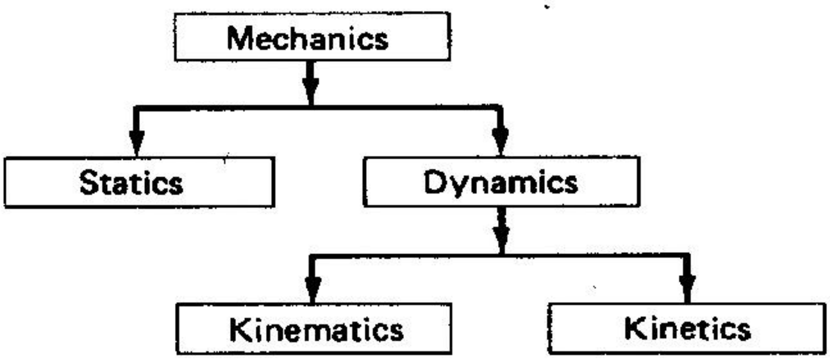
SME1203 KINEMATICS OF MACHINES

UNIT 1 BASICS OF MECHANISMS



Kinematic Link or Element

Each part of a machine, which moves relative to some other part, is known as a **kinematic link** or **element**. A link may consist of several parts, which are rigidly fastened together, so that they do not move relative to one another.

The link should have the following two characteristics:

1. It should have relative motion, and **2.** It must be a resistant body

Types of Links:

§ Rigid: It undergoes no deformation; Example: crank, connecting rod.

§ Flexible: Partial deformation; Example: springs, belts, ropes.

§ Fluid: Motion is transmitted by this link by deformation.

Kinematic Pair

The two links or elements of a machine, when in contact with each other, are said to form a pair. If the relative motion between them is completely or successfully constrained the pair is known as **kinematic pair**.

Classification of Pair is based on:

1. **According to the type of relative motion between the elements.**

Sliding Pair:

The two elements have a sliding motion relative to each other. Example: Piston and cylinder pair rectangular rod is rectangular line.

Turing Pair:

When the two elements are connected such that the element revolves about the other element. Example: Shaft rotates in the bearing rotation of a crank in a slider crank mechanism.

Rolling pair:

When one element is free to roll on another element. Example: The belt and pulley surfaces constitute rolling pair.

Screw Pair:

In this type the contacting surface is having threads. It is also called a helical pair one element turns about another element by means of thread only.

Example: A bolt and nut arrangement screw jack for lifting heavy weights.

Spherical Pair:

One element is in the form of sphere and turns about the fixed element;

Example: ball and socket joint

2. According to the type of contact between the elements.

Lower Pair:

If a pair motion has surface contact between the elements. Example:

§ Piston reciprocating in a cylinder

§ Shaft rotates in a bearing. (Contacting surfaces are similar)

Higher Pair:

In higher pair there is a line or point contact between the elements.

Example: Cam and follower. (Contact surfaces are different.)

3. According to the type of closure.

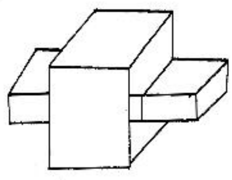
Self Closed Pair:

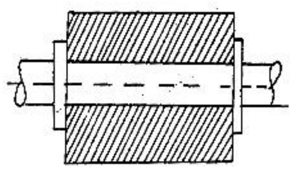
In this pair, two elements are held together mechanically; Example: All lower pair

Unclosed Pair/Force Closed Pair:

The two elements are not held together mechanically; Example: Cam and followers.

Types of Constrained Motions



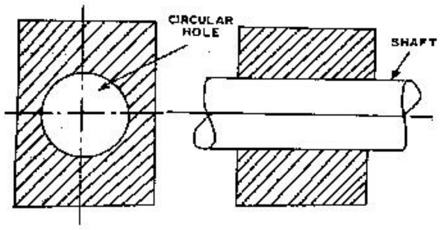


Constraint means: Limitation of motion (or) action.

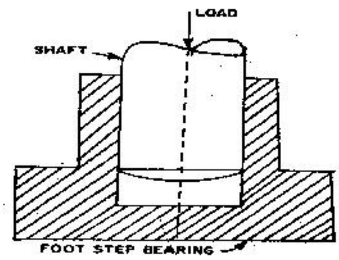
§ Completely Constraint: Moves in a definite direction

Example: square bar moving in square hole.

§ Incompletely Constraint: Moves in all direction direction.
Example: Circular bar moving in a circular hole.



§ Successfully Constraint: Motion is not completed by itself but by some other means.



Difference between a Machine and a Structure

The following differences between a machine and a structure are important from the subject point of view :

1. The parts of a machine move relative to one another, whereas the members of a structure do not move relative to one another.

2. A machine transforms the available energy into some useful work, whereas in a structure no energy is transformed into useful work.

3. The links of a machine may transmit both power and motion, while the members of a structure transmit forces only.

Kinematic Chain

A kinematic chain may be defined as a combination of kinematic pairs, joined in such a way that eachlink forms a part of two pairs and the relative motion between the links or elements is completely or successfully constrained.

<u>Relation between Links, Pairs and Joints</u>

$l=2p-4$

$j=(3/2)\,l-2$

l => No of Links

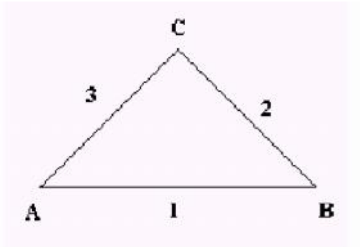
p => No of Pairs

j => No of Joints

L.H.S > R.H.S => Locked chain

L.H.S = R.H.S => Constrained Kinematic Chain

L.H.S < R.H.S => Unconstrained Kinematic Chain



l = 3;, p = 3;j = 3

l = 2p – 4

3 = 2 × 3 – 4 = 2

i.e. L.H.S. > R.H.S.

j=(3/2) l – 2

3=(3/2)3 – 2 = 2.5

i.e. L.H.S. > R.H.S.

ABC does not form a Kinematic chain but forms a structure.

Types of Joints:

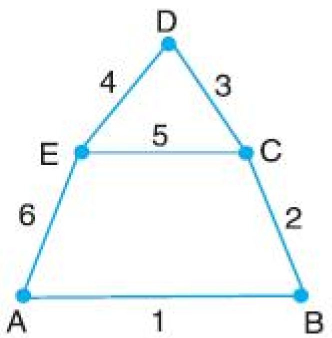
(a) Binary Joint: If two links are connected at the same end it is called as binary joint.

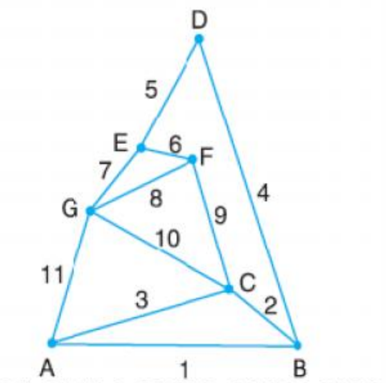
(b) A.W Klein:

J + h/2 = 3/2 n - 2

J - Joints (B); h - higher pairs; n - links

(c) **Ternary joint**. When three links are joined at the same connection, the joint is known as ternary joint. It is equivalent to two binary joints as one of the three links joined carry the pin for the other two links.





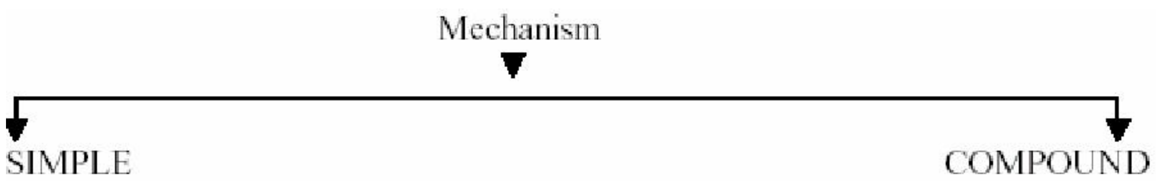
(d)Quaternary joint. When four links are joined at the same connection, the joint is called a quaternary joint. It is equivalent to three binary joints. In general, when l number of links are joined at the same connection, the joint is equivalent to (l – 1) binary joints.

Mechanism

When one of the links of a kinematic chain is fixed, the chain is known as **mechanism**. It may be used for transmitting or transforming motion. Example: engine, indicator, type writer.

Difference between Machine and Mechanism:

Machine	Mechanism
1. It is like the human body, it transforms energy into useful work.,	1. It is like frame work and has definite motion between various links.
2. It relates to energy only.	2. Relates to motion
3. It has many links.	3. It also has many links.
4. E.g. lathe, shaper	4. E.g. Engine ,indicator, typewriter

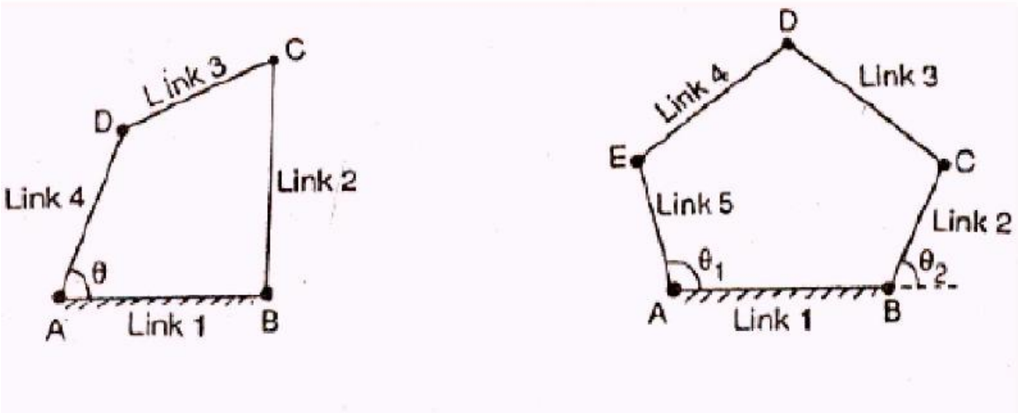


A mechanism with four links is called simple mechanism.

