Chapter 2: **Design Engineering: Power Transmission Elements**

Mechanical Engineering: DESIGN stream

Syllabus:

1. Overview of Power Transmission Drives, Belt Drives. Types, Velocity Ratio, Initial Tension. Numerical Problems.
2. Length of Belt. Ratio of Tensions. Power Transmitted, Numerical Problems
3. Gears. Spur Gear, Rack and Pinion, Worm Gear, Bevel Gear, Helical Gears. Speed, Torque, and Power in Gear pair. Numerical Problems
4. Simple and Compound Gear trains. Numerical Problems
5. Ball and Roller Bearings, Types, Applications

Rotating elements which possess mechanical energy has to be utilized at required place by transmitting.

– From prime mover to machine

– From one shaft to another

The system that is used to transmit power from one mechanical element to another mechanical element

– Belt drives, Rope drives, Chain drives, and Gear drives

BELT DRIVES

1. A belt is a looped strip of flexible material, used to mechanically link two or more rotating shafts.
2. They may be used as a source of motion, to efficiently transmit power, or to track relative movement. Belts are looped over pulleys.
3. In a two pulley system, the belt can either drive the pulleys in the same direction, or the belt may be crossed, so that the direction of the shafts is opposite.

In factories, the power or rotary motion, from one shaft to another at a considerable distance is, usually, transmitted by means of belts, ropes and gears.

Factors to select transmission system

Distance between driver and driven pulley shaft.

Operational speed.

Power to be transmitted

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.

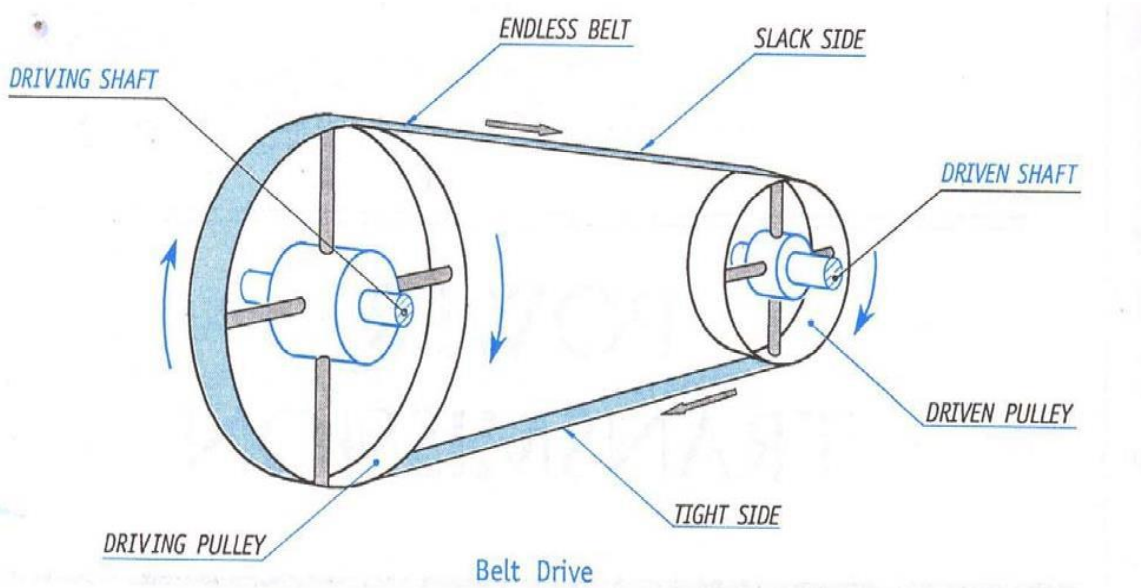
Mainly used for running of various industrial appliances using prime movers like electric motors, I.C. Engine etc.

3. Replacement of rigid type power transmission system.

A gear drive may be replaced by a belt transmission system

Belt drives

- Power is to be transmitted between the parallel shafts.
- Consists of two pulleys over which an endless belt is passed encircling the both.
- Rotary motion is transmitted from driving pulley to driven pulley.



Belt Drive

Terminology of a belt drive

Driver: in a transmission system the onewhich drives or supplies power to other mechanical element.

Driven: in a transmission system the one which follows the driver or receives power from driver.

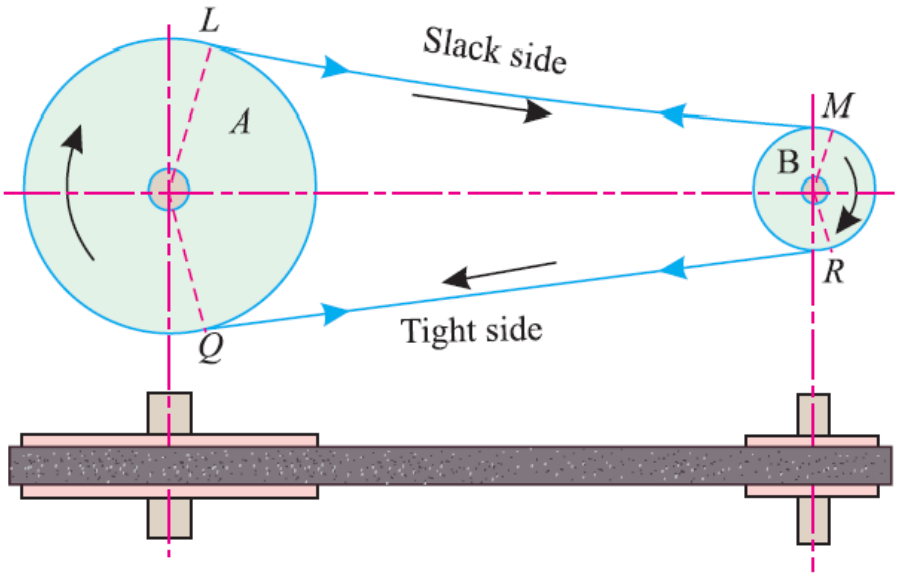
Tight side: the portion of the belt in maximum tension. Denoted by T_1 Newton

Slack side: the portion of the belt in minimum tension. Denoted by T_2 Newton

Arc / angle of contact: it is the portion of the belt which is in contact with pulley surface. Denoted by Θ in radians.

