LEARNING MATERIAL

Theory Of Machine

4th Semester

Mechanical engineering

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CONTENTS

Chapter-1

Simple Mechanism

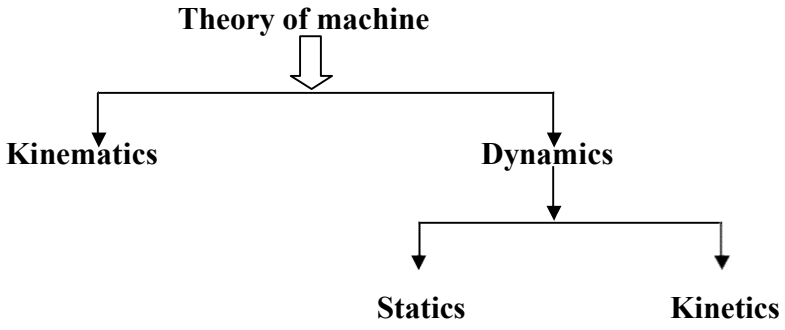
Syllabus:

1.1 Link, kinematic chain, mechanism, machine 1.2 Inversion, four bar link mechanism and its inversion 1.3 Lower pair and higher pair 1.4 Cam and followers

Introduction:

The subject theory of machine may be defined as that branch of science which deals with the study of relative motion between the various parts of a machine and forces which act on them.

Classification of theory of machine:



Kinematic:

- Kinematic of machines is that branch of theory of machines which deals with the study of relative motion of parts of which the machines are constituted, neglecting consideration of forces producing it.

Dynamics:

- Dynamics of machine is that branch of theory of machines which deals with study of forces acting on different parts of the machine.

Statics:

- Statics deals with the study of forces acting on the various parts of machines (assumed to be without mass), when they are at rest.

Kinetics:

- Kinetics deals with the study of inertia forces which are produced by the combined effect of the mass and the motions of the various parts.

Kinematics:

- Kinematics of motion i.e., the relative motion of bodies without consideration of the forces causing the motion.

Machine:

- A machine is a device by means of which available energy can be converted into derived form of useful work. Machines are used to transmit both motion and force.
- It is the assembly of resistant bodies or links whose relative motions are successfully constrained so that available energy can be converted into useful work.

- **Or** a machine is device which receives energy and transforms it into some useful work.
- **Example:** Lathe, Shaper, Scooter etc.
- Theory of machine is the branch of engineering which deals with the relative motion and force between various machine elements.

Resistance Body:

- A body is said to be resistant body if it is capable of transmitting the required force with negligible deformation.
- These bodies are the parts of the machines which are used for transmitting motion and forces.
- A link need not necessary be a rigid body, but it must be a resistant body.

Example:

- Springs, belts and oil used in hydraulic press are not rigid links but they are resistant bodies.
- Structure is an assemblage of a number of resistant bodies having no relative motion between them.

  Note: Structures are meant for taking loads.

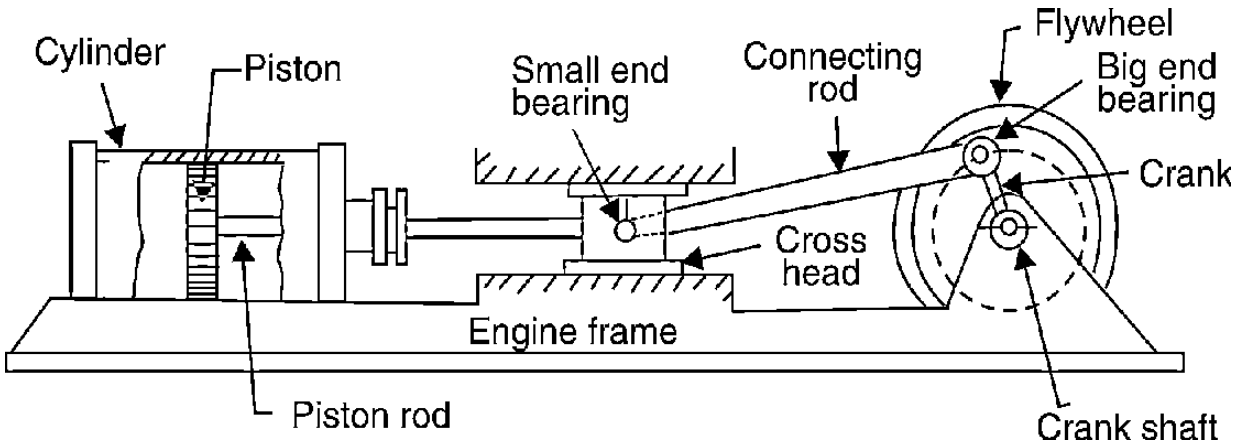
Difference between machine and structure:

