Kinematics and Dynamics of Machines

Kinematics and Dynamics of machines (BMEE207L)

Module 1: Introduction(Terminologies, Degree of freedom, study of planar mechanisms and their inversion)

Tapan Kumar Mahanta, Ph.D.
SMEC Chennai Campus

Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

Course Objectives: :

1. To impart students' knowledge about forces acting on machine parts.
2. To enable students to understand the fundamental concepts of machines.
3. To facilitate students to understand the functions of cams, gears and fly wheels.
4. To make students to get an insight into balancing of rotations and reciprocating masses and the concepts of vibration.

Course Outcome:

1. Apply different mechanisms for designing machines.
2. Compute velocity and acceleration of various plane mechanisms.
3. Apply the principles for analyzing cams, gears and gear trains.
4. Synthesize mechanisms for doing useful work.
5. Analyze dynamic forces acting on mechanism.
6. Balance rotating and reciprocating masses and reduce vibrations.
7. Analyze gyroscopic effects on aero planes, ships and automobiles.
8. Measure and analyze free, forced and damped vibrations of mechanical system.

Syllabus:

Module:1	Basics of Mechanisms	3 hours
Introduction - Terminologies, Degree of Freedom - Study of planar mechanisms and their inversions.		

Module:2	Velocity and Accelerations in Mechanisms	5 hours
Velocity and accelerations in planar mechanisms, Coriolis component of acceleration		

Module:3	Kinematics of Cams, Gears and Gear Trains	4 hours
Cams with different Follower Motion, Gear terminologies - Law of gearing - Interference and undercutting - Epicyclic gear train		

Syllabus:

Module:4	Synthesis of mechanisms	3 hours
Two position and Three position synthesis of planar mechanism - Graphical and analytical methods - Freudenstein equation		

Module:5	Dynamic Force Analysis	5 hours
D'Alembert's Principle, Dynamic Analysis of planar Mechanism. Turning Moment Diagrams - Fly Wheels - Applications.		

Module:6	Balancing and Vibration	5 hours
Static and Dynamic Balancing of Rotating Masses, Balancing of Reciprocating Masses, Introduction to vibration - Terminologies - Single degree of freedom- damped and undamped- free and forced vibration		

Syllabus:

Module:7	**Mechanisms for Control & Gyroscope**	**3 hours**
Governors- types and its characteristics, Gyroscopic Effects on the Movement of Air Planes and Ships – Gyroscope Stabilization		
Module:8	**Contemporary issues:**	**2 hours**
	Total Lecture hours:	**30 hours**

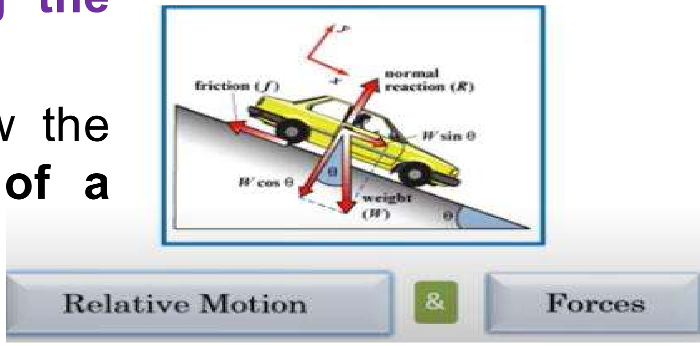
Text Book(s)	
1.	S. S. Rattan, "Theory of Machines", Tata McGraw Hill, 2015
Reference Books	
1.	Joseph Edward Shigley and John Jospeh Uicker JR, Theory of Machines and Mechanisms SI Edition, Oxford University Press, 2014
2.	R L Norton, Kinematics and Dynamics of Machinery, McGraw-Hill Education, 2017
3.	R L Norton, Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines, McGraw-Hill Higher Education, 2011

Introduction:

Theory of Machines: may be defined as that branch of Engineering-science, **which deals with the study of relative motion between the various parts of a machine, and forces which act on them.**

Kinematics of Machinery :

- It deals with the relative motions of different parts of a mechanism ***without taking into consideration*** **the forces producing the motion.**
- Thus, it is a study from geometric point of view, to know the **displacement, velocity and acceleration of different parts of a mechanism.**



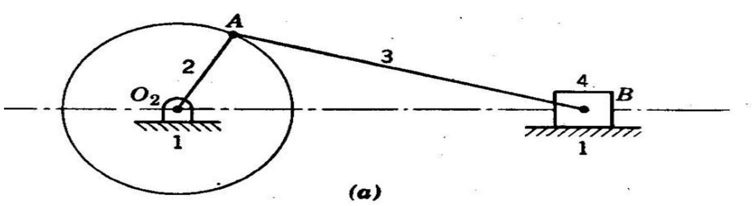
Dynamics of Machines: on the other hand, deals with the study of motion of the different parts of a mechanism considering the inertia forces and/or external forces causing the motion.

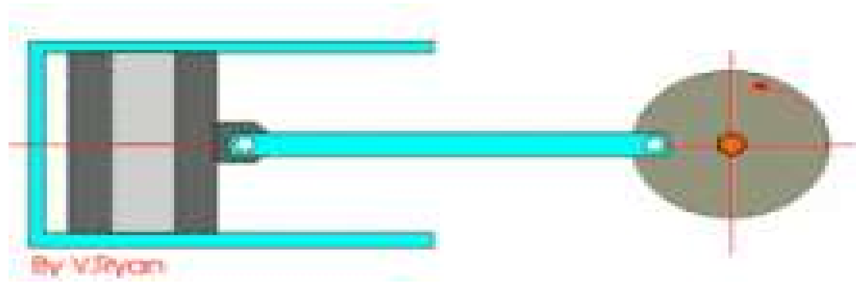
Mechanics of Machines /Theory of Machines:

Mechanics: It is that branch of scientific analysis which deals with motion, time and force.

Mechanisms is a device that transforms input forces and movement into a desired set of output forces and movement.

Example, Slider-crank mechanism used in internal combustion engine or reciprocating air compressor, where the rotary movement of the crank is converted through the connecting rod into the reciprocating motion of the slider, or vice-versa.





Machine is a combination of the mechanisms which receives energy and transforms it into some useful work from which we reduce the human efforts. A machine consists of a number of parts or bodies.

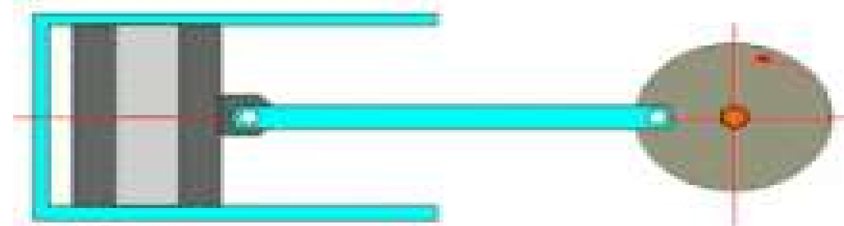
Kinematic Link (or) Element:

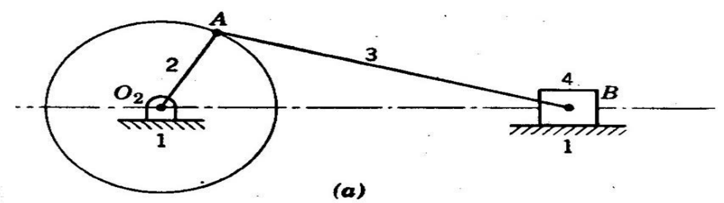
- Each part of a machine, which moves relative to some other part, is known as ***kinematic link or element.***
- Link is defined as a member of a mechanism which is connected to the other members & having relative motion between them.

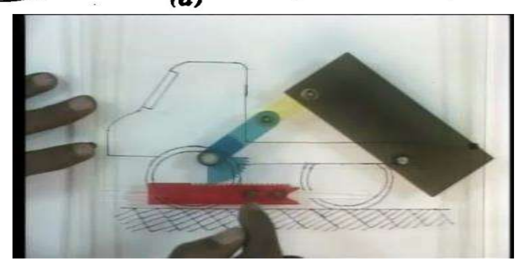
Thus a link should have the following two characteristics:

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

Ex: *Crank, Connecting rod, Engine frame, Piston, etc.*

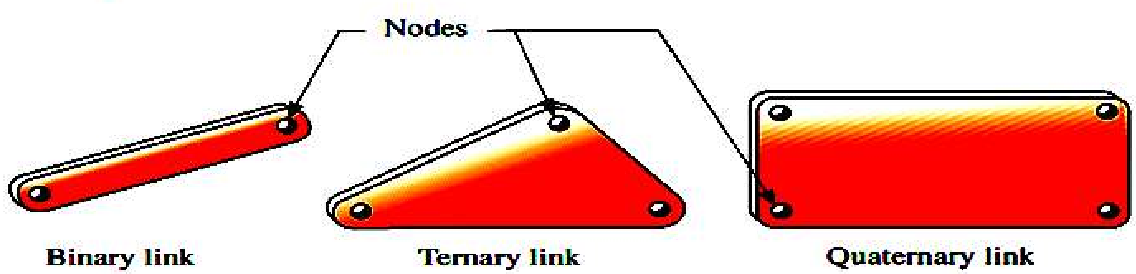






Types:

Binary link	- *one with two nodes.*
Ternary link	- *one with three nodes.*
Quaternary link	- *one with four nodes.*



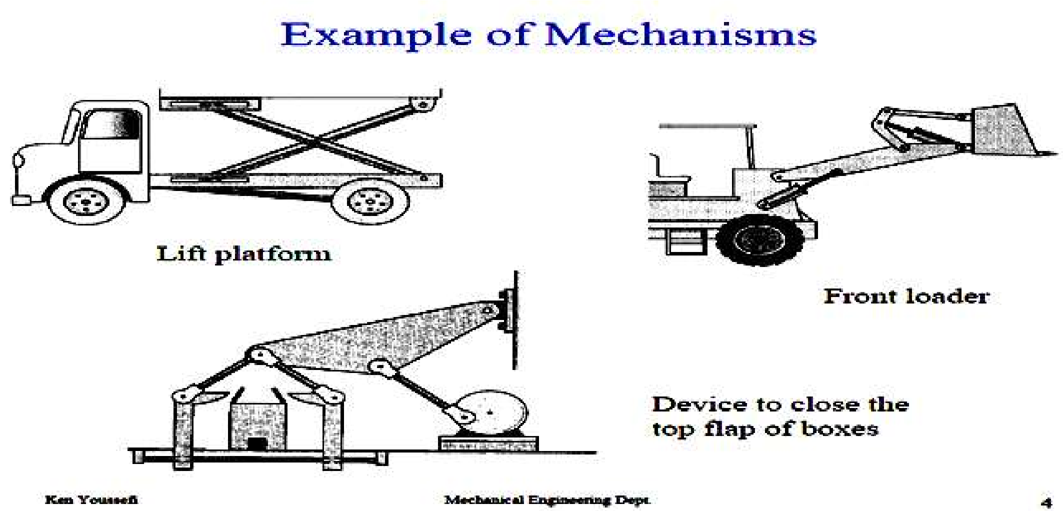
Binary link: Link which is connected to other links at two points.

Types of links-basis of deformation:

1. Rigid link: A rigid link is one which does not undergo any deformation while transmitting motion. No link can be perfectly rigid body, but can be ***resistant*** body.

i.e. it must be capable of transmitting the required motion with negligible deformation.

Ex: Crank, connecting rod, piston, etc.



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2. Flexible link: A flexible link is one which is partly deformed in a manner not to affect the transmission of motion.

Ex: Belts, ropes, chains,

wires which transmit tensile forces only.

3. Fluid link: A fluid link makes use of a ***fluid*** *(liquid or gas) to transmit motion, by means of pressure.* Fluid links always undergo deformation when transmitting motion.

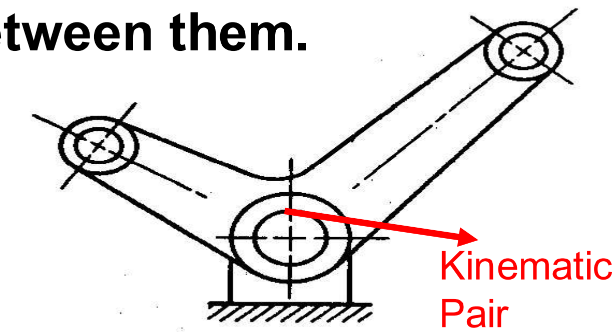
- Some good examples where fluid links are used are pneumatic punching presses, hydraulic jacks and hydraulic brakes.

hydraulic jacks

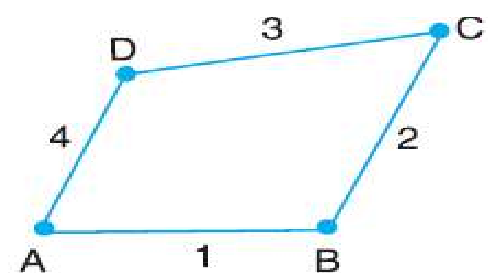
Kinematic Pair :

When two kinematic links are in contact with each other such that the relative motion between them is completely or successfully controlled/constrained (i.e. in a definite direction), the pair is known as ***kinematic pair.***

- **It is a joint of two links having relative motion between them.**



1. Binary joint. When two links are joined at the same connection, the joint is known as binary joint.



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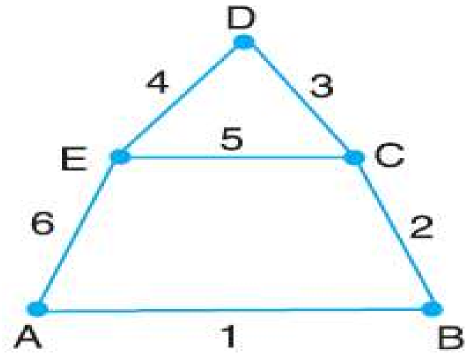
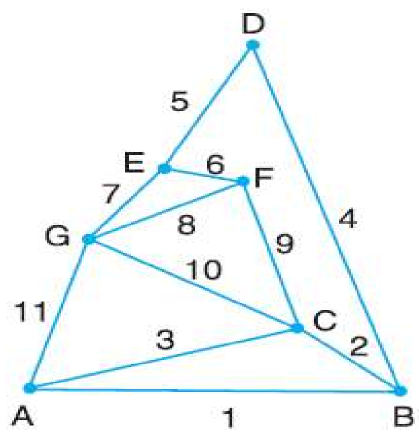
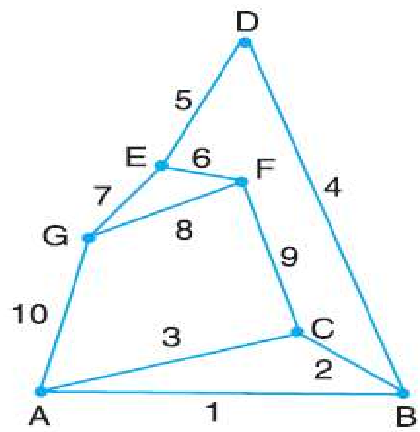
2. Ternary joint. When three links are joined at the same connection, the joint is known as ternary joint.



3. 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.





Classification of Kinematic pair:

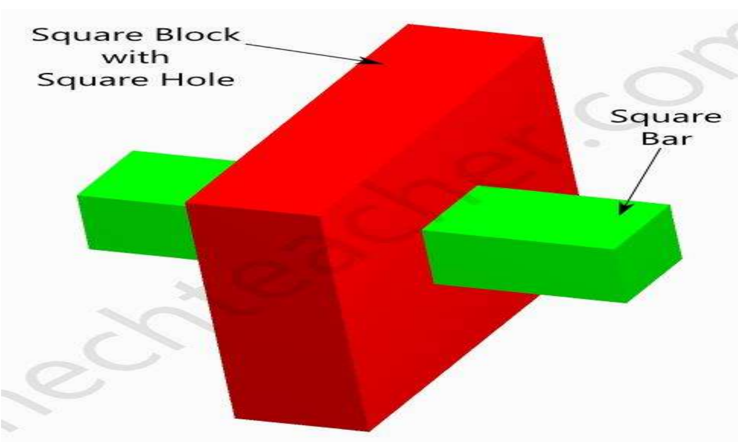
Kinematic pairs are classified on the basis of

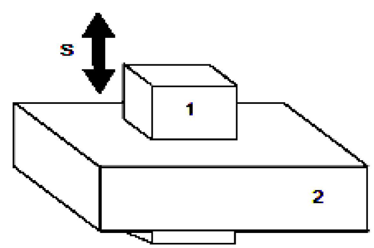
- Nature of relative motion
- Nature of contact between two links
- Nature of mechanical constraint

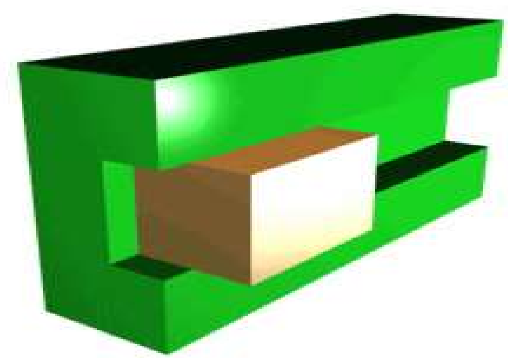
Kinematic pairs based on nature of relative motion:

1. **Prismatic or Sliding Pair** – Sliding pair is constituted by two elements so connected that one is constrained to have a sliding motion relative to the other.

Eg : Prismatic bar & rectangular hole, Piston & cylinder of an engine







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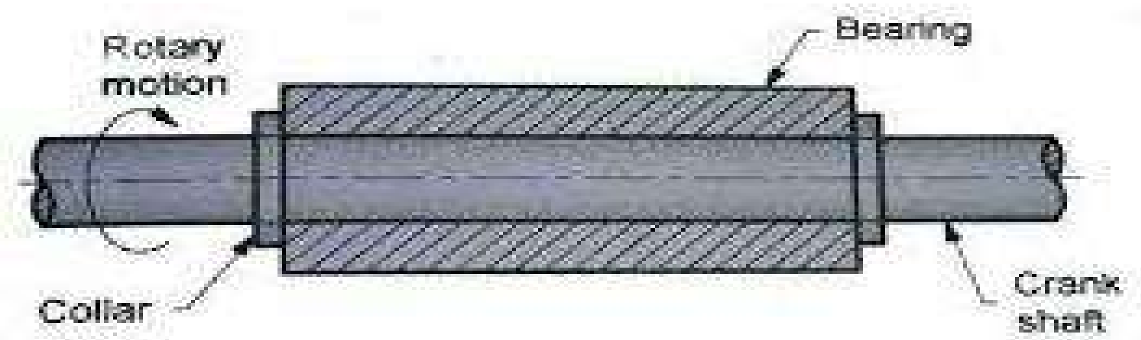
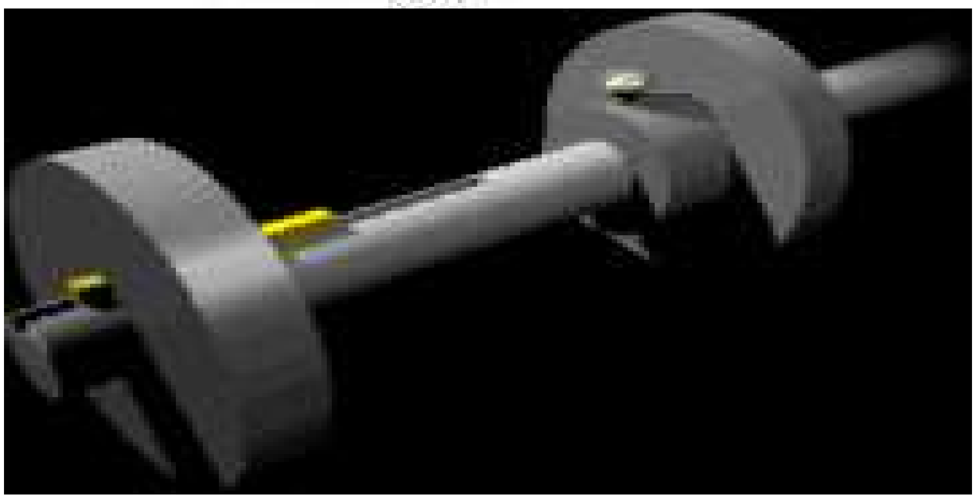
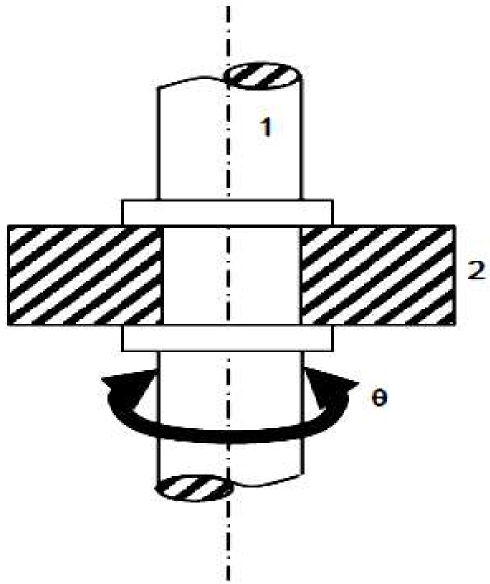
2. Turning pair/Revolute pair – When connections of the two elements are such that only a constrained motion of rotation of one element with respect to the other is possible, the pair constitutes a turning pair



Turning pair





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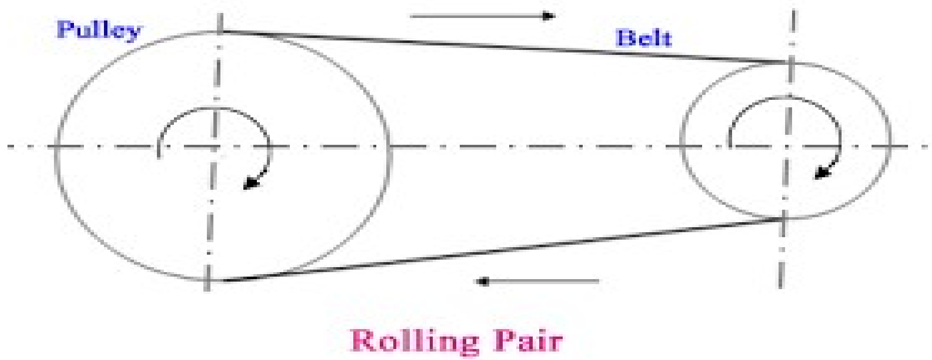
3. Rolling pair – When the pairing elements have rolling contact, the pair formed is called rolling pair. Eg.