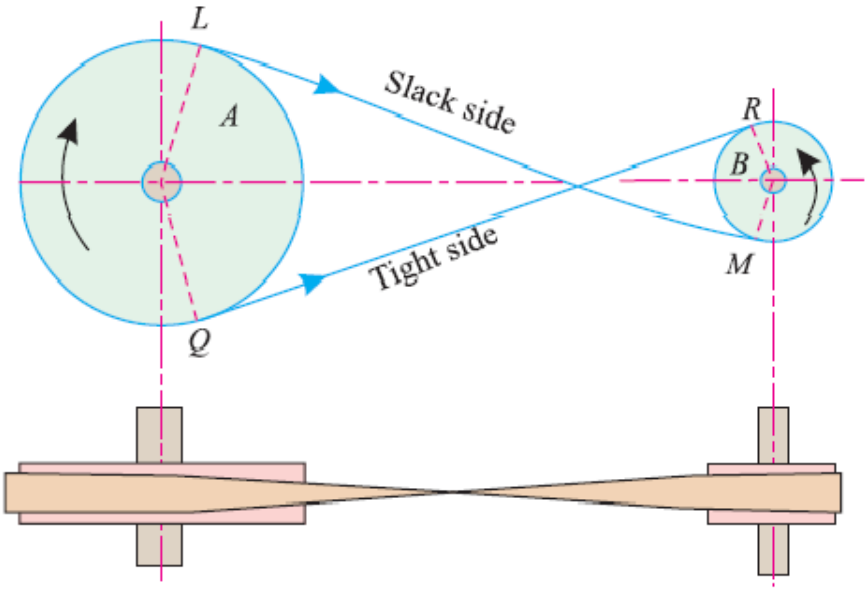
Types of Belt drives

OPEN BELT DRIVE



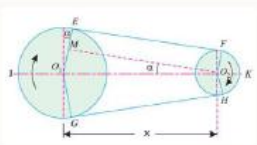
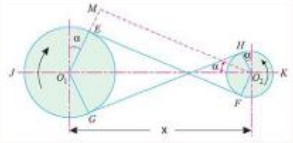
- Two pulleys rotate in the same direction
- Length of the belt is smaller
- Angle of lap is different for driver and driven pulley

CROSSED BELT DRIVE



- Pulleys rotate in the opposite directions
- Length of the belt is larger
- Angle of lap is same for driver and driven pulley

Open belt drive Vs Close belt drive

Item	Open Belt Drive	Closed Belt Drive
Arrangement		
Rotation of pulleys	same direction	opposite direction
useful alignment of shafts	horizontal or inclined	horizontal or inclined or vertical
rubbing	no rubbing point, the life of the belt is more	rubbing point, the life of the belt reduces.
Length of the belt (same centre distance, pulley diameters.)	less length	Require more length
Angle of contact (big and small pullys)	different	Same

- Belt transmission is comparatively simple, trouble free, easy to be serviced, maintained and have relatively low initial cost.
- Belts can connect non-parallel shafts also.
- Belts do not have space constrain, lubrication or heating issues.
- Since belts are flexible material there is inbuilt shock protection.
- Mainly belt drives are Flat belt drive and V- belt drive
- Flat belts although simple and economical they have relatively less grip and make more noise.
- Flat belt are made up of from leather or fabric rubber.
- V belts are made from polyester fabric and cords which carry the load. And outer cover of V belt is made from polychloroprene impregnated.
- Belt drives are found wide in applications ranging from machine tools to automobiles.
- Flat belts are commercially available as rolls, from which required length is cut, whereas V belts are manufactured in standard section sizes and lengths.

Following are the advantages it offers over the gear drive.

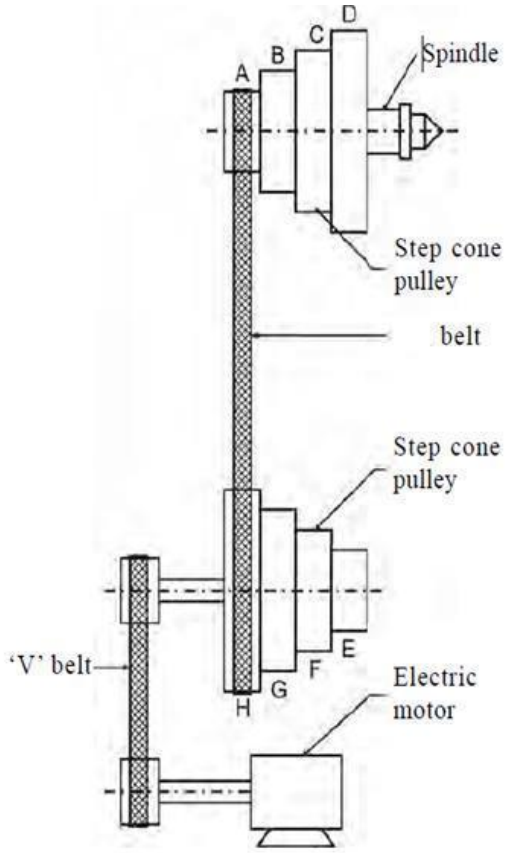
- Belt drives can transmit power over a long distance which is not feasible with gears.
- Since the intermediate link is long and flexible it can absorb the shocks and vibrations
- Due to flexibility there is no space and tolerance constrains like gears.
- Belt drives are very cheaper as compared to the gear drives.
- Belt drives are simple to design.

