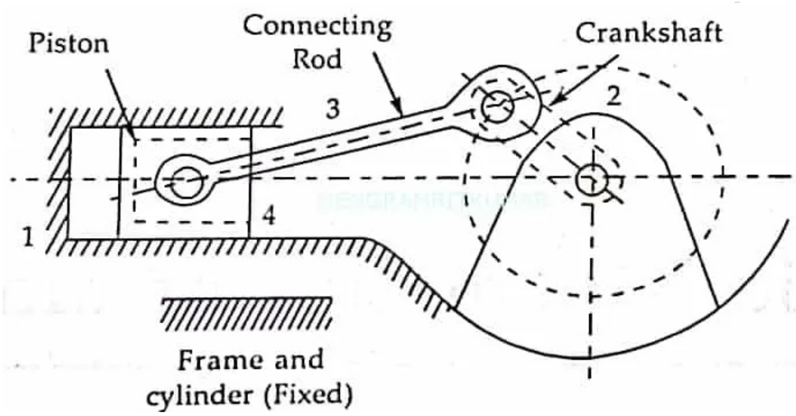
EXPERIMENT 01: To study various types of links, joints and kinematic pairs.
APPARATUS USED: - Kinematics links, pairs, chains & mechanisms
THEORY: -

1.1 Kinematic Link: A link is defined as a member or a combination of members of a mechanism connecting other members and having relative motion between them. The link may consist of one or more resistant bodies. A link may be called as kinematic link or element. Example Kinematic Link: Piston, piston rod and crosshead of a steam engine constitutes one unit and hence called one link shown in the below figure. In this figure, the various link is designated as 1,2,3,4, etc.

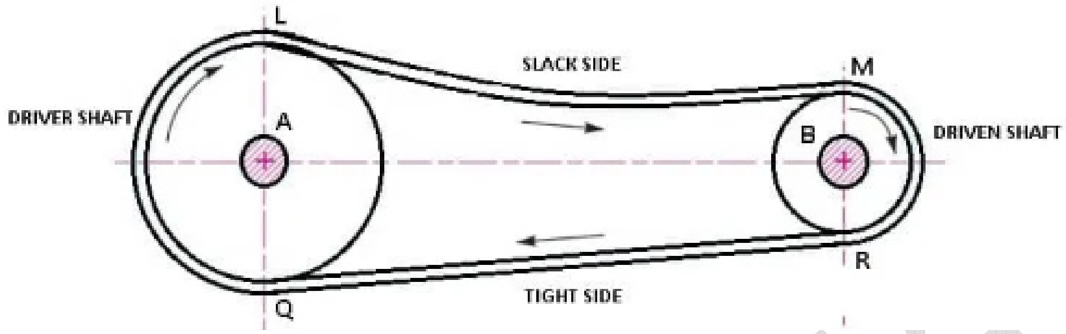


Link 1 is a fixed link that includes frame and all other stationery parts like cylinder, crankshaft bearing, camshaft bearing, etc.
Link 2 is the crankshaft, flywheel, etc all having rotation motion with respect to a fixed axis.
Link 3 is the connecting rod and
Link 4 is the piston which is having reciprocating motion. hence this is called a **4 bar mechanism**.
Link need not be a rigid body but must be a resistant body. Hence link must have the following two characteristics:

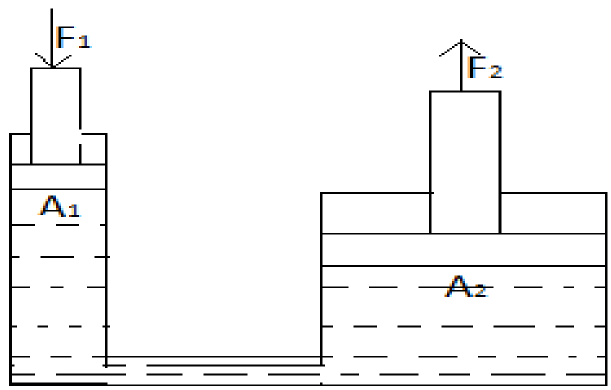
a) It must be a resistant body.
b) It must have relative motion.

1.2 Types of Links:

a) **Rigid Link:** A rigid link is one that does not undergo any deformation while transmitting motion. Links, in general, are elastic in nature. They are considered rigid if they do not undergo appreciable deformation while transmitting motion. F**or Example**, crank and connecting rod.
b) **Flexible Link:** A flexible link is one which while transmitting motion is partly deformed in a manner not to affect the transmission of motion. **For Example**, Spring, Chain, Rope, Belt, etc.

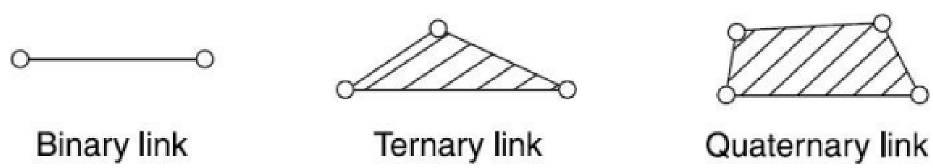


c) **Fluid Link:** A fluid link is one that is deformed by having fluid in a closed vessel and the motion is transmitted through the fluid by pressure. **For Example**, hydraulic press and hydraulic jack.



1.3 A link can also be classified based upon its number and end vertices:

a) Binary link: It having two vertices.
b) Ternary link: This is having three vertices.
c) Quaternary link: This having four vertices.



