DIVISIONS OF DYNAMICS

KINEMATICS – Deals with Motion and Time

(Kinema – Greek Word – Motion)

KINETICS – Deals with Motion, Time and Forces.

Statics	Kinematics	Kinetics
STRUCTURE	MECHANISM	MACHINE

Some Definitions

- Machine – device to transfer or transform energy to do useful work.
- Mechanism – device to transfer or transform given input motion to specified output motion
- Structure – a single body with no motion / combination of bodies with no relative motion

Classification of Mechanisms

- Based on the nature of output speed

- Uniform motion mechanism
- Non-uniform motion mechanism

Shortcut to flat belt.hr

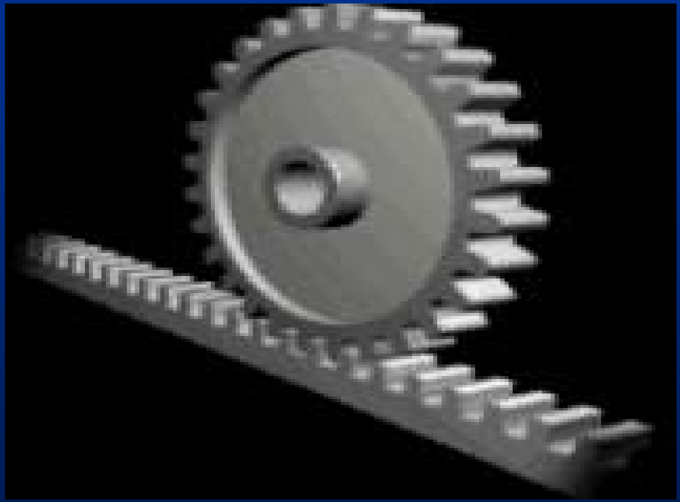
Uniform Motion Mechanisms

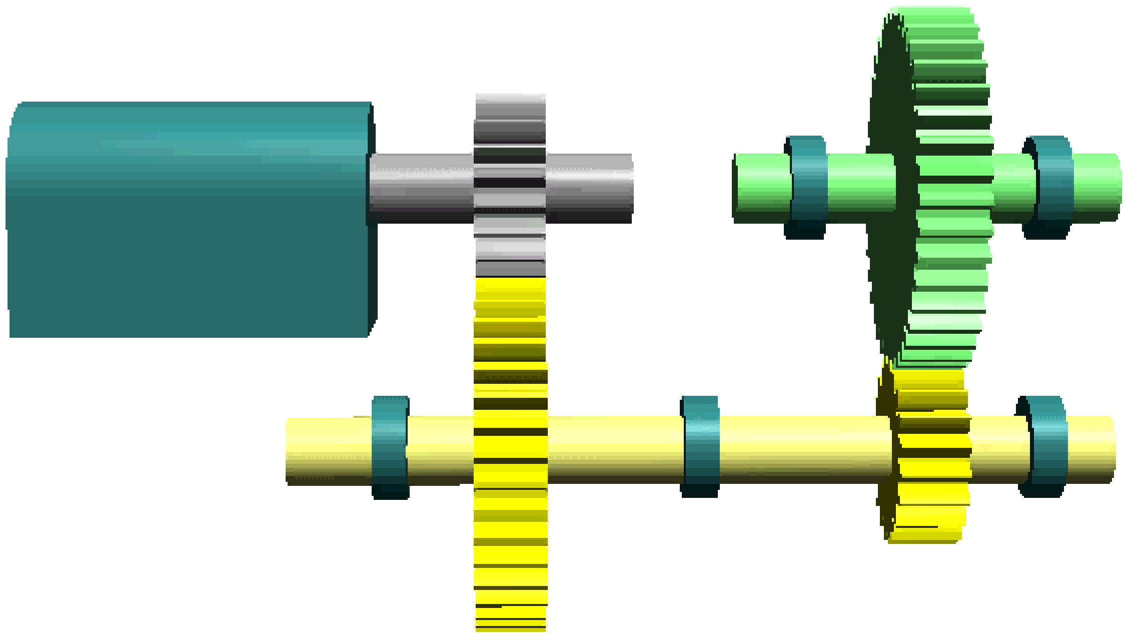
Uniform Motion – Equal Displacement For
Equal Time Interval

Examples : All Gear Drives
All Chain Drives
Belt Drives without slip


C7


C9





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gear_train

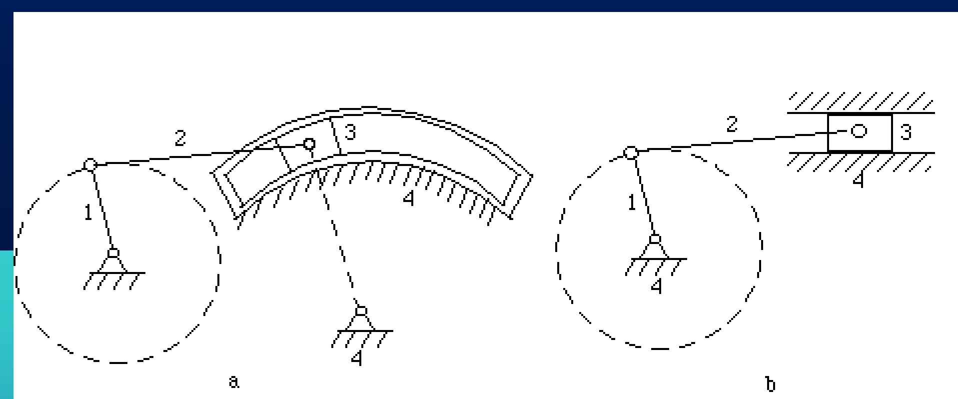
Non-Uniform Motion Mechanisms

Non-Uniform Motion – Unequal Displacement
For Equal Time Interval

Examples : Linkage Mechanisms
Cam Mechanisms
Geneva Wheel


C1


C3


1
2
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a
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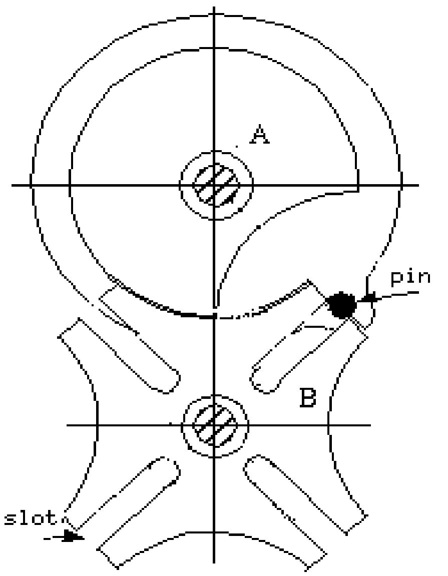
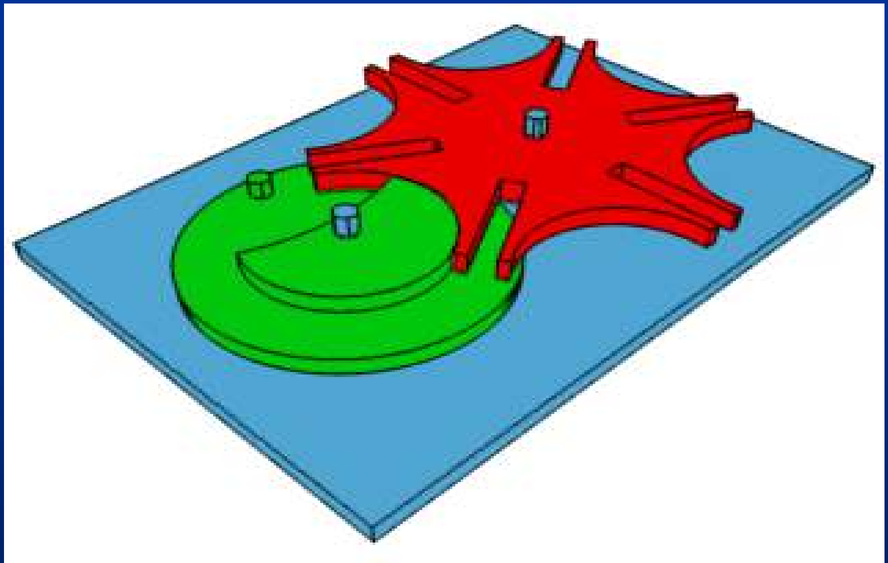
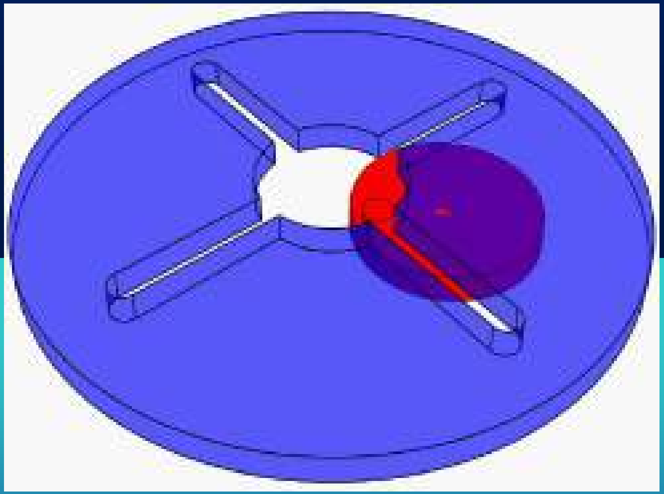

A
pin
B
slot





Classification of mechanisms

Based on mobility (D.O.F) of the mechanism

1. Considering the D.O.F. of output only
   a) Constrained Mechanism
   b) Unconstrained Mechanism
2. Considering the sum of the D.O.F. Of input and output motions
   a) Single (one) d.o.f. mechanism
   b) Multi-d.o.f. mechanism

Constrained Mechanism

- One independent output motion. Output member is constrained to move in a particular manner only.

- Example: Four-bar mechanism
  Slider Crank Mechanism
  Five-bar mechanism with two inputs

Unconstrained mechanism

- Output motion has more than one D.O.F.
- Example: Automobile Differential during turning the vehicle on a curve

Five-bar mechanism with one input

Single D.O.F Mechanism

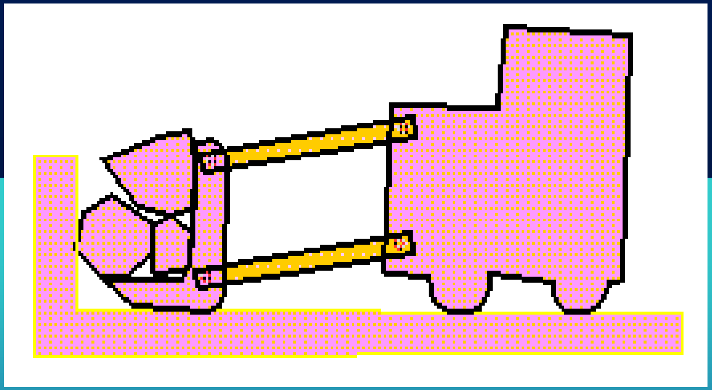
Sum of the input and output D.O.F. is two.

Single D.O.F. Motion - One Independent Input motion and one independent output motion

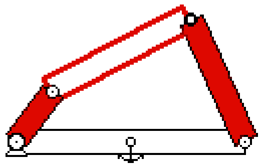
Examples : Four-Bar Mechanism

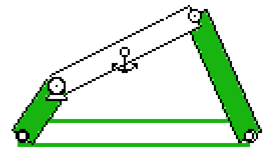
Cam-Follower Mechanism

Kurbelviereck
räumliches Kurbelviereck

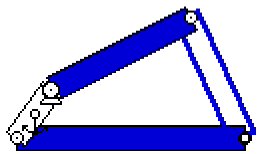


All inversions of the Grashof fourbar linkage

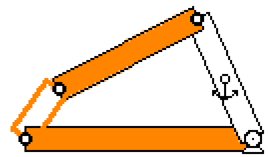




Two non-distinct
crank-rocker inversions



Double-crank inversion
(drag link)



Double-rocker inversion
(coupler rotates)

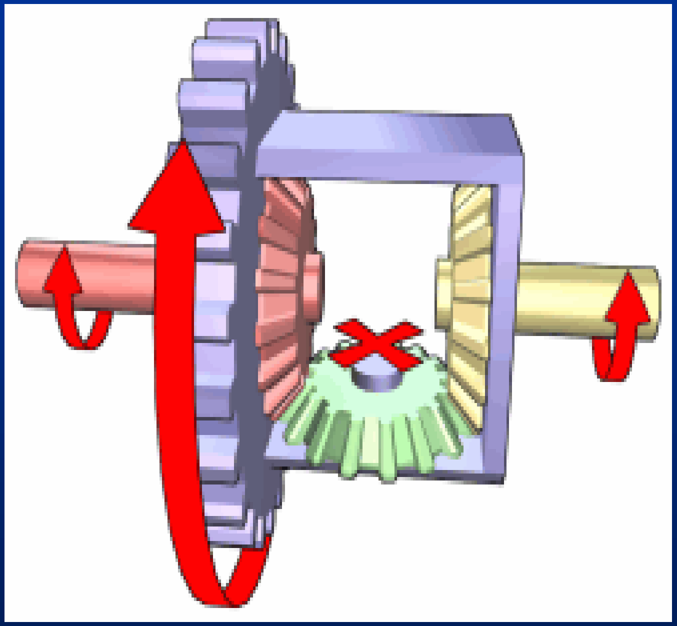
grashof_inversion

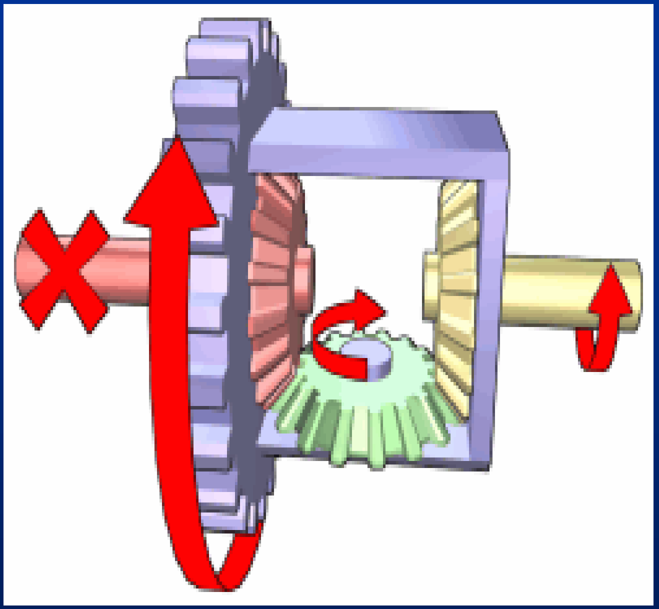
Multi D.O.F. Mechanism

Sum of the input and output motion D.O.F. is more than two.

Multi D.O.F. Motion – More than one
Independent Output / Input Motions

Examples : Automobile Differential
3-D Cam Mechanism
(Camoid)
Five-Bar Mechanism





Classification of mechanisms

- Based on the connection of the output member

- Open mechanism
- Closed mechanism

Open Mechanism

- Output member not connected to the fixed link / frame

- Robot arms
- Arms of earth movers




Closed Mechanism

- Output member connected to the frame.

- Four-bar mechanism
- Slider-crank mechanism
- Cam follower mechanism

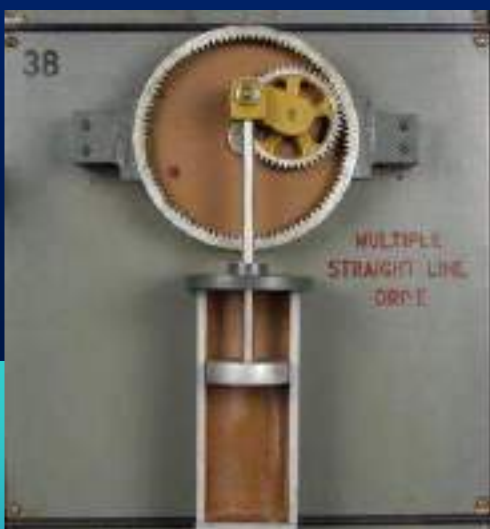
Components of Mechanisms

- Link / element
- Kinematic pairs / joints
- Kinematic chain

Link / Element

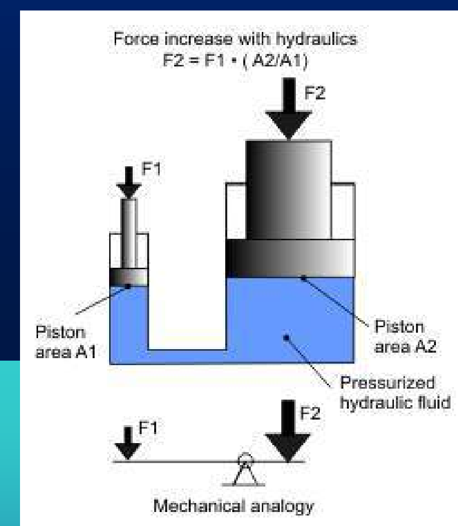
A single resistant body / combination of resistant bodies having relative motion with another resistant body / combination of resistant bodies.

Rigid Body

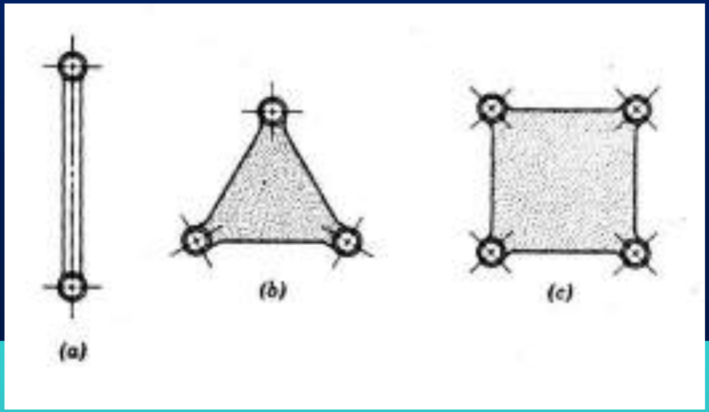


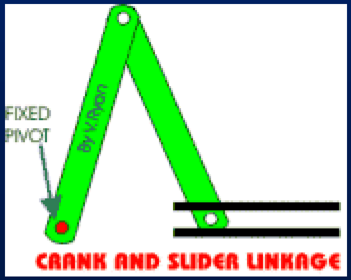
Flexible Body

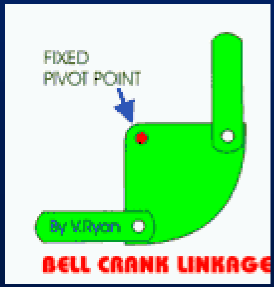
Liquid



- Link with one Node : Unary Link
- Link with two Nodes : Binary Link (a)
- Link with three Nodes : Ternary Link (b)
- Link with four Nodes : Quaternary Link (c)







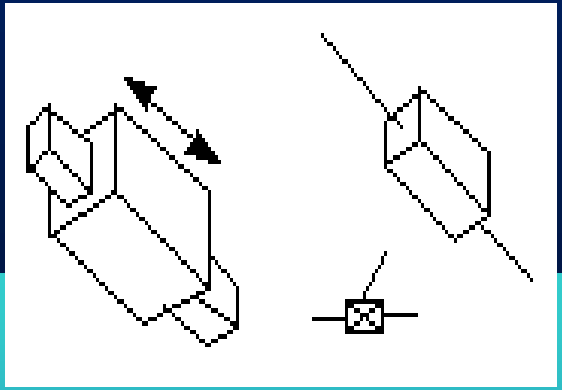
Kinematic Pairs / Joints

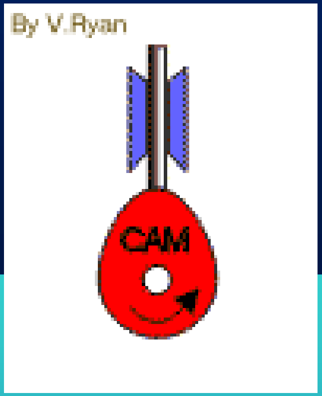
- Combination of two links kept in permanent contact permitting particular kind(s) of relative motion(s) between them

Classification of Pairs

- BASED ON NATURE OF CONTACT BETWEEN LINKS:

  1. Lower Pairs -- Surface Contact
  2. Higher Pairs – Point or Line Contact

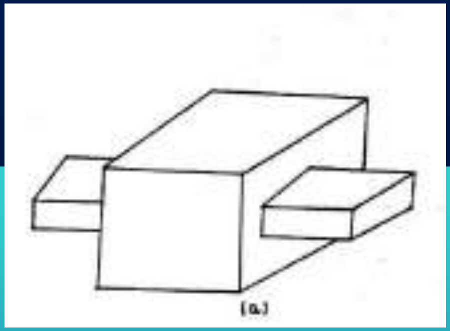


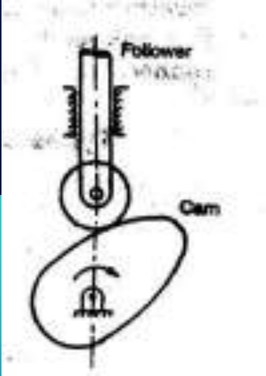


BASED ON HOW THE CONTACT IS MAINTAINED:

1. Self / Form Closed Pairs – Shape/Form of the links maintain the contact. No external force.

2. Force Closed Pairs – External forces like gravitational force, spring force etc., required to maintain the contact.



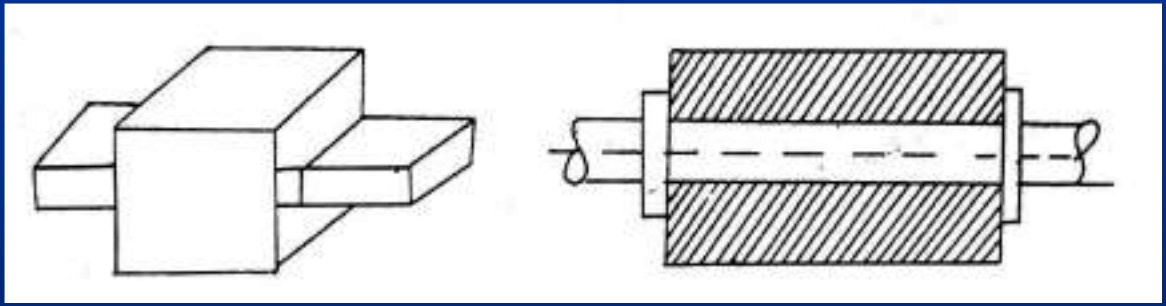


- BASED ON THE DEGREE OF FREEDOM
  1. Type I / Class I – One D.O.F
  2. Type II / Class II – Two D.O.F
  3. Type III / Class III – Three D.O.F
  4. Type IV / Class IV – Four D.O.F
  5. Type V / Class V – Five D.O.F

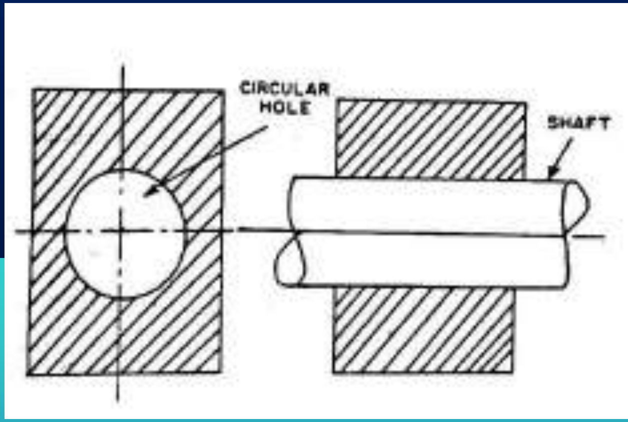
BASED ON THE NATURE OF CONSTRAINT

1. (Completely) Constrained Pair - 1 D.O.F
2. Unconstrained Pair – More than 1 D.O.F
3. Successfully Constrained pair – Unconstrained pair converted as Constrained pair by some means.

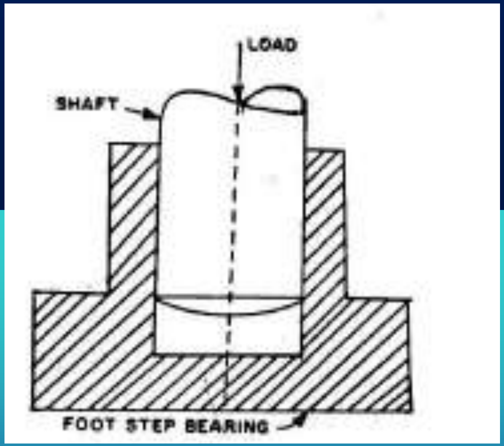
- Completely Constrained Pair



- Unconstrained Pair

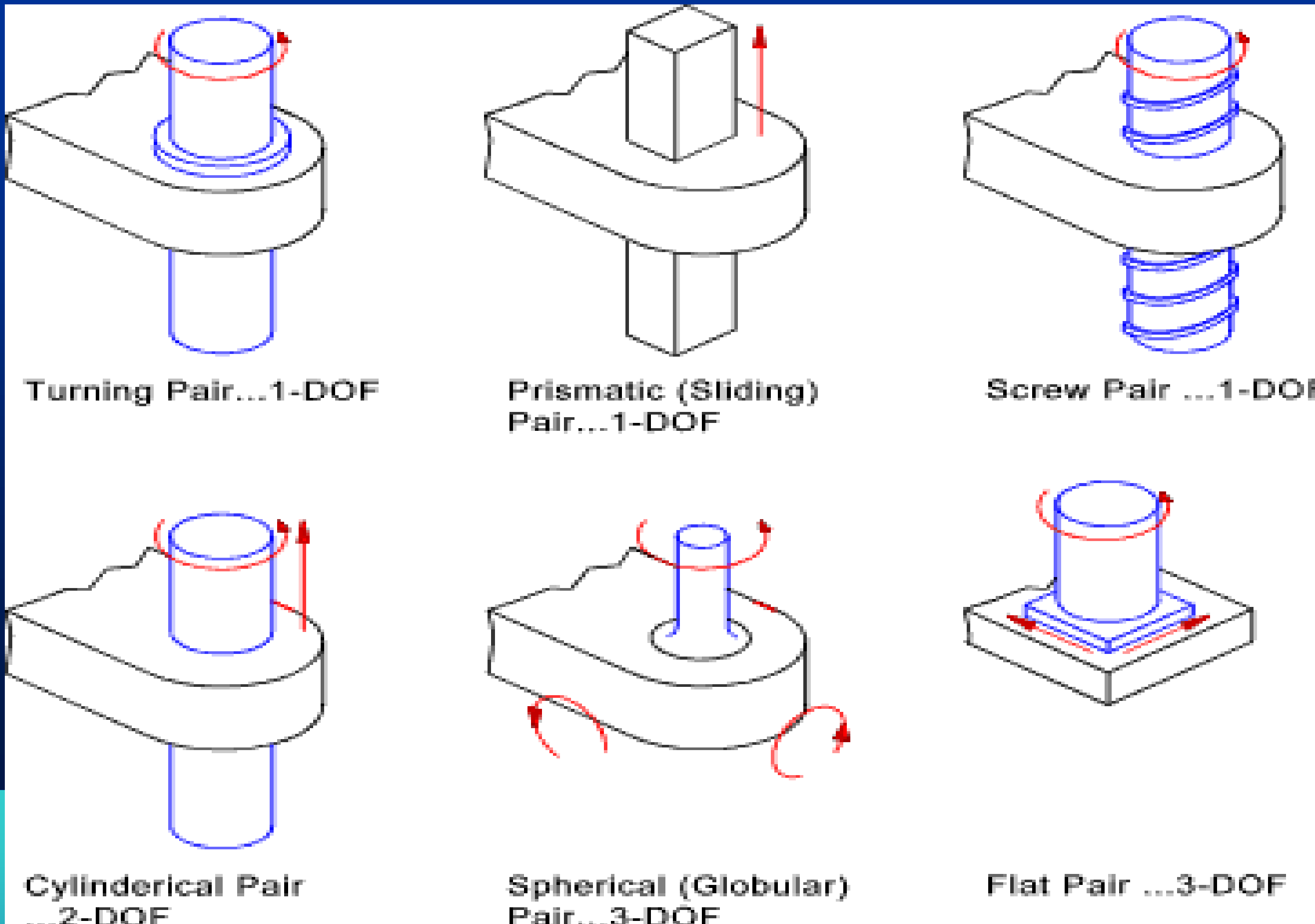


Successfully Constrained Pair



- BASED ON THE POSSIBLE MOTIONS (Few Important Types only)

Name of Pair	Letter Symbol	D.O.F
1. Revolute / Turning Pair	R	1
2. Prismatic / Sliding Pair	P	1
3. Helical / Screw Pair	H	1
4. Cylindrical Pair	C	2
5. Spherical / Globular Pair	S (or) G	3
6. Flat / Planar Pair	E	3
7. Cylindric Plane Pair	Cp	4
8. Spheric Plane Pair	Sp	5


Turning Pair…1-DOF
Prismatic (Sliding) Pair…1-DOF
Screw Pair …1-DOF
Cylinderical Pair …2-DOF
Spherical (Globular) Pair…3-DOF
Flat Pair …3-DOF

Kinematic Chain

- Assembly of links and pairs to produce required / specified output motion(s) for given input motion(s)

Mechanism

- A kinematic chain with one link fixed / stationary

Mobility / D.O.F of Mechanism

- No. of inputs required to get a constrained mechanism (or) no. of position variables needed to sketch the mechanism with all link lengths known.

- KUTZBACH CRITERION FOR PLANAR MECHANISM
- $F = 3(n-1)-2P_1-1P_2$
- F – D.O.F n – No. of links
- P_1 – No. of kinematic pairs with 1 D.O.F.
- P_2 – No. of kinematic pairs with 2 D.O.F.

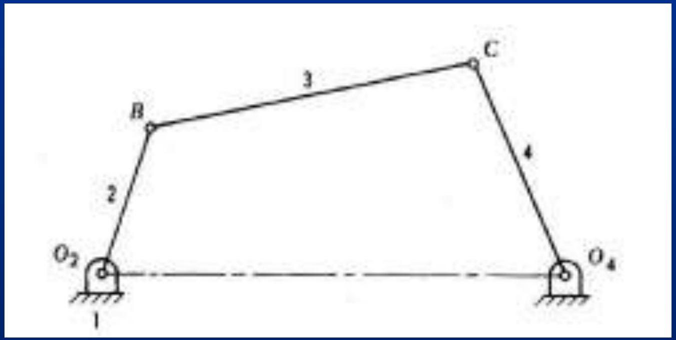
Gruebler's Criterion

- This criterion is used to find out whether an assembly of links with 1 d.o.f. lower pairs is a constrained mechanism or not.

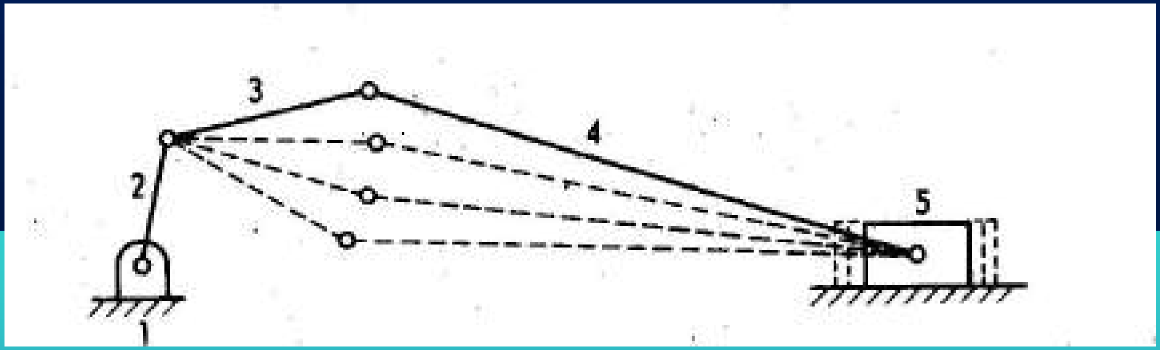
- $3n - 2l - 4 = 0$
- n – no. of links l – no.of lower pairs with one d.o.f

$F < 0$	Pre-loaded structure Super structure
$F = 0$	Structure
$F = 1$	Constrained Mechanism
$F > 1$	Unconstrained Mechanism

- Constrained Mechanism



- Unconstrained Mechanism



LINK / ELEMENT

↓

KINEMATIC PAIR / JOINT

↓

KINEMATIC CHAIN

↓

MECHANISM

↓

MACHINE

- Link / Element – A resistant body which has relative motion with another resistant body of a system.
-
- Kinematic Pair / Joint - Combination / Assembly of two links kept in permanent contact, permitting particular kind(s) of definite relative motion(s) between them.

- Kinematic Chain – Combination / Assembly of links and pairs such that each link has minimum two pairs, permitting controlled definite output motion for a specified input motion.

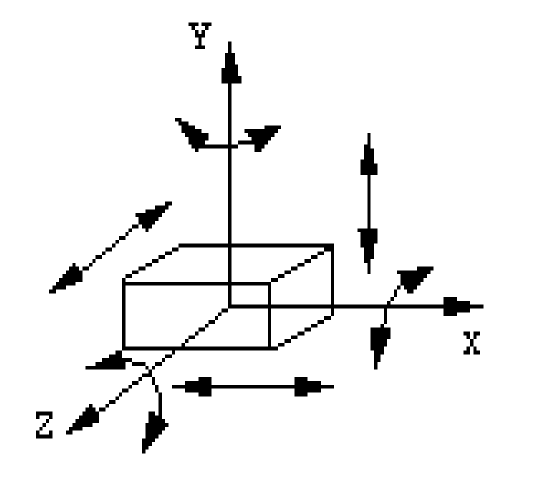
- Mechanism – A kinematic chain with one link fixed / stationary.

- Machine – A device, which has one or more mechanisms, transferring / transforming motion and energy to do required useful work easily.

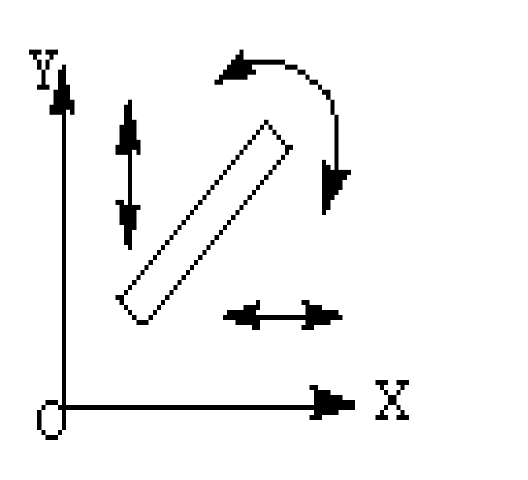
MOBILITY OR DEGREE OF FREEDOM

- For a Link – Six in spatial motion, three in planar motion.
- For a Kinematic Pair – Number of independent co-ordinates/pair variables to specify the position of one link with another link (OR) number of independent relative motions possible between the links. Maximum five and minimum one in spatial motion. Maximum two and minimum one in planar motion.
- For a Kinematic Chain/Mechanism – Number of independent position variables to sketch the configuration with known link lengths (OR) number of input motions required to get a constrained output motion

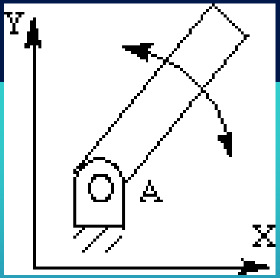
Spatial D.O.F.



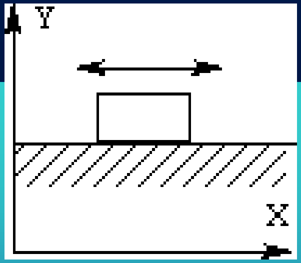
Planar D.O.F.



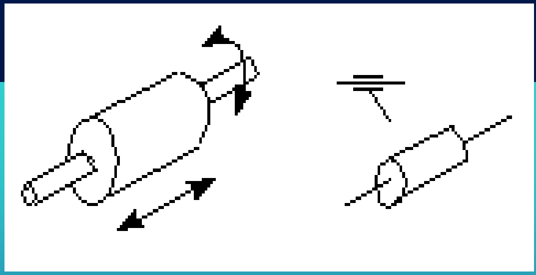
R – Pair



P – Pair



C - Pair



Kinematic Inversions

- Process of obtaining different mechanisms from the same kinematic chain, by fixing different links in turn, is known as kinematic inversion.

Four inversions are possible from four-bar kinematic chain.

Formation of four-bar mechanism

- No. of links – 4,   No. of pairs – 4.
- All the pairs are revolute pairs.
- Links are :1. Fixed link or Frame
- 2. Input Link
- 3. Coupler
- 4. Output link or Follower

Assembly Condition

- Lengths of links: Longest link - l

  Shortest link - s

  Intermediate links – p, q

$$l < s + p + q$$

Grashofian four-bar mechanism

- Atleast one link will have full rotation if

$$S + l \le p + q$$

GRASHOF' S LAW

In a planar four bar revolute pair kinematic chain if the sum of the lengths of the shortest and the longest links is less than or equal to the sum of the lengths of the other two intermediate links at least one link will have full rotation.

Mechanisms obtained from the kinematic chain satisfying these conditions are known as Grashofian Mechanisms.

Mechanisms obtained from the kinematic chain which are not obeying these conditions are known as Non-Grashofian Mechanisms.

Inversions of four bar Mechanisms are named based on the motions of input link and output link.

Crank - Link with 360 degree rotation

Rocker/Lever – Link with less than 360 degree rotation

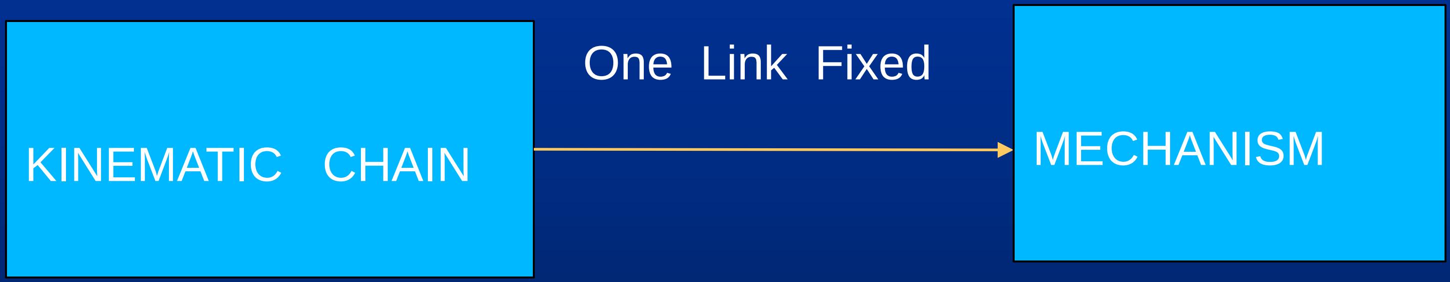
Four- bar Inversions

- Crank – Rocker Mechanisms (Two)
- Drag Link / Double Crank Mechanism
- Double – Rocker Mechanism
- Above are Grashofian Inversions

- All four non-Grashofian inversions are Double – Rocker mechanisms

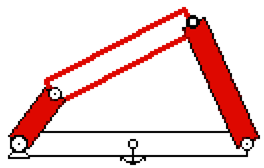
Rockers of Grashofian Mechanisms will have less than 180 degree rotation.

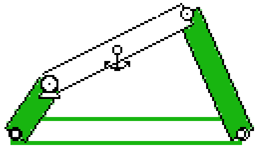
Rockers of Non-Grashofian Mechanisms can have greater than 180 degree rotation.



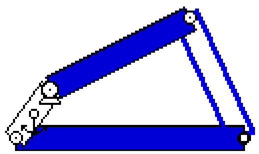
Inversion of the kinematic chain depends upon which link is fixed.