Belt and pulley

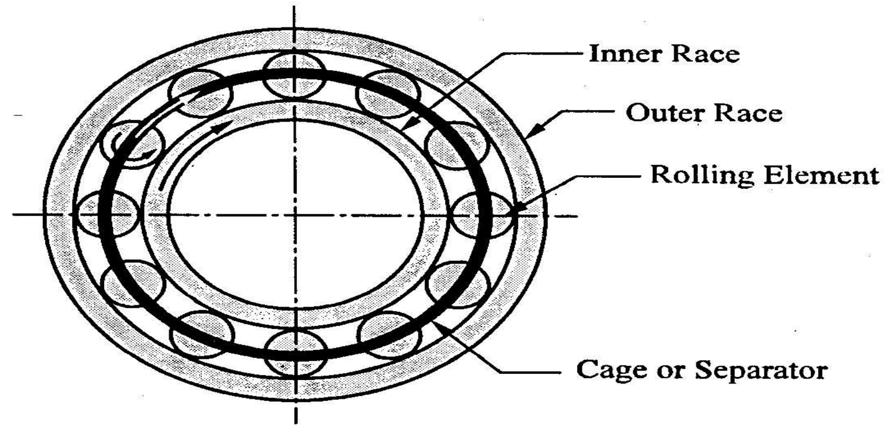
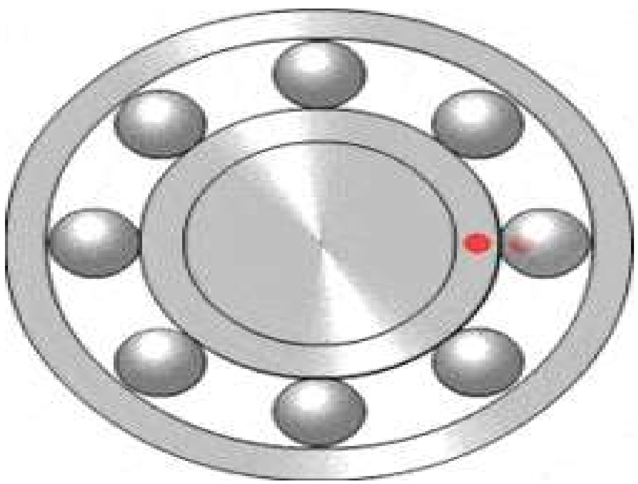
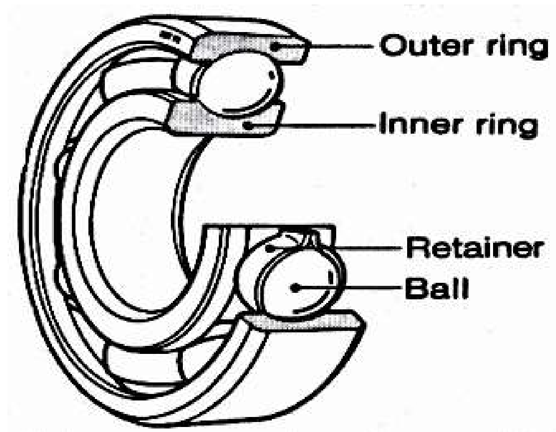


Fig. Ball bearing





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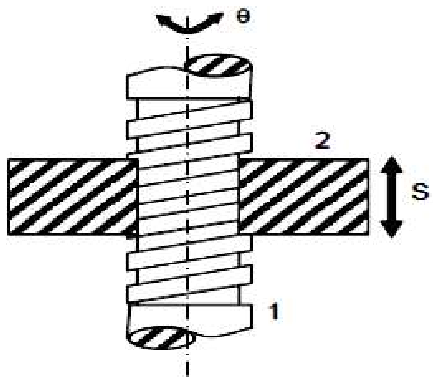
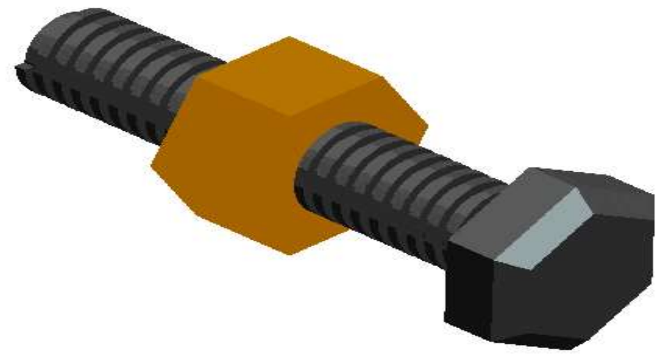
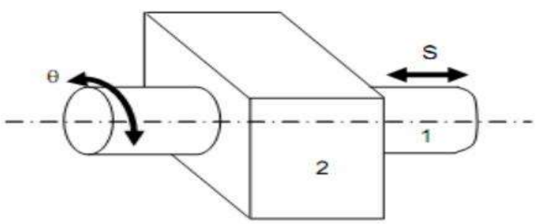
4. Screw / Helical pair – When the nature of contact between the elements of a pair is such that one element can turn about the other by screw threads, it is known as screw pair. Eg. Nut and bolt.

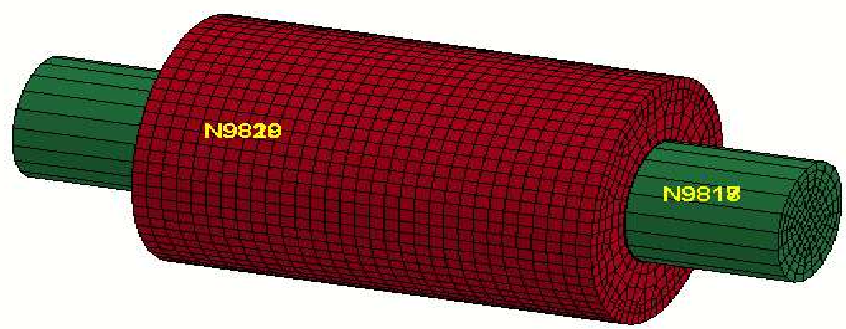




5. Cylindrical Pair

Cylindrical pair





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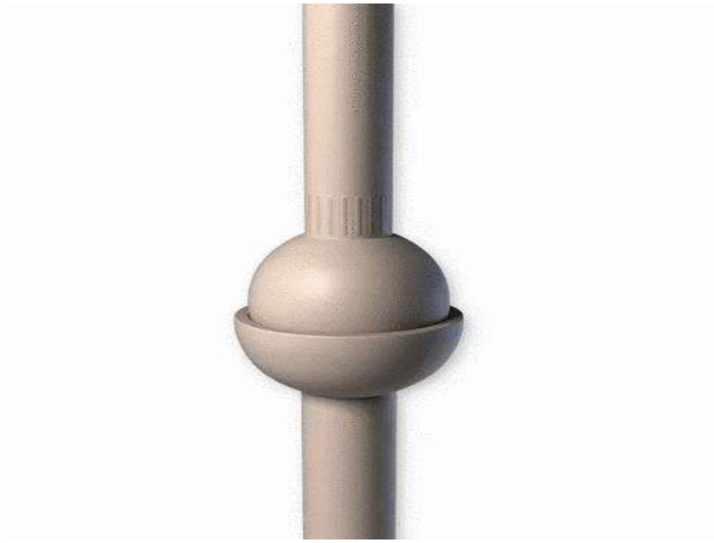
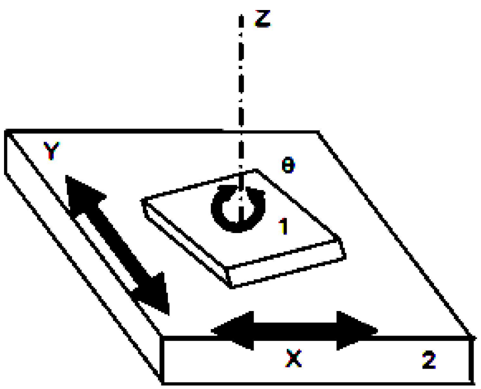
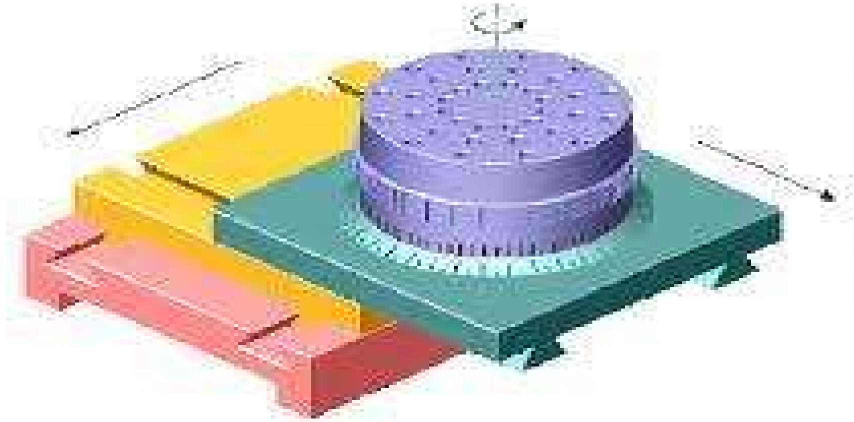
6. Spherical pair – Sphere turns inside a fixed link. A spherical pair will have surface contact

Eg : Ball and socket joint.



7. Planar pair





Summary:

Sliding pair – sliding motion.

Eg : Prismatic bar & rectangular hole, Piston & cylinder of an engine

Turning pair – Turning / revolving motion .

Eg: shaft & bearings, pin joints / hinges

Rolling pair – One can roll over the other.

Eg: Ball bearings, roller bearings.

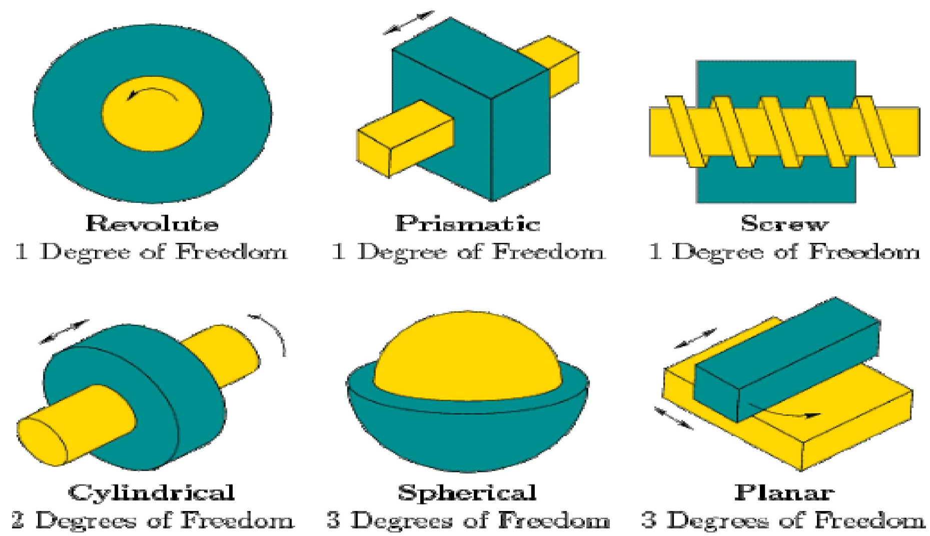
Screw / Helical pair – Turning + sliding motion .

(This is achieved by cutting mating threads on two links)

Eg : lead screw and a nut of a lathe

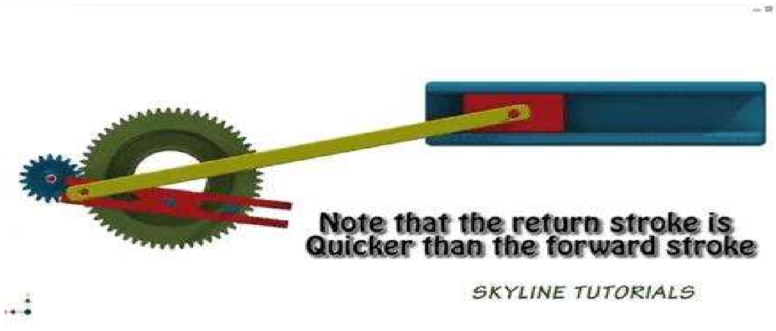
Spherical pair – Sphere turns inside a fixed link.

Eg : Ball and socket joint.

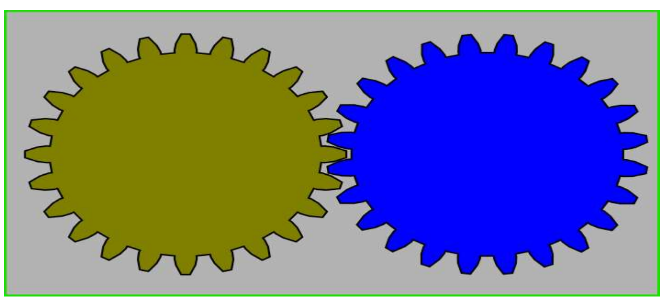


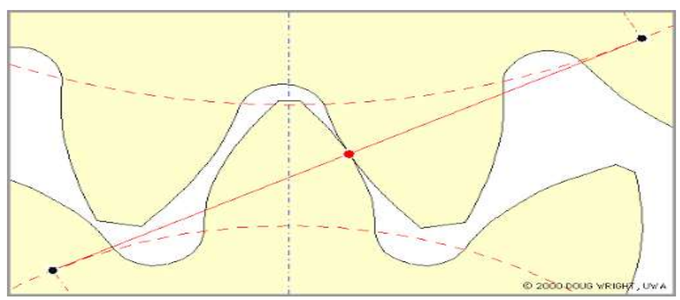
Kinematic Pairs according to Nature of contact:

Lower pair – a pair of links having surface or area contact b/w the members is known as a lower pair.



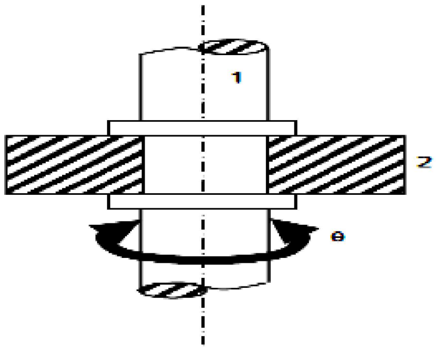
Higher pair – when a pair has a point or line contact b/w the links, is known as Higher pair.



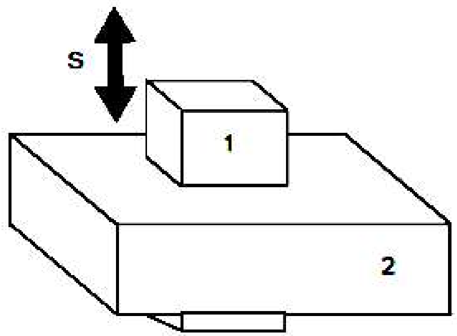


Example of Lower Pair

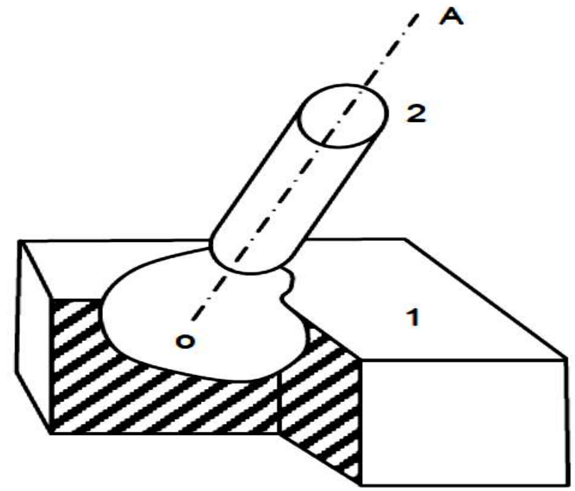
- Revolute or Turning Pair



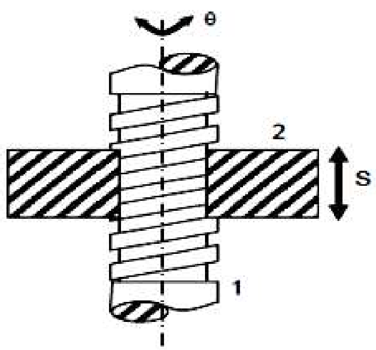
- Prismatic or Sliding Pair



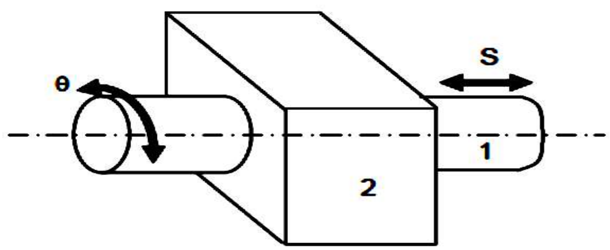
- Spherical Pair



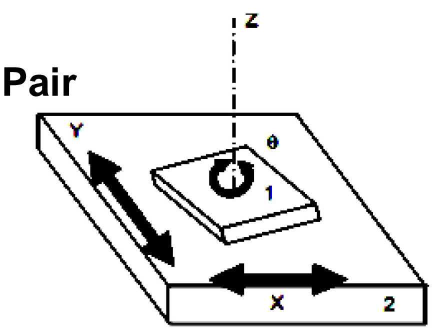
- Screw Pair



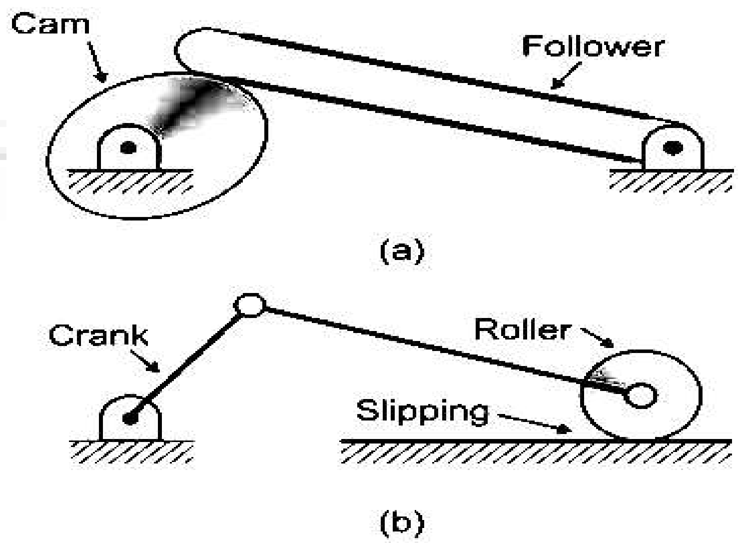
Cylindrical Pair

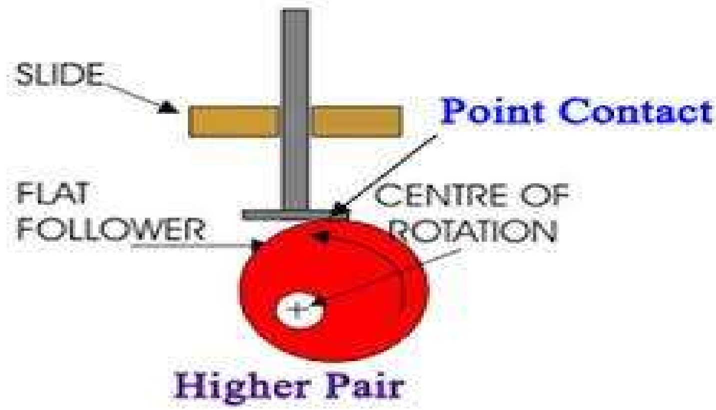


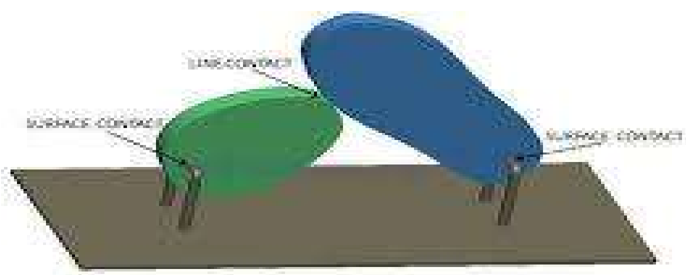
Planar Pair



Example- Higher pair







Kinematic pairs based on nature of mechanical constraint

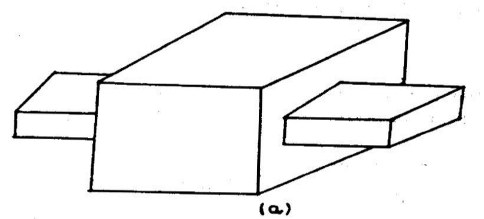
Self Closed pair (form closed):

- Elements of pairs held together mechanically due to their geometry constitute a closed pair. They are also called form-closed or self-closed pair.