A mechanism with more than four links is called compound mechanism.

Degree of Freedom for plane Mechanism m (mobility):

It is defined as the no of input motions, which must be independently controlled in order to bring mechanism into useful engineering purpose.



(a) Four bar chain. **m=1** (b) Five bar chain.**m=2**

Kutzbach eriterion:

In a mechanism, one of the links is to be fixed, therefore the number of movable links will be (l – 1) and thus the total number of degrees of freedom will be 3 (l – 1) before they are connected to any other link. In general l number of links is connected by number of binary joints (or) lower pairs and h number of higher pairs, then the number of degrees of freedom of a mechanism is $n = 3 (l - 1) - 2j-h$.

$n = 3 (l - 1) - 2j - h$ (Kutzbach criterion)

Grubler's criterion for plane motion:

$n = 3 (l - 1) - 2 j - h$

When $h = 0$, $n = 1$

We get a constrained motion given by

$3 l - 2 j - 4 = 0$

Grashof's Law:

- The sum of the longest and the shortest length should not be greater than the sum of remaining two links length if there is to be continuous relative motion between the two links.

- In a four-bar linkage, we refer to the line segment between hinges on a given link as a **bar** where:

· s = length of shortest bar

· l = length of longest bar

· p, q = lengths of intermediate bar

Grashof's theorem states that a four-bar mechanism has at least one revolving link if

s + l <= p + q (1) and all three mobile links will rock if

s + l > p + q (2)

The inequality 1 is **Grashof's criterion**.

- The link opposite the frame is called the **coupler link**, and the links which are hinged to the frame are called **side links**.
- A link which is free to rotate through 360 degree with respect to a second link will be said to **revolve** relative to the second link (not necessarily a frame).
- If it is possible for all four bars to become simultaneously aligned, such a state is called a **change point**.

Some important concepts in link mechanisms are:

Crank: A side link which revolves relative to the frame is called a crank.

Rocker: Any link which does not revolve is called a rocker.

Crank-rocker mechanism: In a four bar linkage, if the shorter side link revolves and the other one rocks (i.e., oscillates), it is called a crank-rocker mechanism.

Double-crank mechanism: In a four bar linkage, if both of the side links revolve, it is called a double-crank mechanism.

Double-rocker mechanism: In a four bar linkage, if both of the side links rock, it is called a double-rocker mechanism

Kinematic Inversions of Mechanisms:

This method of obtaining different mechanisms by fixing different links in a Kinematic chain, it is known as inversion mechanism.

Types of Kinematic Chain:

- Four bar chain (or) quadratic cycle chain (all four turning pairs)
- Slider Crank Chain (three turning and are sledding pair)

- Double slider crank chain (Two turning and two sliding pair)

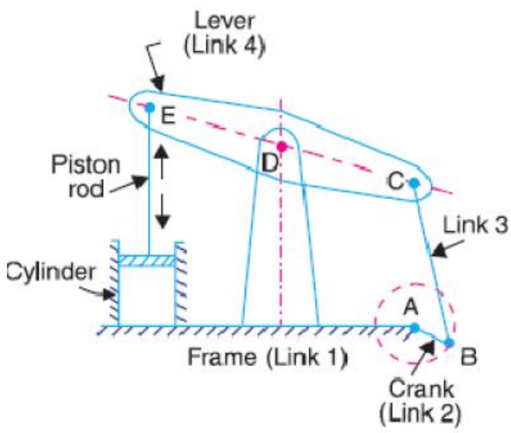
Inversions of Four Bar Chain

Four Bar Chain (Or) Quadratic Cycle Chain

It consists of four links, each of them forms a turning pair at *A, B, C* and *D*. The four links may be of different lengths. Rotating link is known as ***crank*** or ***driver***. *AD* (link 4) is a crank. The link *BC* (link 2) which makes a partial rotation or oscillates is known as ***lever*** or ***rocker*** or ***follower*** and the link *CD* (link 3) which connects the crank and lever is called ***connecting rod*** or ***coupler.*** The fixed link *AB* (link 1) is known as ***frame*** of the mechanism. When the crank (link 4) is the driver, the mechanism is transforming rotary motion into oscillating motion.

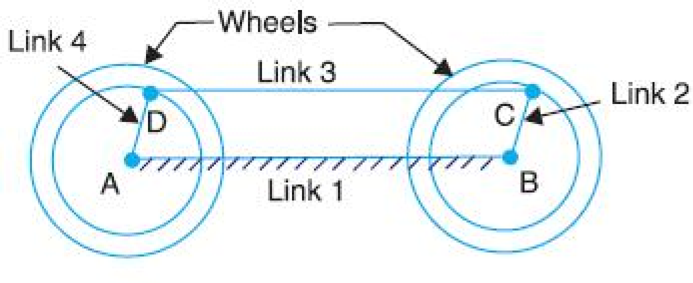
Beam Engine: (Crank and Lever Mechanism)

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.



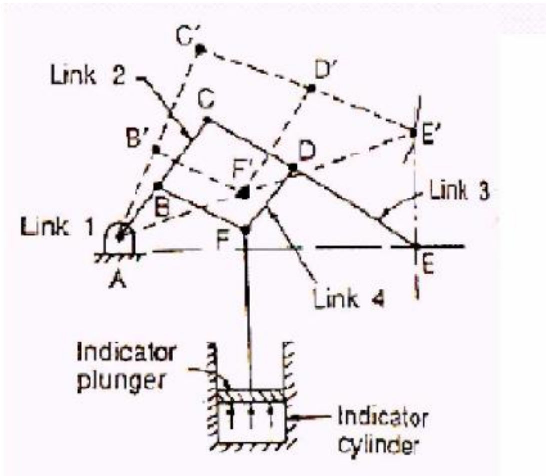
Coupling rod of a locomotive (Double Crank mechanism).

The mechanism of a coupling rod of a locomotive which consists of 4 links is shown in Figure. In this mechanism, the links AD and BC (having equal length) act as crank and are connected to the respective wheels. The links CD act as coupling rod and link AB is fixed in order to maintain constant center to center distance between them. This mechanism is meant for transmitting rotary motion from one wheel together wheel.



Watt’s Indicator Mechanism (Double lever mechanism).

A watt is indicator mechanism (also known as watt's straight line mechanism or double lever mechanism) which consists of four links. The four links are fixed link at A, link AC link CE and link BFD. It may be noted that BF and FD forms one link because these two parts have no relative motion between them.

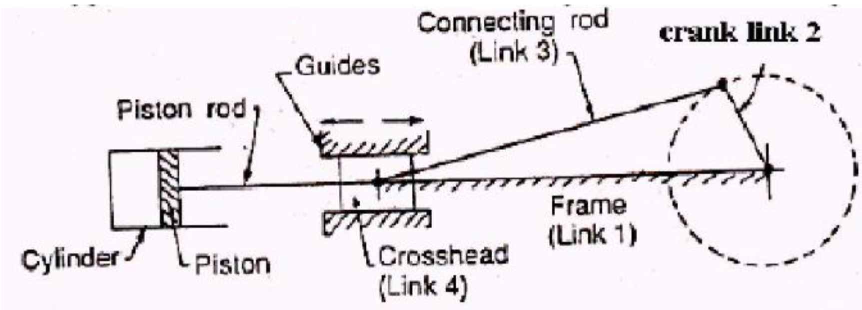


The links CE and BFD act as levers. The displacement of link BFD is directly proportional the pressure of gas or stream which acts on the indicator plunger. On any small displacement of mechanism, the tracing point at the end of the link CE traces out approximately a straight line.

Single Slider - Crank - Chain:

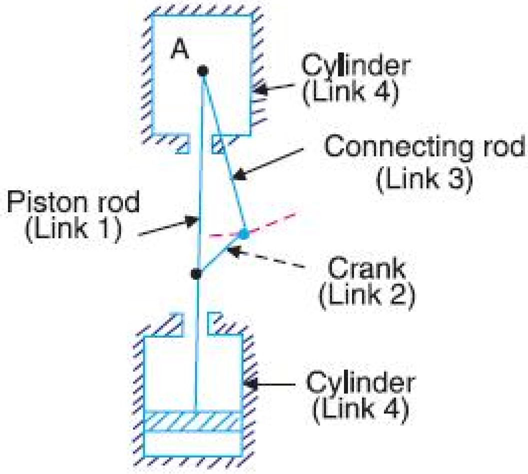
□□A single crank chain is a modification of the basic fou -bar chain. It consists of one sliding pair and three turning pairs. It is found in reciprocating steam engine mechanism.

□□This type of mechanism converts rotary motion into reciprocating motion and vice versa.

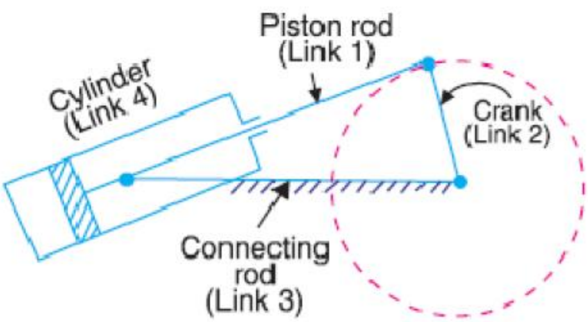


Single slider crank chain.

