IPS ACADEMY,
Institute of Engineering & Science, Indore
Department of Mechanical Engineering

"MACHINE COMPONENT DESIGN"

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CONTENT

- Stress Concentration & Fatigue
- Design of Shaft & Keys Couplings
- Design of Bearings
- Design of Spring & Power Screw
- Design of Gears

INTRODUCTION

- **The Subject deals with the design of various components used in the various machines & engines. Within the subject the complete design procedure of various components are assigned & failure analysis of the parts are done.**

After designing the component the method of checking the part is evolved whether the component is designed according to need or not.

Shaft:

- Shaft is a common and important machine element. It is a rotating member, in general, has a circular cross-section and is used to transmit power. The shaft may be hollow or solid. The shaft is supported on bearings and it rotates a set of gears or pulleys for the purpose of power transmission.

Shaft Design

Shaft Materials

- Steel (low to medium-carbon steel)
- Cast iron
- Bronze or stainless steel
- Case hardened steel

Shaft Stresses

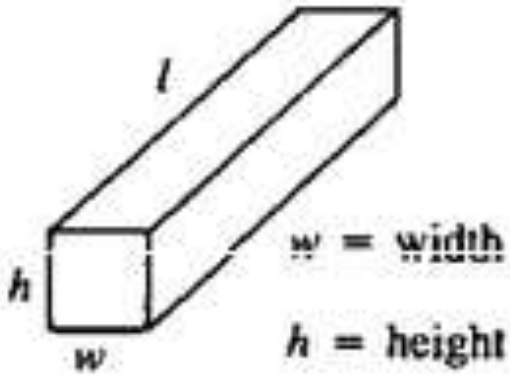
- Bending Stress
- Torsional Shear Stress

General Considerations

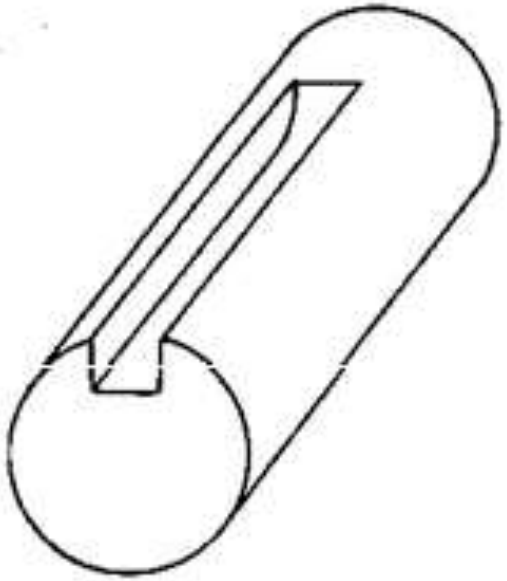
- To minimize both deflections and stresses, the shaft length should be kept as short as possible and overhangs minimized.
- A hollow shaft has a better stiffness/mass ratio (specific stiffness) and higher natural frequencies than a comparably stiff or strong solid shaft, but will be more expensive and larger in diameter.
- General low carbon steel is just as good as higher strength steels (since deflection is typical the design limiting issue).

Couplings and Keys

- It is a device that mechanically connects a member such as gear to a shaft.
- Most common type is a flat key.



(a) Flat key



(b) Keyway in shaft

Rigid couplings

- A coupling is a device used to connect the end of one shaft to the end of a second.
- Rigid couplings do not allow any misalignment of connecting members.

SCREW JACK –

Screw jack is a portable device consisting of a screw mechanism used to raise or lower the load. There are two types of jacks most commonly used,

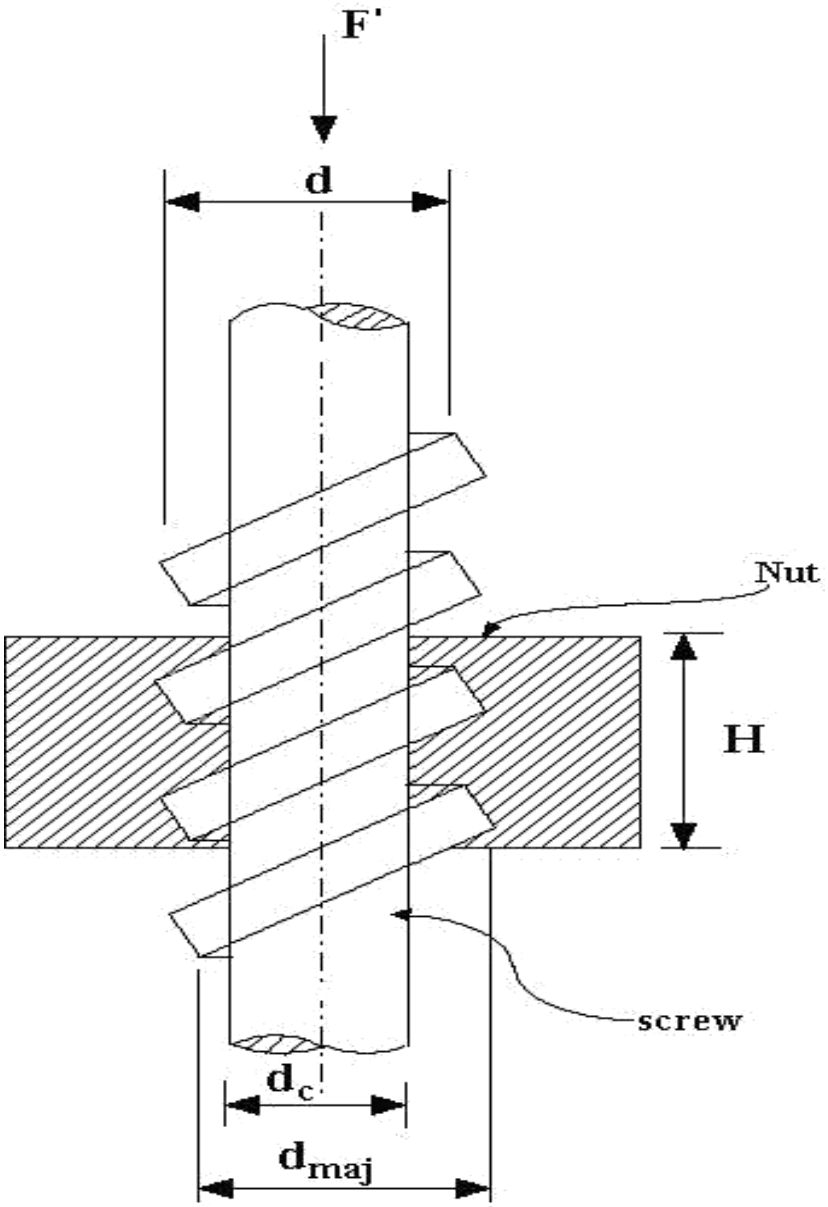
- 1] Hydraulic
- 2] Mechanical

Merits of Screw jack –

- Can be used to lift a heavy load against gravity.
- Load can be kept in lifted position.
- Due to leverage obtained by handle force required to raise load is very less & can be applied manually also.

Stresses in power screws

- Torsional shear stress is developed in the screw due to the turning moment
- Compressive stress is developed in a power screw due to axial load
- Bending stresses are developed in the screw thread.


F'
d
Nut
H
screw
d_c
d_{maj}

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 supporting member may be journal. 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.

Design of Helical Springs

Definition of spring: Spring act as a flexible joint in between two parts or bodies

Commonly used spring materials:

Hard-drawn wire

Oil-tempered wire

Chrome Vanadium

Chrome Silicon

Music wire

Stainless steel

Phosphor Bronze / Spring Brass

Bearings

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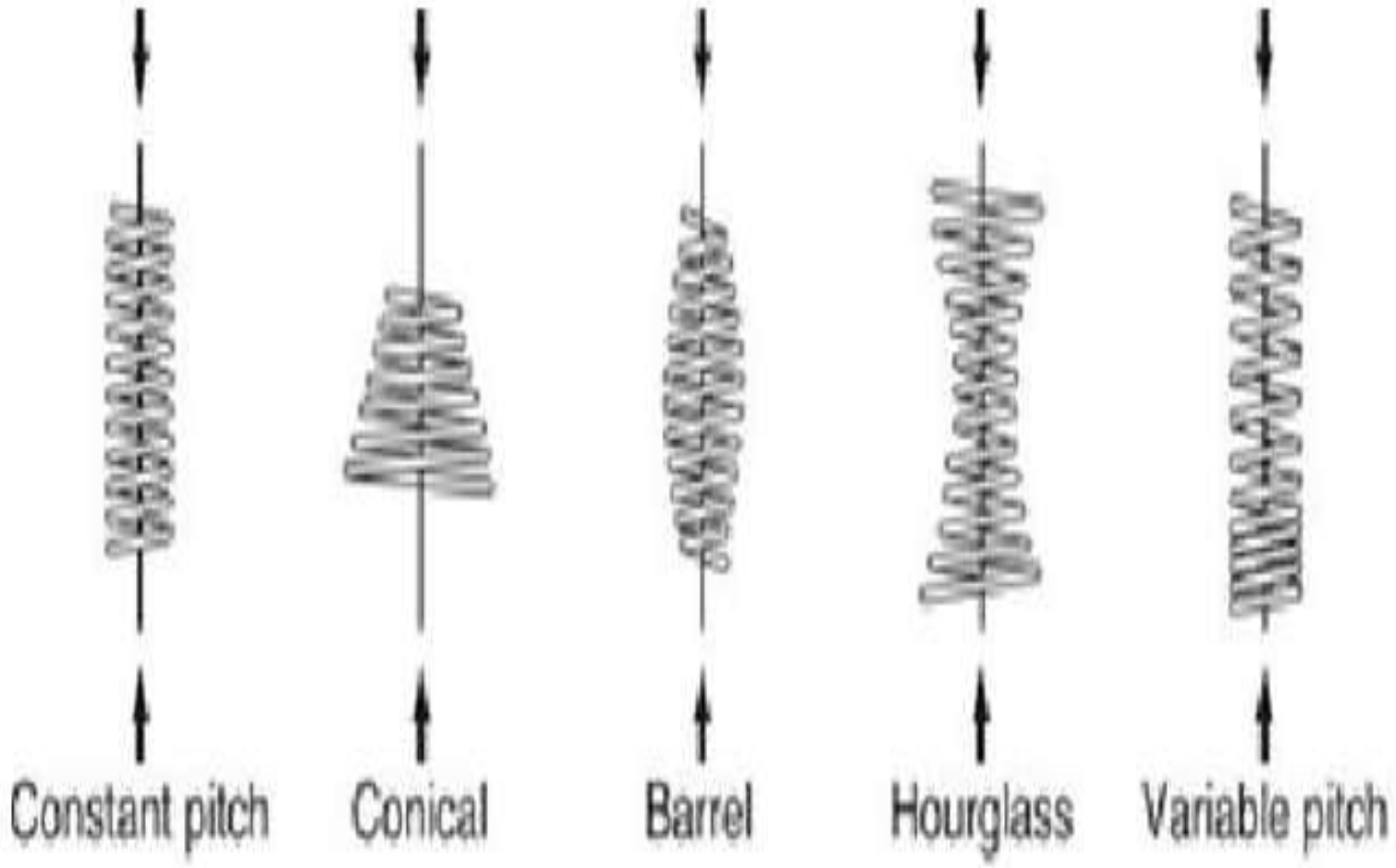


Variations of helical compression springs

Classification:

Bearings are classified as follows:

- Depending upon the nature of contact between the working surfaces:-
- **Sliding contact bearings and**
- **Rolling contact bearings.**

SLIDING BEARINGS:

- **Hydrodynamically lubricated bearings**
- **Bearings with boundary lubrication**
- **Bearings with Extreme boundary lubrication.**
- **Bearings with Hydrostatic lubrication.**

Rolling element bearings:

- **Ball bearings**
- **Roller bearings**
- **Needle roller bearings**

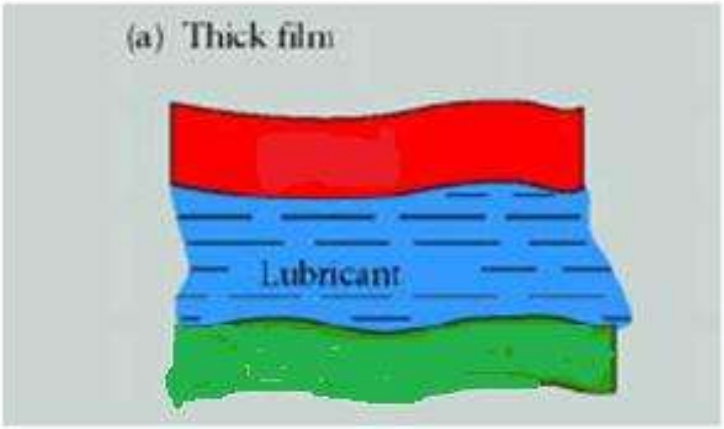
Lubrication:

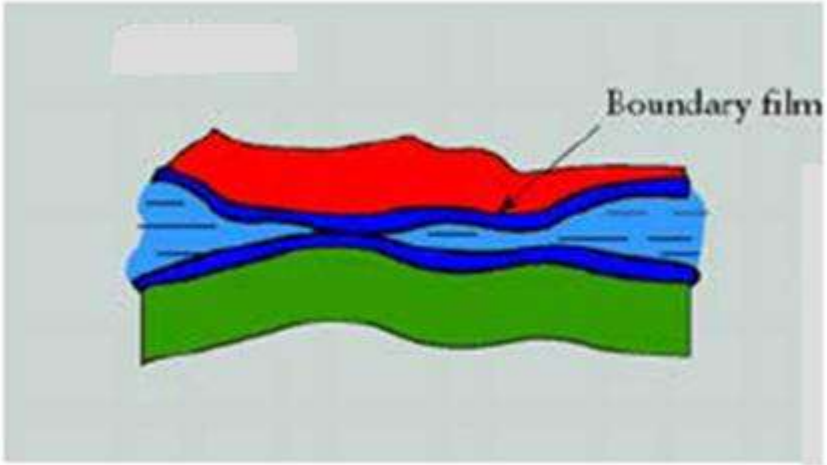
- Prevention of metal to metal contact by means of an intervening layer of fluid or fluid like material.