OR

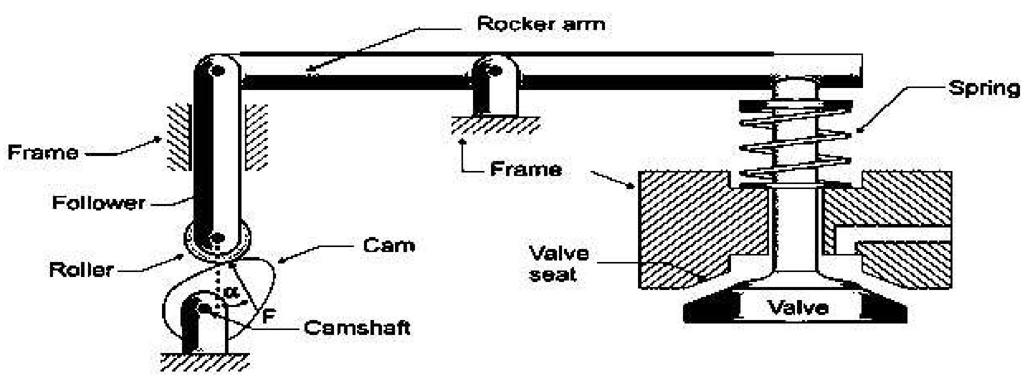
- When the two elements of a pair are **connected together mechanically** in such a way that only required kind of relative motion occurs, it is then known as self closed pair.
- Elements of the pair are held together mechanically.
- All the lower pairs and some of the higher pairs comes under this category.
- If the links in the pair have direct mechanical

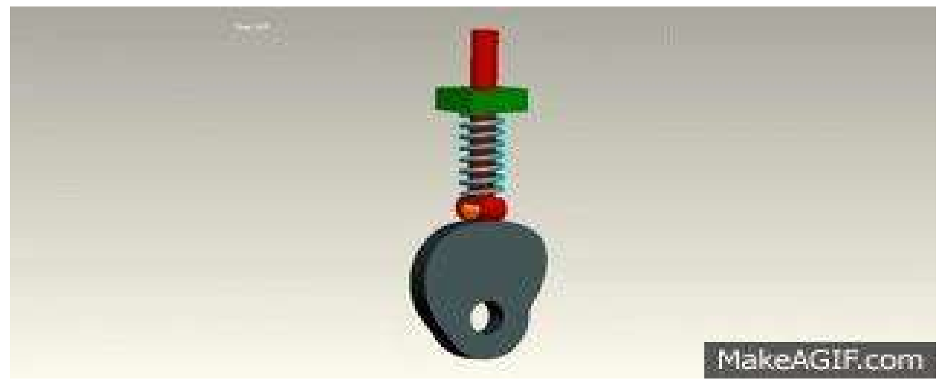
contact even without the application of external force.

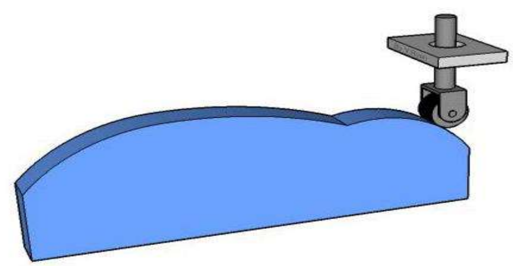


Unclosed pair (force closed) :

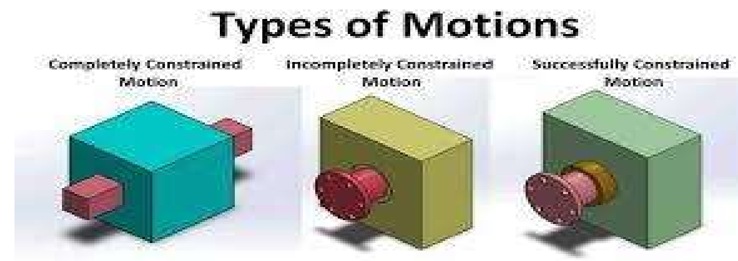
- Elements of pairs held together by the action of external forces constitute unclosed or force closed pair .Eg. Cam and follower.
- The two links of a pair are in contact either due to gravity or some spring action.





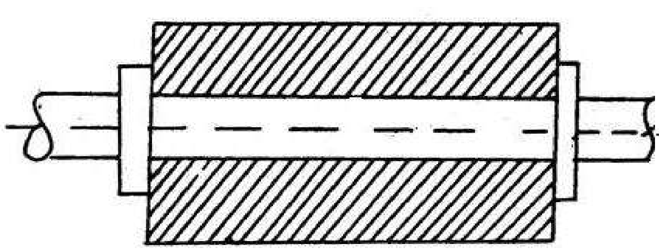


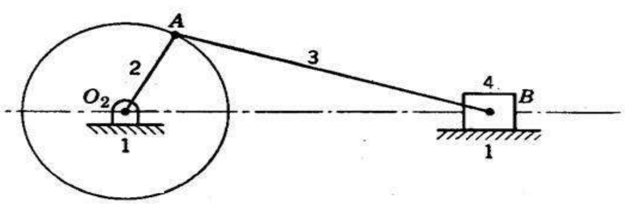
Constrained motion – Types:

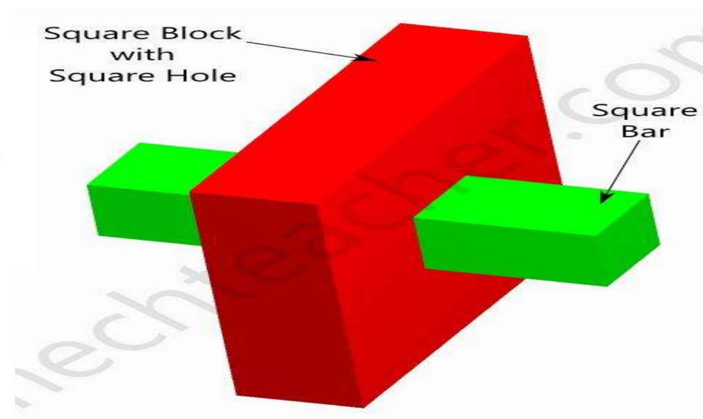


- Completely constrained motion
- Incompletely constrained motion
- Partially (or successfully) constrained motion

1. Completely constrained motion: When relative motion between pairing elements takes place in one direction, it is called completely constrained motion.





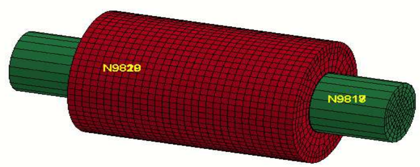


Even when any external force is applied, a square bar always slides inside a square hole. It does not turn.

2. Incompletely constrained motion

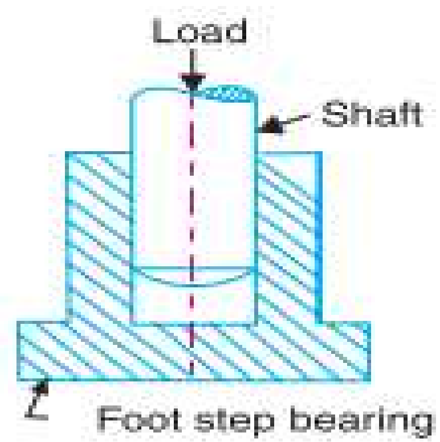
- When relative motion between pairing elements takes place in more than one direction, it is called incompletely constrained motion.
- A good example of incompletely constrained motion is the motion of a shaft inside a circular hole. Depending on the direction of external forces applied, the shaft may slide or turn (or do both) inside the circular hole.

A change in direction of the impressed force may alter the direction of relative motion between the pair.



3.Partially (or successfully) constrained motion

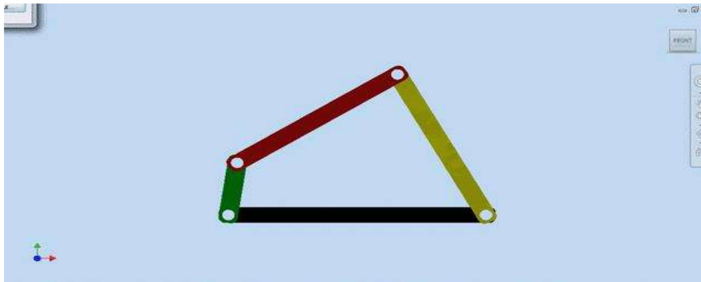
- A kinematic pair is said to be partially or successfully constrained if the relative motion between its links occurs in a definite direction, not by itself, but by some other means.



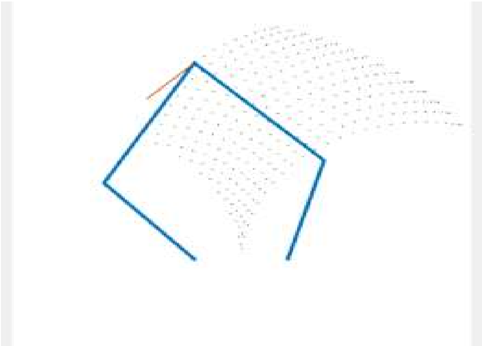
Eg. Foot step bearing, where shaft is constrained from moving upwards, by its self weight.

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.

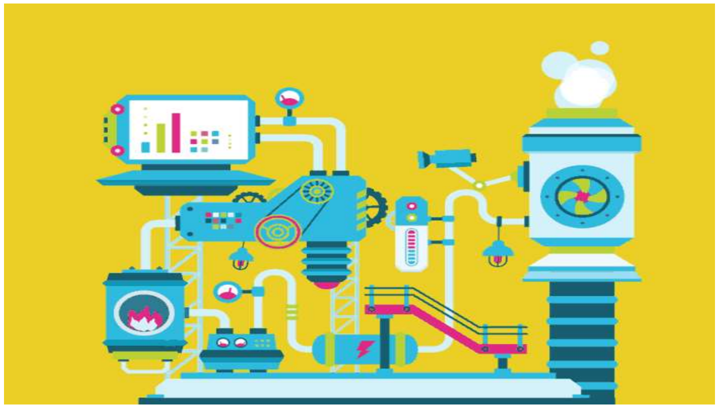


A mechanism with four links is known as simple mechanism, the mechanism with more than four links is known as compound mechanism.



Machine

It is mechanism or a **group of mechanisms used to perform useful work** or converting the available energy into useful work.



Differences between a Mechanism & a Machine

Sl. No	Mechanism	Machine
1	A mechanism is meant to transmit or transform motion.	A machine is meant for transmitting energy to do useful work.
2	No mechanism is necessarily a machine.	A machine is an assemblage of mechanisms.
3	A mechanism is a working model of any machine.	A machine is a practical development of any machine.
	Ex: Clock, Type writer, Mini drafter, etc.	Ex: Steam engine, IC engine, Shaper, etc.

Differences between a Machine & Structure

Sl. No	Machine	Structure
1	The parts of a machine move relative to one another.	The parts of a structure **do not** move relative to one another.
2	A machine transforms the available energy into useful work.	No such energy transformation takes place.
3	The links of a machine can transmit both motion & forces.	The members of a structure can transmit forces only.
	Ex: Lathe, Engine, Pumps, Compressors, etc.	Ex: Roof truss, Bridge, Machine frames, engine frames, etc.

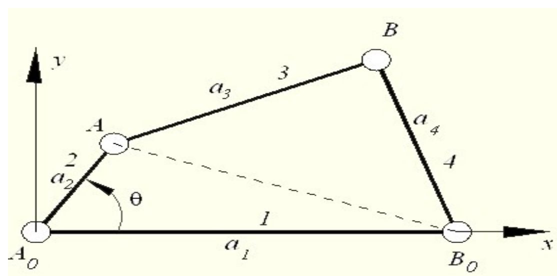
<u>Degrees of freedom of a mechanism/Mobility</u>

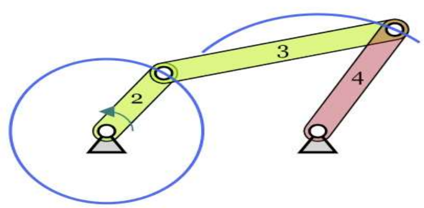
- It is the number of independent coordinates required to describe the position of a body in space. A free body in space can have six degrees of freedom. i.e., linear positions along x, y and z axes and rotational/angular positions with respect to x, y and z axes.

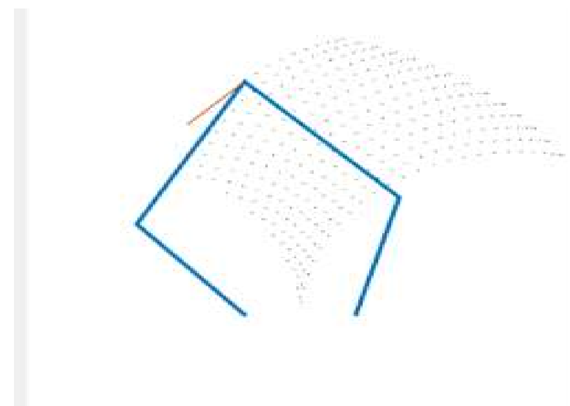
- The number of **independent relative motions possible** for a mechanism.

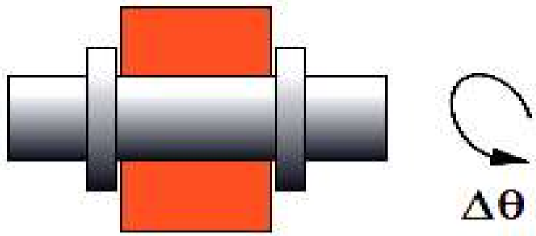
  OR

- The number of inputs that need to be provided in order to create a predictable output.
- Number of variables to determine position of a mechanism in space.

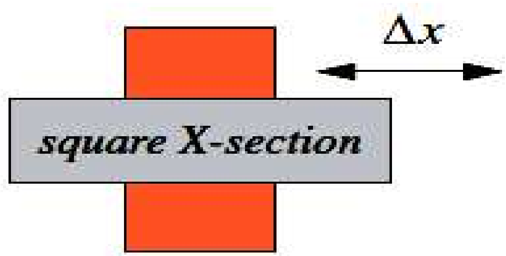




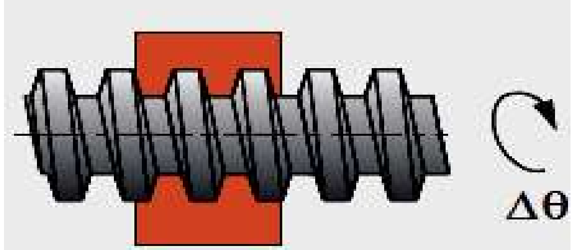




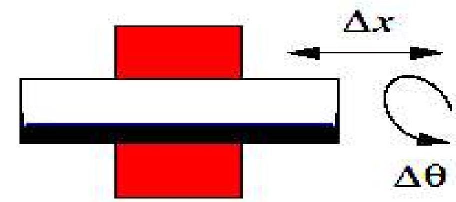
Revolute (R) joint—1 *DOF*



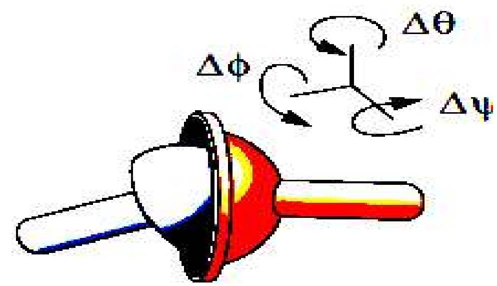
Prismatic (P) joint—1 *DOF*



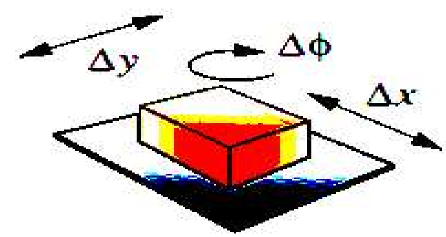
Helical (H) joint—1 *DOF*



Cylindric (C) joint—2 *DOF*

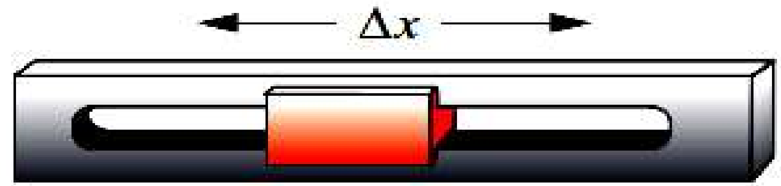


Spherical (S) joint—3 *DOF*



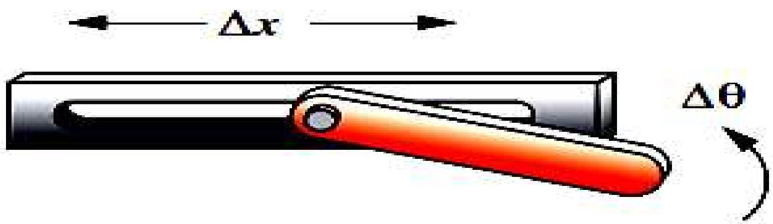
Planar (F) joint—3 *DOF*

Rotating full pin (R) joint (form closed)



Translating full slider (P) joint (form closed)

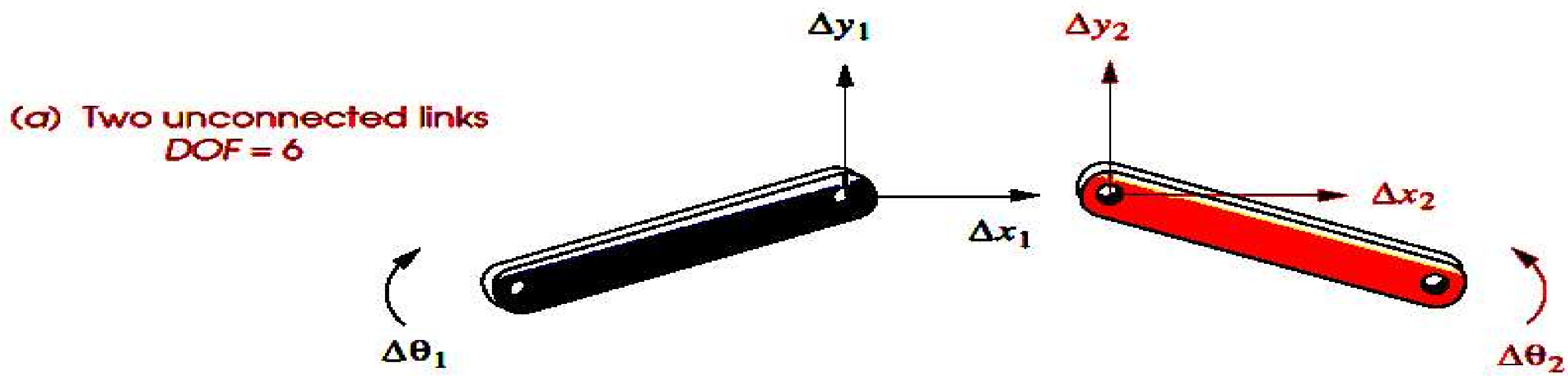
(*b*) Full joints - 1 *DOF* (lower pairs)



Pin in slot (form closed)

- 2 *DOF*

DOF of PLANAR SYSTEM with Two unconnected links

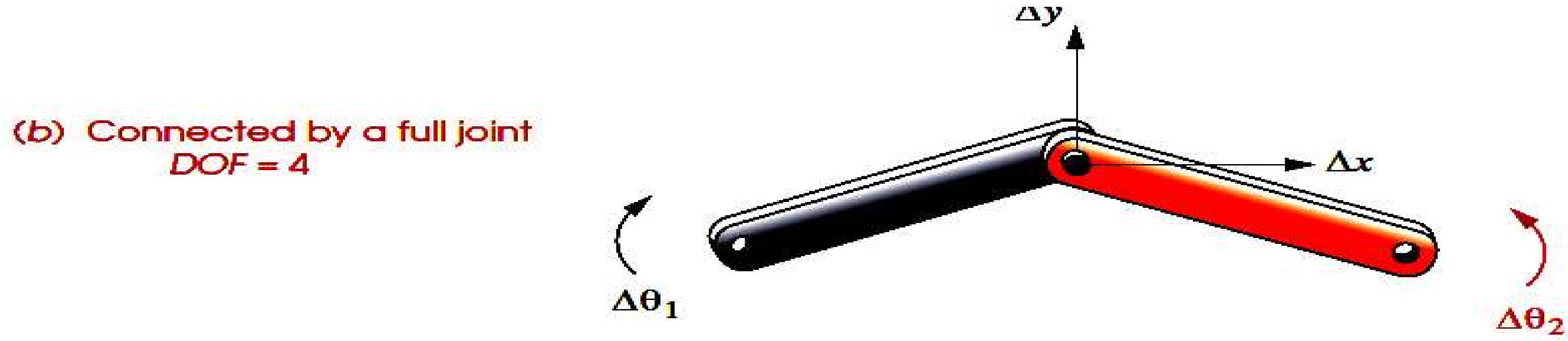


Three independent coordinates needed to specify the location of the link AB in plane, ***x1*, *y1*, and angle** $\theta 1$

Two unconnected links have a total of six *DOF*

A Rigid link in the plane has three degrees of freedom and in space six DOF.

