POWER TRANSMISSION

Introduction

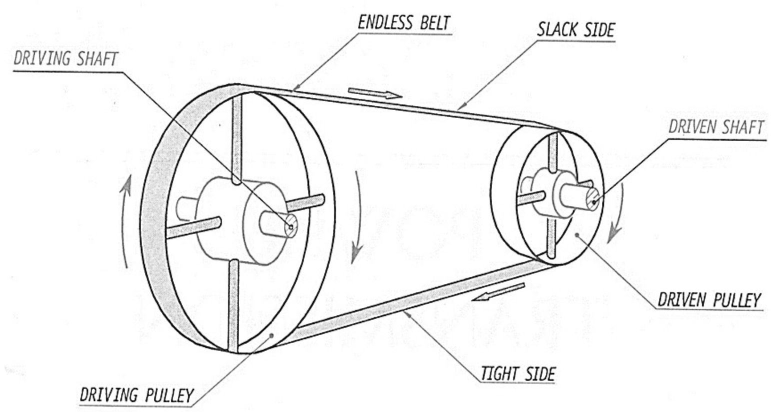
The rotational motion can be transmitted from one mechanical element to the other with the help of certain systems known as power transmission systems. The one that drives is called driving

system and the other which is driven is called driven system. The methods of power transmission are:

i. Belt drive.
ii. Gear drive.
iii. Rope drive.
iv. Chain drive.

Belt Drives

It is one of the most common and effective devices of transmitting motion from one shaft to another by means of a thin inextensible band running over two pulleys. Belt drive is generally employed whenever rotary motion is to be transmitted between two parallel shafts. They are generally used when the driving and driven ends are far apart. The drive consists of 2 pulleys over which an endless belt is passed encircling both of them. The power is transmitted from driving pulley to driven pulley because of the frictional grip that exists between the belt and pulley.



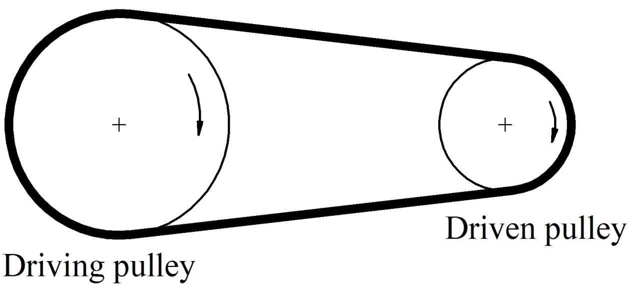
Belt Drive

In the above figure when the system is stationary the belt will be slightly in a stretched condition due to the initial tension T_o prevailing in the belt. As soon as the driving pulley rotates in the clockwise direction it pulls the belt from its lower side due to the friction prevailing between the belt and the pulley surface and the tension on the lower side increases from T_o to T_1 and the belt becomes tight. Hence it is called as the tight side of the belt. The driving pulley delivers the belt to the upper side where the tension in the belt decreases from T_o to T_2. This is known as the slack side of the belt. Here ($T_1 - T_2$) is the effective force driving the belt drive. As long as the frictional force required to cause relative movement between the belt and either the driving or driven pulley surface is greater than ($T_1 - T_2$) the slipping of the belt does not take place and power is transmitted from driving pulley to driven pulley. If ($T_1 - T_2$) is greater than the frictional force the belt slips. Hence higher coefficient of friction is an advantage in case of a belt drive.

Belt materials of power transmission belts are generally made from leather, rubber canvas etc. and are used in mills & factories. Advantage is low cost, low maintenance, and long life. Limitations are not a Positive Drive, less efficiency due to Slip and Creep and not suitable for shorter distances.