Machine	Structure
• There is relative motion between its members. • It converts available energy into useful work. • Members are meant to transmit motion and forces. • Example: car, lathe etc..	• There is no relative motion between them. • It does not convert the available energy into useful work. • Members are meant to take up loads only. • Example: bridge, frames, buildings etc..

Kinematic link:

- Each part of a machine, which moves relative to some other part, is known as kinematic link or element.
- Links are identified by relative motion.
- Link should have two characters.
  1. It should have relative motion.
  2. It should be a resistant body.

Examples:



Reciprocating Steam Engine

Links in reciprocating engine

Link-1: piston, piston rod and cross head

Link-2: crank, crankshaft and flywheel

Link-3: cylinder, engine frame and main bearings

Types of links:

1. Rigid link:

- A rigid link is on which does not undergo any deformation while transmitting motion.
- **Example:** Deformation of a connecting rod, crank etc. is not appreciable.

2. Flexible link:

- A flexible link in one which is partly deformed in a manner not to affect the transmission of motion.
- **Example:** belts, ropes, chains and wires

3. Fluid link:

- A fluid link is one which is formed by having a fluid in a reciprocal and the motion is transmitted through the fluid by pressure or compression only as in the case of hydraulic presses, jacks and brakes.

Kinematic pair:

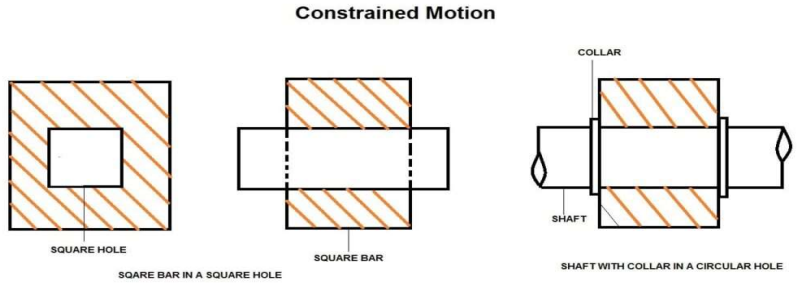
- The two links or elements of a machine, when in contact with each other are said to form a pair or kinematic pair.
- When two elements or links are connected in such a way that their relative motion is constrained, they form a kinematic pair and the process of connecting them is called pairing.

Three types of constrained motions:

1. **Completely constrained motion**
2. **Incompletely constrained motion**
3. **Successfully constrained motion**

1. Completely constrained motion:

- When the motion between two elements of a pair is in a definite direction, irrespective of the direction of force applied, then the motion is said to be in a completely constrained motion.
- The constrained motion may be linear or rotary.
- Example: The motion of a square bar in a square hole.
- **Example:** Sliding pair and turning pair.
- In case of sliding pair, the inner prism can only slide inside the hollow prism.
- But in case of turning pair, the inner shaft can have only rotary motion due to collars at the ends.



