Mechanical power transmission

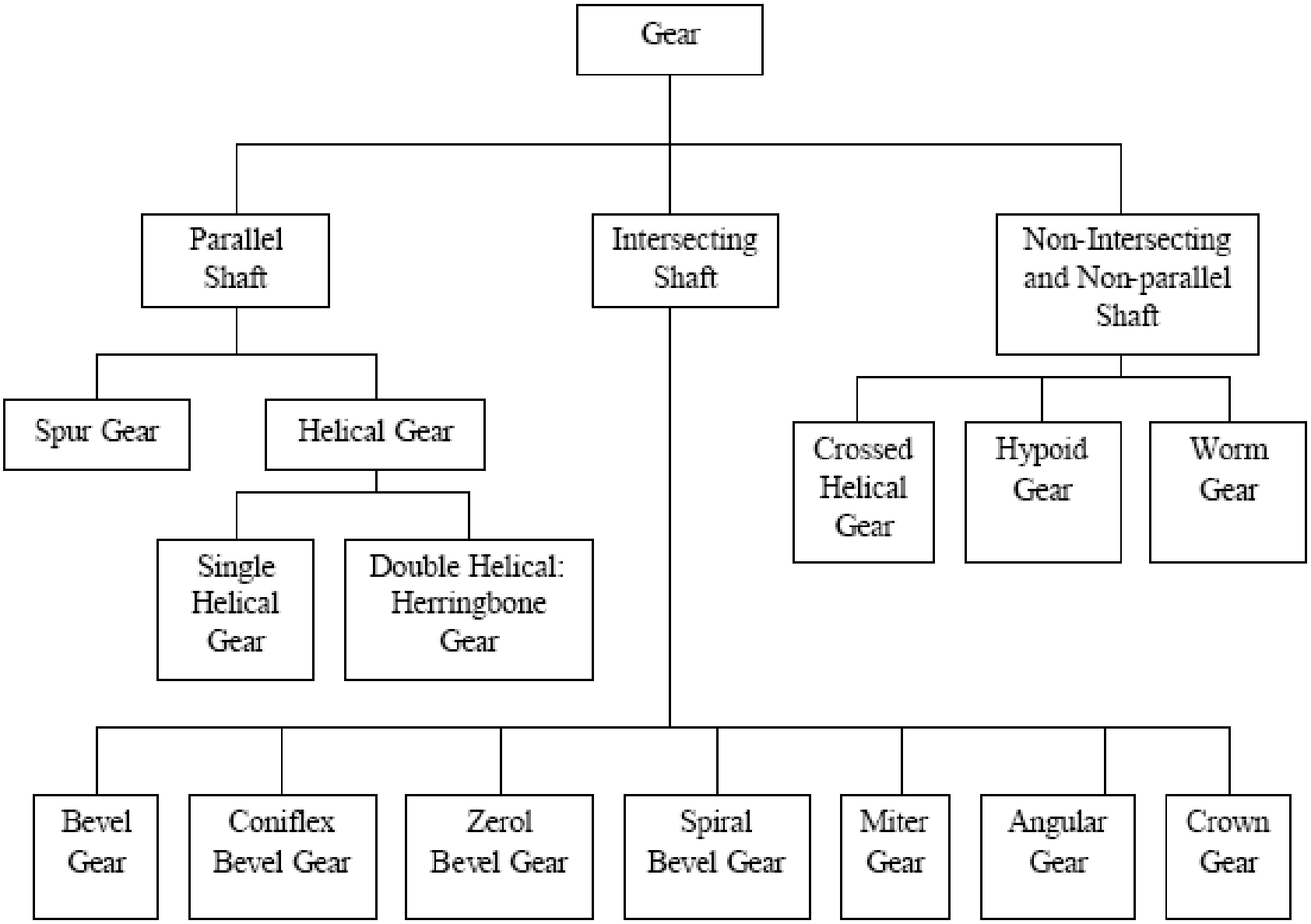
Power transmission

- Power transmission is the movement of energy from its place of generation to a location where it is applied to performing useful work.
- Provides controlled application of the power.
- Mechanical power transmission types
  - Gears
  - Belt drives
  - Cables
  - Roller chains
  - Link – Rod systems

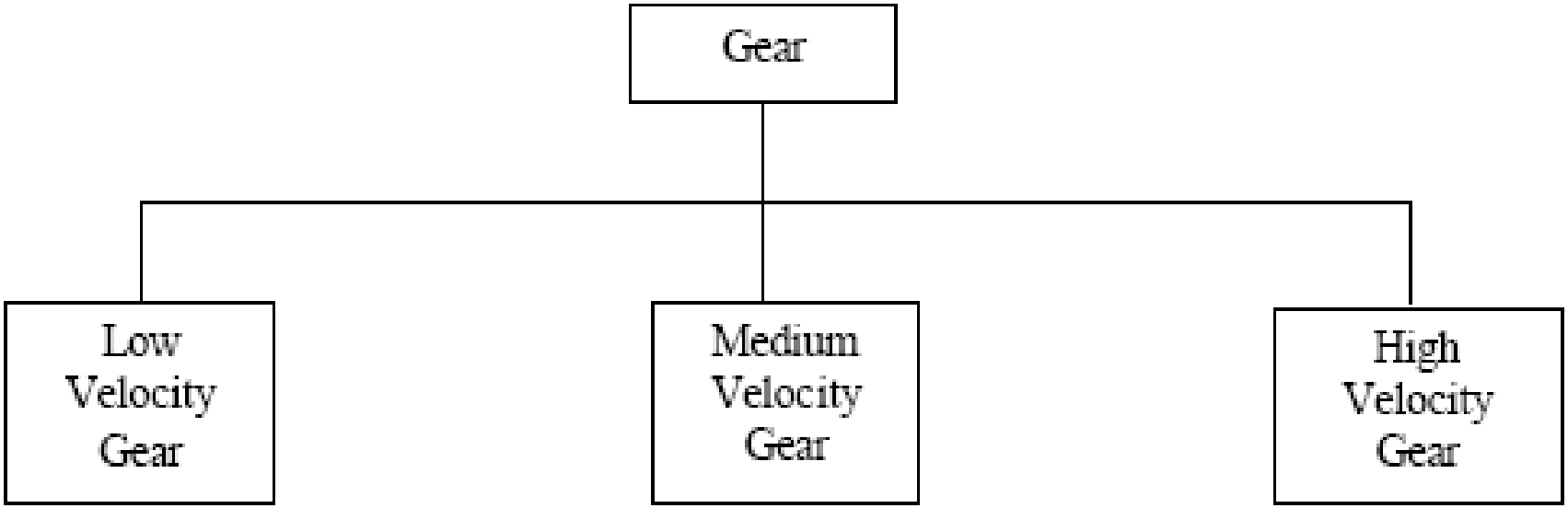
Gears

- Gears are the most common means used for power transmission
- A gear is a rotating machine part having cut teeth which mesh with another toothed part in order to transmit torque.
- They can be applied between two shafts which are
  - Parallel
  - Collinear
  - Perpendicular
  - Inclined at any arbitrary angle

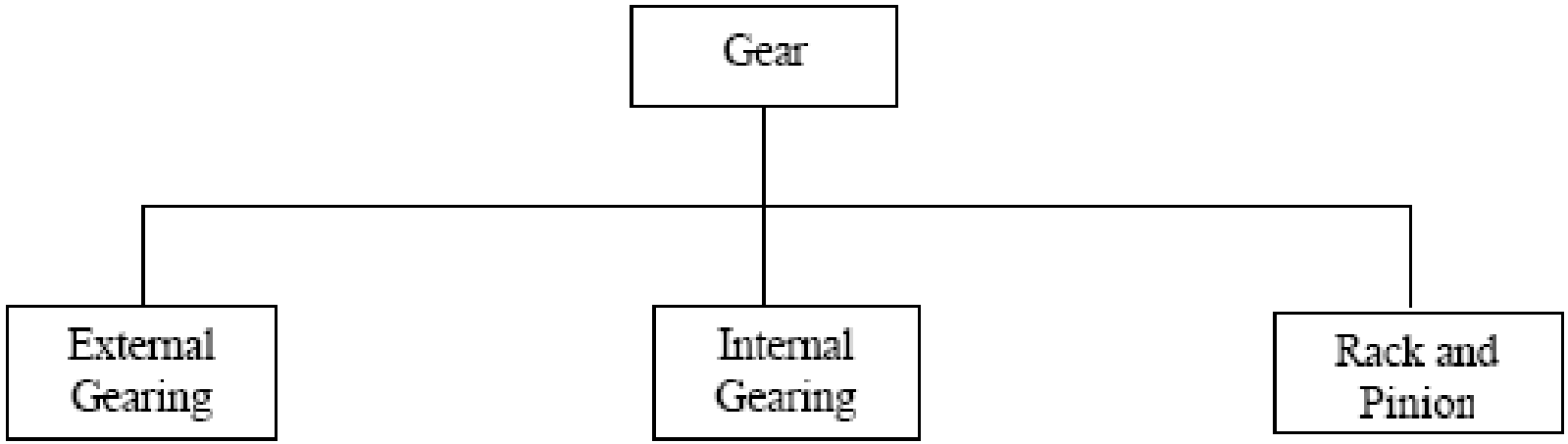
Gears - types


Gear
Parallel Shaft
Intersecting Shaft
Non-Intersecting and Non-parallel Shaft
Spur Gear
Helical Gear
Single Helical Gear
Double Helical: Herringbone Gear
Crossed Helical Gear
Hypoid Gear
Worm Gear
Bevel Gear
Coniflex Bevel Gear
Zerol Bevel Gear
Spiral Bevel Gear
Miter Gear
Angular Gear
Crown Gear