Following are the limitations of belt drives over gear drives.

- There are chances of slip in belts, hence belt drives are not positive drives and not 100% reliable.
- They cause more noise than gears.
- Belt drives occupy more space as compared to gear trains
- Large velocity ratio cannot be obtained with belt drives as compared to gear trains.

Belt Drives Concepts

1. **Stepped Cone Pulley or Speed Cone**



Belt Drives: Stepped Cone Pulley

(Speed cones, speed pulleys, step pulleys, stepped pulleys)

A pair of pulleys, each with a set of steps of increasing diameter, mounted on parallel shafts such that the smallest and largest diameters of one are aligned with the largest and smallest diameters of the other, thereby allowing a wide range of speed ratios to be achieved by shifting a belt from one end of the pair to the other.

Example: Lathe Machine

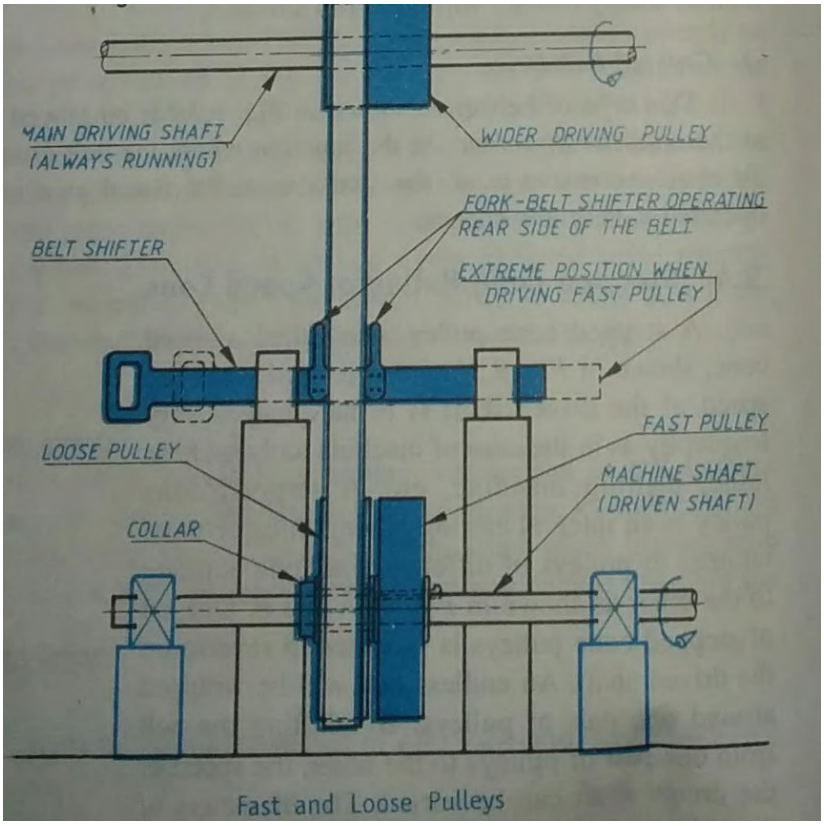
To change speed depending upon the operation given in RPM

Rough Turning (More amount of material removed)

Finish Turning (Less amount of material removed)

Threading speed

2. Fast and Loose Pulley



Belt Drives: Fast and Loose Pulley

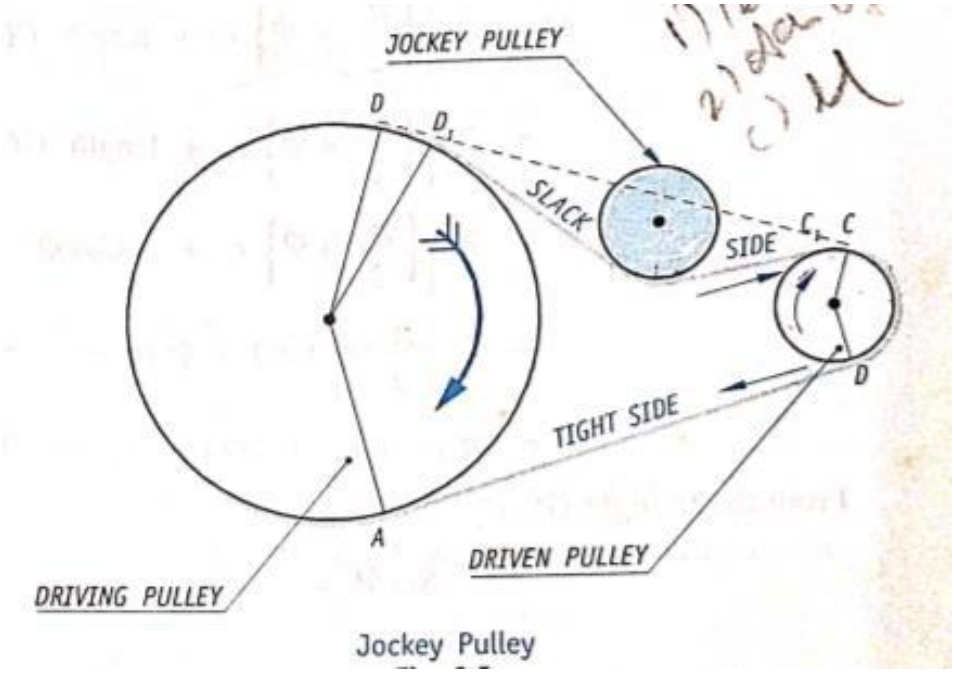
When a number of machines obtain the drive from a main driving shaft, often it may require to run some of machines intermittently without having to start and stop the main driving shaft every time.