DOF of a PLANAR SYSTEM with Two connected links (full joint)



When these links are connected by a full joint, Δy_1 *and* Δy_2 *are combined* as Δy, *and* Δx_1 *and* Δx_2 *are combined as* Δx. *This removes two DOF, leaving four DOF.*

- Note that in any real mechanism, one link of the kinematic chain is grounded (fixed).
- **Gruebler's equation for DOF**

$$n = 3(L-1) - 2J-h$$

n = *degree of freedom or mobility*

L = *number of links*

J = *number of binary joints or kinematic lower pair*

h= *number of higher pair or point joint*

Degrees of Freedom of a mechanism:

Kutzbach's (modified Gruebler's) equation

$$\text{DOF} = 3(L - 1) - 2J$$

DOF = degree of freedom or mobility

L= number of links, including ground link

J = number of joints

h = number of higher pair is zero

DOF ≤ 0 $\Longrightarrow$ **structure**

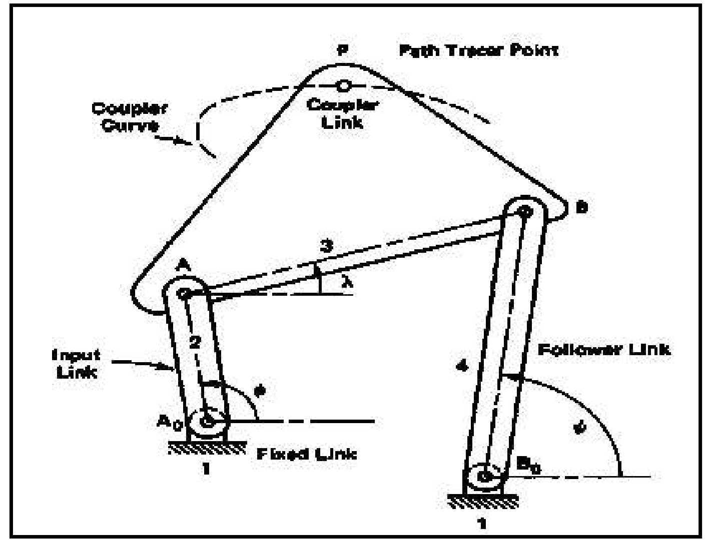
DOF > 0 $\Longrightarrow$ **mechanism**

Degree of Freedom (DOF) – example

Four Bar mechanism

L = 4 , *J* = 4 pin connections, h = 0

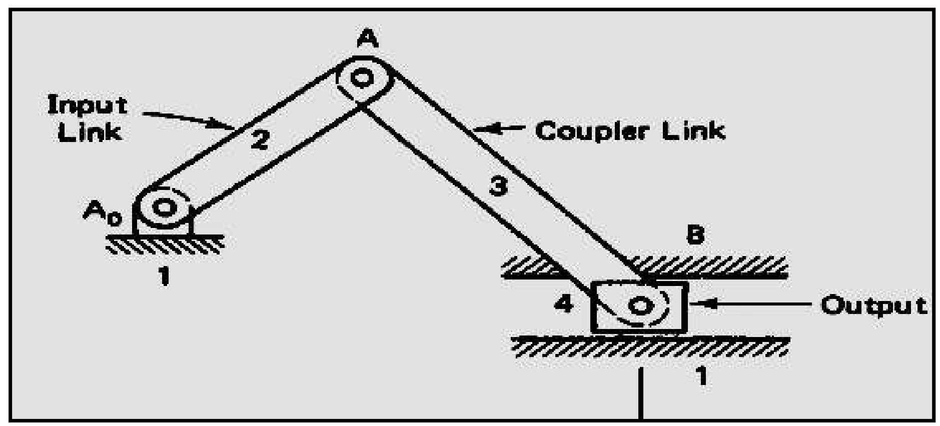
DOF = 3(4 – 1) – 2(4) – (0) = 1



Slider crank mechanism

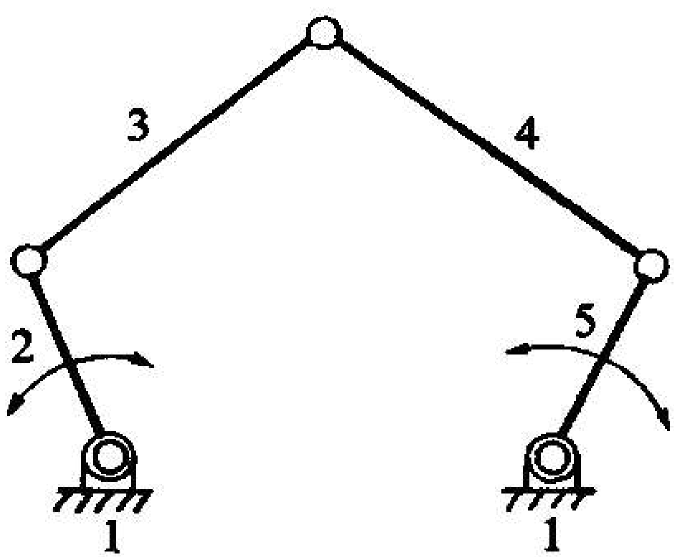
L= 4 , *J* = 3 pin connections + 1 slider = 4 , h = 0

DOF = 3(4 – 1) – 2(4) – (0) = 1



1 DOF means only one input (power source) is needed to control the mechanism

Problem 1:



L = 5

J = 5

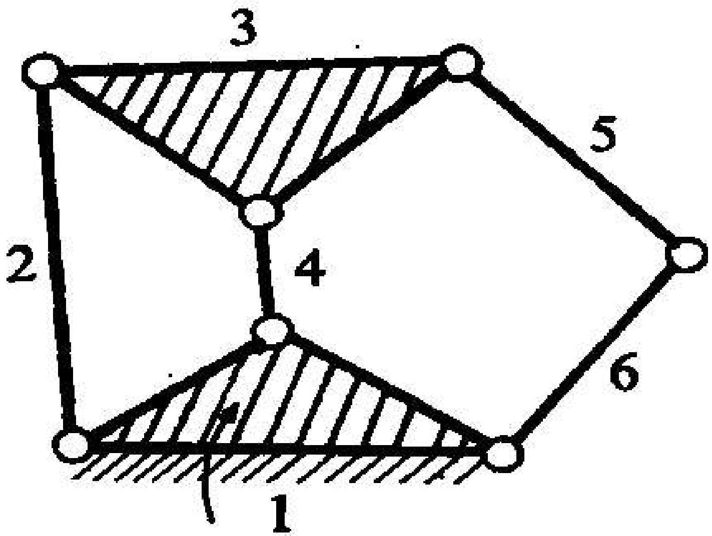
h = 0

DOF=3 x (5 – 1) – 2x5 – 1x0

= 12 – 10 – 0

= 2

Problem 2:



L = 6

J = 7

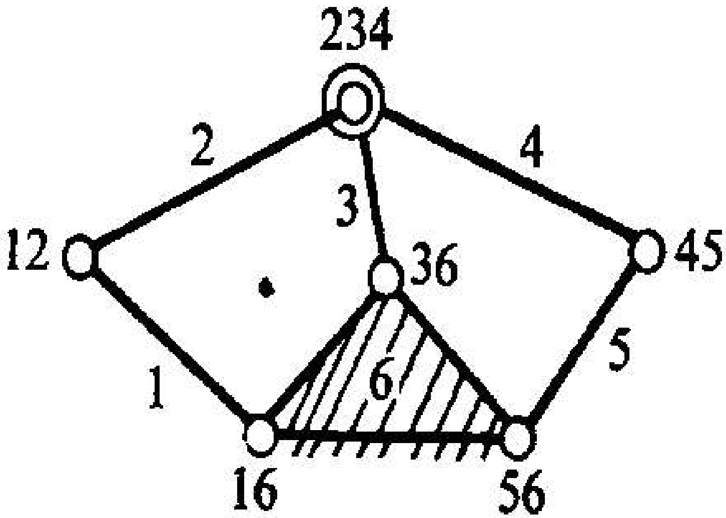
h = 0

DOF =3 x (6 – 1) – 2x7–0 1x0

= 15– 14 – 0

= 1

Problem 3:



L = 6

J = 7

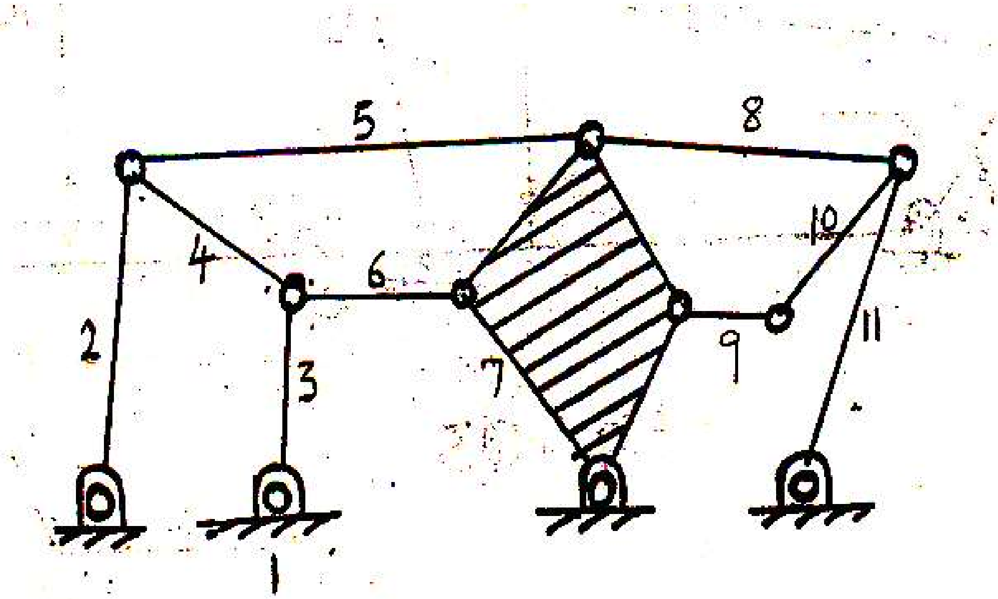
h = 0

DOF =3 x (6 – 1) – 2x7 –1x0

= 15 – 14 – 0

= 1

Problem 4:



L = 11

J = 15

h = 0

$$DOF = 3 \times (11 - 1) - 2 \times 15 - 1 \times 0$$

$$= 30 - 30 - 0$$

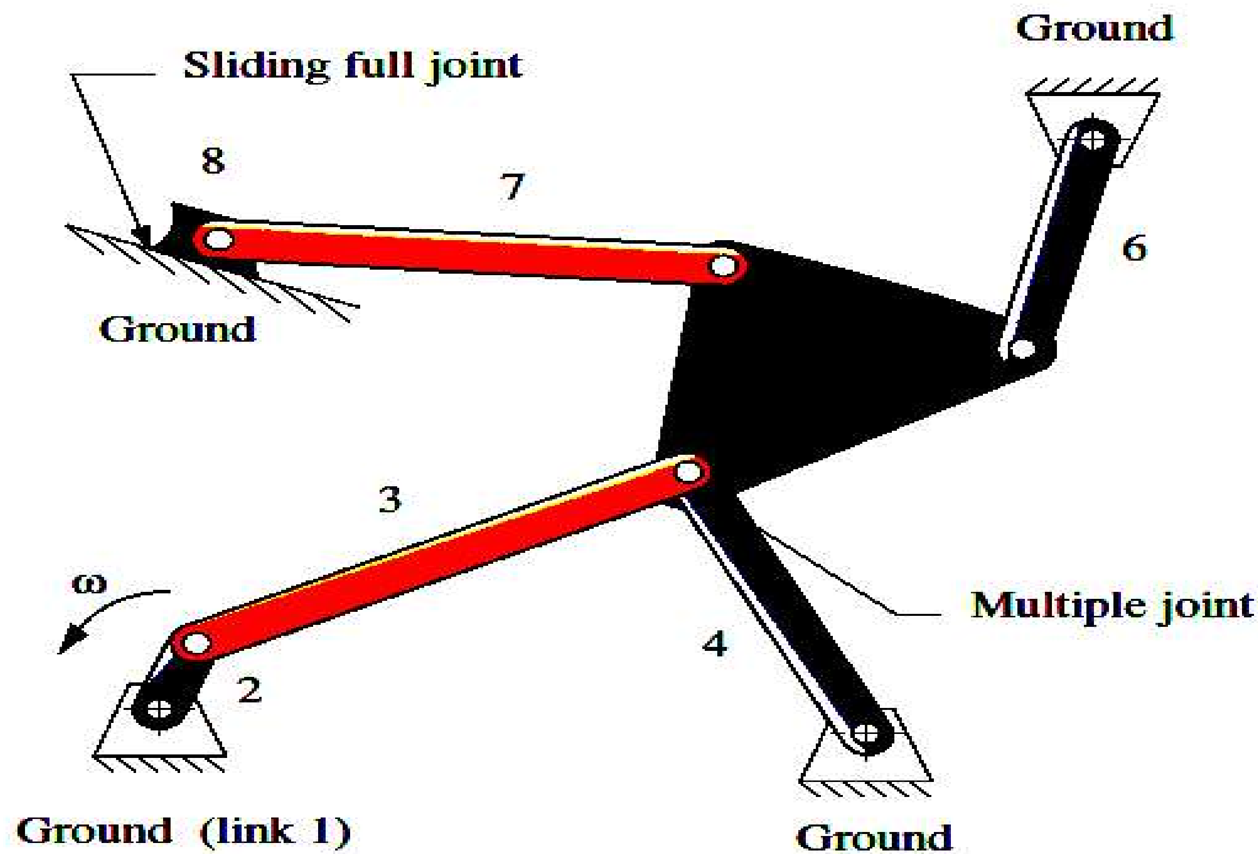
$$= 0$$

Problem 5:

Note:
There are no roll-slide (half) joints in this linkage

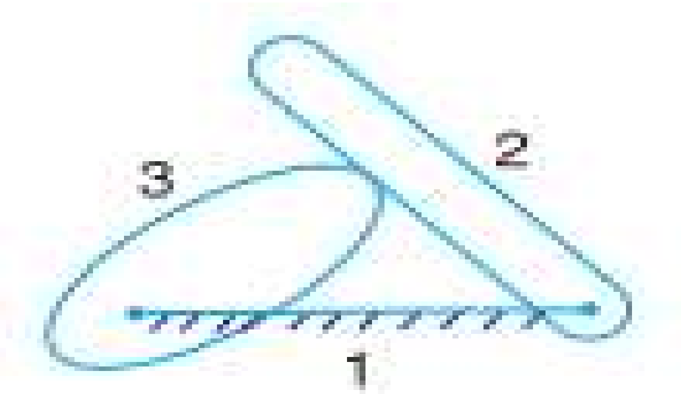
$L = 8, \quad J = 10$

$DOF = 1$



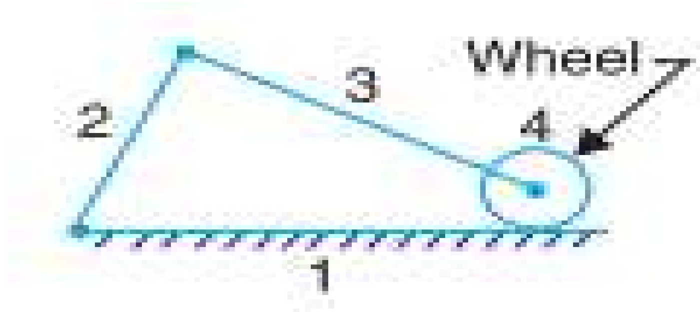
(a) Linkage with full and multiple joints

Problem 6:



$l = 3, j = 2$ and $h = 1$.

$n = 3\ (3 - 1) - 2 \times 2 - 1 = 1$



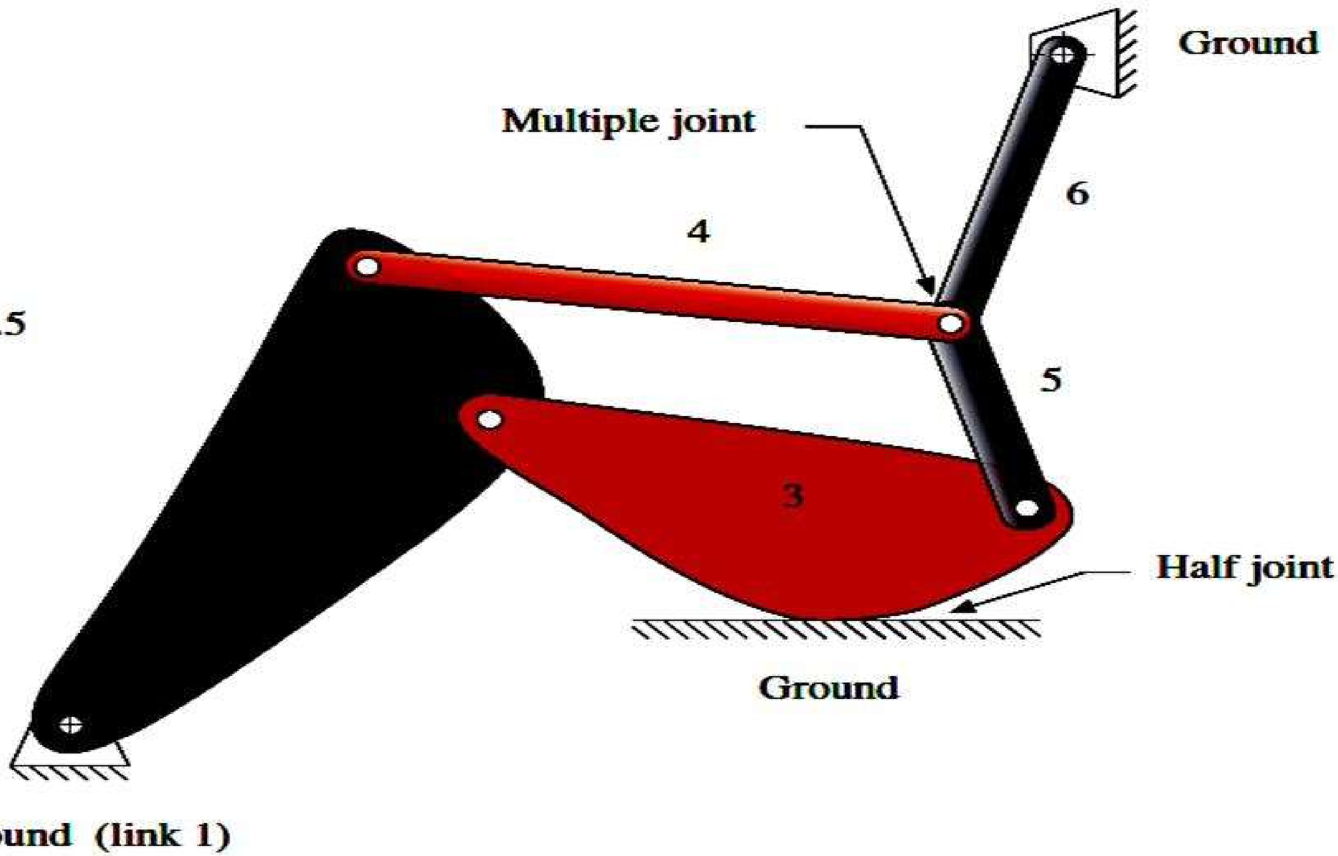
$l = 4,\ j = 3$ and $h = 1$

$n = 3\ (4 - 1) - 2 \times 3 - 1 = 2$

Problem 7:

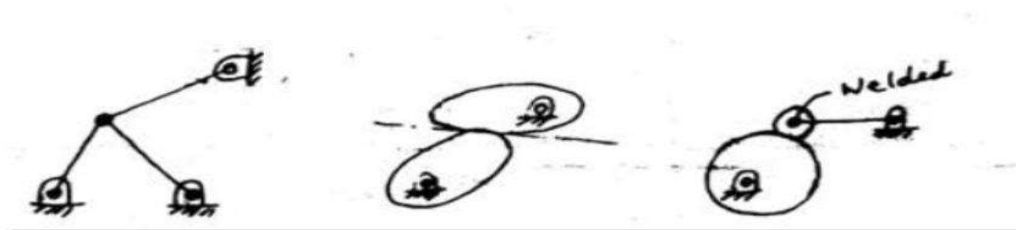
$L = 6, \quad J = 7.5$

$DOF = 0$



(*b*) Linkage with full, half, and multiple joints

Problem 8:



(a)

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

Here, $n = 4$, $l = 5$ and $h = 0$.