Types of sliding lubrication:

- Sliding with Fluid film lubrication.
- Sliding with Boundary lubrication.
- Sliding with Extreme boundary lubrication.
- Sliding with clean surfaces.

Hydrodynamic / thick film lubrication / fluid film lubrication





Selection Guide for Lubricants

- The viscosity of lubricating oil is decisively for the right thickness of the lubricating film (approx. 3-30µm) under consideration of the type of lubricant supply.\

Low sliding speed	High Viscosity
High sliding speed	Low viscosity
High bearing clearance	High Viscosity
High load (Bearing pressures)	Higher Viscosity

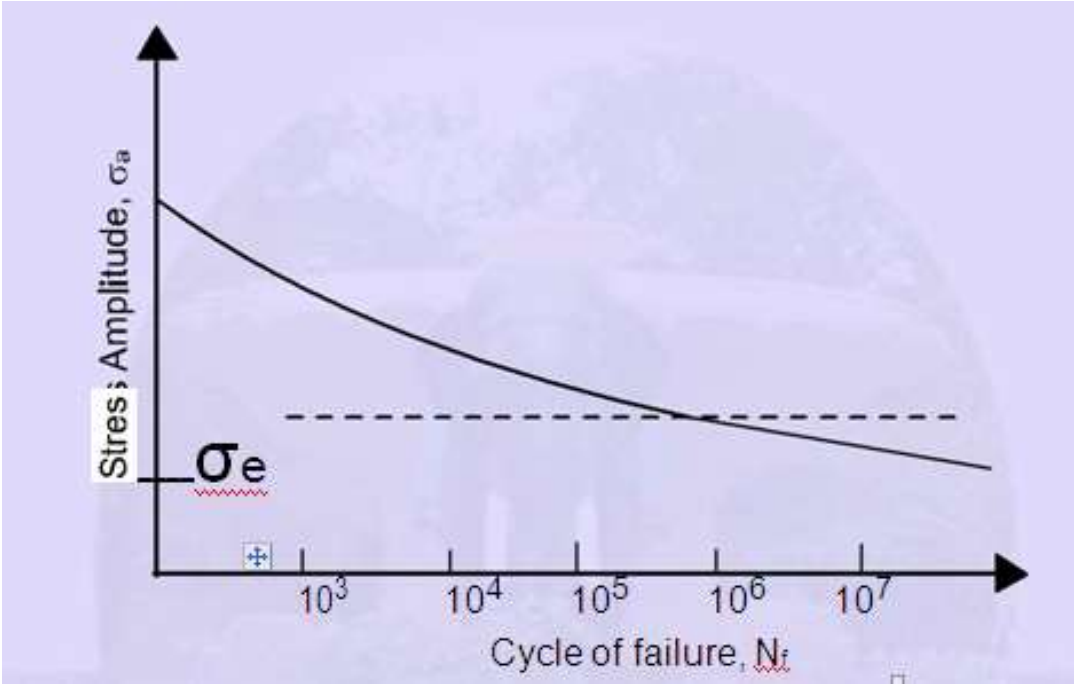
Bearing materials

- **Babbitt or White metal –** usually used as a lining of about 0.5mm thick bonded to bronze, steel or cast iron.
- **Copper Based alloys** - most common alloys are copper tin, copper lead, phosphor bronze: harder and stronger than white metal: can be used **un-backed as a solid bearing.**
  - **Sintered bronze** - Sintered bronze is a porous material which can be impregnated with oil, graphite or Ptfe. Not suitable for heavily loaded applications but useful where lubrication is inconvenient.
- **Nylon** - similar to Ptfe but slightly harder: used only in very light applications

DESIGN APPROACH FOR FATIGUE LOADINGS

Design for Infinite Life

It has been noted that if a plot is made of the applied stress amplitude verses the number of reversals to failure to (S-N curve) the following behaviour is typically observed.



Stress Concentration Effect

- **Fatigue Stress Concentration**

- The existence of irregularities or discontinuities, such as holes, grooves, or notches, in a part increase the magnitude of stresses significantly in the immediate vicinity of the discontinuity. Fatigue failure mostly originates from such places. Hence its effect must be accounted and normally a fatigue stress-concentration factor K_f is applied when designing against fatigue, even if the materials behavior is ductile.

- **Concentration factor K_f**

This form of definition needs that the fatigue stress concentration factor or the endurance strength values for different notch geometries on each of the material to be used should be evaluated. However once sufficient data was available a simple approach, useful at preliminary design stages was evolved to determine the fatigue stress concentration factor value from the geometrical (theoretical) stress concentration values, data charts for which is readily available, using a notch sensitivity relation.

- **Notch Sensitivity**
- Notch sensitivity q is defined by the equation

$$q = \frac{K_f - 1}{K_t - 1}$$

- **FATIGUE CONSIDERATION IN DESIGN**

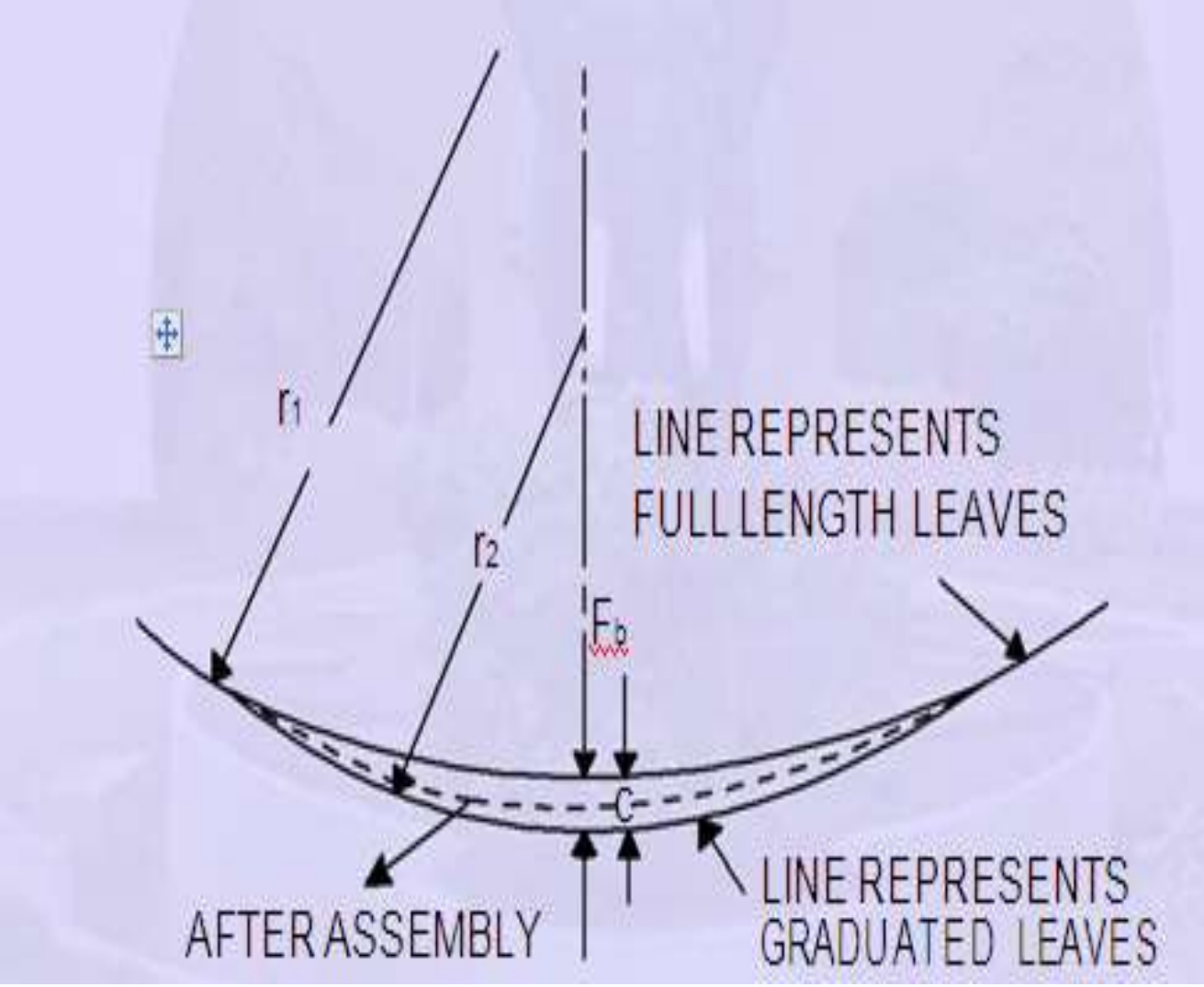
OBJECTIVES AND SCOPE

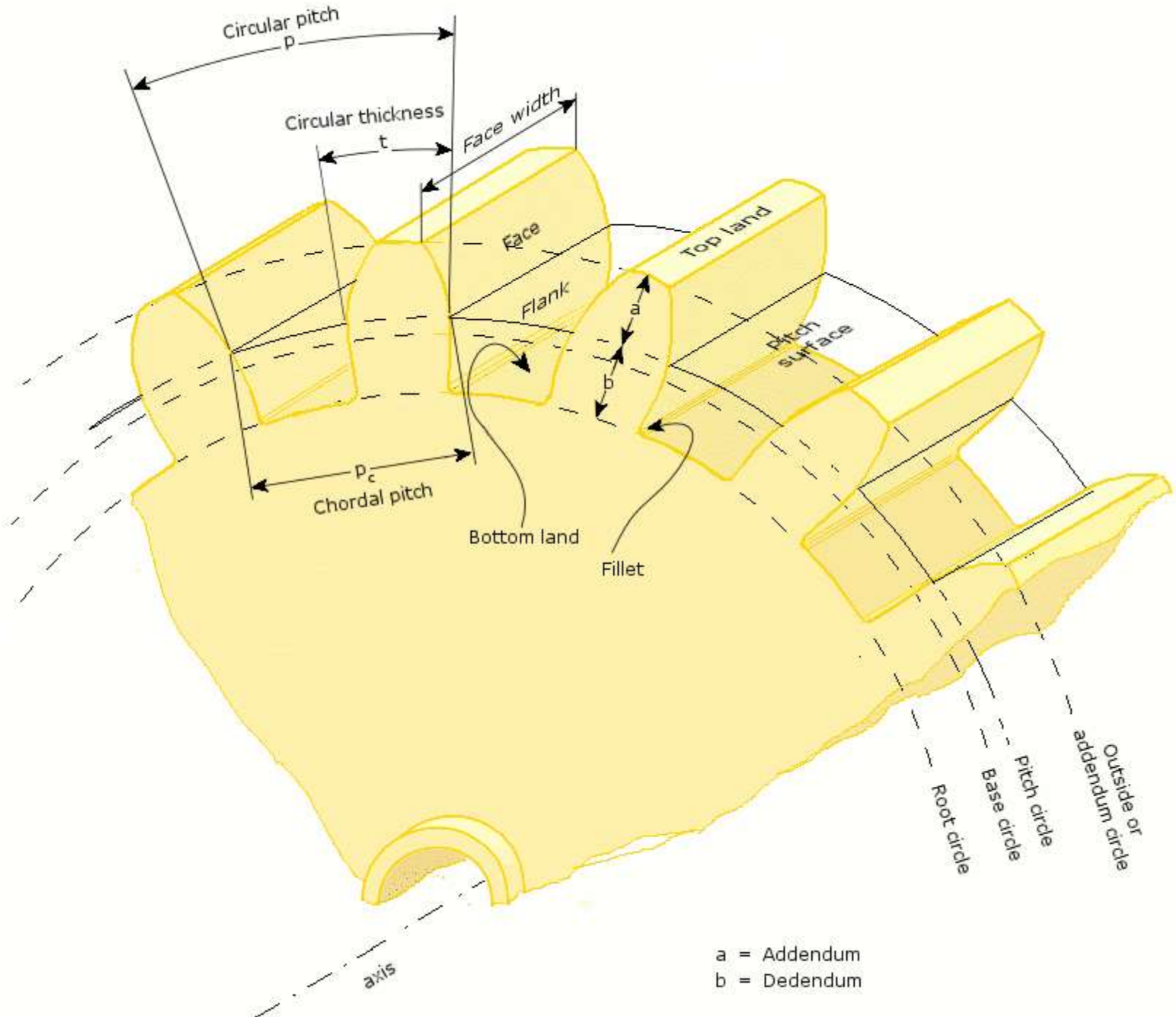
- In this module we will be discussing on design aspects related to fatigue failure, an important mode of failure in engineering components. Fatigue failure results mainly due to variable loading or more precisely due to cyclic variations in the applied loading or induced stresses So starting from the basic concepts of variable (non-static) loading, we will be discussing in detail how it leads to fatigue failure in components, what factors influence them, how to account them and finally how to design parts or components to resist failure by fatigue