Types of Belt drives

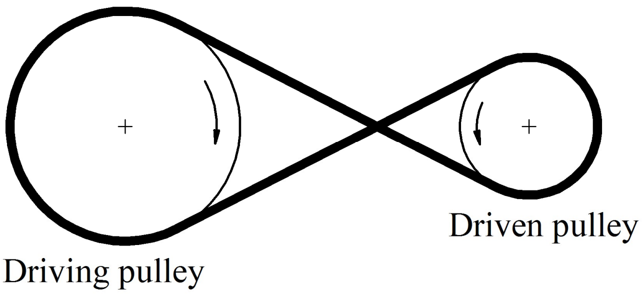
Open Belt Drive: This type of belt drive shown in figure below is employed when the two parallel shafts have to rotate in the same direction. When the shafts are placed far apart, the lower side of the belt should be the tight side and the upper side must be the slack side, so that when the upper side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



Open Belt Drive

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

Crossed Belt Drive: This type of belt drive shown in figure below is employed when two parallel shafts have to rotate in the opposite direction. At the junction where the belt crosses, it rubs against itself and wears off. To avoid excessive wear, the shafts must be placed at a maximum distance from each other and operated at very low speeds.



Crossed Belt Drive

Open Belt Drive	Crossed Belt Drive
Driver and driven shafts rotate in same direction.	Driver and driven shafts rotate in opposite direction
As there is no rubbing, life of the belt is more	Due to rubbing, life of the belt reduces.
Requires less length of the belt.	Requires more length of belt.
Lesser power transmission.	Power transmitted is relatively higher.

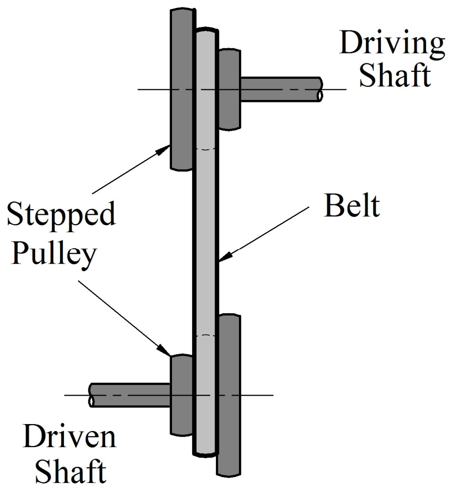
Velocity Ratio of a Belt Drive:

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

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

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

Stepped Cone Pulley (Speed Cone)



Stepped/Speed Cone Pulley

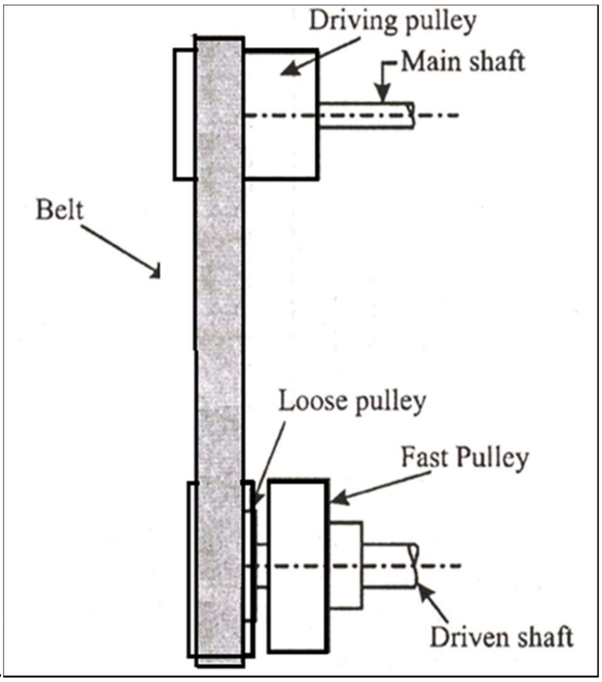
A stepped cone pulley is an Integral casting having three or more number of pulleys of different diameters one adjacent to the other as shown in figure above. One set of stepped cone pulley is mounted on the driving shaft and other set is mounted in the reverse direction on the driven shaft. An endless belt is wrapped around one pair of pulleys. By shifting the belt from one pair of pulleys to the other, the speed of the driven shaft can be varied. The diameters of the driving and driven pulleys are such that the same belt will operate when shifted on different pairs of pulleys.