$F = 3(4-1)-2(5) = -1$

I.e., it is a structure

(b)

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

Here, $n = 3$, $l = 2$ and $h = 1$.

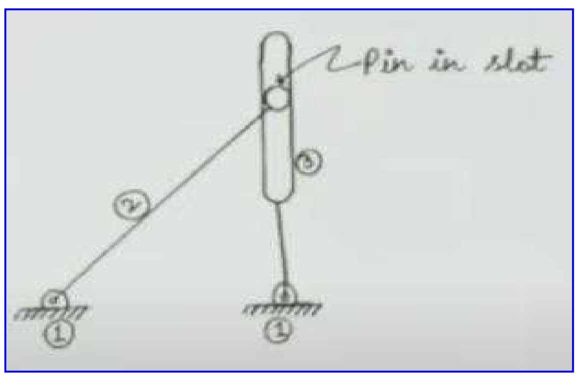
$F = 3(3-1)-2(2)-1 = 1$

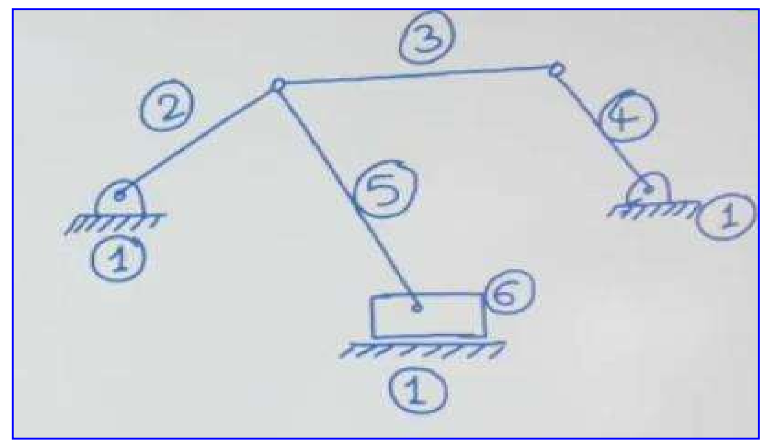
(c)

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

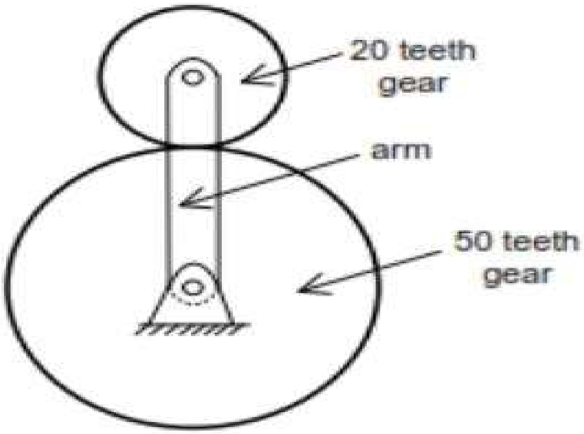
Here, $n = 3$, $l = 2$ and $h = 1$.

$F = 3(3-1)-2(2)-1 = 1$





Problem 9:



no. of link= 4 = n

no. of turning pair = 2 = p_1

no. of rolling pair = 1 = p_2

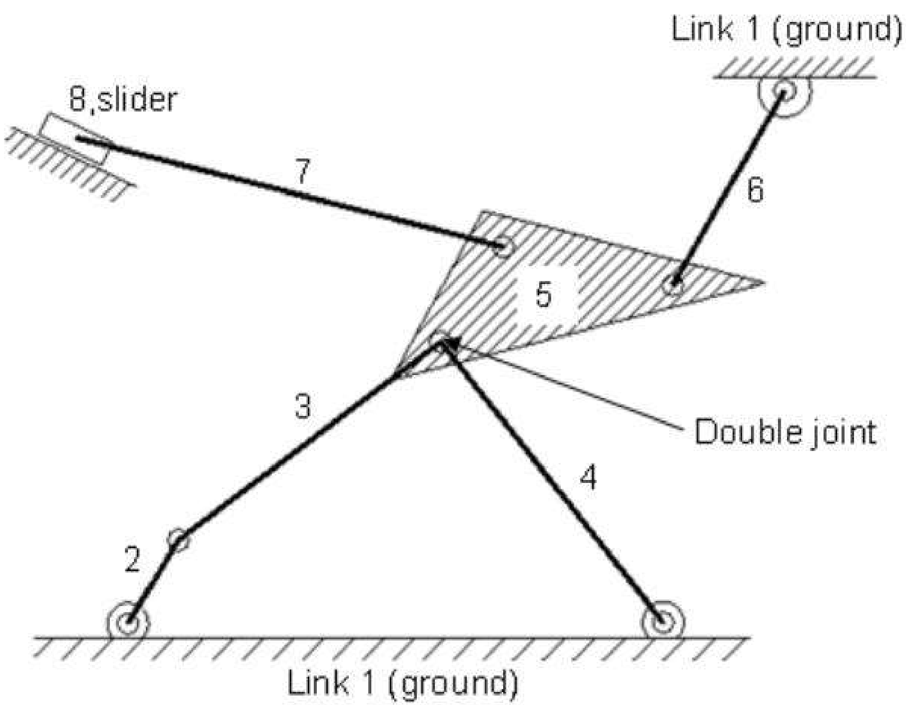
D.O.F= F =3(n-1)-2p_1-3p_2

= 3(4-1)-2(2)-3(1)

= 9-4-3

=2

Problem 9:



L=8

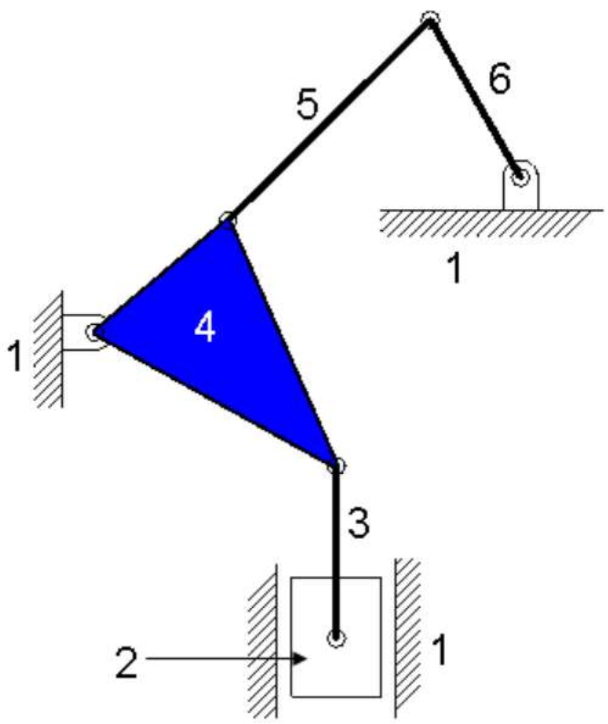
J=2

H=0

DOF= 3(8-1)-2×10

=1

Problem 9:



L=6

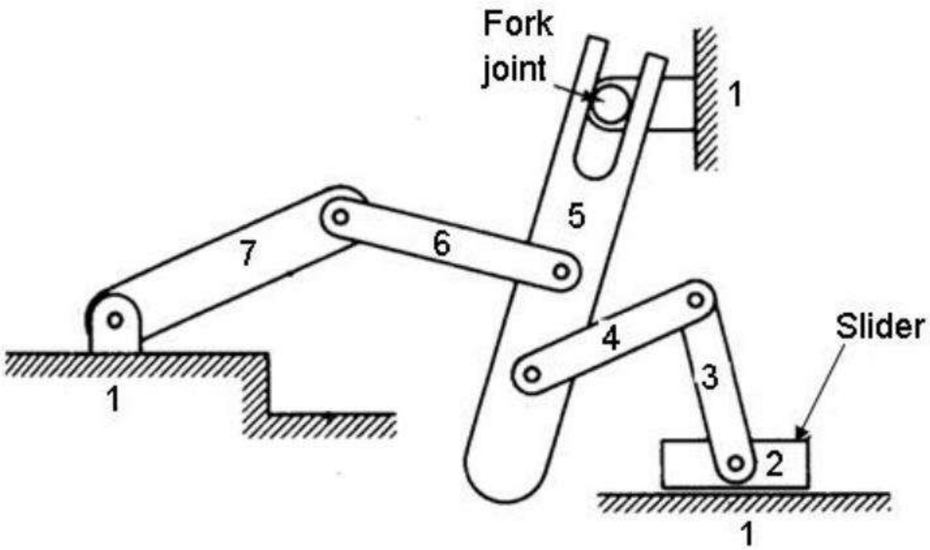
J=7 (six turning pairs and one sliding pair)

H=0

DOF= 3(6-1)-2 × 7

=1

Problem 10:



L=7

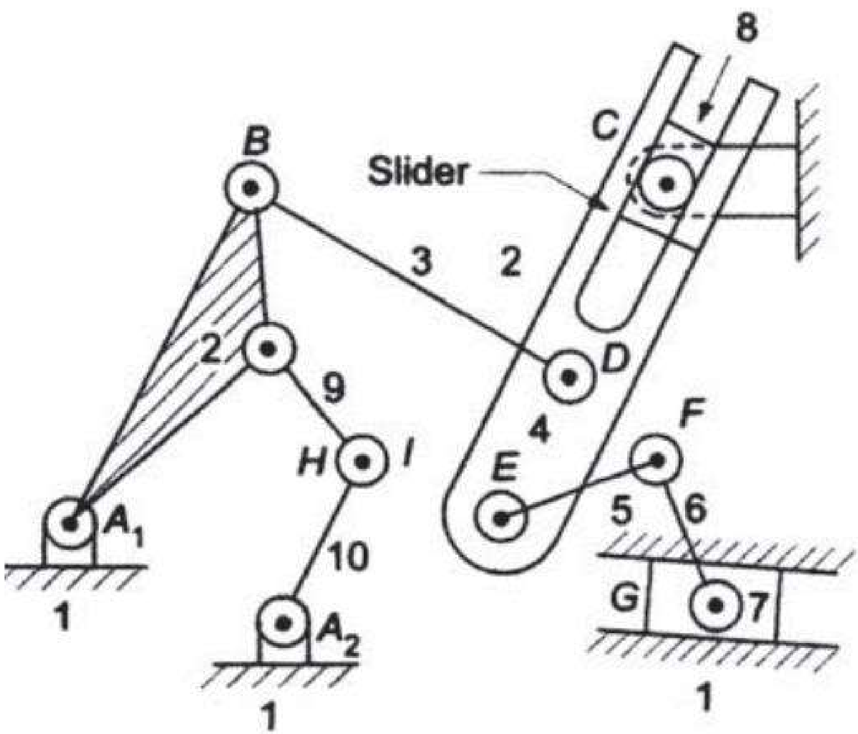
J=7 (six turning pairs and one sliding pair)

H=1 (Fork joint is two DOF joint)

DOF= 3(7-1)-(2×7)-(1×1)

=3

Problem 11:



L=10

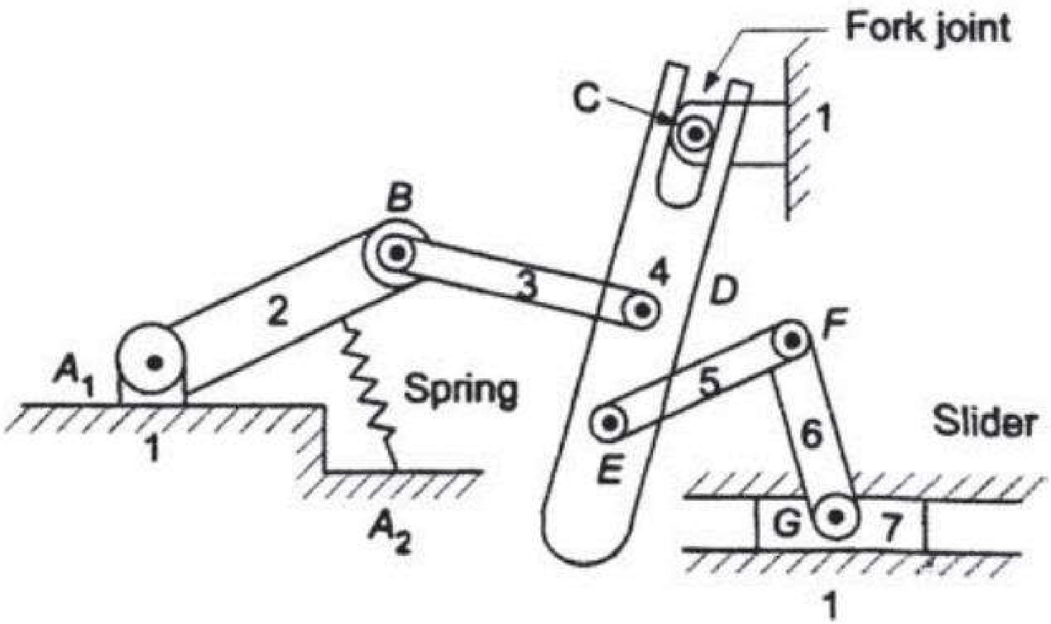
J=12 (10 turning pairs and two sliding pair)

H=0

DOF= 3(10-1)-(2×12)

=3

Problem 12:



$L=7$

$J=7$ (6 turning pairs and one sliding pair)

$H=1$

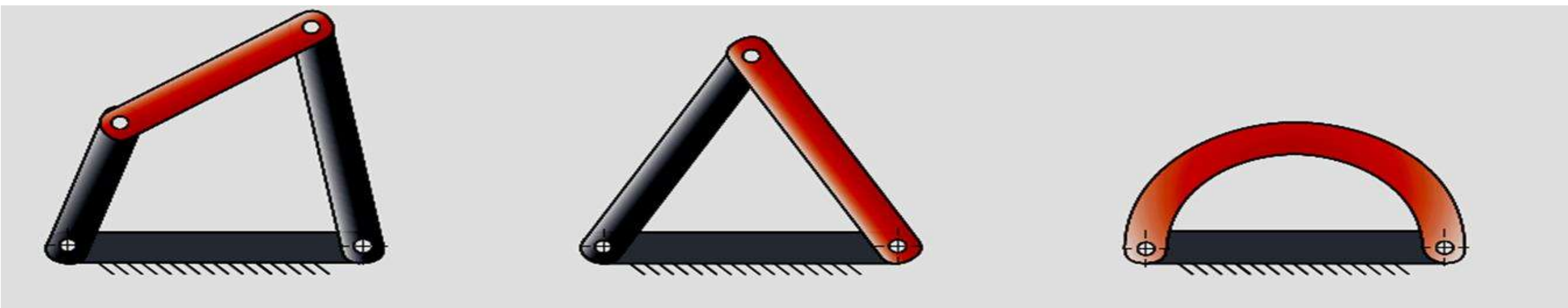
$DOF= 3(7-1)-(2\times 7)-(1\times 1)$

$=3$

- If the DOF is positive, it will be a **mechanism,** and the links will have relative motion.

- If the DOF is exactly zero, then it will be a **structure, and no** motion is possible.

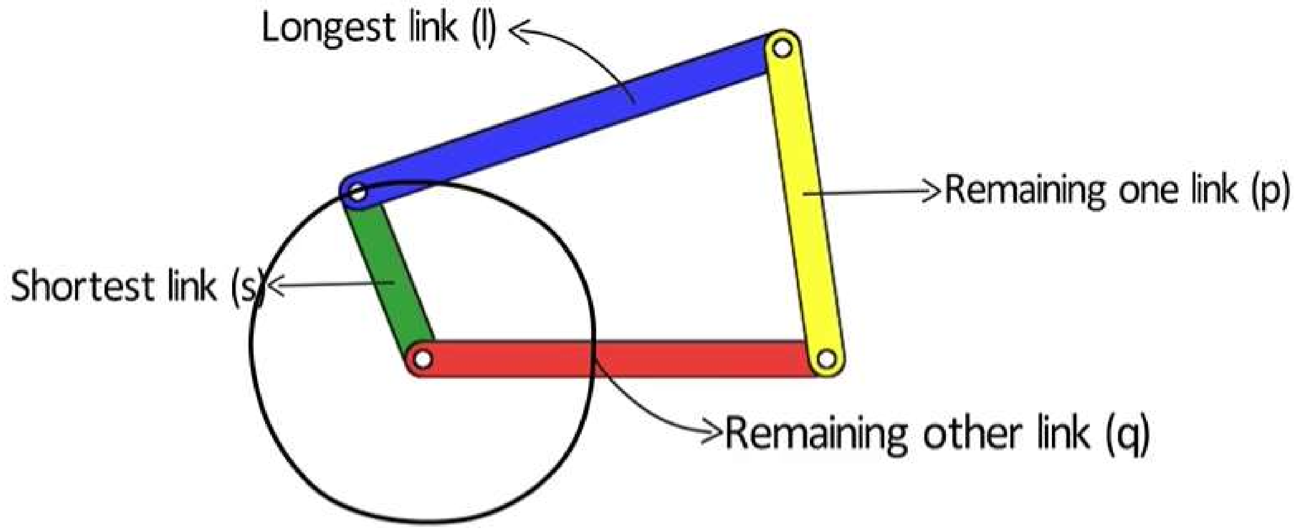
- If the DOF is negative, then it is a **preloaded structure or super structure,** which means that no motion is possible and some stresses may also be present at the time of assembly.