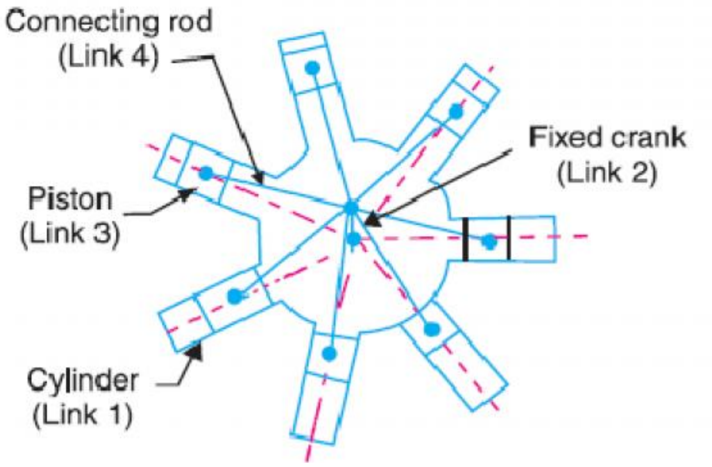
1. *Pendulum pump or Bull engine*. In this mechanism, the inversion is obtained by fixing the cylinder or link 4 (*i.e*. sliding pair), as shown in Fig. In this case, when the crank (link 2) rotates, the connecting rod (link 3) oscillates about a pin pivoted to the fixed link 4 at *A* and the piston attached to the piston rod (link 1) reciprocates.



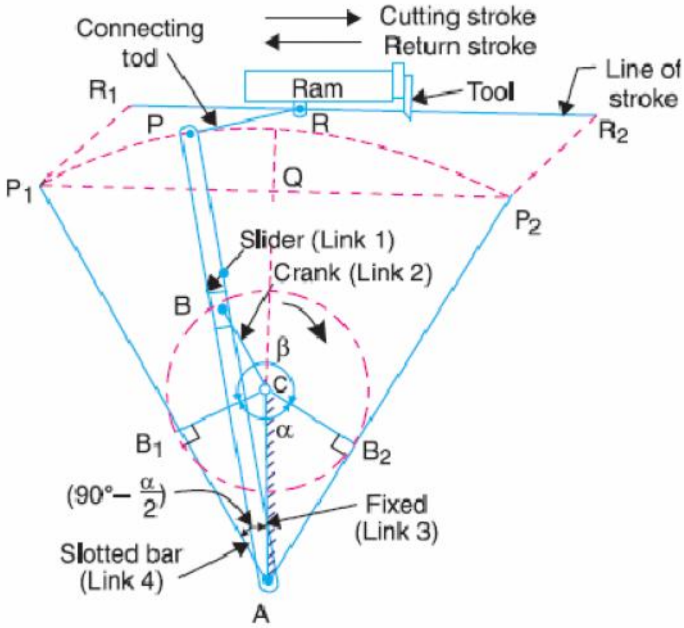
2. *Oscillating cylinder engine*. In this mechanism, the link 3 forming the turning pair is fixed. The link 3 corresponds to the connecting rod of a reciprocating steam engine mechanism. When the crank (link 2) rotates, the piston attached to piston rod (link 1) reciprocates and the cylinder (link 4) oscillates about a pin pivoted to the fixed link at *A*.



3. *Rotary internal combustion engine or Gnome engine*. It consists of seven cylinders in one plane and all revolves about fixed centre *D*, 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.



4. *Crank and slotted lever quick return motion mechanism*. In this mechanism, the link *AC* (*i.e*. link 3) forming the turning pair is fixed. 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 centre *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 *R*1*R*2. The line of stroke of the ram (*i.e*. *R*1*R*2) is perpendicular to *AC* produced.



In the extreme positions, *AP*1 and *AP*2 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 *CB*1 to *CB*2 (or through an angle β) in the clockwise direction. The return stroke occurs when the crank rotates from the position *CB*2 to *CB*1 (or through angle α in the clockwise direction.

$$\frac{\text{Time of cutting stroke}}{\text{Time of return stroke}} = \frac{\beta}{\alpha} = \frac{\beta}{360^\circ - \beta} \quad \text{or} \quad \frac{360^\circ - \alpha}{\alpha}$$

Since the tool travels a distance of $R_1 R_2$ during cutting and return stroke, therefore travel of the tool or length of stroke

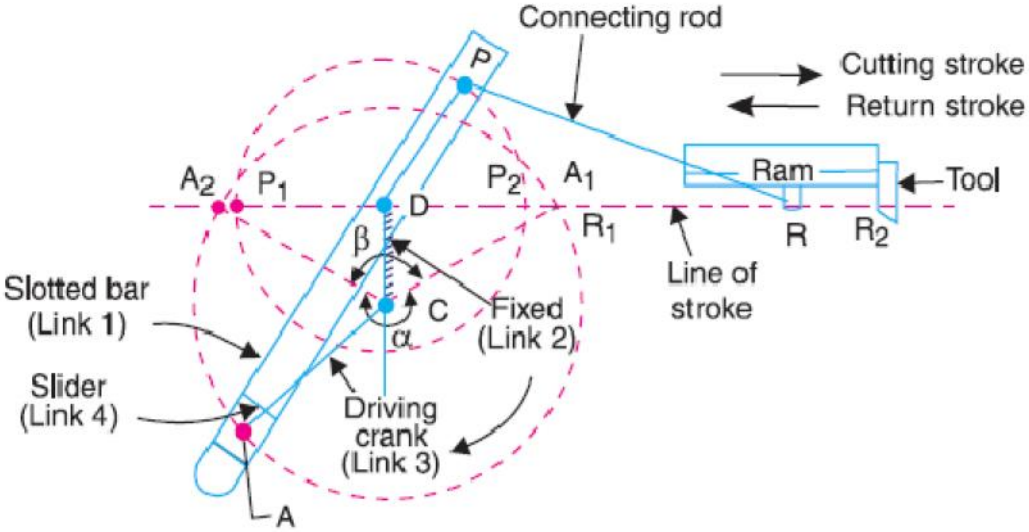
$$= R_1R_2 = P_1P_2 = 2P_1Q = 2AP_1 \sin \angle P_1AQ$$

$$= 2AP_1 \sin\left(90^\circ - \frac{\alpha}{2}\right) = 2AP \cos \frac{\alpha}{2}$$

$$= 2AP \times \frac{CB_1}{AC}$$

$$= 2AP \times \frac{CB}{AC}$$

Whitworth quick return motion mechanism. This mechanism is mostly used in shaping and slotting machines. In this mechanism, the link *CD* (link 2) forming the turning pair is fixed, as shown in Fig. 5.27. The link 2 corresponds to a crank in a reciprocating steam engine. The driving crank *CA* (link 3) rotates at a uniform angular speed. The slider (link 4) attached to the crank pin at *A* slides along the slotted bar *PA* (link 1) which oscillates at a pivoted point *D*. The connecting rod *PR* carries the ram at *R* to which a cutting tool is fixed. The motion of the tool is constrained along the line *RD* produced, *i.e*. along a line passing through *D* and perpendicular to *CD*.

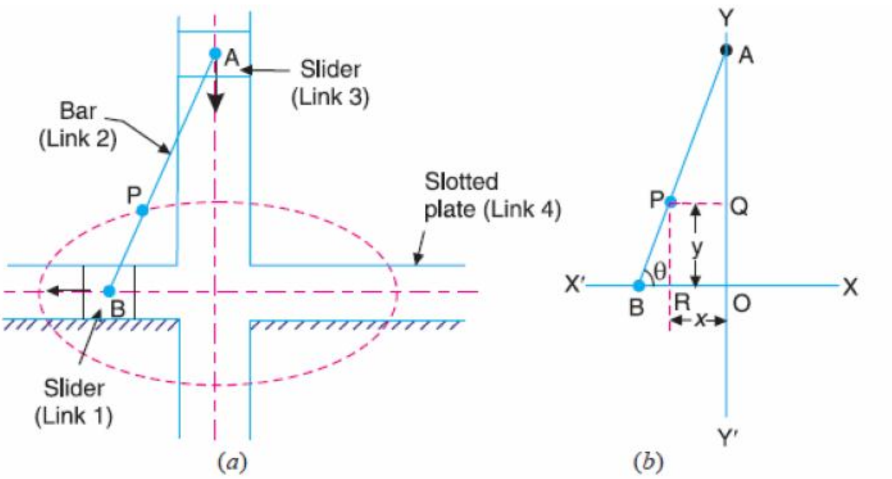


When the driving crank *CA* moves from the position *CA*1 to *CA*2 (or the link *DP* from the position *DP*1 to *DP*2) through an angle α in the clockwise direction, the tool moves from the left hand end of its stroke to the right hand end through a distance 2 *PD*. Now when the driving crank moves from the position *CA*2 to *CA*1 (or the link *DP* from *DP*2 to *DP*1) through an angle β in the clockwise direction, the tool moves back from right hand end of its stroke to the left hand end.

$$\frac{\text{Time of cutting stroke}}{\text{Time of return stroke}} = \frac{\alpha}{\beta} = \frac{\alpha}{360^\circ - \alpha} \quad \text{or} \quad \frac{360^\circ - \beta}{\beta}$$

Inversions of Double Slider Crank Chain

1. ***Elliptical trammels***. It is an instrument used for drawing ellipses. 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 link 4. The link *AB* (link 2) is a bar which forms turning pair with links 1 and 3. When the links 1 and 3 slide along their respective grooves, any point on the link 2 such as *P* traces out an ellipse on the surface of link 4. A little consideration will show that *AP* and *BP* are the semi-major axis and semi-minor axis of the ellipse respectively.



