Theory of Machines

1. 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 machine, and forces which act on them. The knowledge of this subject is very essential for an engineer in designing the various parts of a machine.

1.1 Sub- divisions of theory of Machines:

They Theory of Machines may be sub- divided into the following four branches:

1.1.1. Statics: is that branch of theory of machines which deals with the forces and their effects, while the machine parts are rest. The mass of the pans is assumed to be negligible and the time is not a factor.

1.1.2. Kinematics: is that branch of theory of machines which is responsible to study the motion of bodies without reference to the forces which are cause this motion, i.e it's relate the motion variables (displacement, velocity, acceleration) with the time. Another defines (*Kinematics.* It is that branch of Theory of Machines which deals with the relative motion between the various parts of the machines)

1.1.3. Kinetics: is that branch of theory of machines which is responsible to relate the action of forces on bodies to their resulting motion. (*Kinetics.* It is that branch of Theory of Machines which deals with the inertia forces which arise from the combined effect of the mass and motion of the machine parts).

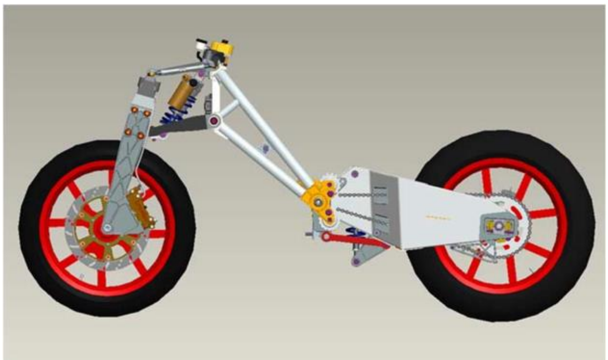
1.1.4. Dynamics: is that branch of theory of machines which deals with the forces and their effects, while acting upon the machine parts in motion.

1.1.5. Rigid Body: is that body whose changes in shape are negligible compared with its overall dimensions or with the changes in position of the body as a whole, such as rigid link, rigid disc…. etc.

1.1.6. Mechanism: is a combination of rigid bodies which are formed and connected together by some means, so that they are moved to perform some functions, such as the crank- connecting rod mechanism of the I.C. engines, steering mechanisms of automobiles……. etc.

1.1.7. Machine: An apparatus for applying mechanical power, consisting of a number of interrelated parts (links) each having a definite function. [machine =receive energy and transforms it into useful work**].**

Bicycle is a simple example of a kinematic system that contains a chain drive to provide Torque.



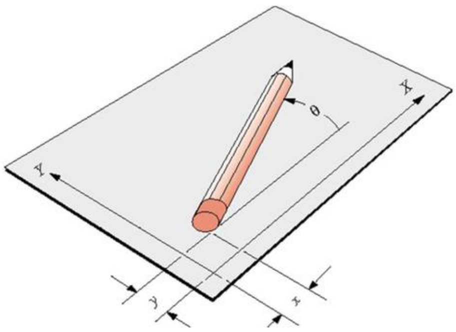
1.1.8. Structure:

Is an assemblage of resistant bodies which are not kinematic links because there is no relative motion between the links. There is only straining action due to forces acting on them for example trusses roof.

2- Degrees of freedom (DOF) or mobility:

Number of **independent** parameters (measurements) needed to uniquely define position of a system in space at any instant of time.

a) Rigid body in a plane has 3 DOF: x,y,z.



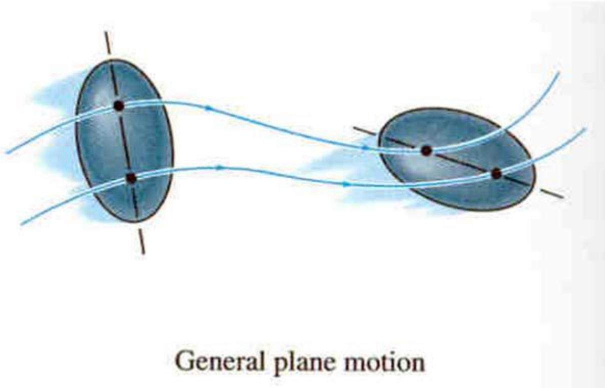
b) Rigid body in 3D-space has 6 DOF, 3 translations & 3 rotations, **three lengths** (x, y, z), plus **three angles** (θ, φ, ρ). The pencil in these examples represents a **rigid body**, or **link**.

