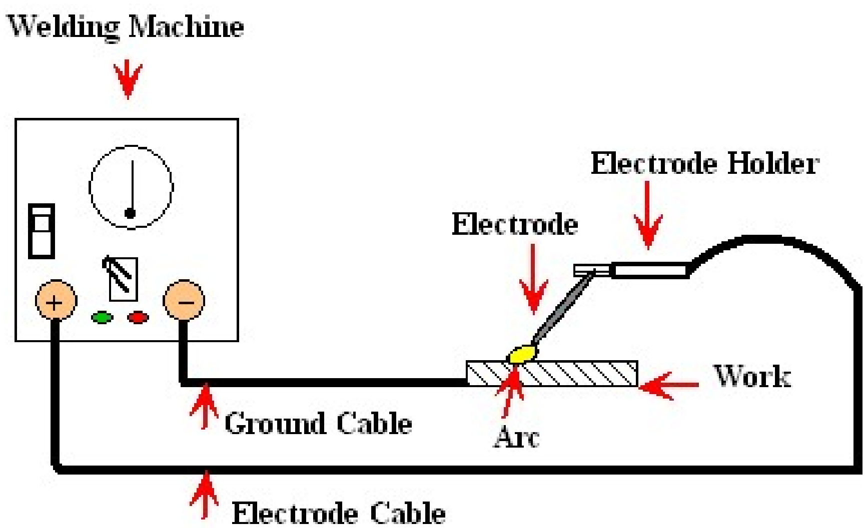
Fusion welding (or) Non pressure welding:

In this type of welding, the metal pieces to be joined are heated to molten state and allowed to solidify without the application of pressure. A filler material is used during the welding process.

Ex: Arc welding, Gas welding, Thermit welding

ARC WELDING

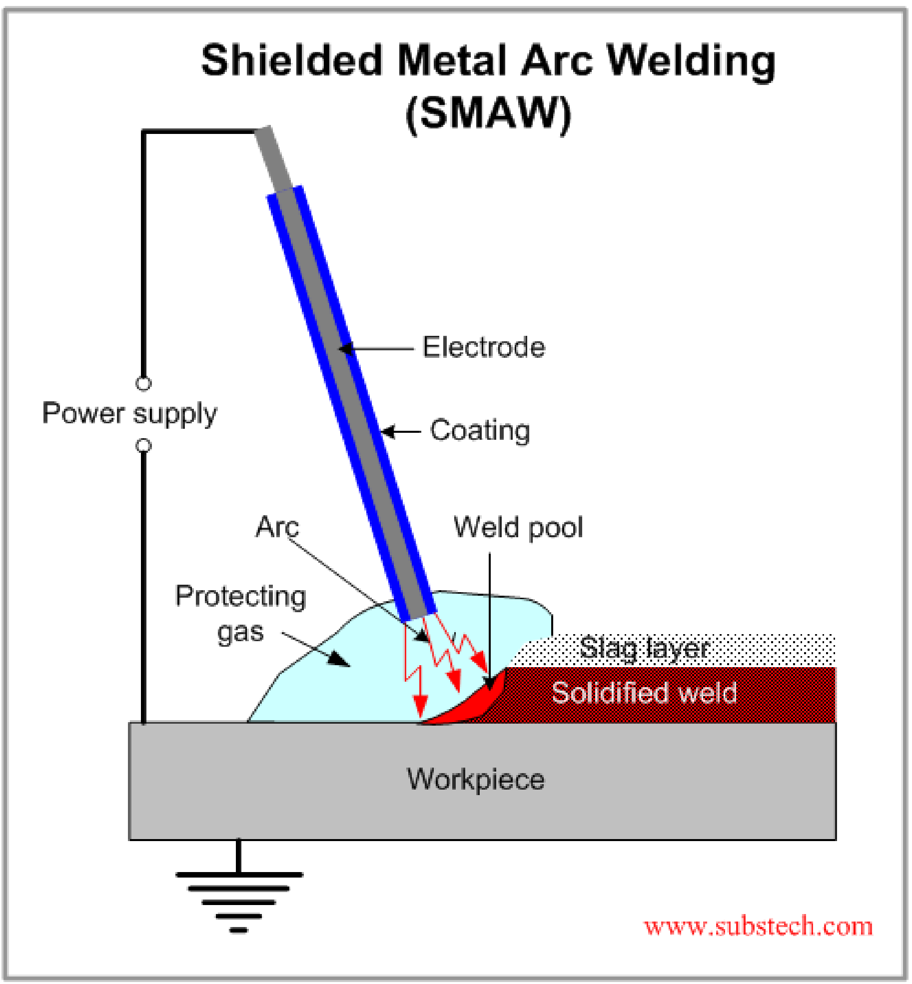
- The principle of arc welding is that, when two conductors of an electric circuit are touched together momentarily and then instantaneously separated slightly, an electric arc is formed.
- A high heat density is produced throughout the length of the arc at a temperature of 5000 to 6000^{0}C.
- The bare section at the end of the electrode is clamped to one terminal of the power source & the other terminal is connected to the workpiece being welded.



Arc welding set up

- The function of a welding machine is to generate a low voltage (10 to 50 V) and high current. (50 A to 300 A)
- The current may be alternating current or direct current & the polarity of the electrode may be positive or negative, depending on the type of electrode and the metals to be welded.

- In A.C arc welding, a ***step down transformer*** is used to step down the voltage from 220/440 V to 80 to 100 V & a current of 100 to 400 A.
- In D.C welding, the ***workpiece*** is connected to the ***+ve pole*** of a D.C generator and the ***electrode*** to ***–ve pole.***
- It is called ***'straight polarity'*** and is used when high heat is required.
- When less heat is required, the polarity is reversed.
- Because of the option of reversing the polarity, D.C welding may be used to weld many metals which require more heat to melt.
- In A.C welding, the polarity changes in every cycle.
- Also the current & the voltage acquire a value of zero twice in every cycle, and hence higher voltage is required to maintain the arc.



- When the arc is struck, the intense heat quickly melts the workpiece and forms a small molten metal pool.
- At the same time, the electrode also melts and mixes with the base metal.
- A solid joint will be formed when the molten metal cools & solidifies.
- A ***flux coating*** over the electrode produces an inert gaseous shield and protects the molten metal from atmospheric oxidation.

Arc welding Electrodes

- The electrode used in arc welding is of consumable type & it is coated with flux.
- The flux coating is usually made of ***chalk (lime), Ferro manganese, cellulose, Starch, Kaolin (China clay), iron powder, etc.***
- The flux forms a slag after welding which can be removed by chipping hammer & a wire brush.
- The purpose of coating the electrodes are;

  (i) *Protection of molten metal from oxidation*

  (ii) To prevent rapid cooling of molten metal

  (iii) To establish & maintain the arc.

  (iv) Addition of alloying elements.

Purpose of each ingredient of flux coating

- ***China clay***, ***mica*** etc. produce a slag which because of its light weight forms a layer on the molten metal and protects the same from atmospheric contamination.
- Ingredients, like ***cellulose, wood, starch***, calcium carbonate etc., form a protective gas shield around the electrode end, arc and weld pool.
- Deoxidizing elements like ***Ferro-manganese*** refine the molten metal.
- Alloying elements like ***Ferro alloys of manganese, molybdenum*** etc. may be added to impart suitable properties and strength to the weld metal.
- ***Iron powder*** in the coating improves arc behavior, bead appearance; helps increase metal deposition rate and arc travel speed.

Safety Devices used in arc welding

- The welding shield protects the eyes from infra-red & ultra -violet radiations.
- Gloves are used to protect the hands from spark & to insulate from electric shocks.
- Chipping hammer & wire brush to clear the slag.
- Apron to protect the clothing from sparks & spatter.
- Earthing clamp will avoid the risk of electric shock.

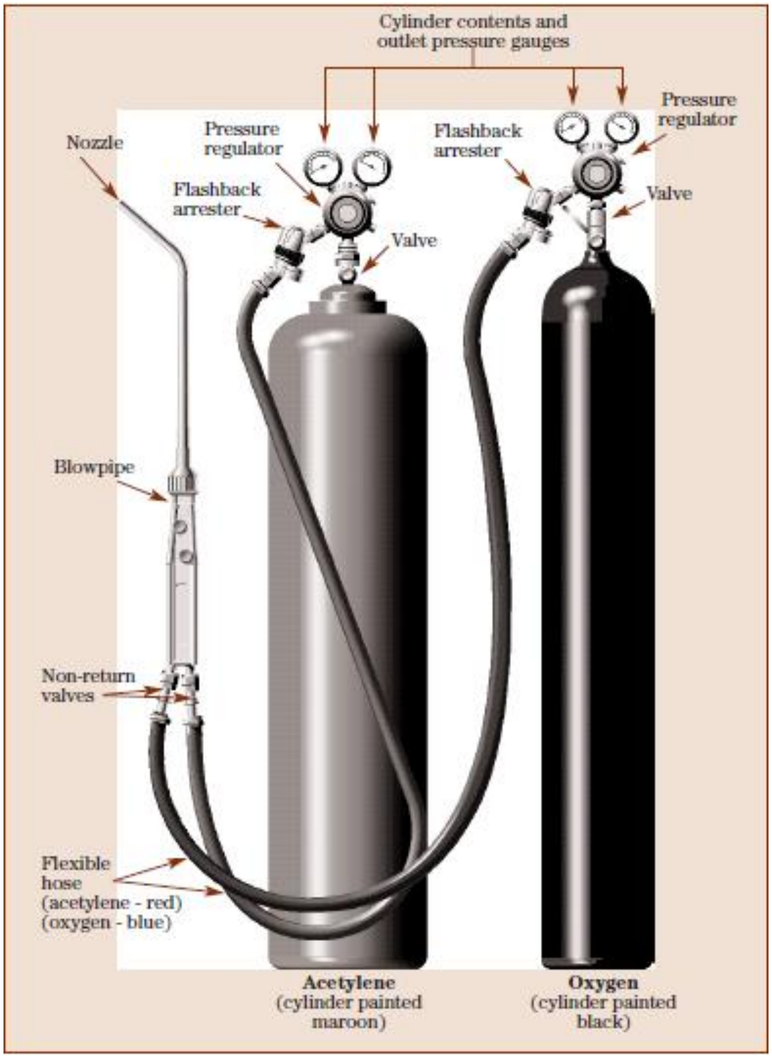
Gas welding

- Gas welding is a fusion method of welding in which a strong gas flame is used to raise the temperature of the workpieces to melt them.
- As in arc welding, a filler material is used to fill the joint.
- The gas combinations that can be used for heating are;

1. ***Oxygen & Acetylene***
2. ***Oxygen & Hydrogen***

Oxy-acetylene gas mixture is most commonly used in gas welding.

The temperature of gas welding is around 3500^0C

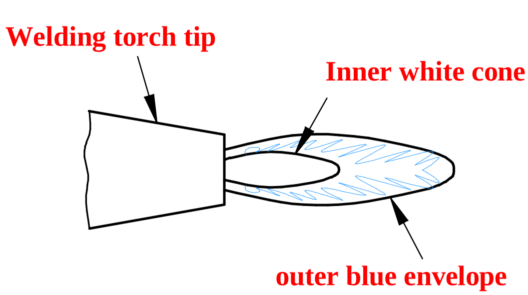


- The oxy-acetylene gas equipment consists of two large steel cylinders; one containing oxygen at high pressure and the other dissolved acetylene also at high pressure.
- It also consists of rubber tubes, pressure regulators, & blow torch.
- The oxygen and acetylene are supplied to the blow torch separately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

Gas Flames

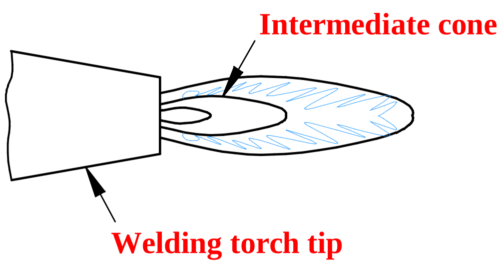
A ***neutral flame*** is obtained by supplying equal volumes of oxygen & acetylene. (Oxygen: Acetylene = 1: 1)

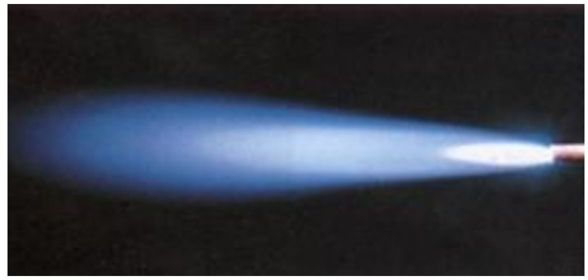
- A neutral flame consists of an inner small whitish cone surrounded by a sharply defined blue flame.
- Most of the oxy-acetylene welding is done with the neutral flame.



Carburizing flame

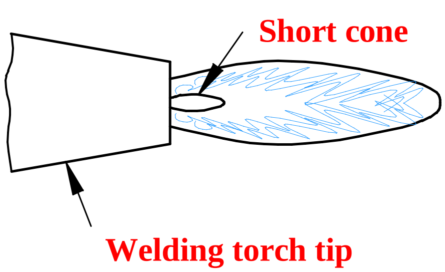
- A ***Carburizing flame*** or ***reducing flame*** is obtained by supplying excess acetylene. (Oxygen : Acetylene = 0.95 :1)
- It has three cones; an inner white cone, surrounded by an intermediate whitish cone & a bluish envelope flame.
- Carburizing flame is used for welding alloy steels, cast iron & aluminium to protect from oxidizable elements.





Oxidizing flame

- The ***Oxidizing flame*** is obtained when there is excess oxygen having gas ratio as high as 1.5. (Oxygen: Acetylene = 1.5 : 1)
- In appearance, it resembles a neutral flame except that the inner white cone is somewhat shorter.
- It is used for welding Monel metal, nickel and many non ferrous materials.