All inversions of the Grashof fourbar linkage

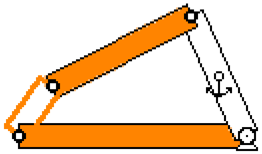




Two non-distinct
crank-rocker inversions



Double-crank inversion
(drag link)



Double-rocker inversion
(coupler rotates)

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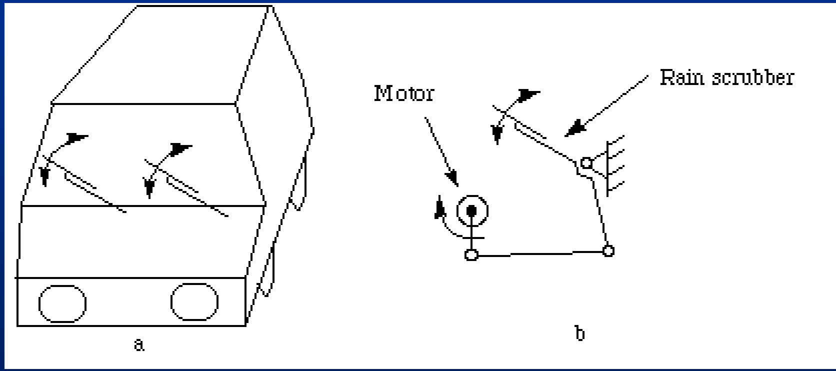
grashof_inversion

Conditions for Inversions

POSITION OF SHORTEST LINK	F0UR – BAR INVERSION
Adjacent to the fixed link	Crank – Rocker
Fixed link itself	Drag Link (Double Crank)
Opposite to fixed link	Double Rocker

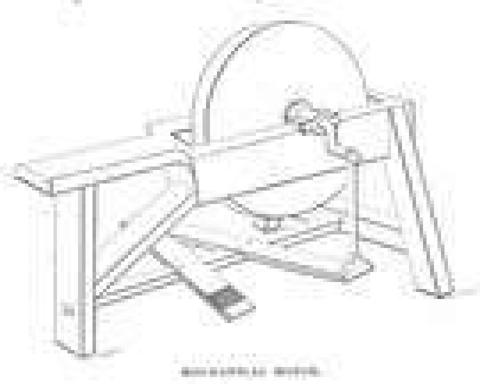
Examples for Crank – Rocker Mechanism

1. Wind shield wiper mechanism on Driver Side

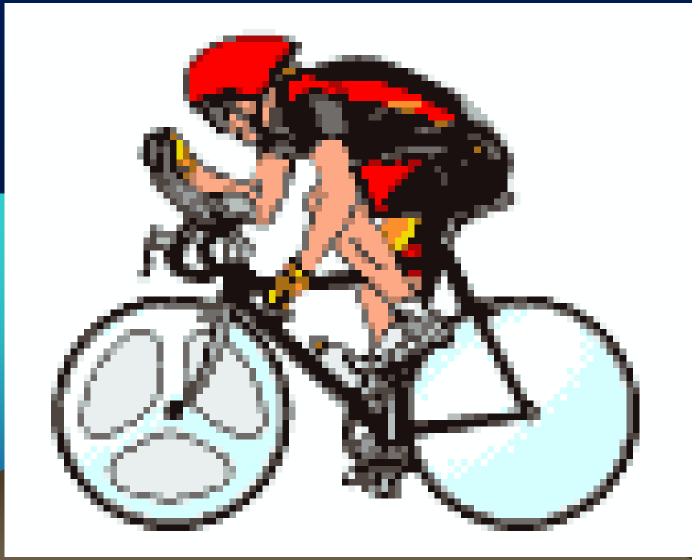


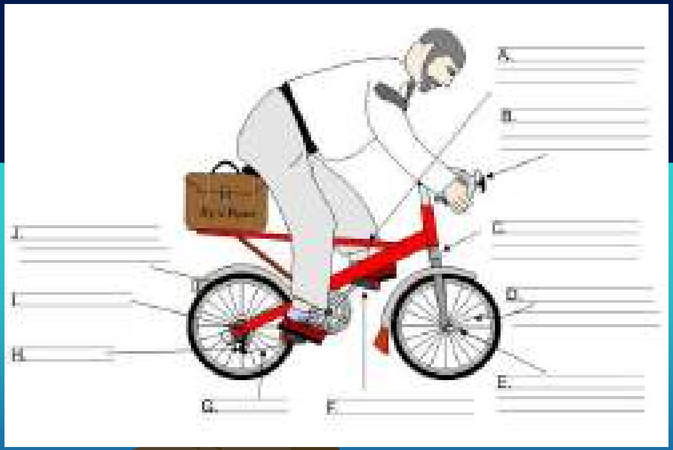
2. Sewing Machine Treadle Mechanism

3. Grinding Wheel Treadle Mechanism



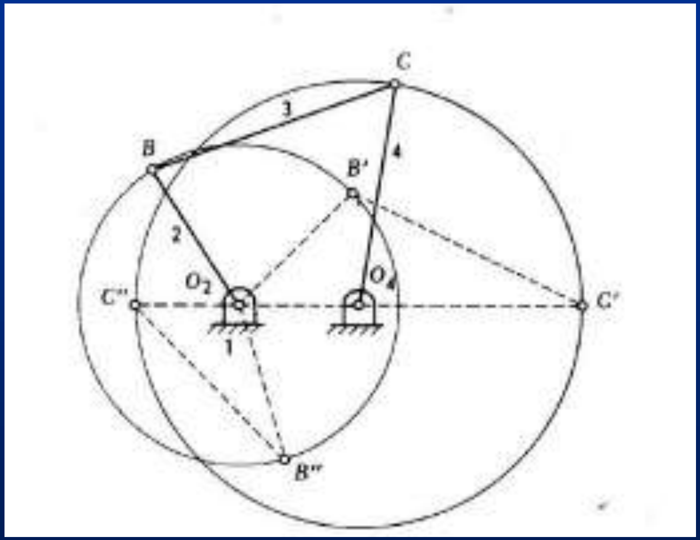
4. Pedaling action of a Bicycle



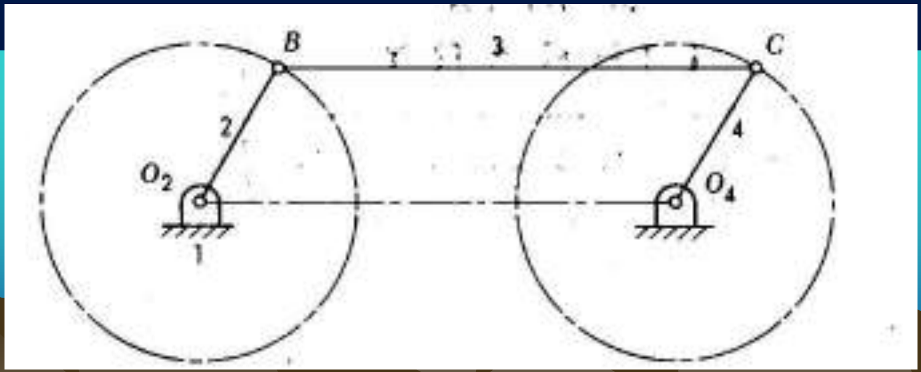


Example for Double Crank / Drag Link Mechanism

1.

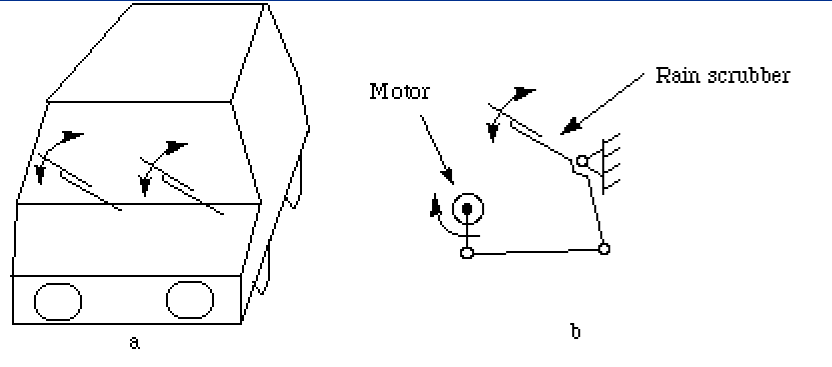


2. Locomotive Wheels Mechanism

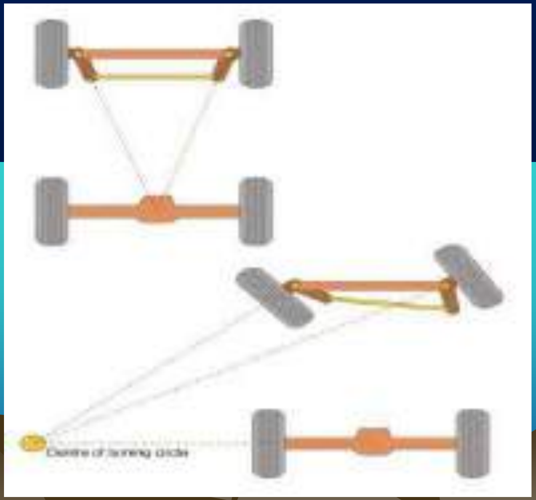


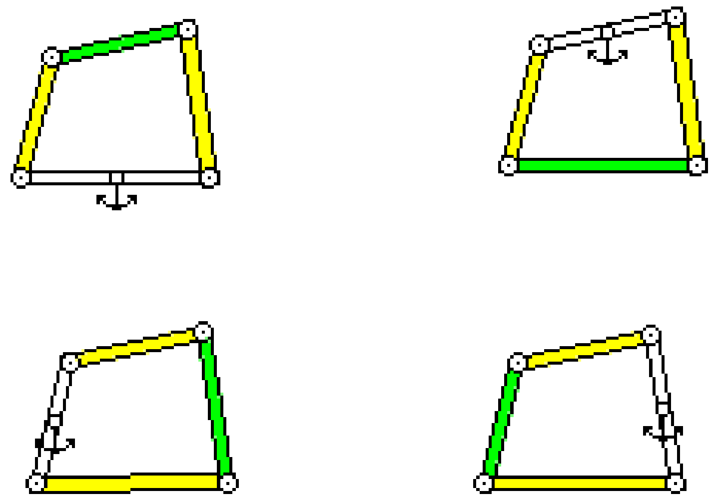
Example for Double Rocker Mechanism

1. Wind Shield wiper on Passenger Side



2. Ackerman's Steering Gear Mechanism





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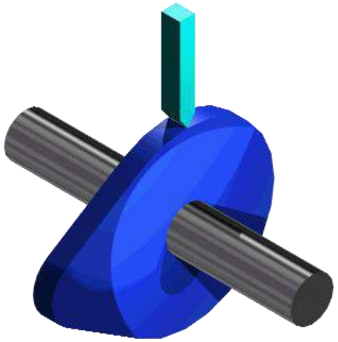
inversions_non-grashof

Cams



- Cams are used to convert rotary motion to oscillatory motion (almost always) or oscillatory motion to rotary motion (rarely)
- For high speed applications – example, internal combustion engines
- Objectives of this chapter:
  - Learn fundamental concepts and terminology
  - Learn how to design a cam and follower set to achieve a desired output motion.

Cam types

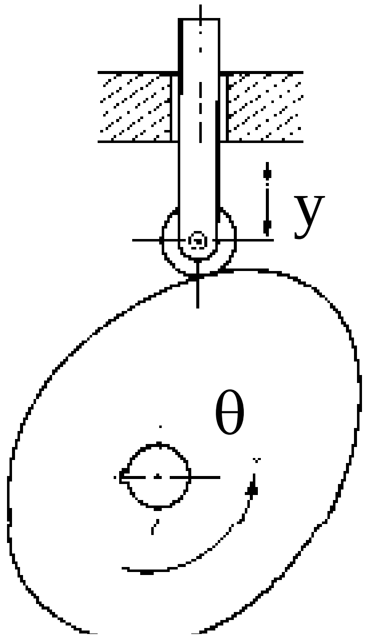
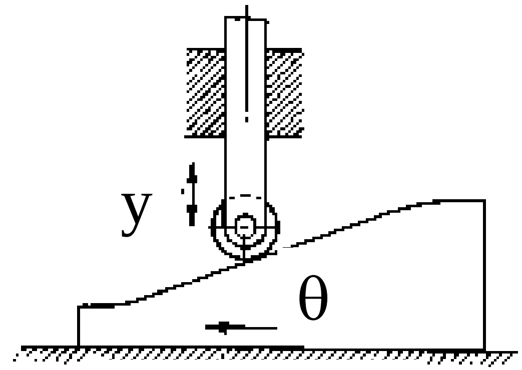
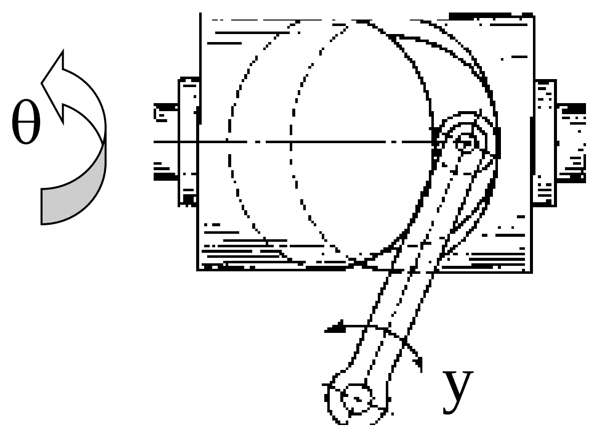


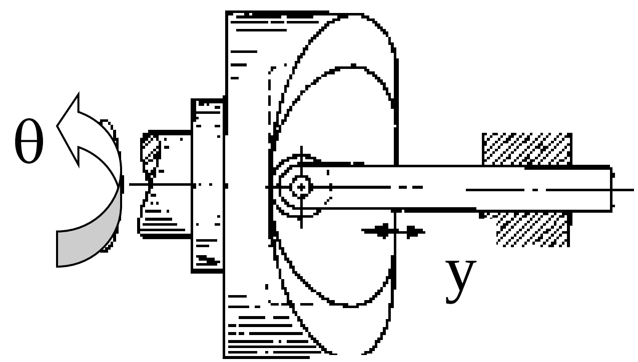
Plate cam



Wedge cam



Barrel cam

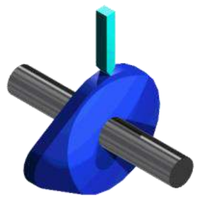


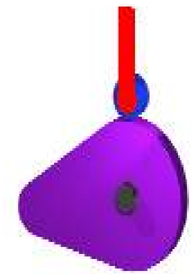
Face cam

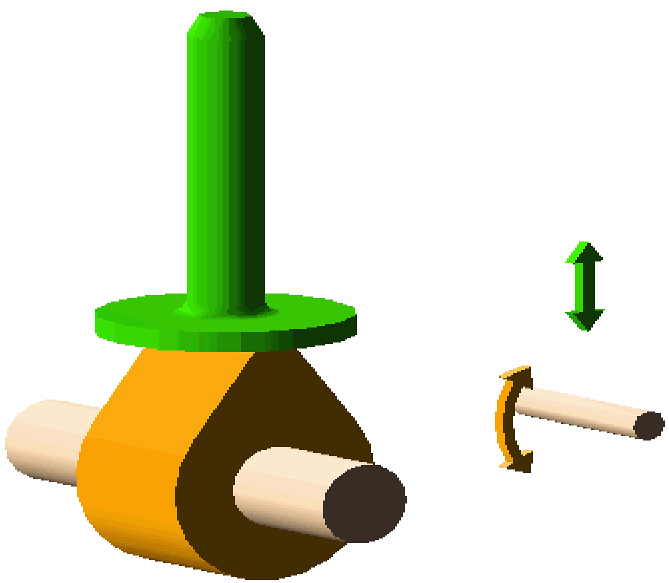
1.3 Classification of followers

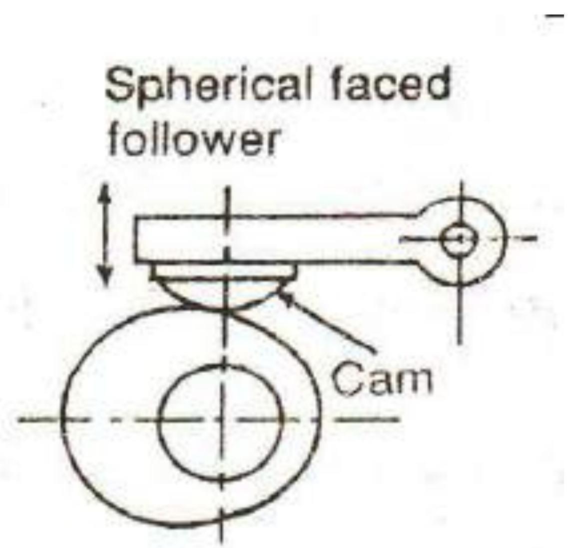
1.3.1 According to the shape of follower

- Knife edge follower
- Roller follower
- Flat faced follower
- Spherical faced follower







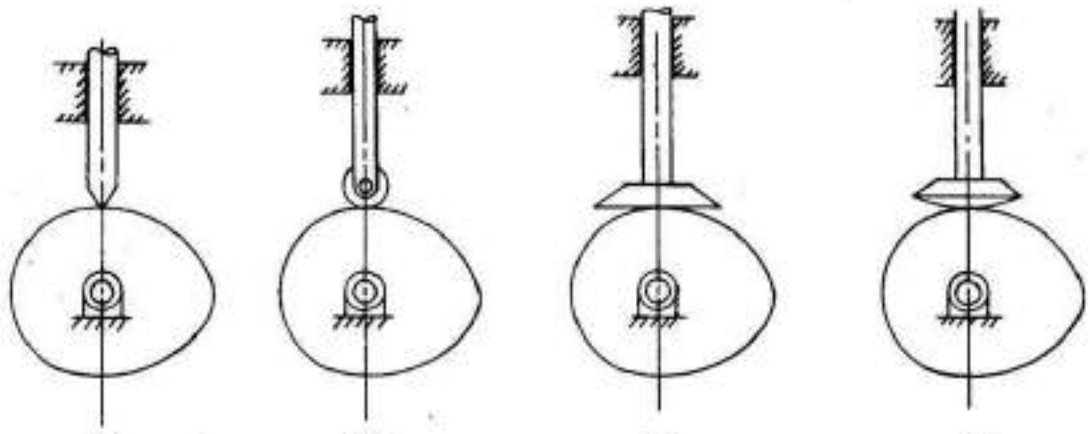

Spherical faced follower
Cam

1.3.2 According to the path of motion of follower

a) Radial follower

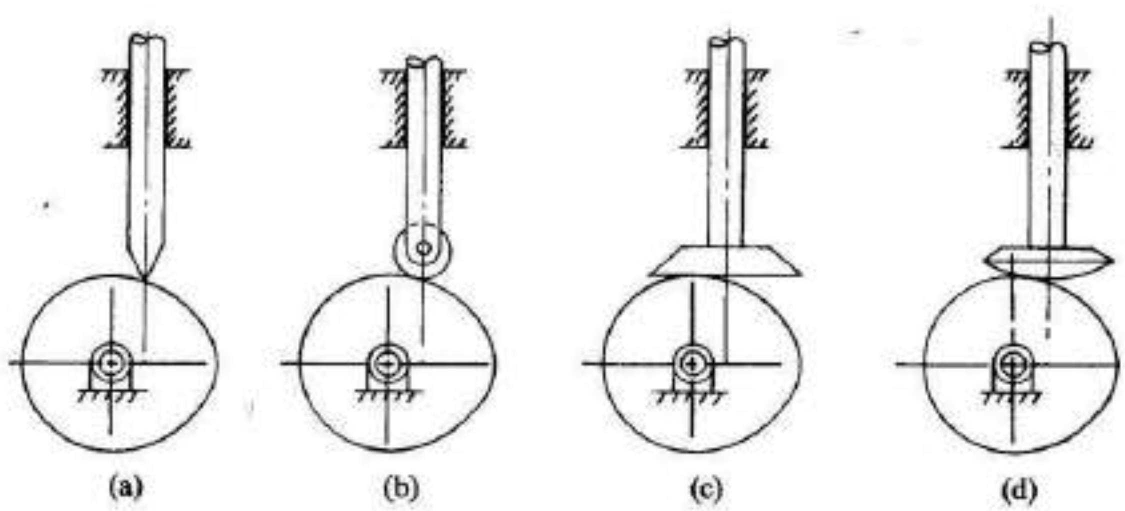
b) Offset follower

a) Radial follower



- When the motion of the follower is along an axis passing through the centre of the cam, it is known as radial followers. Above figures are examples of this type.