In each pair of Pulleys, one will be Fast pulley, which is keyed to shaft and another will be loose pulley which is not keyed to shaft. Fast pulley is working pulley and loose pulley is Idler pulley.

When the belt is on the fast pulley, the power is transmitted to the machine shaft. When the machine shaft is to be brought to rest, the belt is shifted from fast pulley to loose pulley.

Example: Floor Mill (Different flour machines for Jowar, Wheat, Chilli keyed to main shaft)

3. **Jockey Pulley**



Jockey Pulley

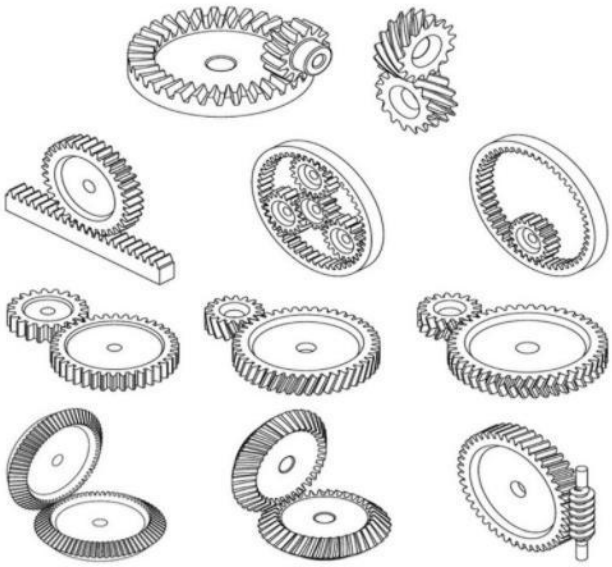
Belt Drives: Jockey Pulley

In an open belt drive arrangement, if the center distance is small or if the driven pulley is very small, the arc of contact with the driven pulley will be very small, which reduces tensions in belt, a idler pulley called Jockey pulley is placed on slack side of belt to get required tension on the belt for power transmission.

Placing Jockey pulley on slack side increases the arc of contact, thereby tension and power transmission.

GEAR DRIVES

- Power transmission is the movement of energy from its place of generation to a location where it is applied to performing useful work
- A gear is a component within a transmission device that transmits rotational force to another gear or device



Gears are toothed, mechanical transmission elements used to transfer motion and power between machine components, and in this article, we discuss the different types of gears available and how gears work. Operating in mated pairs, gears mesh their teeth with the teeth of another corresponding gear or toothed component which prevents slippage during the transmission process. Each gear or toothed component is attached to a machine shaft or base component, therefore when the *driving gear* (i.e., the gear that provides the initial rotational input) rotates along with its shaft component, the *driven gear* (i.e., the gear or toothed component which is impacted by the driving gear and exhibits the final output) rotates or translates its shaft component. Depending on the design and construction of the gear pair, the transference of motion between the driving shaft and the driven shaft can result in a change of the direction of rotation or movement. Additionally, if the gears are not of equal sizes, the machine or system experiences a mechanical advantage which allows for a change in the output speed and *torque* (i.e., the force which causes an object to rotate).

Gears and their mechanical characteristics are widely employed throughout industry to transmit motion and power in a variety of mechanical devices, such as clocks, instrumentation, and equipment, and to reduce or increase speed and torque in a variety of motorized devices, including automobiles, motorcycles, and machines. Other design characteristics, including construction material, gear shape, tooth construction and design, and gear pair configuration, help to classify and categorize the various types of gears available. Each of these gears offers different behaviors and advantages, but the requirements and specifications demanded by a particular motion or power transmission application determine the type of gear most suitable for use.

Gear Design Characteristics

Gears are available in a variety of designs, constructions, and configurations to suit a wide range of industries and applications. These various characteristics allow gears to be classified and categorized in several different ways, which include:

- Gear shape
- Gear tooth design and construction
- Gear axes configuration

Gear Shape

Most types of gears are circular—i.e., the gear teeth are arranged around a cylindrical gear body with a circular face—but some non-circular gears are also available. These gears can feature elliptical, triangular, and square-shaped faces.

Devices and systems which employ circular gears experience constancy in the *gear ratios* (i.e., the ratio of the output to the input) expressed—both for rotary speed and torque. The constancy of the gear ratio means that given the same input (either speed or torque), the device or system consistently provides the same output speed and torque.

On the other hand, devices and systems which employ non-circular gears experience variable speed and torque ratios. Variable speed and torque enable non-circular gears to fulfill special or irregular motion requirements, such as alternatingly increasing and decreasing output speed, multi-speed, and reversing motion. Additionally, linear gears, such as gear racks, can convert the rotational motion of the driving gear into the translational motion (or a combination of translational and rotational motion) of the driven gear.

TYPES OF GEARS

1. According to the position of axes of the shafts.

   a. Parallel

      1. Spur Gear
      2. Helical Gear
      3. Rack and Pinion

b. Intersecting

      Bevel Gear

c. Non-intersecting and Non-parallel

      Worm and worm gears

Different Types of Gears and Uses

Based on the design characteristics indicated above, there are several different types of gears available. Some of the more common types of gears employed throughout industry include:

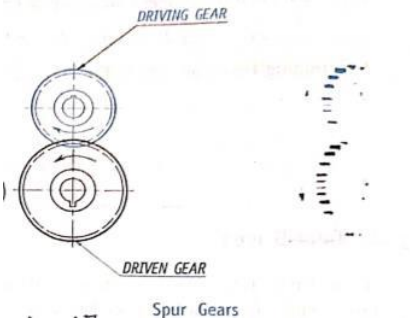
- Spur gears
- Helical gears
- Bevel gears
- Worm gears
- Rack and pinion