1.4 **Kinematic Pair:** When two kinematic links are connected in such a way that their motion is either– completely or successfully constrained, these two links are said to form a kinematic pair. Kinematic pairs can be classified according to:–

a) Kinematic pairs according to nature of contact:

i. Lower Pair: A pair of links having surfaced or area contact between the members is known as a lower pair. The contact surfaces of two links are similar. o Examples: Nut turning on a screw, shaft rotating in a bearing.

ii. Higher Pair: When a pair has a point or line contact between the links, it is known as a higher pair. The contact surfaces of two links are similar. o Example: Wheel rolling on a surface, Cam and Follower pair etc.

b) Kinematic pairs according to Nature of Relative Motion:

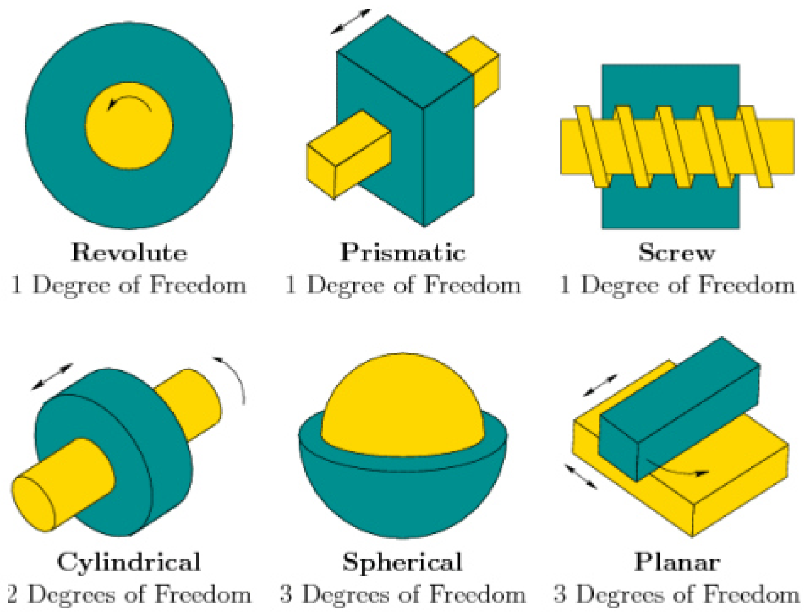
i. Sliding/Prismatic pair: When two links have a sliding motion relative to another; the kinematic pair is known as sliding pair.

i. Turning/Revolute pair: When one link is revolve or turn with respect to the axis of first link, the kinematic pair formed by two links is known as turning pair.

ii. Rolling/cylinderical pair: When the links of a pair have a rolling motion relative to each other, they form a rolling pair.

iii. Screw pair: If two mating links have a turning as well as sliding motion between them, they form a screw pair.

iv. Spherical pair: When one link in the form of sphere turns inside a fixed link, it is a spherical pair.

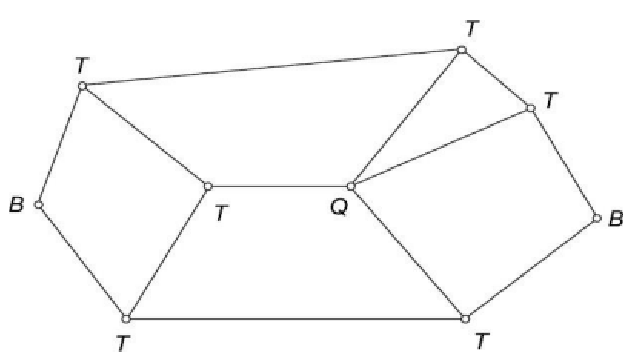


1.5 Types of Joint: The usual types of joints in a chain are:–

a) Binary Joint: If two links are joined at the same connection, it is called a binary joint. For example, in fig. at joint B

b) Ternary Joint: If three links joined at a connection, it is known as a ternary link. For example point T in fig.

c) Quaternary Joint: If four links joined at a connection, it is known as a quaternary link. For example point Q in fig.



EXPERIMENT 02: To study inversions of 4 Bar Mechanisms.

APPARATUS USED: - 4 Bar Mechanisms

THEORY: -

Inversion of Mechanism: When the number of links in kinematic chain is more than three, the chain is known as– mechanism. When one link of the kinematic chain at a time is fixed, give the different mechanism of the kinematic chain. The method of generating different mechanism by fixing a link is called the inversion of mechanism. The number of inversion is equal to the numbers of links in the kinematic chain.

The inversion of four-bar chain mechanism are: may be classified as:–

a) **First inversion: coupled wheel of locomotive:** The mechanism of a coupling rod of a locomotive (also known as double crank– mechanism) which consists of four links is shown in Fig.

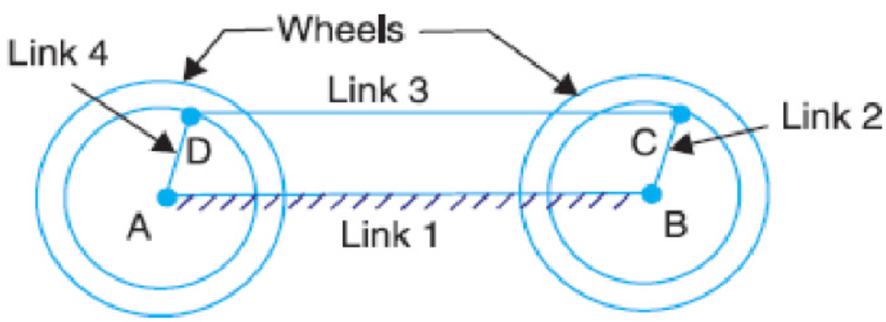


Fig. Coupled wheel of locomotive

In this mechanism, the links AD and BC (having equal length) act as cranks and are connected to the respective wheels. The link CD acts as a coupling rod and the link AB is fixed in order to maintain a constant centre to Centre distance between them. This mechanism is meant for transmitting rotary motion from one wheel to the other wheel.