Let us take *OX* and *OY* as horizontal and vertical axes and let the link *BA* is inclined at an angle θ with the horizontal.Now the co-ordinates of the point *P* on the link *BA* will be

$$x = PQ = AP \cos\theta; \text{ and } y = PR = BP \sin\theta$$

or

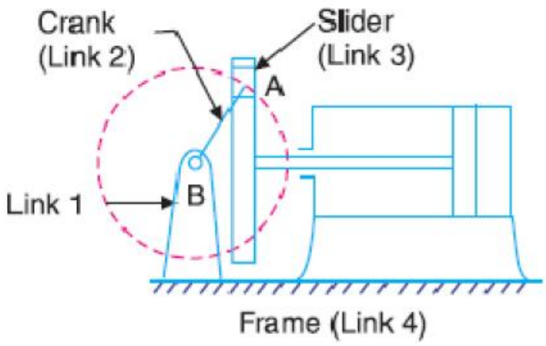
$$\frac{x}{AP} = \cos\theta; \text{ and } \frac{y}{BP} = \sin\theta$$

Squaring and adding,

$$\frac{x^2}{(AP)^2} + \frac{y^2}{(BP)^2} = \cos^2\theta + \sin^2\theta = 1$$

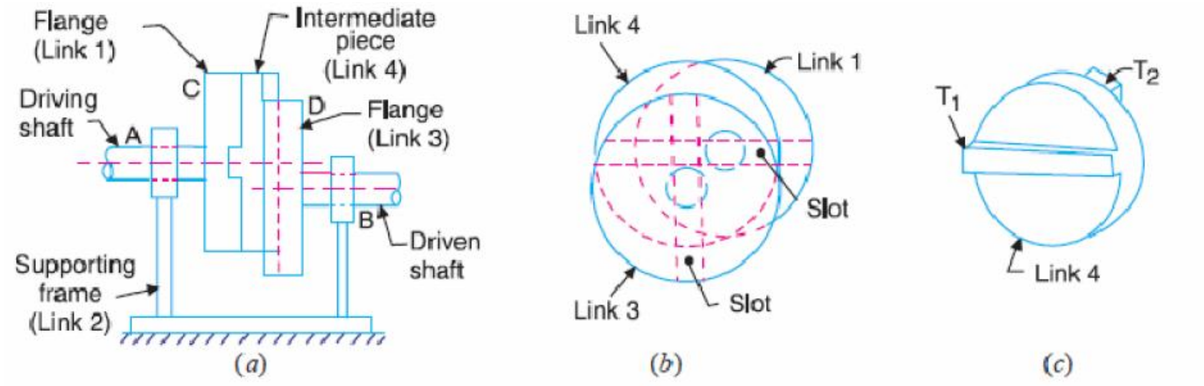
This is the equation of an ellipse. Hence the path traced by point *P* is an ellipse whose semimajor axis is *AP* and semi-minor axis is *BP*.

Scotch yoke mechanism. This mechanism is used for converting rotary motion into a reciprocating motion. The inversion is obtained by fixing either the link 1 or link 3. In Fig., link 1 is fixed. In this mechanism, when the link 2 (which corresponds to crank) rotates about *B* as centre, 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 are 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 link 1 and link 3 form turning pairs with link 2. These flanges have diametrical slots cut in their inner faces. The intermediate piece (link 4) which is a circular disc, have two tongues (*i.e.* diametrical projections) *T*1 and *T*2 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 link 3). The link 4 can slide or reciprocate in the slots in the flanges.



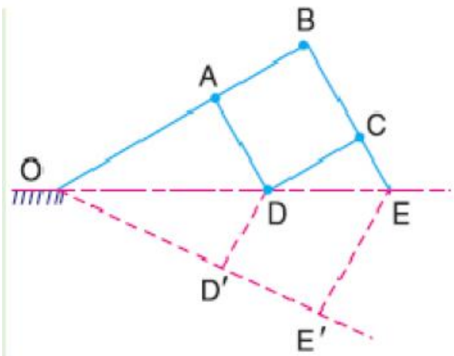
When the driving shaft *A* is rotated, the flange *C* (link 1) causes the intermediate piece (link 4) to rotate at the same angle through which the flange has rotated, and it further rotates the flange *D* (link 3) at the same angle and thus the shaft *B* rotates. Hence links 1, 3 and 4 have the same angular velocity at every instant. A little consideration will show, that there is a sliding motion between the link 4 and each of the other links 1 and 3.

Pantograph

A pantograph is an instrument used to reproduce to an enlarged or a reduced scale and as exactly as possible the path described by a given point. It consists of a jointed parallelogram *ABCD* . It is made up of bars connected by turning pairs. The bars *BA* and *BC* are extended to *O* and *E* respectively, such that

OA/*OB* = *AD*/*BE*

Thus, for all relative positions of the bars, the triangles *OAD* and *OBE* are similar and the points *O*, *D* and *E* are in one straight line. It may be proved that point *E* traces out the same path as described by point *D*.



A pantograph is mostly used for the reproduction of plane areas and figures such as maps, plans etc., on enlarged or reduced scales. It is, sometimes, used as an indicator rig in order to reproduce to a small scale the displacement of the crosshead and therefore of the piston of a reciprocating steam engine. It is also used to guide cutting tools. A modified form of pantograph is used to collect power at the top of an electric locomotive.

Peaucellier mechanism. It consists of a fixed link *OO*1 and the other straight links *O*1*A*, *OC*, *OD*, *AD*, *DB*, *BC* and *CA* are connected by turning pairs at their intersections. The pin at *A* is constrained to move along the circumference of a circle with the fixed diameter *OP*, by means of the link *O*1*A*.

AC = *CB* = *BD* = *DA* ; *OC* = *OD* ; and *OO*1 = *O*1*A*

It may be proved that the product *OA* × *OB* remains constant, when the link *O*1*A* rotates. Join *CD* to bisect *AB* at *R*. Now from ri

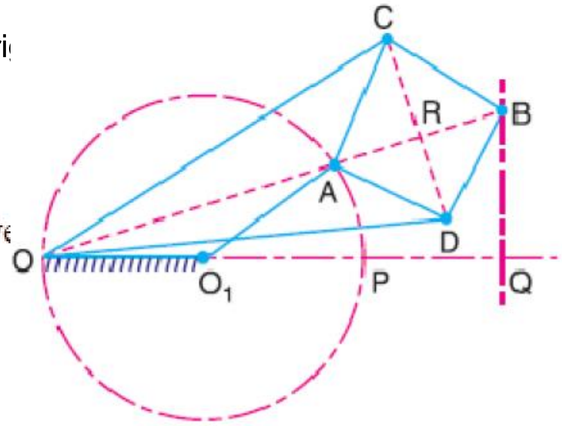
$$OC^2 = OR^2 + RC^2$$

and

$$BC^2 = RB^2 + RC^2$$

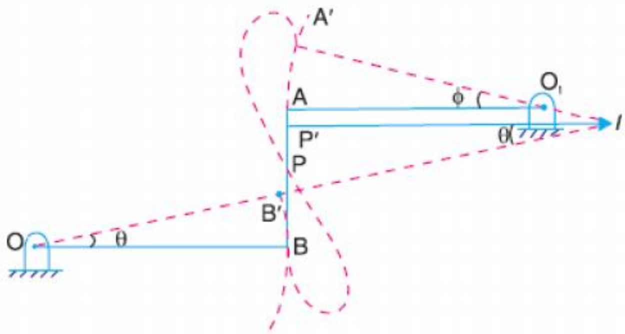
Subtracting equation (*ii*) from (*i*), we

$$OC^2 - BC^2 = OR^2 - RB^2$$
$$= (OR + RB)(OR - RB)$$
$$= OB \times OA$$



Since *OC* and *BC* are of constant length, therefore the product *OB* × *OA* remains constant. Hence the point *B* traces a straight path perpendicular to the diameter *OP*.

Watt's mechanism. The approximate straight line motion mechanisms are the modifications of the four-bar chain mechanisms. Following mechanisms to give approximate straight line motion. It is a crossed four bar chain mechanism and was used by Watt for his early steam engines to guide the piston rod in a cylinder to have an approximate straight line motion.



1. Explain the term kinematic link. Give the classification of kinematic link.
2. What is a machine ? Giving example, differentiate between a machine and a structure.
3. Write notes on complete and incomplete constraints in lower and higher pairs, illustrating your answer with neat sketches.
4. Explain Grubler's criterion for determining degree of freedom for mechanisms.
5. Explain the terms : 1. Lower pair, 2. Higher pair, 3. Kinematic chain, and 4. Inversion.
6. In what way a mechanism differ from a machine ?
7. What is the significance of degrees of freedom of a kinematic chain when it functions as a mechanism?
8. Explain different kinds of kinematic pairs giving example for each one of them.
9. Sketch and explain the various inversions of a four bar chain mechanism?
10. Sketch and explain the various inversions of a slider crank chain
11. Sketch and describe the working of two different types of quick return mechanisms. Give examples of their applications. Derive an expression for the ratio of times taken in forward and return stroke for one of these mechanisms.
12. Sketch and explain any two inversions of a double slider crank chain.
13. In a crank and slotted lever quick return motion mechanism, the distance between the fixed centres is 240 mm and the length of the driving crank is 120 mm. Find the inclination of the slotted bar with the vertical in the extreme position and the time ratio of cutting stroke to the return stroke. If the length of the slotted bar is 450 mm, find the length of the stroke if the line of stroke passes through the extreme positions of the free end of the lever.

SME1203 KINEMATICS OF MACHINES

UNIT 1 BASICS OF MECHANISMS

KINEMATICS

Kinematics is the branch of mechanics which tells us about the motion without considering the cause of motion. In this portion, we study the displacement, speed and acceleration without bothering about the input force or torque.

KINEMATIC LINK OR ELEMENT

Each part of a machine, which moves relative to some other part, is known as a kinematic link or element. A link may consist of several parts, which are rigidly fastened together, so that they do not move relative to one another. The link should have the following two characteristics

1. It should have relative motion, and
2. It must be a resistant body

They are 4 types of links: Rigid, flexible, Fluid and Floating Links.

- Rigid link is one which does not undergo any deformation while transmitting motion. Ex: Connecting rod, crank etc.
- Flexible link is partly deformed in a manner not to affect the transmission of motion. Ex: Belts, ropes, springs, chains and wires are flexible links and transmit tensile forces only.
- Fluid link one which is formed by having a fluid in a receptacle and the motion is transmitted through the fluid by pressure or compression only, as in the case of hydraulic presses, jacks and brakes.
- Floating Link is a link which is not connected frame.