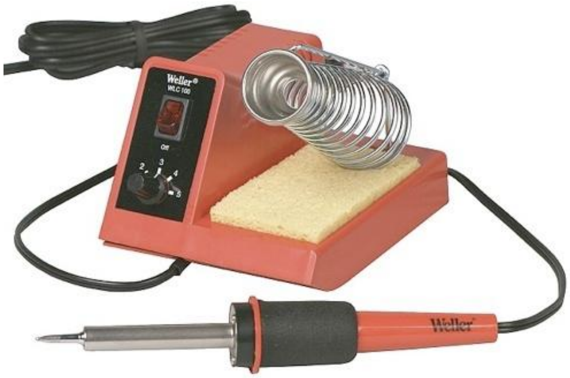
Defects in welding

Common weld defects include:

- ***Lack of fusion:*** It results from too little heat input and too rapid traverse of the welding torch (gas or electric)
- ***Porosity:*** This occurs when gases are trapped in the solidifying weld metal.
- ***Inclusions:*** These can occur when the slag covering a weld is not totally removed before another weld run.
- ***Cracking:*** This can occur due to thermal shrinkage.
- ***Undercut:*** This is due to excess melting of the parent metal which reduces the strength of the joint.

Soldering

- **Soldering** is a process in which two or more metal items are joined together by melting and flowing a filler metal (solder) into the joint.
- The filler metal will have a lower melting point than the workpiece ***(between 150^0C-350^0C)***
- Soldering differs from welding in that ***soldering does not involve melting the work pieces.***
- An alloy of lead & tin called '***soft solder'*** is used for sheet metal work, plumbing work & electrical junctions.
- To clean the surfaces to be joined & to prevent oxidation, Zinc chloride is used as a flux.
- A *soldering iron* is used to apply heat produced from an electrical source.



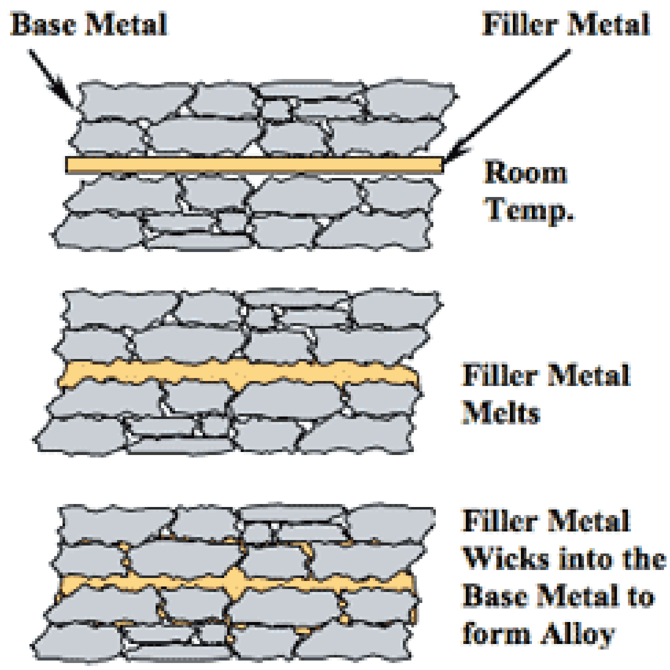
Soldering Iron

Soldering Flux

Soldering wire

Brazing

- **Brazing** is a method of joining two similar or dissimilar metals using a special fusible alloy. (Which melts above *450^0C).* It produces joints stronger than soldering.
- The molten filler material flows into the joint space by capillary action and after cooling produces a strong joint.
- However the base metal does not reach its melting temperature.
- The filler materials used in brazing are ***copper base & silver base alloys.***
- The heat source is oxy acetylene welding torch & the flux used is ***borax (sodium borate) and mixtures of borax & boric acid.***



Transmission of Motion & power

- Motion (usually rotation) & power from a driving system to a driven system is done with the help of round rods called ***shafts.***
- Transmission system may be classified depending on the distance between the shafts, speeds & power.
- Usually power is transmitted through;

1. ***Belt drives (Flat/V-belt)***
2. ***Rope drives***
3. ***Chain drives***
4. ***Gear drives***

Belt Drives

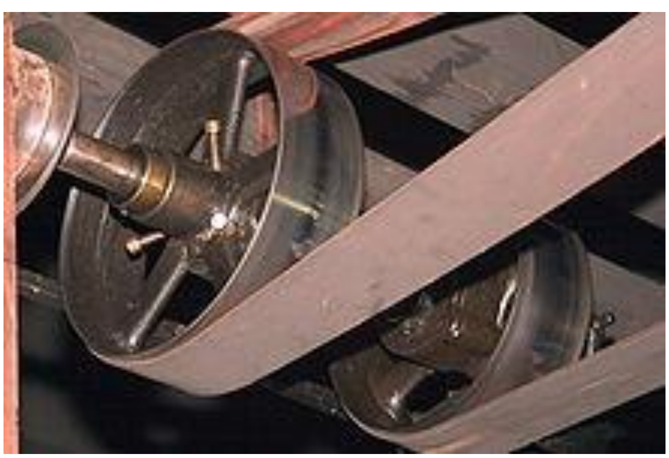
Belt drives are called flexible machine elements. Flexible machine elements are used for a large number of industrial applications, some of them are as follows:

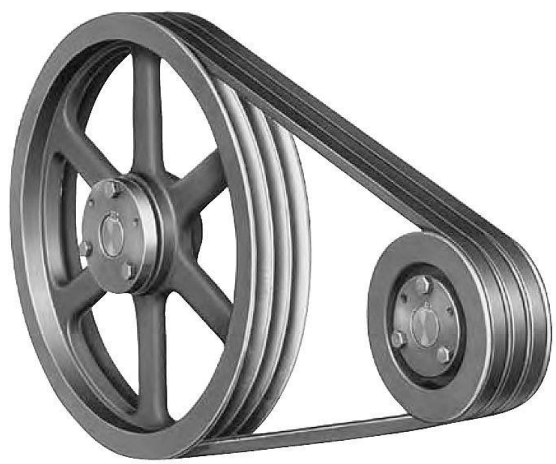
1. Used in conveying systems:

Transportation of coal, mineral ores etc. over a long distance.

2. Used for transmission of power.

Mainly used for running of various industrial appliances using prime movers like electric motors, I.C. Engine etc.

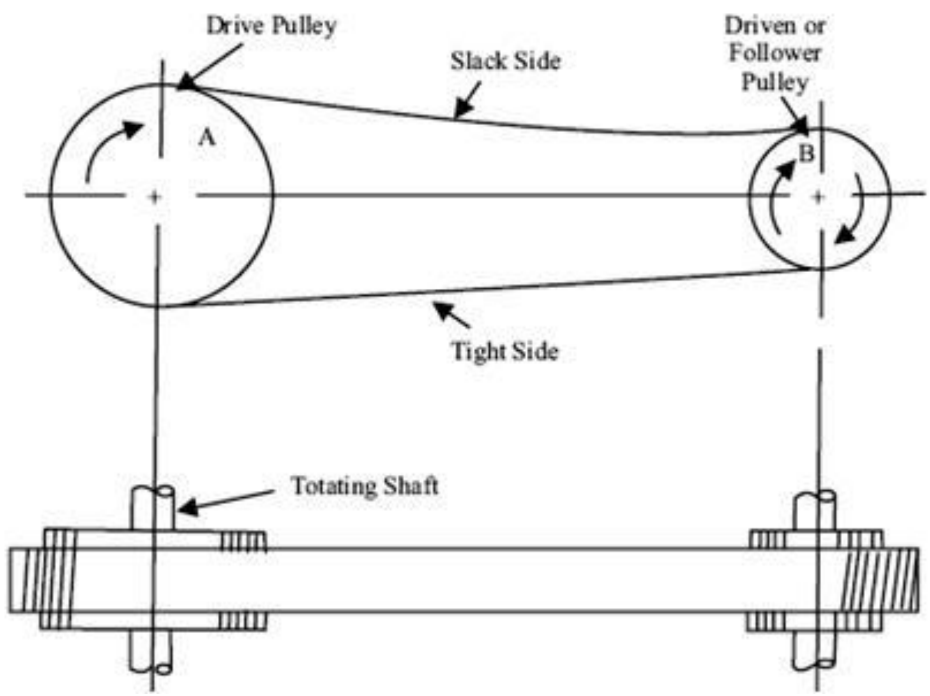




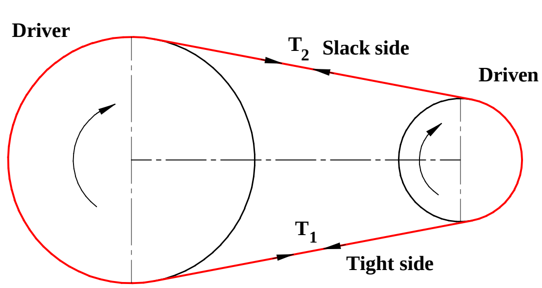
The lower side of the belt will have more tension & is called the ***Tight side.***

The upper side of the belt will have less tension & is called the ***Slack side.***

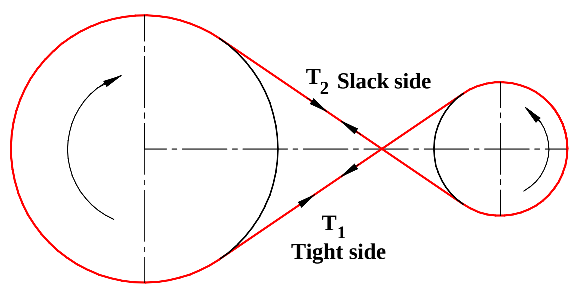
Belt Materials: Leather, rubber, canvas, balata (rubber with cotton)



- Two types of belt drives, an open belt drive, and a crossed belt drive are shown.
- In both the drives, a belt is wrapped around the pulleys.
- Let us consider the larger pulley to be the driving pulley. This pulley will transmit motion to the belt and the motion of the belt in turn will give a rotation to the smaller driven pulley.
- In open belt drive system the rotation of both the pulleys is in the same direction, whereas, for crossed belt drive system, opposite direction of rotation is observed.

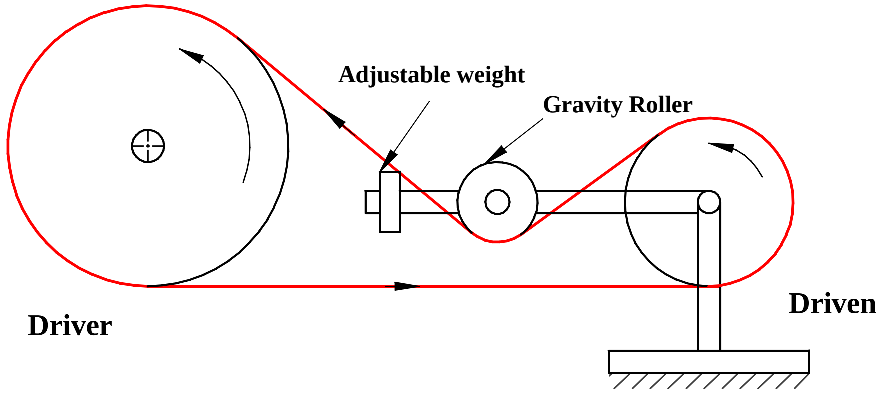


OPEN BELT DRIVE



CROSSED BELT DRIVE

Jockey pulleys or Gravity Idler Pulleys

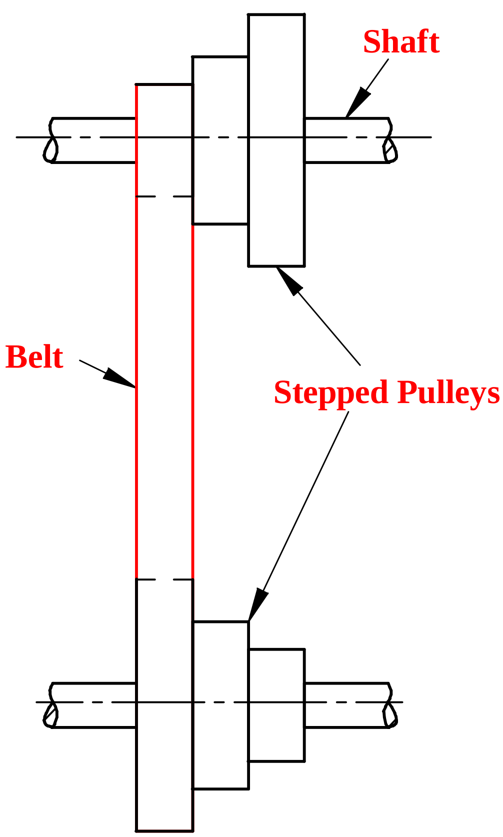


Gravity Roller Or Jockey Pulley

Jockey pulleys are used to get proper arc of contact. It increases the angle of wrap and there by reduce the belt tensions required for a given power. Normally the idler pulley is located near to the smaller diameter pulley. Its disadvantages are;

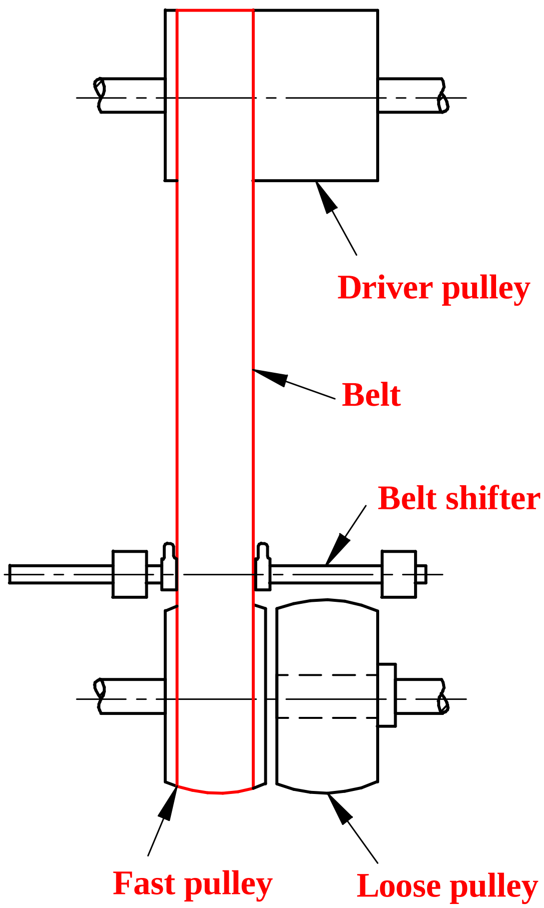
1. It is non reversible.
2. The bending stress developed in the belt reduces the belt drive.
3. Requires endless belt.