b) **Second inversion: Beam Engine:** A part of the mechanism of a beam engine (also known as cranks and lever mechanism) which consists of four links is shown in Fig. In this mechanism, when the crank rotates about the fixed centre A, the lever– oscillates about a fixed centre D. The end E of the lever CDE is connected to a piston rod which reciprocates due to the rotation of the crank. In other words, the purpose of this mechanism is to convert rotary motion into– reciprocating motion

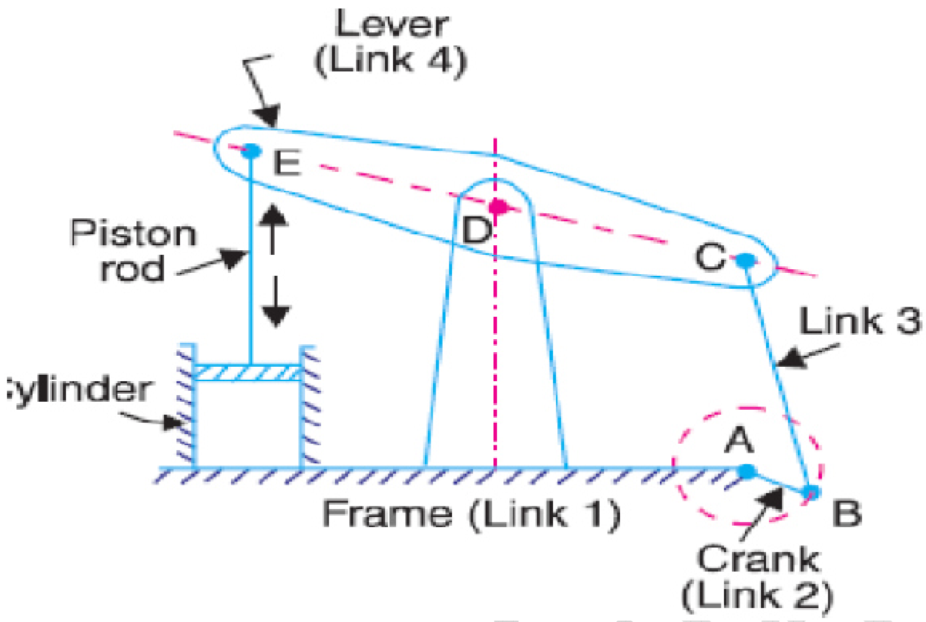


Fig. beam engine

c) **Third inversion: watts indicator mechanism**: A Watt's indicator mechanism (also known as Watt's straight line mechanism or double lever mechanism) which consists of four links is shown in Fig. The four links are: fixed link at A, link AC, link CE and link BFD. It may be noted that BF and FD form one link because these two parts have no relative motion between them. The links CE and BFD act as levers. The displacement of the link BFD is directly proportional to the pressure of gas or steam which acts on the indicator plunger. On any small displacement of the mechanism, the tracing point E at the end of the link CE traces out approximately a straight line.

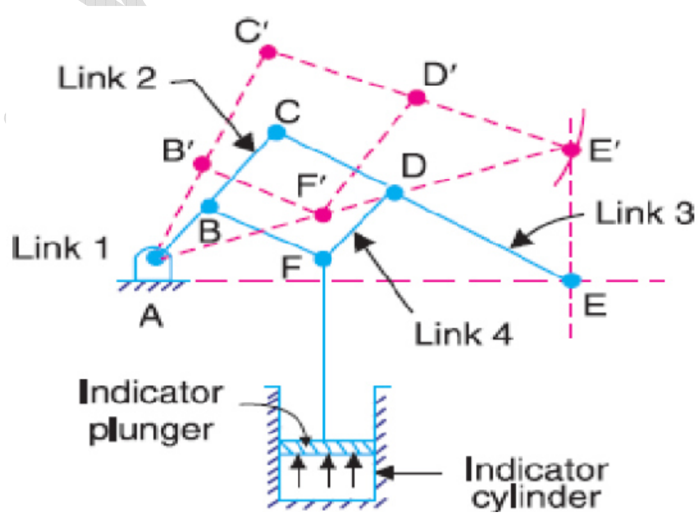
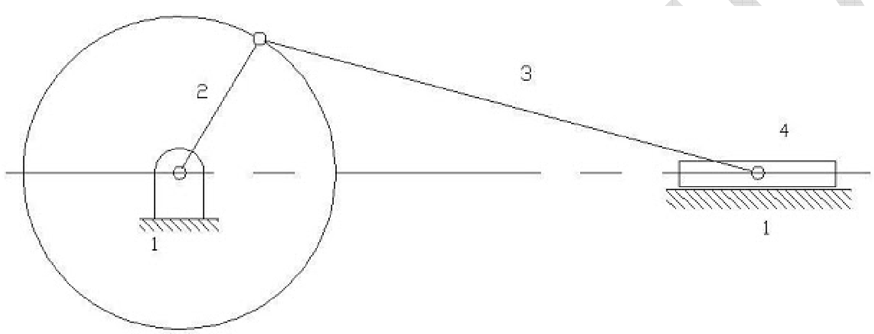


Fig. **watts indicator mechanism**

EXPERIMENT 03: To study inversions of Single Slider Mechanisms.
APPARATUS USED: - Single Slider Mechanisms
THEORY: - INVERSIONS OF SINGLE SLIDER–CRANK CHAIN :- Different mechanisms obtained by fixing different links of a kinematics chain are known as its inversions. A slider – crank chain has the following inversions :-