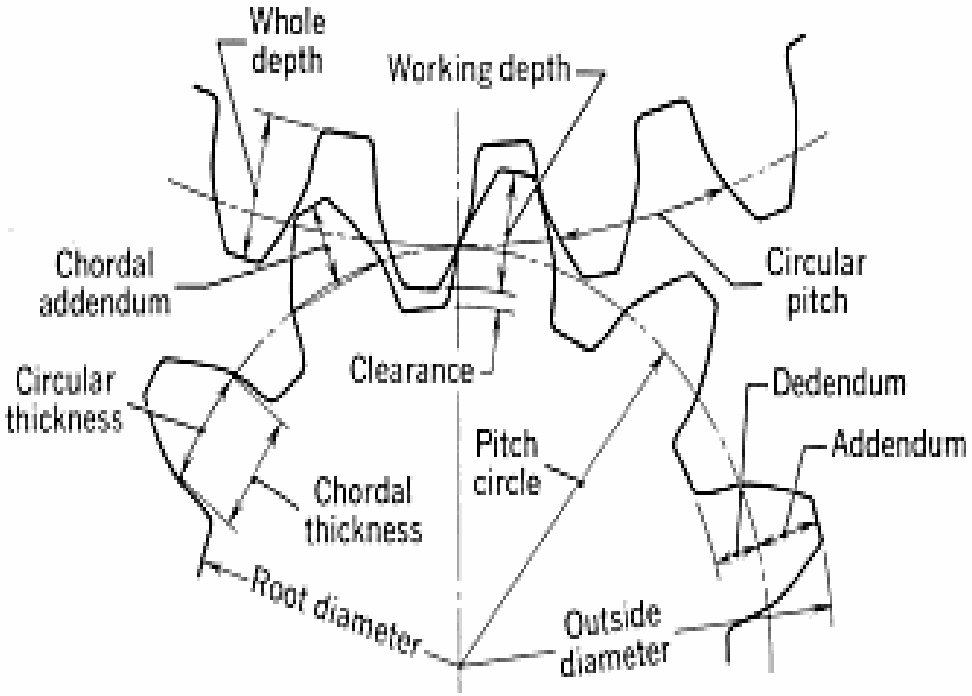
- **WHAT IS FATIGUE?**
- Fatigue is a phenomenon associated with variable loading or more precisely to cyclic stressing or straining of a material. Just as we human beings get fatigue when a specific task is repeatedly performed, in a similar manner metallic components subjected to variable loading get fatigue, which leads to their premature failure under specific conditions.

- **WHAT IS FATIGUE LOADING?**
- Fatigue loading is primarily the type of loading which causes cyclic variations in the applied stress or strain on a component. Thus any variable loading is basically a fatigue loading.

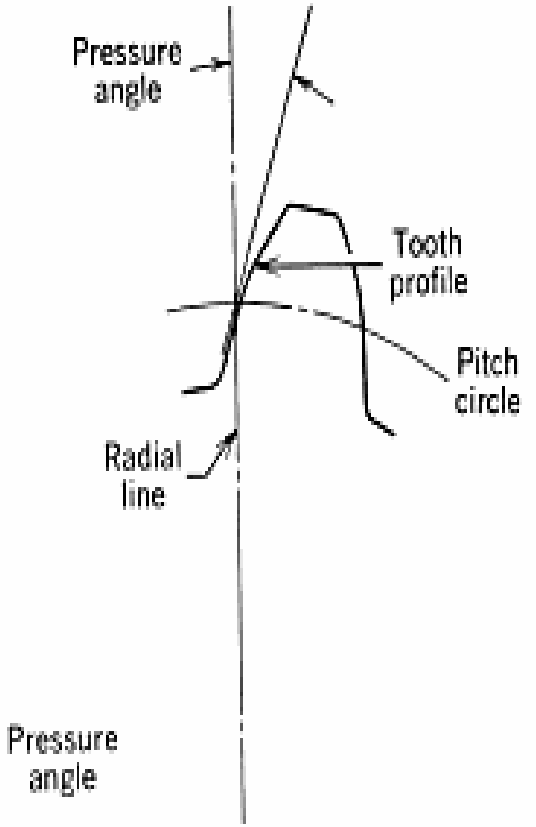
- **Nipping Of Leaf Springs**
- As discussed, the stresses in extra full length leaves are 50% more than the stresses in graduated –length leaves. One of the methods of equalizing the stresses in different leaves is to pre-stress the spring. The pre-stressing is achieved by bending the leaves to different radii of curvature, before they are assembled with the centre clip. As shown in Figure the full-length leaf is given a greater radius of curvature than the adjacent leaf.


r1
r2
LINE REPRESENTS
FULL LENGTH LEAVES
Fb
C
AFTER ASSEMBLY
LINE REPRESENTS
GRADUATED LEAVES


Circular pitch
p
Circular thickness
t
Face width
Face
Flank
Top land
a
b
Pitch surface
p_c
Chordal pitch
Bottom land
Fillet
Outside or addendum circle
Pitch circle
Base circle
Root circle
axis
a = Addendum
b = Dedendum



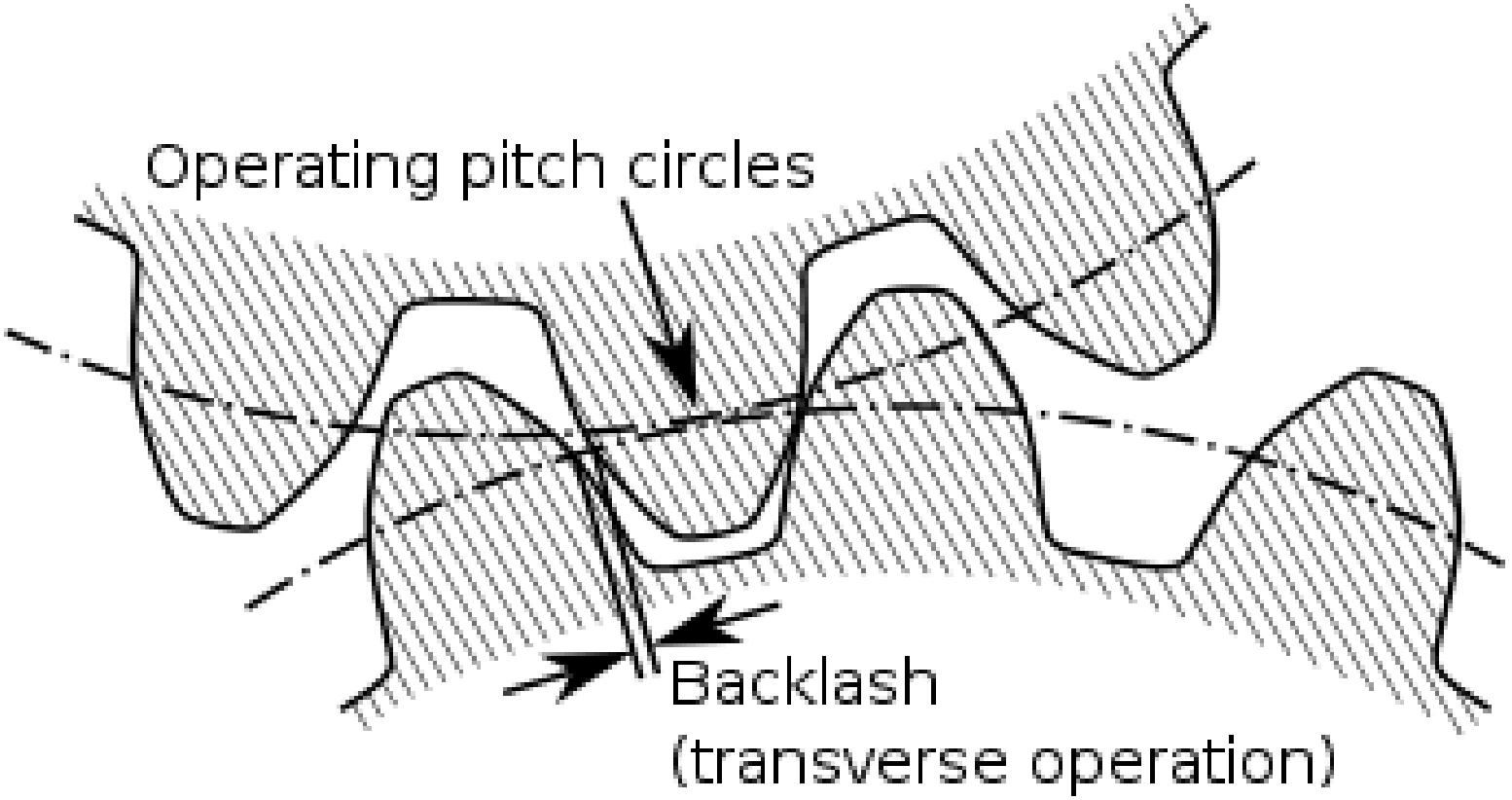
Spur gear terms.



Pressure angle.

In mechanical engineering, backlash, sometimes called lash or play, is clearance between mating components, sometimes described as the amount of lost motion due to clearance or slackness when movement is reversed and contact is re-established. For example, in a pair of gears, backlash is the amount of clearance between mated gear teeth. Theoretically, the backlash should be zero, but in actual practice some backlash must be allowed to prevent jamming. It is unavoidable for nearly all reversing mechanical couplings, although its effects can be negated. Depending on the application it may or may not be desirable. Reasons for requiring backlash include allowing for lubrication, manufacturing errors, deflection under load and thermal expansion.

BACKLASH is the error in motion that occurs when gears change direction. It exists because there is always some gap between the trailing face of the driving tooth and the leading face of the tooth behind it on the driven gear, and that gap must be closed before force can be transferred in the new direction. The term "backlash" can also be used to refer to the size of the gap, not just the phenomenon it causes; thus, one could speak of a pair of gears as having, for example, "0.1 mm of backlash." A pair of gears could be designed to have zero backlash, but this would presuppose perfection in manufacturing, uniform thermal expansion characteristics throughout the system, and no lubricant. Therefore, gear pairs are designed to have some backlash. It is usually provided by reducing the tooth thickness of each gear by half the desired gap distance. In the case of a large gear and a small pinion, however, the backlash is usually taken entirely off the gear and the pinion is given full sized teeth. Backlash can also be provided by moving the gears farther apart.

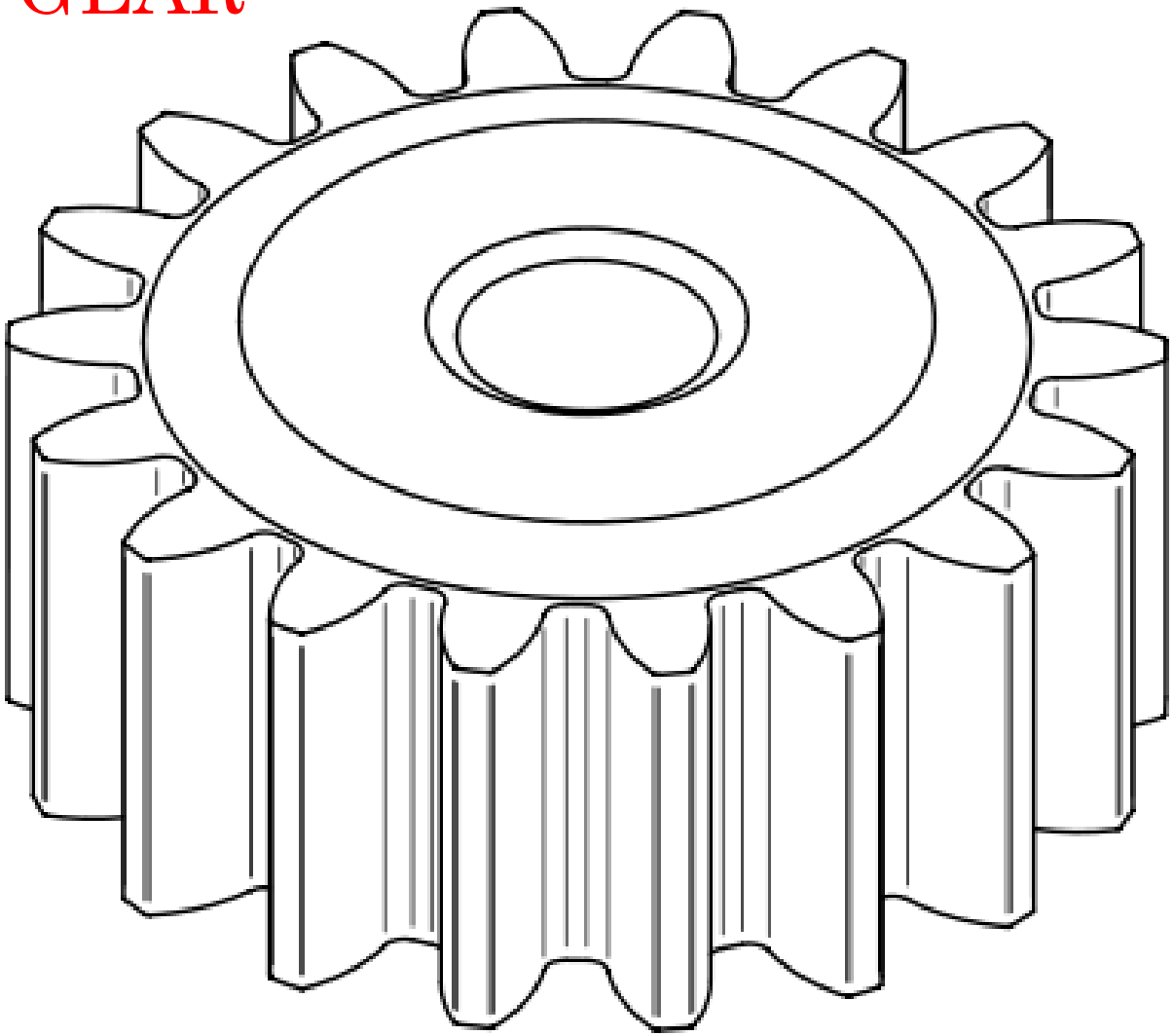

Operating pitch circles
Backlash
(transverse operation)

GEAR MATERIALS:-

Numerous nonferrous alloys, cast irons, powder-metallurgy and even plastics are used in the manufacture of gears. However steels are most commonly used because of their high strength to weight ratio and low cost. Plastic is commonly used where cost or weight is a concern. A properly designed plastic gear can replace steel in many cases because it has many desirable properties, including dirt tolerance, low speed meshing, and the ability to "skip" quite well. Manufacturers have employed plastic gears to make consumer items affordable in items like copy machines, optical storage devices, VCRs, cheap dynamos, consumer audio equipment, servo motors, and printers.