Stepped cone pulley



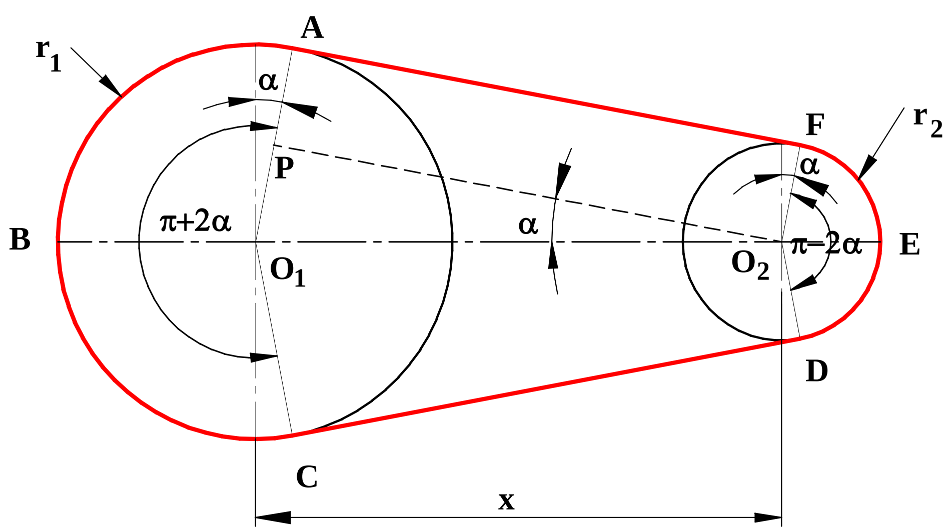
- A stepped cone pulley is used when the speed of the driven shaft it is to be changed very frequently as in case of machine tools such as lathe, drilling machine, etc.
- A stepped cone pulley is an integral casting having 3 or more steps.
- By shifting the belt from one pair of pulleys to another, the same belt will transmit different speeds.

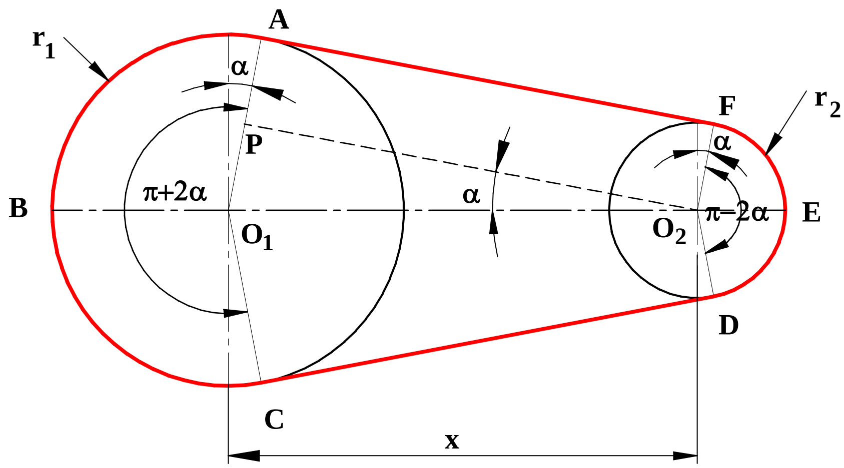
Fast & Loose Pulley



- Fast & loose pulley is used when it is required to stop the driven pulley without stopping the driving pulley.
- A fast pulley will be keyed to the driven shaft while a loose pulley fitted with a brass bush is freely rotating on the shaft.
- The driving pulley will be wider and the belt may be shifted to the loose pulley whenever the driven shaft is required to be brought to rest.

LENGTH OF BELT FOR OPEN BELT DRIVE





Consider an open belt drive as shown in fig.

Let r_1 be the radius of the larger pulley & r_2 be the radius of the smaller pulley

x=Center distance between the pulleys. From the fig, Length of open belt

$$L_{open} = Arc\ ABC + 2(AF) + Arc\ DEF = r_1(\pi + 2\alpha) + 2(AF) + r_2(\pi - 2\alpha)$$

$$From\ triangle\ O_1O_2P,\ O_2P = \left\{(O_1O_2)^2 - (O_1P)^2\right\}^{\frac{1}{2}}$$

$$From\ triangle\ O_1O_2P,\ O_2P = \left\{(O_1O_2)^2 - (O_1P)^2\right\}^{\frac{1}{2}}$$

$$O_2P = \left\{(x)^2 - (r_1 - r_2)^2\right\}^{\frac{1}{2}} = x\left\{1 - \left(\frac{r_1 - r_2}{x}\right)^2\right\}^{\frac{1}{2}}$$

$$Expanding\ u\sin g\ binomial\ theorem\ \&\ negelcting\ higher\ order\ terms,$$

$$O_2P = AF = x\left\{1 - \frac{1}{2}\left(\frac{r_1 - r_2}{x}\right)^2\right\} = x - \frac{1}{2x}(r_1 - r_2)^2\ \ From\ fig, \sin\alpha \approx \alpha = \left(\frac{r_1 - r_2}{x}\right)$$

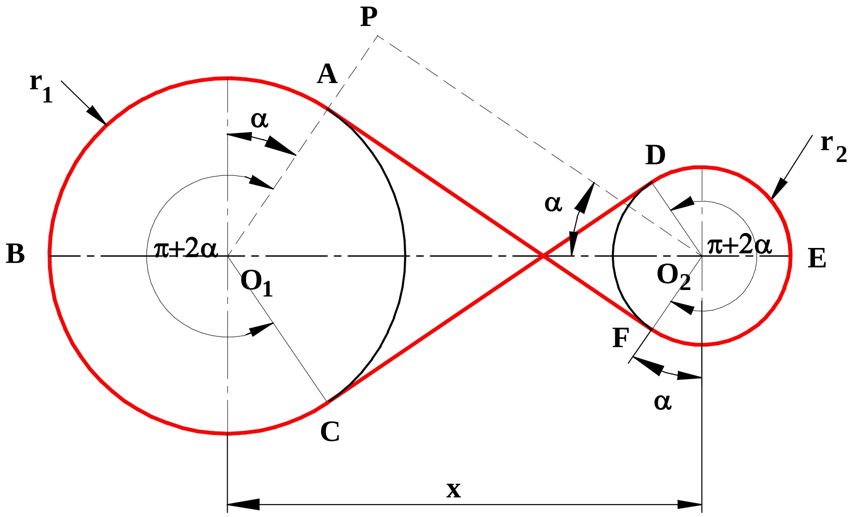
$$\Rightarrow L_{open} = r_1(\pi + 2\alpha) + 2\left(x - \frac{1}{2x}(r_1 - r_2)^2\right) + r_2(\pi - 2\alpha)$$

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

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

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

LENGTH OF BELT FOR CROSSED BELT DRIVE



Consider an crossed belt drive as shown in fig.

Let r_1 be the radius of the larger pulley & r_2 be the radius of the smaller pulley

x=Center distance between the pulleys. From the fig, Length of crossed belt

$$L_{crossed} = Arc\ ABC + 2(AF) + Arc\ DEF = r_1(\pi + 2\alpha) + 2(AF) + r_2(\pi + 2\alpha)$$

$$From\ triangle\ O_1O_2P,\ O_2P = \left\{(O_1O_2)^2 - (O_1P)^2\right\}^{\frac{1}{2}}$$

$$O_2P = \left\{(x)^2 - (r_1 + r_2)^2\right\}^{\frac{1}{2}} = x\left\{1 - \left(\frac{r_1 + r_2}{x}\right)^2\right\}^{\frac{1}{2}}$$

Expanding using binomial theorem & negelcting higher order terms,

$$O_2P = AF = x\left\{1 - \frac{1}{2}\left(\frac{r_1 + r_2}{x}\right)^2\right\} = x - \frac{1}{2x}(r_1 + r_2)^2$$

$$From\ fig,\ \sin\alpha \approx \alpha = \left(\frac{r_1 + r_2}{x}\right)$$

$$\Rightarrow L_{crossed} = r_1(\pi + 2\alpha) + 2\left(x - \frac{1}{2x}(r_1 + r_2)^2\right) + r_2(\pi + 2\alpha)$$

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

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

$$\therefore L_{crossed} = \pi(r_1 + r_2) + 2x + \frac{(r_1 + r_2)^2}{x}$$

Ratio of Tensions in a flat belt drive

$$\log_e\left(\frac{T_1}{T_2}\right)=\mu\theta \quad \text{OR} \quad \left(\frac{T_1}{T_2}\right)=e^{\mu\theta}$$

where T_1 and T_2 are the tensions on tight & slack sides of the belt

$\mu=$ Coefficeint of friction between the belt & pulley.

Note :

(1) *The angle θ must be in radians*

(2) *For open belt drive,* $\theta=\theta_s=\pi-2\sin^{-1}\left(\frac{r_1-r_2}{x}\right)$

(3) *For crossed belt drive,* $\theta=\pi+2\sin^{-1}\left(\frac{r_1+r_2}{x}\right)$

Power Transmitted by Belt Drive :

The net driving tension on the pulley $=(T_1-T_2)$

$\therefore$ Torque on the pulley $=(T_1-T_2)\times r$ where r=radius of the pulley.

Power transmitted by the belt drive $P=\dfrac{2\pi n(T_1-T_2)\times r}{60000}\,KW$

$\Rightarrow P=\dfrac{(T_1-T_2)\times v}{1000}\,KW$ where v=velocity of belt= $\dfrac{2\pi rn}{60}=\dfrac{\pi dn}{60}$ m/sec

Velocity ratio Transmitted by Belt Drive :

It is the ratio of speed of the driven pulley to the speed of the driving pulley.

If the driving pulley is suffixed as 1 & driven pulley as 2,

Velocity ratio = $\dfrac{n_2}{n_1}=\dfrac{d_1}{d_2}$ (neglecting slip & belt thickness)

Velocity ratio = $\dfrac{n_2}{n_1}=\left(\dfrac{d_1+t}{d_2+t}\right)$ (neglecting slip &considering belt thickness)

Velocity ratio $\dfrac{n_2}{n_1}=\dfrac{d_1}{d_2}\left(1-\dfrac{S}{100}\right)$ where S=Total % slip on driving & driven pulleys

Slip in belt drives

Slip in belt drives is the relative motion between the belt & pulley due to lack of frictional grip between them.

This results in the forward motion of the driving pulley without carrying the belt with it and the forward motion of the belt without carrying the driven pulley with it.

Slip is expressed as a percentage and it results in reduction in velocity ratio transmitted by the belt.

Velocity ratio $\frac{n_2}{n_1}=\frac{d_1}{d_2}\left(1-\frac{S}{100}\right)$ where S=Total % slip on driving & driven pulleys

Creep in belt drives

Creep in belt drives is the relative motion between the belt & pulley due to elongation and contraction of the belt as it moves from tight side to slack side.

Creep occurs when the material of the belt is ***not perfectly elastic*** resulting in slightly more elongation than contraction of the belt.

Creep also results in reduction in velocity ratio and power transmitted by the belt.

Initial Tension in Belts

- The tension provided in the belt while mounting it on the pulleys when stationary is known as '*Initial Tension*' represented by T_o.
- When the pulleys start rotating, the tension on the tight side increases to T_1 & that on the slack side decreases to T_2 due to expansion & contraction of the belt.

i.e. if α=coefficient of expansion or contraction, $\alpha(T_1-T_0)=\alpha(T_0-T_2)$

$\Rightarrow (T_1+T_2)=2T_0 \quad \therefore T_0=\left(\frac{T_1+T_2}{2}\right)$

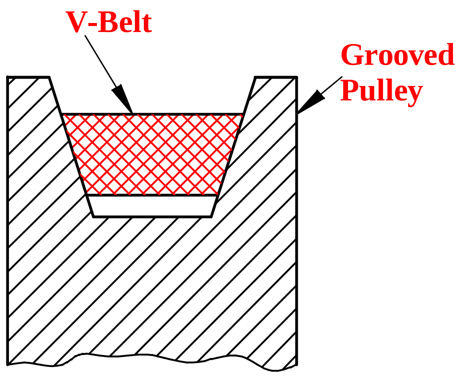
Advantages of flat belt drives

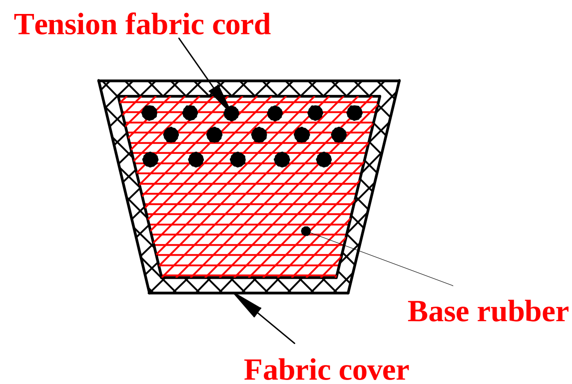
1. Easy, flexible equipment design, as tolerances are not important.
2. Isolation from shock and vibration between driver and driven system.
3. Belt drives require no lubrication.
4. Maintenance is relatively convenient
5. Very quiet compared to chain drives, and direct spur gear drives.