2. Incomplete constrained motion:

- When the motion between two elements of a pair is possible in more than one direction and depends upon the direction of the force applied, then the motion is called an incompletely constrained motion.
- Example: Turning pair without a collar i.e.- if the turning pair does not have the collars, then the shaft may have sliding or rotary motion depending upon the direction of the force applied.
- **Example:** circular shaft in a circular hole may rotate or slide.
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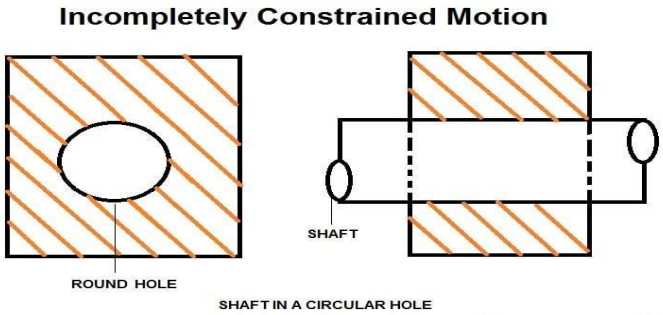
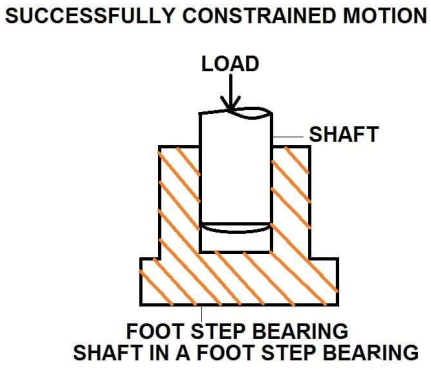
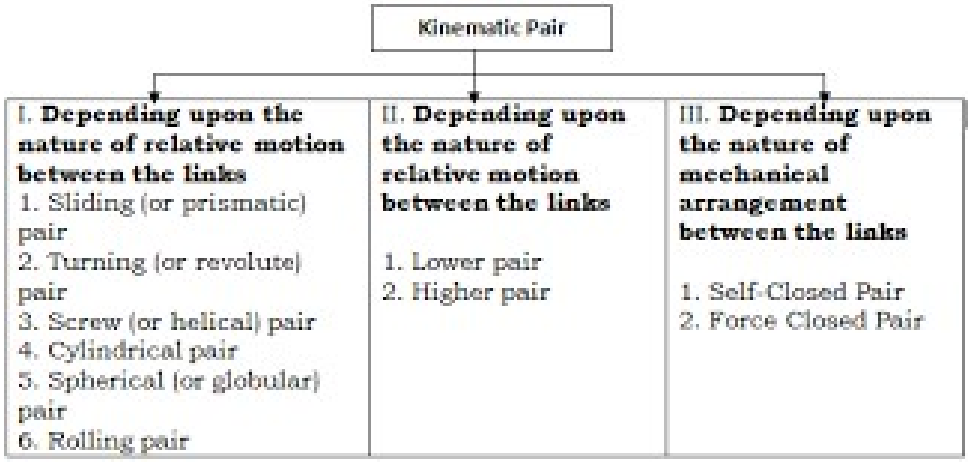


3. Successfully constrained motion:

- When the motion between the elements of a pair is possible in more than one direction but is made to have motion only in one direction by using some external means, then the motion is said to be successfully constrained motion.
- **Example:** A shaft in a foot step bearing.
- The shaft may rotate in the bearing or it may move upwards. But if the load is placed on the shaft to prevent axial upward movement of the shaft, then the motion of the pair is said to be successfully constrained motion.



Kinematic pair classification:



1. **<u>According to type of relative motion between the elements:</u>**

- **Sliding pair:** When the two elements or kinematic pair are connected such that only sliding motion is possible between the two.

  Examples: Piston and cylinder, tail stock on lathe machine.

- **Turning pair:** When the two elements are connected such that one can only turn or revolve about the fixed axis of other link such pairs are called as turning pairs.

  Examples: Shaft with collars, crank shaft in journal bearings, lathe spindle supported in head stock.

- **Rolling pair:** When two elements are connected such that one rolls over the other fixed link, the pair is called as rolling pair.

  Examples: Ball and roller bearings.

- **Screw pair:** When the two elements are connected such that one element can turn about the other by screw threads.

  Examples: Lead screw of a lathe, nut and bolt etc.

- **Spherical pair:** When the two elements are connected such that one element with spherical shape turns about the other fixed element, the pair is formed is spherical pair.

  Examples: Ball and socket joint, attachment of a car mirror, pen stand etc.

2. **<u>According to the type of contact between the elements</u>**

Lower pair: When the two elements of a pair have a surface contact while relative motion takes place is known as lower pair.

- **Example:** sliding pair, turning pair, piston cross head, tailstock on the leather bed, shaft revolting in a bearing, steering gear, universal joint, pantograph, all pairs of slider-crank mechanism, ball and socket joint etc.