Gears - types


Gear
Low Velocity Gear
Medium Velocity Gear
High Velocity Gear

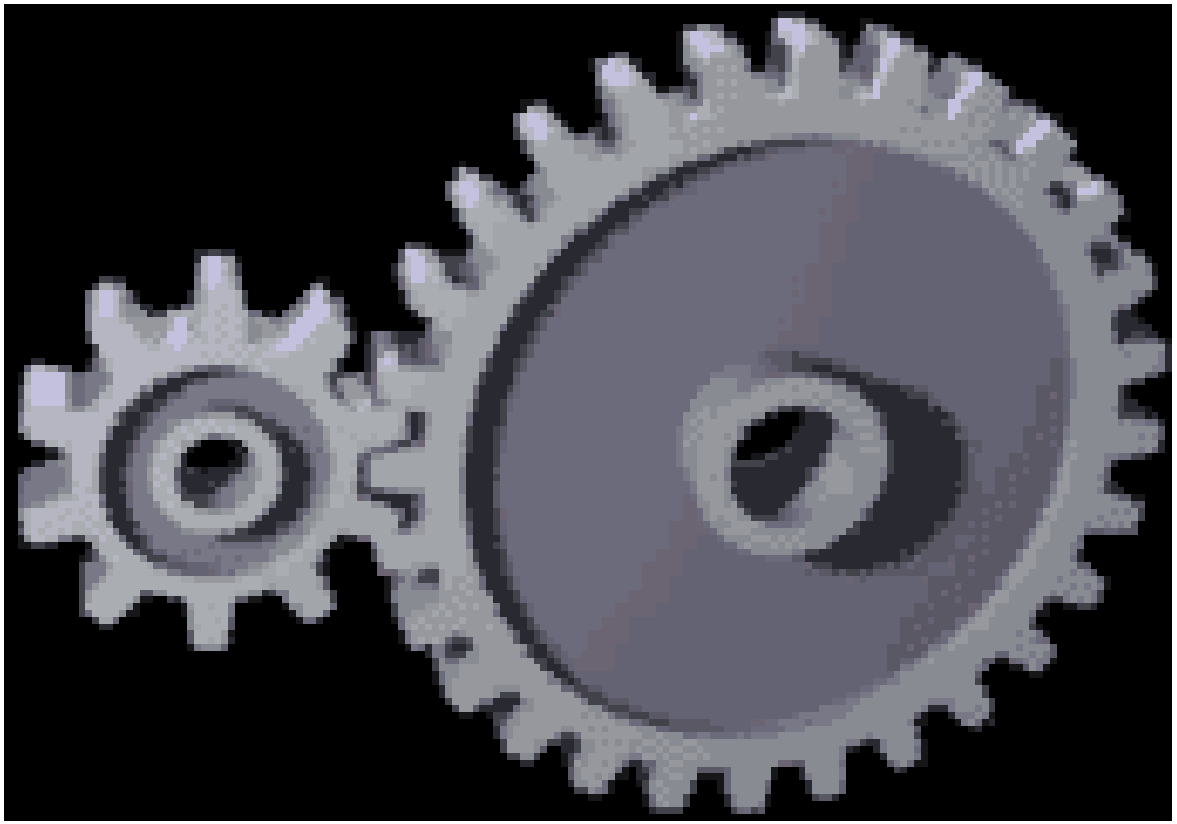
Gears - types



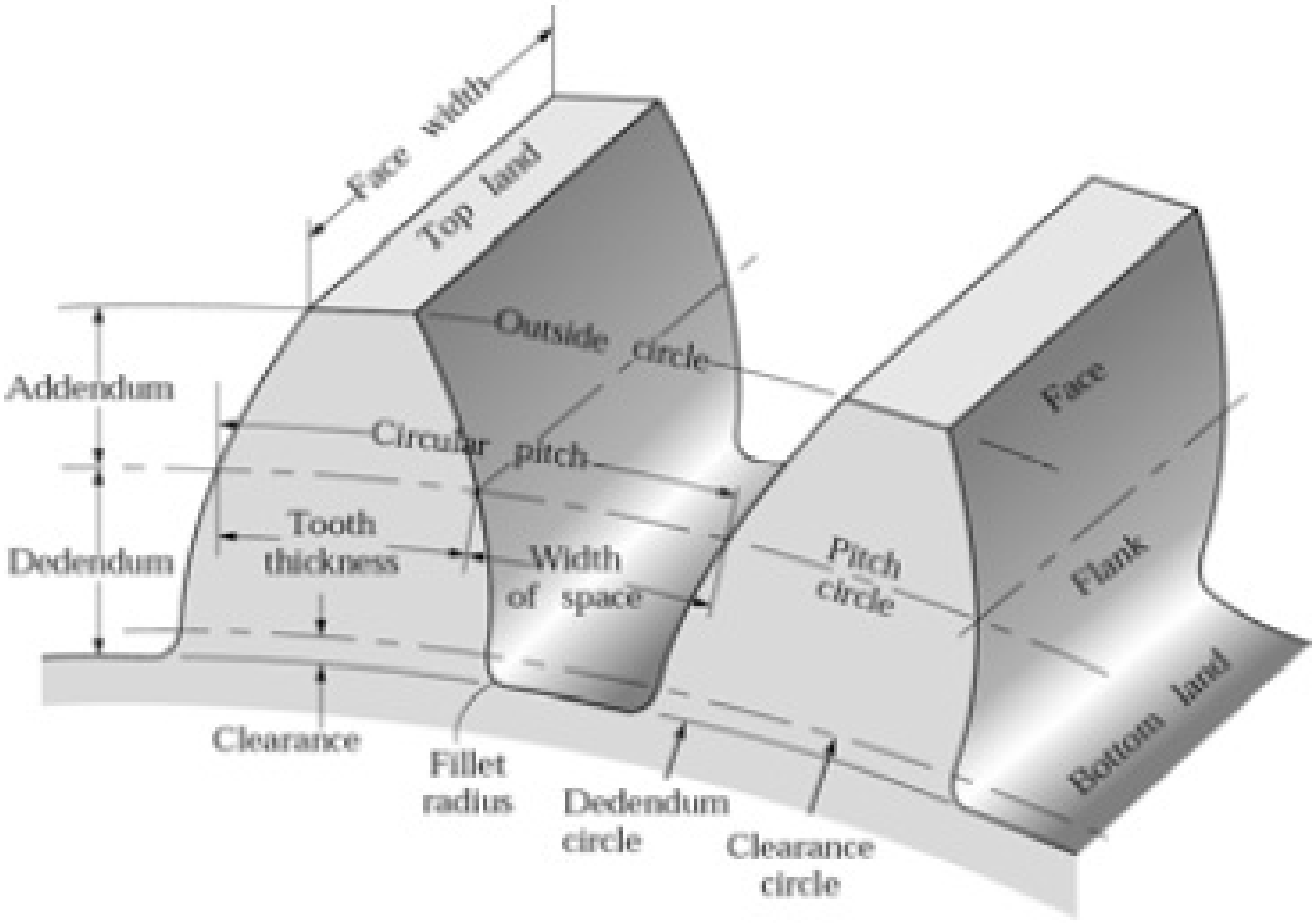
Spur Gears

- Most commonly used gear type
- Teeth are perpendicular to the face of the gear
- Cannot be used when a direction change between the two shafts is required
- Easy to find, inexpensive, and efficient

Spur Gears



Spur Gears


Face width
Top land
Outside circle
Addendum
Circular pitch
Tooth thickness
Dedendum
Width of space
Pitch circle
Face
Flank
Clearance
Fillet radius
Dedendum circle
Clearance circle
Bottom land

Spur Gears

- Velocity ratio is defined as the ratio of rotational speed of the input gear to that of the output gear.
- Pitch circle is the imaginary circle on which most gear calculations are made. When two gears meet their pitch circles, they are tangent to each other.
- Pitch diameter (Dp) and pitch radius (r) are the diameter and radius of the pitch circle.
- Pitch point - The point on the imaginary line joining the centers of the two meshing gears where the pitch circle touch.

Spur Gears

- Addendum circle is the circle that bounds the outer ends of the teeth.
- Dedendum circle is the circle that bounds the bottoms of the teeth and whose center is at the center of the gear.
- Circular pitch (Pc) is the distance between corresponding points on adjacent teeth measured along the pitch circle.
- Diametral pitch (Pd) specifies the number of teeth per inch of pitch diameter.

Spur Gears

- Tooth space is the space between the adjacent teeth measured along the pitch circle.
- Tooth thickness is the thickness of the tooth measured along the pitch circle.

Helical Gears

- The teeth are at an angle to the shaft.
- Teeth are longer than the teeth on a spur gear of equivalent pitch diameter.
- Tooth strength is greater because the teeth are longer.
- Greater surface contact on the teeth allows a helical gear to carry more load.
- The longer surface of contact reduces the efficiency of a helical gear relative to a spur gear.
- Used to mesh two shafts that are not parallel.
- Helical gears are used as a crossed gear mesh, in which the two shafts are perpendicular to each other.
- Helix angle 7 to 23 degrees.
- Helix angle must be the same for both the mating gears.

Helical Gears

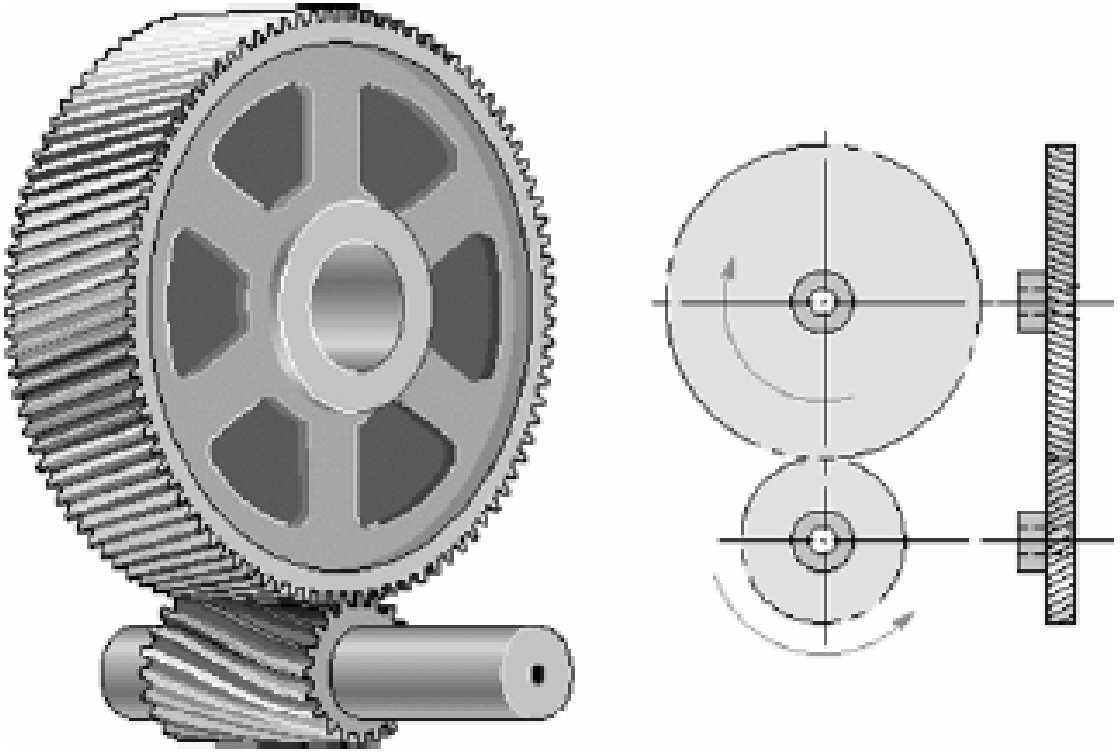
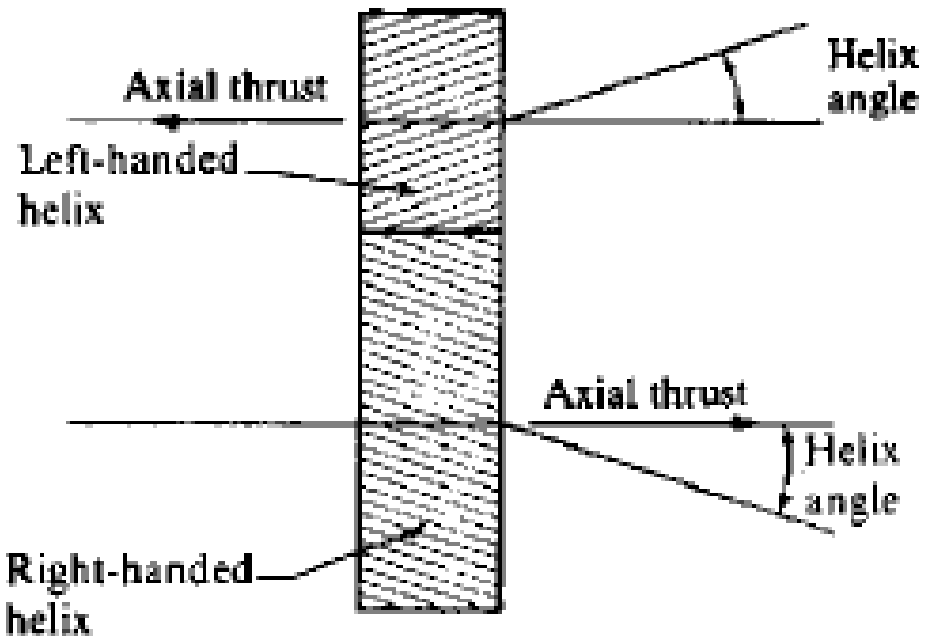
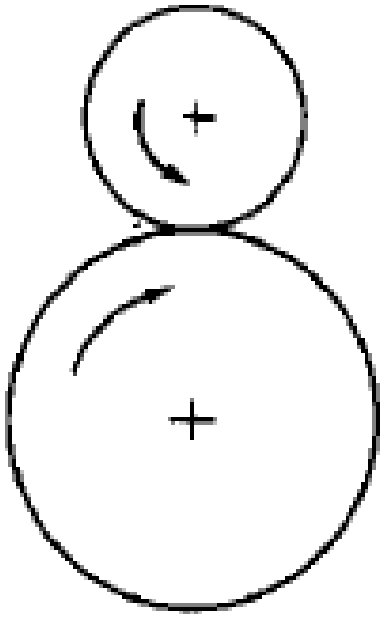