It is used when speed of the driven shaft is to be changed very frequently as in the case of machine tools such as lathe, drilling machine etc.

Fast and loose pulley:

When many machines obtain the drive from a main driving shaft, it may be required to run some machines intermittently without having to start or stop the main driving shaft. Fast and loose pulley arrangement shown in the figure below is used for this purpose. It consists of two pulleys mounted on the driven shaft, a fast pulley which is securely keyed to the driven shaft and a loose pulley which is mounted with a brass bush and is free to rotate on the driven shaft or the machine shaft. The main driving pulley is slightly larger in width and is securely keyed to the driving shaft. The belt will always be on the driving pulley and either on the fast pulley or loose pulley depending upon the requirement. When the belt is on the fast pulley power is transmitted to the machine shaft and when the machine shaft is to be brought to rest belt is shifted from fast pulley to loose pulley.

shaft.



Fast and Loose Pulley

Length of Belt

Length of Open Belt

L = length of the belt = $\boldsymbol{\pi (r_1+r_2) + (r_1-r_2)^2 / X + 2X}$

where,

r_1 = Radius of the larger pulley P

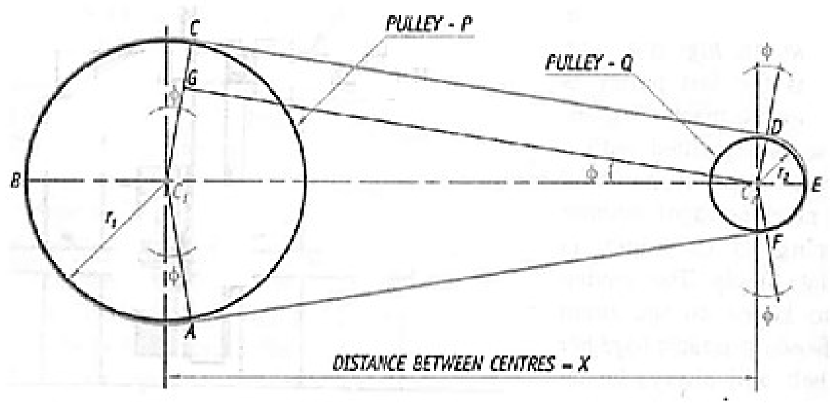
r_2 = Radius of the smaller pulley Q and

X = Distance between the centers of the pulleys.

Angle of lap = $\theta = \pi - 2\varphi$

where

$$\phi = \sin^{-1}\left(\frac{r_1 - r_2}{X}\right)$$



Open Belt Drive

Length of Crossed Belt

L = length of the belt = $\boldsymbol{\pi (r_1+r_2) + (r_1+r_2)^2 / X + 2X}$

Where,

r_1 = Radius of the larger pulley P

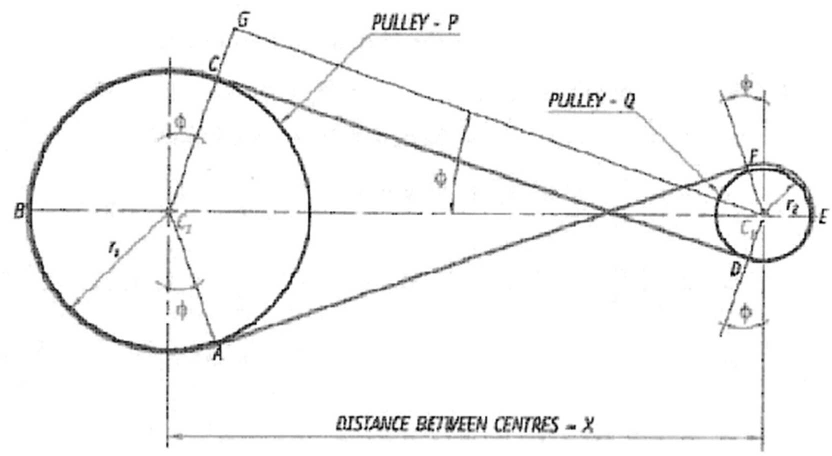
r_2 = Radius of the smaller pulley Q and

X = Distance between the centers of the pulleys.