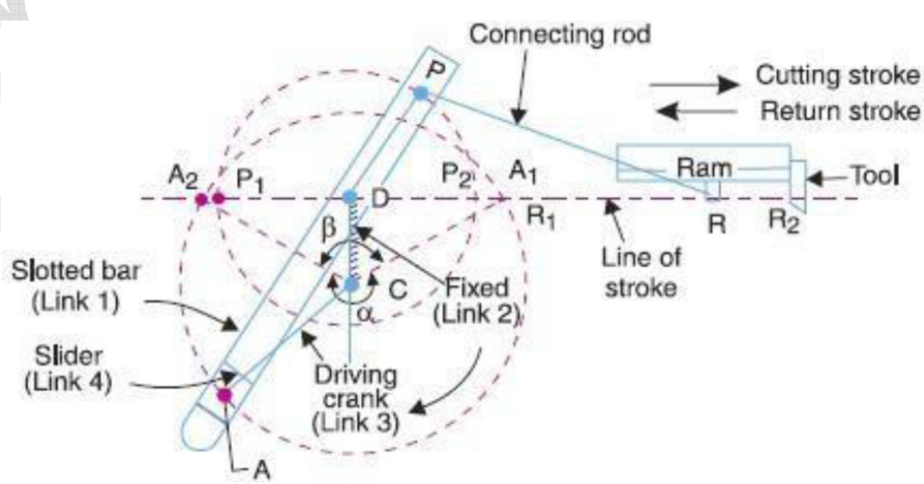
a) First inversion (i.e; Reciprocating engine and compressor)
b) Second inversion (i.e., Whitworth quick return mechanism and Rotary engine)
c) Third inversion (i.e., Oscillating cylinder engine and crank & slotted lever mechanism)
d) Fourth inversion (Hand pump)

a) **First inversion:** This inversion is obtained when link 1 is fixed and links 2 and 4 are made the– crank and slider respectively. (fig.a) Applications:– a Reciprocating engine b Reciprocating compressor.



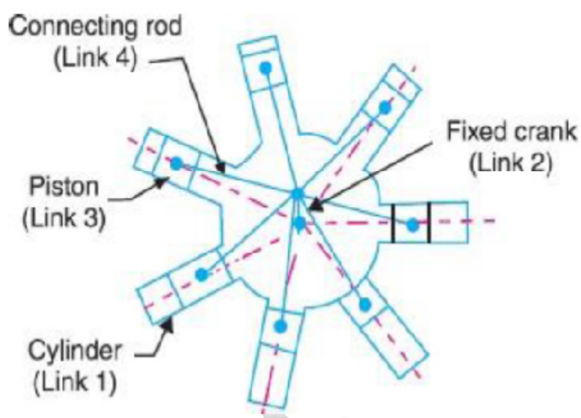
b) **Second inversion** Fixing of the link 2 of a slider-crank chain results in the second inversion. Applications:– a Whitworth quick-return mechanism b Rotary engine

i) **Whitworth Quick-Return Mechanism:** This mechanism used in shaping and slotting machines.– In this mechanism the link CD (link 2) forming the turning pair is fixed; the driving– crank CA (link 3) rotates at a uniform angular speed and the slider (link 4) attached to the crank pin at a slides along the slotted bar PA (link 1) which oscillates at D. The connecting rod PR carries the ram at R to which a cutting tool is fixed and the– motion of the tool is constrained along the line RD produced.



$$\frac{time\ of\ return}{time\ of\ cutting} = \frac{\beta}{\alpha} = \frac{\beta}{360° - \beta} = \frac{360° - \alpha}{\alpha}$$

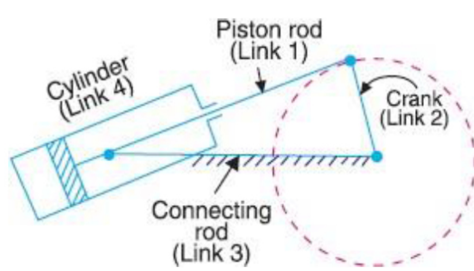
ii) **Rotary engine** Sometimes back, rotary internal combustion engines were used in aviation. But now a days gas turbines are used in its place.– It consists of seven cylinders in one plane and all revolves about fixed center D, as shown in Fig., while the crank (link 2) is fixed. In this mechanism, when the connecting rod (link 4) rotates, the piston (link 3) reciprocates inside the cylinders forming link 1.



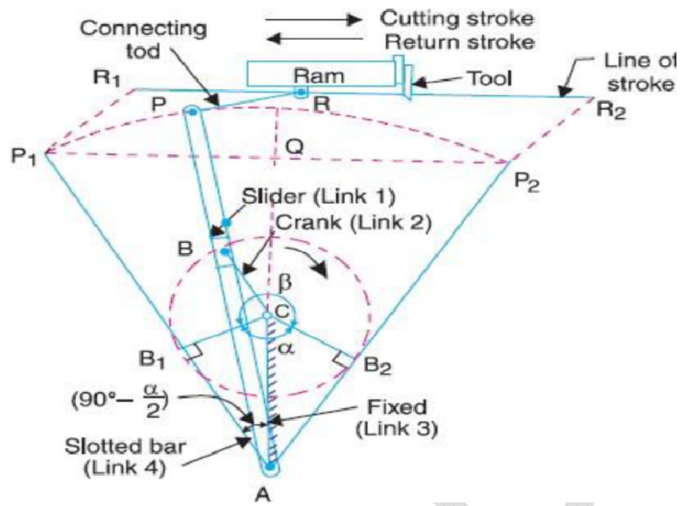
c) **Third Inversion** By Fixing of the link 3 of the slider-crank mechanism, the third inversion is– obtained. Now the link 2 again acts as a crank and the link 4 oscillates.