(a) Mechanism—*DOF* = +1 (b) Structure—*DOF* = 0 (c) Preloaded structure—*DOF* = −1

Grashof's Law:

- States that a four bar mechanism has at least one crank (rotating link) if the sum of the length of largest and shortest links is less than the sum of length of the other two links.



$$s + l \leq p + q$$

- For $s + l > p + q$ no link will be able to make a complete revolution

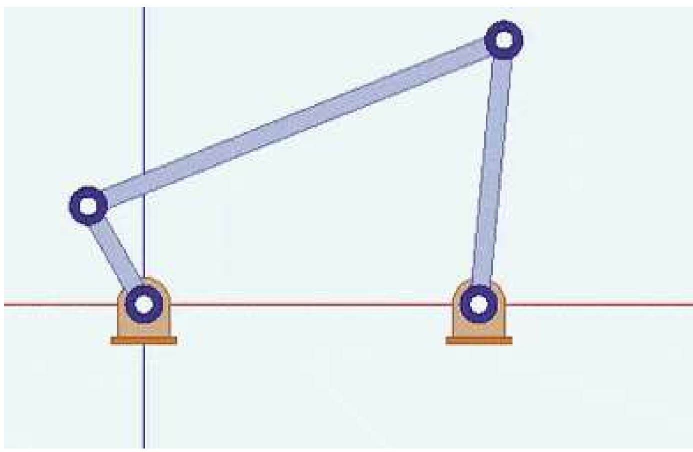
Four bar chain:

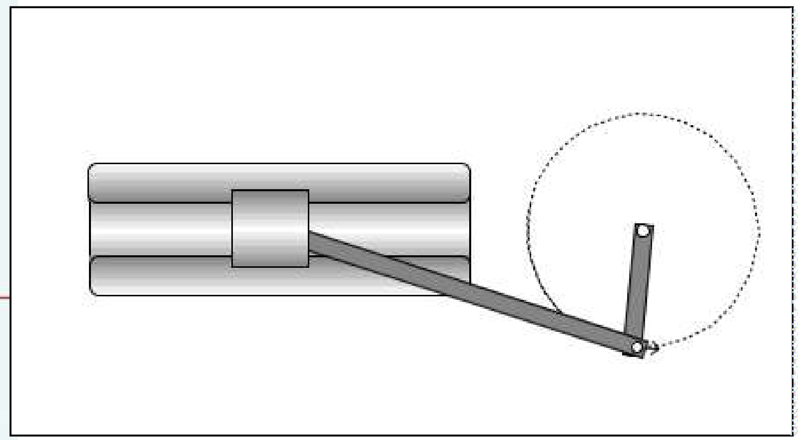
Four Links

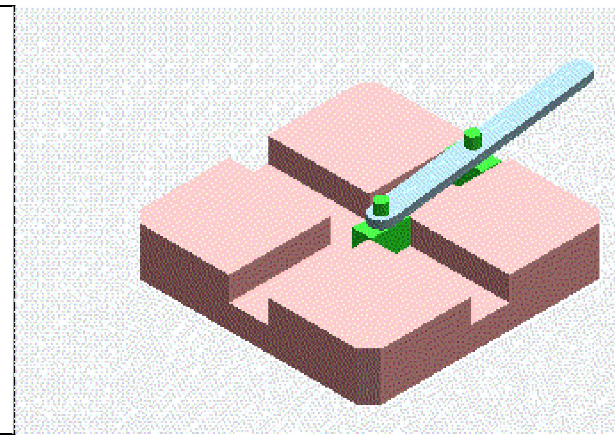
- One link fixed (**Mechanism**)
- Link that makes complete revolution (**Crank**)
- Link opposite to the fixed link (**Coupler**)
- Fourth link (**Rotation**---**Crank**, Oscillates-----**lever/Rocker**)

Type of Kinematic chains:

- Four bar chain or quadric cycle chain
- Single slider crank chain
- Double slider crank chain





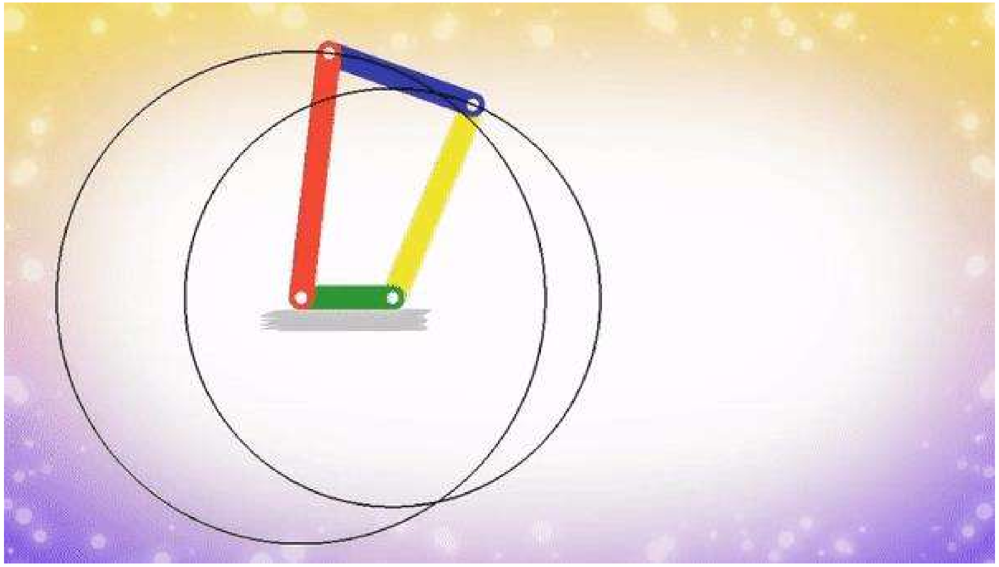


Four bar chain and their inversions:

- An inversion of a mechanism is obtained by fixing the different links of a kinematic chain.
- Inverting a mechanism does not change the relative motion between the links, but drastically changes their absolute motions. (w.r.t. the fixed link)

a) Shortest link fixed (double crank mechanism):

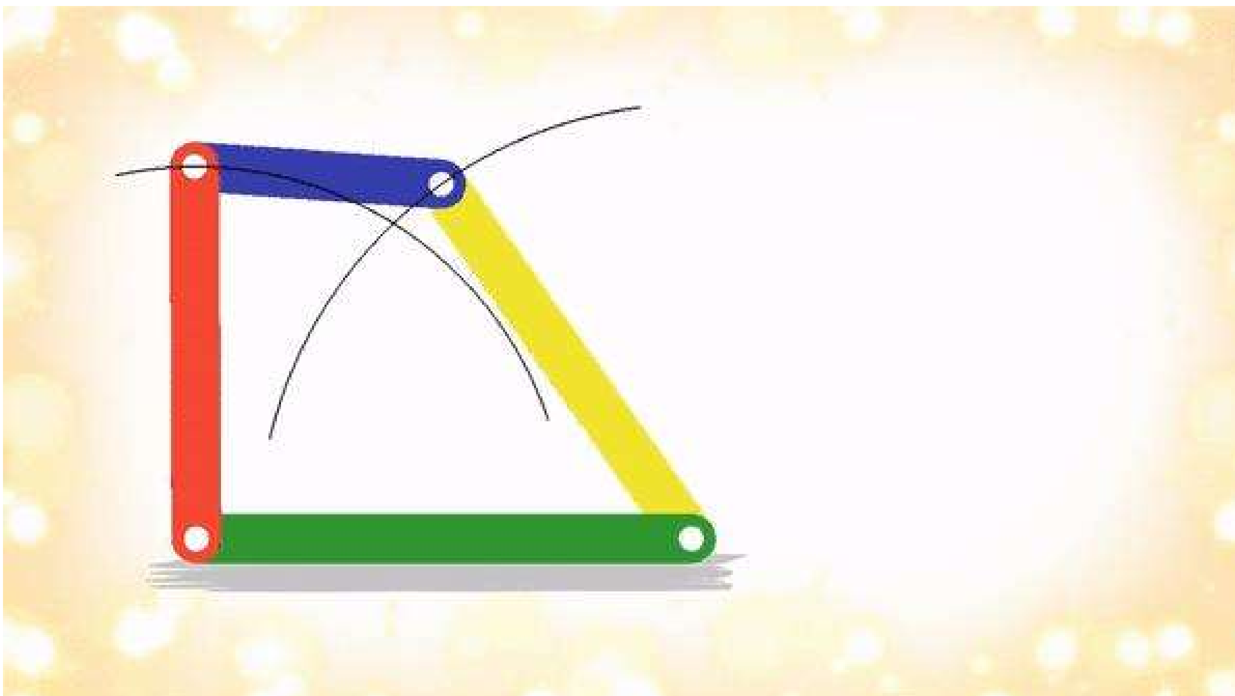
- Example: Coupling rod of locomotive



Four bar chain and their inversions continued:

b) Link opposite to the shortest link fixed (double rocker mechanism):

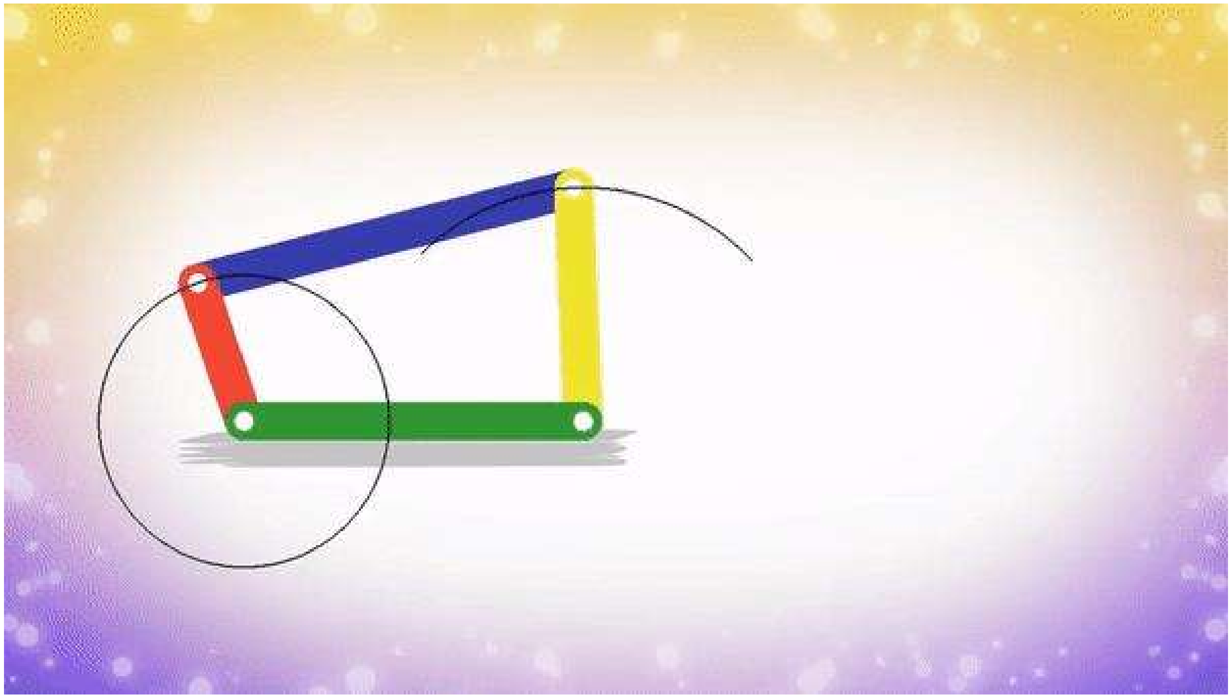
Example: Watt's Indicator mechanism



Four bar chain and their inversions continued:

c) Link adjacent to the shortest link fixed (crank rocker mechanism):

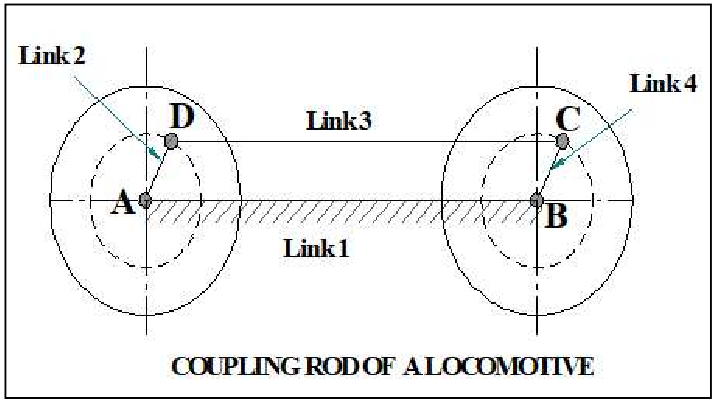
Example: Beam Engine mechanism

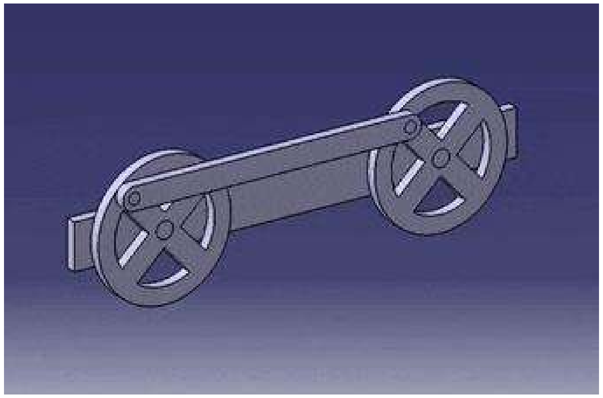


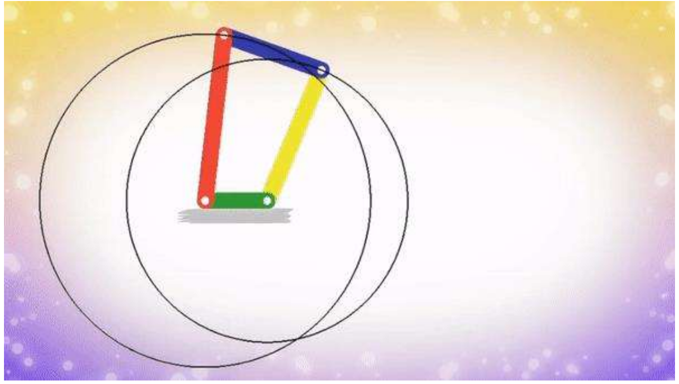
Special case of four bar chain inversions:

1) Coupling rod locomotive (Double crank mechanism):

- This is an example of a double crank mechanism where both cranks rotate about fixed centers **A** & **B** as shown In fig.
- In this mechanism, the opposite links are equal in length i.e. AB=CD, AD=BC, Link AB is fixed. Link CD is the coupling rod which is meant for transmitting rotary motion from one wheel to another.

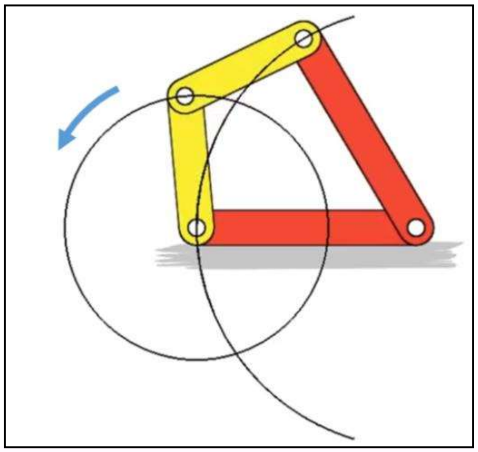


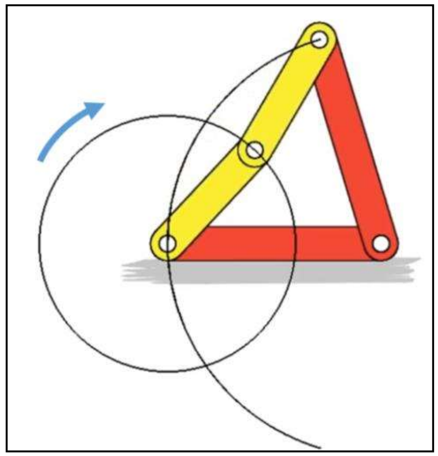


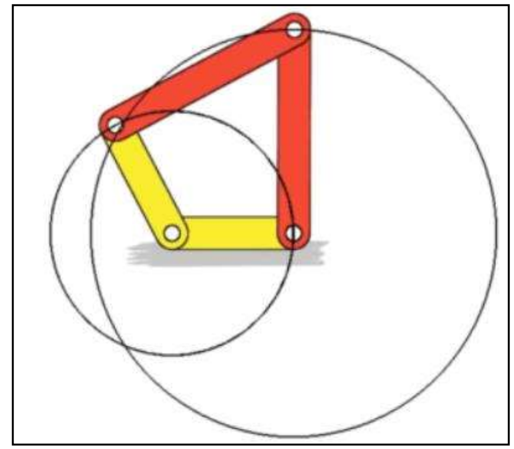


Special case of four bar chain inversions:

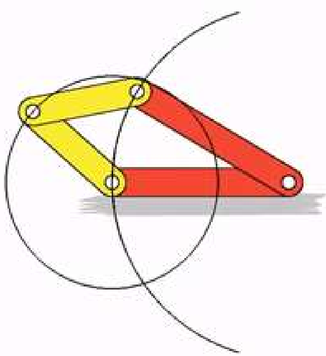
2) Deltoid mechanism:

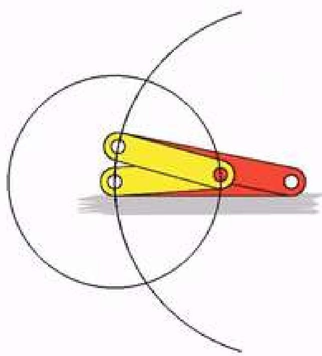




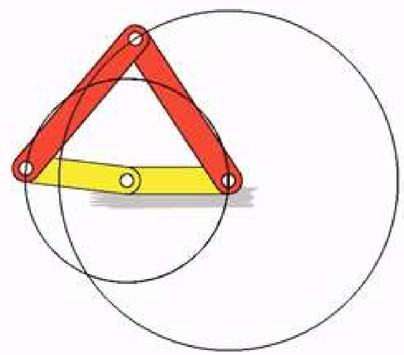


Case1: Longest link is fixed:





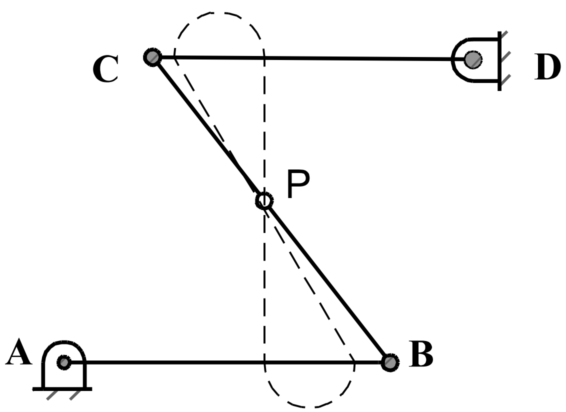
Case2: Shortest link is fixed:

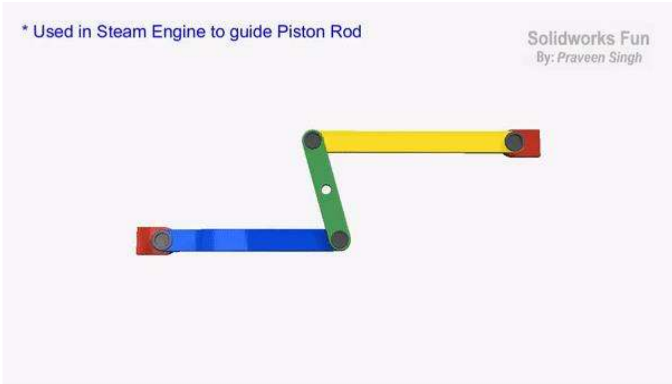


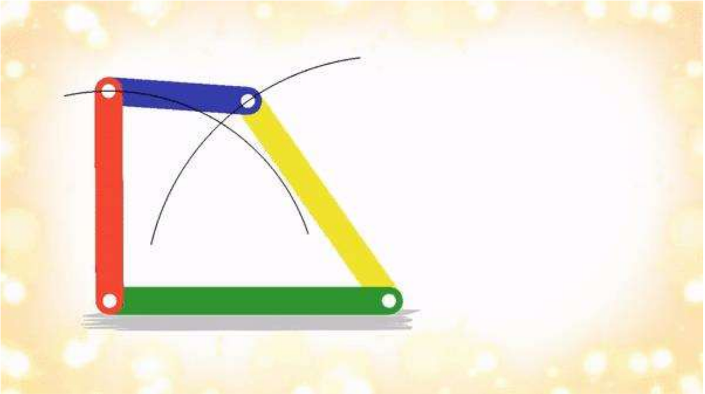
Special case of four bar chain inversions:

3) Watt’s Indicator mechanism (Double rocker mechanism):

- This is an example of double lever mechanism where both the pivoted links can only oscillate about the fixed center as shown in fig.
- The links AB & CD oscillate about the fixed centers A & D and the point P on the connecting link CB traces a figure–eight shaped path, a considerable portion of which is approximately straight line.



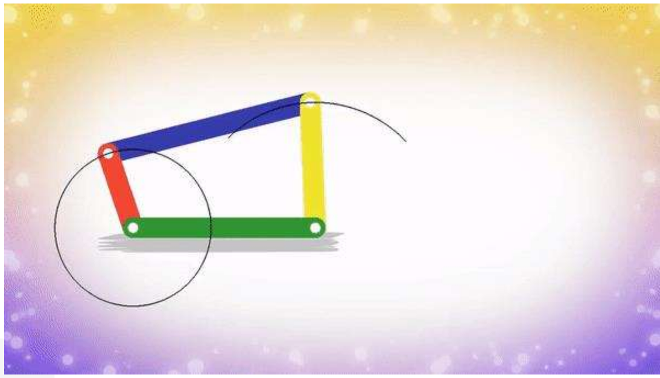


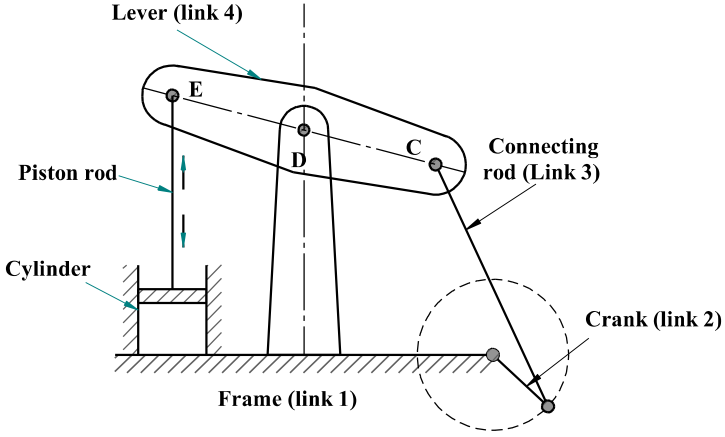


Special case of four bar chain inversions:

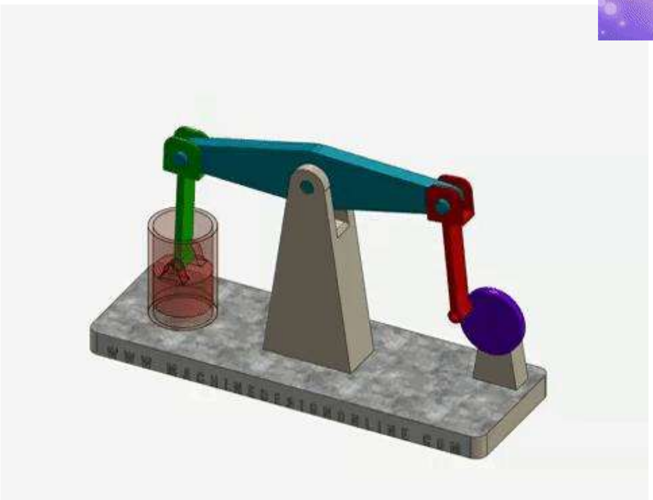
4) Beam Engine(crank rocker mechanism):

- This mechanism, the crank rotates about the fixed center A, the lever oscillates a fixed center D. The end E of the lever CDE is connected to a piston rod which reciprocates due to rotation of the crank.