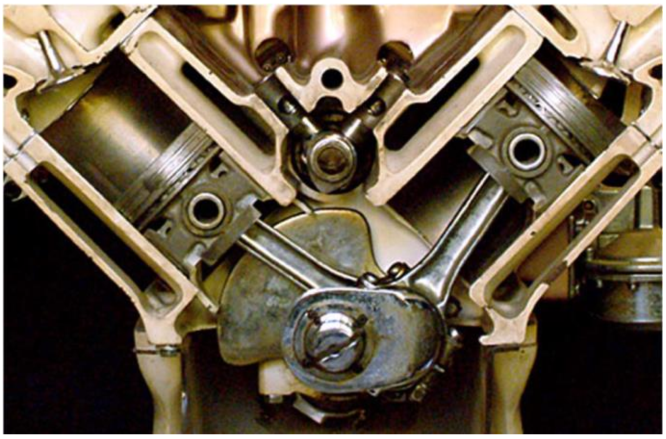
2.1 Types of Motion

a) Pure rotation: the body possesses one point (center of rotation) that has no motion with respect to the "stationary" frame of reference. All other points move in circular arcs.

b) Pure translation: all points on the body describe parallel (curvilinear or rectilinear) paths.

c) Complex motion: a simultaneous combination of rotation and translation.





2.2 **Linkage design**

1) Linkages are the basic building blocks of all mechanisms.

2) All common forms of mechanisms (cams, gears, belts, chains) are in fact variations on a common theme of linkages.

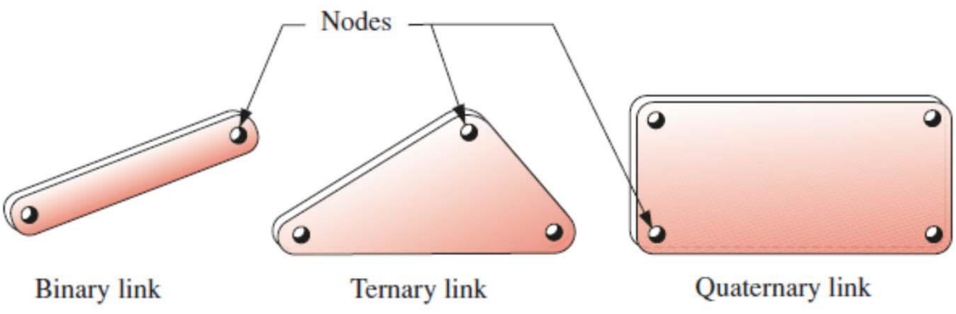
3) Linkages are made up of links and joints.

2.2.1 mechanical Links

are rigid bodies each having hinged holes or slot to be connected together by some means to constitute a mechanism which able to transmit motion or forces to some another location.

a). From geometric point of view the links can be divided to the following types:

1. Binary link. 2. Ternary link. 3. Quaternary link.



b) In order to transmit motion

The driver and the follower may be connected by the following three types of links:

a. Rigid link

A rigid link is one which does not undergo any deformation while transmitting motion. Strictly speaking, rigid links do not exist. However, as the deformation of a connecting rod, crank etc. of a reciprocating steam engine is not appreciable, they can be considered as rigid links.

b. Flexible link

A flexible link is one which is partly deformed in a manner not to affect the transmission of motion. For example, belts, ropes, chains and wires are flexible links and transmit tensile forces only.

c. Fluid link

A fluid link is 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.

2.2.2 mechanical joint

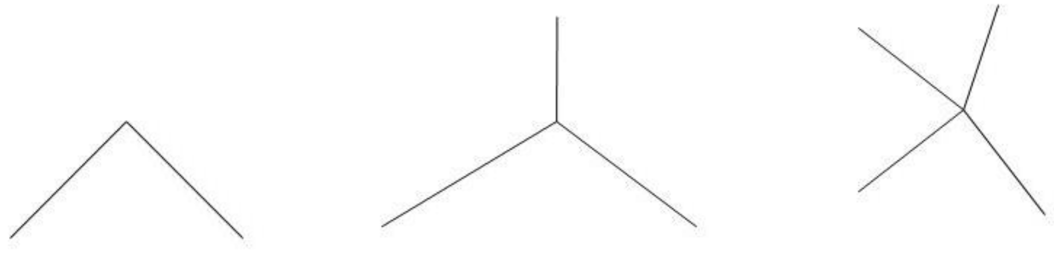
Is a section of a machine which is used to connect one or more **mechanical** part to another. Most mechanical joints are designed to allow relative movement of these mechanical parts of the machine in one degree of freedom.

2.2.3 Types of mechanical joint

a. Binary Joint: When two links are joined together at a connection the joint is known as binary joint.

b. Ternary Joint: When three links are joined together at a connection the joint is known as binary joint.

c. Quaternary Joint: When four links are joined together at a connection the joint is known as binary joint.



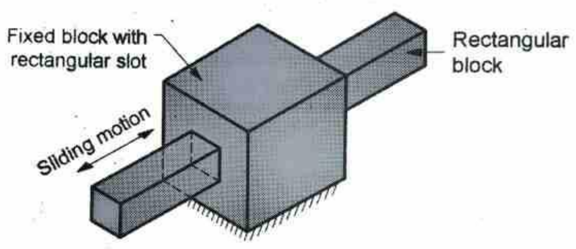
Binary joint   Ternary Joint   Quaternary Joint

(Joints also called kinematic pairs) can be classified in several ways.