TYPES OF JOINTS

The usual types of joints in a chain are

- Binary joint
- Ternary joint
- Quaternary joint

Binary Joint

If two links are joined at the same connection. It is called a binary joint.

Ternary Joint

If three links are joined at a connection, it is known as a ternary joint. It is considered equivalent to two binary joints since fixing of any one link constitutes two binary joints with each of the other two links.

Quaternary Joint

If four links are joined at a connection, it is known as a quaternary joint. It is considered equivalent to three binary joints since fixing of any one link constitutes three binary joints.

In general, if ‘n’ number of links are connected at a joint, it is equivalent to (n-1) binary joints.

KINEMATIC PAIRS

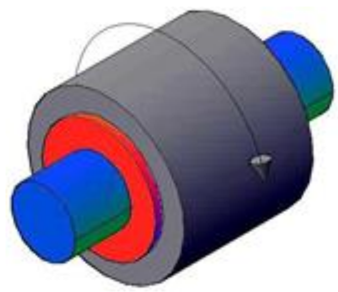
Pairing elements: the geometrical forms by which two members of a mechanism are joined together, so that the relative motion between these two is consistent are known as pairing elements and the pair so formed is called kinematic pair. Each individual link of a mechanism forms a pairing element.

KINEMATIC CONSTRAINTS

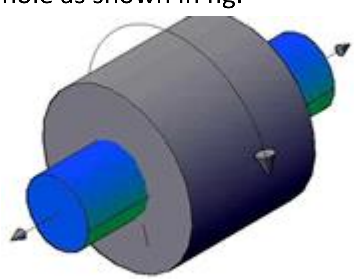
Two or more rigid bodies in space are collectively called a rigid body system. We can hinder the motion of these independent rigid bodies with kinematic constraints. Kinematic constraints are constraints between rigid bodies that result in the decrease of the degrees of freedom of rigid body system.

The three main types of constrained motion in kinematic pair are,

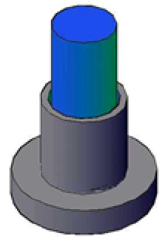
Completely constrained motion: If the motion between a pair of links is limited to a definite direction, then it is completely constrained motion. E.g.: Motion of a shaft or rod with collars at each end in a hole as shown in fig.



Incompletely Constrained motion: If the motion between a pair of links is not confined to a definite direction, then it is incompletely constrained motion. E.g.: A spherical ball or circular shaft in a circular hole may either rotate or slide in the hole as shown in fig.



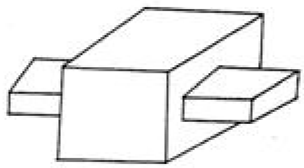
Successfully constrained motion or partially constrained motion: If the motion in a definite direction is not brought about by itself but by some other means, then it is known as successfully constrained motion. E.g.: Foot step Bearingshown in fig.



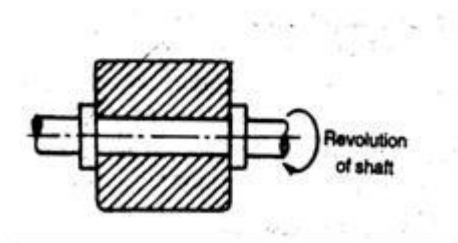
TYPES OF KINEMATIC PAIRS

Kinematic pairs according to nature of relative motion.

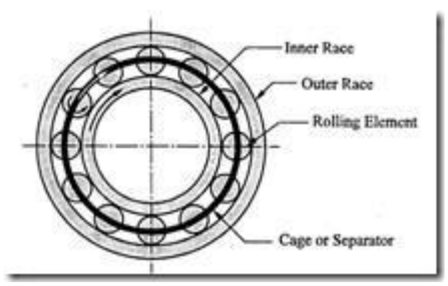
Sliding pair: If two links have a sliding motion relative to each other, they form a sliding pair. A rectangular rod in a rectangular hole in a prism is an example of a sliding pair.



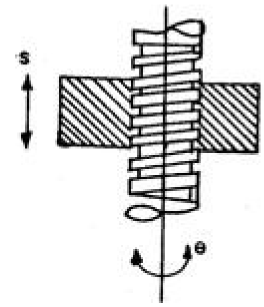
Turning Pair: When on link has a turning or revolving motion relative to the other, they constitute a turning pair or revolving pair.



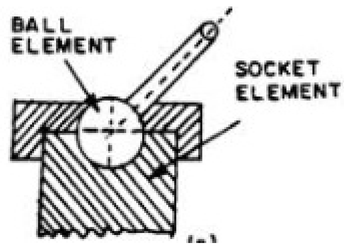
Rolling pair: When the links of a pair have a rolling motion relative to each other, they form a rolling pair. A rolling wheel on a flat surface, ball ad roller bearings, etc. are some of the examples for a Rolling pair.



Screw pair (Helical Pair): if two mating links have a turning as well as sliding motion between them, they form a screw pair. This is achieved by cutting matching threads on the two links. The lead screw and the nut of a lathe is a screw Pair.

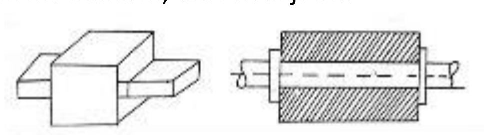


Spherical pair: When one link in the form of a sphere turns inside a fixed link, it is a spherical pair. The ball and socket joint is a spherical pair.

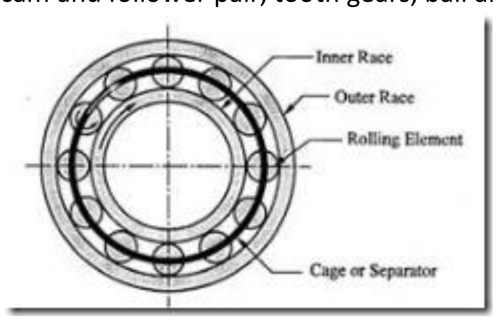


Kinematic pairs according to nature of contact:

Lower Pair: A pair of links having surface or area contact between the members is known as a lower pair. The contact surfaces of the two links are similar. e.g.: Nut turning on a screw, shaft rotating in a bearing, all pairs of a slider-crank mechanism, universal joint.

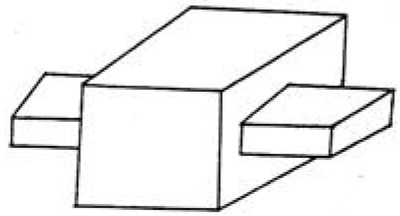


Higher Pair: When a pair has a point or line contact between the links, it is known as a higher pair. The contact surfaces of the two links are dissimilar.
e.g.: Wheel rolling on a surface cam and follower pair, tooth gears, ball and roller bearings, etc

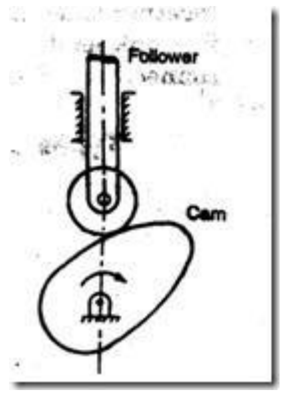


Kinematic pairs according to nature of mechanical constraint:

Closed pair: When the elements of a pair are held together mechanically, it is known as a closed pair. The contact between the two can only be broken only by the destruction of at least one of the members. All the lower pairs and some of the higher pairs are closed pairs.

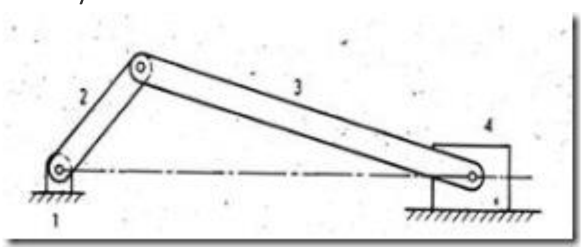


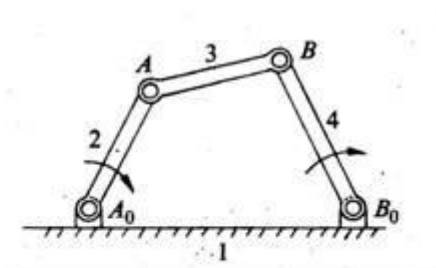
Open pair: When two links of a pair are in contact either due to force of gravity or some spring action, they constitute an unclosed pair. In this the links are not held together mechanically. Ex.: Cam and follower pair.



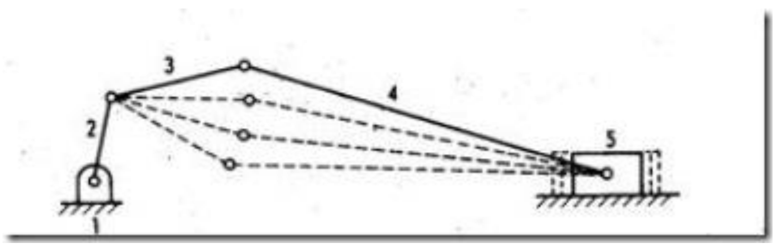
MECHANISM AND MACHINES

Mechanism: A mechanism is a constrained kinematic chain. This means that the motion of any one link in the kinematic chain will give a definite and predictable motion relative to each of the others. Usually one of the links of the kinematic chain is fixed in a mechanism.

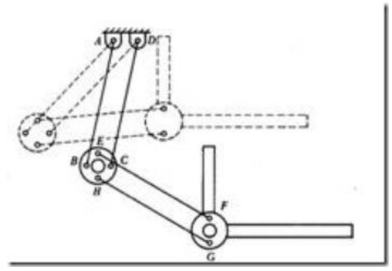




If, for a particular position of a link of the chain, the positions of each of the other links of the chain cannot be predicted, then it is called as unconstrained kinematic chain and it is not mechanism.