Disadvantages of flat belt drives

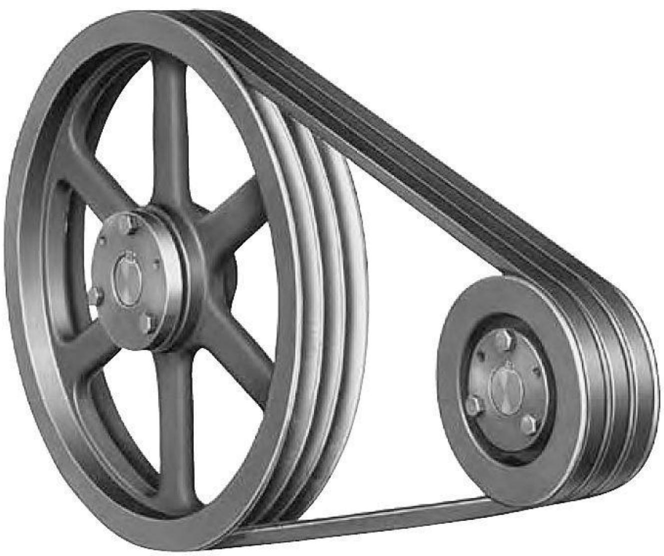
1. Not suitable for short center distances.
2. Exact velocity ratio can not be maintained.
3. Large power can not be transmitted effectively.

V-Belts





- V-belts are used in high power transmission due to wedging action between the trapezoidal belt & the grooves on the pulley.
- They are moulded as endless loops from rubber reinforced with fibrous material.
- They run V-grooves on the pulleys and multiple belts can be used for high power transmission upto 150 KW.



V-belt on grooved pulley **Cross section of V-belt**

Problem 1

In a belt drive, the velocity ratio is 3. The driving pulley runs at 400 rpm. The diameter of the driven pulley is 30 cm. Find the speed of the driven pulley and the diameter of the driving pulley.

Data : Velocity ratio = $\left(\frac{n_2}{n_1}\right)=3$

Speed of driving pulley $n_1 = 400\ rpm$,

Diameter of driven pulley $d_2 = 30cm$

Solution : We know that $\frac{n_2}{n_1} = \frac{d_1}{d_2} \Rightarrow 3 = \frac{d_1}{30}$

$\therefore$ ***Diameter of driving pulley d_1 = 90 cm***

Also $\frac{n_2}{n_1} = 3 \Rightarrow \frac{n_2}{400} = 3 \therefore$ ***Speed of driven pulley n_2 = 1200rpm***

Problem 2

The sum of diameters of two pulleys is 1000 mm and the pulleys are connected by a belt. If the pulleys rotate at 600 rpm & 1800 rpm, determine the size of each pulley.

Data : Velocity ratio = $\left(\frac{n_2}{n_1}\right)=\left(\frac{1800}{600}\right)=3$

Sum of diameters $(d_1 + d_2) = 1000\ mm$

Solution : We know that $\frac{n_2}{n_1} = \frac{d_1}{d_2} \Rightarrow 3 = \frac{d_1}{d_2} \quad \therefore\ d_1 = 3 \times d_2$

Given $(d_1 + d_2) = 1000 \ \Rightarrow (3d_2 + d_2) = 1000$

$\therefore$ ***Diameter of driven pulley d_2 = 250 mm***

& ***Diameter of driving pulley d_1 = 750 mm***

Problem 3

An engine shaft running at 200 rpm is required to drive a generator at 300 rpm by means of a flat belt drive. Pulley on the driving shaft has 500 mm diameter. Determine the diameter of the pulley on the generator shaft if the belt thickness is 8 mm & slip is 4%.

Data :

Velocity ratio = $\left(\dfrac{n_2}{n_1}\right)=\left(\dfrac{300}{200}\right)$=1.5, Diameter of the driving pulley $d_1 = 500\ mm$

Thickness of the belt $t = 8mm$, Slip=4%

Solution :

We know that $\dfrac{n_2}{n_1}=\left(\dfrac{d_1+t}{d_2+t}\right)\left(1-\dfrac{S}{100}\right) \Rightarrow 1.5=\left(\dfrac{500+8}{d_2+8}\right)\left(1-\dfrac{4}{100}\right)$

$\therefore$ ***Diameter of pulley on generator d_2 = 317.12mm***

Problem 4

Power is to be transmitted from a pulley of 600 mm diameter to another pulley of 300 mm diameter by means of a belt. The center distance between the pulleys is 3m. Determine the length of the belt required if the pulleys are connected by

(i) Open belt

(ii) Crossed belt

Data :

$Diameter\ of\ the\ larger\ pulley\ d_1 = 600\ mm \Rightarrow r_1 = 0.3m$

$Diameter\ of\ the\ smaller\ pulley\ d_2 = 300\ mm \Rightarrow r_2 = 0.15m$

$Center\ distance\ between\ pulleys\ x = 3m$

Length of open belt drive : $L_{open} = \pi(r_1+r_2)+2x+\dfrac{(r_1 - r_2)^2}{x}$

$$L_{open} = \pi(0.3+0.15)+(2\times 3)+\frac{(0.3-0.15)^2}{3} \quad \therefore L_{open} = 7.421m$$

Length of crossed belt drive : $L_{crossed} = \pi(r_1+r_2)+2x+\dfrac{(r_1+r_2)^2}{x}$

$$L_{crossed} = \pi(0.3+0.15)+(2\times 3)+\frac{(0.3+0.15)^2}{3} \therefore L_{crossed} = 7.4812\ m$$

Problem 5

A flat open belt drive consists of pulleys of diameters 1000 mm & 500 mm with a center distance of 1500 mm. The coefficient of friction between the pulley and the belt is 0.3. When the maximum tension in the belt is 700 N, find the power transmitted by the belt when the smaller pulley rotates at 400 rpm.

Data :

Dia of the larger pulley $d_1 = 1000\ mm$, Dia of the smaller pulley $d_2 = 500\ mm$

Center distance $x = 1500 mm$, Speed of the smaller pulley $n_2 = 400\ rpm$

Maximum tension in the belt $T_1 = 700\ N$, Coefficient of friction $\mu = 0.3$

Solution :

Angle of contact for open belt $\theta = \pi - 2\sin^{-1}\left(\frac{d_1 - d_2}{2x}\right)$

$\theta = \pi - 2\sin^{-1}\left(\frac{1000-500}{2\times 1500}\right) \therefore \boldsymbol{\theta = 2.8067\ rad}$

Ratio of tensions in the belt : $\frac{T_1}{T_2} = e^{\mu\theta} = e^{0.3\times 2.8067} = 2.321$

i.e. $\frac{700}{T_2} = 2.321 \Rightarrow T_2 = 301.6N$

Velocity of the belt $V = \frac{\pi d_2 n_2}{60} \Rightarrow V = \frac{\pi \times 0.5 \times 400}{60} \therefore V = \boldsymbol{10.472\ m/sec}$

Power transmitted by the belt :

$P = (T_1 - T_2)\times V = (700 - 301.6)\times 10.472 =$ 4172 Watt $\therefore$ P $\boldsymbol{= 4.172\ KW}$

Problem 6

In a belt drive, the angle of lap on the driven pulley is 160^0 and the coefficient of friction between the pulley & the belt material is 0.28. If the width of the belt is 200 mm and the maximum tension in the belt is not to exceed 5 N per mm width, find the initial tension in the belt.

Data : Angle of contact $\theta = 160^0 = \left(\frac{\pi}{180}\right)\times 160 = 2.794 rad$

Width of the belt =200 mm Maximum tension in the belt =5N per mm width of belt

i.e. $T_1 = 5\times 200 = 1000N$, Coefficient of friction $\mu = 0.28$

$$Ratio\ of\ tensions\ in\ the\ belt: \frac{T_1}{T_2} = e^{\mu\theta} = e^{0.28\times 2.794} = 2.187$$

$$i.e.\ \frac{1000}{T_2} = 2.187 \Rightarrow T_2 = 457.24N$$

$$Initial\ tension\ in\ the\ belt\ T_0 = \left(\frac{T_1+T_2}{2}\right) = \left(\frac{1000+457.24}{2}\right) = 728.62N$$

Gears

Gears are toothed wheels used to transmit power from one shaft to another when a constant velocity ratio is desired and the distance between shafts is relatively small.

Gears are classified as follows:

(i) According to relative position of shaft axes:

Parallel axes: Spur gear, helical gear

Intersecting axes: Bevel gears

Non parallel, Non intersecting: Worm gears

(ii) According to peripheral velocity (v) of gears:

V< 3 m/sec: Low velocity gears

3<V< 15 m/sec: Medium velocity gears

V>15 m/sec: High velocity gears

(iii) According to type of gearing:

Gears mesh externally & hence rotate in opposite directions: External gearing

Gears mesh internally & hence rotate in same directions: Internal gearing

(iv) According to position of the teeth on gear surface:

Straight teeth: Spur gears

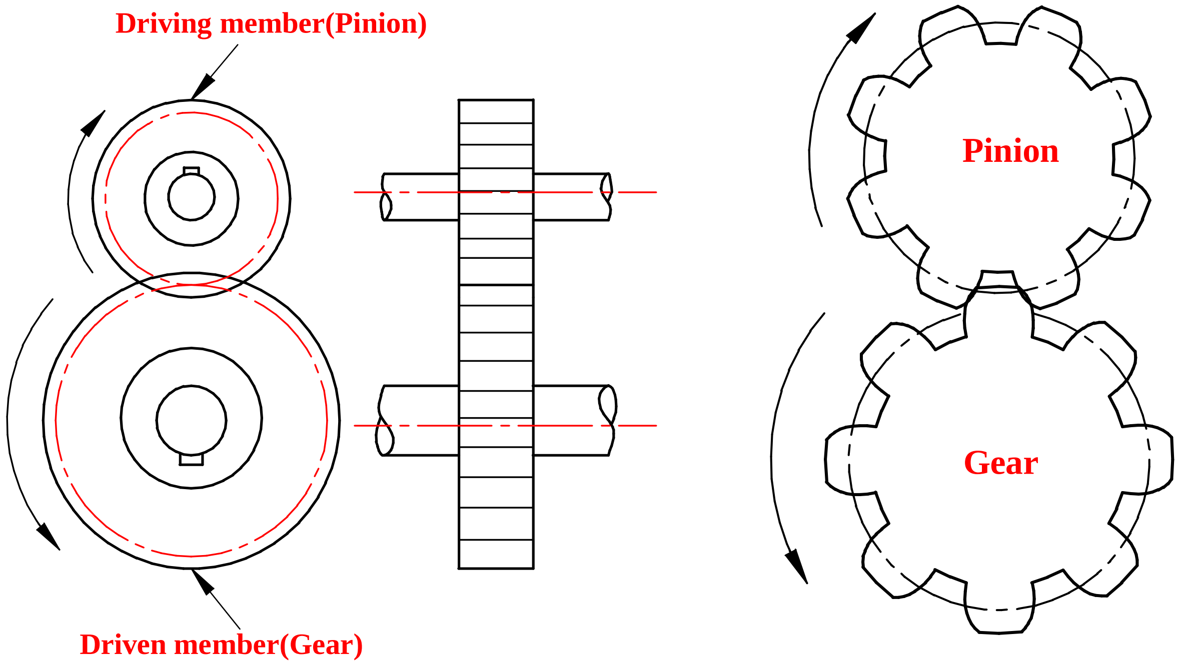
Inclined teeth: Helical gears

Skewed (curved) teeth: Spiral gear

Spur Gears

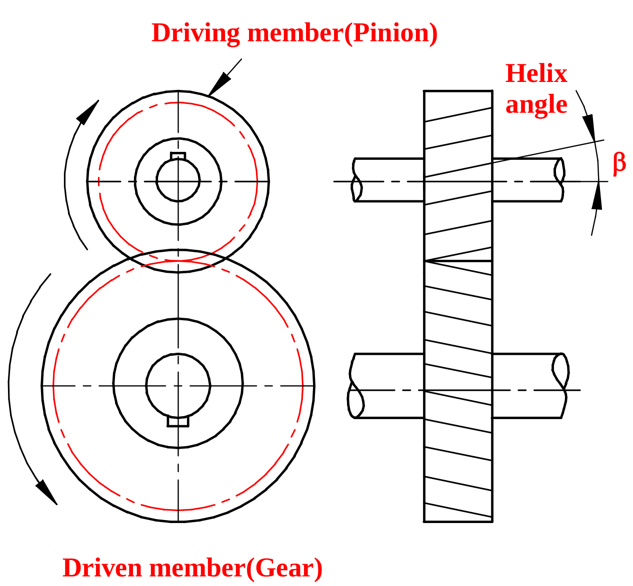
- This is the simplest form of gears for transmitting power between two parallel shafts. The teeth are straight & parallel to the axis.
- Spur gears impose only radial loads on bearings.
- Because of the instantaneous line contact during meshing, the drive will be noisy.
- Spur gear drive is widely used in machine tools, automobile gear boxes, etc.

Spur Gears

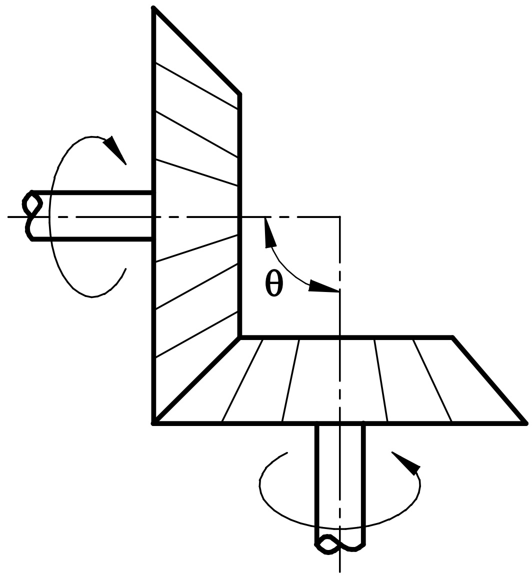


Helical Gears

- Helical gears are used to transmit power between parallel shafts.
- In these gears, the teeth are inclined to the axis of the shaft at an angle known as ***Helix angle (15^0 to 45^0).***
- Helical gears are preferred to spur gears as their operation is quiet due to progressive engagement of teeth.
- The disadvantage of helical gears is it produces an axial thrust. Hence double helical gears (herringbone gears) are used.