Angle of lap = $\theta = \pi + 2\varphi$

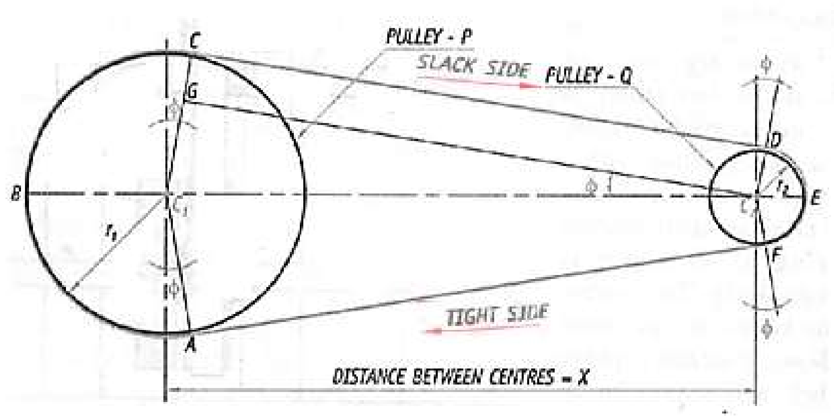
Where

$$\phi = \sin^{-1}\frac{(r_1 + r_2)}{X}$$



Crossed Belt Drive

Ratio of Tensions in belt drive:



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

where, T_1 = Tight side tension

T_2 = Slack side tension

μ = coefficient of friction

θ = angle of contact

Slip in a belt drive:

A belt drive transmits power as long as the frictional force required to create relative movement between the belt and either the driving or driven pulley surface is greater than $(T_1 - T_2)$. When this condition exists the friction prevailing between the belt and the pulley surface will provide the necessary grip to prevent the sliding of the belt over the pulley. When $(T_1 - T_2)$ is greater than the frictional grip between the belt and the pulley surface then the belt begins to slide over the pulley surface causing relative motion between the pulley surface and the belt. This phenomena is called slip in a belt drive. It tends to decrease the velocity ratio.

Velocity Ratio = $N_2 / N_1 = d_1 / d_2$ [100-S/100]

where, S = % Slip

Slip mainly occurs when the difference between tensions in the tight and the slack side is very large or when the coefficient of friction between the belt and the pulley surface decreases owing to stretching of the belt or when the smoothness of the pulley surface is more or due to a layer of air trapped between the pulley rim and the belt.

Creep in a belt drive:

In a belt drive the belt is alternatively subjected to higher and lower tensions. The portion of the belt between the driving and driven pulley has lower tension and the portion of the belt between the driven and driving pulley has higher tension. Thus the belt undergoes alternate stretching and contraction. While passing from slack side to tight side the belt extends and while passing from tight side to slack side the belt contracts. Due to this alternate stretching and contraction over a period of time the length of the belt increases leading to relative motion between the belt and the pulley surface. This relative motion is called creep which results in loss of power and decreases the velocity ratio.

Initial Tension in Belt:

It is the uniform tension that exists initially when the drive is not in motion. It is given by making the free length of the belt slightly shorter than what is required as per geometrical calculations. It is designated as T_o.

Initial Tension in Belt = $T_o = (T_1+T_2) / 2$

Power transmitted by a belt drive: The power transmitted by a belt drive is given by the relation

$P = (T_1 - T_2)\, v / 60000$ kW,

Where

T_1 & T_2 are tight and slack side tensions in newtons and

v is the linear velocity of the belt drive $= \pi\, d_1\, N_1 = \pi\, d_2\, N_2$

where d_1 & d_2 are the diameters of driving and driven pulleys in metres.