Applications:– a Oscillating cylinder engine b Crank and slotted-lever mechanism

i) **Oscillating cylinder engine:** The arrangement of oscillating cylinder engine mechanism, as shown in Fig. Is used– to convert reciprocating motion into rotary motion. In this mechanism, the link 3 forming the turning pair is fixed. The link 3 corresponds to the connecting rod of a reciprocating steam engine mechanism. When the crank (link 2) rotates, the piston attached to piston rod (link 1) reciprocates and the cylinder (link 4) oscillates about a pin pivoted to the fixed link at A.



ii) **Crank and slotted-leverMechanism** This mechanism is mostly used in shaping machines, slotting machines and in rotary– internal combustion engines. In this mechanism, the link AC (i.e. link 3) forming the turning pair is fixed, as shown– in Fig. The link 3 corresponds to the connecting rod of a reciprocating steam engine. The driving crank CB revolves with uniform angular speed about the fixed center C. A sliding block attached to the crank pin at B slides along the slotted bar AP and thus causes AP to oscillate about the pivoted point A. A short link PR transmits the motion from AP to the ram which carries the tool and– reciprocates along the line of stroke R1R2. The line of stroke of the ram (i.e. R1R2) is perpendicular to AC produced.

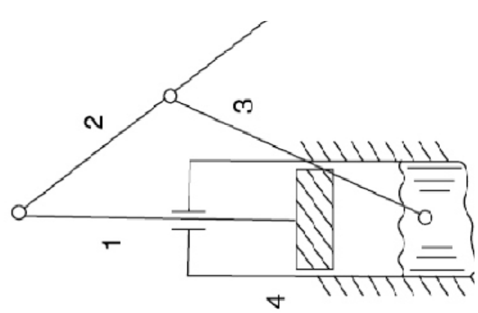


In the extreme positions, AP1 and AP2 are tangential to the circle and the cutting tool is at the end of the stroke. The forward or cutting stroke occurs when the crank rotates from the position CB1 to CB2 (or through an angle β) in the clockwise direction. The return stroke occurs when the crank rotates from the position CB2 to CB1 (or through angle α) in the clockwise direction. Since the crank has uniform angular speed, therefore

$$\frac{time\ of\ cutting}{time\ of\ return} = \frac{\beta}{\alpha} = \frac{\beta}{360° - \beta} = \frac{360° - \alpha}{\alpha}$$

d) Fourth Inversion If the link 4 of the slider-crank mechanism is fixed, the fourth inversion is obtained.– Link 3 can oscillates about the fixed pivot B on the link 4. This makes the end A of the link 2 to oscillate about B and the end O to reciprocate along the axis of the fixed link 4.

Application: Hand Pump



EXPERIMENT 04: To study inversions of Double Slider Mechanisms.

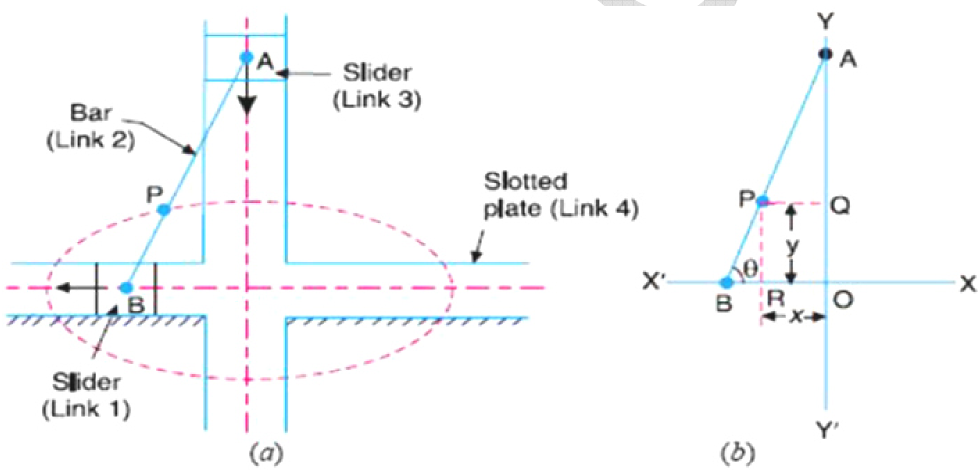
APPARATUS USED: - Double Slider Mechanisms

THEORY: - INVERSIONS OF DOUBLE SLIDER–CRANK CHAIN :-

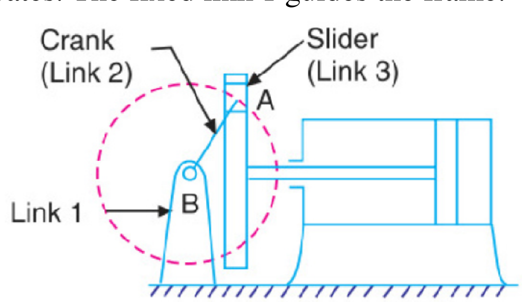
A kinematic chain which consists of two turning pairs and two sliding pairs is known as double slider chain. We see that the link2 and link1 form one turning pair and link2, and link3 form the second turning pair. The link 3 and link4 form one sliding pair and link 1 and link 4 form the second sliding pair.