Figure 2: Helical Gear

Helical Gears





Helical Gears - types

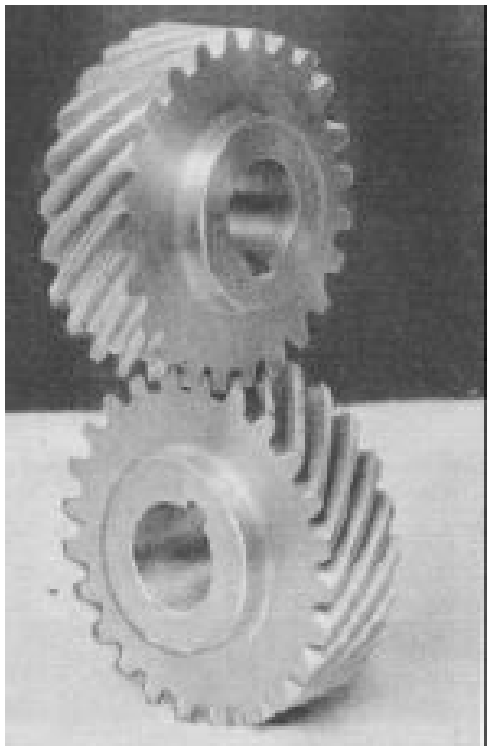


Figure 3: Crossed Helical Gear

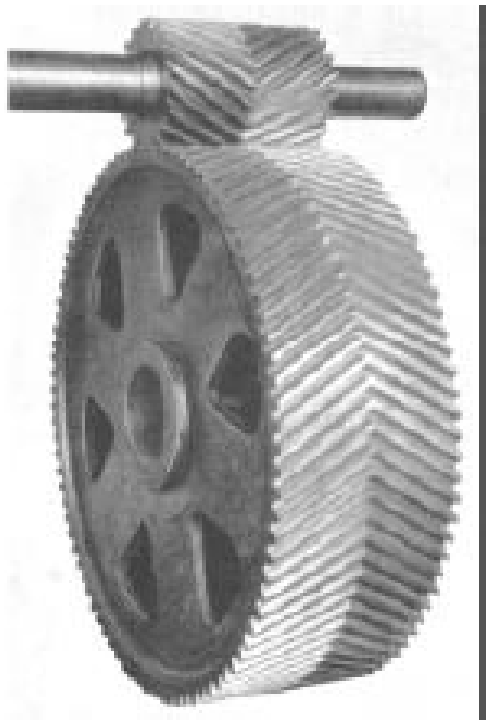
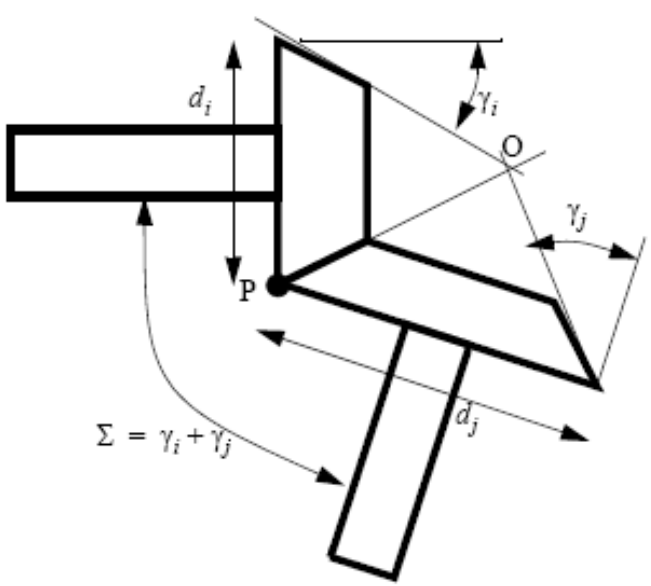


Figure 4: Herring Bone Gear

Bevel Gears

- These gears are like normal spur gears, except that they have a conical form.
- Used to
  - couple shafts with intersecting axes
  - change the direction
- Bevel gears are meshed so that the points of their cones are coincident.

Bevel Gears



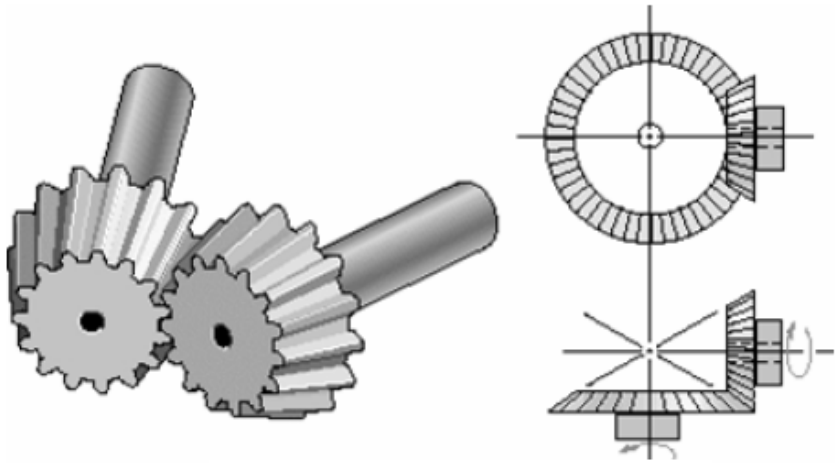
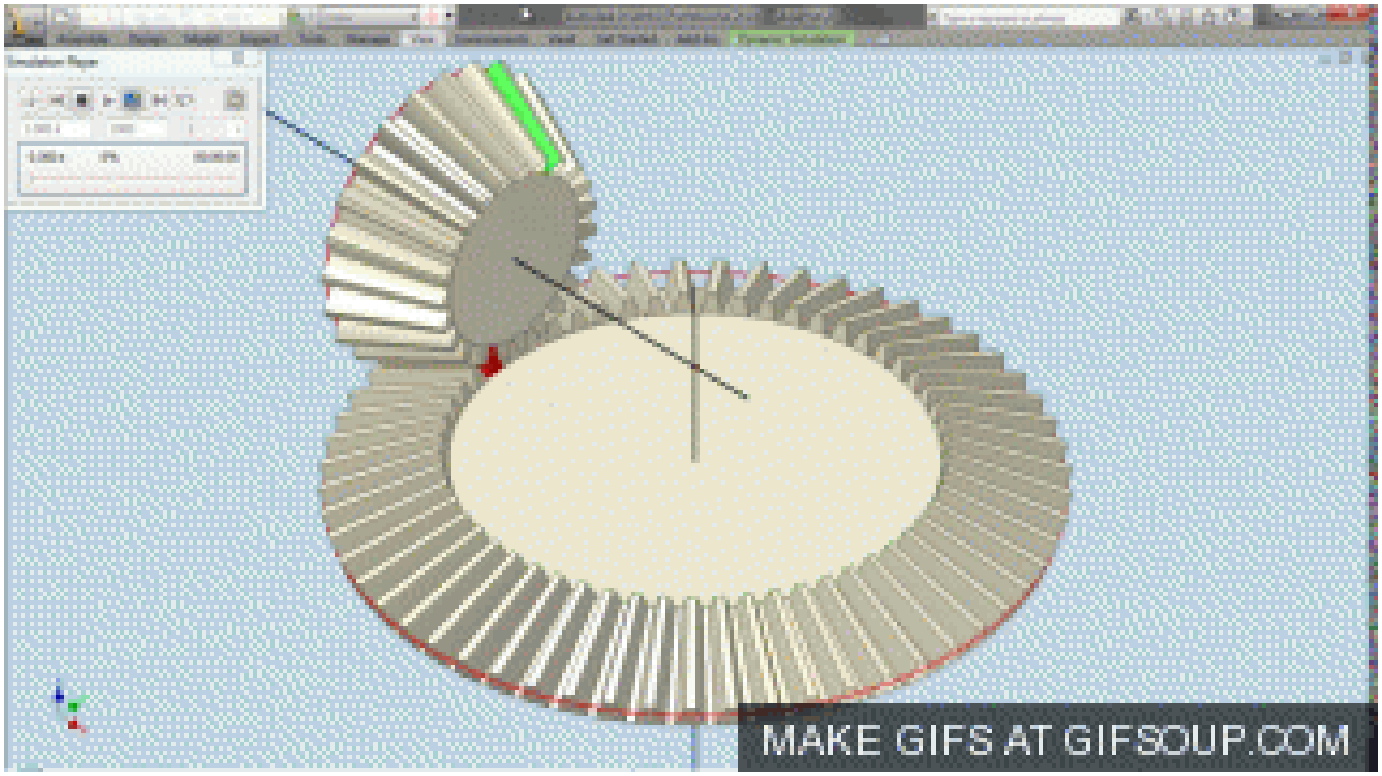