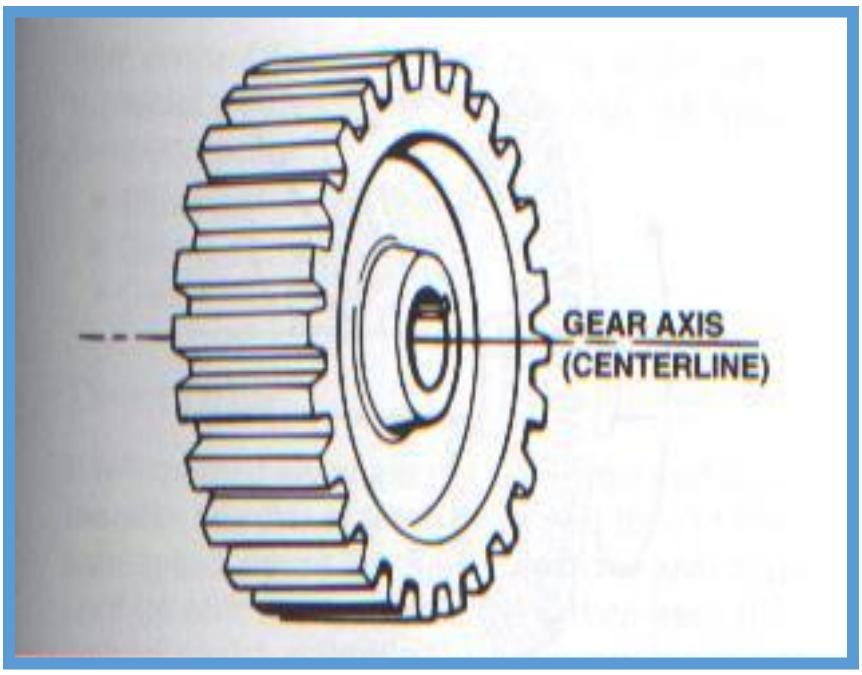
Spur Gears

The most common type of gears employed, spur gears are constructed with straight teeth cut or inserted parallel to the gear's shaft on a circular (i.e., cylindrical) gear body. In mated pairs, these gears employ the parallel axes configuration to transmit motion and power. Depending on the application, they can be mated with another spur gear, an internal gear (such as in a planetary gear system), or a gear rack (such as in a rack and pinion gear pair).

The simplicity of the spur gear tooth design allows for both a high degree of precision and easier manufacturability. Other characteristics of spur gears include lack of *axial load* (i.e., the thrust force parallel to the gear shaft), high-speed and high-load handling, and high efficiency rates. Some of the disadvantages of spur gears are the amount of stress experienced by the gear teeth and noise produced during high-speed applications.

This type of gear is used for a wide range of speed ratios in a variety of mechanical applications, such as clocks, pumps, watering systems, power plant machinery, material handling equipment, and clothes washing and drying machines. If necessary for an application, multiple (i.e., more than two) spur gears can be used in a gear train to provide higher gear reduction.





- Spur Gear
  - Cut Straight across
  - Spur gears only have one tooth in contact at a time
  - Minimizes chance of popping out of gear
  - Handles torque well
  - Used for Reverse

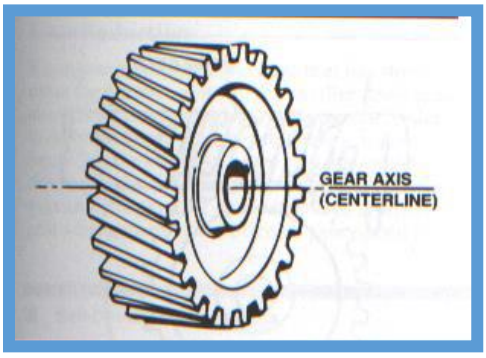
Helical Gears

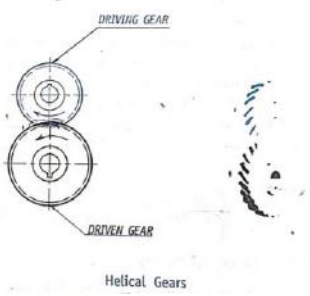
Similar to spur gears, helical gears typically employ the parallel axes configuration with mated gear pairs, but, if aligned properly, they can also be used to drive non-parallel, non-intersecting shafts. However, unlike spur gears, these gears are constructed with teeth which twist around the cylindrical gear body at an angle to the gear face. Helical gears are produced with right-hand and left-hand angled teeth with each gear pair comprised of a right-hand and left-hand gear of the same helix angle.

The angled design of helical teeth causes them to engage with other gears differently than the straight teeth of spur gears. As properly matched helical gears come in contact with one another, the level of contact between corresponding teeth increases gradually, rather than engaging the entire tooth at once. This gradual engagement allows for less impact loading on the gear teeth and smoother, quieter operation. Helical gears are also capable of greater load capabilities but operate with less efficiency than spur gears. Further disadvantages include the complexity of the helical tooth design, which increases the degree of difficulty in its manufacturing (and, consequently, the cost) and the fact that the single helical gear tooth design produces axial thrust, which necessitates the employment of thrust bearings in any application which uses single helical gears. This latter necessity further increases the total cost of using helical gears.

As helical gears are also capable of handling high speeds and high loads, they are suitable for the same types of applications as spur gears, such as pumps and generators. Their smoother, quieter operation also suits them for automobile transmissions where spur gears are typically not used.

Example of helical gears.