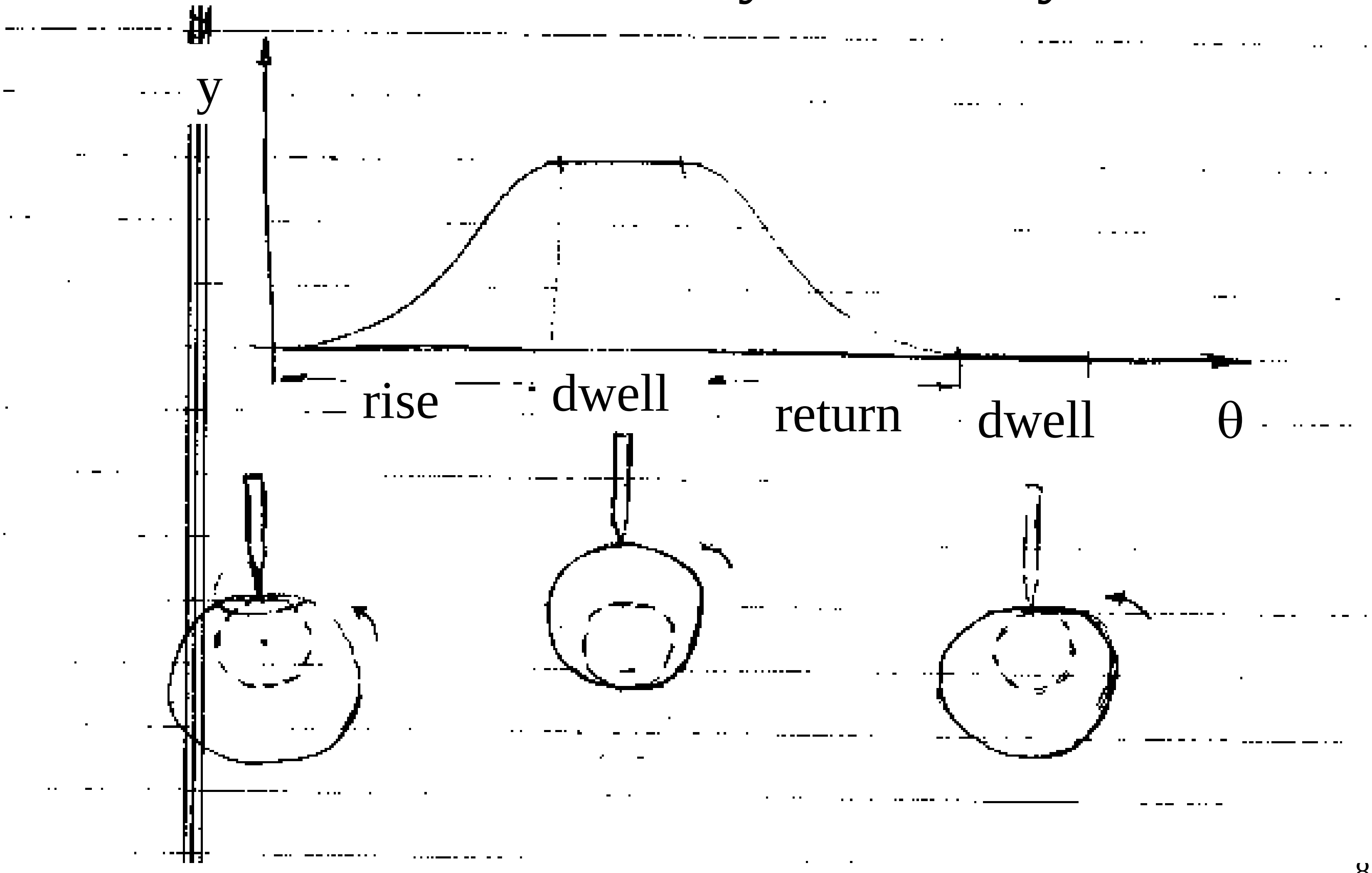
b) Offset follower



When the motion of the follower is along an axis away from the axis of the cam centre, it is called off-set follower. Above figures are examples of this type.

Displacement diagrams

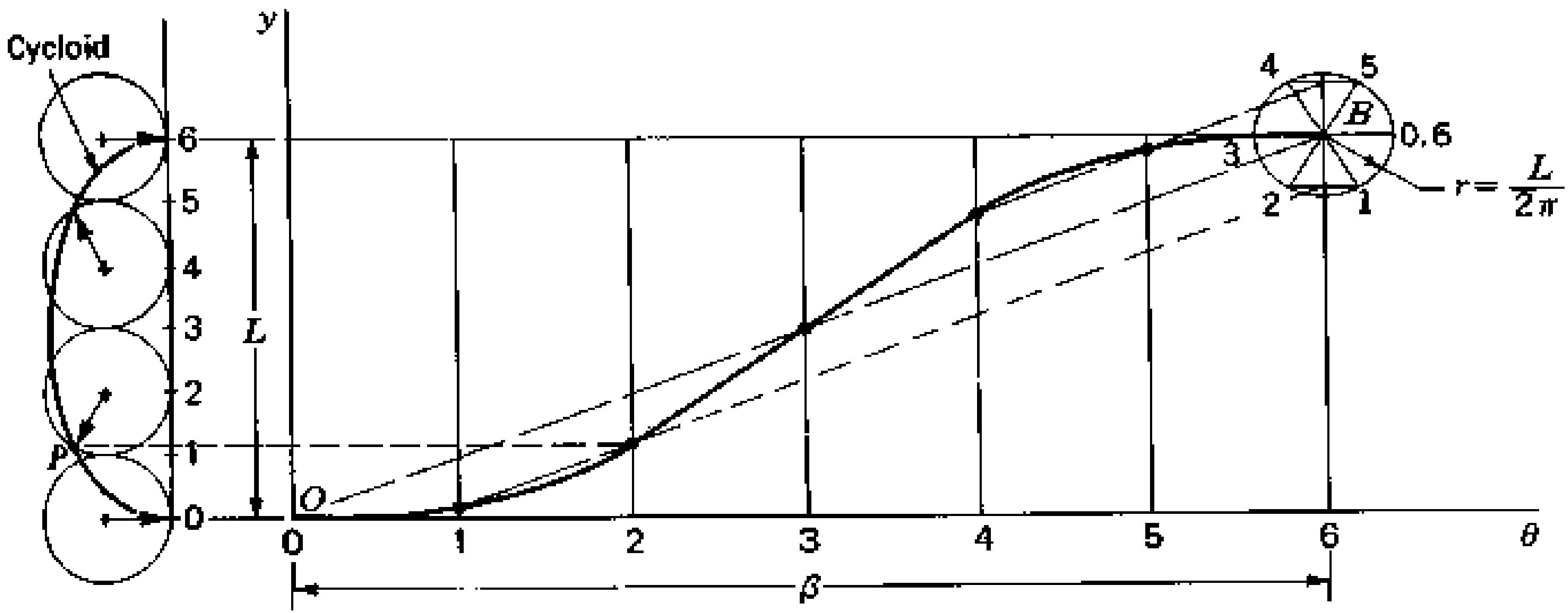
- Cam-follower: usually 1-DOF system



Displacement diagram types

- Uniform motion,
  - Constant velocity
  - Problem: infinity acceleration at point where dwell portion starts
- Parabolic-uniform
  - Can be shown that acceleration is constant
- Sinusoidal (simple harmonic motion)
- Cycloidal

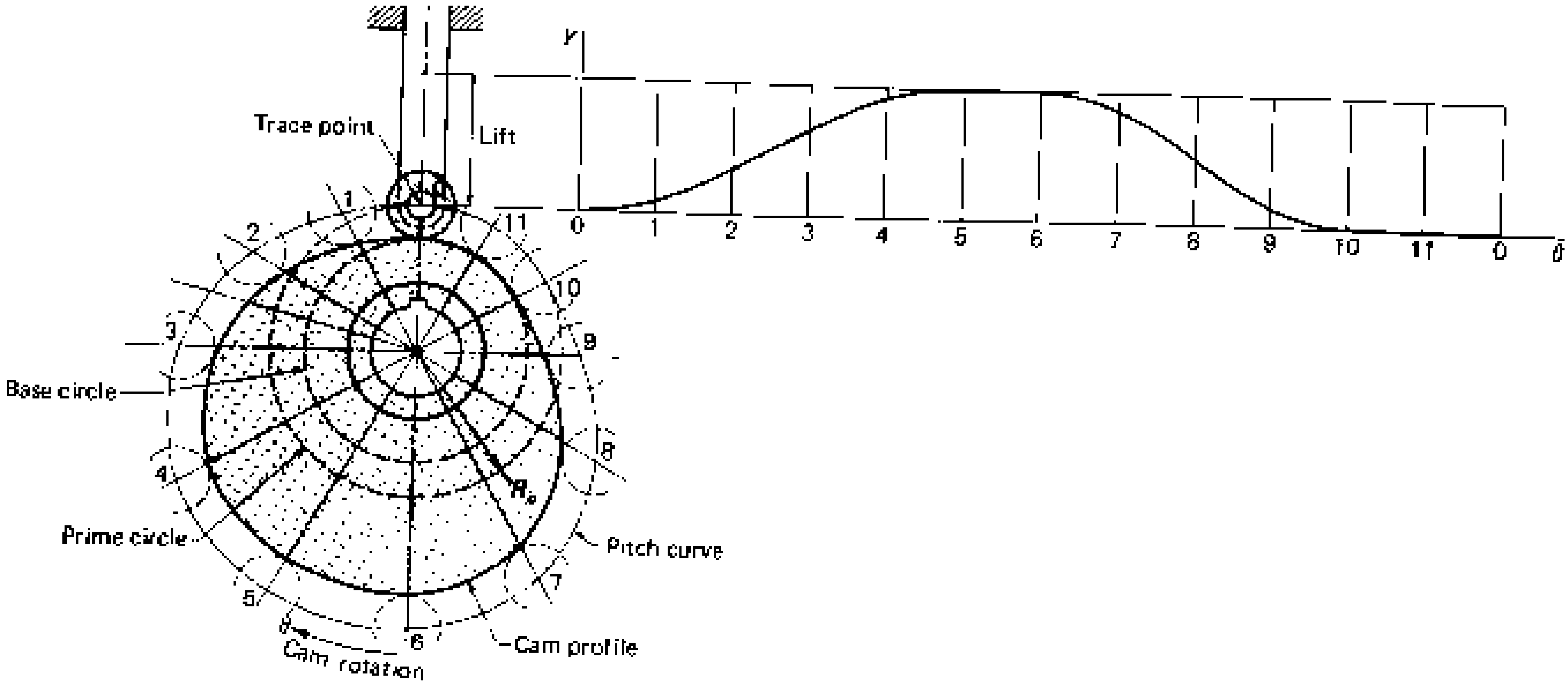
Cycloidal displacement diagram



Graphical layout of cam profiles

- Terminology
  - Trace point: on follower; point of fictitious knife-edge follower. Center of roller, surface of flat-faced follower.
- Pitch curve
  - Locus generated by trace point as follower moves relative to cam
- Prime circle
  - Smallest circle that can be drawn with center at the cam rotation axis and is tangent to the pitch circle
- Base circle
  - Smallest circle centered on cam rotation axis and is tangent to the cam surface

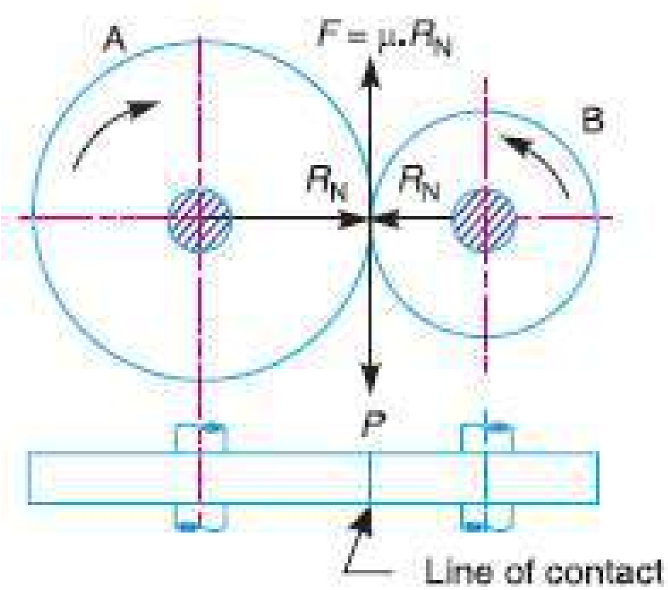
Layout of cam profile: roller follower



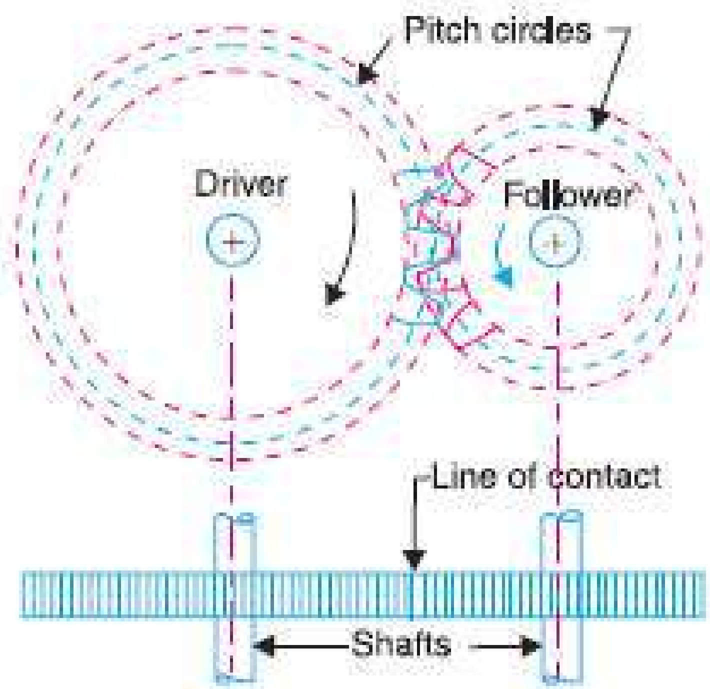
NEED FOR GEARS

- The slipping of a belt or rope is a common phenomenon, in the transmission of motion or power between two shafts.
- The effect of slipping is to reduce the velocity ratio of the system
- The only positive drive is by means of ***gears.***
- A gear drive is also provided, when the distance between the driver and the follower is very small.

FRICTION WHEELS



(a) Friction wheels.



(b) Toothed wheels.

Advantages of Gear Drive

- It transmits exact velocity ratio.
- It may be used to transmit large power.
- It has high efficiency.
- It has reliable service.
- It has compact layout.

Disadvantages of Gear Drive

- The manufacture of gears require special tools and equipment.

- The error in cutting teeth may cause vibrations and noise during operation.

Classification of Gears

- ***According to the position of axes of the shafts.***

  (a) Parallel, (b) Intersecting, and

  (c) Non-intersecting and non-parallel.

- ***According to the peripheral velocity of the gears.***

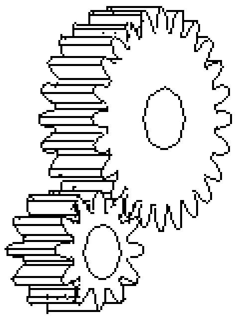
  (a) Low velocity, (b) Medium velocity, and (c) High velocity.

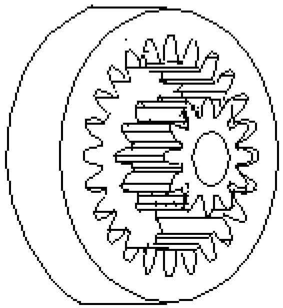
- ***According to the type of gearing.***

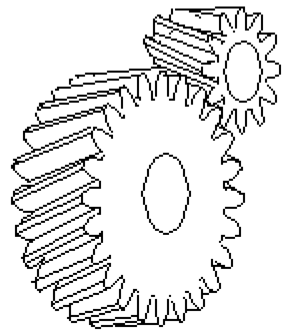
  (a) External gearing, (b) Internal gearing, and (c) Rack and pinion.

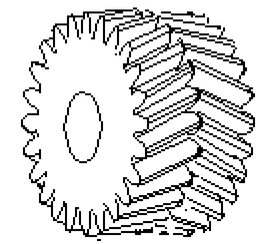
According to the position of axes of the shafts

Gears for connecting parallel shafts









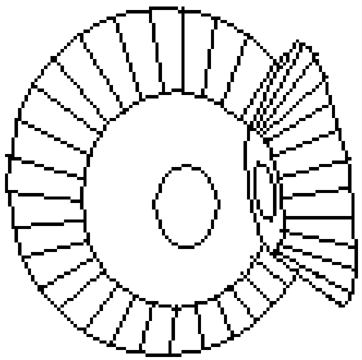
Spur gears

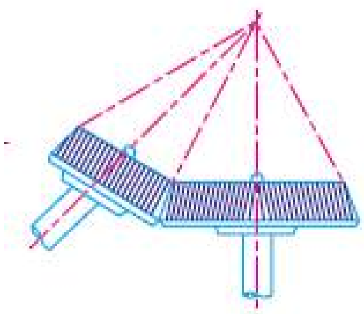
Parallel helical gears

Herringbone gears
(or double-helical gears)

According to the position of axes of the shafts

Gears for connecting intersecting shafts

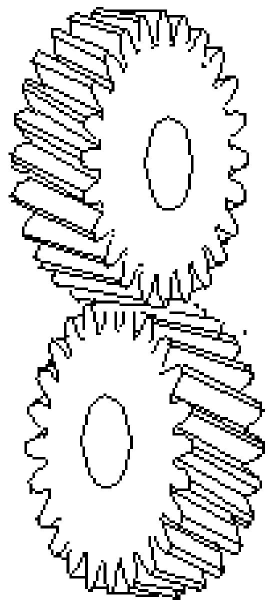




Bevel gears

According to the position of axes of the shafts

Neither parallel nor intersecting shafts

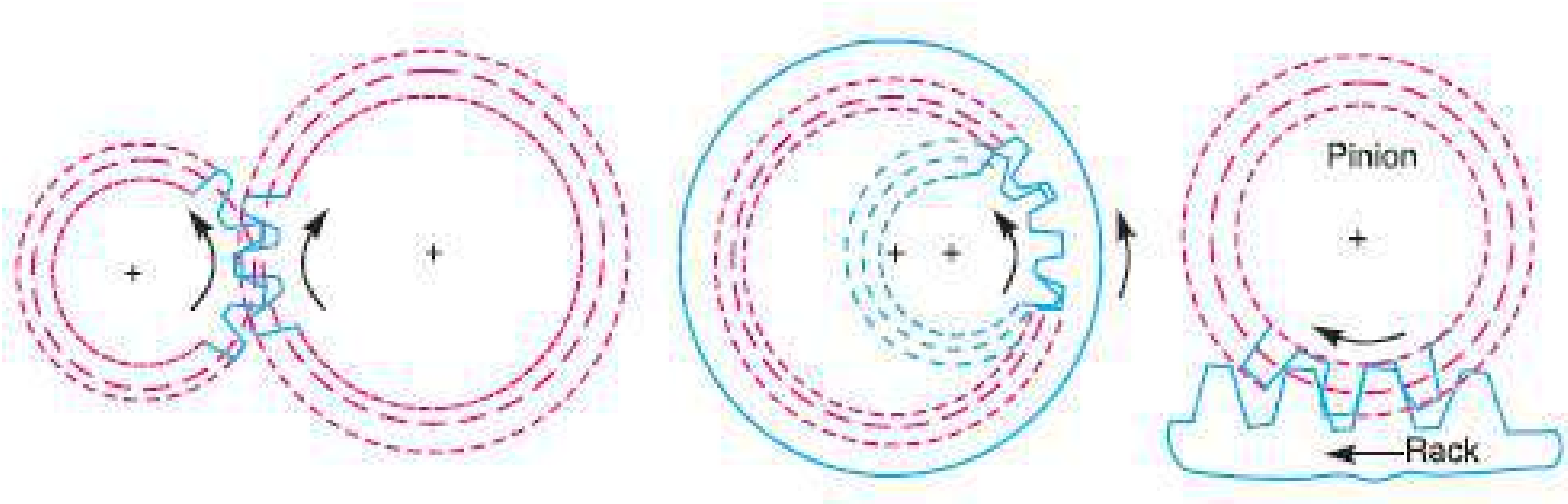


Crossed-helical gears

According to the peripheral velocity of the gears

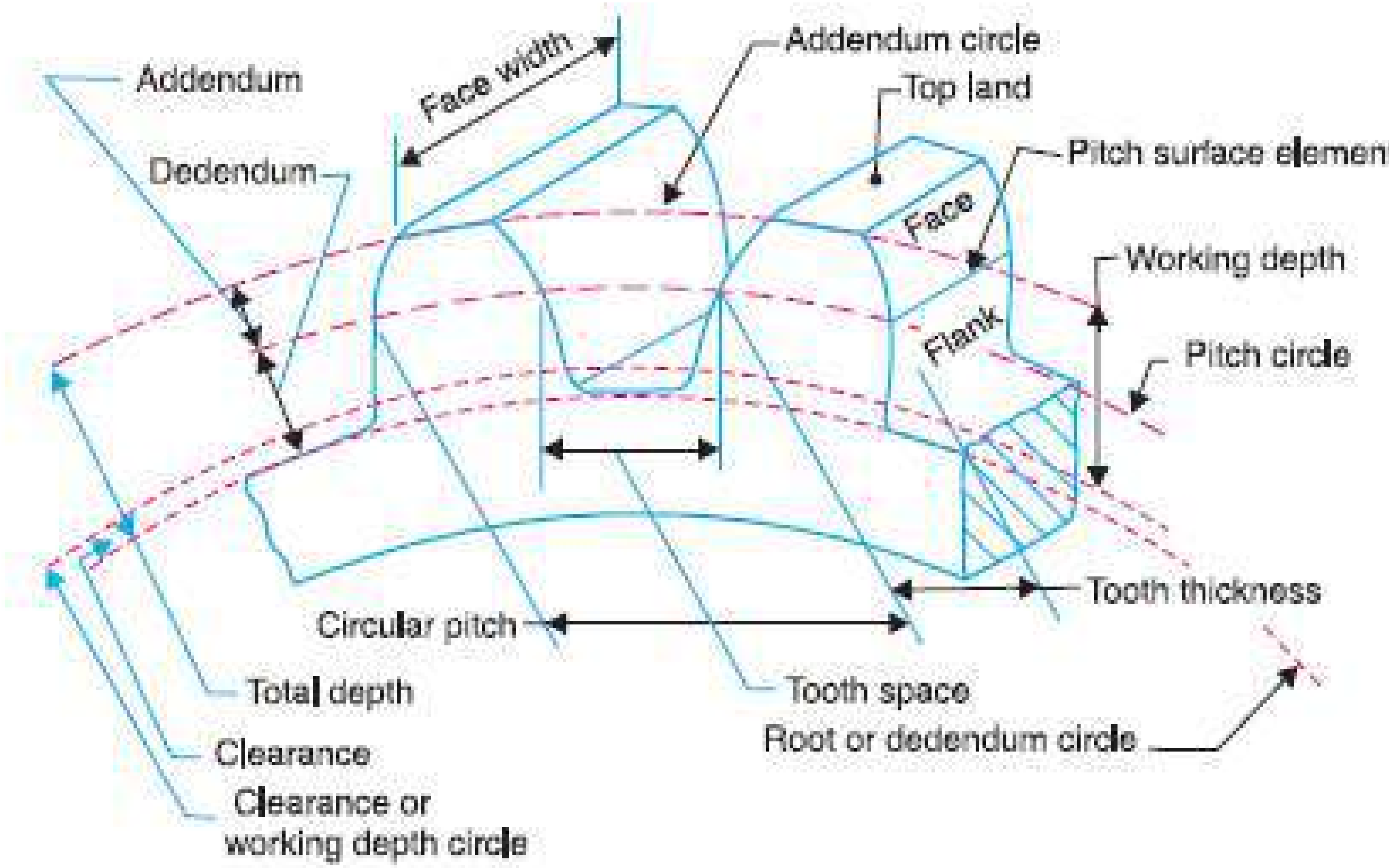
- The gears having velocity less than 3 m/s are termed as ***low velocity gears.***
- *Gears having* velocity between 3 and 15 m/s are known as ***medium velocity gears.***
- *If the velocity of gears is more* than 15 m/s, then these are called ***high speed gears.***