Higher pair: When the two elements of a pair have a line or point contact while in motion, the pair so formed is known as a higher pair.

- The relative motion being the combination of sliding and turning, thus it is complex.
- **Example:** belt, rope and chain drives, gears, cam and follower, ball and roller bearing etc.

3. **<u>According to the type of closure</u>**

Self-closed pair: When the two elements of a pair are connected together mechanically in such a way that only required kind of relative motion occurs, it is then known as self-closed pair.
Examples: The lower pairs are self-closed pair.

Force-closed pair: When the two elements of a pair are not connected mechanically but are kept in contact by the action of external forces, the pair is said to be a force-closed pair.
Examples: The cam and follower are an example of force closed pair, as it is kept in contact by the forces exerted by spring and gravity.

Kinematics chain:

- When kinematic pair are so coupled that the last link is joined to the first link to transmit a definite motion (i.e.- completely or successfully constrained motion) it is called a kinematic chain.
- Or it is an assembly of links in which the relative motion of links is possible and the motion of each relative to other is definite.
- So, to be a kinematic chain: it must be a closed pair, shall be completely or successful constrained motion and degree of freedom must be equal to one.
- If each link is assumed to form two parts, with two adjacent links, then the relation.

$$L = 2p - 4 \text{ -------- (i)}$$

$$J = (3L/2) \text{ ---------(ii)}$$

L → no. of links, p→ no. of pairs, J= no. of joints

Conditions for different kinematic chains.

- **LHS > RHS (Locked/Redundent structure)**
- **LHS = RHS (Constrained chain)**
- **LHS < RHS (Unconstrained chain)**

Note- Both equation (i) & (ii) are applicable to kinematic chain with lower pairs. Also applicable to kinematic chain with higher pairs.

- Higher pair is equivalent to two lower pairs with an additional element or link.

DEGREES OF FREEDOM (DOF): (F)

- It is the number of independent coordinates required to describe the position of a body.
- Or it is defined as the number of input parameter which must be controlled independently, in order to bring the mechanism into a useful engineering purpose.
- A rigid body possesses 6 degree of freedom.
- Number of degrees of freedom of a mechanism is given by **$F = 3(L-1)-2J-h$**
- This equation is called **Kutzbach criterion** where, F = Degrees of freedom
  L = Number of links in the mechanism.
  J = Number of binary joints or lower pair, which is obtained by counting the number of joints.
  If more than two links are joined together at any point, then, one additional lower pair is to be considered for every additional link.
  h = Number of higher pairs
- when F=1 and h=0 in kutzbach equation then the equation is known as the **Grubler's Criterion**.

Mechanism:

- When one element or link of a kinematic chain is fixed, the arrangement may be used for transmitting or transforming motion, it is termed as mechanism.
- So, if a number of bodies are assembled in such a way that the motion of one cause constrained and predictable motion to other is known as a mechanism.
- And when a mechanism is required to transmit power to do some particular type of work, it becomes a **machine**.

Types of mechanism

Simple mechanism | Compound mechanism

Simple mechanism: Mechanism having four links.

Example: Coupling rod mechanism of a locomotive beam engine etc.

Compound mechanism: Mechanism having more than four lines. It may be formed combining two or more simple mechanism.

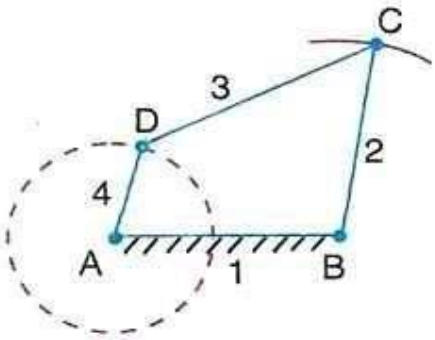
Inversion:

- The method of obtaining different mechanism by fixing different links in a kinematic chain is known as inversion of the mechanism.
- Suppose number of links of a kinematic chain = n. So, n different mechanisms may be obtained by fixing each of the lines in turn. Each mechanism is termed as inversion.
- When one of links is fixed in a kinematic chain, it is called a mechanism.