Helical Gears

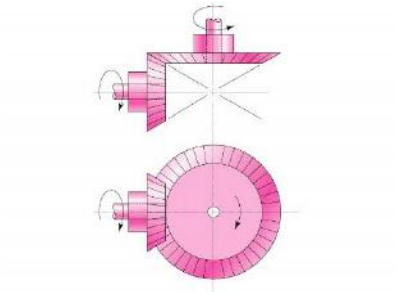
- Helical Gears are quieter than spur gears ,Two teeth at a time contact,Has a tendency to move shaft for and aft,Are left and right hande d,Opposites on parallel shafts

Bevel Gears

Bevel Gears are used to transmit rotary motion between intersecting shafts

Bevel gears are cone-shaped gears with teeth placed along the conical surface. These gears are used to transmit motion and power between intersecting shafts in applications which require changes to the axis of rotation. Typically, bevel gears are employed for shaft configurations placed at 90-degree angles, but configurations with lesser or greater angles are also manageable.

Teeth are formed on conical surfaces, the teeth could be straight or spiral.

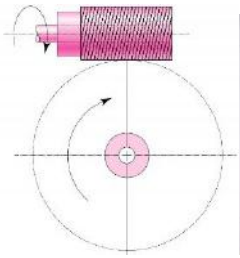


Worm Gears

Worm gear pairs are comprised of a worm wheel—typically a cylindrical gear—paired with a worm—i.e., a screw-shaped gear. These gears are used to transmit motion and power between non-parallel, non-intersecting shafts. They offer large gear ratios and capabilities for substantial speed reduction while maintaining quiet and smooth operation.

One distinction of worm gear pairs is that the worm can turn the worm wheel, but, depending on the angle of the worm, the worm wheel may not be able to turn the worm. This characteristic is employed in equipment requiring self-locking mechanisms. Some of the disadvantages of worm gears are the low transmission efficiency and the amount of friction generated between the worm wheel and worm gear which necessitates continuous lubrication.

Are used for transmitting motion between non parallel and non-transmitting shafts, Depending on the number of teeth engaged called single or double. Worm gear mostly used when speed ratio is quiet high, 3 or more.


- Worm gears are used when large gear reductions are needed. It is common for worm gears to have reductions of 20:1, and even up to 300:1 or greater
- Many worm gears have an interesting property that no other gear set has: the worm can easily turn the gear, but the gear cannot turn the worm
- Worm gears are used widely in material handling and transportation machinery, machine tools, automobiles etc

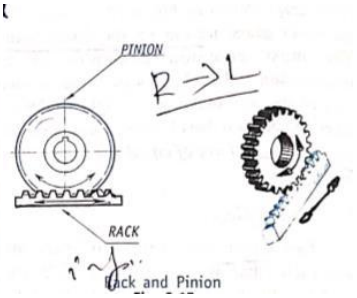
Rack and Pinion Gears

Rack and pinion gears are a pair of gears comprised of a gear rack and a cylindrical gear referred to as the pinion. The gear rack can be considered as a gear of infinite radius (i.e., a flat bar) and is constructed with straight teeth cut or inserted on the bar's surface. Depending on the type of pinion gear with which it is mated, the gear rack's teeth are either parallel (when mated with spur gears) or angled (when mated with helical gears). For either of these rack designs, rotational motion can be converted into linear motion or linear motion can be converted into rotational motion.

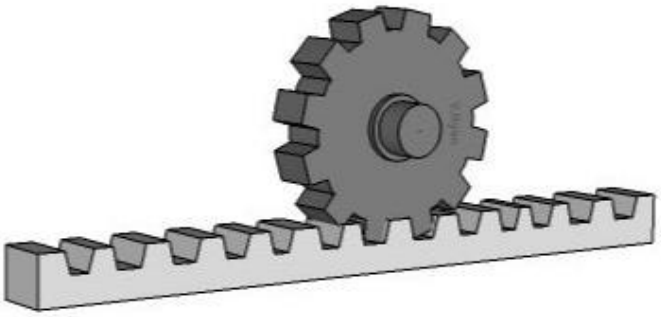
Some of the advantages of a rack and pinion gear pair are the simplicity of the design (and the low cost of manufacturing) and high load carrying capacities. Despite the advantages of this design, gears which employ this approach are also limited by it. For example, transmission cannot continue infinitely in one direction as motion is limited by the designated length of the gear rack. Additionally, rack and pinion gears tend to have a greater amount of backlash (i.e., additional space between mated gear teeth) and, consequently, the teeth experience a significant amount of friction and stress.

Some of the common applications of rack and pinion gear pairs include the steering system of automobiles, transfer systems, and weighing scales.

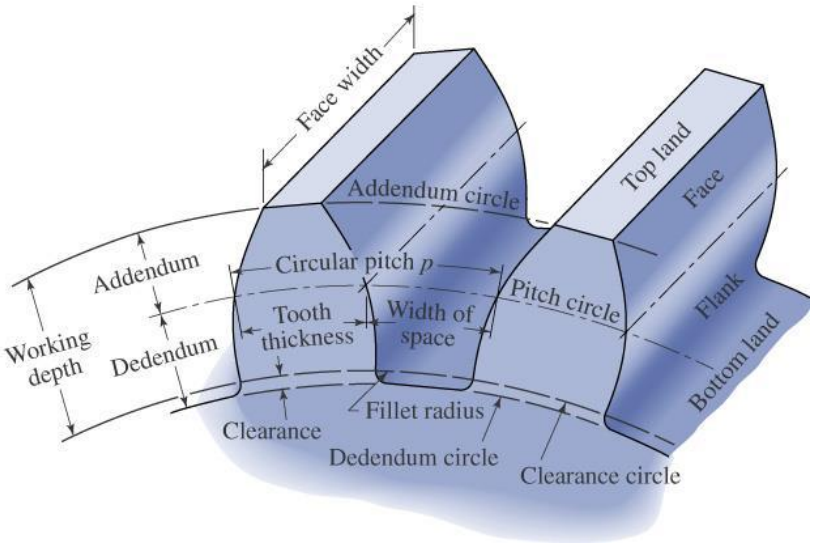
(Note: whereas in rack and pinion gears, the term "pinion" refers to the gear which meshes with the gear rack, in pairs of other types of gears, the term "pinion" refers, when applicable, to the gear with the smallest number of teeth)



Rack and Pinion



GEAR TERMINOLOGY



Gears are widely used in mechanical industries for power transmission. It is used where small distance between driver and driven shaft. It is the only positive drive which can transfer exact velocity ratio to the driven shaft, that's why it is widely used in various machines and other mechanical devices. Gear terminology means all definitions used to describe a gear or the terms used to design a gear.