According to the type of gearing



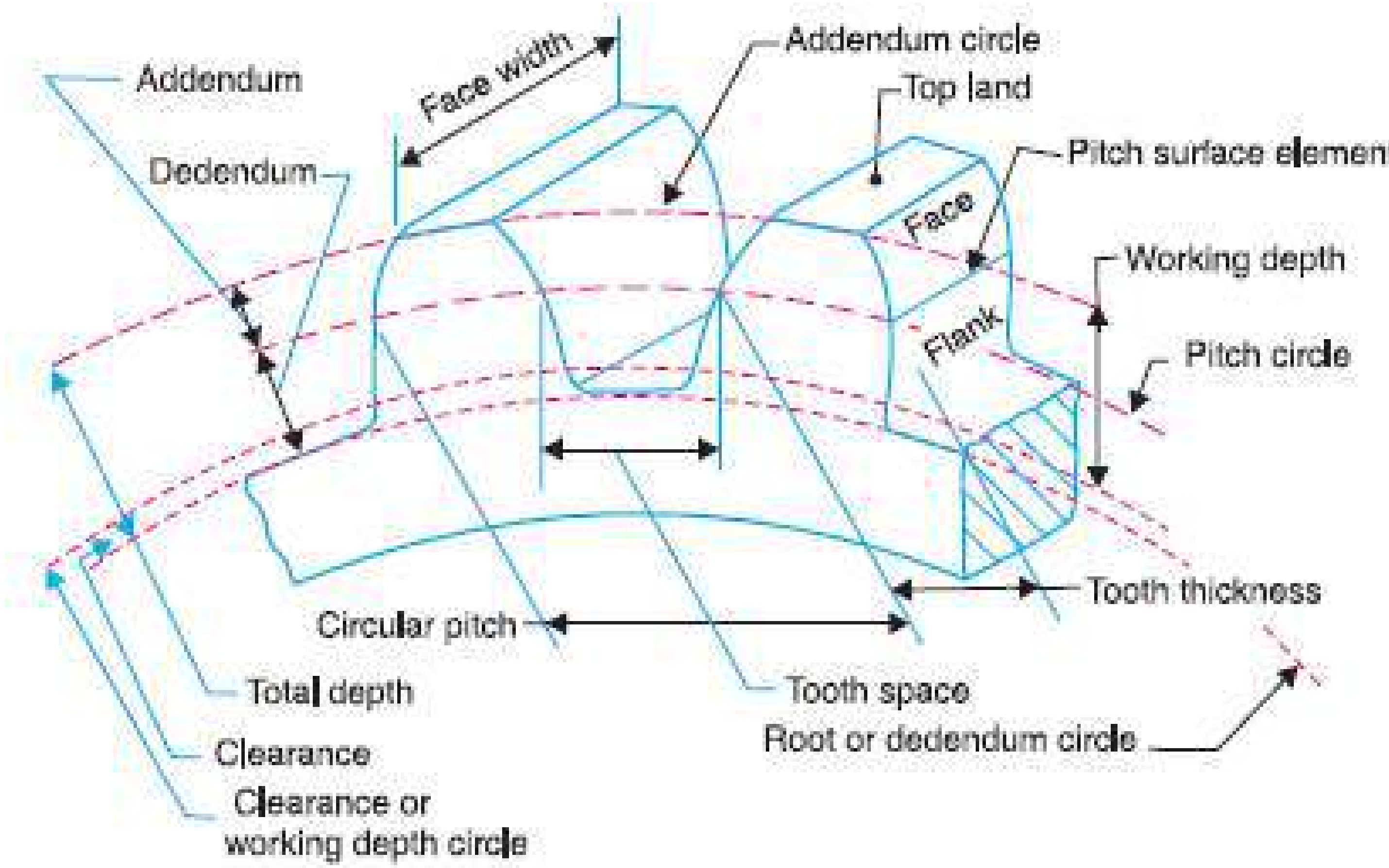
(a) External gearing, ***(b) Internal gearing,*** ***(c) Rack and pinion.***

Terms Used in Gears



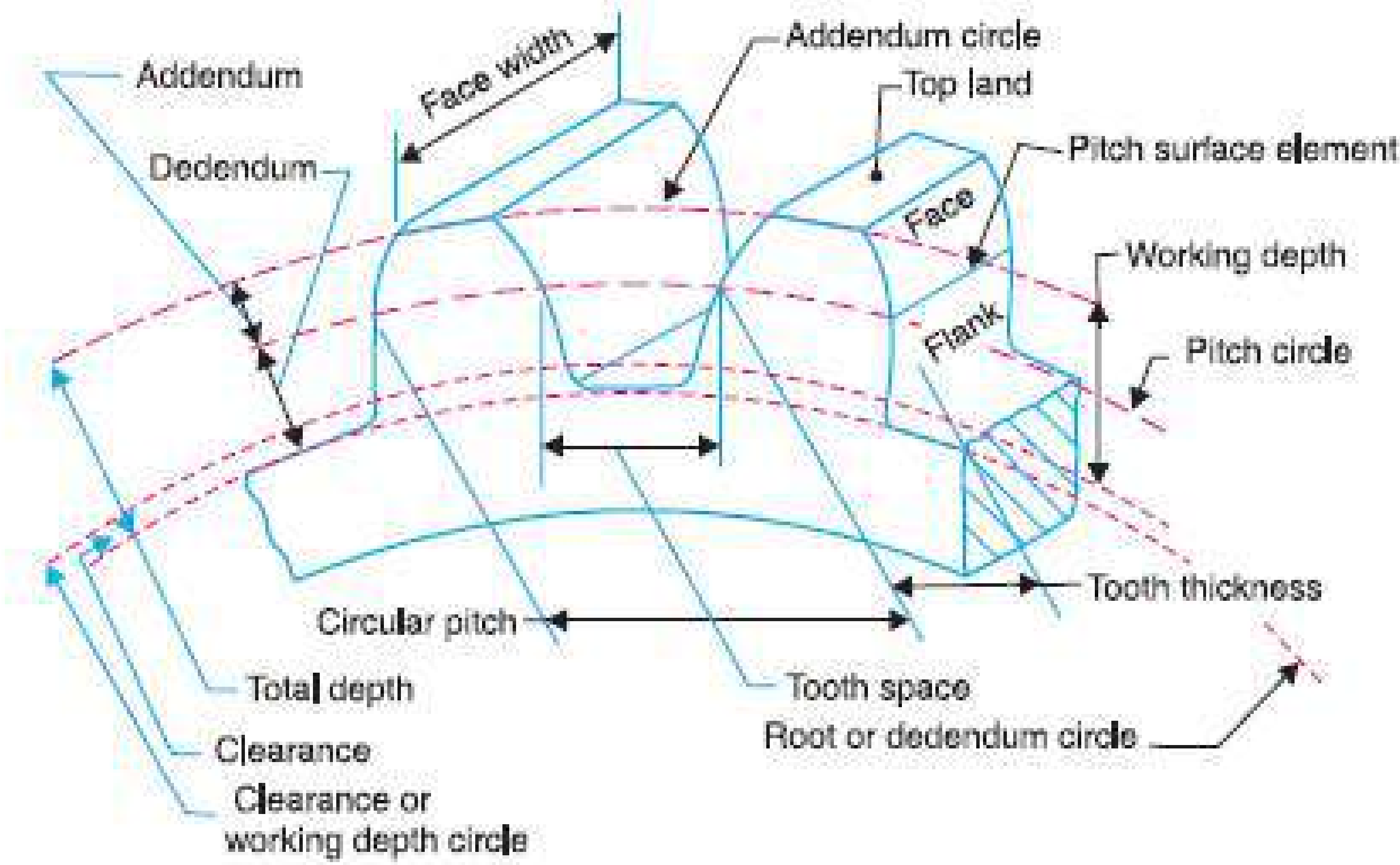
Pitch circle: It is an imaginary circle which by pure rolling action, would give the same motion as the actual gear.

Terms Used in Gears



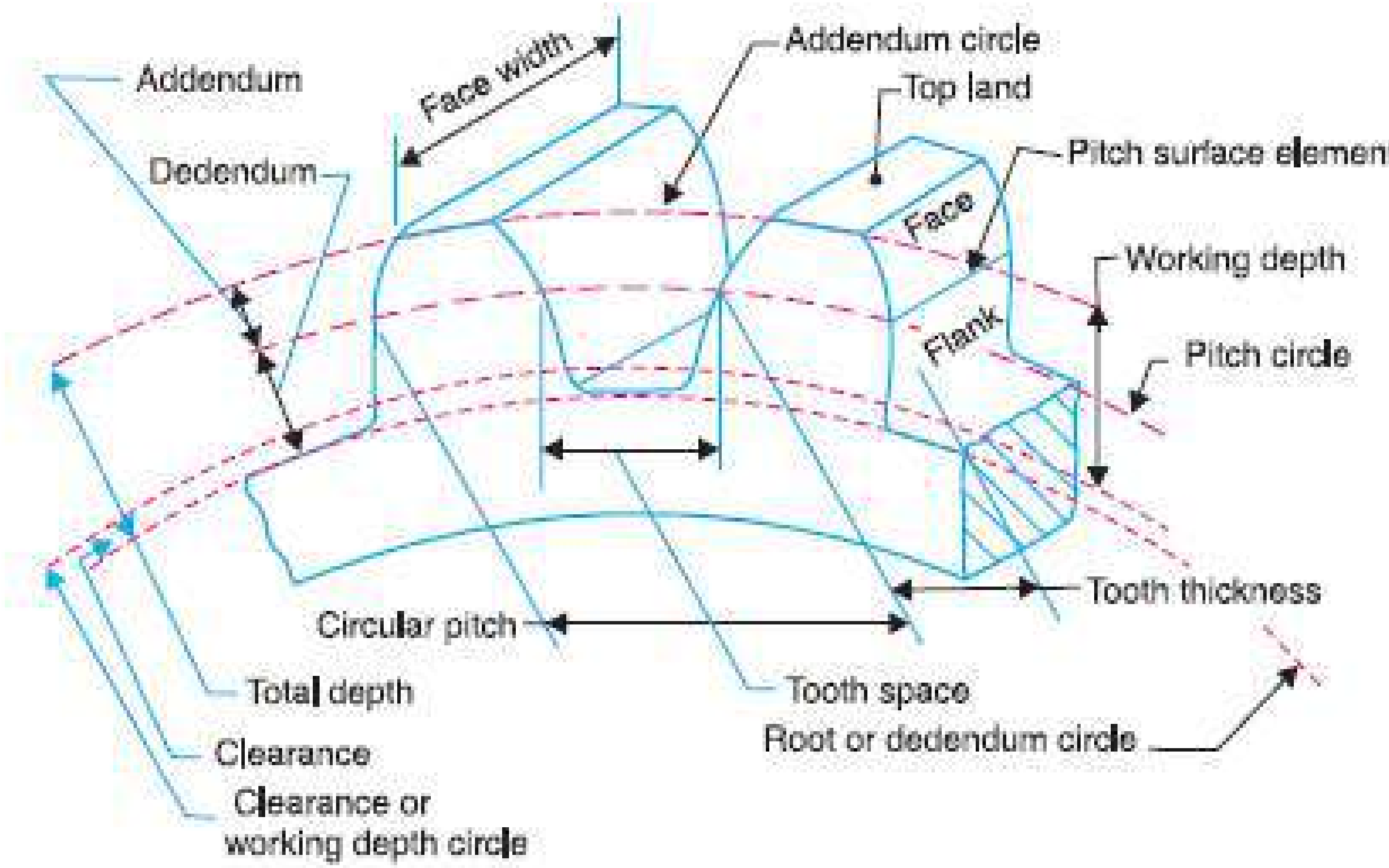
Pitch circle diameter: It is the diameter of the pitch circle. The size of the gear is usually specified by the pitch circle diameter. It is also known as pitch diameter.

Terms Used in Gears



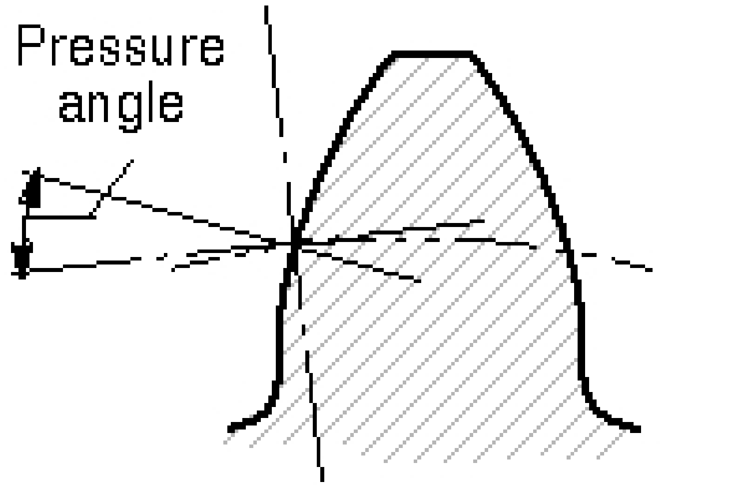
Pitch point: It is a common point of contact between two pitch circles.

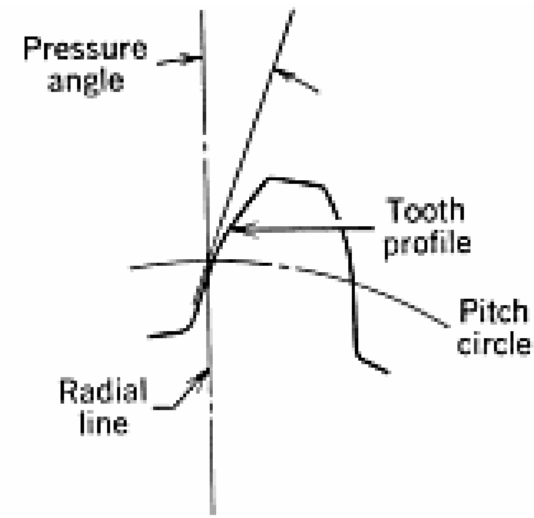
Terms Used in Gears



Pitch surface: It is the surface of the rolling discs which the meshing gears have replaced at the pitch circle.