Machine: A machine is a mechanism or collection of mechanisms, which transmit force from the source of power to the resistance to be overcome. Though all machines are mechanisms, all mechanisms are not machines. Many instruments are mechanisms but are not machines, because they do no useful work nor do they transform energy. Eg. Mechanical clock, drafter.



PLANAR MECHANISMS

When all the links of a mechanism have plane motion, it is called as a planar mechanism. All the links in a planar mechanism move in planes parallel to the reference plane.

KINEMATIC CHAIN

A kinematic chain is a group of links either joined together or arranged in a manner that permits them to move relative to one another. If the links are connected in such a way that no motion is possible, it results in a locked chain or structure.

It is a combination of several successively arranged joints constituting a complex motor system. Kinematic chain is when a number of links are united in series.

Relation between Links, Pairs and Joints

$$l=2p-4$$

$$j=(3/2)\,l-2$$

l = No of Links

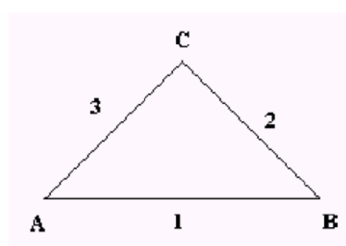
p = No of Pairs

j = No of Joints

L.H.S >R.H.S = Locked chain

L.H.S = R.H.S = Constrained Kinematic Chain

L.H.S <R.H.S = Unconstrained Kinematic Chain



l = 3;, p = 3;j = 3

l = 2p – 4

3 = 2 × 3 – 4 = 2

i.e. L.H.S. > R.H.S.

j=(3/2) l – 2

3=(3/2)3 – 2 = 2.5

i.e. L.H.S. > R.H.S.

ABCdoesnotformaKinematicchainbutformsa structure.

DEGREES OF FREEDOM

An unconstrained rigid body moving in space can describe the following independent motions.Translational Motions along any three mutually perpendicular axes x, y and z, Rotational motions along these axes.

Thus a rigid body possesses six degrees of freedom. The connection of a link with another imposes certain constraints on their relative motion. The number of restraints can never be zero (joint is disconnected) or six (joint becomes solid).

Degrees of freedom of a pair is defined as the number of independent relative motions, both translational and rotational, a pair can have.

Degrees of freedom = 6 – no. of restraints.

To find the number of degrees of freedom for a plane mechanism we have an equation known as Grubler's equation and is given by

$$F = 3(n-1) - 2j_1 - j_2$$

F = Mobility or number of degrees of freedom n = Number of links including frame.

j_1 = Joints with single (one) degree of freedom. J_2= Joints with two degrees of freedom.

If

$F > 0$, results a mechanism with 'F' degrees of freedom.

$F = 0$, results in a statically determinate structure.

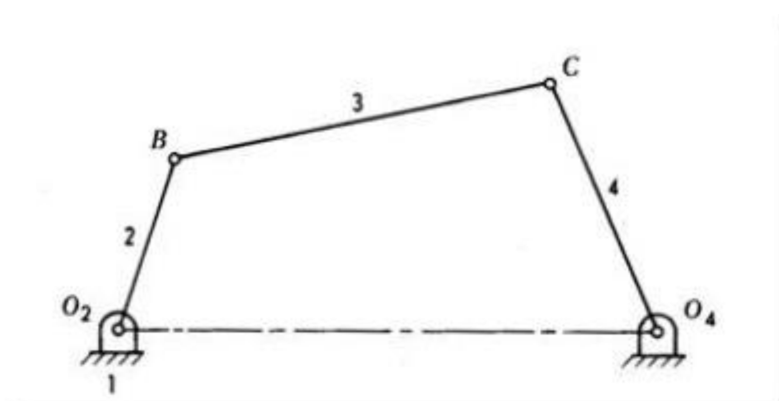
$F < 0$, results in a statically indeterminate structure.

KINEMATIC INVERSION

Inversions of mechanism: A mechanism is one in which one of the links of a kinematic chain is fixed. Different mechanisms can be obtained by fixing different links of the same kinematic chain. These are called as inversions of the mechanism. By changing the fixed link, the number of mechanisms which can be obtained is equal to the number of links. Excepting the original mechanism, all other mechanisms will be known as inversions of original mechanism. The inversion of a mechanism does not change the motion of its links relative to each other.

Kinematic Inversions of Four Bar Chain, Slider Crank and Double Slider Crank Mechanism

Four bar chain

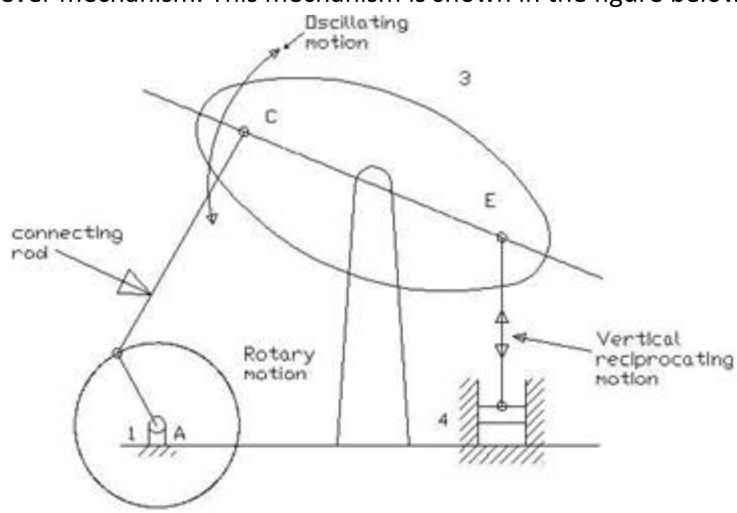


One of the most useful and most common mechanisms is the four-bar linkage. In this mechanism, the link which can make complete rotation is known as crank (link 2). The link which oscillates is known as rocker or lever (link 4). And the link connecting these two is known as coupler (link 3). Link 1 is the frame.

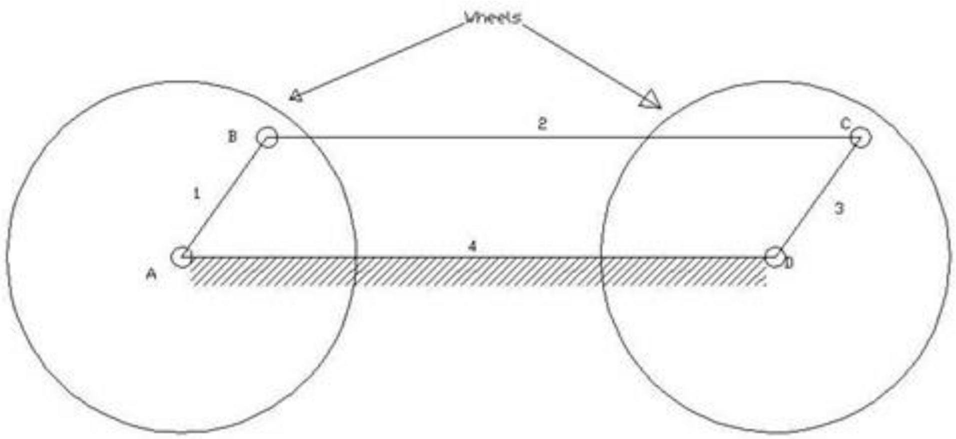
Inversions of four bar chain

- Beam Engine or Crank and lever mechanism.
- Coupling rod of locomotive or double crank mechanism.
- Watt's straight line mechanism or double lever mechanism.

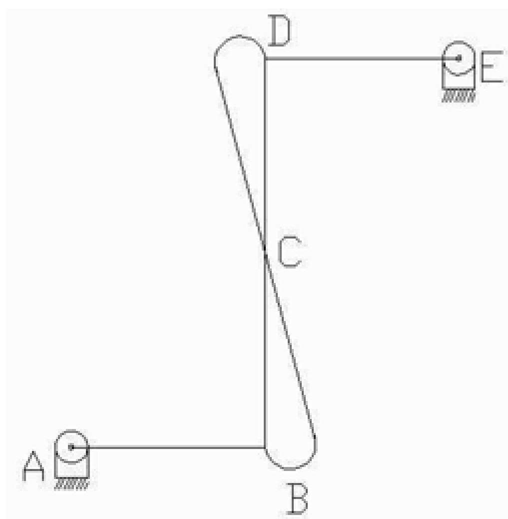
Beam Engine: When the crank AB rotates about A, the link CE pivoted at D makes vertical reciprocating motion at end E. This is used to convert rotary motion to reciprocating motion and vice versa. It is also known as Crank and lever mechanism. This mechanism is shown in the figure below.



Coupling rod of locomotive: In this mechanism the length of link AD = length of link C. Also length of link AB = length of link CD. When AB rotates about A, the crank DC rotates about D. this mechanism is used for coupling locomotive wheels. Since links AB and CD work as cranks, this mechanism is also known as double crank mechanism. This is shown in the figure below.



Watt's straight line mechanism or Double lever mechanism: In this mechanism, the links AB & DE act as leversat the ends A & E of these levers are fixed. The AB & DE are parallel in the mean position of the mechanism and coupling rod BD is perpendicular to the levers AB & DE. On any small displacement of the mechanism the tracing point 'C' traces the shape of number '8', a portion of which will be approximately straight. Hence this is also an example for the approximate straight line mechanism. This mechanism is shown below.



SLIDER CRANK CHAIN

It is a four bar chain having one sliding pair and three turning pairs. It is shown in the figure below the purpose of this mechanism is to convert rotary motion to reciprocating motion and vice versa.