Inversions of Double Slider crank chain: The following three inversions of a double slider crank chain are important from the subject point of view:

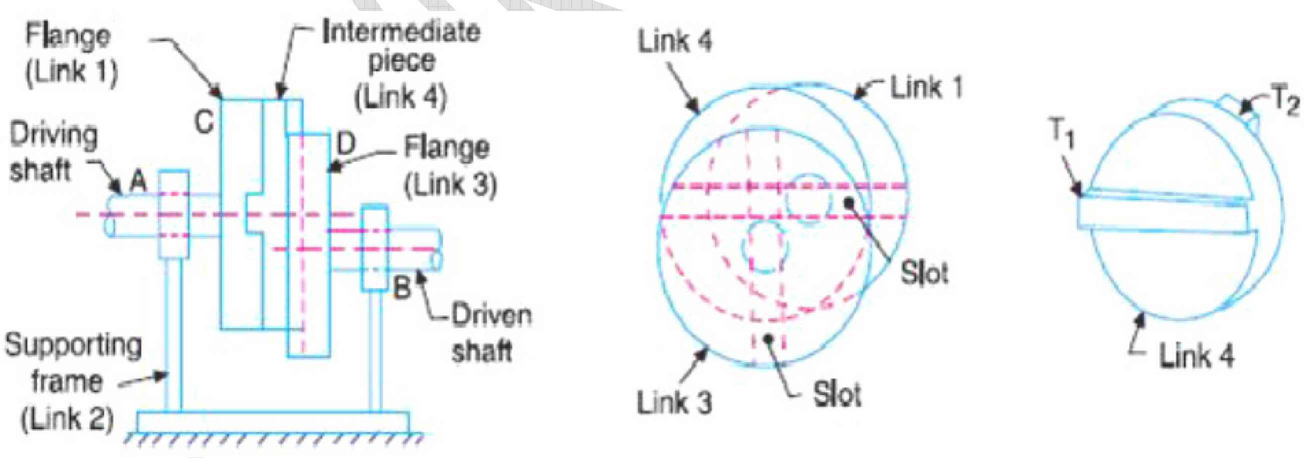
1. **Elliptical trammels.** It is an instrument used for drawing ellipse. This inversion is obtained by fixing the slotted plate (link 4). The fixed plate or link 4 has two straight grooves cut in it, at right angles to each other. The link 1 and link 3, are known as sliders and form sliding pairs with link4. The link AB (link 2) is a bar, which forms turning pair with links 1 and 3. When the links 1and 3 slide along their respective grooves, any point on the link 2 such as P traces out an ellipse on the surfaces an ellipse on the surface of link4. A little consideration will show that AP and BP are the semi-major axis and semi-minor axis of the ellipse respectively.



2. **Scotch yoke mechanism**. This mechanism is used for converting rotary motion into a reciprocating motion. The inversion is obtained by the fixing either the link1 or link3. Link 1 is fixed. In this mechanism, when the link2 (which corresponds to crank) rotates about B as center, the link 4 (which corresponds to a frame) reciprocates. The fixed link 1 guides the frame.