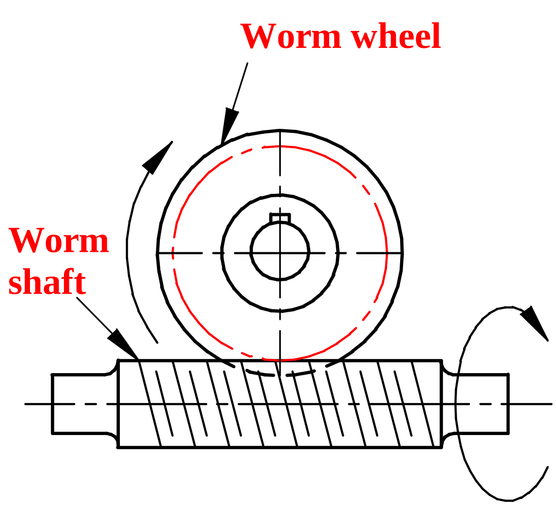


Bevel gears



- Bevel gears are most commonly used for transmitting power between intersecting shafts.
- The pitch surfaces of bevel gears are rolling cones. The tooth section becomes gradually smaller as the apex of the cone is approached.
- They impose thrust as well as radial loads on the bearings supporting the shaft.
- When two ***equal*** bevel gears have their axes ***at right angles***, they are called ***Miter bevel*** gears.

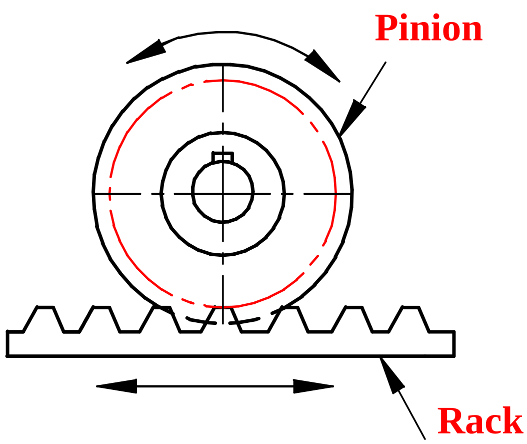
Worm gears



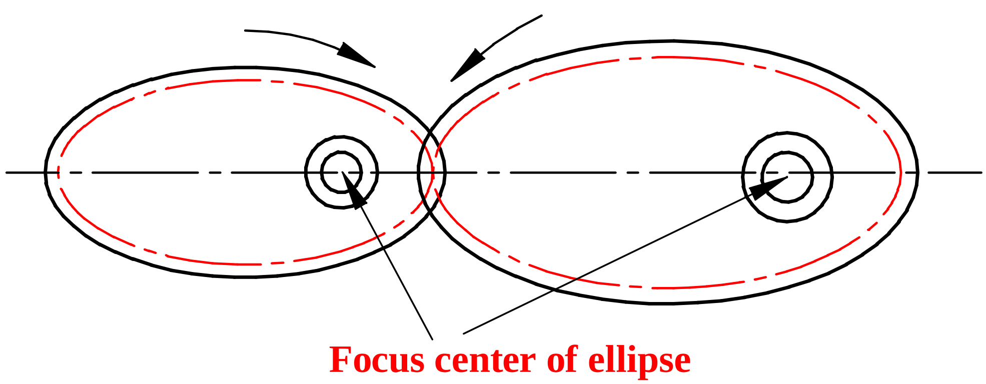
- Worm gears are used to transmit power between two non parallel, non intersecting shafts.
- A worm drive consists of a ***worm shaft*** with helical grooves which meshes with a gear called ***worm wheel.***
- Worm gear drives are used for high speed reduction as high as 60:1.
- The worm gear drive may be made self ***locking,*** i.e. does not allow the reversal in the direction of the drive.

Rack & Pinion

- When a rotary motion is to be converted into a linear motion, rack & pinion arrangement is used.
- Theoretically rack is a straight gear of infinite diameter.



Elliptical Gears



- Elliptical gears are used when there is need for varying speeds of the driven gear in each revolution.
- In each revolution of the driven shaft, there are four different speeds, two maximum & two minimum.
- They are used in printing machines, packaging machines, quick return motion mechanisms, etc.

Gear tooth profiles

- Gears are mainly used for transmission of motion & power and must be of accurate profile to obtain exact velocity ratio.
- Two commonly used profiles of gear teeth are the *Involute profile* & the *Cycloidal profile*
- Involute is defined as the path described by a point on an inextensible cord which is unwound from a stationary cylinder.
- Cycloid is defined as the curve traced by a point on the rim of a circle which rolls without slipping on a fixed straight line.

Advantages of Gear drives

1. They are positive drives and used to connect closely spaced shafts.
2. High efficiency, compactness, reliability, longer life, less maintenance.
3. They can transmit heavier loads.

Disadvantages of Gear drives

1. Not suitable for large center distances.
2. High production cost.
3. Due to errors and inaccuracies in manufacture, the drive may become noisy and produce vibrations at high speeds.

Velocity ratio in Gear Drives :

$\frac{n_2}{n_1} = \frac{d_1}{d_2} = \frac{z_1}{z_2}$, where $n_1 =$ Speed of driving pulley, $n_2 =$ Speed of driven pulley

$d_1 =$ Pitch circle diameter (PCD) of driver gear, $d_2 =$ PCD of of driven gear

$z_1 =$ No of teeth on driver gear, $z_2 =$ No of teeth on driven gear

Gear Trains

A gear train is an arrangement of two or more successively meshing gears through which power can be transmitted between the driving & driven shafts.

Train Value:

Train value is the ratio of speed of the driven gear to that of the driving gear. It is the reciprocal of the velocity ratio.

Direction of rotation

When gears mesh externally they rotate in the opposite direction and when they mesh internally, they rotate in the same direction.

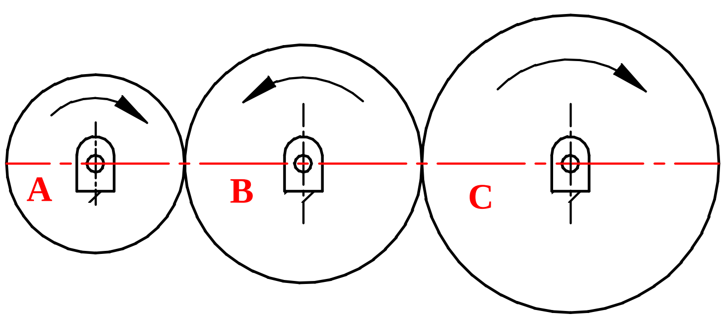
Types of Gear Trains

A gear train may be broadly classified into the following;

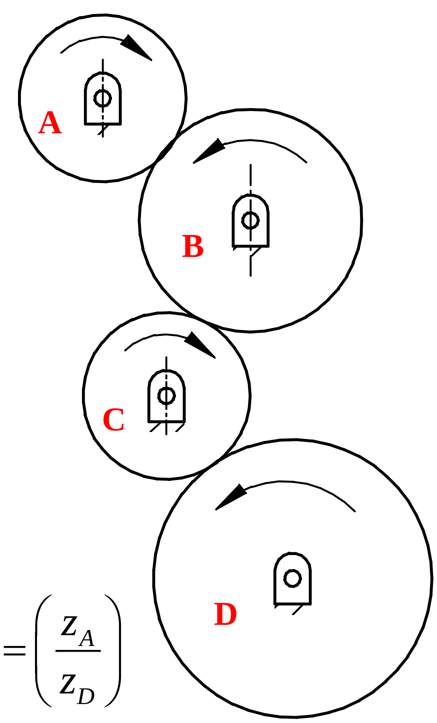
1. *Simple Gear Train*
2. *Compound Gear Train*
3. *Reverted Gear Train*
4. *Epicyclic Gear Train*

Simple gear train

- A **simple gear train** is one in which ***each shaft carries only one gear.***
- From the fig, gear A is the driving gear and gear D is the driven gear. B & C are the intermediate gears or ***Idler gears.***
- The idler gears do not affect the velocity ratio but simply bridge the gap between the driver & the driven gears.
- Also if ***odd*** number of intermediate gears are used, the driver & the driven gears rotate in the ***same direction***.
- If ***even*** number of intermediate gears are used, the driver & the driven gears rotate in the ***opposite directions***.



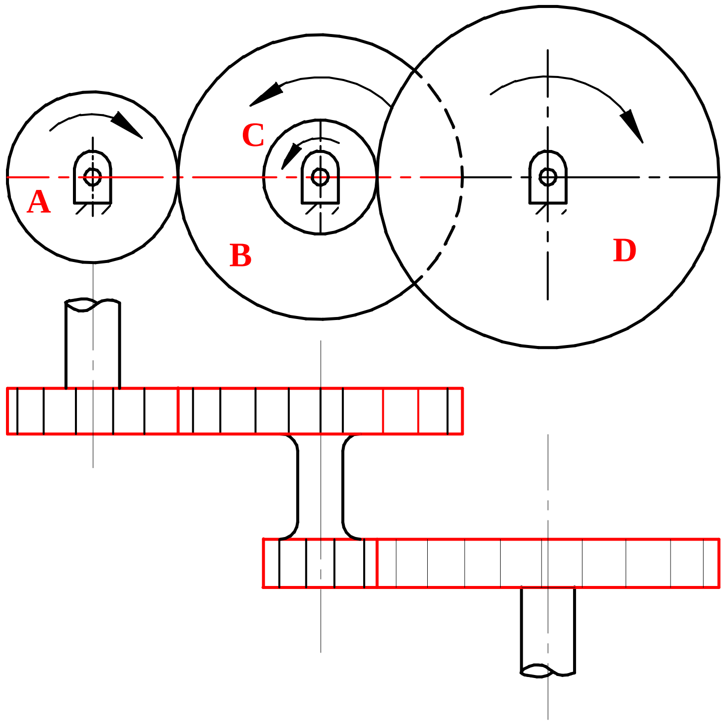
$$\text{Velocity ratio } \left(\frac{N_C}{N_A}\right) = \left(\frac{z_A}{z_C}\right)$$



$$\text{Velocity ratio } \left(\frac{N_D}{N_A}\right) = \left(\frac{z_A}{z_D}\right)$$

Compound gear train

- In a **compound gear train *the intermediate shaft carries two or more gears*** which are keyed to it.
- Compound gears are used when a high velocity ratio is required in a limited space.
- The intermediate gears will have an effect on the overall velocity ratio.



From the fig, $\left(\frac{N_B}{N_A}\right) = \left(\frac{z_A}{z_B}\right)$ and also $\left(\frac{N_D}{N_C}\right) = \left(\frac{z_C}{z_D}\right)$

$$\therefore \left(\frac{N_B}{N_A}\right) \times \left(\frac{N_D}{N_C}\right) = \left(\frac{z_A}{z_B}\right) \times \left(\frac{z_C}{z_D}\right)$$

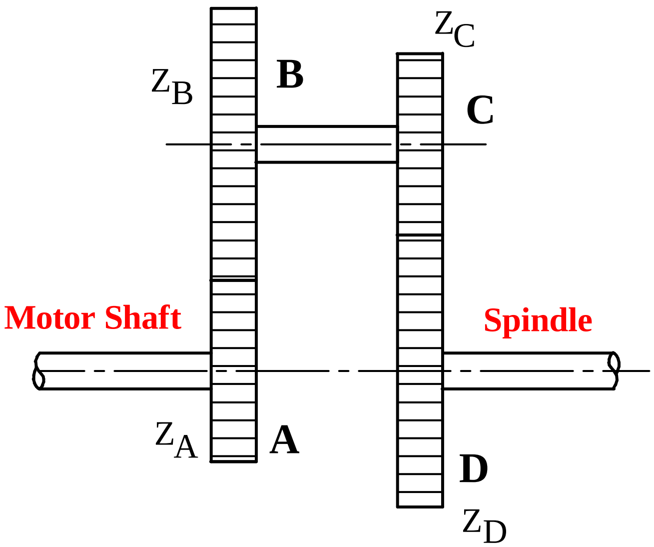
As gears B & C are on same shaft, $N_B = N_C$

$$\Rightarrow \left(\frac{N_D}{N_A}\right) = \left(\frac{z_A \times z_C}{z_B \times z_D}\right)$$

$$i.e. \frac{\text{Speed of last driven shaft}}{\text{Speed of the first driving shaft}} = \frac{\text{Product of no of teeth on driver}}{\text{Product of no of teeth on driven}}$$

Reverted gear train

- A reverted gear train is a compound gear train in which the first & the last gears are on the same axis.
- Hence, in a reverted gear train, the center distances for the two gear pairs must be same.
- Reverted gear trains are used in automotive transmissions, lathe back gears, and in clocks.



As $\left(\frac{d_A + d_B}{2}\right) = \left(\frac{d_C + d_D}{2}\right)$

But d=mz, and the module 'm' is same for all gears,

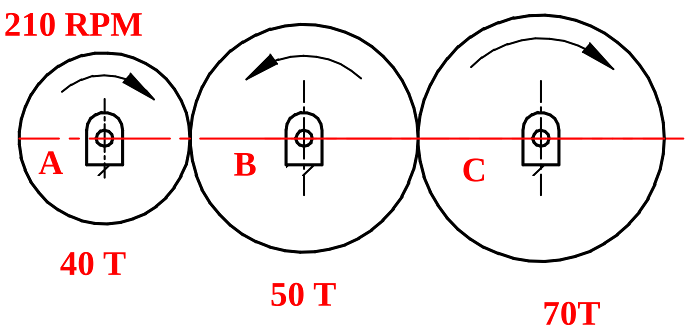
$\therefore z_A + z_B = z_C + z_D$

EPICYCLIC GEAR TRAIN

- An epicyclic gear train is one in which the axis of one or more gears moves relative to the frame.
- Large speed reductions are obtained with an epicyclic train.
- They are compact in size and automobile differential.