Figure 5: Bevel Gear

Bevel Gears



Bevel Gears - types

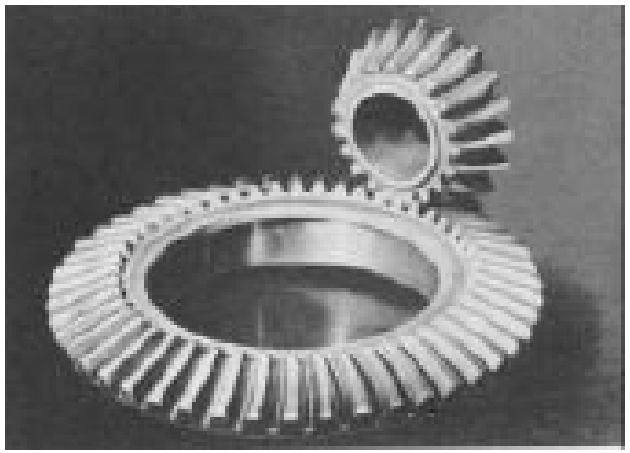


Figure 6: Zerol Bevel Gear

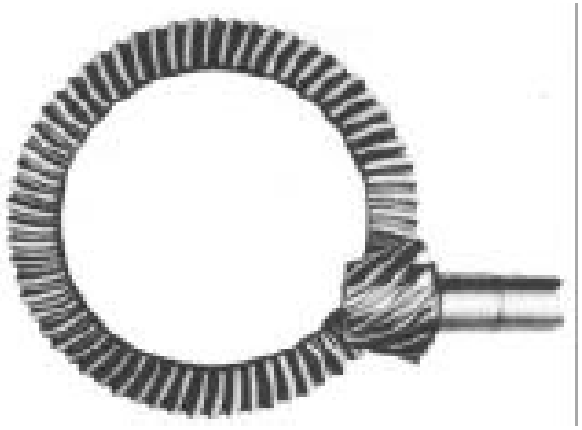


Figure 7: Hypoid Gear

Bevel Gears - types

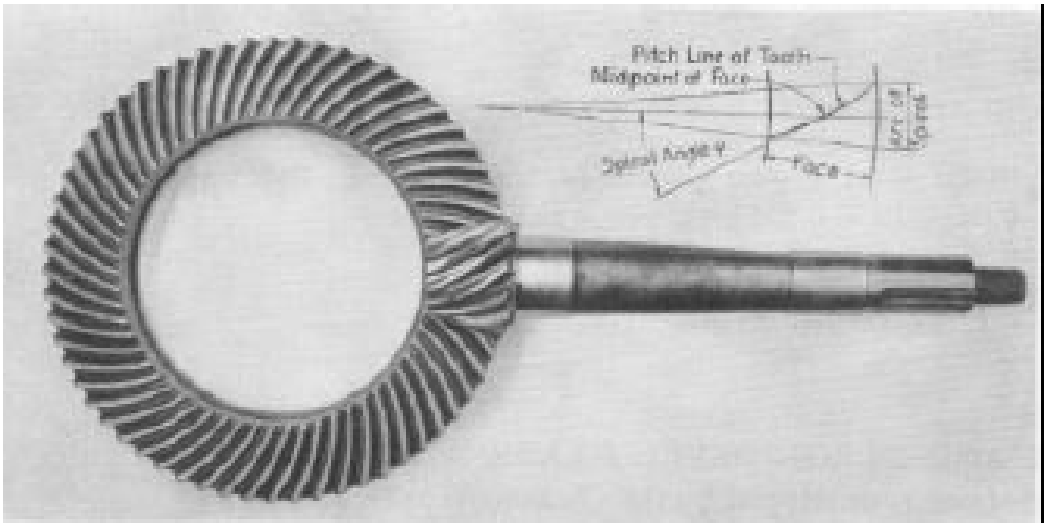


Figure 8: Spiral Bevel Gear

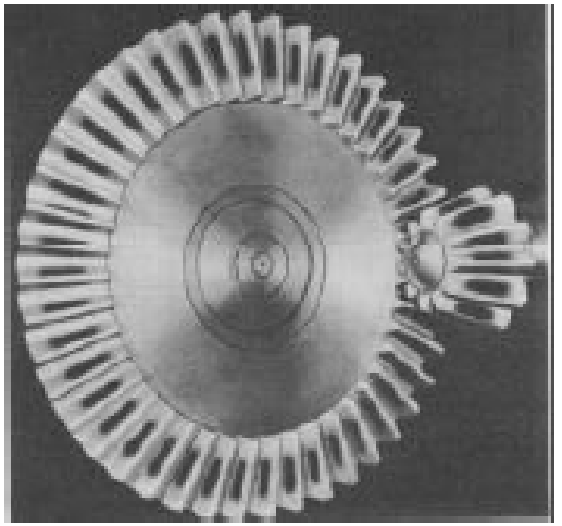


Figure 9: Coniflex Gear

Bevel Gears - types

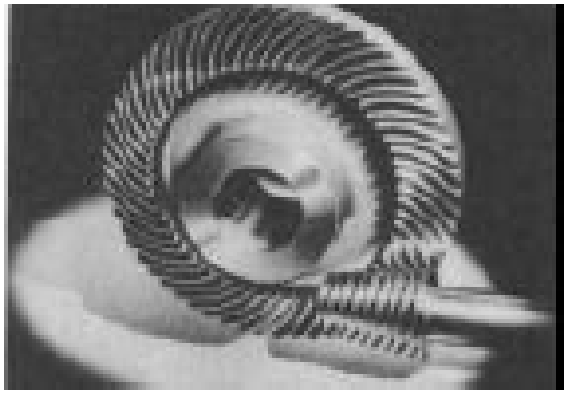


Figure 10: Spiroid Gear

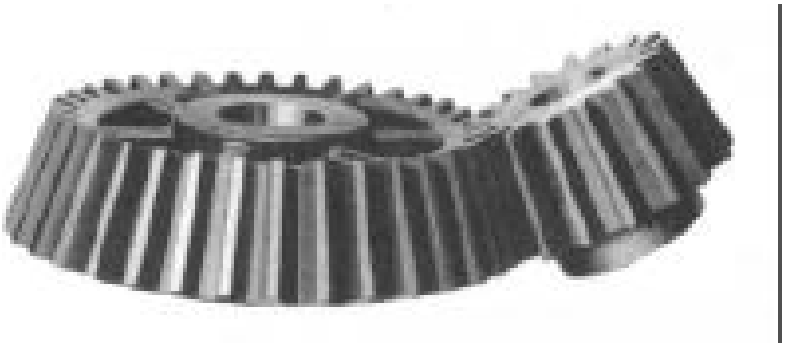


Figure 11: Angular Gear

Bevel Gears - types

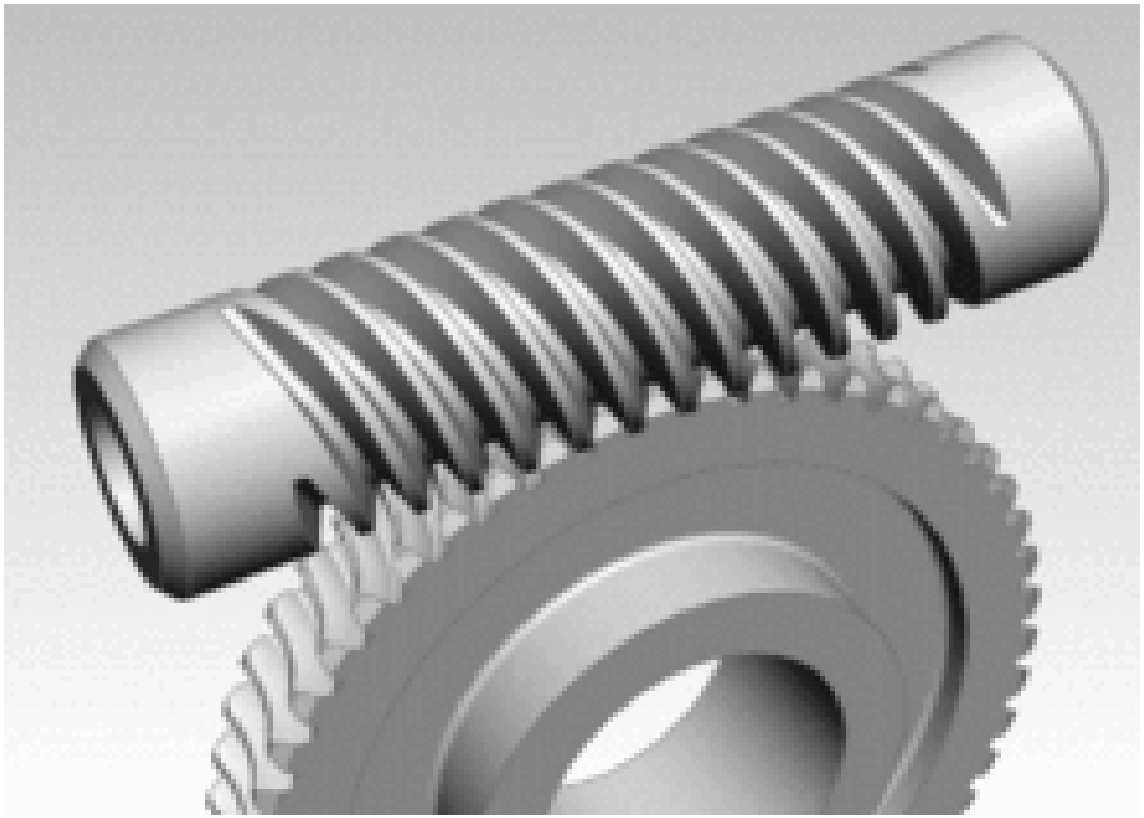
Figure 12: Miter Gear

Figure 13: Internal Gear

Worm gears

- Worm gears are special gears that resemble screws, and can be used to drive spur gears or helical gears.
- Worm gears are normally used when a high gear ratio is desired, or again when the shafts are perpendicular to each other.
- Irreversibility *:* when *a* worm gear is turned, the meshing spur gear will turn, but turning the spur gear will not turn the worm gear.

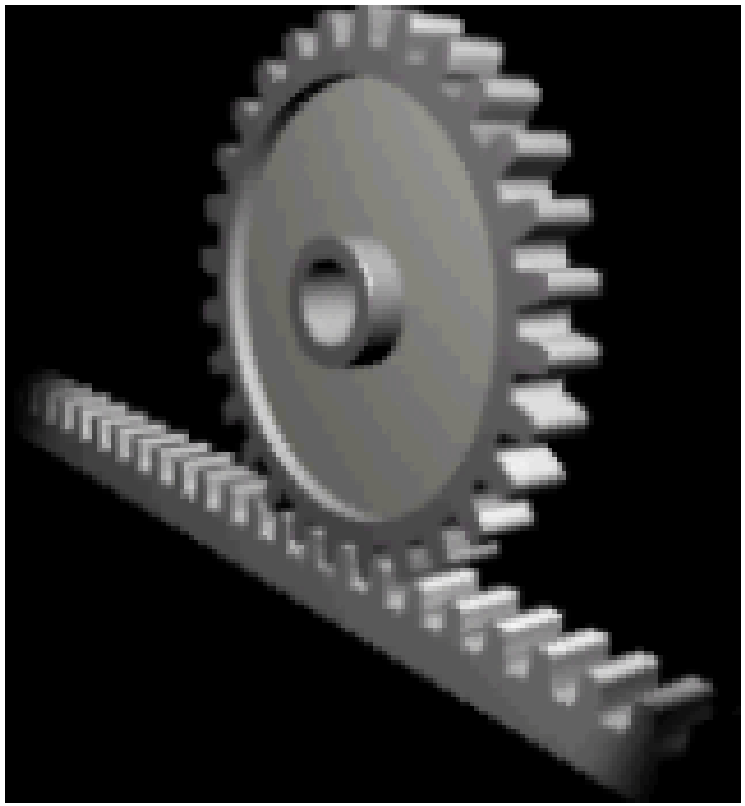
Worm gears



Rack & Pinion

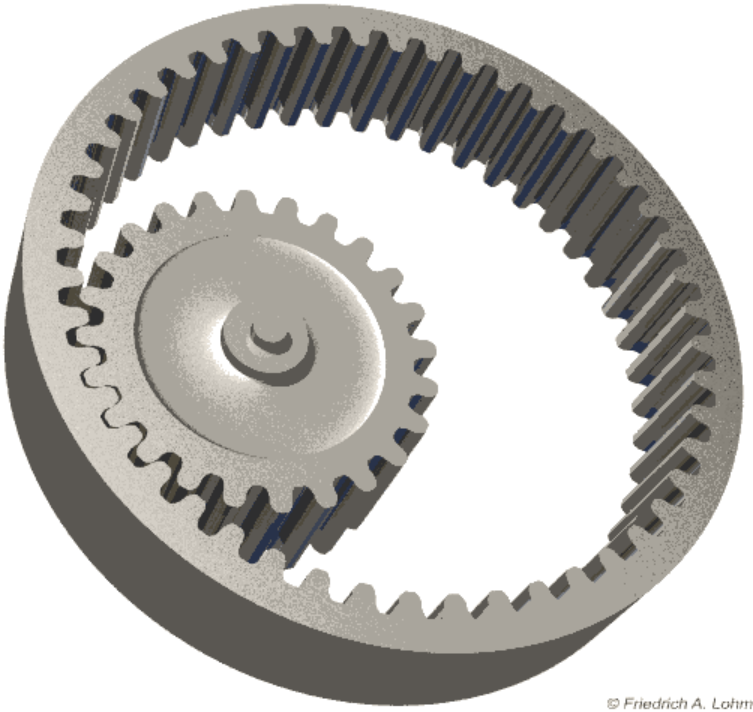
- A rack is a gear whose pitch diameter is infinite, resulting in a straight line pitch circle.
- Involute of a very large base circle approaches a straight line.
- Used to convert rotary motion to straight line motion.
- Used in machine tools.

Rack & Pinion



Internal Gear

Internal gears typically resemble inverted spur gears but are occasionally cut as helical gears.



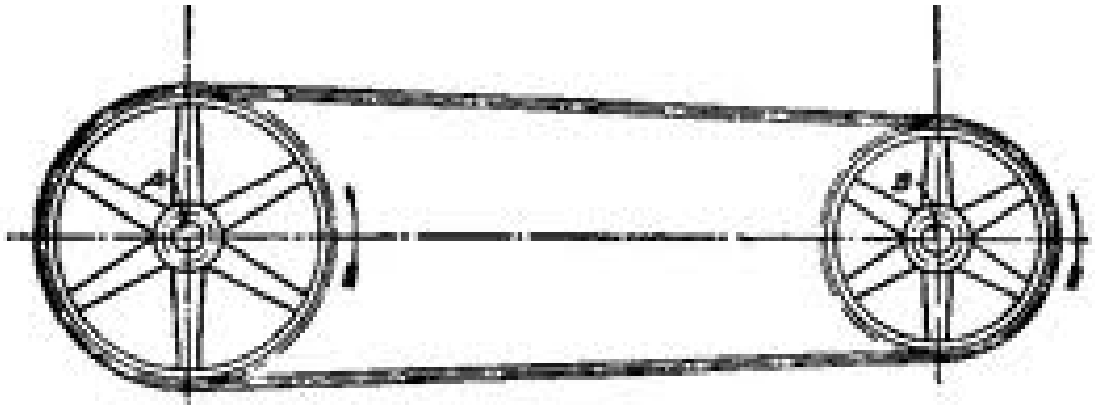
Belt drive

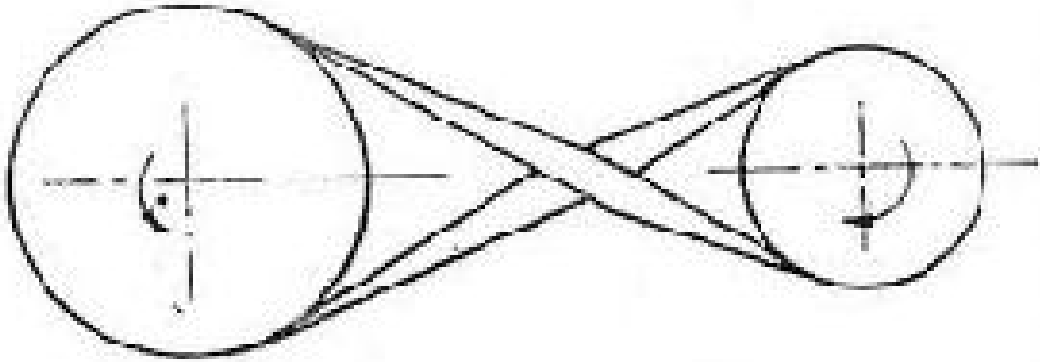
- Belt drives are called flexible machine elements.
- Advantage over gears
  - It can absorb a good amount of shock and vibration.
  - It can take care of some degree of misalignment between the driven and the driver machines
  - It can be used for long distance power transmission.