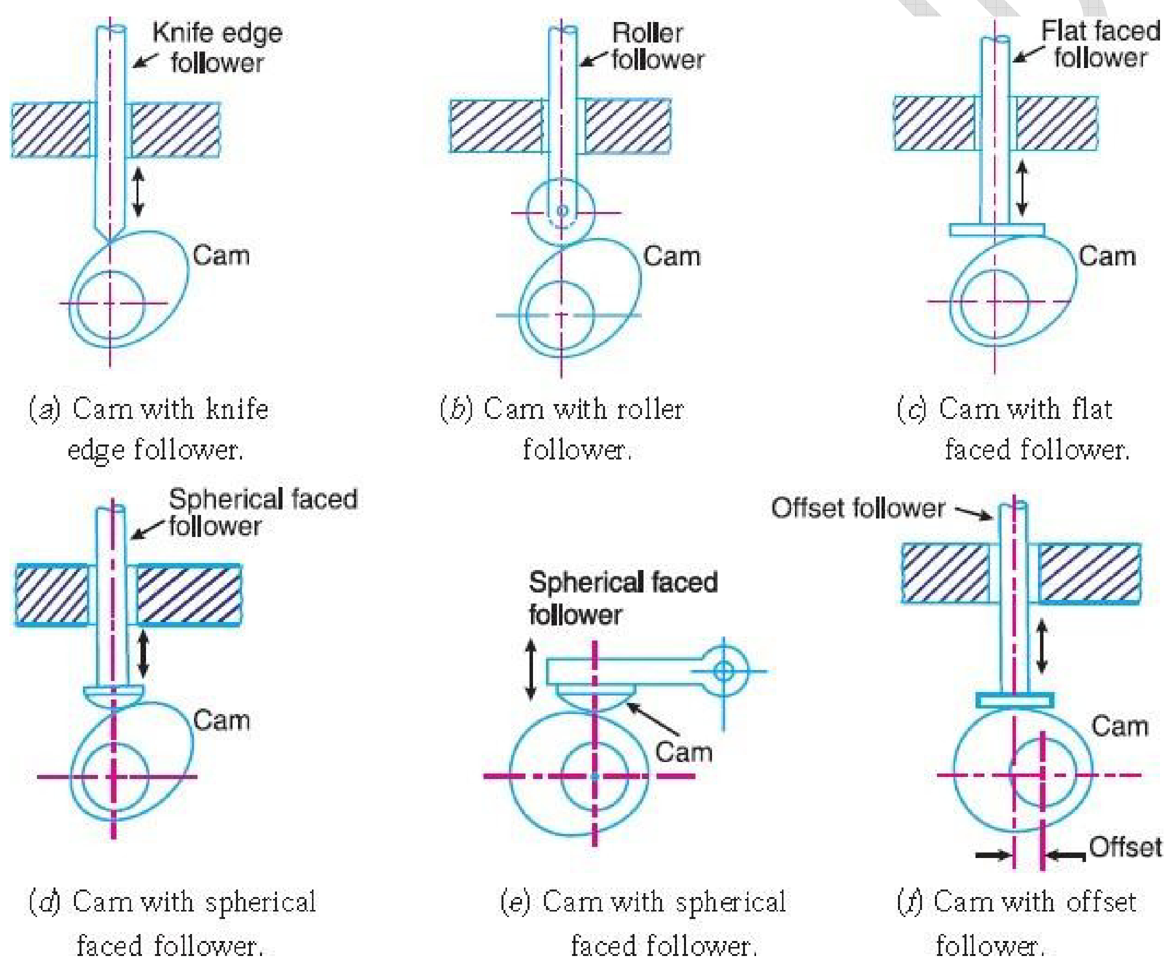


Oldham's coupling. An Oldham's coupling is used for connecting two parallel shafts whose axes at a small distance apart. The shafts are coupled in such a way that if one shaft rotates, the other shaft also rotates at the same speed. The inversion is obtained by the fixing the link 2. The shafts to be connected have two flanges (link 1 and link 3) rigidly fastened at their ends by forging. The link 1 and link3 form turning pairs with link 2. These flanges have diametrical slots cut in their inner faces. The intermediate piece (link4), which is a circular disc, has two tongues (i.e. diametrical projections) T1 and T2 on each face at right angles to each other. The tongues on the link 4 closely fit into the slots in the two flanges (link 1 and link3). The link 4 can slide or reciprocate in the slots in the flanges. When the driving shaft A is rotated, the flange C (link1) causes the intermediate piece (link4) to rotate at the same angle through which the flange has rotated, and it further rotates the flange D (link3) at the same angle and thus the shafts B rotates. Hence link 1,3 and 4 have the same angular velocity at every instant. A little consideration will show, that there is a sliding motion between the link4 and each of the other link 1 and 3. If the distance between the axes of the shafts is constant, the center of intermediate piece will describe a circle of radius equal to the distance between the axes of the two shafts. Therefore, the maximum sliding speed of each tongue along its slot is equal to the peripheral velocity of the center of the disc along its circular path. Let ω = Angular velocity of each shaft in rad/s, and r = Distance between the axes of the shafts in metres. Maximum sliding speed of each tongue (in m/s), $V = \omega r$



EXPERIMENT 05: To study various types of Cams and Followers. Also discuss their nomenclature.
APPARATUS USED: - Cams & Followers
THEORY: - A cam is a rotating machine element which gives reciprocating or oscillating motion to another element known as follower. The cam and the follower have a line contact and constitute a higher pair. The cams are usually rotated at uniform speed by a shaft, but the follower motion is pre-determined and will be according to the shape of the cam. The cam and follower isone of the simplest as well as one of the most important mechanisms found in modern machinery today. The cams are widely used for operating the inlet and exhaust valves of internal combustion engines, automatic attachment of machineries, paper cutting machines, spinning and weaving textile machineries, feed mechanism of automatic lathes etc.

5.1 Classification of Followers: The followers may be classified as discussed below in fig. 5.1:



(a) Cam with knife edge follower.
(b) Cam with roller follower.
(c) Cam with flat faced follower.
(d) Cam with spherical faced follower.
(e) Cam with spherical faced follower.
(f) Cam with offset follower.

5.1.1 According to surface in contact

a) Knife edge follower
   - When the contacting end of the follower has a sharp knife edge, it is called a knife edge follower, as shown in Fig. 5.1 (a).
   - The sliding motion takes place between the contacting surfaces (i.e. the knife edge and the

cam surface). It is seldom used in practice because the small area of contacting surface results in excessive wear. In knife edge followers, a considerable side thrust exists between the follower and the guide.

b) Roller follower
- When the contacting end of the follower is a roller, it is called a roller follower, as shown in Fig. 5.1 (b). Since the rolling motion takes place between the contacting surfaces (i.e. the roller and the cam), therefore the rate of wear is greatly reduced.
- In roller followers also the side thrust exists between the follower and the guide. The roller followers are extensively used where more space is available such as in stationary gas and oil engines and aircraft engines.

c) Flat faced or mushroom follower
- When the contacting end of the follower is a perfectly flat face, it is called a flat-faced follower, as shown in Fig. 5.1 (c). It may be noted that the side thrust between the follower and the guide is much reduced in case of flat faced followers.
- The only side thrust is due to friction between the contact surfaces of the follower and the cam. The relative motion between these surfaces is largely of sliding nature but wear may be reduced by off-setting the axis of the follower, as shown in Fig. 5.1 (f) so that when the cam rotates, the follower also rotates about its own axis.
- The flat faced followers are generally used where space is limited such as in cams which operate the valves of automobile engines.

d) Spherical faced follower
- When the contacting end of the follower is of spherical shape, it is called a spherical faced follower, as shown in Fig. 5.1 (d). It may be noted that when a flat-faced follower is used in automobile engines, high surface stresses are produced. In order to minimize these stresses, the flat end of the follower is machined to a spherical shape.

5.1.2 According to the motion of follower

a) Reciprocating or Translating Follower
- When the follower reciprocates in guides as the cam rotates uniformly, it is known as reciprocating or translating follower. The followers as shown in Fig. 5.1 (a) to (d) are all reciprocating or translating followers.

b) Oscillating or Rotating Follower
- When the uniform rotary motion of the cam is converted into predetermined oscillatory motion of the follower, it is called oscillating or rotating follower. The follower, as shown in Fig 5.1 (e), is an oscillating or rotating follower.