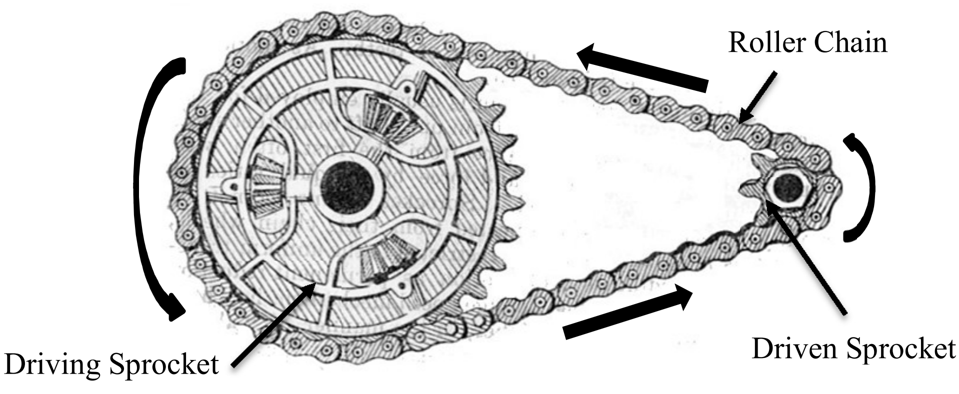
and N_1 and N_2 are the speed of driving and driven pulleys in RPM.

Chain Drives:

Chain drives are positive drives having no slip and velocity ratio remaining constant. Chain drives are suitable for small centre distances and can be used generally up to 3metre but in special cases even up to 8 meters. The velocity ratio can be as high as 8:1.

Chain drives are employed in bicycles, motor cycles, rolling mills, agricultural machineries, machine tools, conveyors etc.

A chain drive consists of a chain and two sprockets. The sprockets are teethed wheels over which an endless chain fitted.



Roller Chain

Advantages

- Positive non-slip drives
- Efficiency is high
- Employed for small as well as large centre distances up to 8m.
- Permit high velocity ratio up to 8:1

- Transmit more power than belt drives
- They produce less load on shafts compared to belt drives
- Maintenance is low

Disadvantages

- Driving and driven shafts should be in perfect alignment.
- Requires good lubrication
- High initial cost

Rope Drives

Used when centre distances are greater than 10m and power to be transmitted is more than 200 HP. Used in lifts, hoists etc. Ropes can be made from nylon or metal wires.

Gear Drives:

Gear drives find a very prominent place in mechanical power transmission. Gear drives are preferred when considerable power needs to be transmitted over a short distance positively and with a constant velocity ratio.

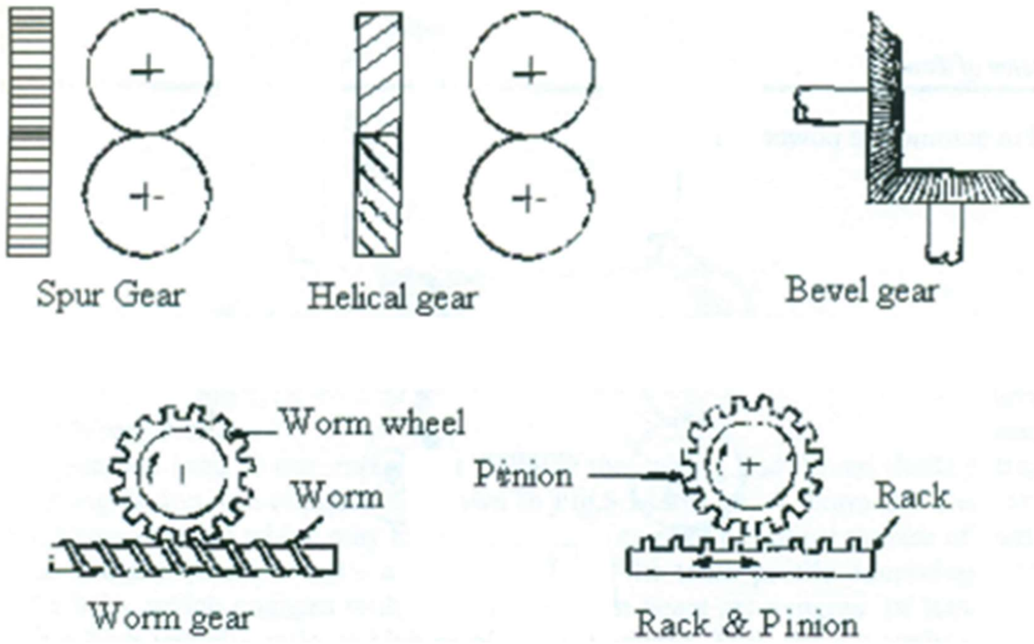
Types Gears:

There are different types of gears to suit various applications. They differ in the shape of the gear wheel like cylindrical or conical, the orientation of their axes and the angle at which the teeth mesh. Gear drives transmit power between the shafts when their axes are:

i) Parallel ii) Intersecting iii) Neither parallel nor intersecting.

The different types of gears used are:

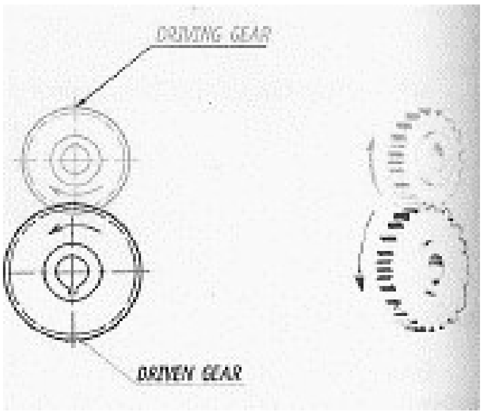
1. Spur Gears - For Parallel Axes shafts.
2. Helical Gears - For both Parallel and Non-parallel and Non-intersecting Axes shafts.
3. Bevel Gears - For Intersecting Axes shafts.
4. Worm Gears - For Non-Parallel and Non-co-planar Axes shafts.
5. Rack and Pinion - For converting rotary motion into linear motion.



Different types of Gears

1. Spur Gears:

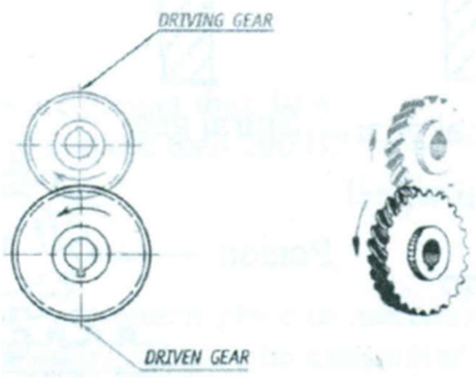
When the axes of the driving and driven shafts are parallel and co-planar and the teeth of the gear wheels are parallel to the axes, the gears are called spur gears. The contact between the mating gears will be along a line, hence spur gears can transmit higher power. Because of the instantaneous line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



Spur Gears

2. Helical Gears:

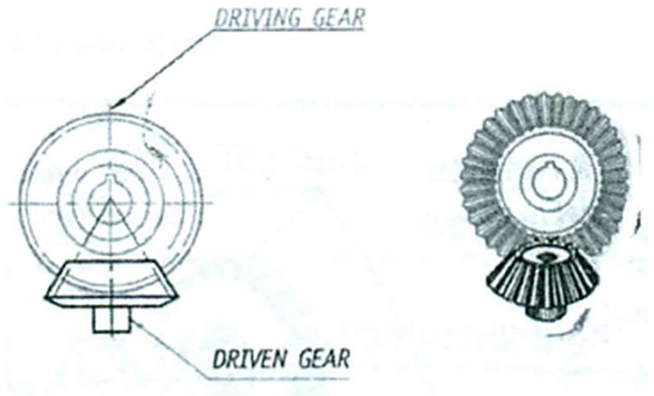
Helical gears are similar to the spur gears except that the teeth are cut in the form of the helix around the gear. The teeth are cut at an angle to the axis of the gear. Helical gears are used for transmitting power between two parallel shafts and also between non parallel, non-intersecting shafts.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