Types of kinematic chains (most important kinematic chain)

1. Four bar chain or quadric cycle chain
2. Single slider crank chain
3. Double slider crank chain

Four bar chain or Quadric cycle chain:



- The kinematic chain is a combination of four links or four kinematic pairs, such that the relative motion between the links or elements is completely constrained.
- Four links A, B, C & D each of them form a turning pair.

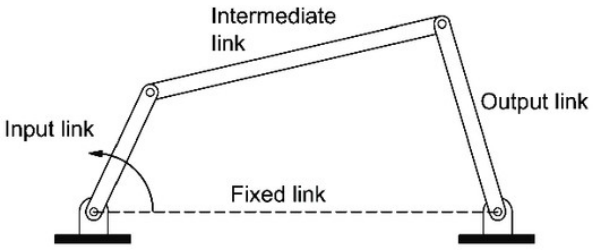
Grasthof's law:

- According to Gasthof's law for a four-bar mechanism, the sum of the shortest and longest link lengths should not be greater than the sum of the remaining two link lengths if there is to be continuous relative motion between the two links.

Let S = shortest links length, L= Longest links length
P&Q = remaining links length
So according to Grashof's law, **S+L ≤ P+Q**

- This criterion is used to find the inversion of four bar chain and to find resulting motions of a four-bar mechanism.
- A mechanism consists of:
  1. a fixed link
  2. input &output links are adjacent to fixed link
  3. link connecting input & output links called coupler or intermediate link

- Where crank is a link which makes full rotation.
- The shortest link will be the crank.
- Link which doesn't make full rotation (partial rotation) is called a rocker or lever or oscillator or reciprocating link.



Possible mechanisms are:

1. **Double crank mechanism or crank-crank mechanism**, where it converts rotary motion into rotary motion. (This is the case of when shortest link is fixed)
2. **Crank-rocker mechanism**, where it converts rotary motion into oscillatory or vice versa. (This is the case of when adjacent to shortest link is fixed)
3. **Double rocker or rocker-rocker mechanism**, where it converts reciprocating motion to oscillatory motion. (This is the case of when opposite to shortest link is fixed)

Link description:

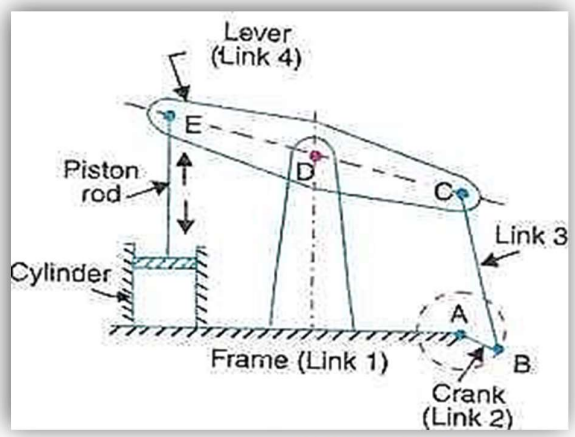
- In a four-bar chain the mechanism in which if no link makes a complete revolution will not be useful.
- In four bar chain, one of the links in particular the shortest link will make a complete revolution relative to the other three links, if it satisfies the Grashof's law. Such a link is known as crank or driver (i.e., AB)
- Link BC which makes a partial rotation or oscillation is known as lever or rocker or follower.
- The link CD which connects the crank and lever is called connecting rod or coupler.
- The fixed link AB is known a frame of the mechanism.

Inversions of four bar mechanism:

1. **Beam engine** (Crank rocker mechanism)
2. **Coupling rod of a locomotives** (Double crank mechanism)
3. **Watt's indicator mechanism** (Double rocker mechanism

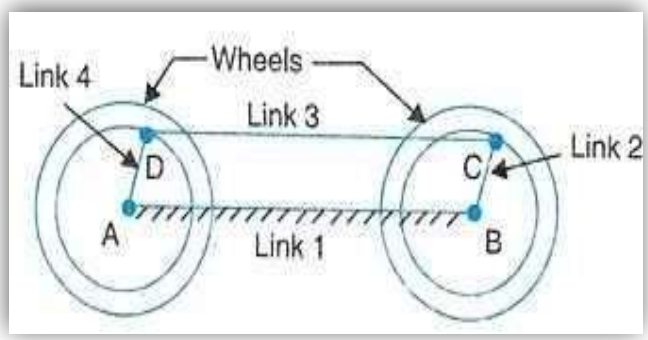
1. Beam engine (Crank rocker mechanism):