Belt drive

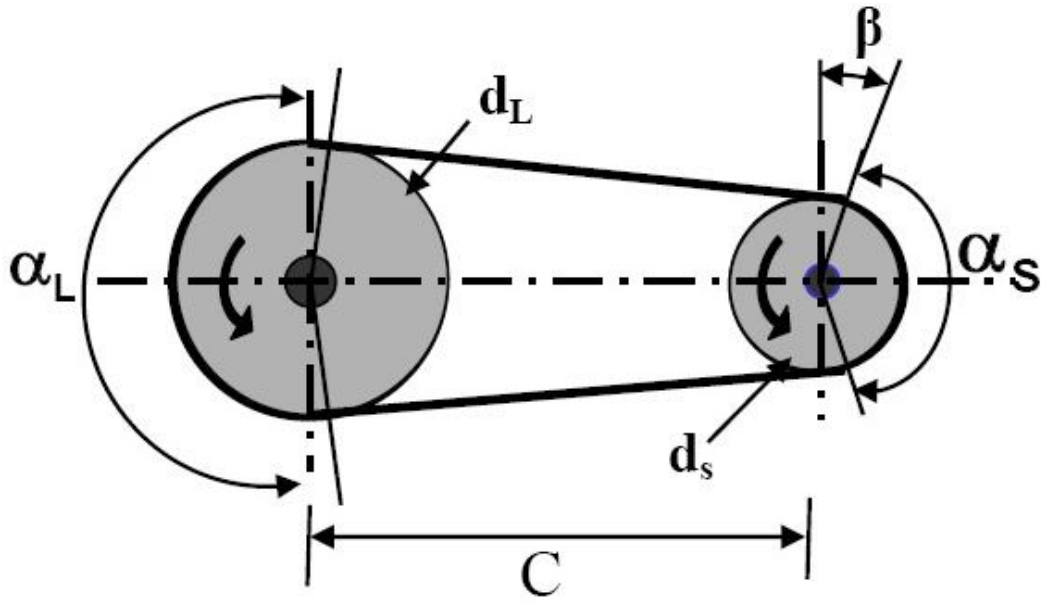
- A belt drive includes one pulley on each shaft and one or more continuous belts over the two pulleys.
- The motion of the driving pulley is transferred to the driven pulley via the friction between the belt and the pulley.
- Two types of belt drives
  - Open belt drive
    - The rotation of both the pulleys is in the same direction
  - Crossed belt drive
    - The rotation of the pulleys are in opposite direction

Belt drive





Belt drive



d_L - Diameter of the larger pulley

d_S – Diameter of the smaller pulley

α_L - Angle of wrap of the larger pulley

α_S – Angle of wrap of the smaller pulley

C- Center distance between the two pulleys

Open Belt drive

- $\alpha_L = 180^o + 2\beta$
- $\alpha_S = 180^o - 2\beta$
  where angle β is,

$$\beta = \sin^{-1}\left(\frac{d_L - d_S}{2C}\right)$$

- L_0 = Length of open belt

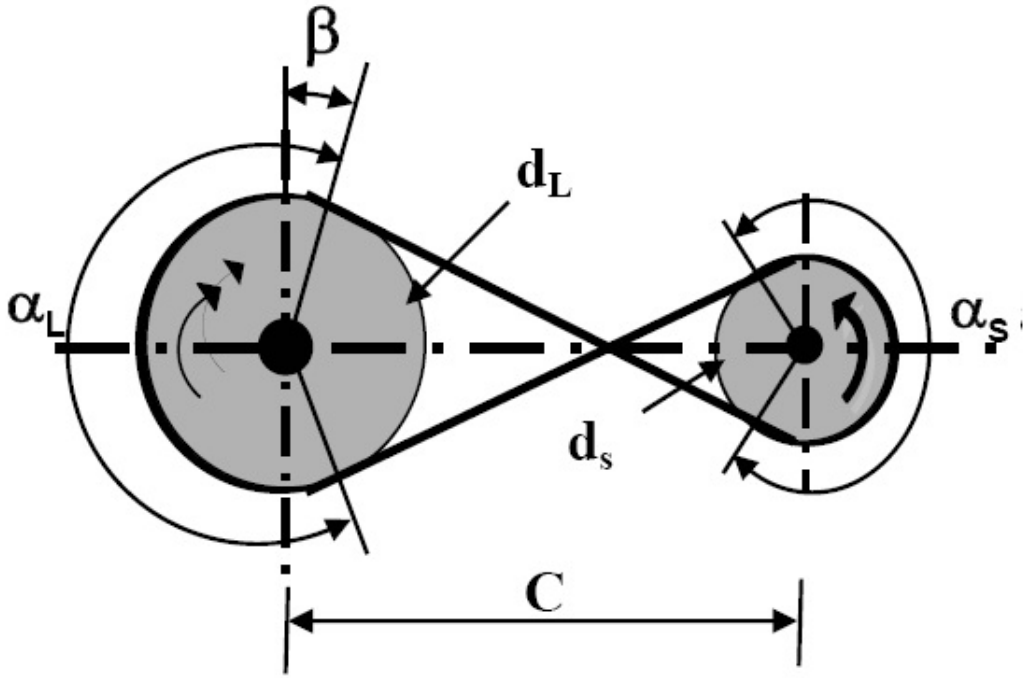
$$L_o = \frac{\pi}{2}(d_L + d_S) + 2C + \frac{1}{4C}(d_L - d_S)^2$$

Crossed Belt drive

$\alpha_L = \alpha_S = 180^o + 2\beta$

$$\beta = \sin^{-1}\left(\frac{d_L - d_S}{2C}\right)$$

$$L_c = \frac{\pi}{2}(d_L + d_S) + 2C + \frac{1}{4C}(d_L + d_S)^2$$



Flat Type

- Transfers torque by friction of the belt over a pulley.
- Needs tensioner.
- Belt made from leather, woven cotton, rubber, balata.

Vee type

- Better torque transfer possible compared to flat belt.
- Generally arranged with a number of matched vee belts to transmit power.
- Smooth and reliable.
- Made from hi-text woven textiles, polyurethane, etc.

Ribbed belt

- A ribbed belt is a power transmission belt featuring lengthwise grooves
- It operates from contact between the ribs of the belt and the grooves in the pulley.

Timing/ Synchronous type

- Belt toothed on the inside driving via grooved pulleys.
- They have no slippage, run at constant speed, and are often used to transfer direct motion for indexing or timing purposes.

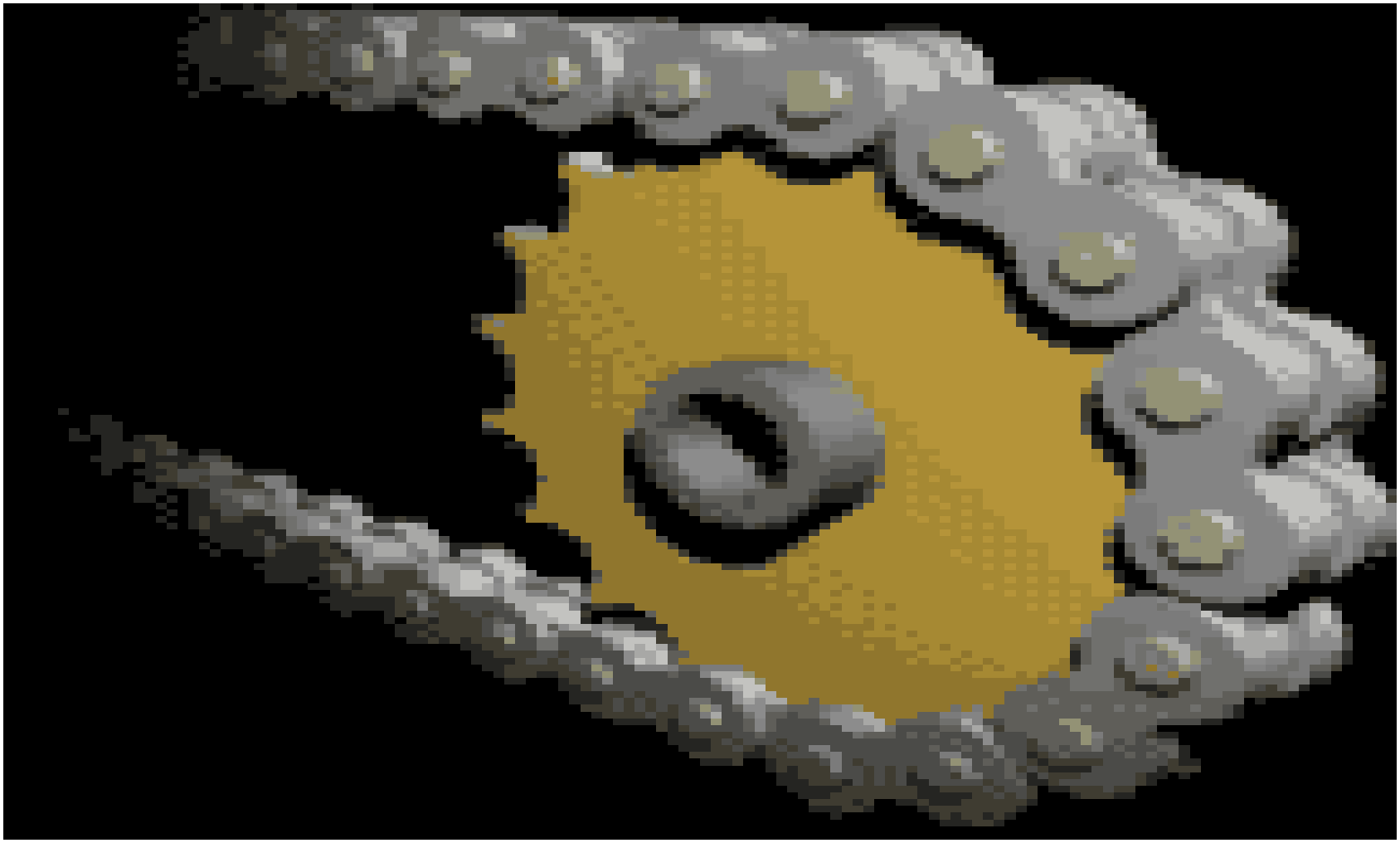
Multi-groove belts

- A multi-groove or polygroove belt is made up of usually 5 or 6 "V" shapes along side each other.
- This gives a thinner belt for the same drive surface, thus it is more flexible.

Roller chain

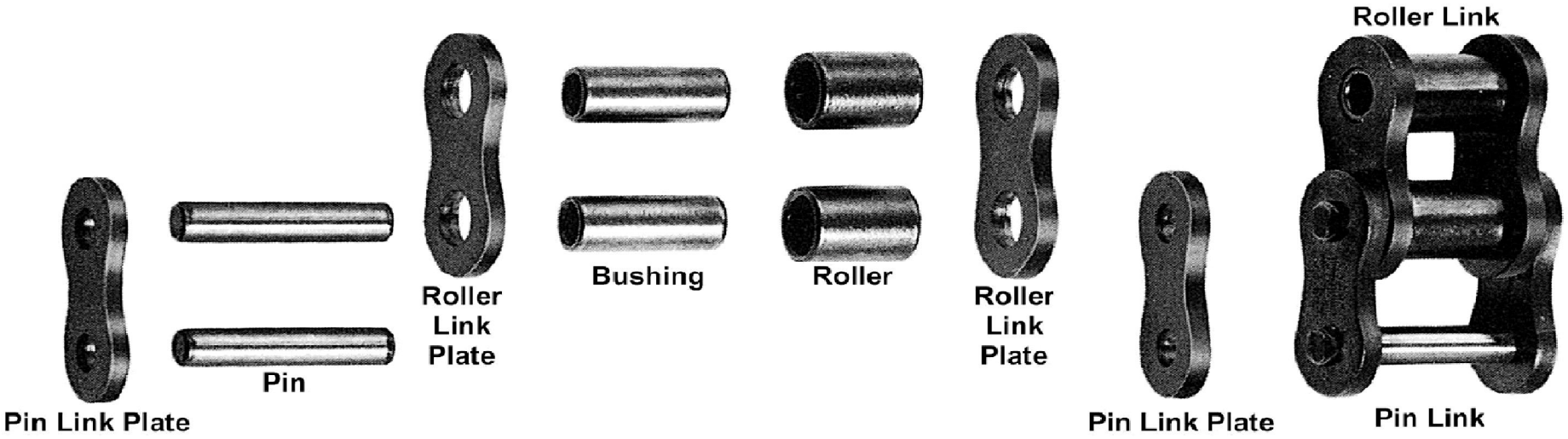
- Belt: high speed/low torque
- Chain: Low speed/high torque
- The power is conveyed by a roller chain, known as the drive chain, passing over a sprocket gear, with the teeth of the gear meshing with the holes in the links of the chain.
- When the gear rotates, it pulls the chain putting mechanical force into the system.

Roller chain and sprocket



Roller chain - Construction

- It consist of alternate connections of roller links and pin links.
- The roller link consists of a roller plate to which two bushings with rotatable roller are press fitted.
- This roller link is alternately connected to the pin link plate in which two pins have been securely press-fitted.



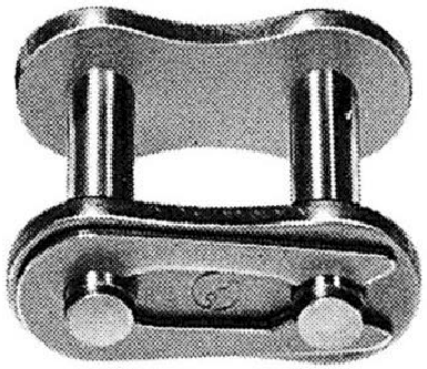
Roller chain - parts

- **PINS**
  - Pins resist shearing force and rotate in the bushings, providing bearing surfaces when the chain rotates over a sprocket.
- **ROLLER**
  - Rollers are free to rotate over the bushings.
  - When the chain engages with the sprocket, the roller work as bearings and serve to reduce shock and wear.
  - When the chain is running on rails, the rollers reduce running friction on the chain.
- **LINK PLATES**
  - Link plates are the component part receiving chain tension.
  - The holes for press-fitted pins or bushings are accurately punched to maintain uniform pitch.