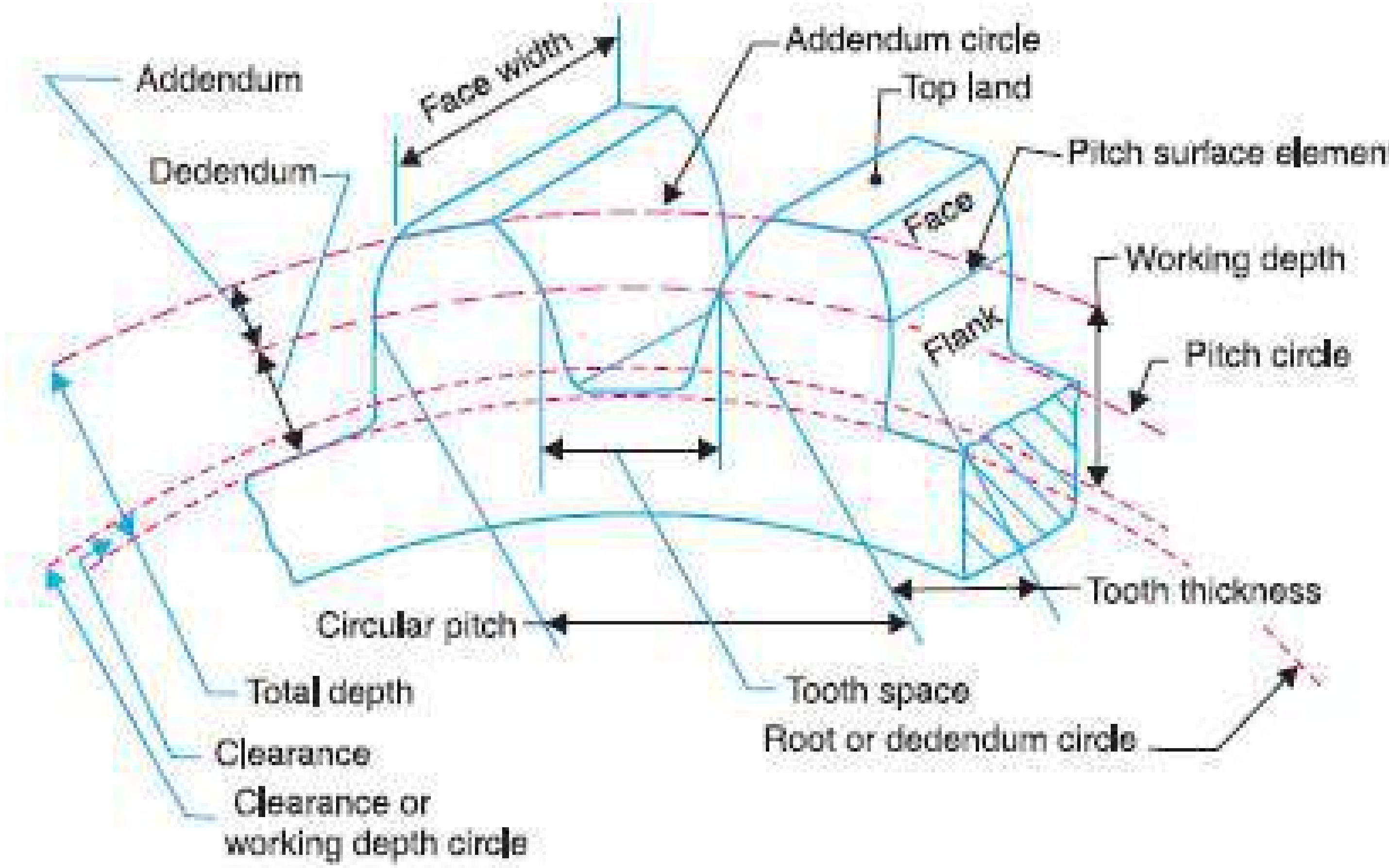
Terms Used in Gears





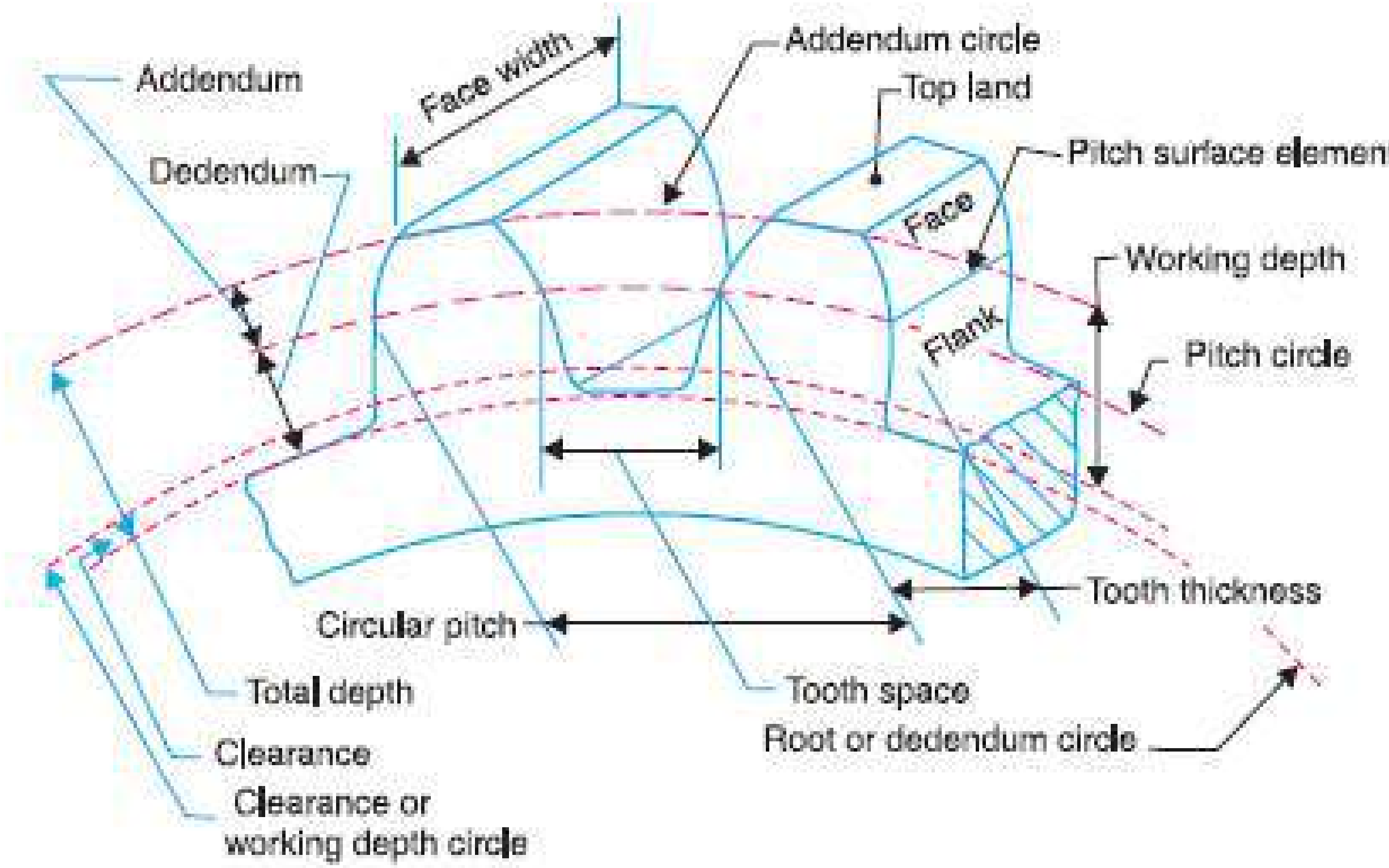
Pressure angle or angle of obliquity: It is the angle between the common normal to two gear teeth at the point of contact and the common tangent at the pitch point. It is usually denoted by φ. The standard pressure angles are 14.5° and 20°. It can also be defined as The angle between a tooth profile and a radial line at the pitch circle.

Terms Used in Gears



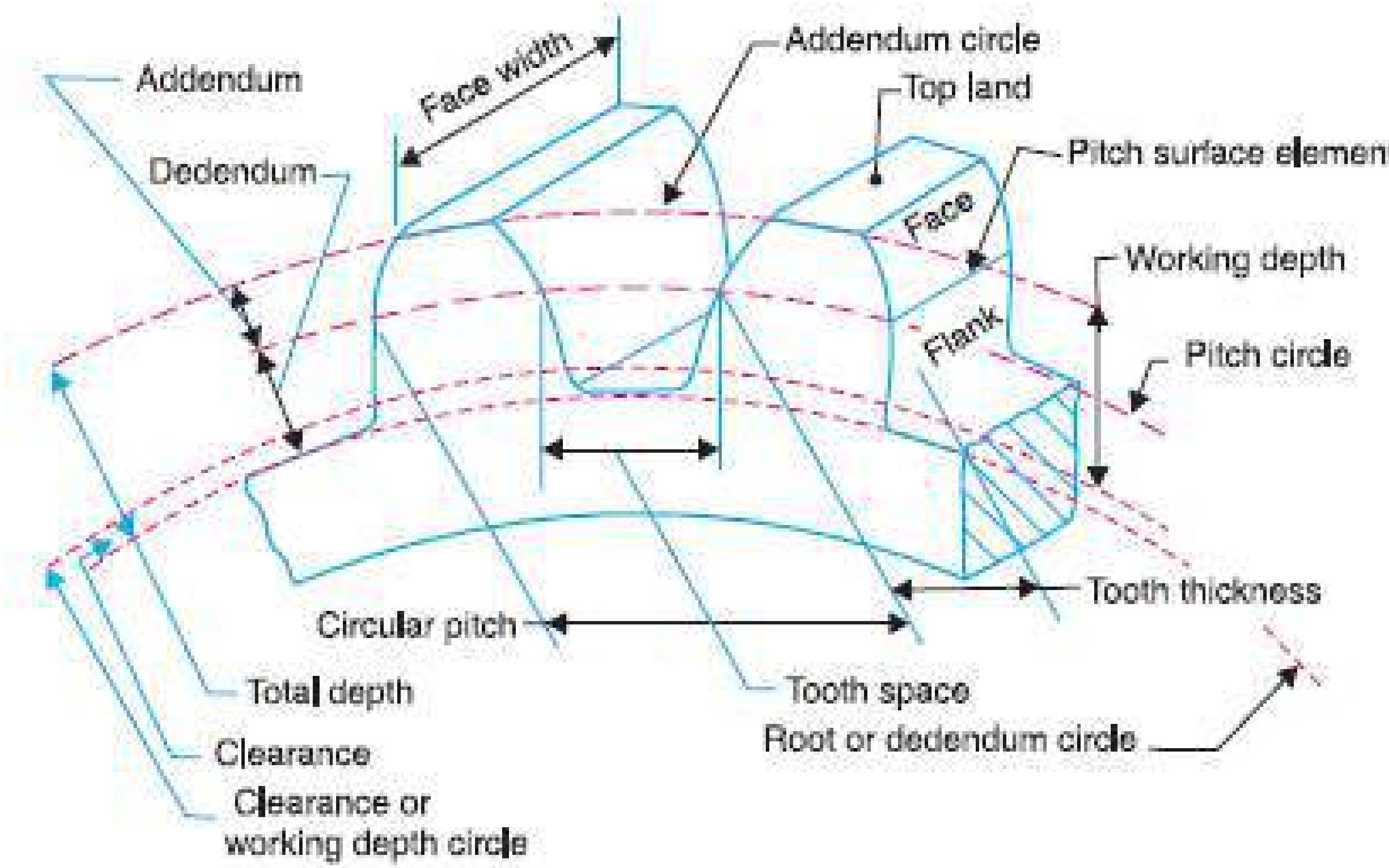
Addendum: It is the radial distance of a tooth from the pitch circle to the top of the tooth.

Terms Used in Gears



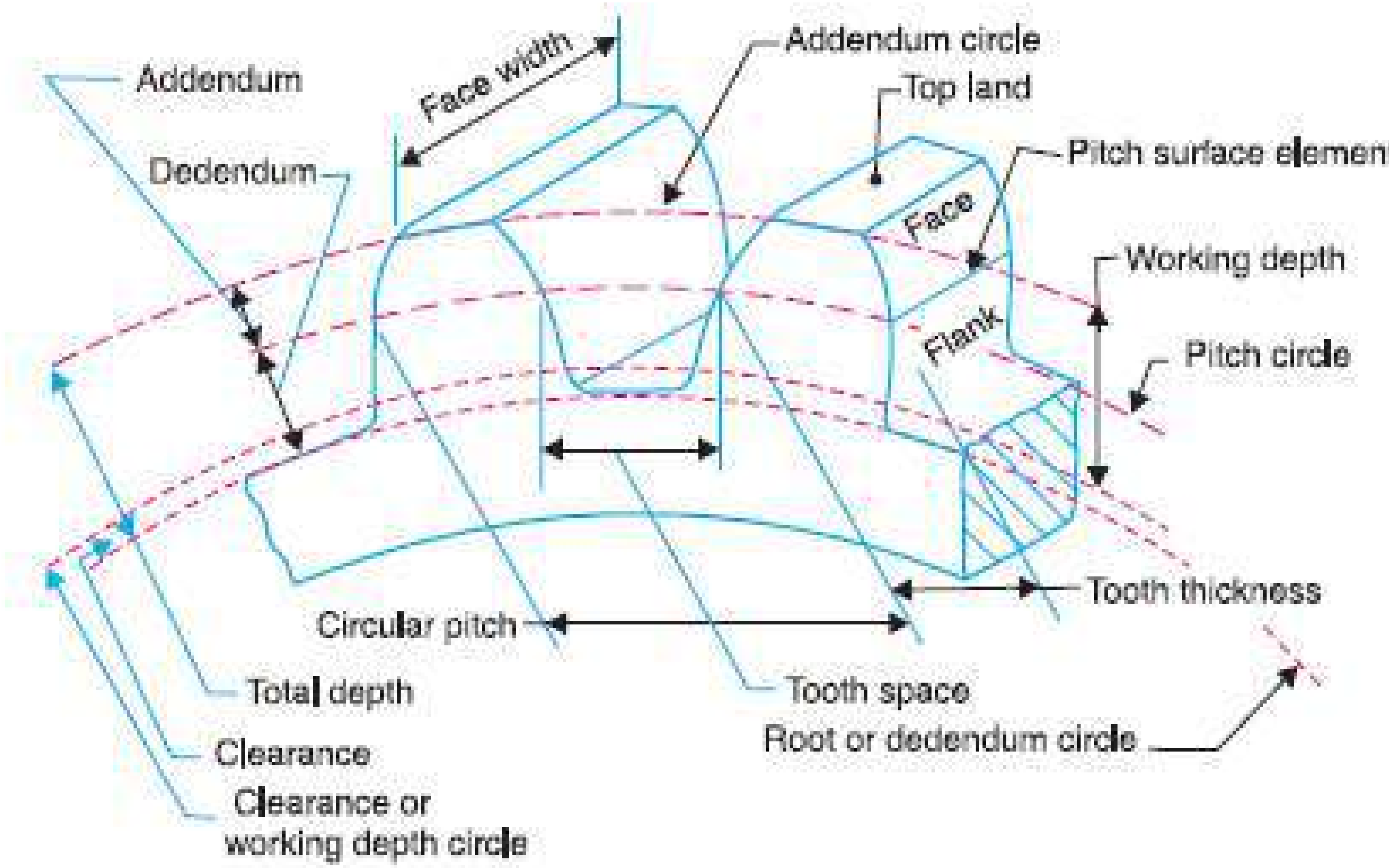
Dedendum: It is the radial distance of a tooth from the pitch circle to the bottom of the tooth.

Terms Used in Gears



Addendum circle : It is the circle drawn through the top of the teeth and is concentric with the pitch circle.

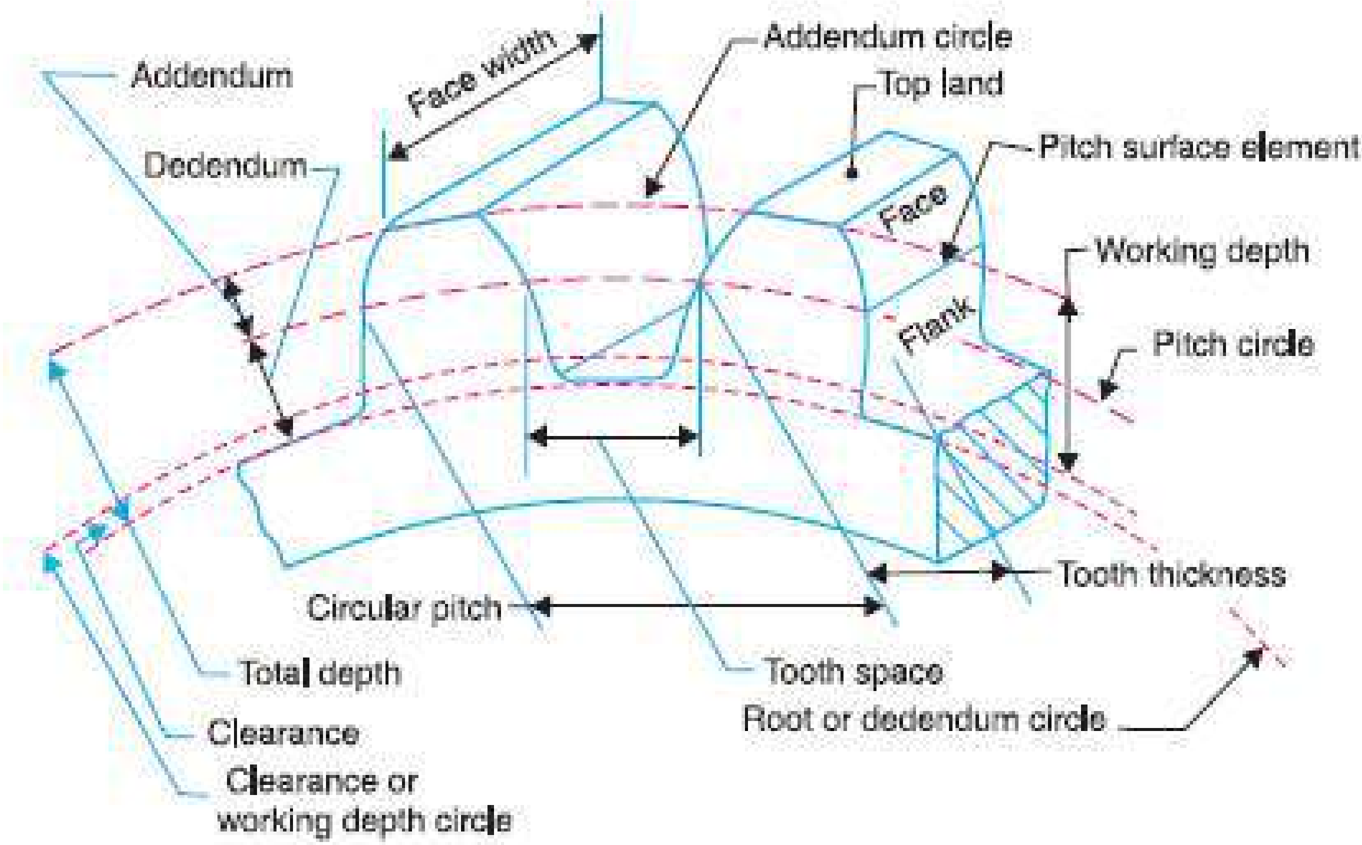
Terms Used in Gears



Dedendum circle: It is the circle drawn through the bottom of the teeth. It is also called root circle.

Root circle diameter = Pitch circle diameter × cos φ, where φ is the pressure angle.

Terms Used in Gears



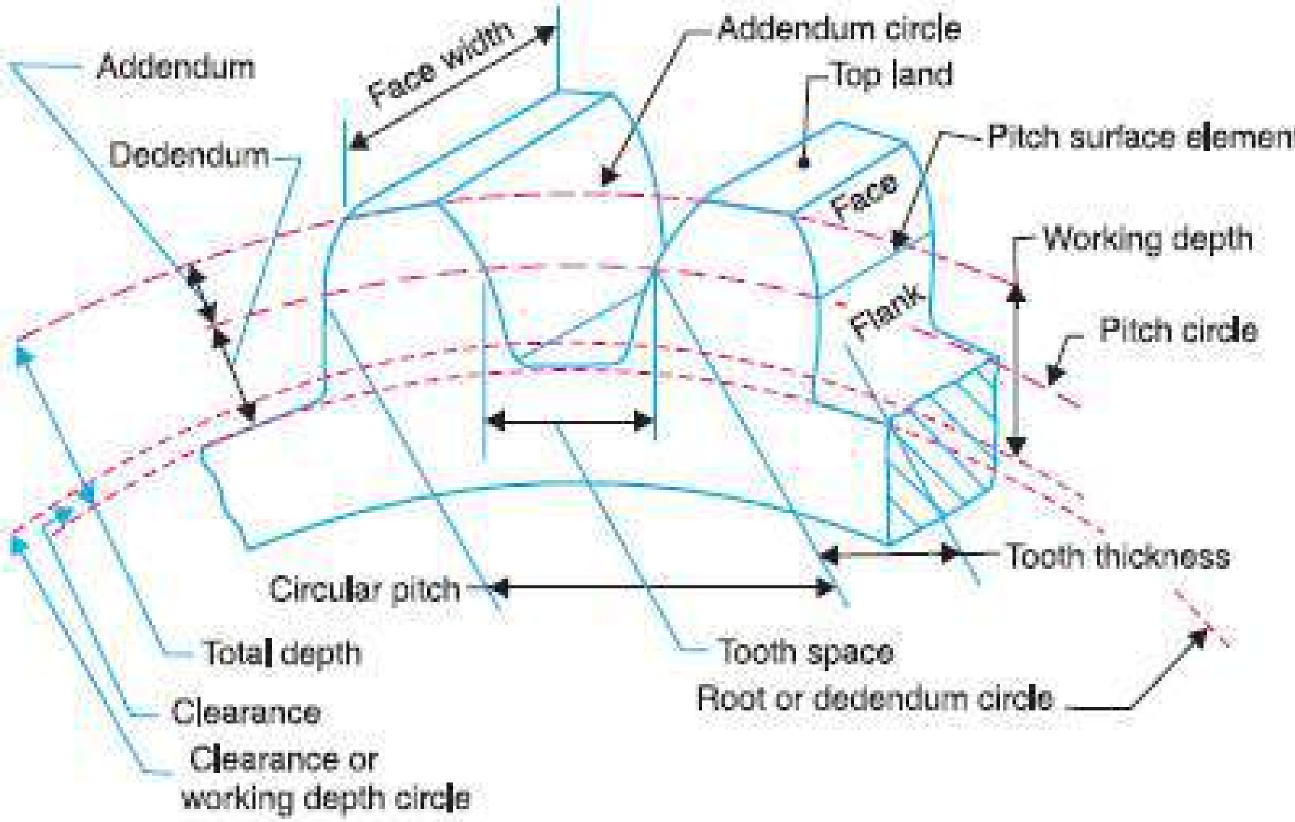
Circular pitch: It is the distance measured on the circumference of the pitch circle from a point of one tooth to the corresponding point on the next tooth. It is usually denoted by *pc*.

Circular pitch, $pc = \pi D/T$

where *D = Diameter of the pitch circle, and*

T = Number of teeth on the wheel

Terms Used in Gears



Diametral pitch: It is the ratio of number of teeth to the pitch circle diameter in millimetres.