BEAM ENGINE

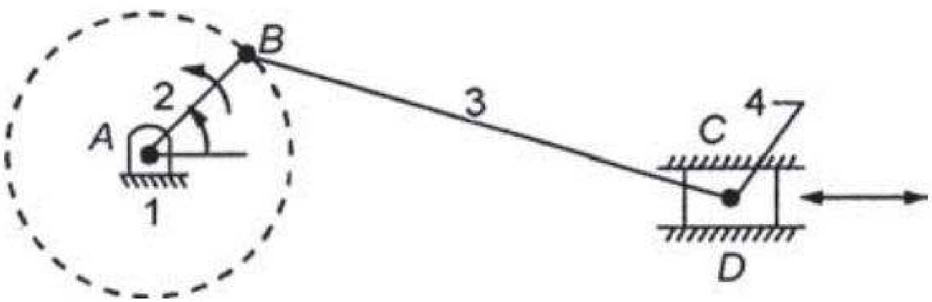


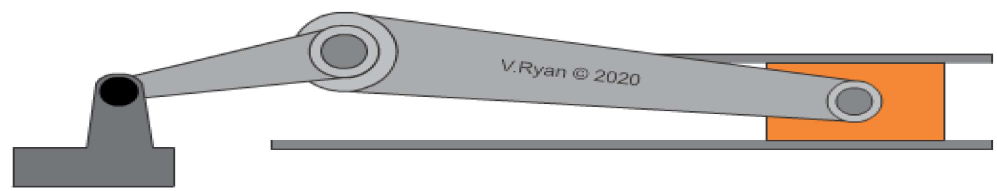
2.Single Slider Crank Chain:

In this mechanism, the crank rotates about a fixed center, the connecting rod oscillates The end of the connecting rod is connected to a piston or slider which reciprocates in a fixed guide or cylinder.

Three revolute pair and one sliding pair

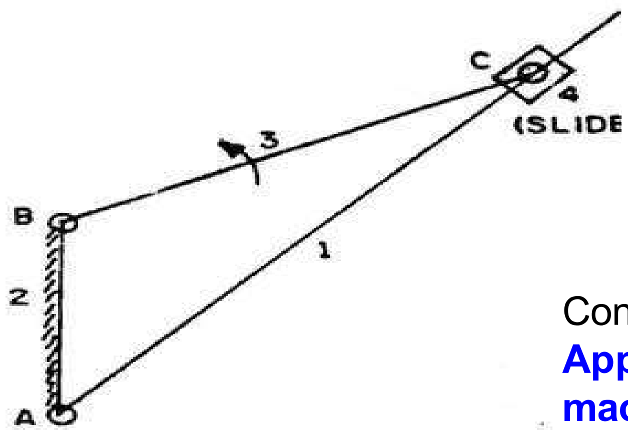
Applications: Reciprocating engine, Reciprocating compressor





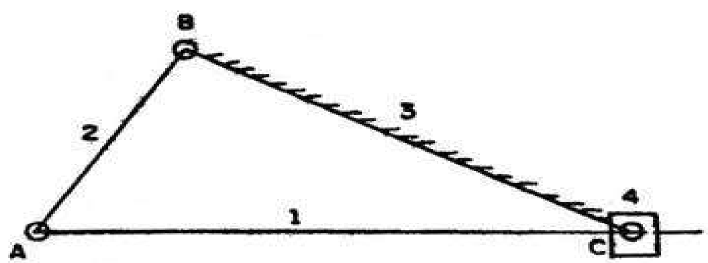
Single Slider Crank Chain & its Inversions:

By fixing the different links, one can obtain many inversions which will find application in different mechanisms.



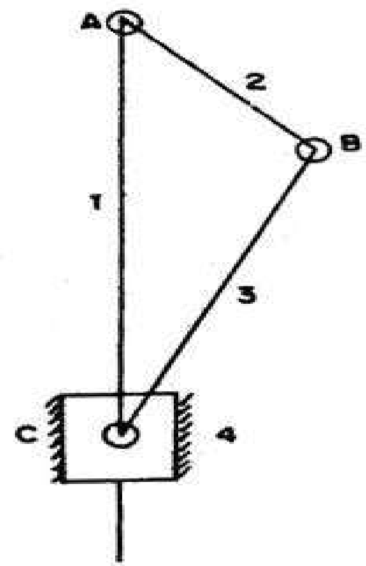
Small link, Crank fixed

Application-Quick return motion mechanism and rotary engine



Connecting rod fixed-adjacent link of crank

Application- Oscillatory engine and slotter machine



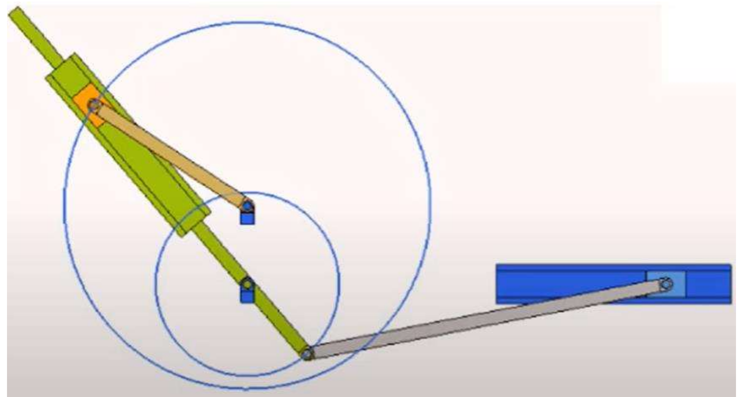
Slider fixed- opposite link of crank

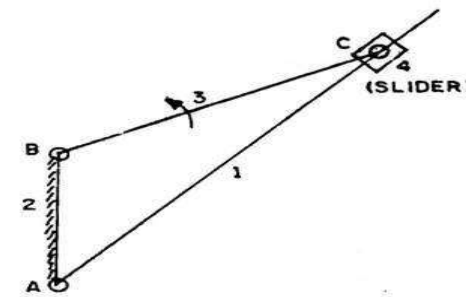
Application-Beam engine

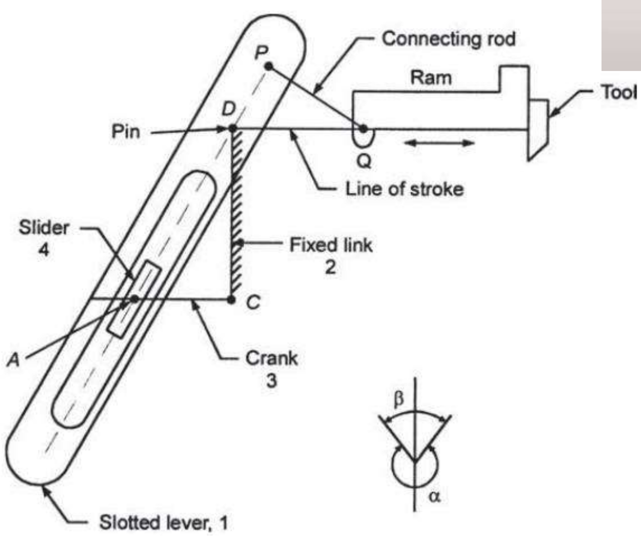
Small link, crank fixing-First Inversion:

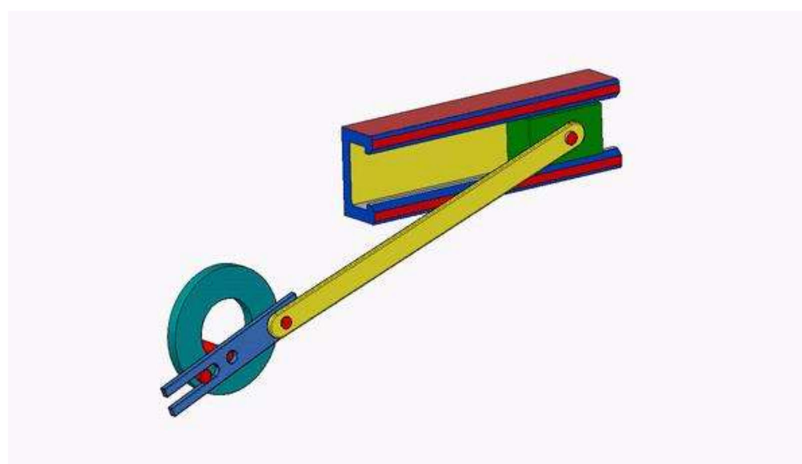
Whitworth quick return motion mechanism (small link fixed).

In this mechanism, as shown in Fig., link CD (link 2) is fixed. The driving crank CA (link 3) rotates about C. The slider (link 4) attached to the crank pin at A slides along the slotted lever PA (link 1), which oscillates about pivot D.



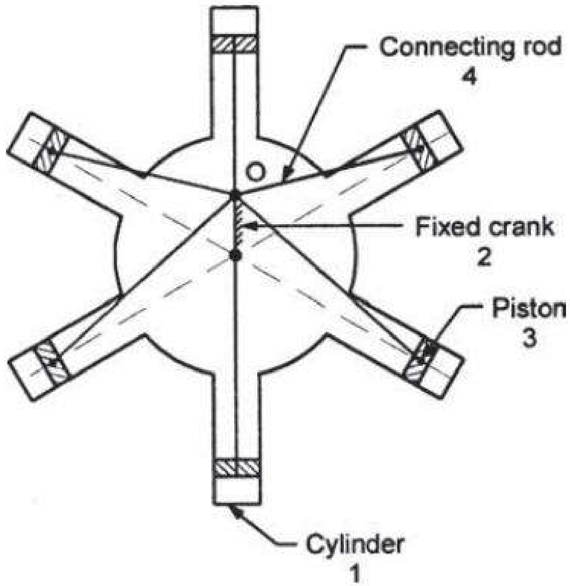


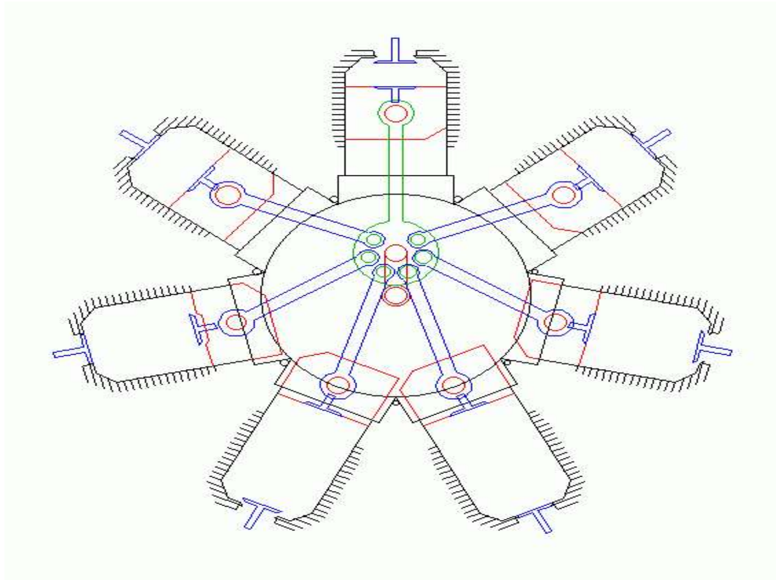




Small link, crank fixing-First Inversion:

Rotary internal combustion engine or Gnome engine. Used in gas turbines.
It consists of several cylinders in one plane and all revolve about fixed centre O, as shown in Fig. The crank (link 2) is fixed. When the connecting rod (link 4) rotates, the piston (link 3) reciprocates inside the cylinder forming link 1

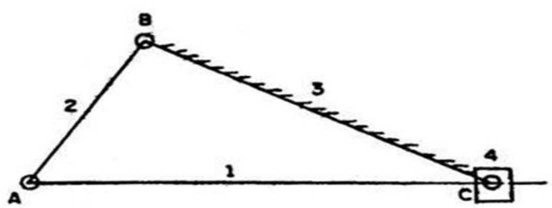




Adjacent link of Small link is fixed-Second Inversion:

Oscillating cylinder engine/ Reciprocating engine. The arrangement of oscillating cylinder engine mechanism, as shown in Fig. is used to convert reciprocating motion into rotary motion.

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*.



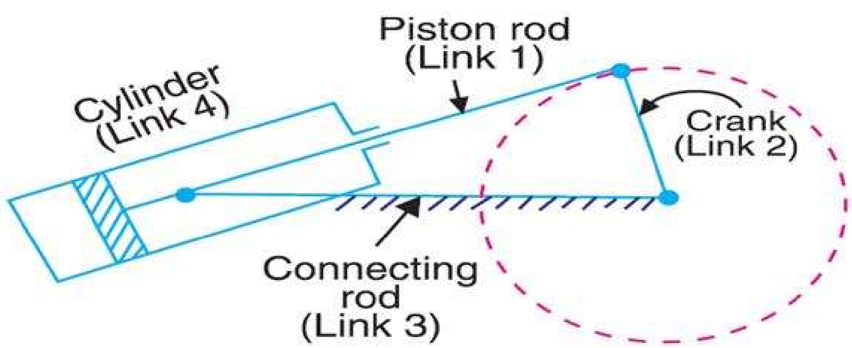
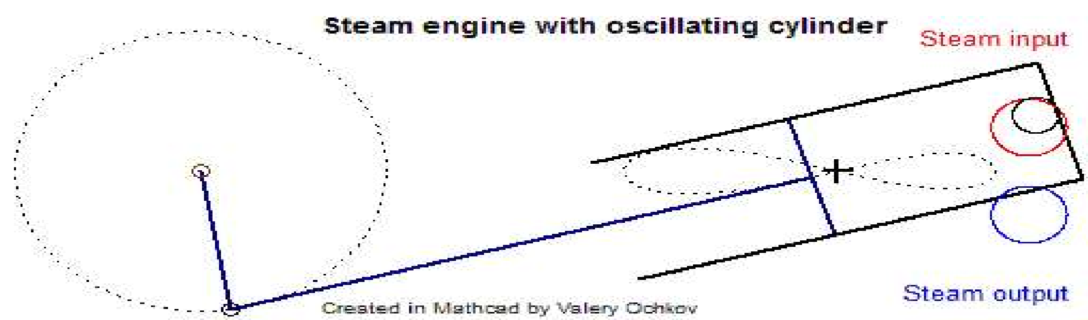
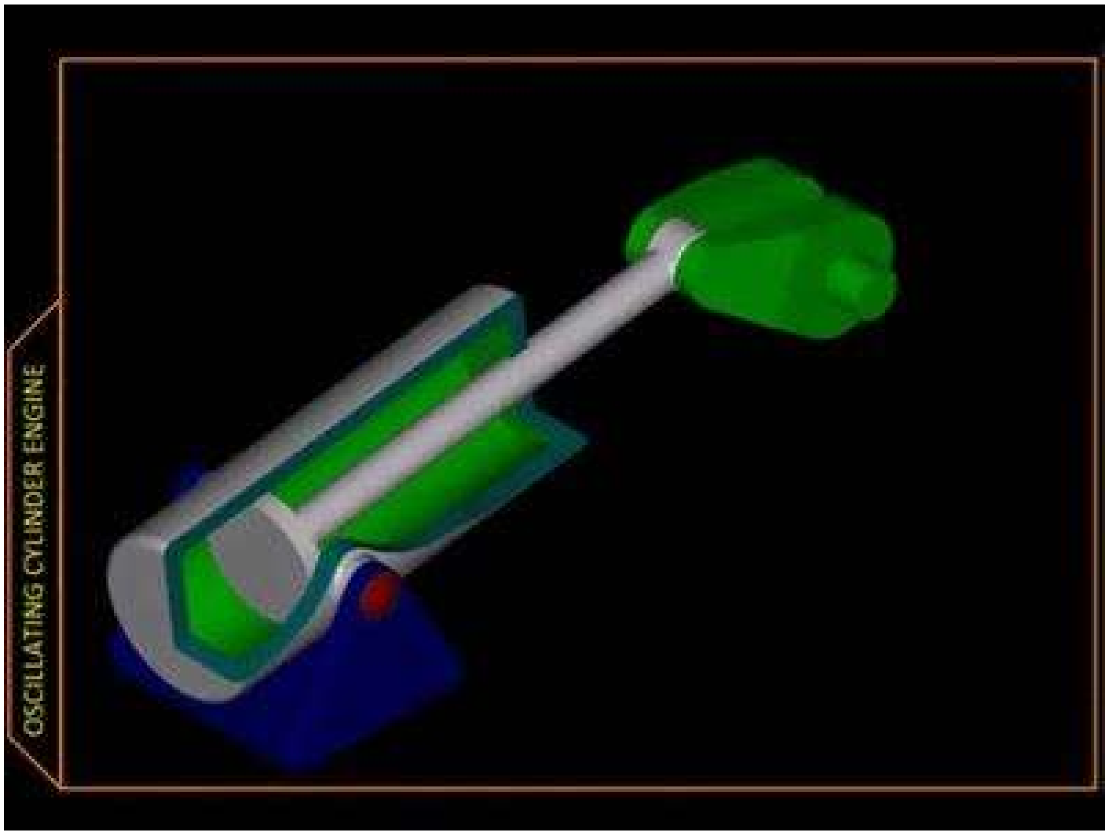


Fig. Oscillating cylinder engine.





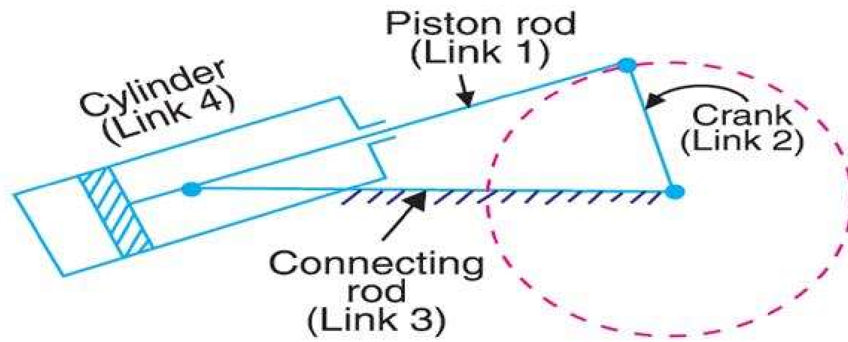
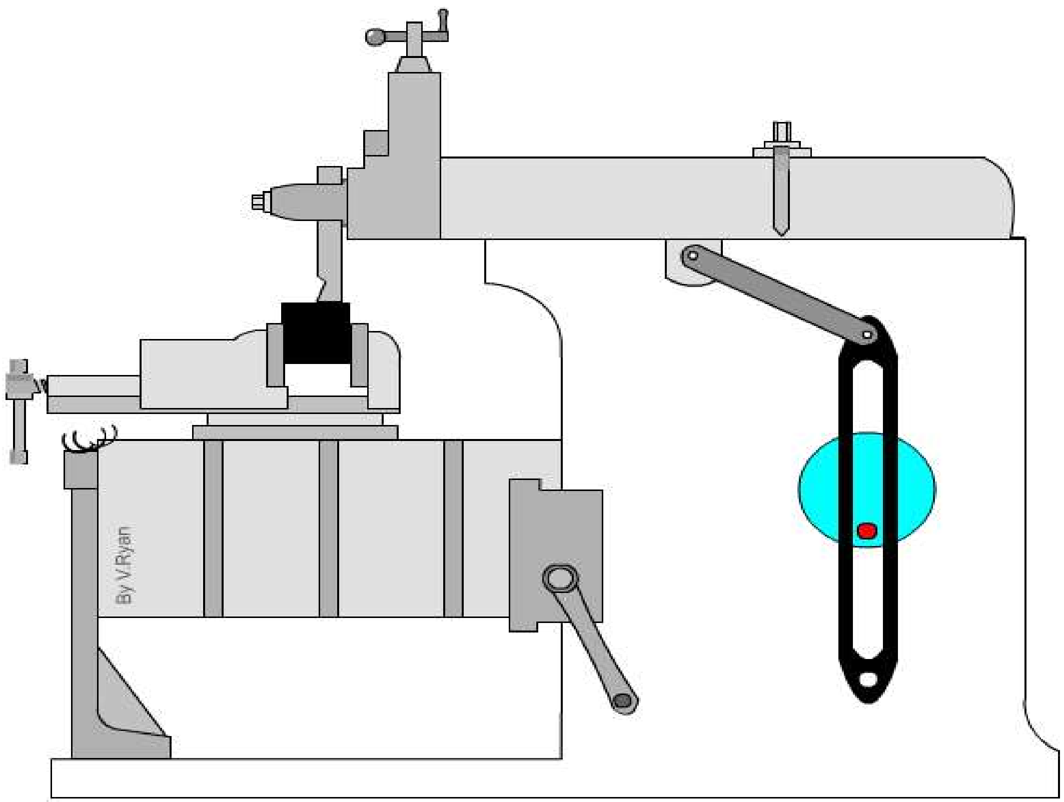


Fig. Oscillating cylinder engine.