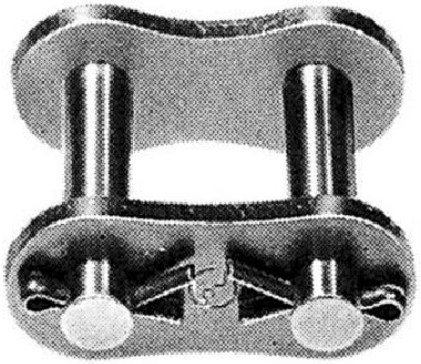
Roller chain - parts

- **BUSHINGS**
  - Bushings are made to achieve high wear resistance and are press-fitted to the roller link plates.
- **ROLLER CHAIN CONNECTING LINKS**
  - Roller Chain links can be easily connected using standard connecting links.
  - An offset-type connecting link is available for connection of an odd number of links.
  - Two types of connecting links and generally two types of fastener for Roller Chain:
    - A regular connecting link with either a spring clip or cotter pin type fastener.
    - An offset connecting link with either a spring clip or cotter pin type fastener.

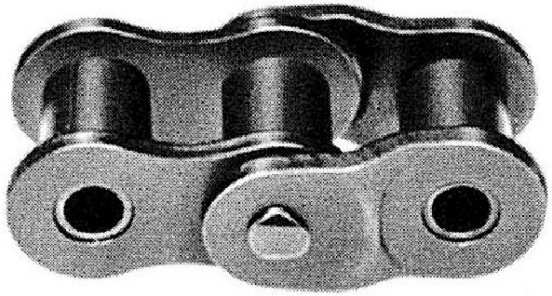
Connecting link - types

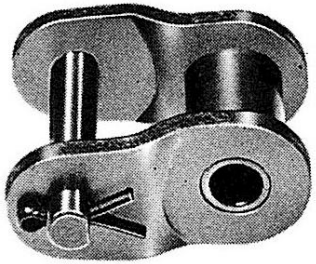


Spring Clip



Cotter Pin





Roller chain

- Disadvantages
  - Must be lubricated
  - Wear
  - Noise
  - Weight
  - Vibration
- Advantages
  - Strength
  - length flexibility

Motion Conversion

- Motion conversion is a process to provide match between the actuator and load in order to transfer maximum energy to the load.
- Need
  - To change the direction of rotation.
  - To change axis
  - For torque multiplication or reduction
  - For Speed reduction or multiplication
  - To convert linear to rotary or vice versa.
  - To couple non-linear devices

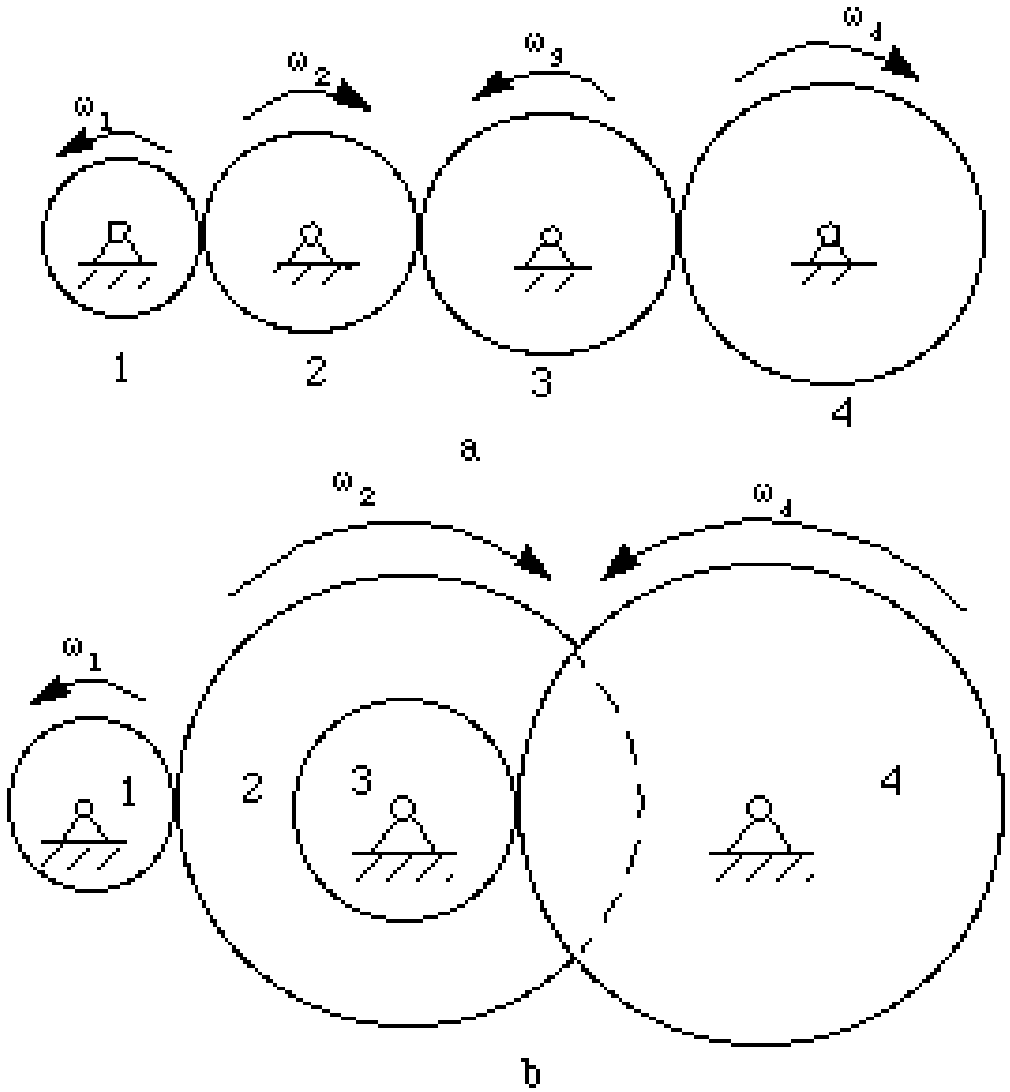
Rotary to rotary motion conversion

- Gear trains
- Harmonic drives
- Belts and pulleys
- Chains

Gear trains

- Gear trains consist of two or more gears for the purpose of transmitting motion from one axis to another.
- Ordinary gear trains have axes, relative to the frame, for all gears comprising the train.
- Compound ordinary train is seen to be one in which two or more gears may rotate about a single axis.

Gear trains



Gear trains

- Velocity ratio of a pair of gears is the inverse proportion of the diameters of their pitch circle
- The diameter of the pitch circle equals to the number of teeth divided by the diametral pitch.
- It is necessary for the two mating gears to have the same diametral pitch so that to satisfy the condition of correct meshing.
- Velocity ratio of a pair of gears is the inverse ratio of their number of teeth.

Gear trains

$$\frac{\omega_1}{\omega_2} = \frac{N_2}{N_1} \qquad \frac{\omega_2}{\omega_3} = \frac{N_3}{N_2} \qquad \frac{\omega_3}{\omega_4} = \frac{N_4}{N_3}$$

$$\frac{\omega_1}{\omega_4} = \frac{N_2 N_3 N_4}{N_1 N_2 N_3} = \frac{N_4}{N_1}$$

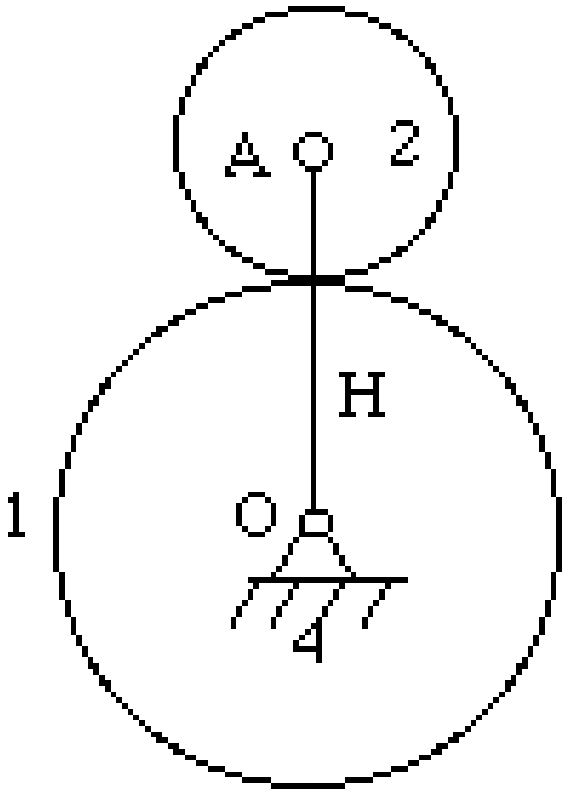
Gear trains

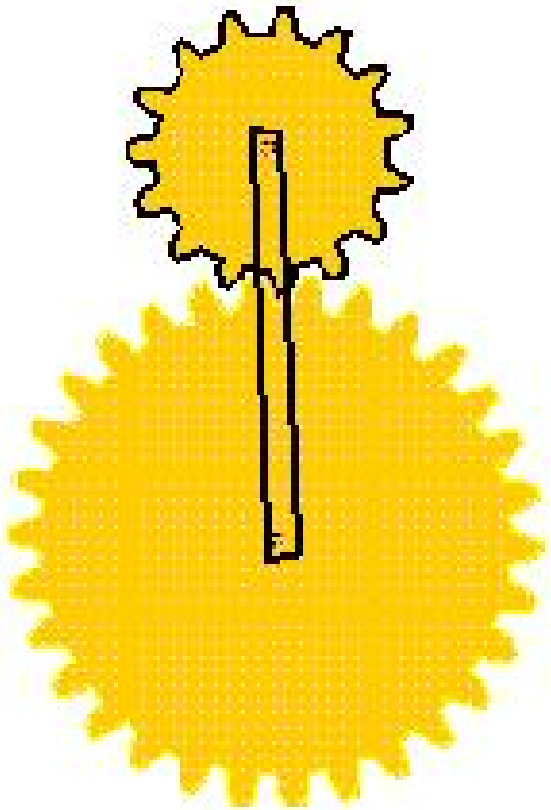
- The tooth number in the numerator are those of the driven gears, and the tooth numbers in the denominator belong to the driver gears.
- Gear 2 and 3 both drive and are, in turn, driven. Thus, they are called idler gears.
- Since their tooth numbers cancel, idler gears do not affect the magnitude of the input-output ratio, but they do change the directions of rotation.

Planetary gear trains

- Planetary gear trains, also referred to as epicyclic gear trains, are those in which one or more gears orbit about the central axis of the train.
- They differ from an ordinary train by having a moving axis or axes.
- Gear 1 is called a sun gear , gear 2 is a planet, link H is an arm, or planet carrier.

Planetary gear trains





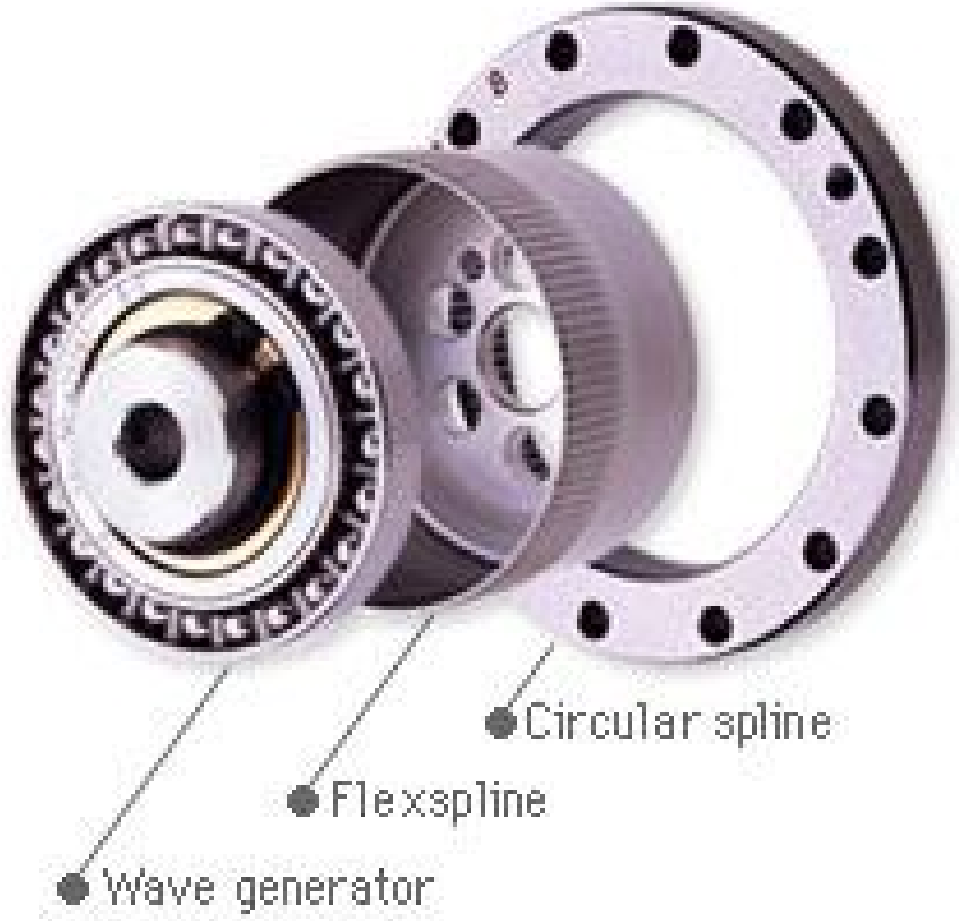
Harmonic drives

- Conveying driving power and motion in a faster and more accurate method.
- A special type of mechanical gear system that can improve certain characteristics compared to traditional gearing system.
- The advantages include:
  - no backlash
  - compactness and light weight
  - high gear ratios
  - reconfigurable ratios within a standard housing
  - good resolution and excellent repeatability when repositioning loads
  - high torque capability
  - coaxial input and output shafts

Harmonic drives - construction

- It is generally made up of just three components:
  - Wave generator
  - Flexspline
  - Circular spline.