5.1.3 According to the path of motion of the follower

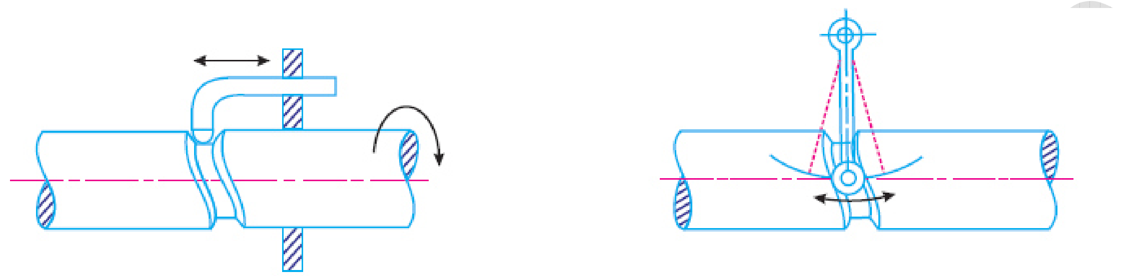
a) Radial Follower: When the motion of the follower is along an axis passing through the centre of the cam, it is known as radial follower. The followers, as shown in Fig. 5.1 (a) to (e), are all radial followers.

b) Off-set 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. The follower, as shown in Fig.5.1 (f), is an off-set follower.

5.2 Classification of cams

a) **Radial or Disc cam:** In radial cams, the follower reciprocates or oscillates in a direction perpendicular to the cam axis. The cams as shown in Fig. 5.1 are all radial cams.

b) **Cylindrical cam:** In cylindrical cams, the follower reciprocates or oscillates in a direction parallel to the cam axis. The follower rides in a groove at its cylindrical surface. A cylindrical grooved cam with a reciprocating and an oscillating follower is shown in Fig. 5.2 (a) and (b) respectively.



(*a*) Cylindrical cam with reciprocating follower.

(*b*) Cylindrical cam with oscillating follower.

Fig. 5.2 cylindrical cam

5.3 Terminology used in radial cams

- **Base circle:** It is the smallest circle that can be drawn to the cam profile.
- **Trace point:** It is a reference point on the follower and is used to generate the pitch curve. In case of knife edge follower, the knife edge represents the trace point and the pitch curve corresponds to the cam profile. In a roller follower, the centre of the roller represents the trace point.
- **Pressure angle:** It is the angle between the direction of the follower motion and a normal to the pitch curve. This angle is very important in designing a cam profile. If the pressure angle is too large, a reciprocating follower will jam in its bearings.
- **Pitch point:** It is a point on the pitch curve having the maximum pressure angle.
- **Pitch circle:** It is a circle drawn from the centre of the cam through the pitch points.
- **Pitch curve:** It is the curve generated by the trace point as the follower moves relative to the cam. For a knife edge follower, the pitch curve and the cam profile are same whereas for a roller follower, they are separated by the radius of the roller.
- **Prime circle:** It is the smallest circle that can be drawn from the centre of the cam and tangent to the pitch curve. For a knife edge and a flat face follower, the prime circle and the base circle are identical. For a roller follower, the prime circle is larger than the base circle by the radius of the roller.
- **Lift or Stroke:** It is the maximum travel of the follower from its lowest position to the topmost position.

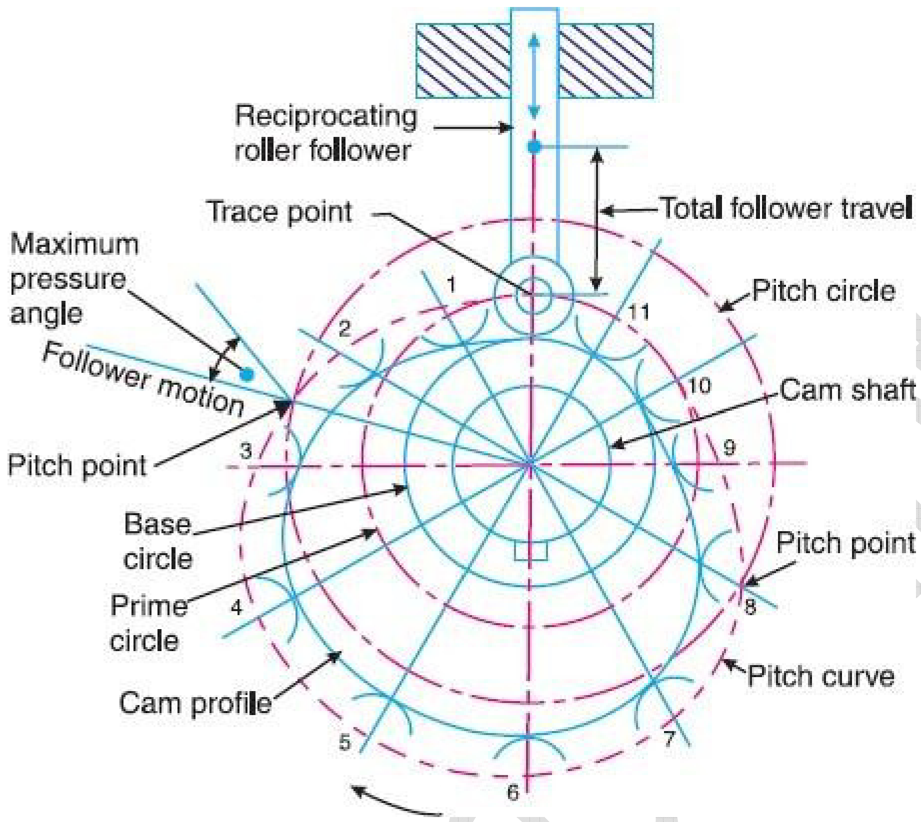


Fig. 5.3 terms used in radial cams