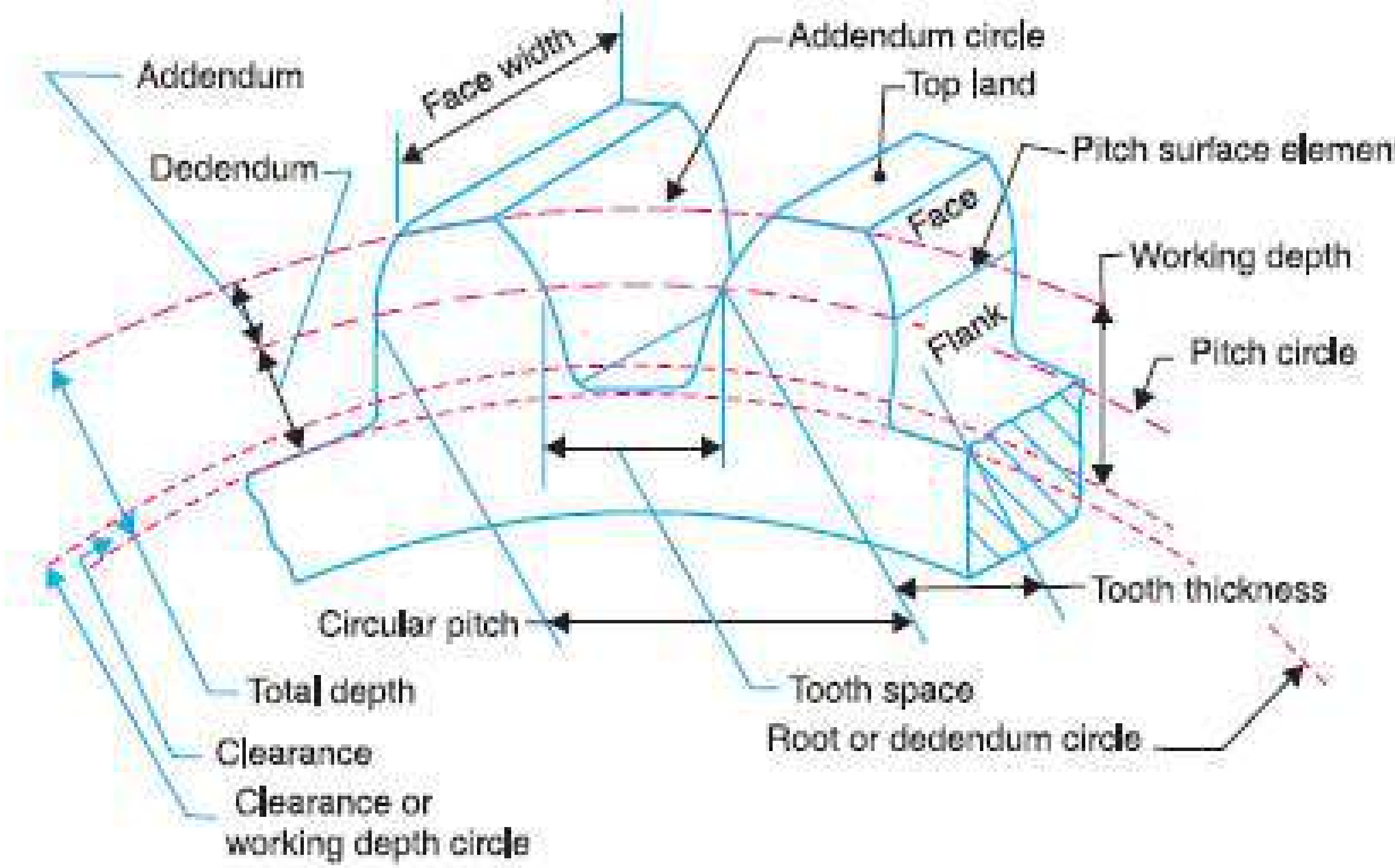
It is denoted by p_d. Mathematically,

Diametral pitch, $p_d = \frac{T}{D} = \frac{\pi}{p_c}$ $\quad \ldots \left(\because\ p_c = \frac{\pi D}{T}\right)$

where T = Number of teeth, and

D = Pitch circle diameter.

Terms Used in Gears

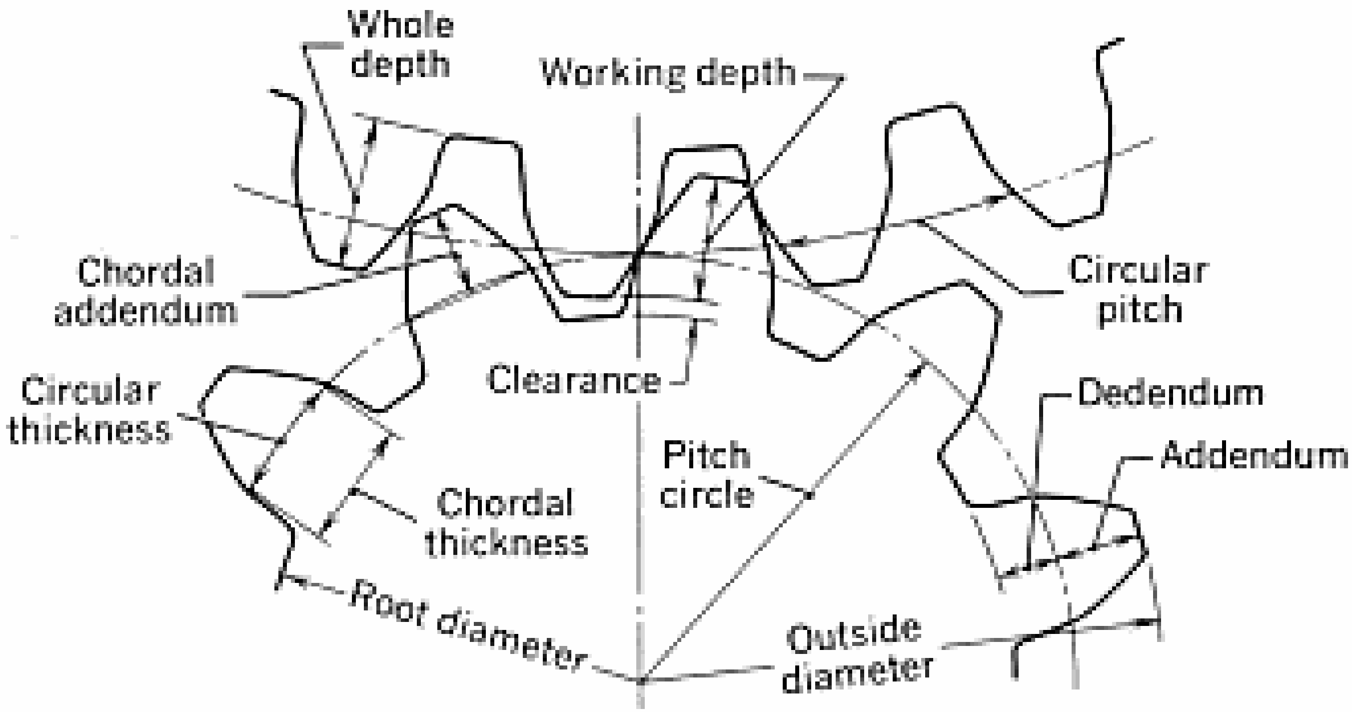


Module: It is the ratio of the pitch circle diameter in millimeters to the number of teeth. It is usually denoted by m.

Mathematically,

Module, $m = D / T$

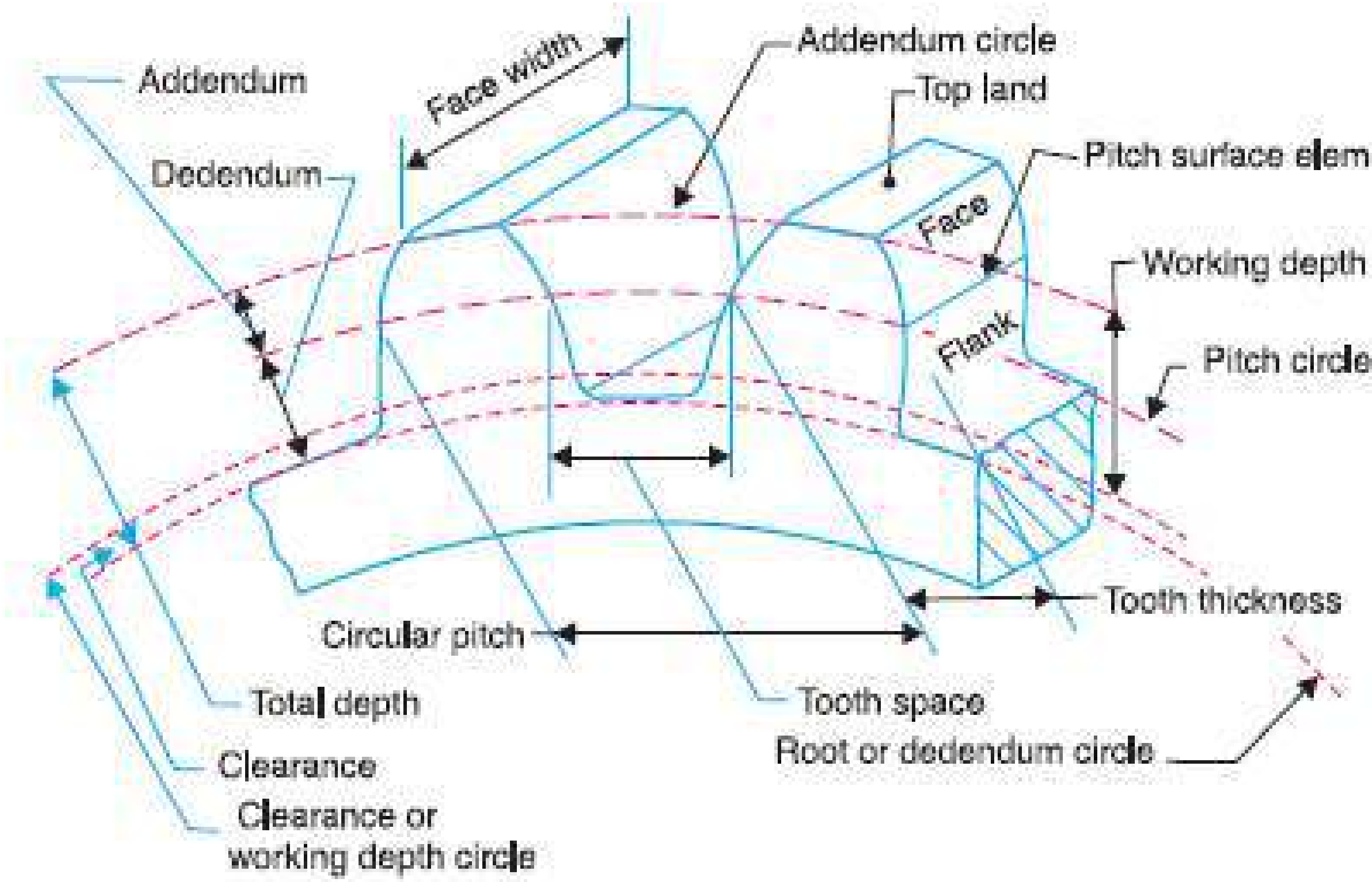
Terms Used in Gears



Spur gear terms.

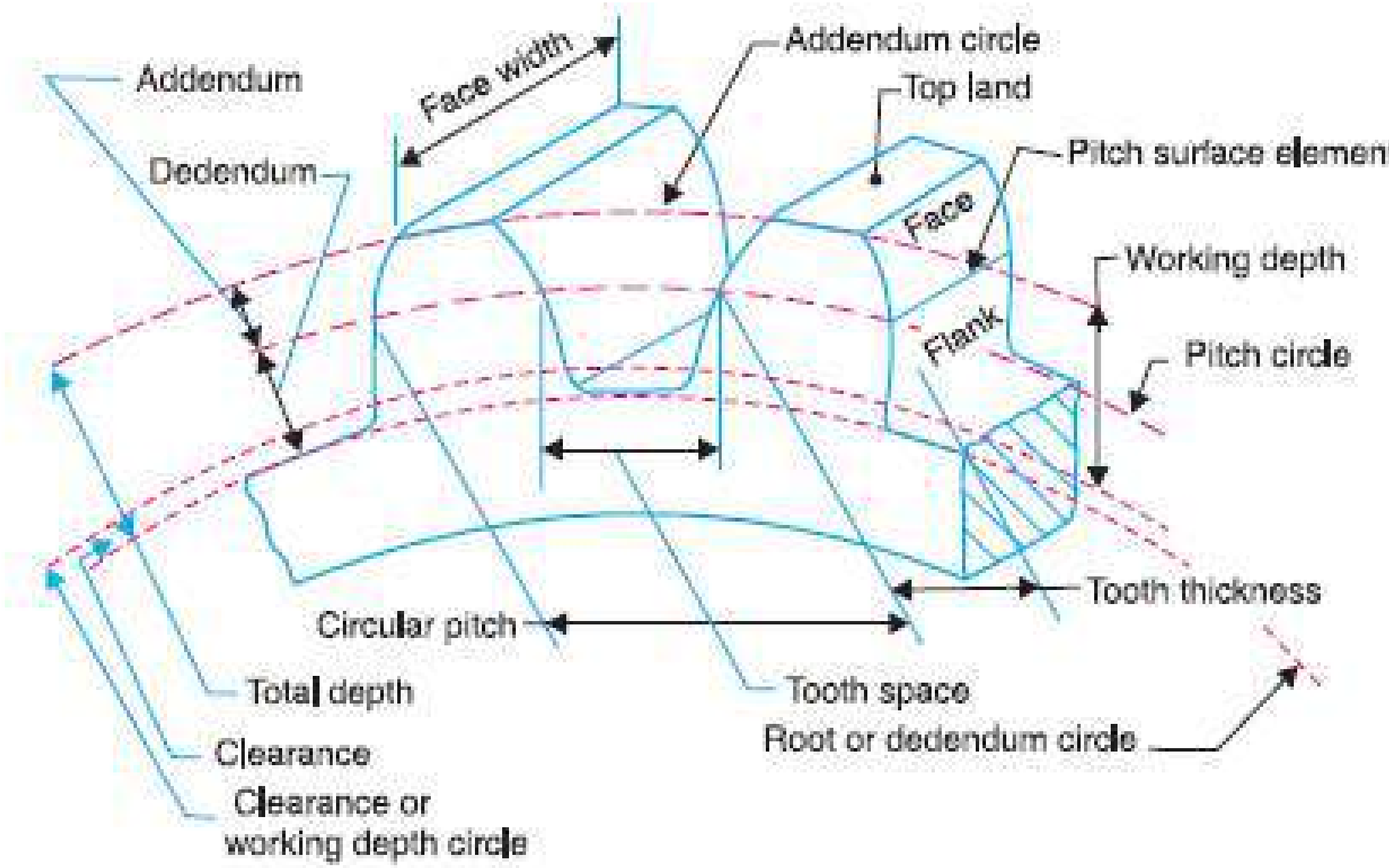
Clearance: *It is the radial distance from the top of the tooth to the bottom of the tooth, in* a meshing gear. A circle passing through the top of the meshing gear is known as *clearance circle.*

Terms Used in Gears



Total depth: It is the radial distance between the addendum and the dedendum circles of a gear. It is equal to the sum of the addendum and dedendum.

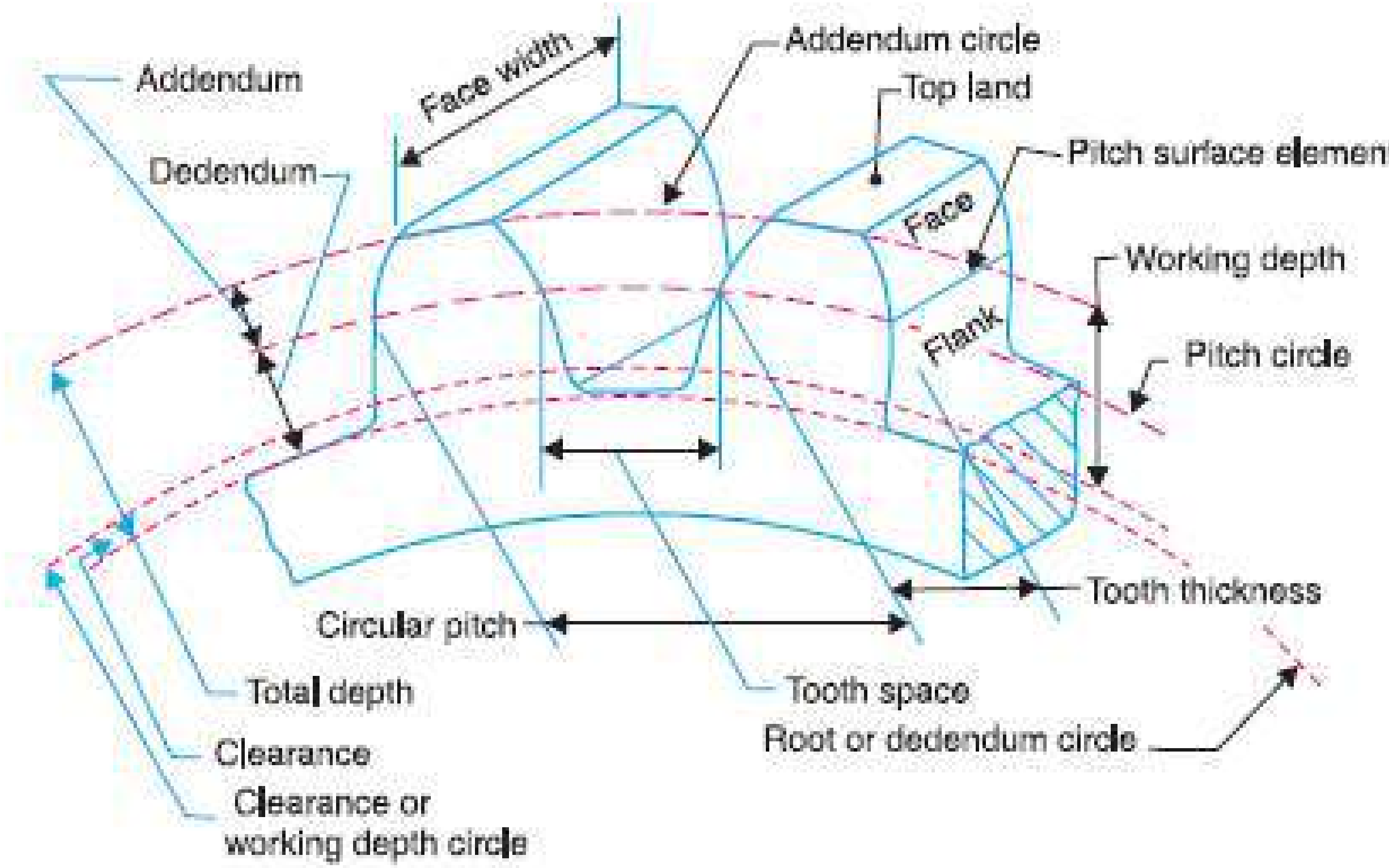
Terms Used in Gears



Working depth: It is the radial distance from the addendum circle to the clearance circle.

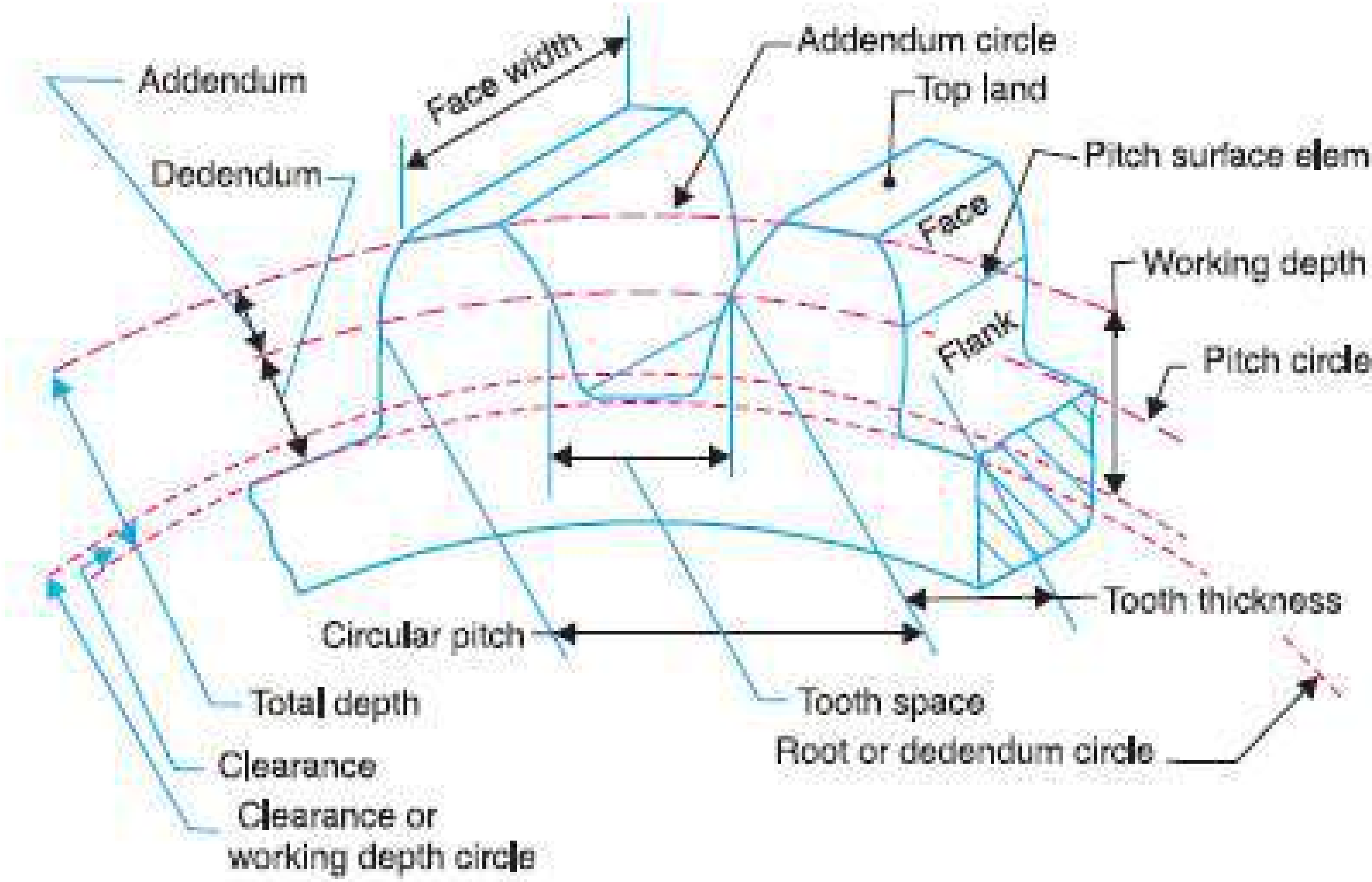
It is equal to the sum of the addendum of the two meshing gears.