Problem 1

A simple train of wheels consists of successively engaging three wheels having number of teeth 40, 50 & 70 respectively. Find its velocity ratio. If the driving wheel having 40 teeth runs at 210 rpm clockwise, find the speed of the driven wheel and its direction of rotation.



From the fig, $\left(\frac{N_B}{N_A}\right) = \left(\frac{z_A}{z_B}\right)$ and also $\left(\frac{N_C}{N_B}\right) = \left(\frac{z_B}{z_C}\right)$

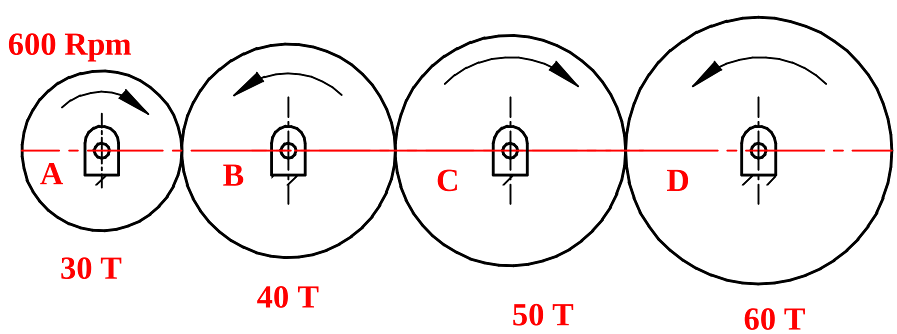
$$\therefore \left(\frac{N_B}{N_A}\right) \times \left(\frac{N_C}{N_B}\right) = \left(\frac{z_A}{z_B}\right) \times \left(\frac{z_B}{z_C}\right) \Rightarrow \left(\frac{N_C}{N_A}\right) = \left(\frac{z_A}{z_C}\right)$$

The speed of gear C, $N_C = \left(\frac{z_A}{z_C}\right) \times N_A \Rightarrow N_C = \left(\frac{40}{70}\right) \times 210 = 120 \text{ rpm.}$

As there is odd number of idler gears, the driven gear rotates at 120 rpm clockwise. (i.e. same as that of driving gear)

Problem 2

In a simple gear train consists of four wheels having number of teeth 30, 40, 50 & 60 teeth respectively. Determine the speed and the direction of rotation of the last gear if the first makes 600 rpm, clockwise.



From the fig, $\left(\frac{N_D}{N_A}\right)=\left(\frac{z_A}{z_B}\right)\times\left(\frac{z_B}{z_C}\right)\times\left(\frac{z_C}{z_D}\right)$

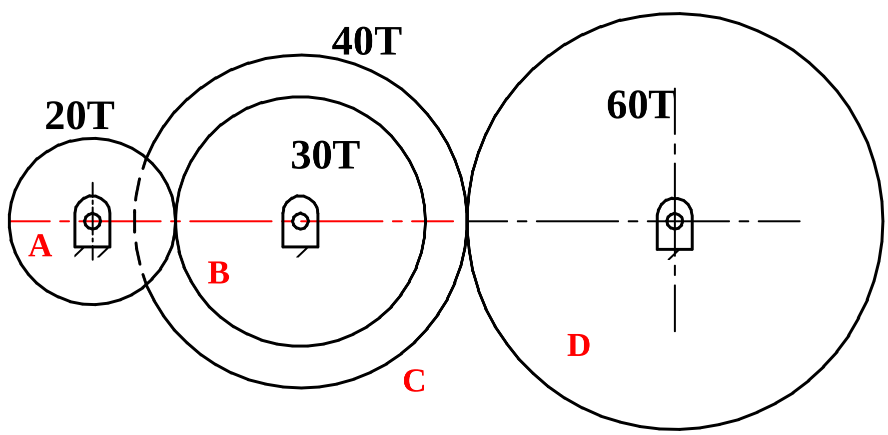
$$\Rightarrow \quad \left(\frac{N_D}{N_A}\right)=\left(\frac{z_A}{z_D}\right)$$

The speed of gear D, $N_D=\left(\frac{z_A}{z_D}\right)\times N_A \Rightarrow N_C=\left(\frac{30}{60}\right)\times 600 = 300 \text{ rpm.}$

As there is even number of idler gears, the driven gear rotates at 300 rpm counter clockwise. (i.e. opposite to that of driving gear)

Problem 3

A compound gear train consists of 4 gears, A, B, C & D and they have 20, 30, 40 & 60 teeth respectively. A is keyed to the driving shaft, and D is keyed to the driven shaft, B & C are compound gears. B meshes with A & C meshes with D. If A rotates at 180 rpm, find the rpm of D.



From the fig, $\left(\frac{N_B}{N_A}\right)=\left(\frac{z_A}{z_B}\right)$ and also

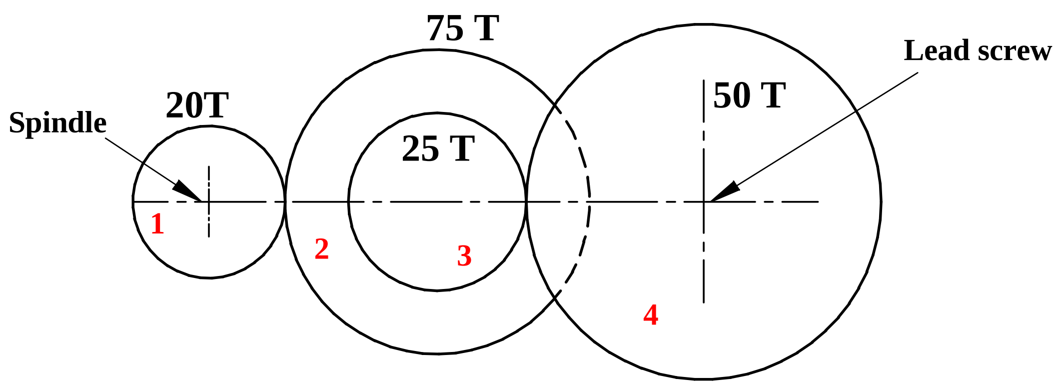
$$\left(\frac{N_D}{N_C}\right)=\left(\frac{z_C}{z_D}\right) \qquad \therefore \left(\frac{N_B}{N_A}\right)\times\left(\frac{N_D}{N_C}\right)=\left(\frac{z_A}{z_B}\right)\times\left(\frac{z_C}{z_D}\right)$$

As gears B & C are on same shaft, $N_B = N_C \Rightarrow \left(\frac{N_D}{N_A}\right)=\left(\frac{z_A\times z_C}{z_B\times z_D}\right)$

$$\therefore N_D=\left(\frac{20\times 40}{30\times 60}\right)\times 180 = 80 \text{ RPM}$$

Problem 4

Fig shows a train of gears from the spindle of a lathe to the lead screw used for cutting a screw thread of a certain pitch. If the spindle speed is 150 rpm, what is the lead screw speed? Gears 2 & 3 form a compound gear.



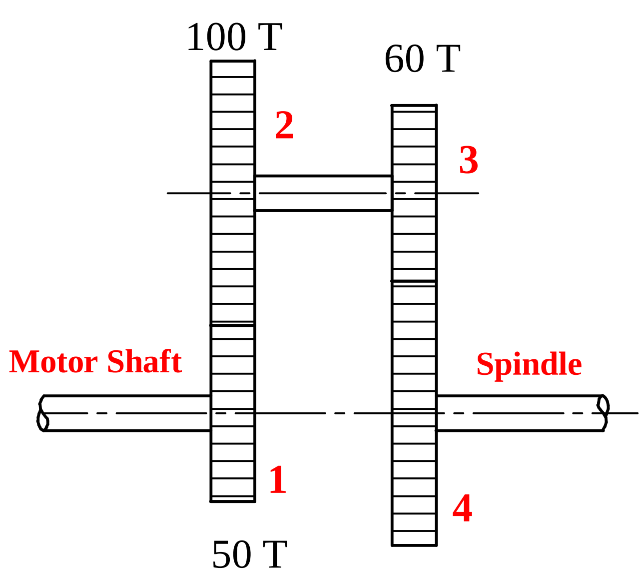
From the fig, velocity ratio

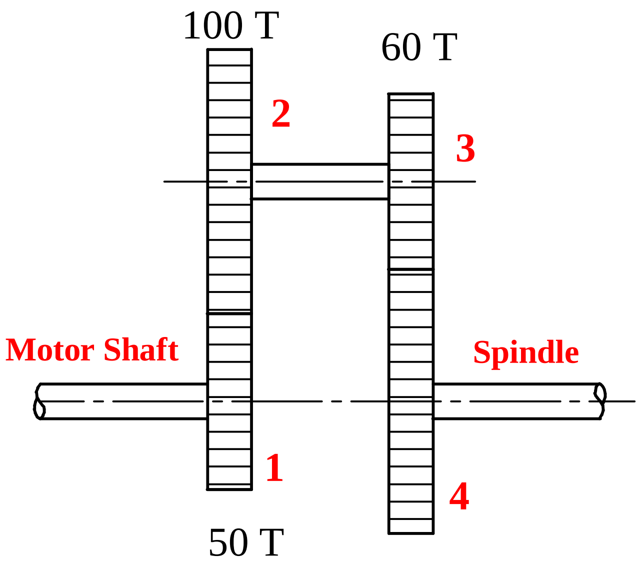
$$\left(\frac{\text{Speed of the driven shaft}}{\text{Speed of the driving shaft}}\right) = \left(\frac{\text{Product of the no of teeth on driver}}{\text{Product of the no of teeth on driven}}\right)$$

$$\Rightarrow \left(\frac{N_4}{N_1}\right) = \left(\frac{z_1 \times z_3}{z_2 \times z_4}\right) \quad \text{As } N_1 = 150\text{rpm}, N_4 = \left(\frac{20 \times 25}{75 \times 50}\right) \times 150 = 20 \text{ RPM}$$

Problem 5

Fig shows a reverted gear train used in a lathe headstock. If the motor runs at 1200 rpm, find the speed of the spindle.





As the center distance between the shafts is same,

$$\left(\frac{d_1+d_2}{2}\right)=\left(\frac{d_3+d_4}{2}\right) \Rightarrow (d_1+d_2)=(d_3+d_4)$$

The circular pitch $=\left(\frac{\pi d}{z}\right)=\pi m \quad \Rightarrow d = mz$ where 'm' is known as module.

For two gears in mesh, circular pitch and hence the module is same.

As $z_1+z_2=z_3+z_4 \quad \Rightarrow \quad 50+100=60+z_4$

No of teeth on gear 4=90 teeth. $\therefore$ Speed of the spindle $N_4=\left(\frac{z_1\times z_3}{z_2\times z_4}\right)\times N_1$

$$\Rightarrow \mathbf{N_4=\left(\frac{50\times 60}{100\times 90}\right)\times 1200=400\ rpm}$$

Lubrication

- ***Friction*** is the resistance to relative motion between two surfaces in contact.
- Any substance placed between the rubbing surfaces, which reduces friction is called ***lubricant.***

The important functions of lubricant in bearings are;

1. To reduce friction & wear between the sliding surfaces by separating them by a thin film of oil.
2. To remove the heat generated by friction.
3. To provide a protective film against corrosion.
4. In machine tools, it flushes out the metal chips.
5. In automobile engines, a detergent added to lubricant removes sludge deposits.

Types of Lubricants

Lubricants are classified as;

(i) Liquid lubricants

(ii) Semi-liquid lubricants

(iii) Solid lubricants.

Liquid lubricants may be

mineral oils (produced from refining of petroleum products)

synthetic oils (produced from sand, coal, etc.)

Animal & vegetable oils (fish oils, lard oil, Castor oil, cotton seed oil, Olive oil, etc.)

Liquid lubricants

Liquid lubricants have good adhering properties and high fluidity.

They are used in metal cutting, high speed machineries and transmission systems where lubricant is re circulated.

The important advantage is that special additives may be added to impart special properties.

Semi liquid lubricant or Grease

- ***Semi liquid lubricant or Grease*** is obtained by compounding the petroleum products with soap mixtures.
- They are highly viscous. They can withstand high pressure, temperature and also they resist corrosion.
- They are used in gear drives, chain drives, flexible cables, etc.
- They may be of Aluminium base, Calcium base, sodium base or mixed base types.

Solid lubricants

- ***Solid lubricants*** are useful in reducing friction where oil films can not be maintained because of high pressure or temperature.
- Generally they are used in powder form or as suspension in liquid carries and will be softer than the materials to be lubricated.
- Graphite is the most common solid lubricant.
  The other solid lubricants are soap stone, talc, wax, mica, French chalk, etc.

Properties of Lubricants

The following are the important properties of a lubricant.

Viscosity:

- It is the property of a fluid by virtue of which it offers resistance to shear (flow).
- If the viscosity is too low, a liquid film can not be maintained between the moving surfaces.
- On the other hand, high viscosity oil will offer greater resistance to moving parts.
- The viscosity decreases with increase in operating temperature.
- ***A good lubricant, the change of viscosity with temperature must be a minimum.***

Types of viscosity

Viscosity of a lubricant may be defined by

(i) Absolute (or Dynamic) Viscosity (μ)

- It is the force required to move a surface of unit area at unit velocity when separated by an oil film of unit thickness.
- In SI system, unit of absolute viscosity is N-sec/m^2 (Pascal-sec)

(ii) Kinematic Viscosity (ν)

- It is the ratio of absolute viscosity to mass density of the fluid. Its SI unit is m^2/sec.

$$i.e.\ \nu = \left(\frac{\mu}{\rho}\right)$$

Flash Point:

- Flash point is the minimum temperature at which an oil gives off sufficient vapour to ignite momentarily on introduction of flame.
- A good lubricant must have its flash point ***above the operating temperature.***

Fire Point:

- Fire point is the lowest temperature at which oil gives off sufficient vapour to burn continuously when bought in contact with a flame.
- A good lubricant must have ***a high fire point.***

Oiliness:

- It is the ability of oil to maintain an unbroken lubricating oil film between the rubbing surfaces.
- A good lubricant must have enough oiliness to adhere to surfaces even at high pressures.