Helical Gears

3. Bevel gears:

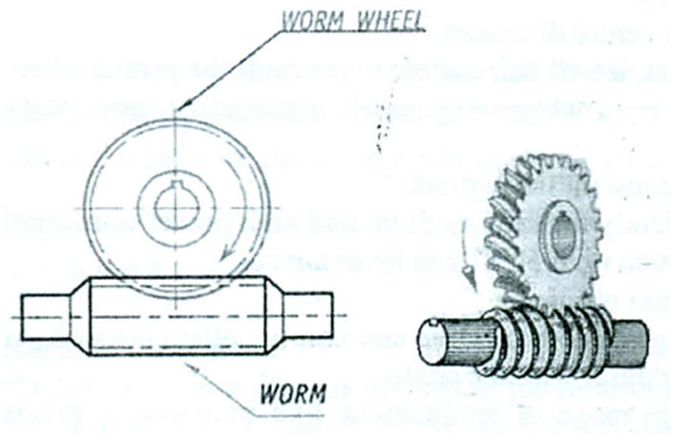
When the axes of the two shafts are inclined to one another, and intersect when produced bevel gears are used. The angle of intersection can be right angle, acute or obtuse. The most common examples of power transmission by bevel gears are those in which the axes of the two shafts are at right angles to each other. Teeth of the bevel gears are cut on the conical surfaces and the width of the teeth is less at the front end as compared to the rear end. When two bevel gears have their axes at right angles and are of equal sizes, they are called miter gears. They are used in automobile power transmission, machine tools and industrial machinery.



Bevel Gears

4. Worm Gear:

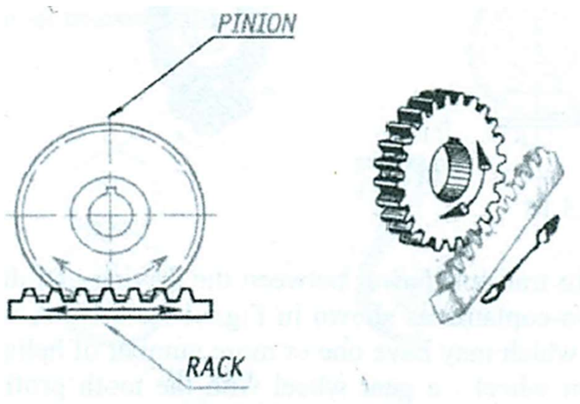
Worm gears are used to transmit power between the driving and driven shafts having their axes at right angles and non-coplanar. A worm drive consists of a worm (essentially a screw) which may have one or more number of helical threads cut on it and a worm wheel - a gear wheel which engages with the worm. Worm gears are suitable for transmission of power when a high velocity ratio as high as 300:1 is required. They are generally employed in machine tools like lathe, milling, drilling machines etc. to get large speed reduction.



Worm and Worm Wheel

5. Rack and Pinion:

When a rotary motion is to be converted into a linear motion, rack and pinion arrangement is used. Rack is a rectangular bar with a series of straight teeth cut on it. Theoretically rack is considered to be a spur gear of infinite diameter. Rack and pinion arrangement, find their application in machine tools such as lathe, drilling, planing machines, and in automobile steering systems.



Rack and Pinion

Advantages and Disadvantages of Gear Drives:

Advantages:

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

Disadvantages:

1. They are not suitable for shafts of very large centre distances.
2. They always require some kind of lubrication.
3. At very high speeds noise and vibrations will be more.
4. They are not economical because of the increased cost of production of precision gears.
5. Use of large number of gear wheels in gear trains increases the self-weight of the machine.

Nomenclature:

Circular Pitch (Pc) : It is the distance measured along the circumference of the pitch circle of a gear from a point of one tooth to the corresponding point on the adjacent tooth. It is the width of a tooth and a space, measured on the pitch circle

$$P_c = \frac{\pi D}{T}$$

Where D is the pitch circle diameter and T is the number of teeth.