Adjacent link of Small link is fixed-Second Inversion:



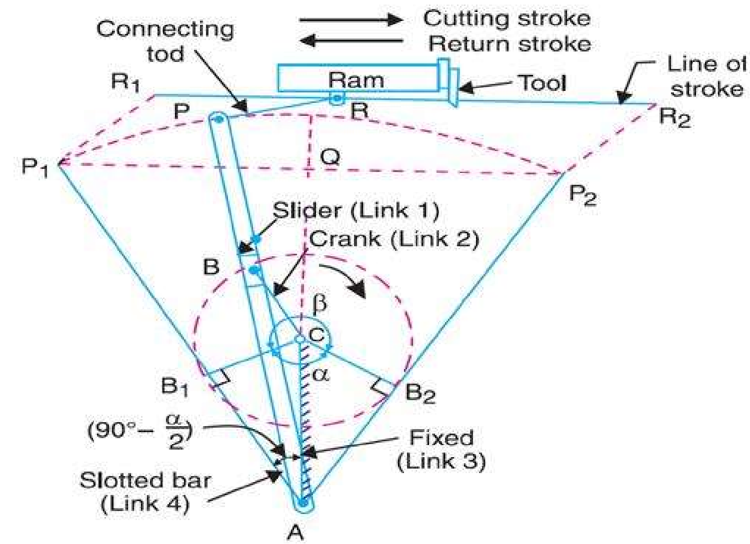
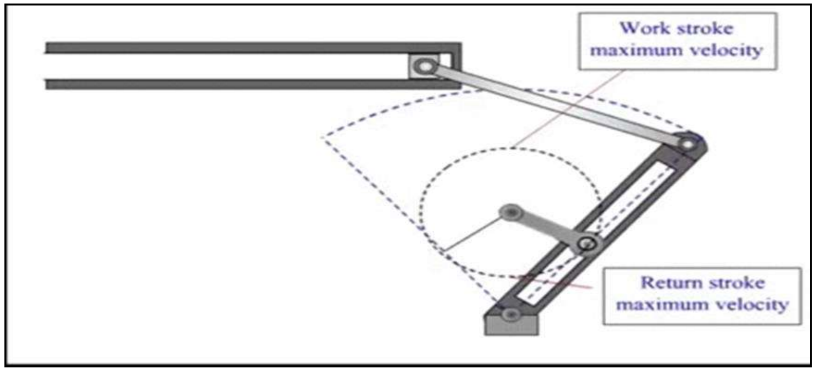


Fig. Crank and slotted lever quick return motion mechanism.



Opposite link of Small link is fixed- Third Inversion

***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. The mechanism is used in duplex pump in boilers, and also in manual hand pumps fitted on bore well.

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.

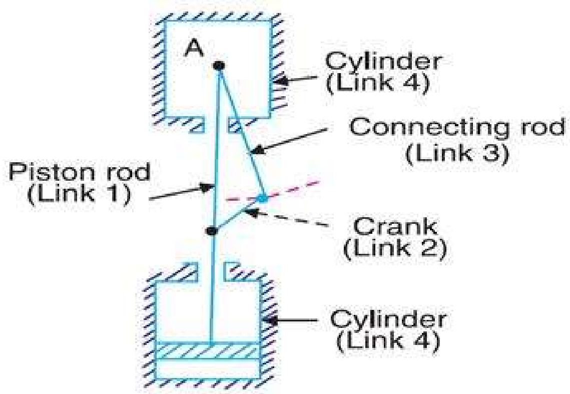
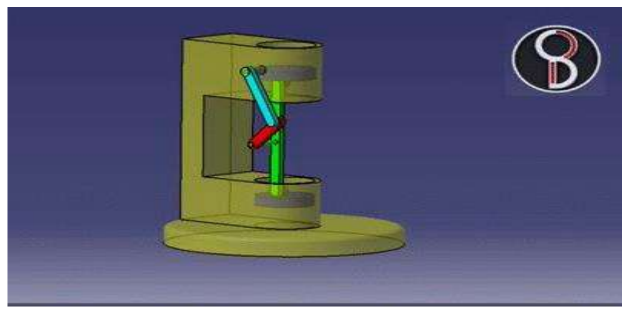
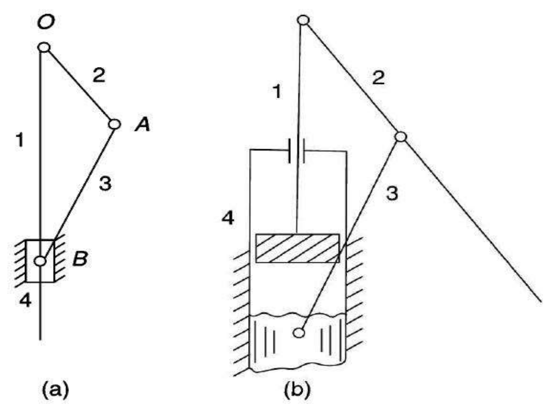
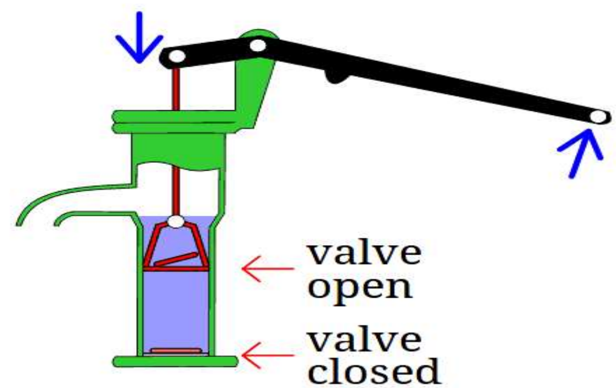


Fig. Pendulum pump.



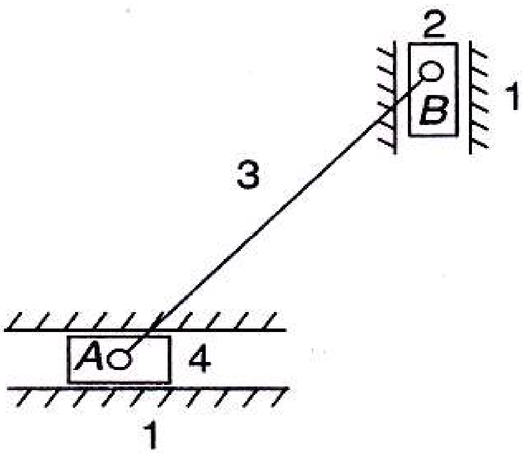
Another application- Hand Pump





Double slider crank chain:

- A four bar chain having two turning pairs and two sliding pairs.

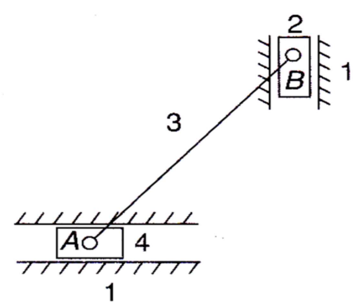


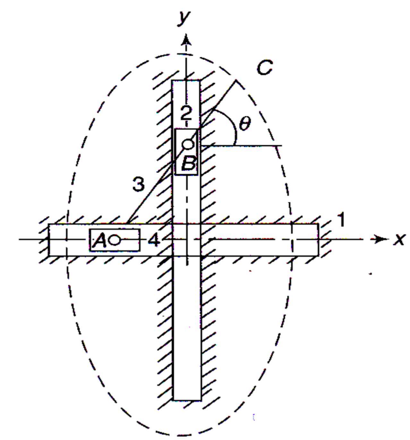
First Inversion-Link 1 is fixed

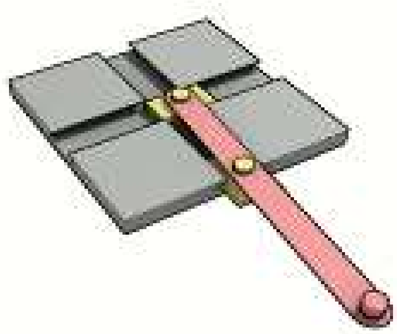
- Link 1 is fixed.
- Links 2,3 and 3,4 are connected by turning pairs.
- Links1,2 and 4,1 are sliding pairs.

Application

1.Elliptical Trammel



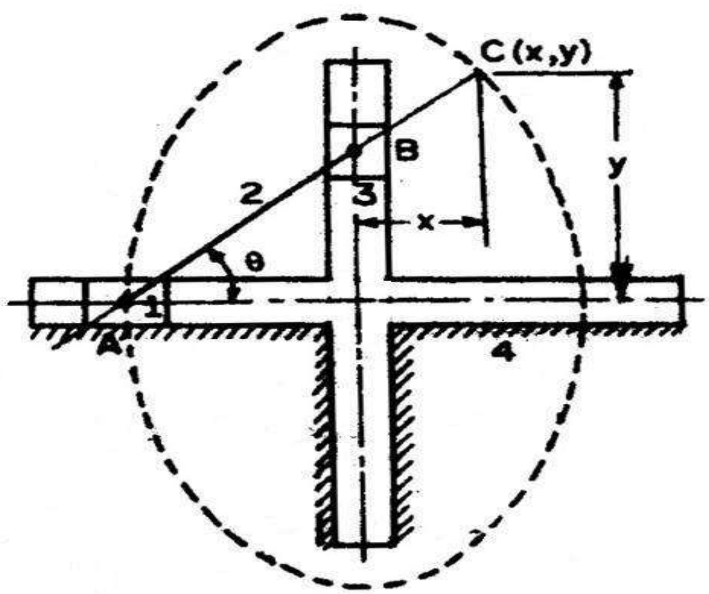




Elliptical trammel:

AC = p and BC = q, then, $x = q.\cos\theta$ and $y = p.\sin\theta$.
Rearranging,

$$\left(\frac{x}{q}\right)^2 + \left(\frac{y}{p}\right)^2 = \cos^2\theta + \sin^2\theta = 1$$



Second Inversion:

If any of the slide-blocks of the first inversion is fixed, the second inversion of the double-slider-crank chain is obtained. When the link 4 is fixed, the end *B* of the crank 3 rotates about *A* and the link 1 reciprocates in the horizontal direction.

Application Scotch yoke

Scotch Yoke A scotch-yoke mechanism (Fig.) is used to convert the rotary motion into a sliding motion. As the crank 3 rotates, the horizontal portion of the link 1 slides or reciprocates in the fixed link 4.

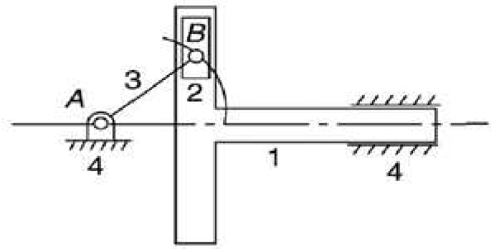
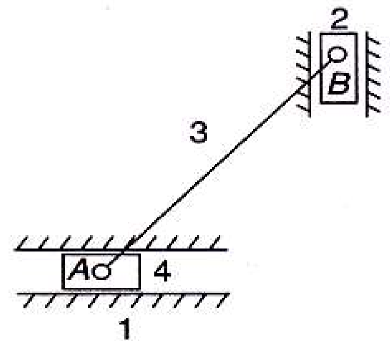
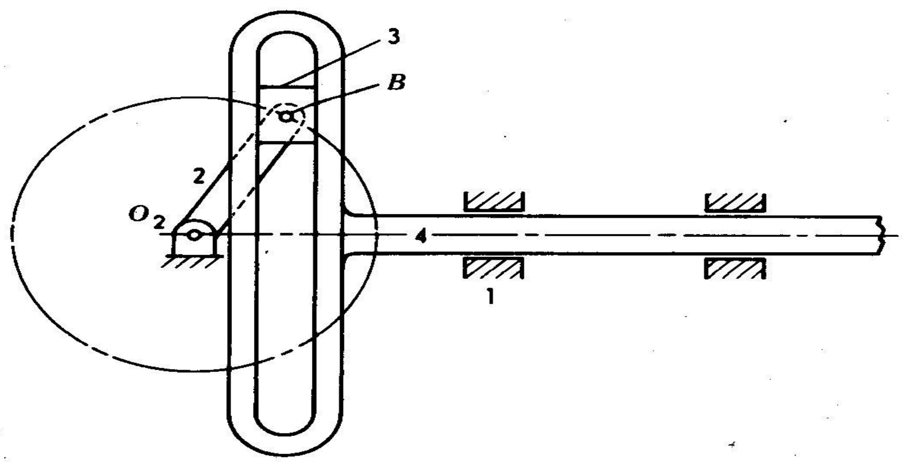
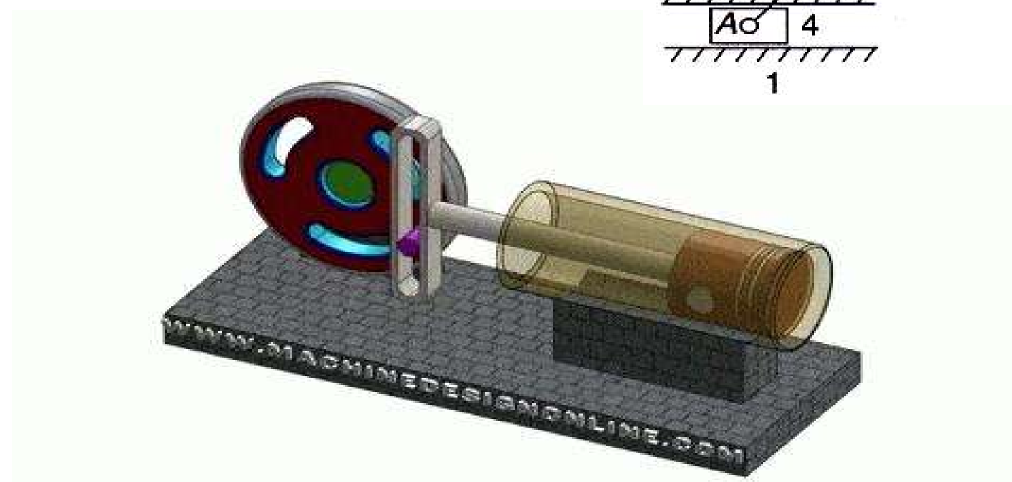


Fig.







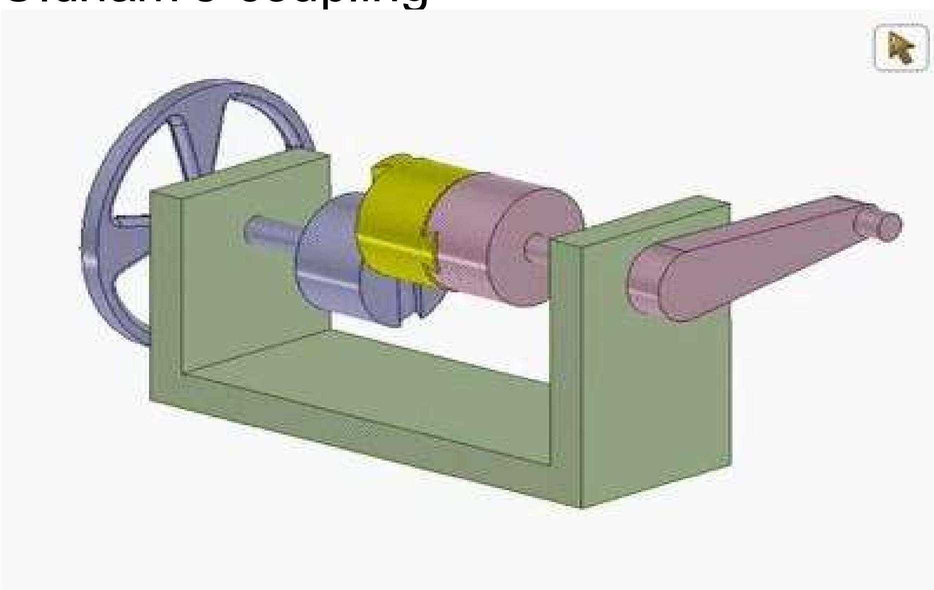
The **Scotch yoke mechanism** is most commonly used in control valve actuators in high-pressure oil and gas pipelines, as well as in various internal combustion engines,

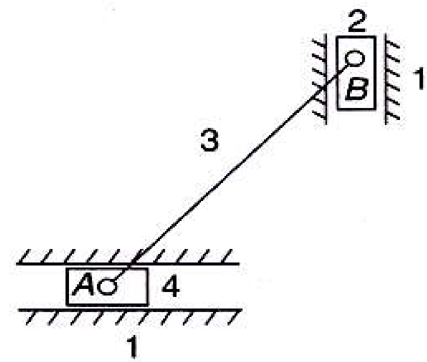
Third Inversion:

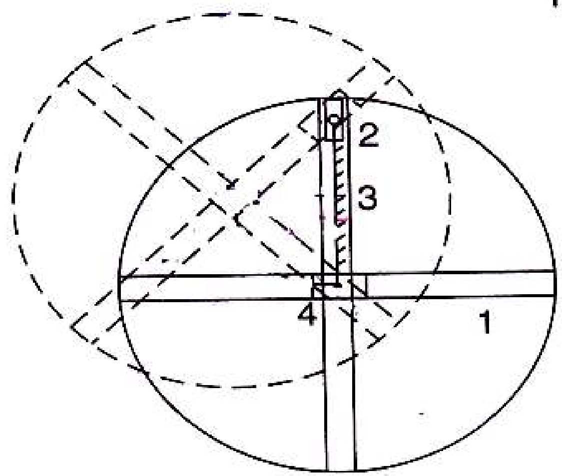
Link ‘3’ of the first inversion is fixed.
Link ‘1’ is free to move.
Link ‘2’ and link ‘4’ can rotate about their own axis.

Application

Oldham’s coupling





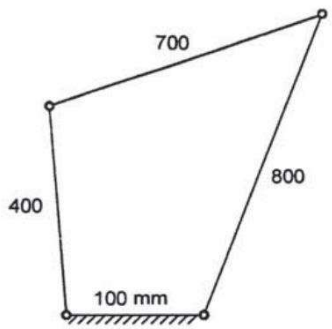


Oldham couplings are three-piece flexible shaft couplings that are used to connect driving and driven shafts in mechanical power transmission assemblies. Flexible shaft couplings are used to counter the inevitable misalignment that occurs between connected shafts and, in some cases, to absorb shock.

- An **Oldham coupling** is used to transfer torque between two parallel but not collinear shafts.
- It has three discs, one coupled to the input, one coupled to the output, and a middle disc that is joined to the first two by tongue and groove. The tongue and groove on one side is perpendicular to the tongue and groove on the other.
- The coupler is named for **John Oldham** who invented it in Ireland, in 1820, to solve a paddle placement problem in a steamship design.
- The middle disc rotates around its center at the same speed as the input and output shafts.
- Its center traces a circular orbit, twice per rotation, around the midpoint between input and output shafts.

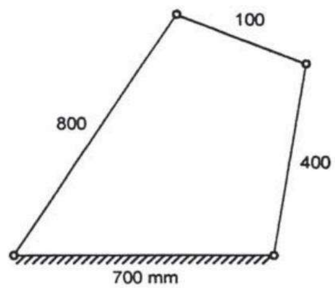
Second Inversion:

Identify the nature of the mechanisms shown



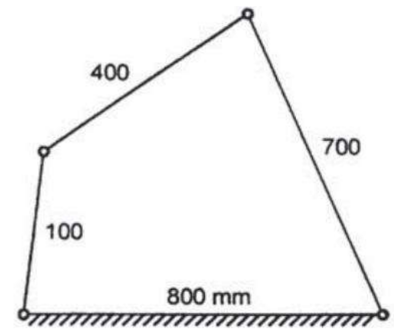
shortest link is fixed

crank-crank mechanism



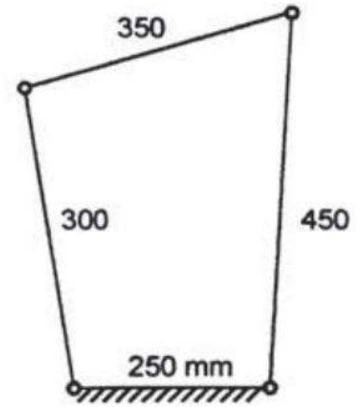
opposite to the shortest link

rocker-rocker



adjacent to the shortest link

crank-rocker mechanism



rocker-rocker mechanism of class-II