Terms Used in Gears



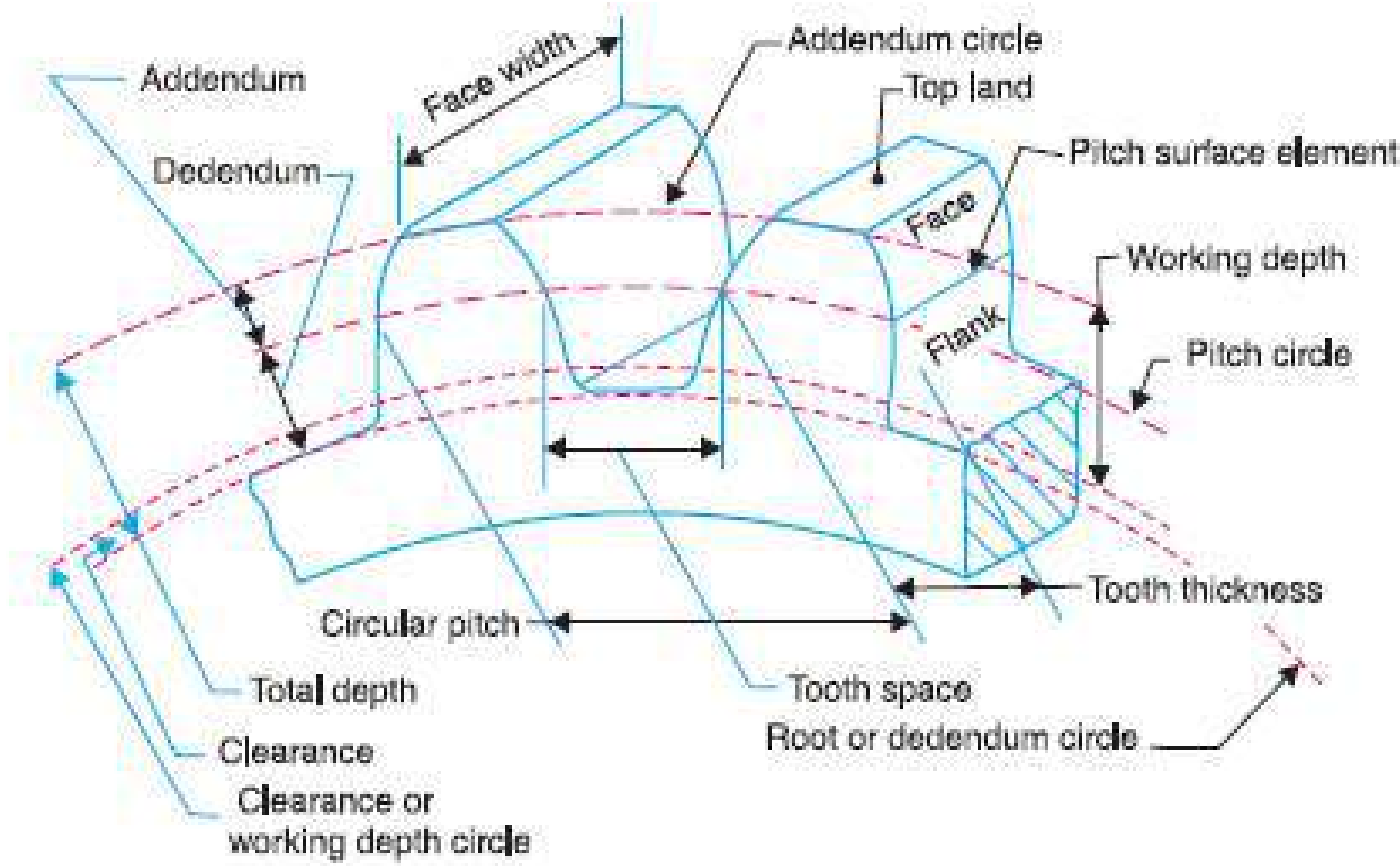
Tooth thickness: It is the width of the tooth measured along the pitch circle.

Terms Used in Gears



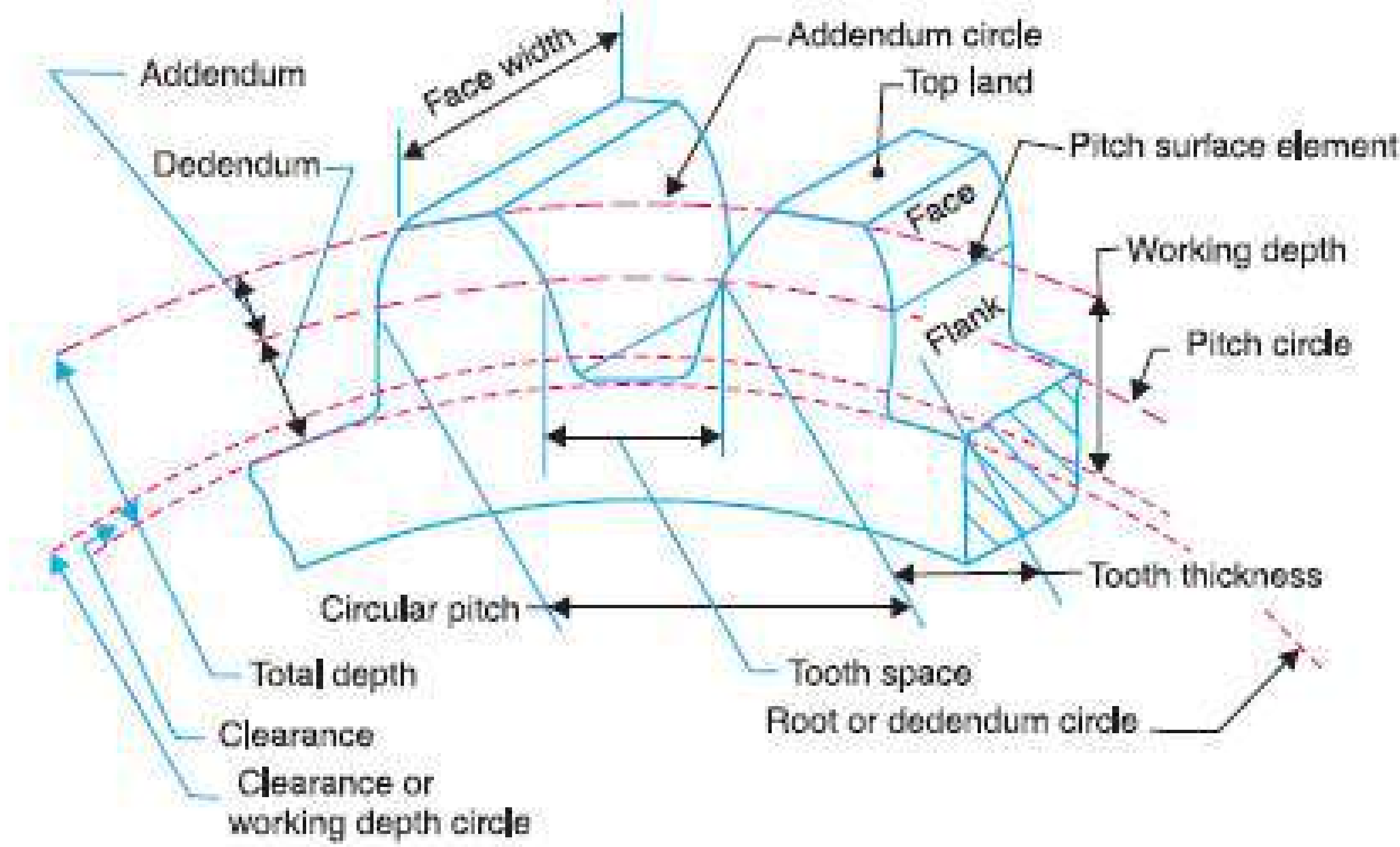
Tooth space : *It is the width of space between the two adjacent teeth measured along the pitch* circle.

Terms Used in Gears



Backlash: It is the difference between the tooth space and the tooth thickness, as measured along the pitch circle. Theoretically, the backlash should be zero, but in actual practice some backlash must be allowed to prevent jamming of the teeth due to tooth errors and thermal expansion.

Terms Used in Gears



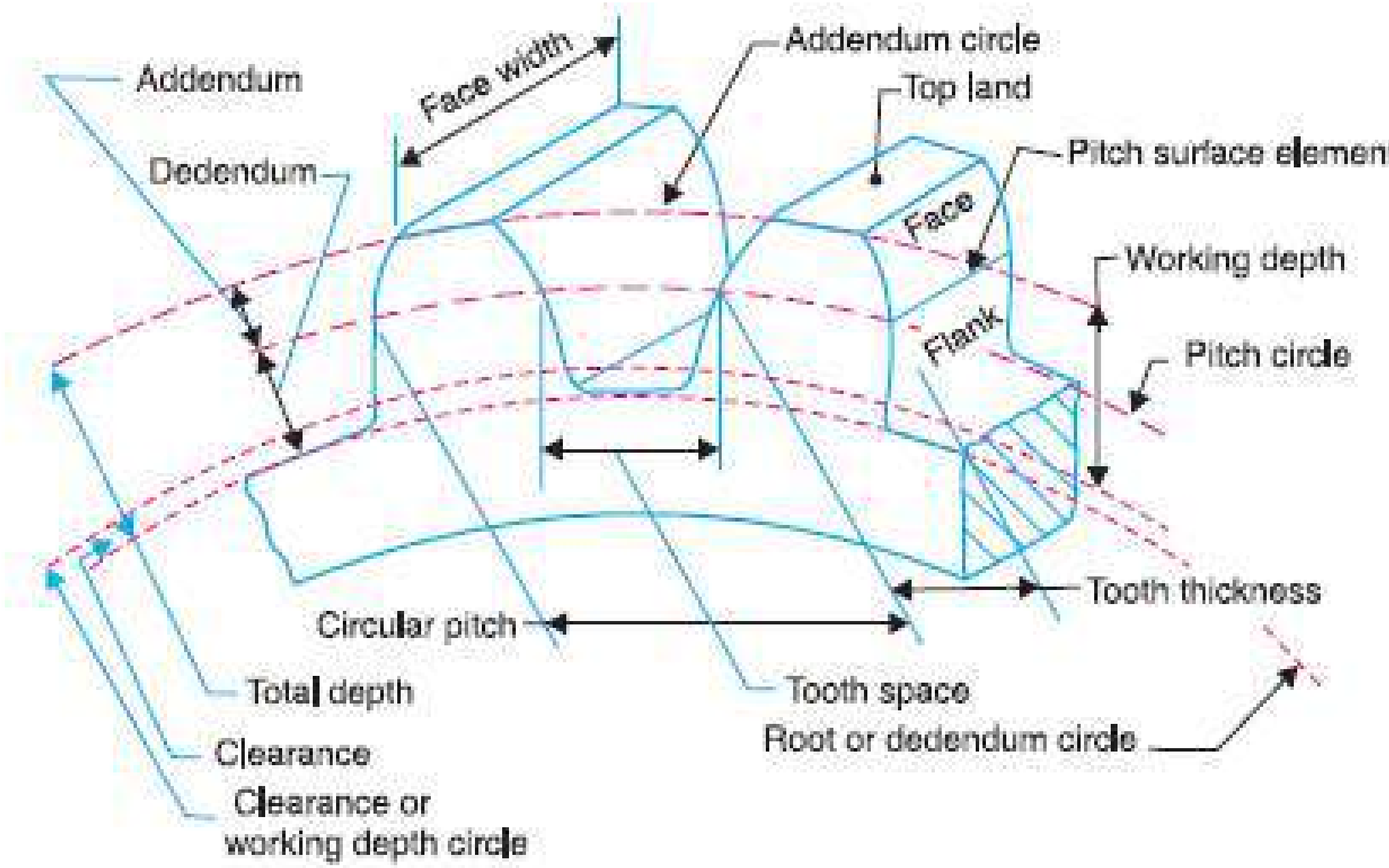
Face of tooth: ***It is the surface of the gear tooth above the pitch surface.***

Flank of tooth: ***It is the surface of the gear tooth below the pitch surface.***

Top land: ***It is the surface of the top of the tooth. Face width. It is the width of the gear tooth measured parallel to its axis.***

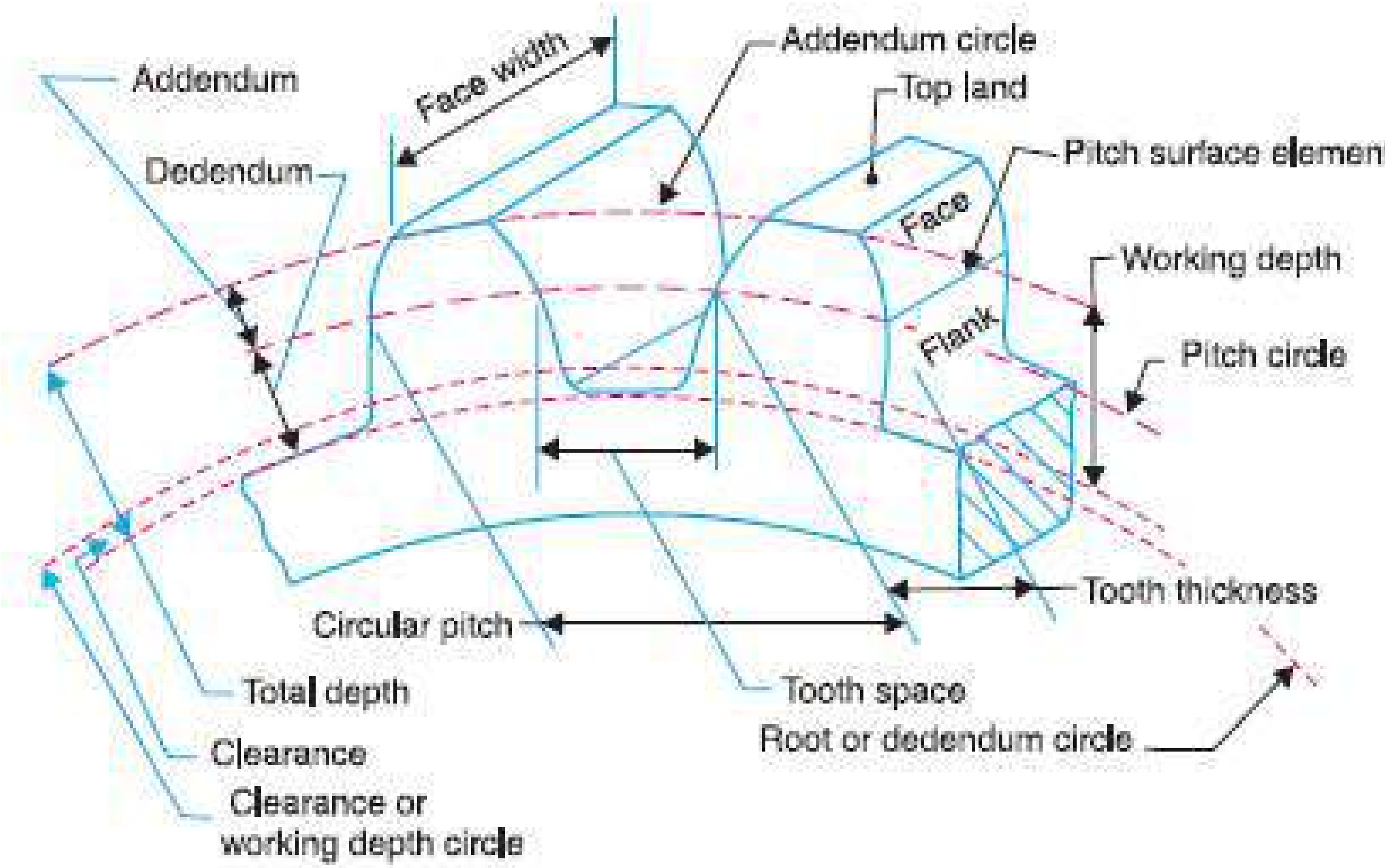
Profile: ***It is the curve formed by the face and flank of the tooth.***

Terms Used in Gears



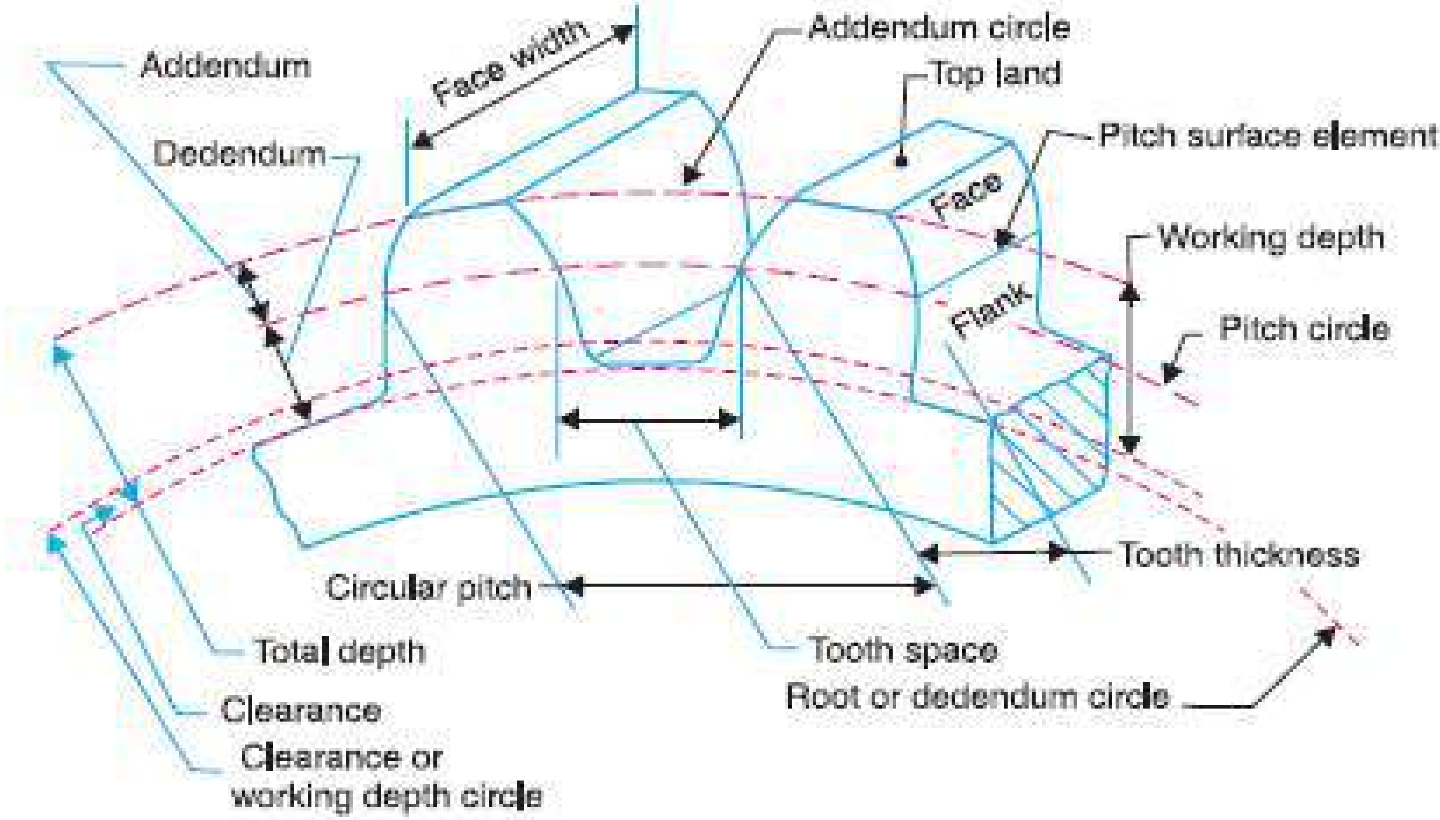
Path of contact: It is the path traced by the point of contact of two teeth from the beginning to the end of engagement.

Terms Used in Gears



Length of the path of contact : *It is the length of the common normal cut-off by the* addendum circles of the wheel and pinion.

Terms Used in Gears



Arc of contact: It is the path traced by a point on the pitch circle from the beginning to the end of engagement of a given pair of teeth. The arc of contact consists of two parts, *i.e.*

Arc of approach: It is the portion of the path of contact from the beginning of the engagement to the pitch point.

Arc of recess: It is the portion of the path of contact from the pitch point to the end of the engagement of a pair of teeth