Face of tooth:
It is defined as the surface of the tooth above the pitch circle is known as face.

Flank of tooth:
The surface of the tooth below the pitch circle is known as flank.

Top land:
The top most surface of the tooth is known as the top land of the tooth.

Face width:
Width of the tooth is known as face width.

Pitch Circle:
It is an imaginary circle which is in pure rolling action. The motion of the gear is describe by the pitch circle motion.

Pitch Circle diameter:
The diameter of the pitch circle from the center of the gear is known as pitch circle diameter. The gear diameter is described by its pitch circle diameter.

Pitch point:
When the two gears are in contact, the common point of both of pitch circle of meshing gears is known as pitch point.

Pressure angle or angle of obliquity:
Pressure angle is the angle between common normal to the pitch circle to the common tangent to the pitch point.

Addendum:
Distance between the pitch circle to the top of the tooth in radial direction is known as addendum.

Dedendum:
Distance between the pitch circle to the bottom of the tooth in radial direction, is known as dedendum of the gear.

Addendum circle:
The circle passes from the top of the tooth is known as addendum circle. This circle is concentric with pitch circle.

Dedendum circle:
The circle passes from the bottom of the tooth is known as dedendum circle. This circle is also concentric with pitch circle and addendum circle.

Circular pitch:
The distance between a point of a tooth to the same point of the adjacent tooth, measured along circumference of the pitch circle is known as circular pitch. It is plays measure role in gear meshing. Two gears will mesh together correctly if and only they have same circular pitch.

Diametrical pitch:
The ratio of the number of teeth to the diameter of pitch circle in millimeter is known as diametrical pitch.

Module:
The ratio of the pitch circle diameter in millimeters to the total number of teeth is known as module. It is reciprocal of the diametrical pitch.

Clearance:
When two gears are in meshing condition, the radial distance from top of a tooth of one gear to the bottom of the tooth of another gear is known as clearance. The circle passes from the top of the tooth in meshing condition is known as clearance angle.

Total depth:
The sum of the addendum and dedendum of a gear is known as total depth. It is the distance between addendum circle to the dedendum circle measure along radial direction.

Working depth:
The distance between addendum circle to the clearance circle measured along radial direction is known as working depth of the gear.

Tooth thickness:
Distance of the tooth measured along the circumference of the pitch circle is known as tooth thickness.

Tooth space:
Distance between the two adjacent tooth measured along the circumference of the pitch circle is known as the tooth space.

Backlash:
It is the difference between the tooth thickness and the tooth space. It prevents jamming of the gears in meshing condition.

Profile:
It is the curved formed by the face and flank is known as profile of the tooth. Gear tooth are generally have cycloidal or involute profile.

Gear Trains

1. Simple Gear Train

2. Compound Gear Train

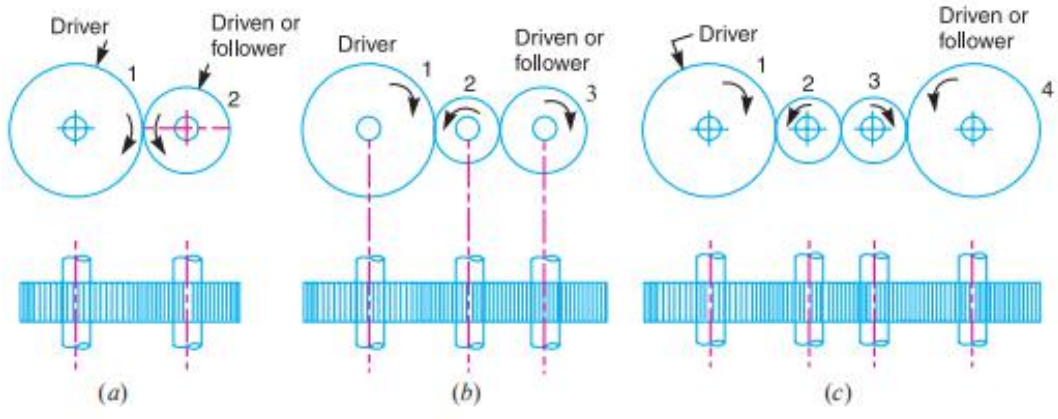
Sometimes, two or more gears are made to mesh with each other to transmit power from one shaft to another. Such a combination is called ***gear train*** or ***train of toothed wheels.*** The nature of the train used depends upon the velocity ratio required and the relative position of the axes of shafts.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

Types of Gear Trains

Following are the different types of gear trains, de- pending upon the arrangement of wheels: Simple gear train, 2. Compound gear train, 3. Re- verted 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 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. 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