C.W. Musser,
inventor of
"Harmonic Drive®"

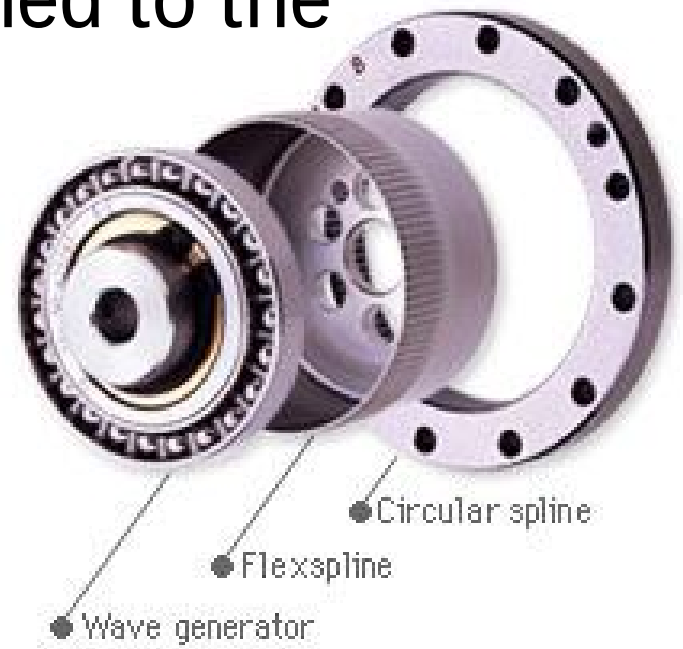


Wave Generator

- The wave generator is a component having small ball bearings built into the outer circumference of the elliptical cam.
- The inside raceway of the bearings is fixed to the cam while the outer raceway is subjected to elastic deformation via the ball bearings.
- The wave generator is usually attached to the input shaft.

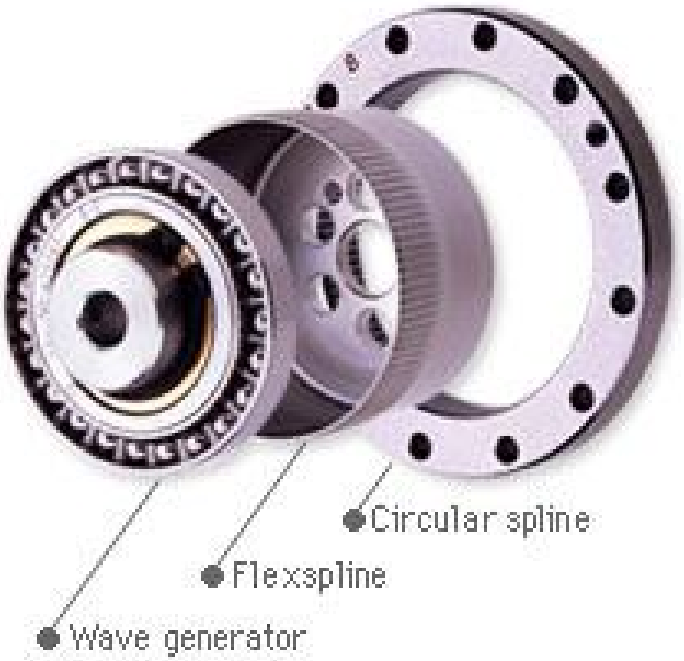
Flexspline

- The flexpline is a thin cup-shaped metal rim component with external teeth.
- The bottom of the flexspline (cup bottom) is called the diaphragm.
- The diaphragm is usually attached to the output shaft.

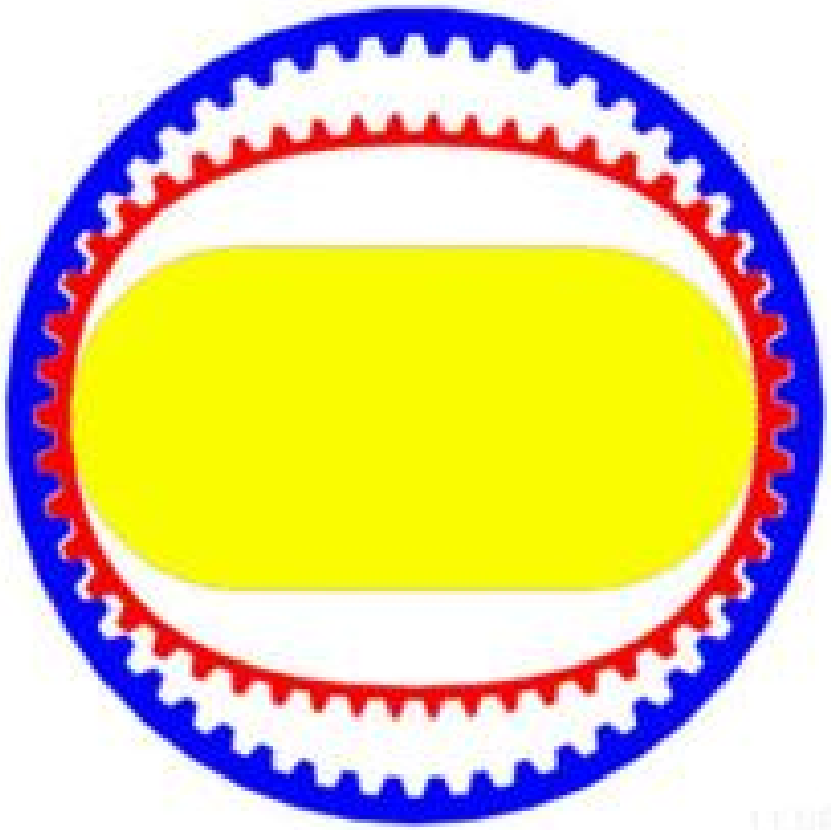


Circular Spline

- The circular spline is a rigid steel ring with internal teeth.
- The circular spline has two teeth more than the flexpline and is usually fixed to a casing.

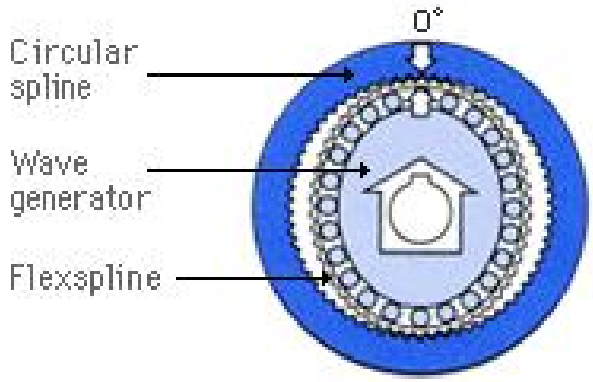


Harmonic drives



Operation step 1

- The flexspline is deflected by the wave generator into an elliptical shape causing the flexspline teeth to engage with those of the circular spline at the major axis of the wave generator ellipse, with the teeth completely disengaged across the minor axis of the ellipse.



Operation step 2

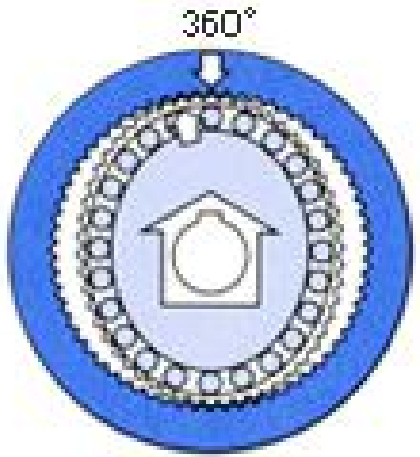
- When the wave generator is rotated clockwise with the circular spline fixed, the flexspline is subjected to elastic deformation and its tooth engagement position moves by turns relative to the circular spline.

Operation step 3

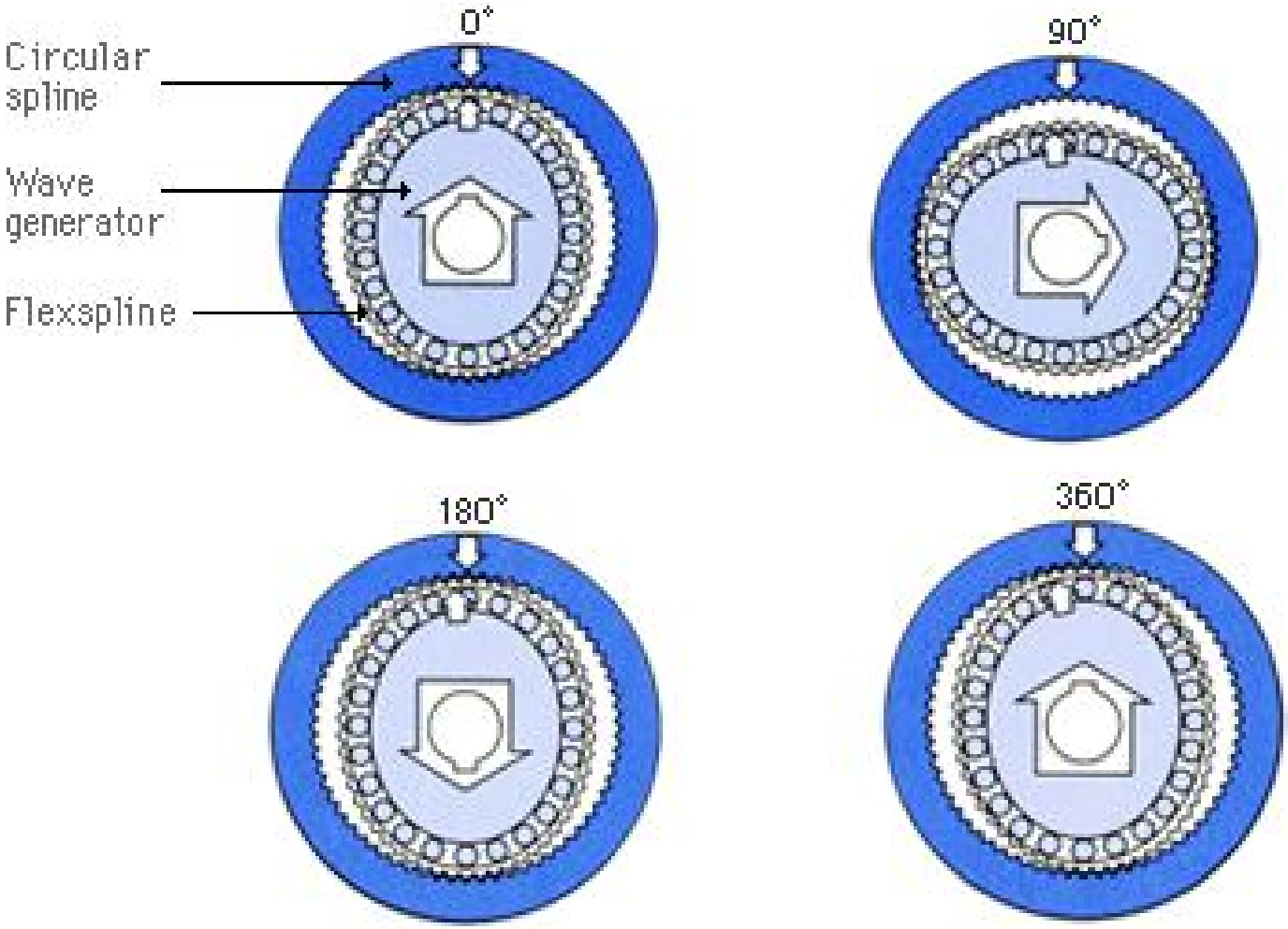
- When the wave generator rotates 180 degrees clockwise, the flexspline moves counterclockwise by one tooth relative to the circular spline.