Diametrical pitch (Pd): It is defined as the number of teeth per unit length of pitch circle diameter.

$$P_d = \frac{T}{D}$$

Where, Pd = Diametrical pitch, T = number of teeth &D = pitch diameter

Module (m): It is the ratio of the pitch circle diameter to the number of teeth. Module is the inverse of diametrical pitch

m = D/T

m= 1/Pd

Velocity Ratio of Gear drive:

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

Velocity Ratio of a gear drive $\frac{N_2}{N_1} = \frac{d_1}{d_2} = \frac{T_1}{T_2}$

where,

N_1 & N_2 are the RPM's of driver and driven gears respectively.

d_1 & d_2 = Pitch circle diameter of the driver and driven gears respectively.

T_1 & T_2 = no. of teeth on the driver and driven gears respectively

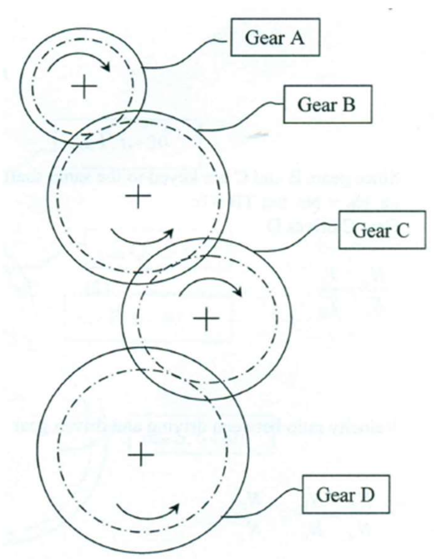
Gear Train:

A gear train is an arrangement of number of successively meshing gear wheels through which the power can be transmitted between the driving and driven shafts. The gear wheels used in gear train may be spur, bevel or helical etc.

The widely used gear trains are:

1. Simple gear train.
2. Compound gear train.

1. Simple gear train:



Simple Gear Train

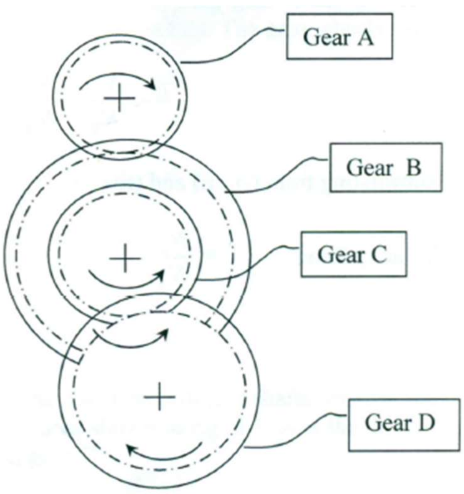
In a simple gear train a series of gear wheels arc mounted on different shafts between the driving and driven shafts each shaft carrying only one gear. In the figure, A is the driving gear. B and C are intermediate gears and D is the driven gear. Intermediate gears in a simple gear train do not influence the velocity ratio but only the direction of rotation of the driven gear.

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

Where, N & T = speed (in rpm) and no. of teeth on respective gears.

2. Compound gear train:

A compound gear train is one in which except the driving and driven shaft each shaft carries two gears. Figure below represents a compound gear train in which gears Band C constitute compound gears. It is used when a large velocity ratio is required and there is as restriction on centre distance between driver and driven shafts.



Compound Gear Train

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

where, N & T = speed (in rpm) and no. of teeth on respective gears.

SIMPLE GEAR TRAIN	COMPOUND GEAR TRAIN
Each shaft carries only one gear wheel.	Except the first and last shaft each shaft carries two gear wheels.
Velocity ratio is lower	Velocity ratio is higher
Velocity ratio is independent of intermediate gears	Velocity ratio is depends on intermediate gears
Intermediate gears influence only the	Intermediate gears influence not only the

direction of rotation of the last gear.	direction of rotation of the last gear but also the velocity ratio.
Occupies more space	Occupies less space.
Gears used should be of the same type	Different types of gears can be used but meshing gears should be of the same type.
Gears used should be of the same module	Gears having different module can be used but meshing gears should be of the same module.