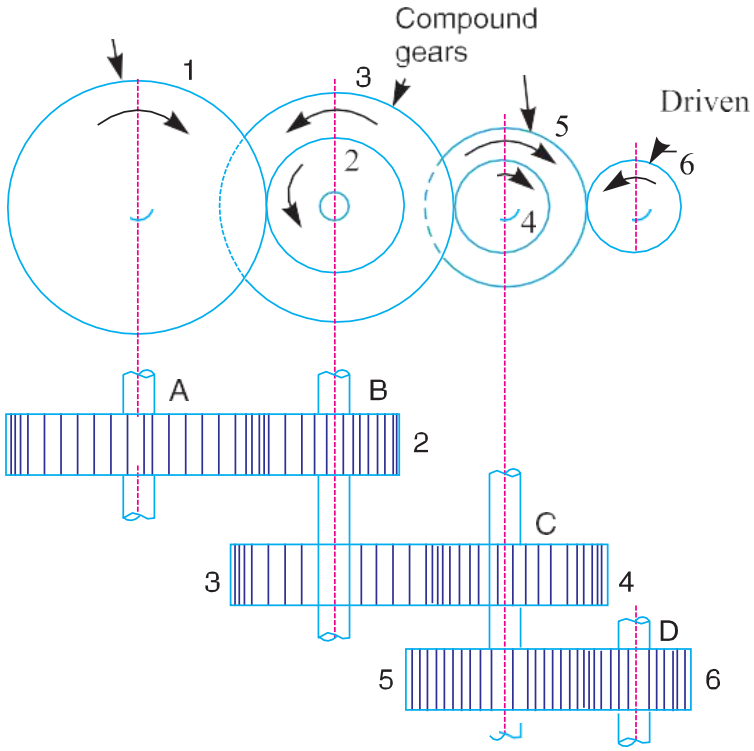


Compound Gear Train

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

Idle gears, in a simple train of gears do not effect 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.



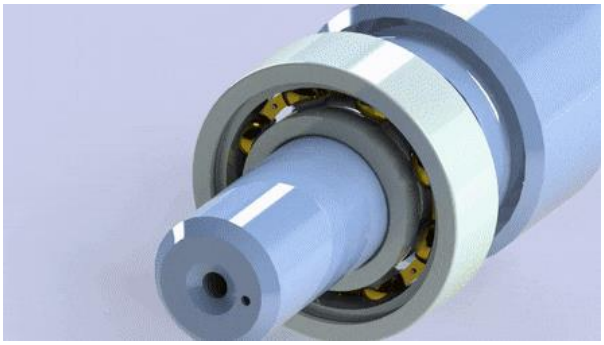
In a compound train of gears, as shown, the gear 1 is the driving gear mounted on shaft *A*, gears 2 and 3 are compound gears which are mounted on shaft *B*. The gears 4 and 5 are also compound gears which are mounted on shaft *C* and the gear 6 is the driven gear mounted on shaft *D*

Bearings

The concept behind a bearing is very simple: Things roll better than they slide. Bearings reduce friction by providing smooth metal balls or rollers, and a smooth inner and outer metal surface for the balls to roll against. These balls or rollers "bear" the load, allowing the device to spin smoothly.

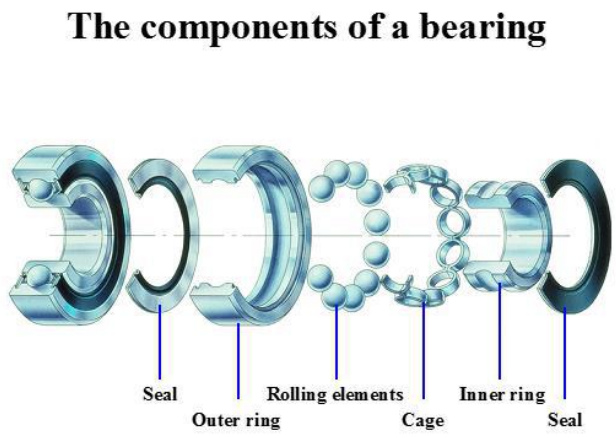
Bearings: Reduce friction, Carry Loads, Guide moving parts

While designing machines, often it needs to provide supports for the rotating shafts. Such support is called Bearing which also facilitates smooth running as well. Almost all kinds of machineries have bearings like crankshaft of engines, axles of automobiles, spindles of Machine tools etc.



Components of Bearing: Bearings typically consist of the following components:

- Two rings, inner and outer, with raceways.
- Rolling **elements** - rollers or balls.
- A cage which keeps the rolling **elements** and helps guide motion
- A seal on either sides



Classification of Bearings

Sliding Contact Bearings: Nature of motion between shaft and the bearing surface is pure sliding. Because of surface contact, the friction between the rotating shaft and bearing surface is high, hence requires lubrication.

Sliding contact bearings are classified according to the direction in which load acts on bearing surface.

The bearings in which load acts perpendicular to the axis of shaft are called Journal/Radial Bearings.

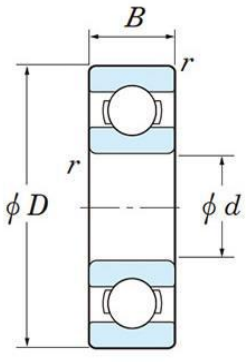
The bearings in which load acts along the axis of the shaft is called Thrust bearings or Collar Bearings.

Rolling Contact Bearings:

It is a well-known fact that a smooth rounded surface will roll over a similar surface more easily than when it is sliding. In rolling contact bearings, the motion between shaft and bearing surface is pure rolling. Since rolling friction is less than the sliding friction, the bearings of this type are called antifriction bearings. Two types of Anti friction bearings are Ball bearings and Roller Bearings.

Ball Bearings:

It consists of hardened steel balls positioned between two suitable grooved, hardened steel rings. These rings are known as races. The balls are retained in position by a separator known as cage. Inner race rotates with the shaft and outer race fits tightly in the housing. Although Ball bearings are antifriction bearings, these need to be lubricated which enables balls to rotate freely. In Ball bearing there is point contact between the balls and races, and therefore it is not suited heavy loads.



Roller Bearings:

The roller bearing, the other type of antifriction bearing, probably evolved based on the most commonly found and experienced fact that heavy weights can be moved more easily , if cylindrical rods are used between the weight and ground. The roller bearings are better suited for heavy loads as there is a line contact between rollers and the races. In roller bearing, a series of small hardened steel cylinders called rollers are fitted between the inner and outer races.