Operation step 4

- When the wave generator rotates one revolution clockwise (360 degrees), the flexspline moves counterclockwise by two teeth relative to the circular spline because the flexspline has two fewer teeth than the circular spline. In general terms, this movement is treated as output pow



Operation



Rotary to linear motion conversion

- Converting rotational motion and torque into linear motion and force.
- Linear displacement devices
  - Lead screw
  - Rack and pinion
  - Rohlix
- Non linear displacement devices
  - Slider crank assembly
  - Cams

Lead screw

- A lead screw also known as a power screw or translation screw, is a screw designed to translate turning motion into linear motion.
- It consists of a screw and a nut.
- Screw is fixed with its ends free to rotate.
- As the screw is turned, the nut moves along the shaft with the load attached to it.
- Coupling ratio is defined as the input shaft rotation per unit of linear motion. Other wise called as pitch.
- Pitch $P = \theta/x$ turns/in

  where θ – rotary displacement of the shaft.

  x – linear displacement of the nut.
- $x = \theta/P = L\theta$

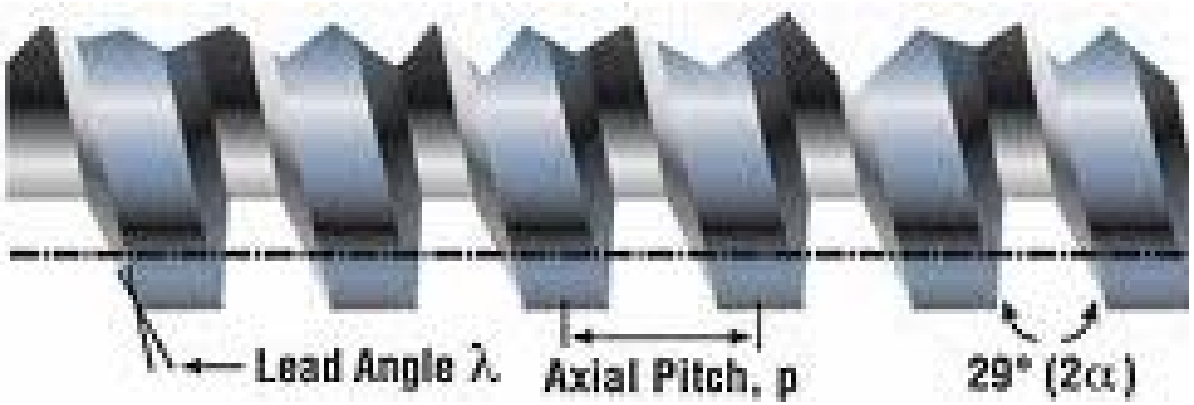
  where $L = 1/P$

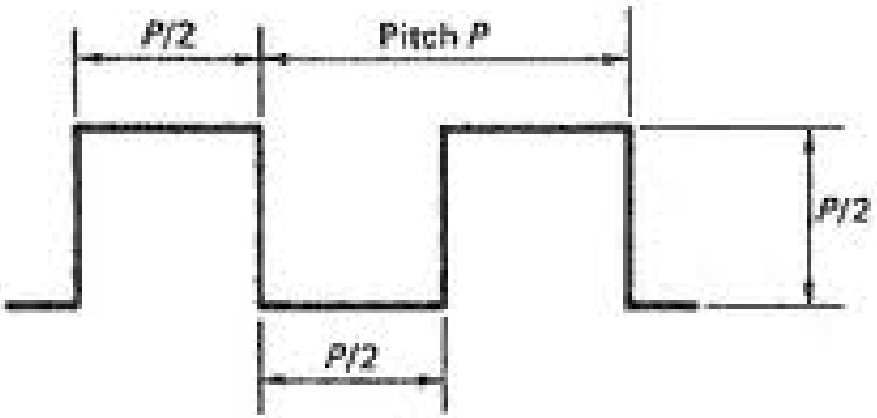
Lead screw

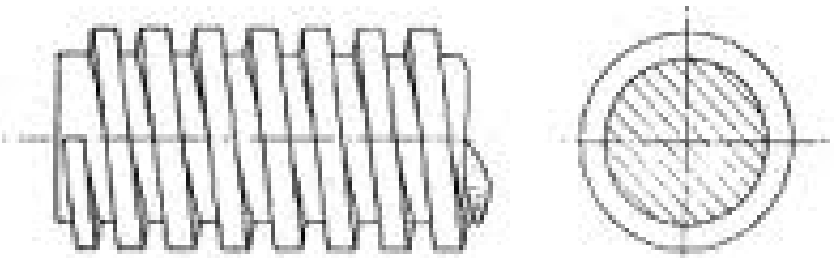
Types

- Power screws are classified by the geometry of their thread.
- Square thread
  - Square threads are named after their square geometry.
  - They are the most efficient, having the least friction, so they are often used for screws that carry high power.
  - But they are also the most difficult to machine, and are thus the most expensive.

Square thread



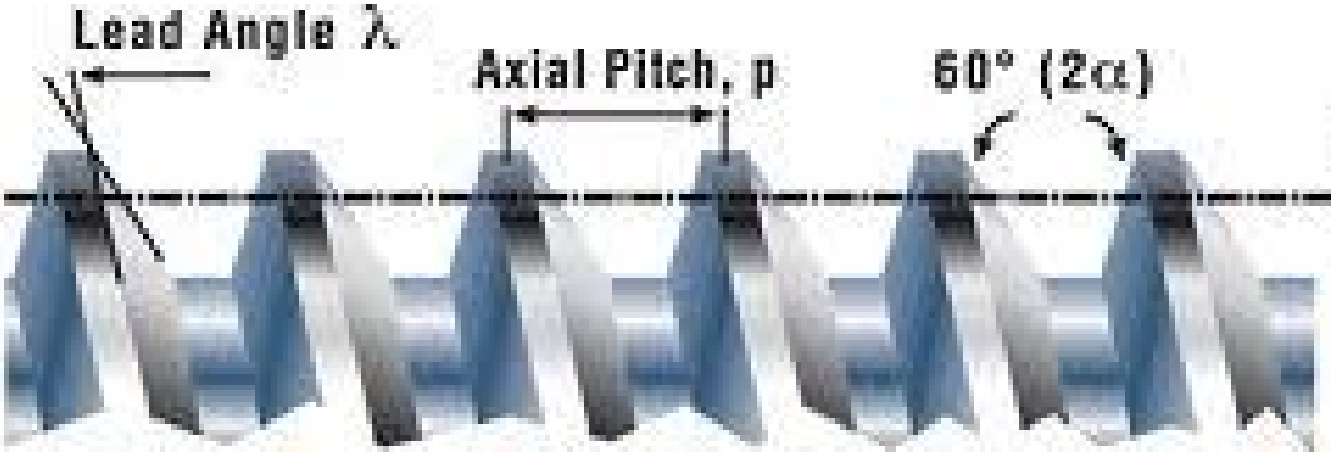


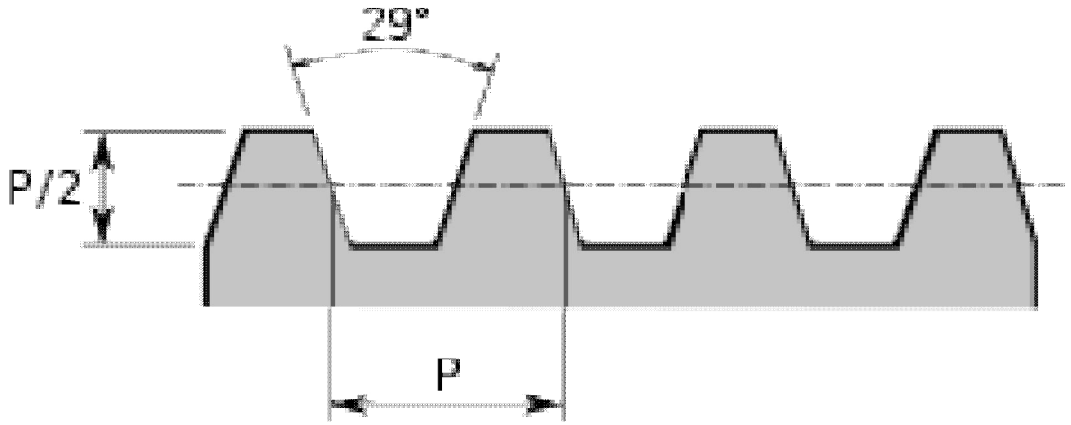


Types

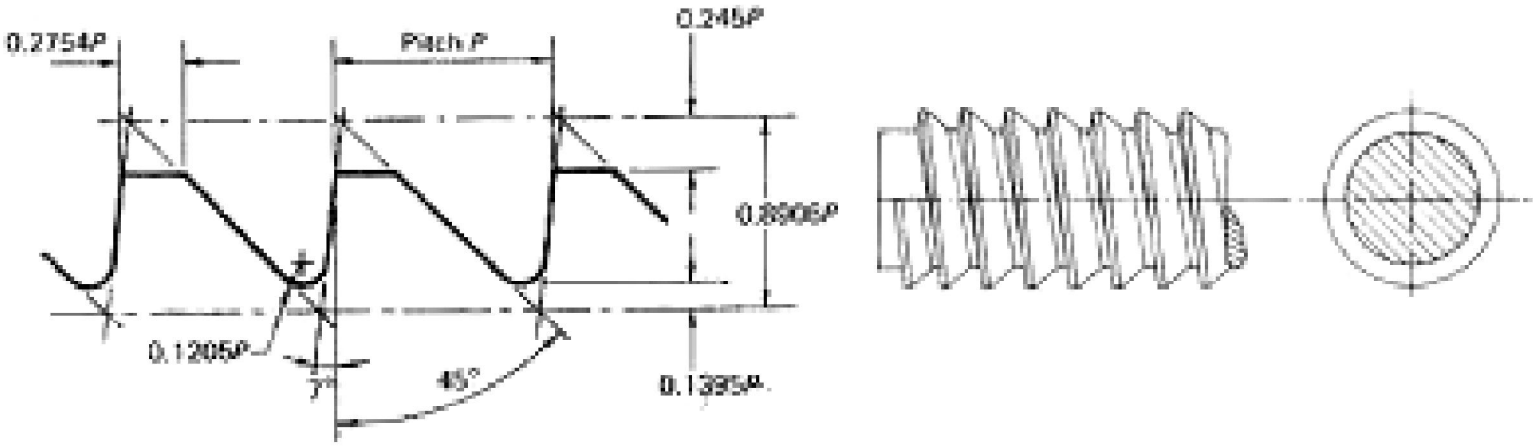
- Acme thread
  - Acme threads have a 29° thread angle, which is easier to machine than square threads.
  - They are not as efficient as square threads, due to the increased friction induced by the thread angle.
- Buttress thread
  - Buttress threads are of a triangular shape.
  - These are used where the load force on the screw is only applied in one direction.
  - They are as efficient as square threads in these applications, but are easier to manufacture.

Acme thread





Buttress thread



Advantages

- Large load carrying capability
- Compact
- Simple to design
- Easy to manufacture; no specialized machinery is required
- Precise and accurate linear motion
- Smooth, quiet, and low maintenance
- Minimal number of parts

Disadvantages

- Not very efficient
- Cannot be used in continuous power transmission applications
- High degree for friction on the threads, which can wear the threads out quickly

Roh’lix

- The Roh’lix uses rolling element ball bearings that trace a helix pattern along the shaft, which produces a Rolling Helix, or Roh’lix for short.
- The Roh’lix Linear Actuator consists of six preloaded bearings that contact the shaft at an angle.
- When the shaft is rotated, the bearings trace out an imaginary screw thread, causing the Roh’lix to travel linearly along the shaft.
- Three shafts are at each end of the nut which are mounted at an angle relative to the axis of the drive shaft.
- The amount of linear distance the Roh’lix travels per shaft revolution is called lead.
- The lead is determined by the angle of the bearings in the Roh’lix block.

Roh’lix

- Roh’lix Actuators have six precision ball bearings, three at each end of a two-piece aluminum block.
- Mounted at an angle relative to the drive shaft axis, the bearings convert drive shaft rotation into proportional linear travel. This is called lead.