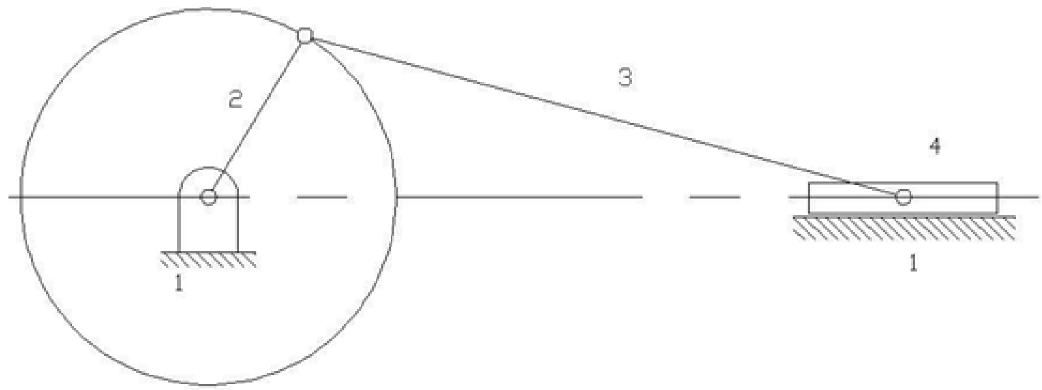
Inversions of a Slider crank chain

There are four inversions in a single slider chain mechanism. They are

- Reciprocating engine mechanism (1^{st} inversion)
- Oscillating cylinder engine mechanism (2^{nd} inversion)
- Crank and slotted lever mechanism (2^{nd} inversion)
- Whitworth quick return motion mechanism (3^{rd} inversion)
- Rotary engine mechanism (3^{rd} inversion)

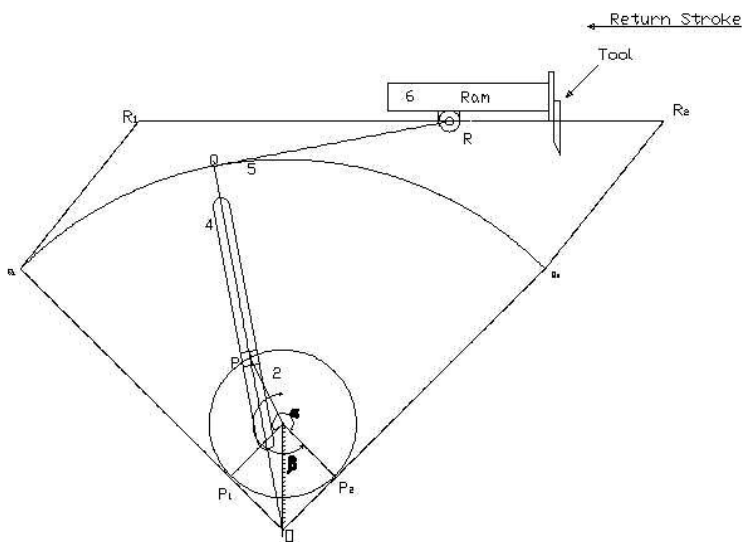
- Bull engine mechanism (4th inversion)
- Hand Pump (4th inversion)

Reciprocating engine mechanism: In the first inversion, the link 1 i.e., the cylinder and the frame is kept fixed. The fig below shows a reciprocating engine.



A slotted link 1 is fixed. When the crank 2 rotates about O, the sliding piston 4 reciprocates in the slotted link 1. This mechanism is used in steam engine, pumps, compressors, I.C. engines, etc.

Crank and slotted lever mechanism: It is an application of second inversion. The crank and slotted lever mechanism is shown in figure below.

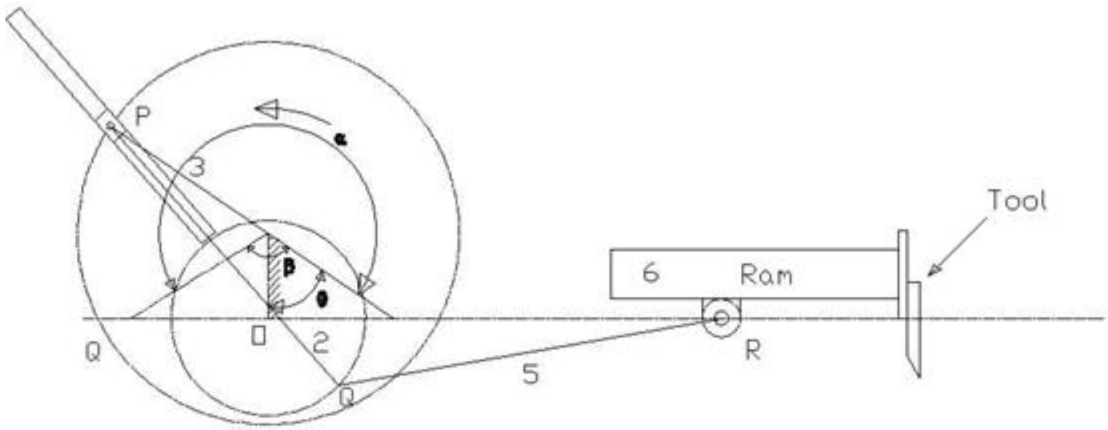


In this mechanism link 3 is fixed. The slider (link 1) reciprocates in oscillating slotted lever (link 4) and crank (link 2) rotates. Link 5 connects link 4 to the ram (link 6). The ram with the cutting tool reciprocates perpendicular to the fixed link 3. The ram with the tool reverses its direction of motion when link 2 is perpendicular to link 4. Thus the cutting stroke is executed during the rotation of the crank through angle α and the return stroke is executed when the crank rotates through angle β or 360 – α. Therefore, when the crank rotates uniformly, we get,

$$\frac{\text{Time to cutting}}{\text{Time of return}} = \frac{\alpha}{\beta} = \frac{\alpha}{360 - \alpha}$$

This mechanism is used in shaping machines, slotting machines and in rotary engines.

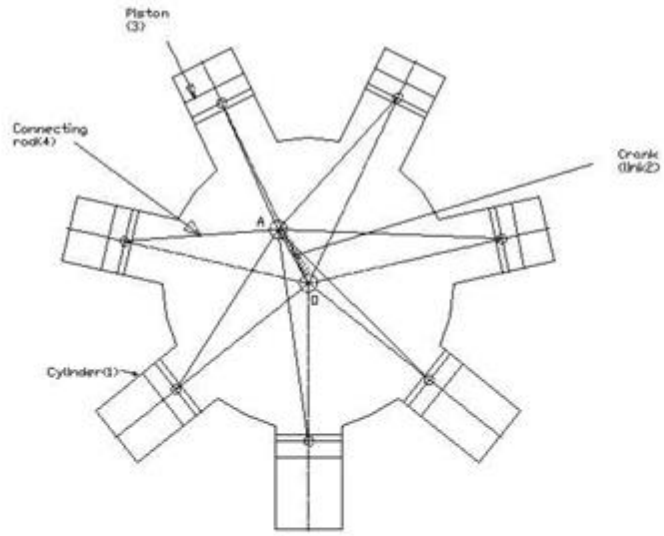
Whitworth quick return motion mechanism: Third inversion is obtained by fixing the crank i.e. link 2.



Whitworth quick return mechanism is an application of third inversion. This mechanism is shown in the figure below. The crank OC is fixed and OQ rotates about O. The slider slides in the slotted link and generates a circle of radius CP. Link 5 connects the extension OQ provided on the opposite side of the link 1 to the ram (link 6). The rotary motion of P is taken to the ram R which reciprocates. The quick return motion mechanism is used in shapers and slotting machines.The angle covered during cutting stroke from P_1 to P_2 in counter clockwise direction is α or 360 - 2θ. During the return stroke, the angle covered is 2θ or β.

$$\frac{\text{Time to cutting}}{\text{Time of return}} = \frac{360 - 2\theta}{2\theta} = \frac{\alpha}{\beta}$$

Rotary engine mechanism or Gnome Engine: Rotary engine mechanism or gnome engine is another application of third inversion. It is a rotary cylinder V – type internal combustion engine used as an aero – engine. But now Gnome engine has been replaced by Gas turbines. The Gnome engine has generally seven cylinders in one plane. The crank OA is fixed and all the connecting rods from the pistons are connected to A. In this mechanism when the pistons reciprocate in the cylinders, the whole assembly of cylinders, pistons and connecting rods rotate about the axis O, where the entire mechanical power developed, is obtained in the form of rotation of the crank shaft. This mechanism is shown in the figure below.



DOUBLE SLIDER CRANK CHAIN

A four bar chain having two turning and two sliding pairs such that two pairs of the same kind are adjacent is known as double slider crank chain.

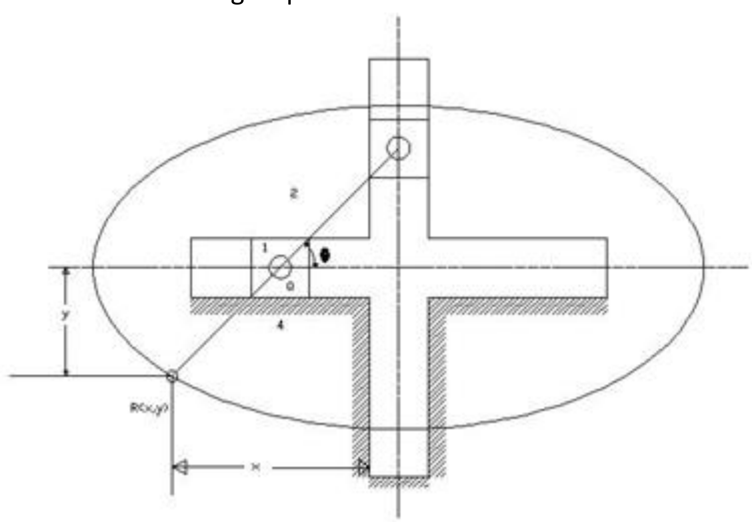
Inversions of Double slider Crank chain

It consists of two sliding pairs and two turning pairs. They are three important inversions of double slider crank chain.

- Elliptical trammel.
- Scotch yoke mechanism.
- Oldham's Coupling.