- the purpose of this mechanism is to convert rotary motion into reciprocating motion.
- Here, when the crank rotates about the fixed center A, the lever oscillates about the fixed center D.
- The end E of CDE is connected to the piston which reciprocates due to the rotation of the crank.
- Rotary motion ---> Reciprocating motion---> To power steam ship



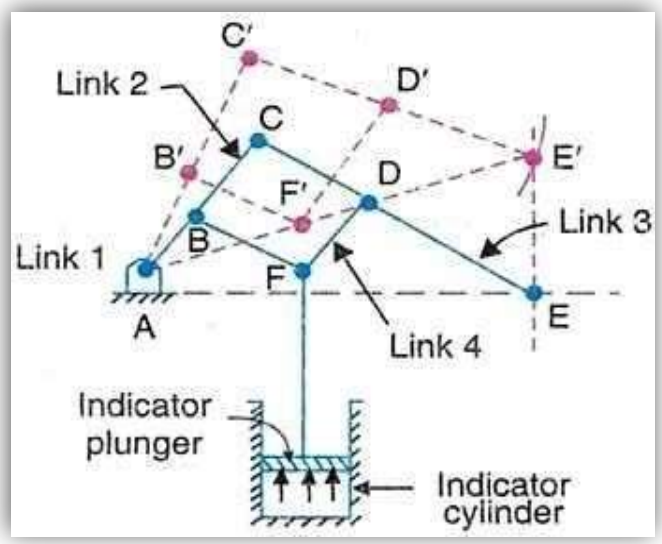
2. Coupling rod of a locomotive (Double crank mechanism):

- This mechanism is meant for transmitting rotary motion from one wheel to the other.
- There AD = BC (Both crank) connected to the respective wheels.
- CD acts as a coupling rod.
- AB is fixed to maintain constant centre to centre distances between the wheels.



3. Watt's Indicator Mechanism: (Crank rocker mechanism)

- It is also known as Watts straight line mechanism which consists of four links.
- Link-1: fixed link A
- Link-2 – link AC
- Link-3 – link CE
- Link-4– link BFD
- BF & FD form one link as these two parts have no relative motion between them.
- The displacement of the link BFD is directly proportional to the pressure of gas or steam which acts on the indicator plunger.
- For small displacement of the mechanism, the tracing point E at the end of the link CE traces out approximately a straight line.



NOTE:

Degree Of Freedom	Resulting Motion	Resulting Mechanism
F<0	No motion or Redundant motion	Super Structure
F=0	No motion	Structure (Frame)
F=1	Constrained motion	Kinematic Mechanism
F>1	Unconstrained motion	Unconstrained Mechanism

CAM AND FOLLOWERS:

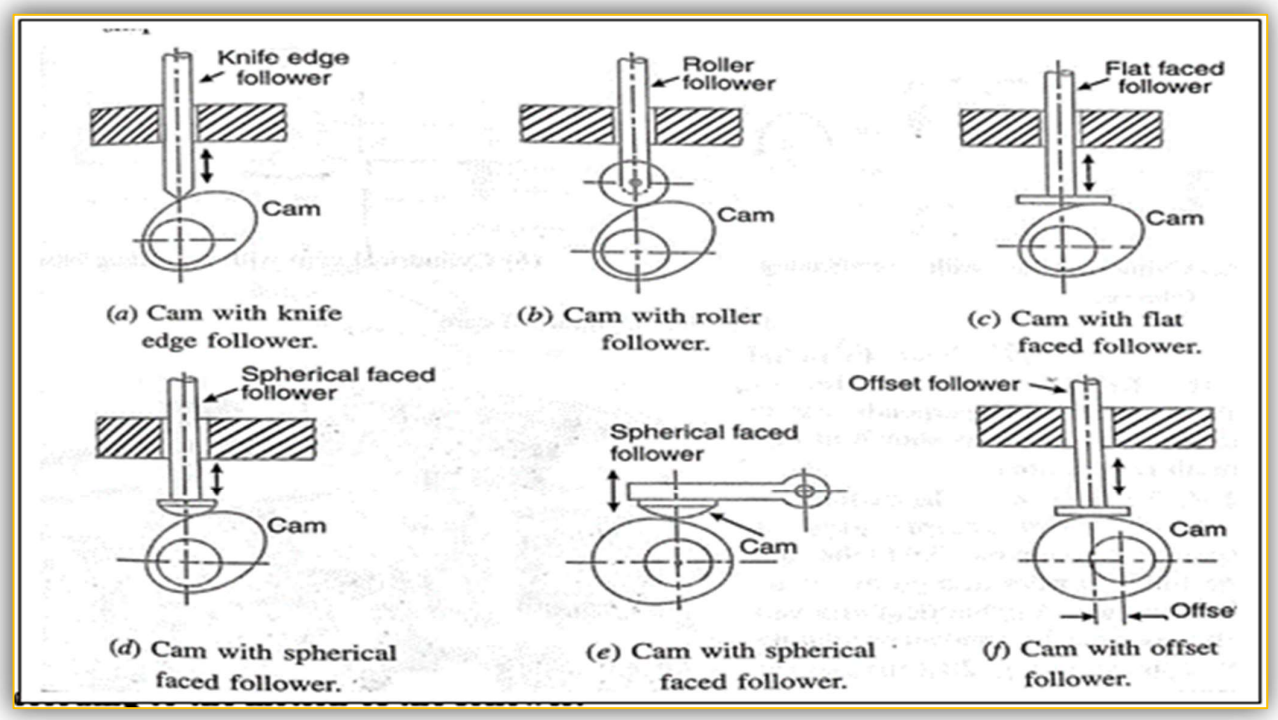
Definition:

- A cam is a mechanical member used to impart desired motion to a follower by direct contact.
- A cam may be defined as a rotating, oscillating or reciprocating body which imparts a reciprocating or oscillating motion to another body, called a follower.
- The cam and the follower have a line or point contact thus constitute a higher pair.
- The cam may be rotating or reciprocating whereas the follower may be rotating, reciprocating or oscillating.
- Complicated output motions which is otherwise difficult to achieve can be produced with the help of cams.
- Cams are usually manufactured by die casting or by punch presses.
- **Application:** Used in clocks, printing machines, internal combustion engines for operating valves, paper cutting machines, automatic screw cutting machines, shoe making machinery, feed mechanism of automatic lathe.

Classification of follower:

Follower

Surface in contact	Motion of the follower	Path of motion of the follower
(i) Knife edge follower	(i) Reciprocating or translating follower	(i) Radial follower
(ii) Roller follower	(ii) Oscillating or rotating follower	(ii) Offset follower
(iii) Flat faced or		
(iv)) Spherical faced follower		



Knife edge follower:

- When the connecting end of the follower has a sharp knife edge, it is called a knife edge follower.
- However, its use is limited because of small area of contacting results in excessive wear at the point of contact.
- A considerable side thrust exists between the follower and the guide.

Roller follower:

- When the connecting end of the follower is a roller, it is called a roller follower.
- Since rolling motion between the contact surfaces, the rate of wear is greatly reduced.
- At low speeds, the follower has a pure rolling action but at high speeds, some sliding also occurs.
- Also, side thrust exist between the follower and the guide.
- Widely used where more space is available.
- Application – Stationary gas and oil engines, aircraft engines

Flat faced or mushroom follower:

- When the contacting end of the follower is a perfectly flat face, it is called a flat faced follower.
- In this case the side thrust between the follower and guide its most reduced and the only side thrust is due to friction between the contact surfaces of the follower and the cam.
- It has the advantage that it does not pose the problem of jamming the cam.
- However, high surface stresses and wear are quite high due to deflection and misalignment.

Spherical faced follower:

- When the contacting end of the follower is of spherical shape, it is called a spherical faced follower.
- The flat faced follower is used in automobile engine produces high surface stresses and in order to minimize these stresses, the flat end is machined to a spherical shape.

Reciprocating or translating follower:

- When the follower reciprocates in guides as the cam rotates uniformly, it is known reciprocating follower.