Material	Outstanding features	Applications	Precision Rating
Ferrous:			
Cast Iron	Low cost, good machining, high internal damping	Big size, moderate power rating, Commercial gears	Commercial quality
Cast Steel	Low cost, high strength	Power Gears, medium rating	Commercial quality
Plain Carbon Steel	Good machining, Heat treated	Power Gears, medium rating	Commercial to medium precision
Alloy Steels	Heat treated, high strength and durability	Strict power requirements	High precision
Stainless Steel	High corrosion resistance, nonmagnetic	Low power rating	Good Precision
Non Ferrous:			
Aluminium alloys	Light weight, noncorrosive, good mach inability	Very light duty instrument gears	High precision
Brass alloys	Low cost, noncorrosive, good mach inability	Low cost commercial equipment	Medium precision
Die cast alloys	Low cost, low strength	High production, low quality, commercial	Low grade commercial
Non Metallic:			
Nylon	No friction or lubricant, high water absorption	Long life, low nose, low loads	Commercial quality
Delrin	Wear resistant, long life	Low loads	Commercial quality

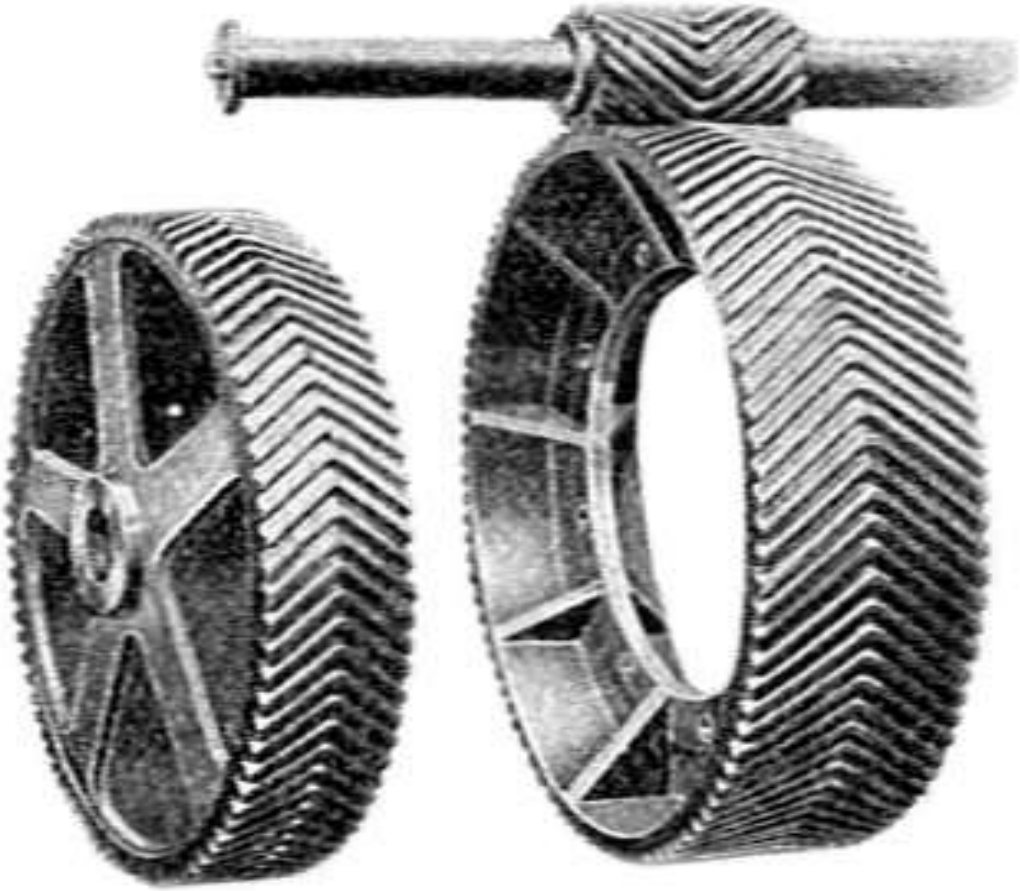
SPUR GEAR



HELICAL GEAR

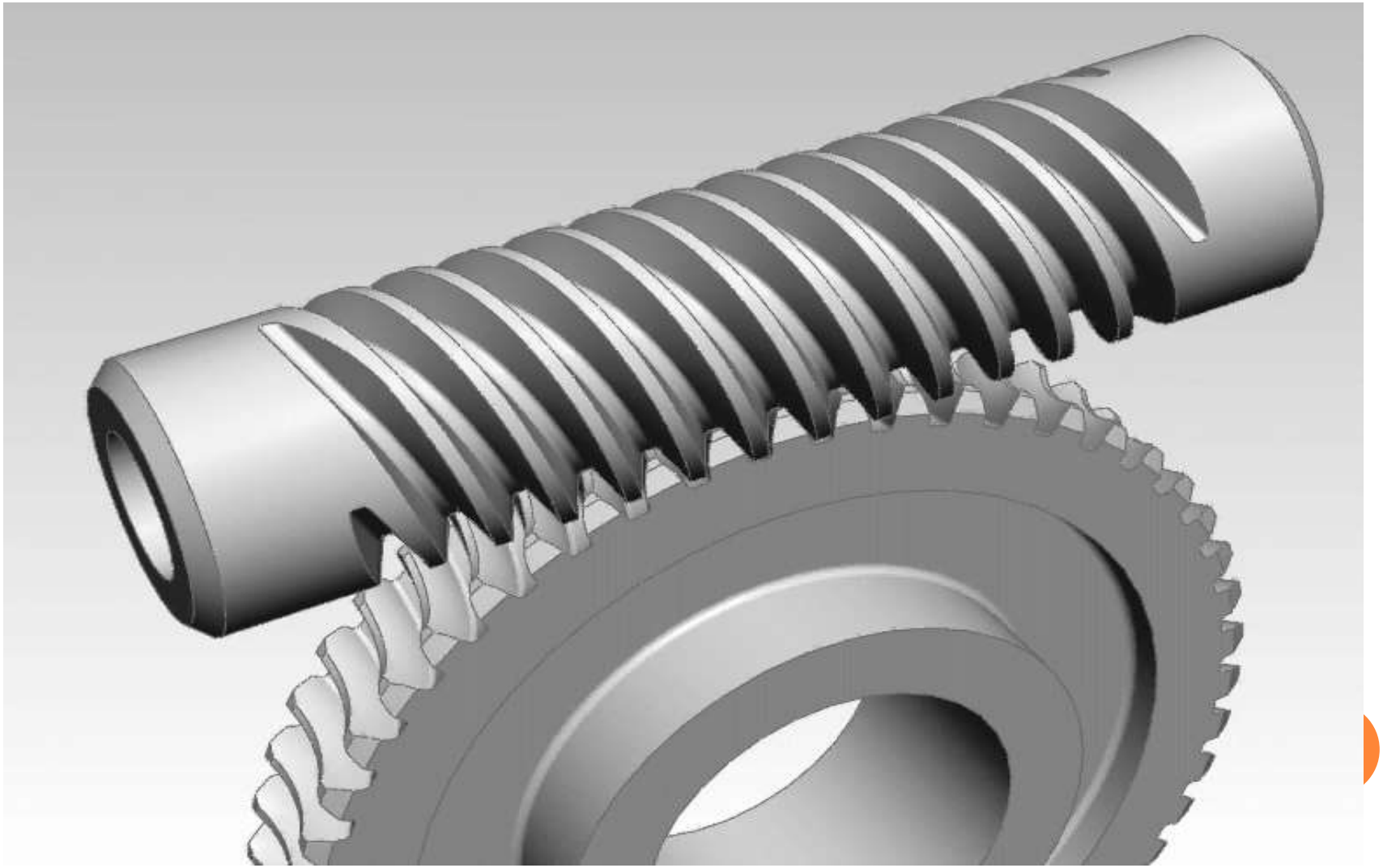
Helical Gear

Herringbone Gear:- Double Helical Gear

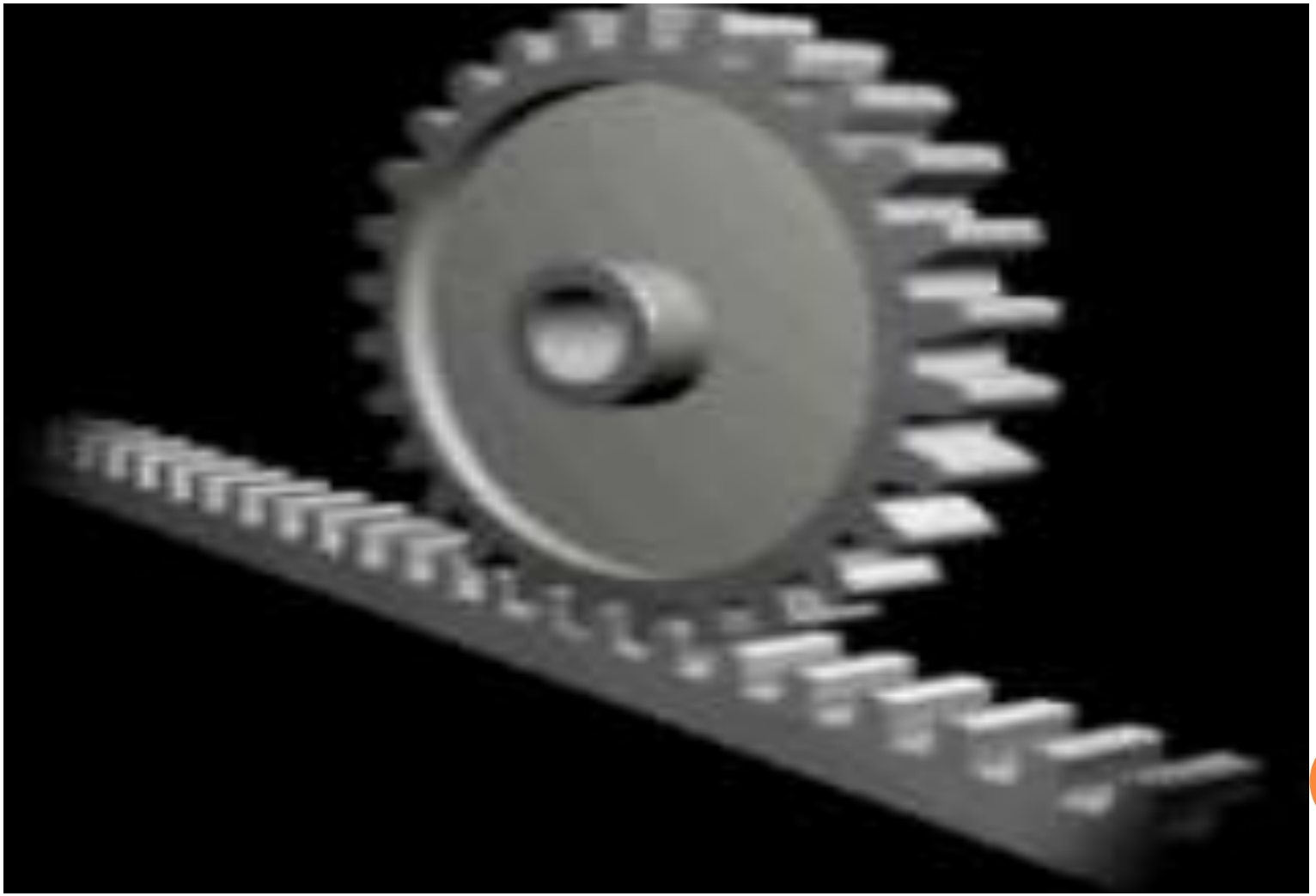


Worm Gear

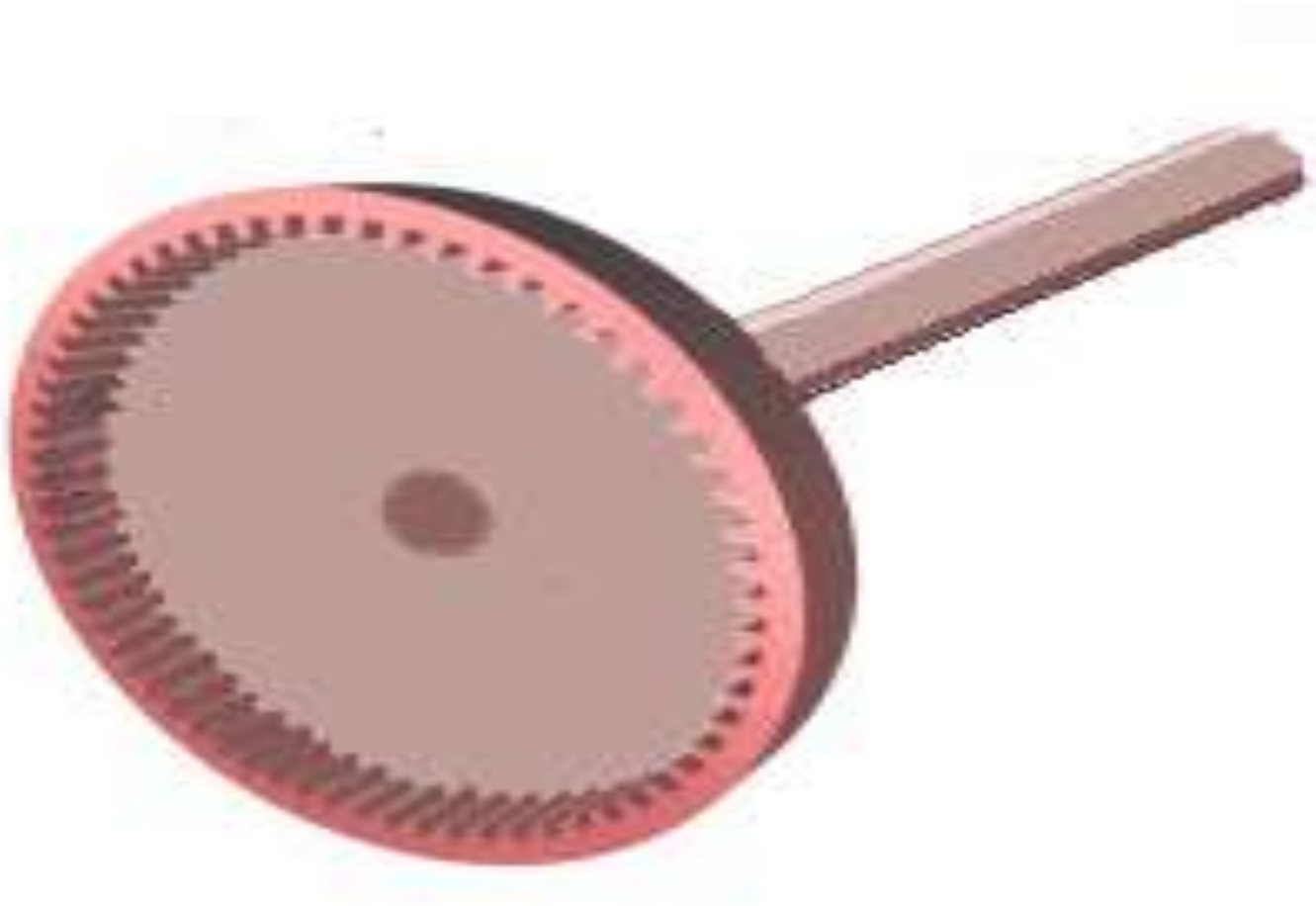
Worm Gear



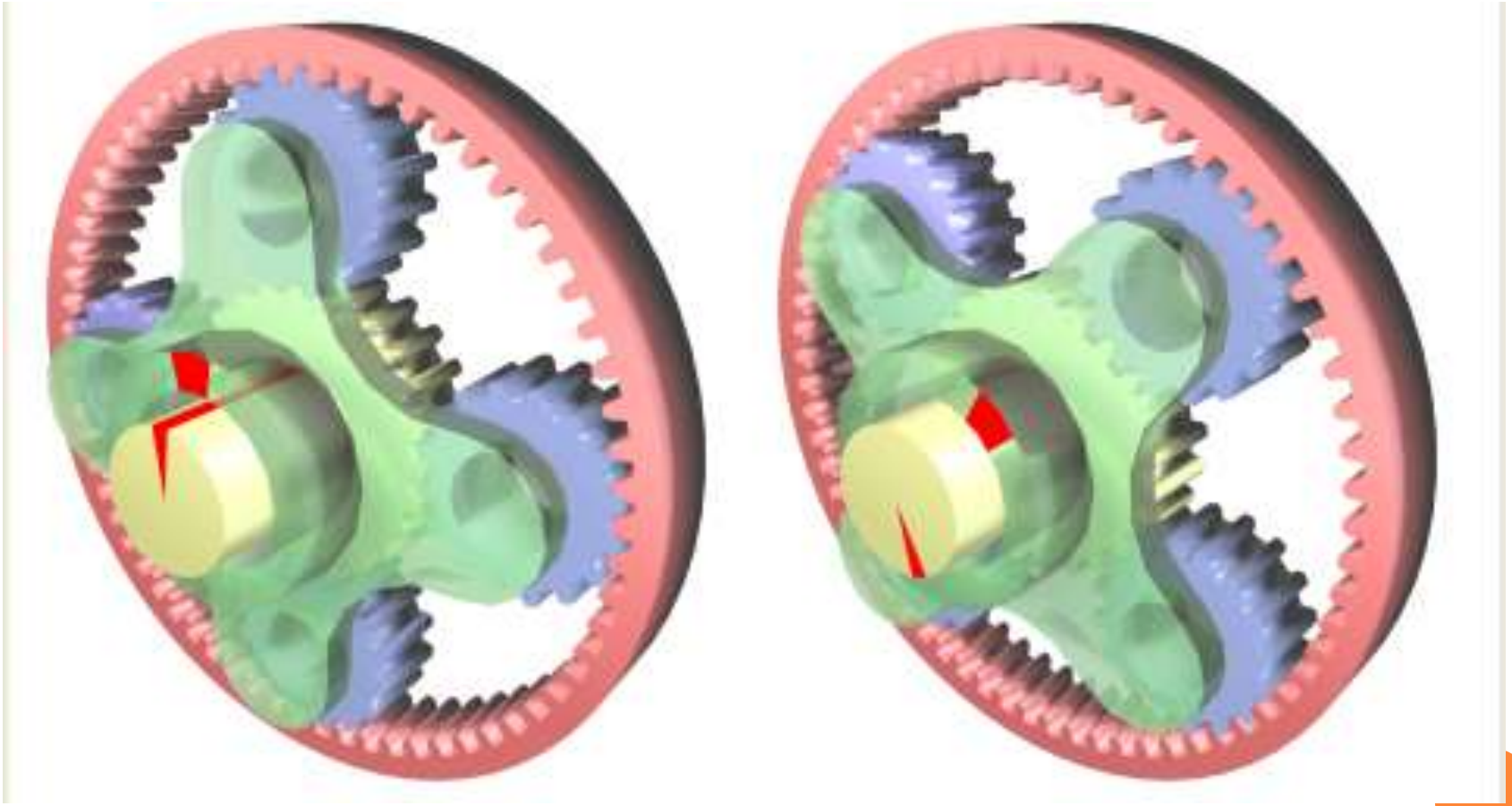
Rack & Pinion Gear



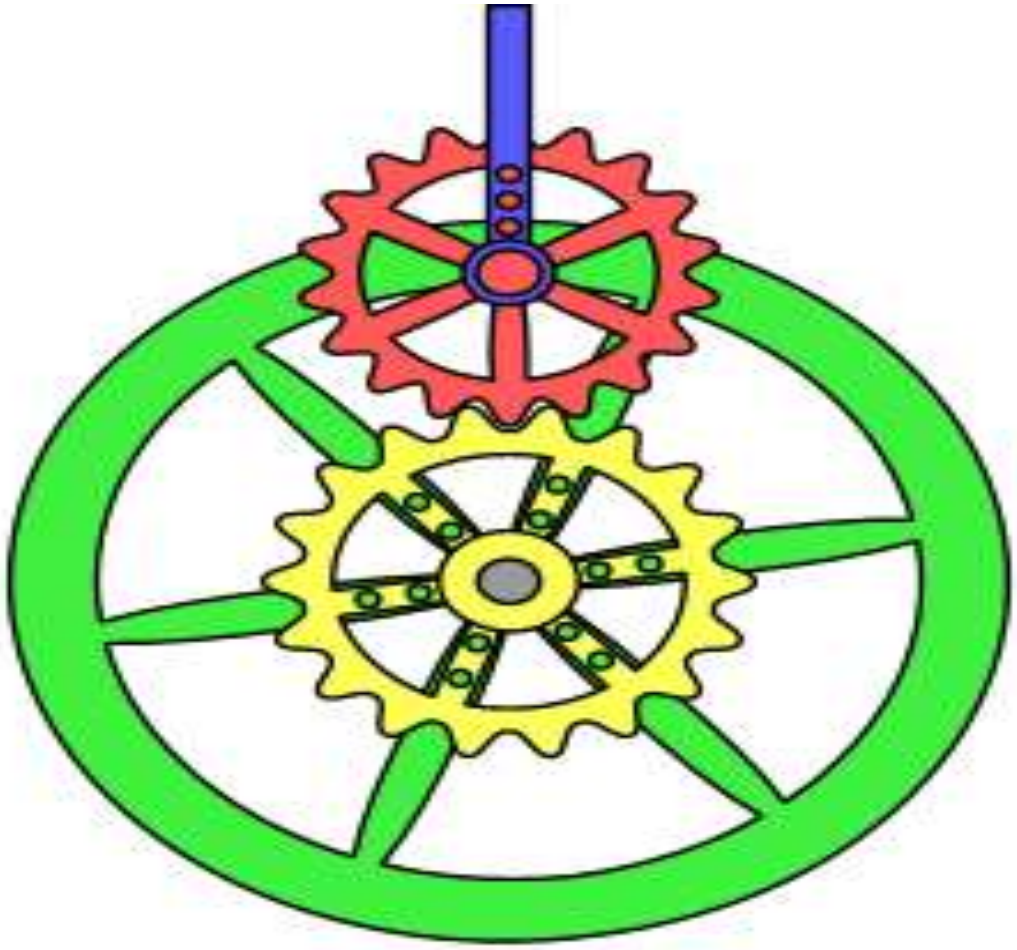
Inside Gear

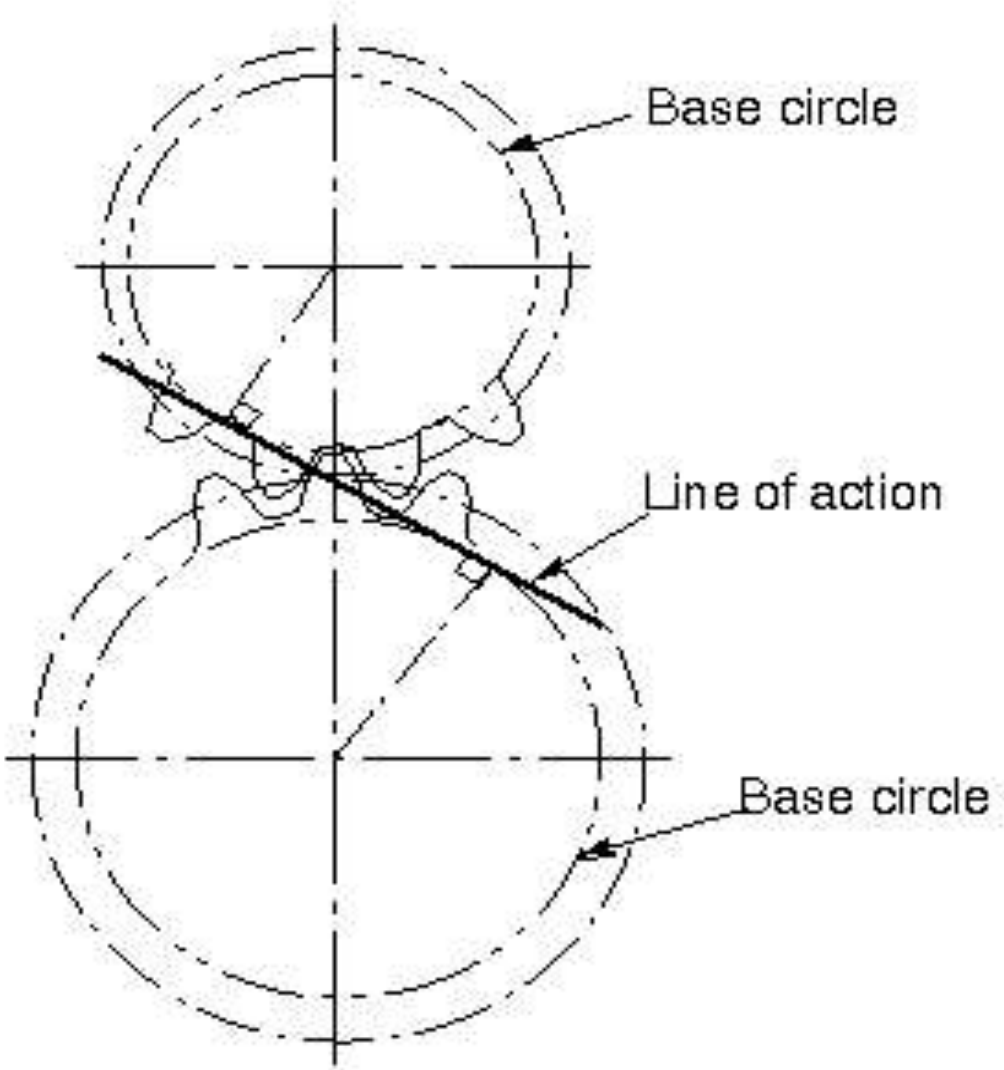


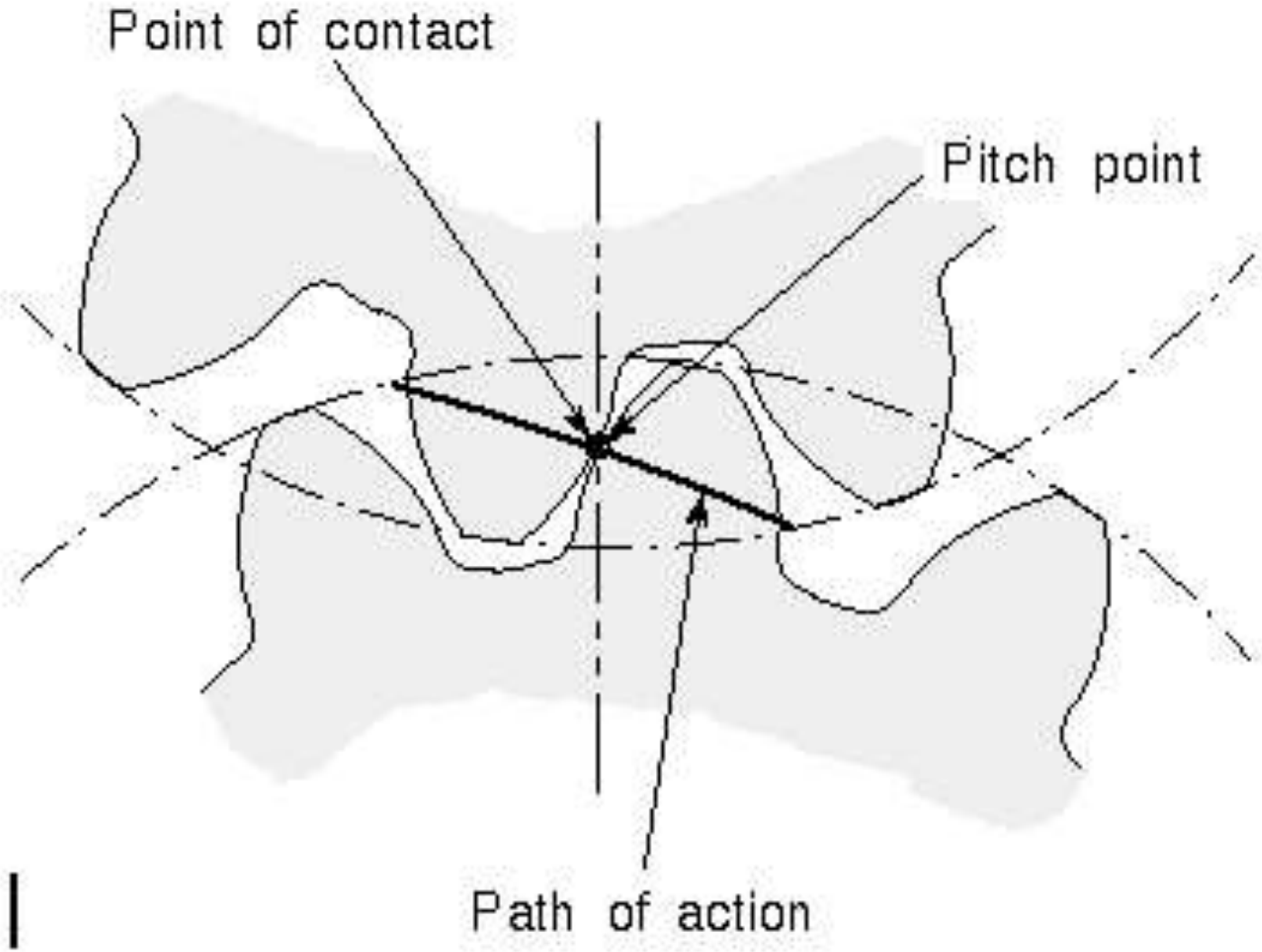
Epicyclic Gear

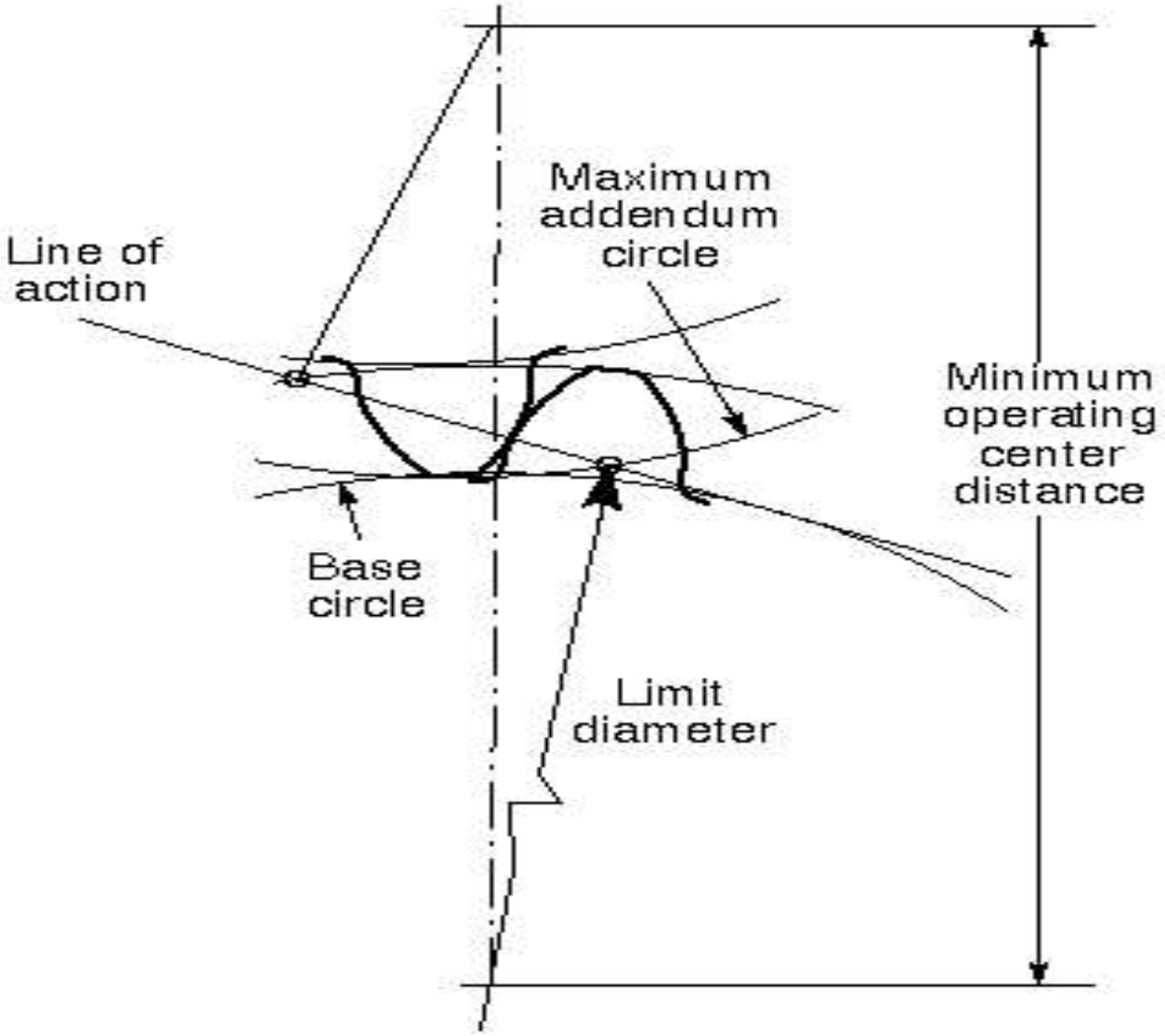