Elliptical Trammel

This is an instrument for drawing ellipses. Here the slotted link is fixed. The sliding block P and Q



in vertical and horizontal slots respectively. The end R generates an ellipse with the displacement of sliders P and Q.

The co-ordinates of the point R are x and y.

From the fig. $\cos \theta = \frac{x}{PR}$.

and $\sin \theta = \frac{y}{QR}$.

Squaring and adding (i) and (ii) we get

$$\frac{x^2}{(PR)^2} + \frac{y^2}{(QR)^2} = \cos^2\theta + \sin^2\theta$$

$$\frac{x^2}{(PR)^2} + \frac{y^2}{(QR)^2} = 1$$

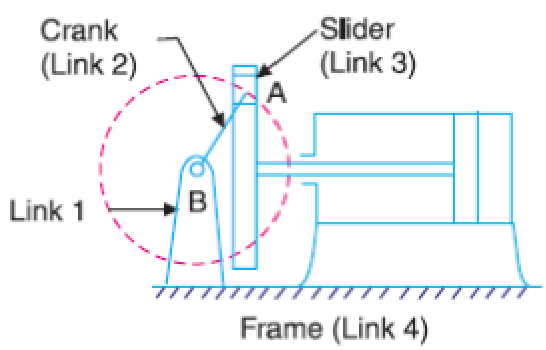
The equation is that of an ellipse, Hence the instrument traces an ellipse.

Path traced by mid-point of PQ is a circle. In this case, PR = PQ.

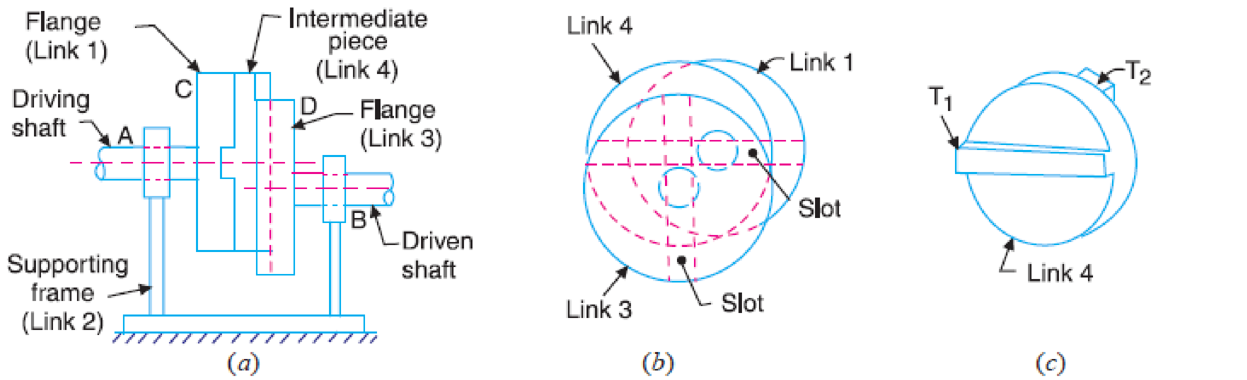
$$\frac{x^2}{(PR)^2} + \frac{y^2}{(QR)^2} = 1$$

Its an equation of circle with PR = QR = radius of a circle.

Scotch yoke mechanism: This mechanism is used for converting rotary motion into a reciprocating motion. The inversion is obtained by fixing either the link 1 or link 3. In Fig., link 1 is fixed. In this mechanism, when the link 2 (which corresponds to crank) rotates about *B* as centre, 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 are 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 link 1 and link 3 form turning pairs with link 2. These flanges have diametrical slots cut in their inner faces. The intermediate piece (link 4) which is a circular disc, have two tongues (*i.e.* diametrical projections) *T*1 and *T*2 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 link 3). The link 4 can slide or reciprocate in the slots in the flanges.

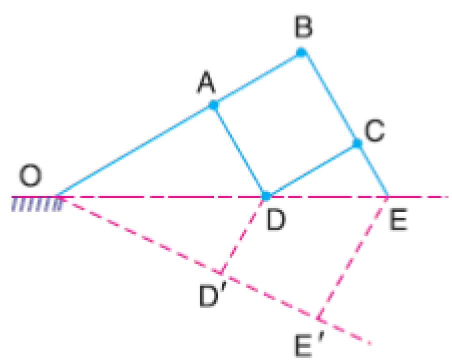


When the driving shaft *A* is rotated, the flange *C* (link 1) causes the intermediate piece (link 4) to rotate at the same angle through which the flange has rotated, and it further rotates the flange *D* (link 3) at the same angle and thus the shaft *B* rotates. Hence links 1, 3 and 4 have the same angular velocity at every instant. A little consideration will show, that there is a sliding motion between the link 4 and each of the other links 1 and 3.

PANTOGRAPH

A pantograph is an instrument used to reproduce to an enlarged or a reduced scale and as exactly as possible the path described by a given point. It consists of a jointed parallelogram *ABCD* . It is made up of bars connected by turning pairs. The bars *BA* and *BC* are extended to *O* and *E* respectively, such that

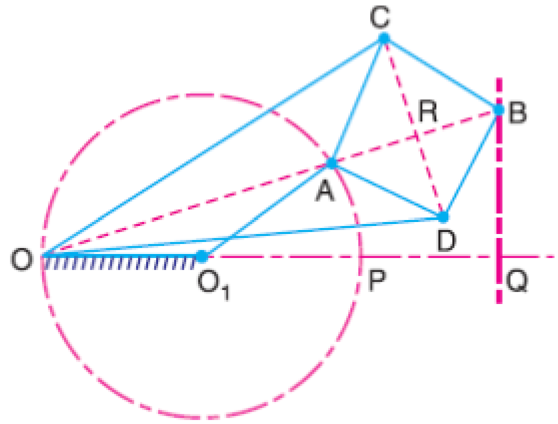
OA/*OB* = *AD*/*BE*.Thus, for all relative positions of the bars, the triangles *OAD* and *OBE* are similar and the points *O*, *D* and *E* are in one straight line. It may be proved that point *E* traces out the same path as described by point *D*.



A pantograph is mostly used for the reproduction of plane areas and figures such as maps, plans etc., on enlarged or reduced scales. It is, sometimes, used as an indicator rig in order to reproduce to a small scale the displacement of the crosshead and therefore of the piston of a reciprocating steam engine. It is also used to guide cutting tools. A modified form of pantograph is used to collect power at the top of an electric locomotive.

PEAUCELLIER MECHANISM

It consists of a fixed link *OO*1 and the other straight links *O1A*, *OC*, *OD*, *AD*, *DB*, *BC* and *CA* are connected by turning pairs at their intersections. The pin at *A* is constrained to move along the circumference of a circle with the fixed diameter *OP*, by means of the link *O1A*.



AC = *CB* = *BD* = *DA* ;*OC* = *OD* ; and *OO*1 = *O1A.* It may be proved that the product *OA* × *OB* remains constant, when the link *O1A* rotates. Join *CD* to bisect *AB* at *R*. Now from right angled triangles *ORC* and *BRC*,

$$OC^2 = OR^2 + RC^2$$

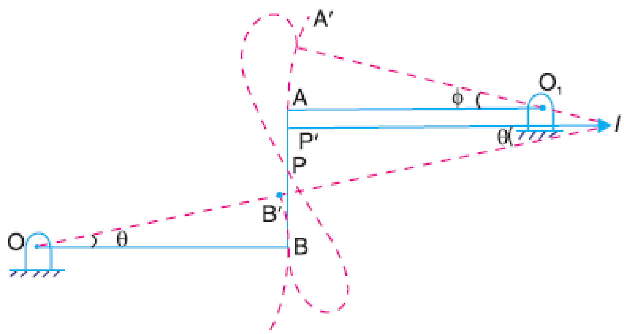
and $$BC^2 = RB^2 + RC^2$$

Subtracting equation (*ii*) from (*i*), we have

$$OC^2 - BC^2 = OR^2 - RB^2$$
$$= (OR + RB)\,(OR - RB)$$
$$= OB \times OA$$

Since *OC* and *BC* are of constant length, therefore the product *OB* × *OA* remains constant. Hence the point *B* traces a straight path perpendicular to the diameter *OP*.

WATT'S MECHANISM: The approximate straight line motion mechanisms are the modifications of the four-bar chain mechanisms. Following mechanisms to give approximate straight line motion. It is a crossed four bar chain mechanism and was used by Watt for his early steam engines to guide the piston rod in a cylinder to have an approximate straight line motion.



QUESTIONS

1. Explain the term kinematic link. Give the classification of kinematic link.
2. What is a machine ? Giving example, differentiate between a machine and a structure.
3. Write notes on complete and incomplete constraints in lower and higher pairs, illustrating your answer with neat sketches.
4. Explain Grubler's criterion for determining degree of freedom for mechanisms.
5. Explain the terms : 1. Lower pair, 2. Higher pair, 3. Kinematic chain, and 4. Inversion.
6. In what way a mechanism differ from a machine ?
7. What is the significance of degrees of freedom of a kinematic chain when it functions as a mechanism?
8. Explain different kinds of kinematic pairs giving example for each one of them.
9. Sketch and explain the various inversions of a four bar chain mechanism?
10. Sketch and explain the various inversions of a slider crank chain
11. Sketch and describe the working of two different types of quick return mechanisms. Give examples of their applications. Derive an expression for the ratio of times taken in forward and return stroke for one of these mechanisms.
12. Sketch and explain any two inversions of a double slider crank chain.
13. In a crank and slotted lever quick return motion mechanism, the distance between the fixed centres is 240 mm and the length of the driving crank is 120 mm. Find the inclination of the slotted bar with the vertical in the extreme position and the time ratio of cutting stroke to the return stroke. If the length of the slotted bar is 450 mm, find the length of the stroke if the line of stroke passes through the extreme positions of the free end of the lever.