Volatility:

- It is the tendency of the oil to vaporize at high temperatures leaving behind a thick residual oil.
- A good lubricant must have ***low volatility.***

Pour Point & Cloud Point:

- Pour point is the lowest temperature at which oil ceases to flow when cooled.
- Cloud point is the lowest temperature at which wax and other substances crystallize and separate out when cooled.
- A good lubricant must have ***a low pour & cloud points.***

Carbon residue:

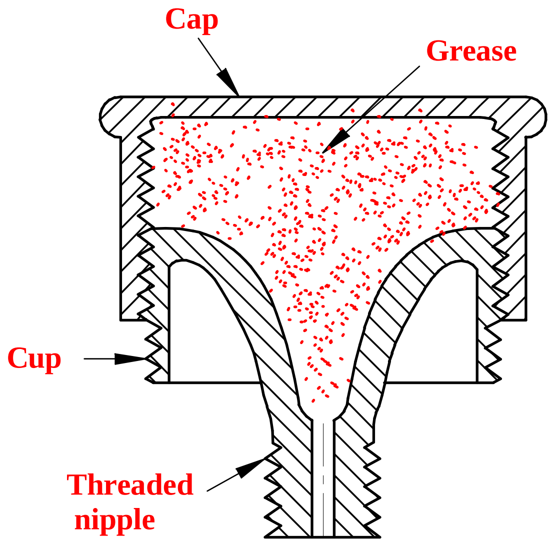
- Lubricating oils contain higher percentage of carbon in the combined form. At high temperatures, they decompose resulting in carbon deposits on bearing surfaces which is undesirable.
- ***A good lubricant should not decompose even at high temperatures.***

Lubricators

- A lubricator is a device used to supply lubricant at regulated rate to machine bearings, gears, engine parts, etc.
- The most commonly used lubricators are;

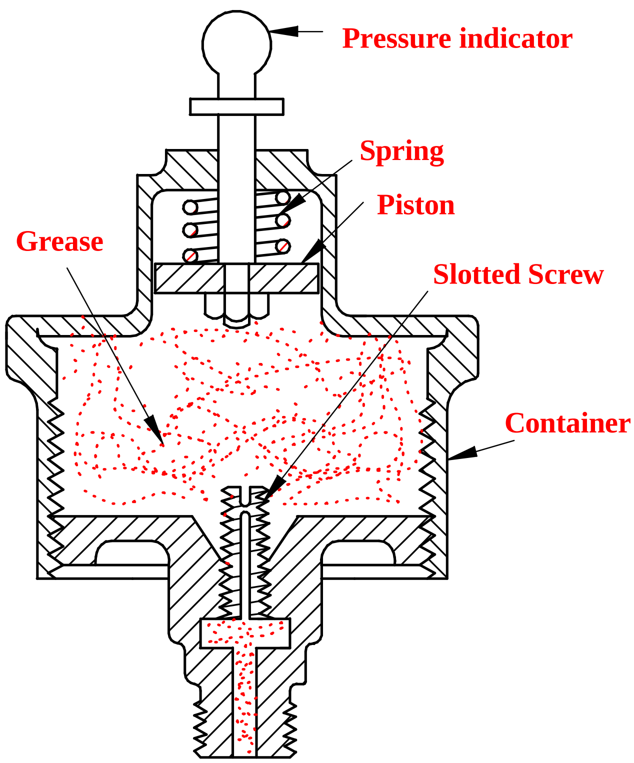
(i) ***Screw cap lubricator***
(ii) ***Tell tale lubricator***
(iii) ***Drop feed lubricator***
(iv) ***Glass bottle needle type lubricator***
(v) ***Syphon wick lubricator***
(vi) ***Ring oil lubricator***
(vii) ***Splash lubricator***

Screw cap Lubricator



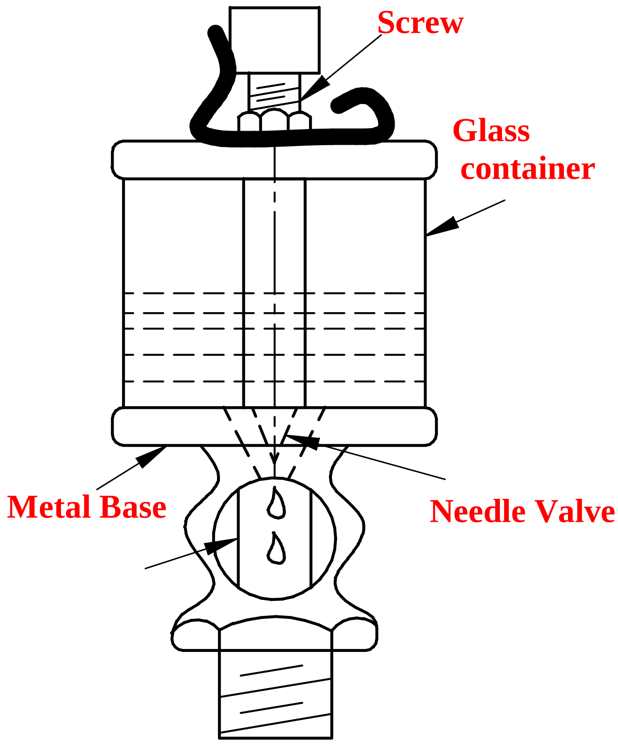
- A screw cap lubricator is used for applying heavy grease.
- It consists of a cap screwed over a lubricator body. The lubricator is attached to the machine part by a threaded nipple.
- The turning of the cap forces grease to flow through the hole on to the surfaces to be lubricated.

Tell Tale Lubricator



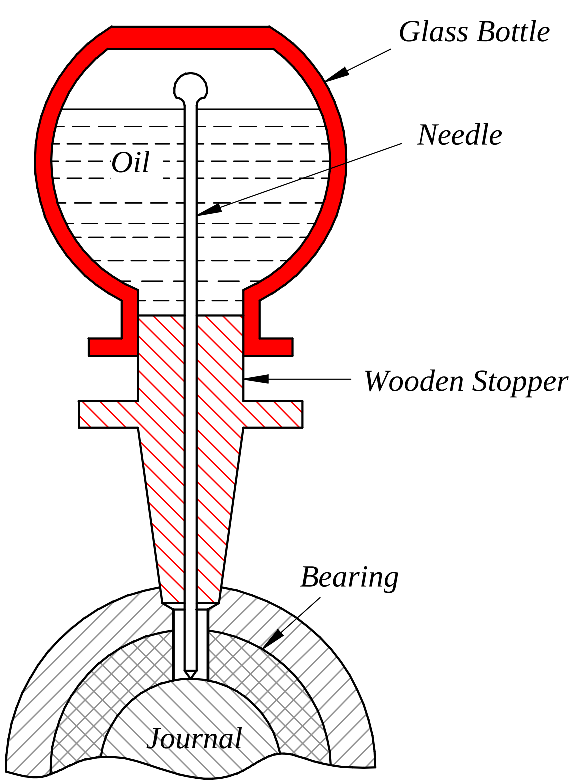
- It consists of a cap that carries a spring loaded piston.
- The pressure on the grease due to the spring forces the grease out to the surface to be lubricated.
- The aperture through which the grease passes can be varied by means of slotted screw.
- The movement of the piston rod end indicates whether the lubrication is in progress or not. Hence the name ***'tell tale'***

Drop feed Lubricator



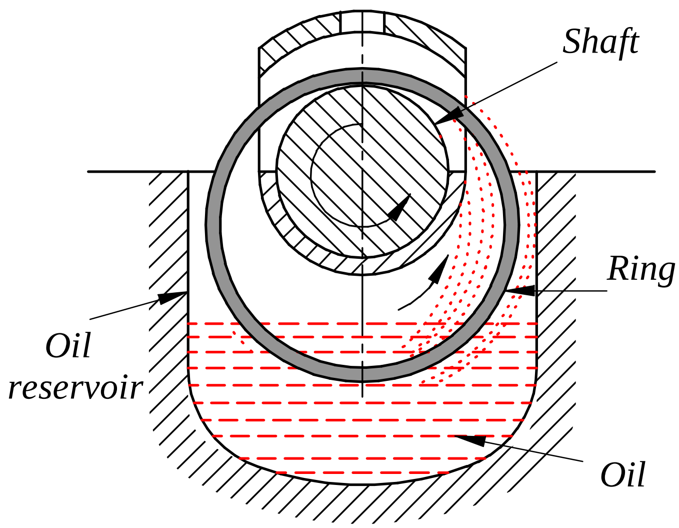
- It consists of a glass container with a metal base which has a drip hole at the center.
- The rate of feed is adjusted by a screw which slightly raises of lowers the needle, and can be seen through a glass window.
- Drop feed oilers are used on high grade machinery and give good service.

Glass-Bottle Needle lubricator



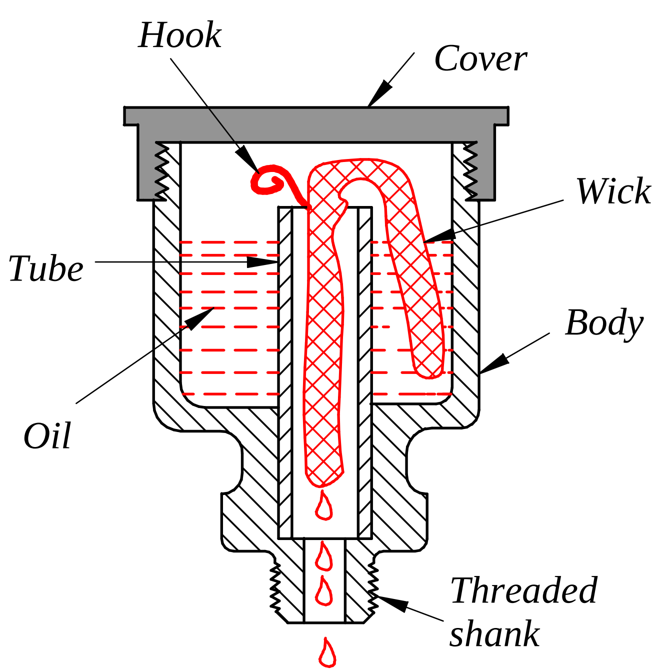
- It consists of an inverted glass container with a needle passing through a wooden stopper to the bearing.
- The needle rests on the shaft and is loosely fitted to the stopper.
- When the journal rotates, the needle is shaken and oil passes from oil reservoir, through the gap between the needle and the stopper.
- When the journal is stationary, there is no oil feed to the bearing.

Ring Oil Lubricator



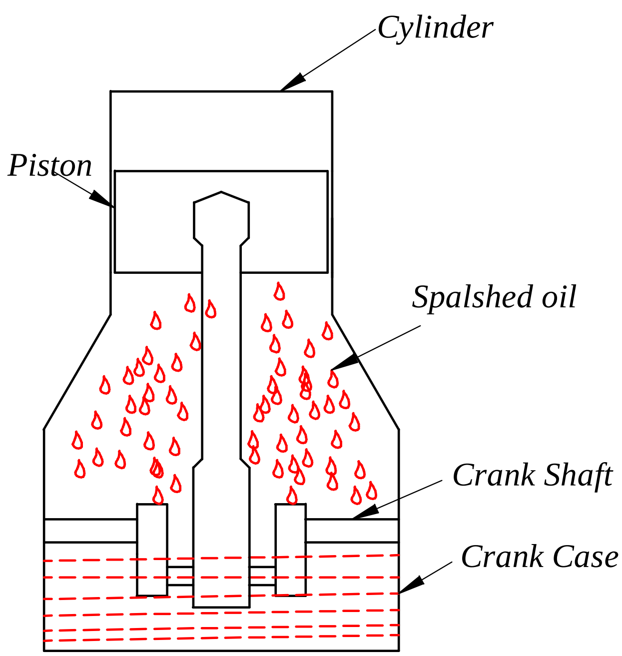
- It consists of an oil well maintained just below the shaft to be lubricated.
- A metallic ring is placed encircling the shaft so as to dip partly in the oil sump.
- When the shaft rotates, the ring also rotates and carries the oil with it and lubricates the shaft.
- This type of lubricator is generally used in main bearings of engine crank shafts.

Syphon Wick lubricator



- It works on the principle of capillary action of the wick in carrying oil to the bearing.
- It consists of a glass container with a central pipe
- Oil is drawn from the reservoir through a wick of wool yarn and due to gravity & vibration the oil drips off from the lower end of the wick.
- To stop feed of oil when shaft is not running, a hook is used to remove the wick out of the pipe.

Splash Lubrication



- This method of lubrication is employed in machines that have cranks or gears enclosed in a housing which acts as an oil reservoir. ***Ex: I.C engines, Gear boxes.***
- The crank partly dips into the oil sump in the crank case.
- As the crank shaft rotates, it continuously splashes the surfaces of the cylinder, piston, etc.

Bearings

- A ***bearing*** is machine part, which support a moving element and confines its motion.
- The supporting member is usually designated as bearing and the supported member may be journal (shaft)
- Since there is a relative motion between the bearing and the moving element, a certain amount of power must be absorbed in overcoming friction, and if the surface actually touches, there will be a rapid wear.

Classification of Bearings

Bearings are classified as follows;

Depending upon the direction of the load to be supported:

- Radial bearing and
- Thrust bearing.