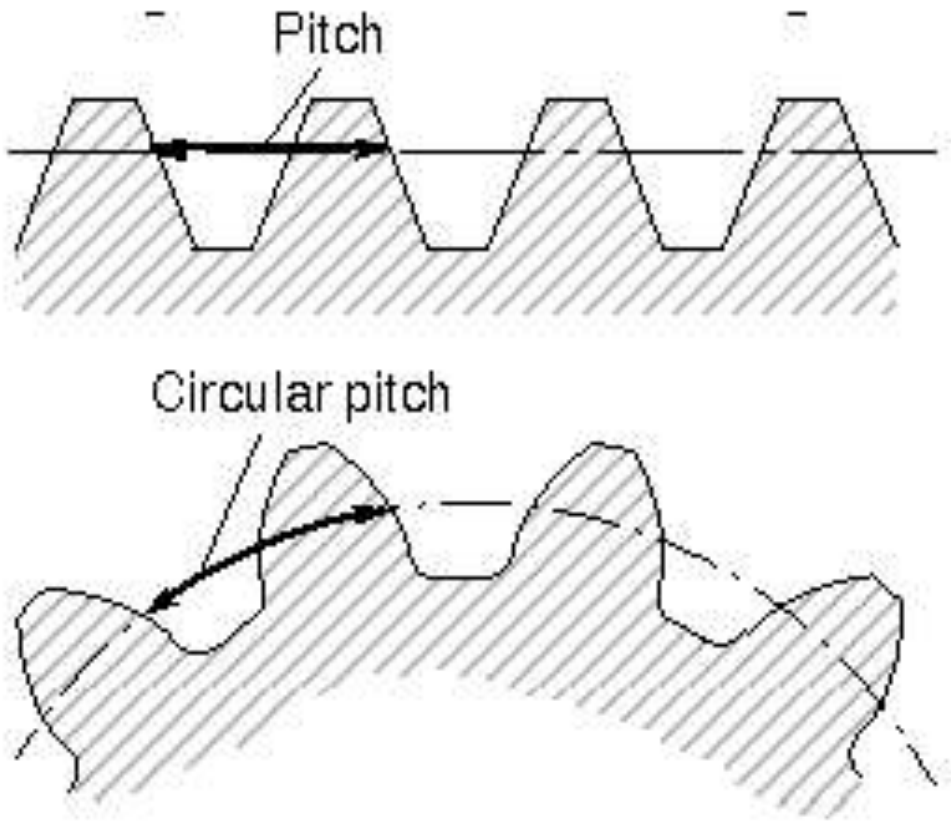
Sun & Planet Gear

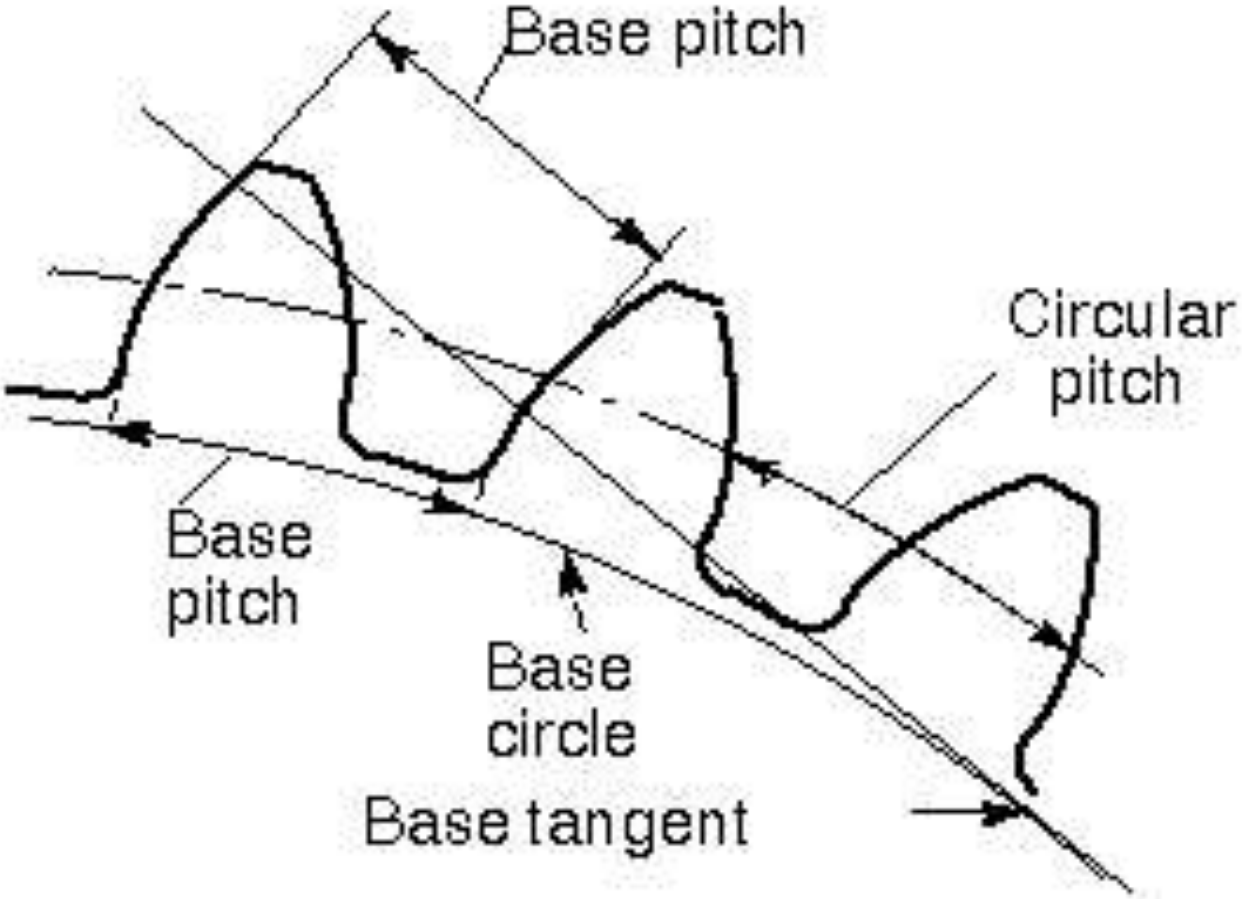


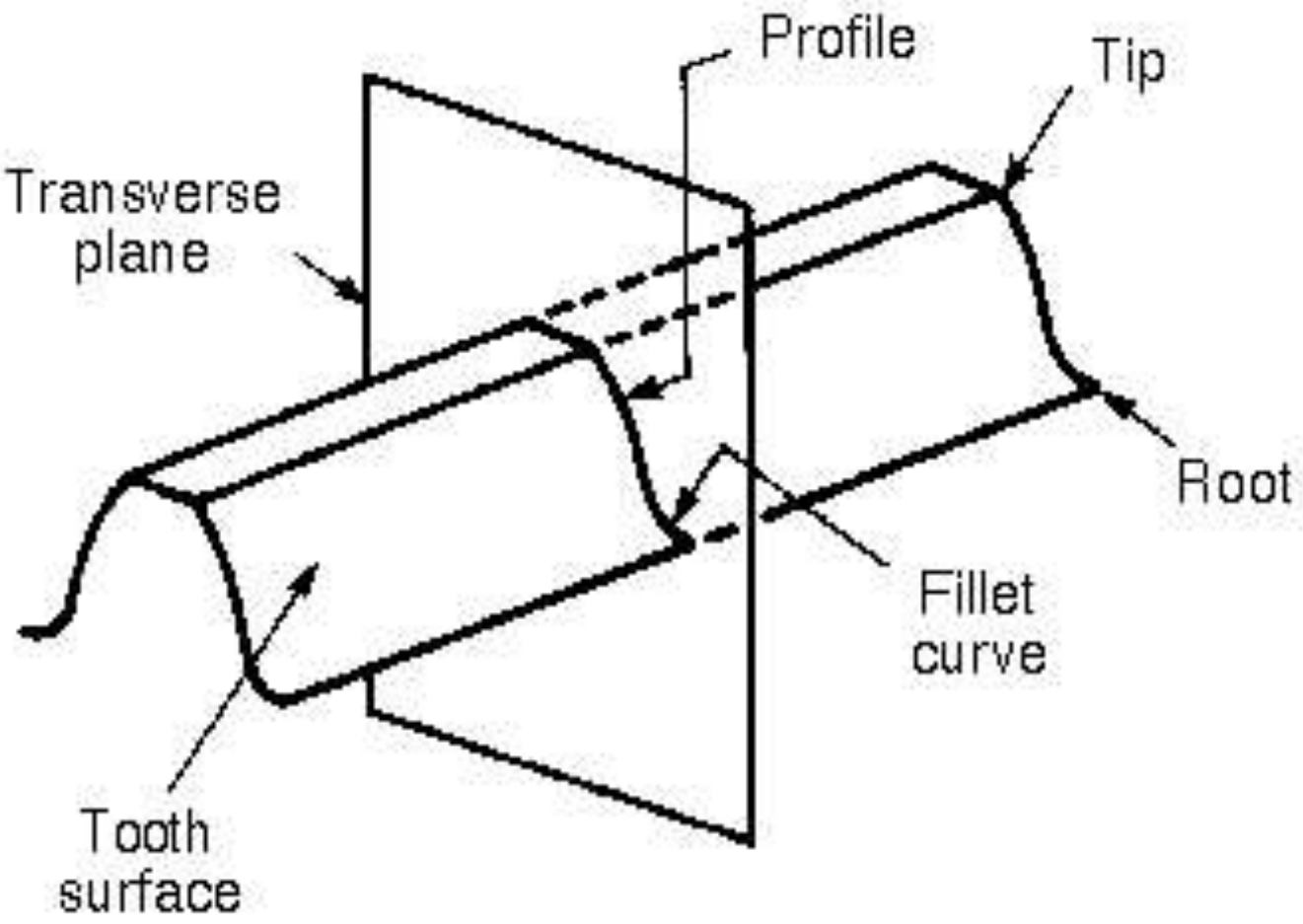

Base circle
Line of action
Base circle

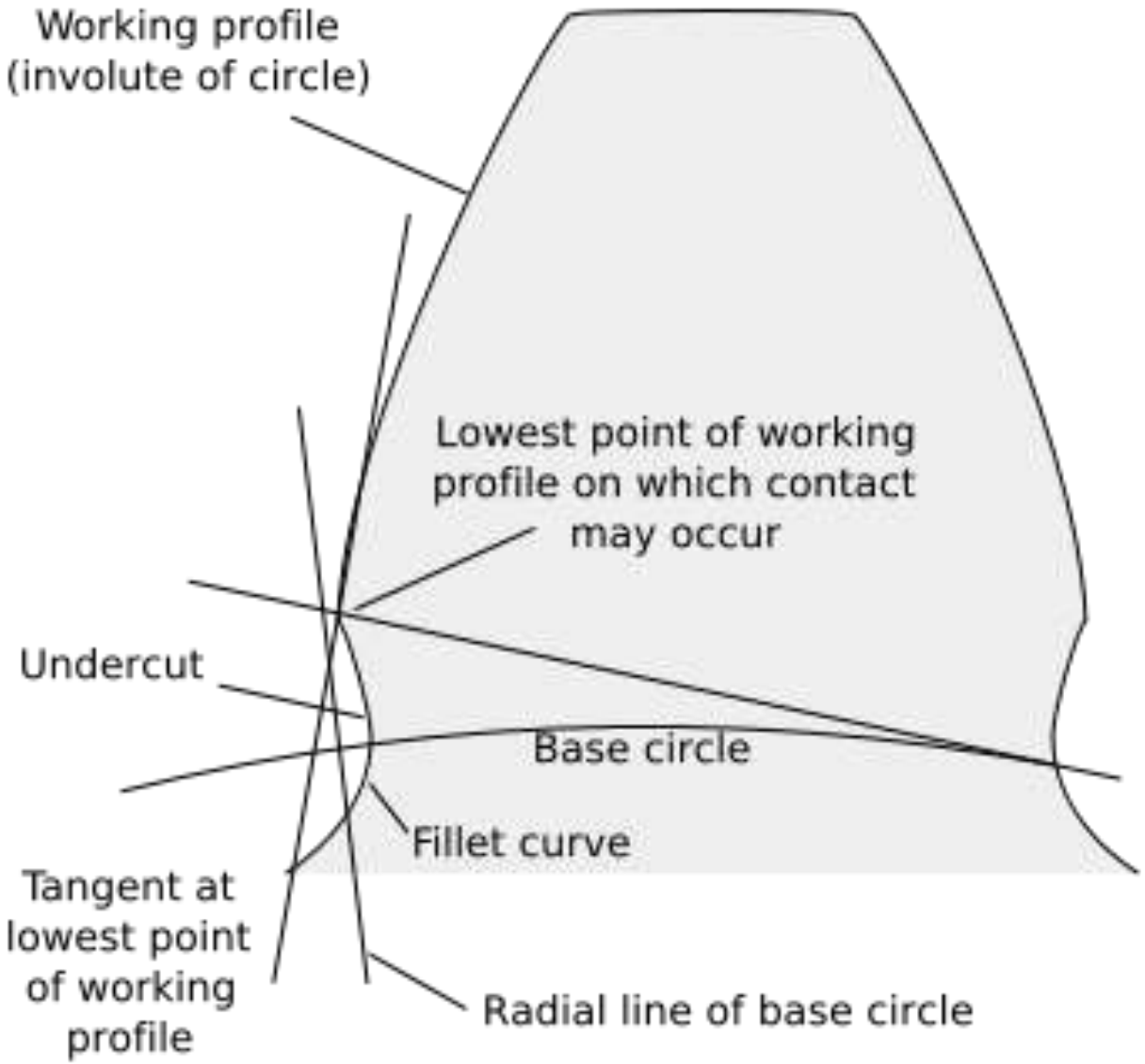

Point of contact
Pitch point
Path of action


Line of action
Maximum addendum circle
Minimum operating center distance
Base circle
Limit diameter


Pitch
Circular pitch


Base pitch
Circular pitch
Base pitch
Base circle
Base tangent

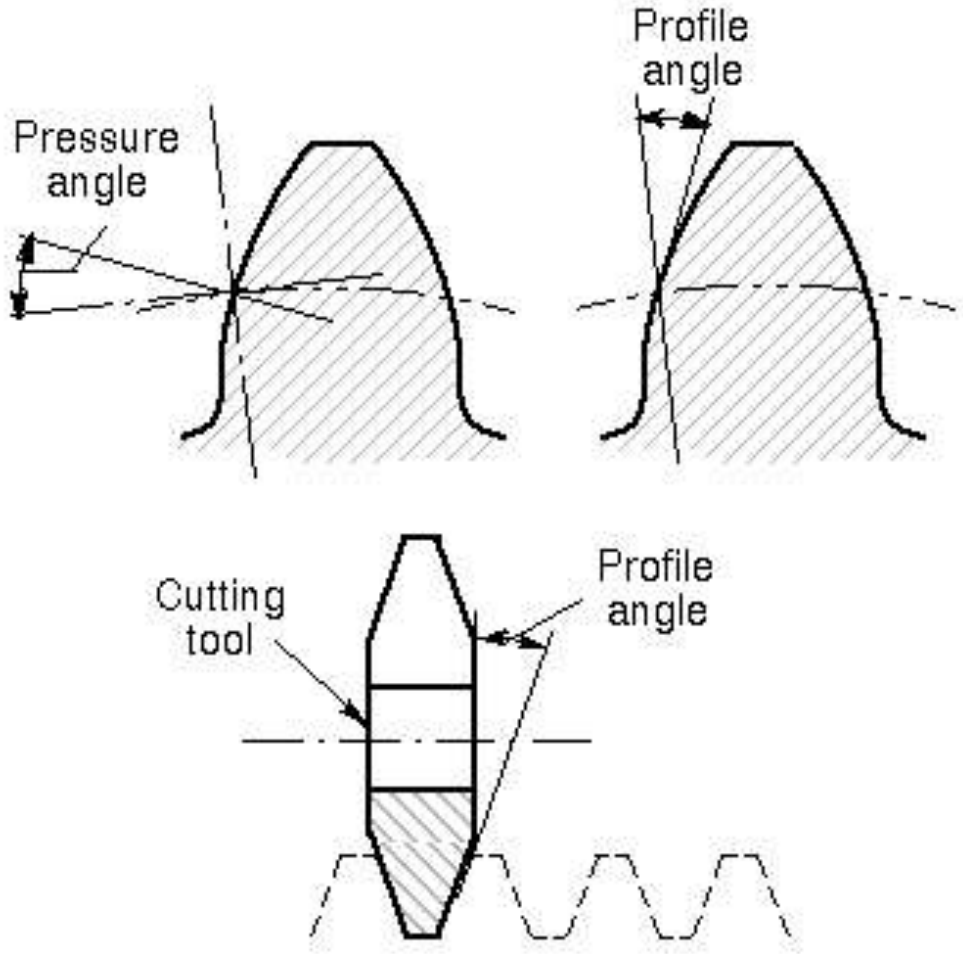

Profile
Tip
Transverse plane
Root
Fillet curve
Tooth surface


Working profile
(involute of circle)
Lowest point of working
profile on which contact
may occur
Undercut
Base circle
Fillet curve
Tangent at
lowest point
of working
profile
Radial line of base circle

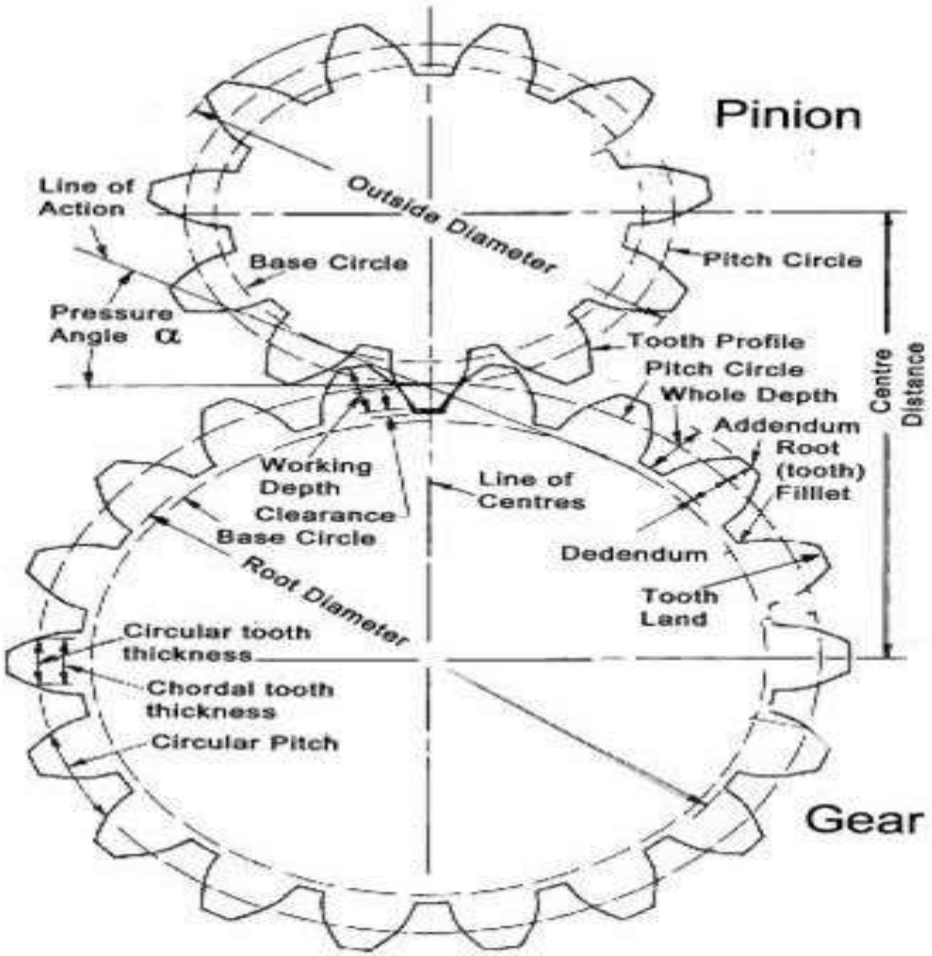
Pressure angle, also known as the **angle of obliquity, is** in general the angle at a pitch point between the line of pressure which is normal to the tooth surface, and the plane tangent to the pitch surface. The pressure angle gives the direction of the normal to the tooth profile. The pressure angle is equal to the profile angle at the standard pitch circle and can be termed the "standard" pressure angle at that point. Standard values include 14.5, 20 and 25 degrees. Earlier gears with pressure angle 14.5 were more commonly used because for a given pressure angle, cosine would be larger for smaller angle, thus resulting in more power transmission and less pressure on the bearing. But for a given material, smaller pressure angles correlate with weaker teeth. To run gears together properly one must match pressure angles.