Oscillating or rotating follower:

- When the uniform rotary motion of the cam is connected into predetermined oscillatory motion of the follower, it is called oscillating or rotating follower.

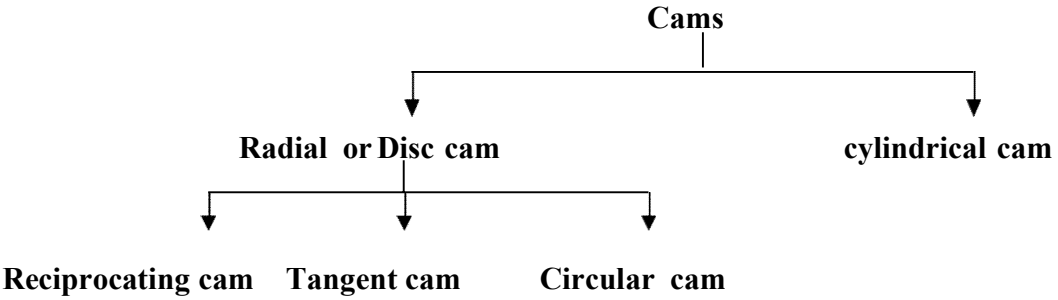
Radial follower:

- When the motion of the follower is along an axis passing through the centre of the cam, it is known as radial follower.

Offset follower:

- When the motion of the follower is along an axis away from the axis. If cam centre, it is called off-set follower. Off-set can be done by springs, gravity or hydraulic means.

Classification of cam:

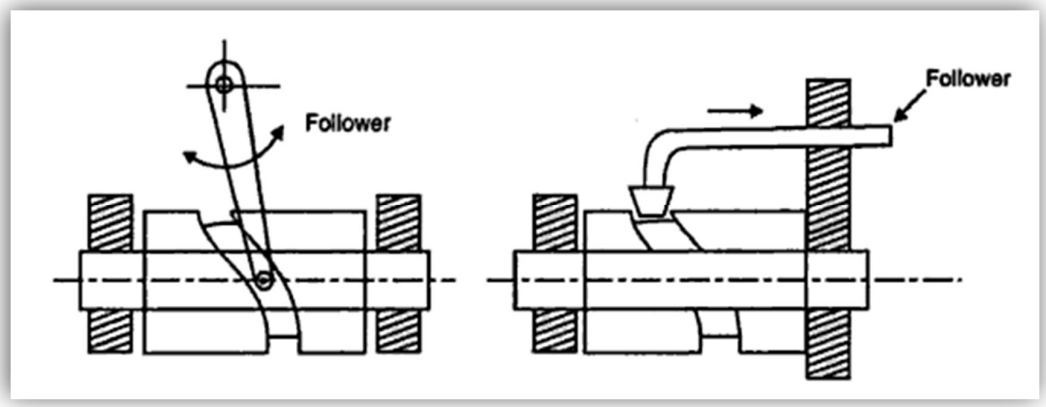


Radial or Disc cam:

- In radial or disc cam, the follower reciprocates or oscillates in a direction perpendicular to the axis of cam rotation or perpendicular to the cam shaft.

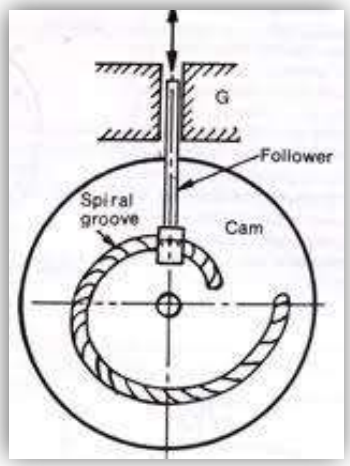
Cylindrical cam:

- In cylindrical cams, the follower reciprocates or oscillates in a direction parallel to the cam axis.
- Here the follower rides in a groove at its cylindrical surface.



Spiral cam:

- A spiral cam is a face cam in which a groove is cut in the form of a spiral.
- The spiral groove consists of a teeth which mesh with a pin or gear follower.
- The velocity of the follower is proportional to the radial distance of the groove from the axis of the cam.
- The use of such a cam its limited as the calm has to reverse the direction to reset the position of the follower.
- It finds its use in computers.



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