Depending upon the nature of contact between the working surfaces:-

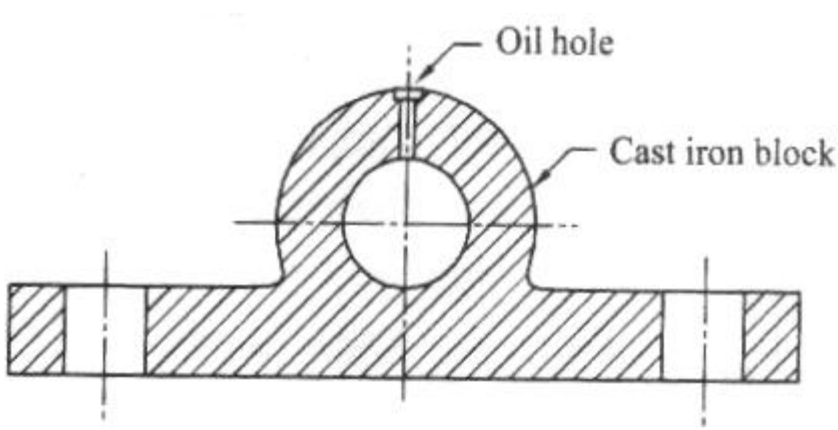
- Sliding contact bearings ***Ex: Journal bearings, thrust bearings.***
- Rolling contact bearings. ***Ex: Ball bearings, Roller bearings.***

Sliding contact Bearings

Journal bearing:

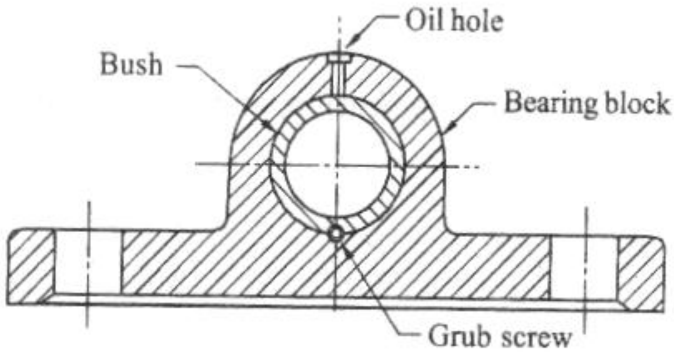
- It is one, which forms the sleeve around the shaft and supports a bearing at right angles to the axis of the bearing.
- The portion of the shaft resting on the sleeve is called the journal. Examples of journal bearings are:
  - Solid bearing
  - Bushed bearing, and
  - Pedestal bearing.

Solid bearing:



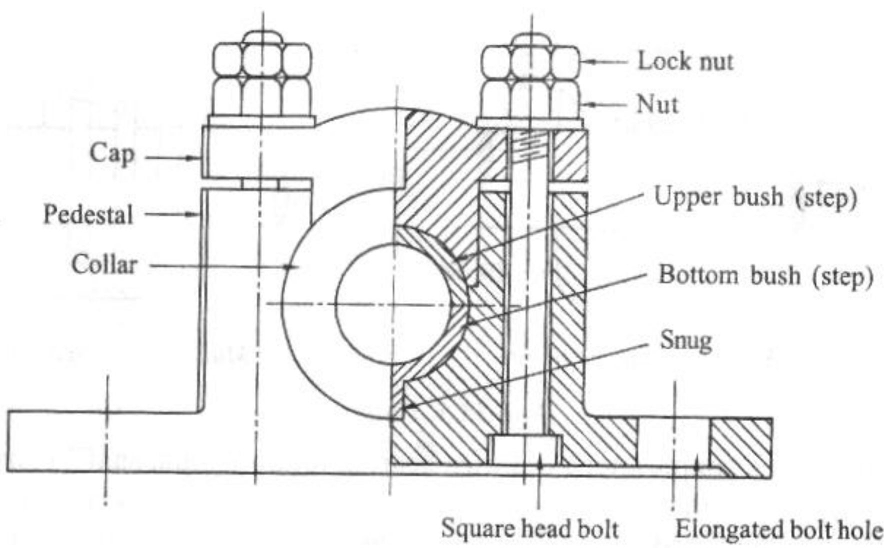
- A cylindrical hole formed in a cast iron machine member to receive the shaft which makes a running fit is the simplest type of solid journal bearing.
- Its rectangular base plate has two holes drilled in it for bolting down the bearing in its position as shown in the figure.
- An oil hole is provided at the top to lubricate the bearing. There is no means of adjustment for wear and the shaft must be introduced into the bearing endwise.
- It is therefore used for shafts, which carry light loads and rotate at moderate speeds.

Bushed Bearing:



- It consists of mainly two parts, the cast iron block and bush; the bush is made of soft material such as brass, bronze or gunmetal.
- The bush is pressed inside the bore in the cast iron block and is prevented from rotating or sliding by means of grub- screw as shown if the figure.
- When the bush gets worn out it can be easily replaced. Elongated holes in the base are provided for lateral adjustment.

Pedestal Bearing (Plummer block):



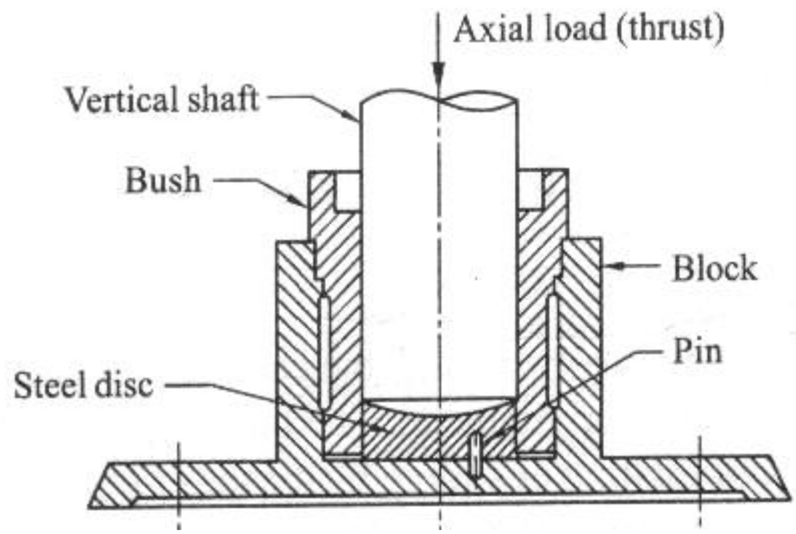
- It is also called ***Plummer block***. Figure shows half sectional front view of the Plummer block.
- It consists of cast iron pedestal, phosphor bronze bushes or steps made in two halves and cast iron cap.
- A cap by means of two square headed bolts holds the halves of the steps together.
- The steps are provided with collars on either side in order to prevent its axial movement.

- The snug in the bottom step, which fits into the corresponding hole in the body, prevents the rotation of the steps along with the shaft. This type of bearing can be placed any where along the shaft length.

Thrust Bearings

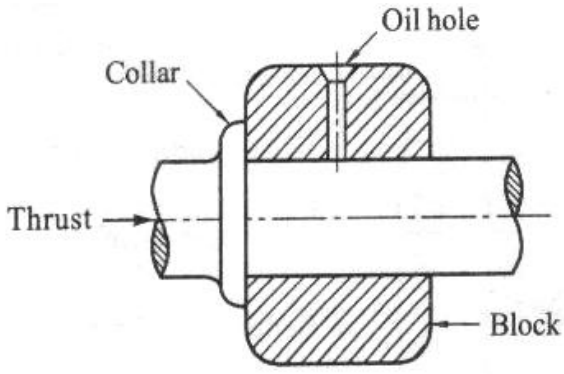
- They are used to guide or support the shaft, which is subjected to a load along the axis of the shaft.
- Since a thrust bearing operates without a clearance between the conjugate parts, an adequate supply of oil to the rubbing surfaces is extremely important.
- Bearings designed to carry heavy thrust loads may be broadly classified in to two groups
  - Foot step bearing, and
  - Collar bearing

Footstep Bearing:

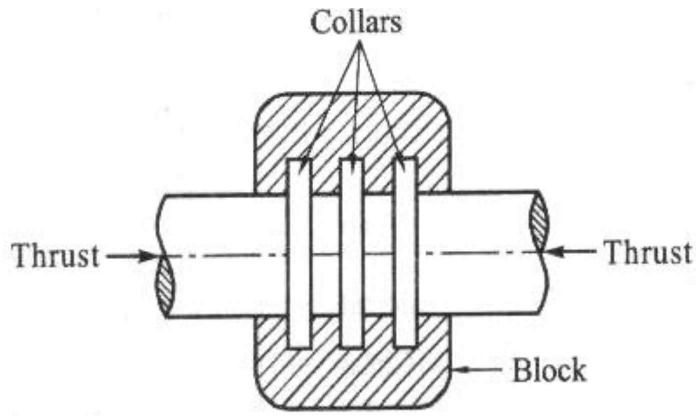


- Footstep bearings are used to support the lower end of the vertical shafts.
- A simple form of such bearing is shown in fig. It consists of cast iron block into which a gunmetal bush is fitted.
- The bush is prevented from rotating by the snug provided at its neck. The shaft rests on a concave hardened steel disc.
- This disc is prevented from rotating along with the shaft by means of pin provided at the bottom.

Collar Bearing:



Single collar bearing



Multi collar bearing

- The simple type of thrust bearing for horizontal shafts consists of one or more collars cut integral with the shaft as shown in fig.
- These collars engage with corresponding bearing surfaces in the thrust block.
- This type of bearing is used if the load would be too great for a step bearing, or if a thrust must be taken at some distance from the end of the shaft.
- Such bearings may be oiled by reservoirs at the top of the bearings

Advantages of sliding contact bearings:

- They can be operated at high speeds.
- They can carry heavy radial loads.
- They have the ability to withstand shock and vibration loads.
- Noiseless operation.

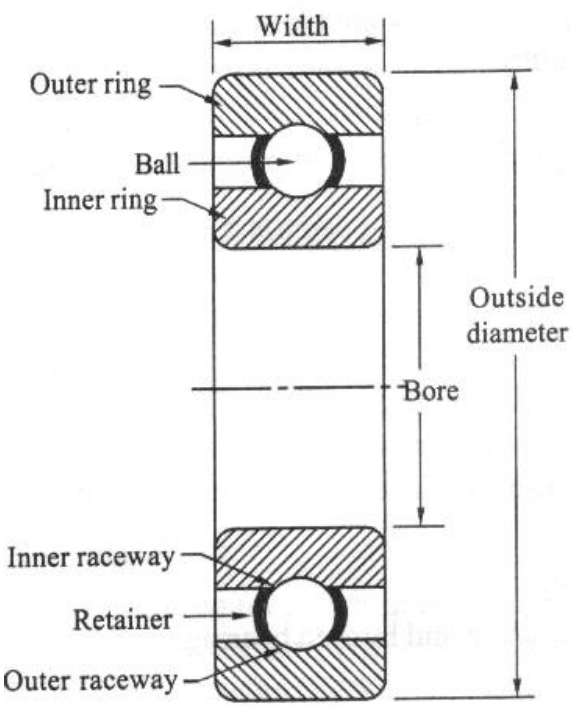
Disadvantages of sliding contact bearings:

- High friction losses during staring.
- More length of the bearing.
- Excessive consumption of the lubricant and high maintenance.

Rolling Contact Bearings

- The bearings in which the rolling elements are included are referred to as rolling contact bearings.
- Since the rolling friction is very less compare to the sliding friction, such friction is known as anti friction bearings.

Ball Bearings:



- It consists of an inner ring which is mounted on the shaft and an outer ring which is carried by the housing.
- The inner ring is grooved on the outer surface called inner race and the outer ring is grooved on its inner surface called outer race.
- In between the inner and outer race there are number of steel balls.
- A cage pressed steel completes the assembly and provides the means of equally spacing and holding the balls in place as shown in the figure.
- Radial ball bearings are used to carry mainly radial loads, but they can also carry axial loads.

Roller Bearings:

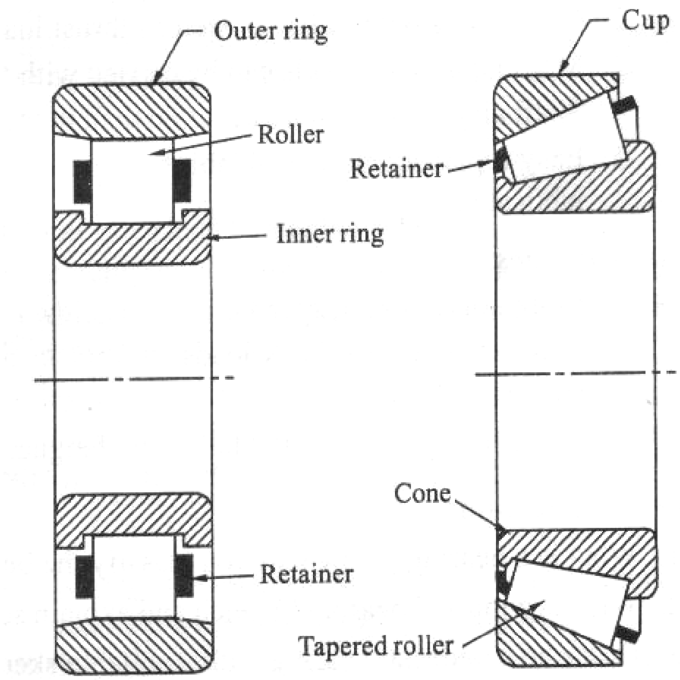


Fig (a)

Cylindrical roller bearing:

- The simplest form of a cylindrical roller bearing is shown in fig (a). It consists of an inner race, an outer race, and set of rollers with a retainer.
- Due to the line contact between the roller and the raceways, the roller bearing can carry heavy radial loads.

Tapered roller bearings:

- In tapered roller bearings shown in the fig (b). The rollers and the races are all truncated cones having a common apex on the shaft center to assure true rolling contact.
- The tapered roller bearing can carry heavy radial and axial loads.
- Such bearings are mounted in pairs so that the two bearings are opposing each others thrust.

Advantages of Rolling contact bearings:

- Low starting and low running friction.
- It can carry both radial as well as thrust loads.
- Momentary over loads can be carried without failure.
- Shaft alignment is more accurate than in the sliding bearings.

Disadvantages of Rolling contact bearings:

- More noisy at high speeds.
- Low resistance to shock loads.
- High initial cost.
- Finite life due to eventual failure by fatigue.