Pressure Angle : If you can draw a common normal line to the meshing teeth surfaces at the contact point between the meshed teeth and a tangent plane common to the pitch circles of both the gear then angle between the common normal line and the tangent plane is called pressure angle.

Pressure Angle



Gear Profile



What is involute gear?

All the gear teeth have top flat portion and two side curves. The side curves for the involute gears are in the form of involute curve of a circle.

Involute curve of a circle can be generated by the locus of an end point of an imaginary taut string unwounding from the circle.

What is cycloidal gear?

Cycloid is a curve generated by locus of any point on a circle which is rolling around another circle. If the second circle rolls outside the first circle then the generated curve is called epicycloid and if it rolls inside the first circle then the generated curve will be hypocycloid. The gear whose teeth profile is made up of cycloidal curves is called cycloidal gear. Each tooth profile will be combination of epicycloid and hypocycloid curves.

Advantage of Involute gear

- Contacts between two mating teeth in involute gear occur in a fixed plane of action irrespective of the centre to centre distances between the gears. Hence, Involute gears can handle centre sifts of the gears better. This provides assembly flexibility.
- Involute gear produces lesser noise than cycloidal gears.
- Manufacturing of accurate involute gear teeth is easy.

Advantage of cycloidal gear

- Cycloid teeth does not undercut or interfere with its mating teeth.
- Lesser number of teeth can be possible for cycloidal gears which facilities large reduction ratios.
- Cycloidal teeth are stronger than involute teeth.

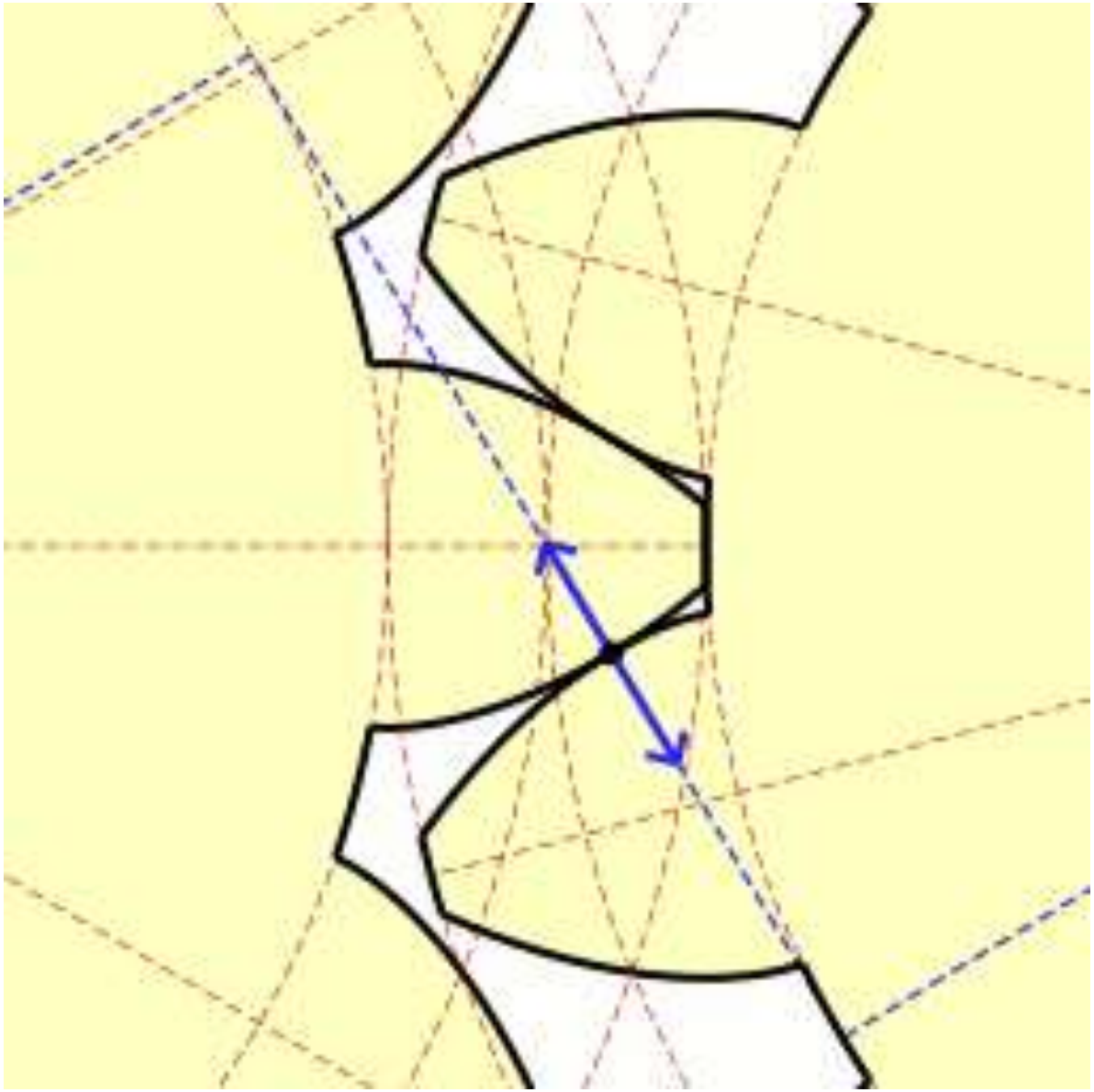
Identification of involute and cycloidal gears

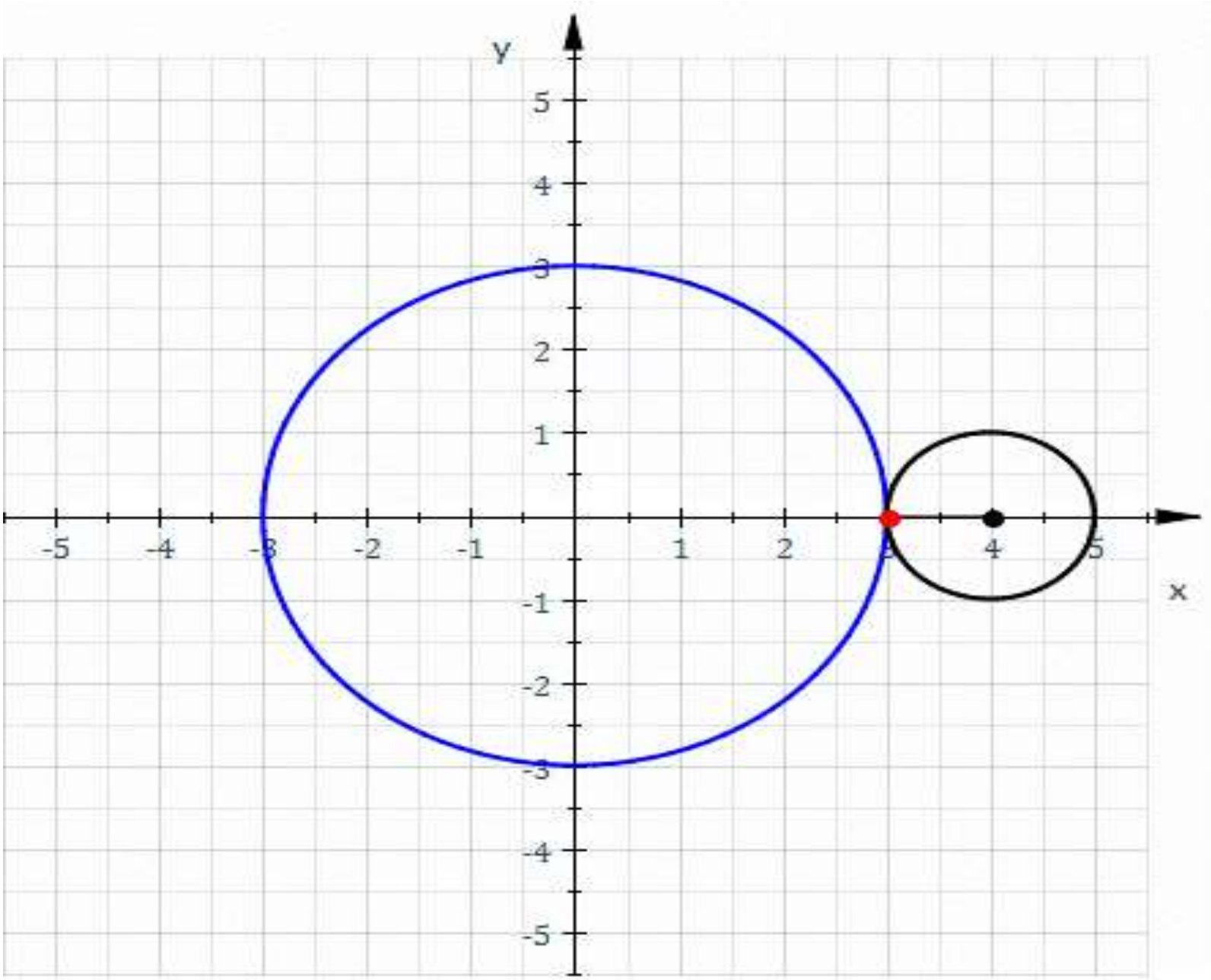
Curve portion of involute teeth is made up of a single curve where as the profile of a cycloidal tooth is made up of two different curves (epicycloid and hypocycloid). If the teeth attached sharply with the base circle then it should be an involute gear or else it may be a cycloidal gear.

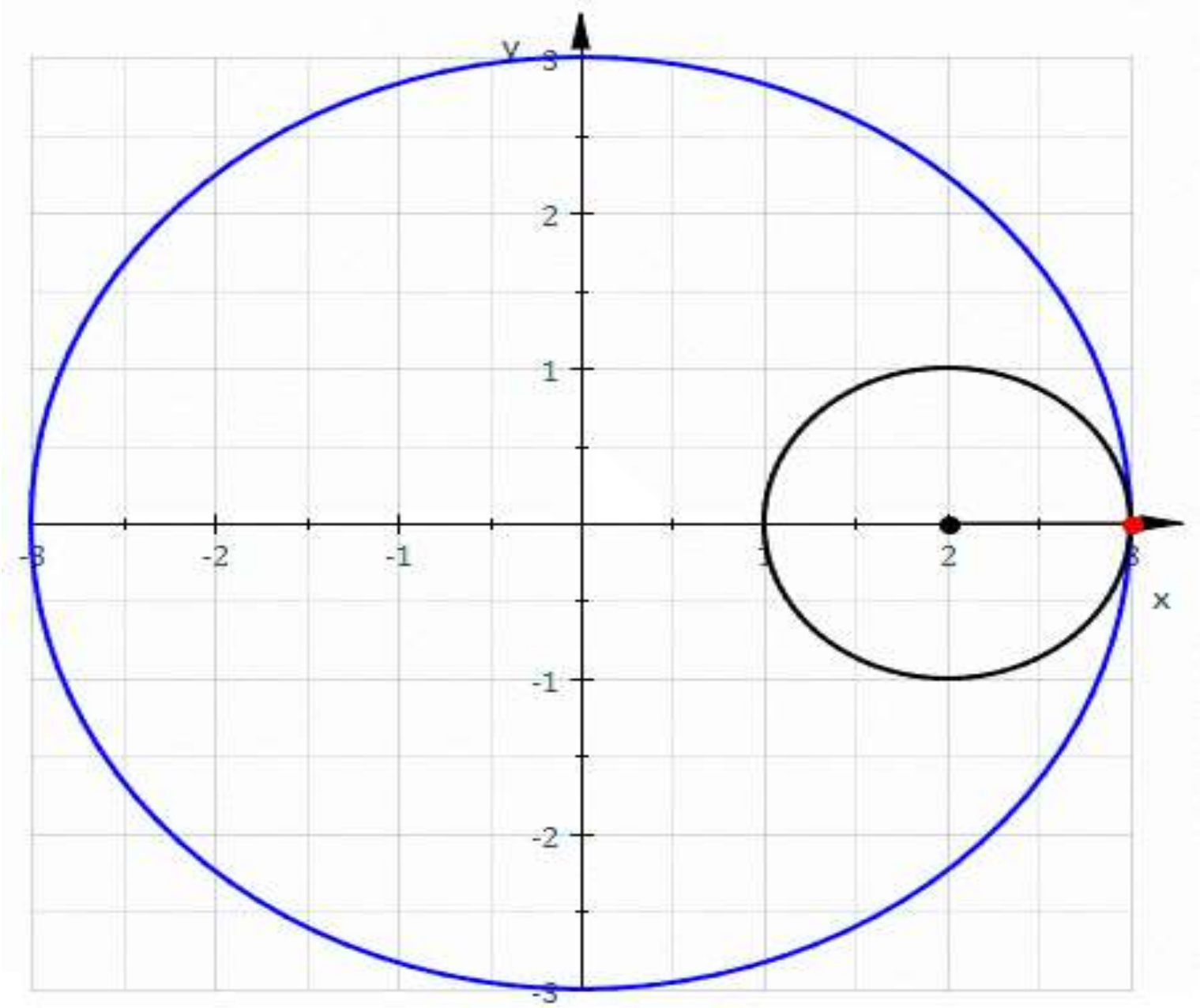
Examples

Involute gear can be seen almost every where, car gear box, ships, robotics application, home appliances, machine tools.

Cycloidal teeth are found mainly in clock and watches.




y
x
5
4
3
2
1
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
1
2
4
5


y
3
2
1
-1
-2
-3
-3
-2
-1
1
2
3
x