2.3 Kinematic pair: A pair is a joint of two links that permits relative motion.

2.3.1 Classification of Kinematic Pairs

The kinematic pairs may be classified according to the following considerations:
I) According to the type of relative motion between the elements.
The kinematic pairs according to type of relative motion between the elements may be classified as discussed below;
(a) ***Sliding pair***.
As the name suggests, a sliding pair is a kinematic pair in which each element has sliding contact with respect to the other element. Some good examples of sliding pairs are piston inside a cylinder, spur gear drive and square bar in a square hole.

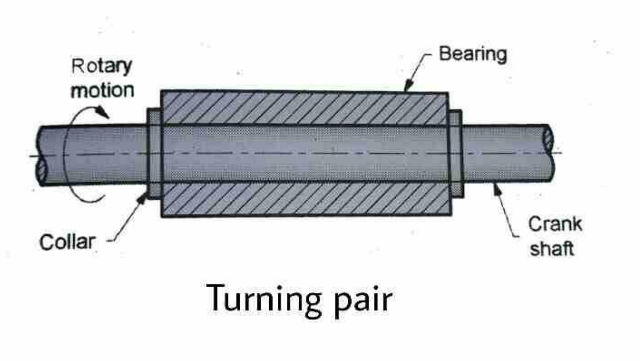


Sliding pair

(b) ***Rolling pair***
In a rolling pair, one element undergoes rolling motion with respect to the other.

(c) Turning pair

In a one link undergoes turning motion relative to the other link. Example is a shaft with collars in a circular hole.

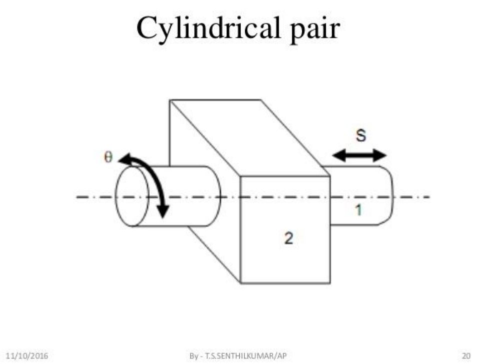


(d) screw pair

A screw pair Consists of links that have both turning and sliding motion relative to each other.

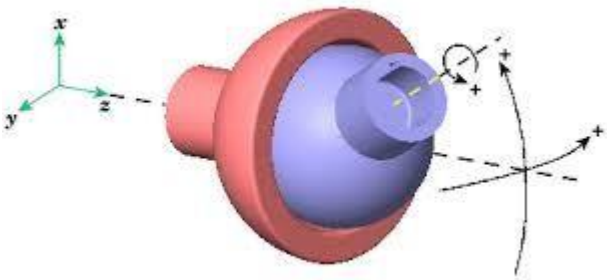
(e) Cylindrical Pair:

A cylindrical pair is a kinematic pair in which the links undergo both rotational and translational motion relative to one another.



(f) Spherical pair.

In a spherical pair, a spherical link turns inside a fixed link.



II) According to the type of contact between the elements.

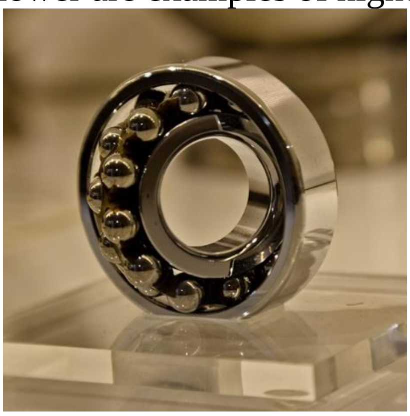
The kinematic pairs according to the type of contact between the elements may be classified as discussed below:

(a)Lower pair.

A kinematic pair is said to be a lower pair if the links in the pair have surface or area contact between them

(b)Higher pair.

A higher pair is a kinematic pair in which the links have point or line contact. Ball bearings, cam and follower are examples of higher pair.



*C. **According to the type of mechanical constraint (or mechanical contact**)*

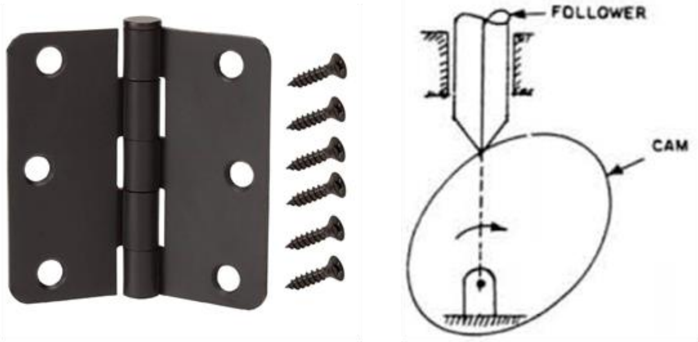
The kinematic pairs according to the type of closure between the elements may be classified as discussed below:

a) Self closed pair.

A pair is said to be self-closed if the links in the pair have direct mechanical contact, even without the application of external force.

b) Force Closed Pair

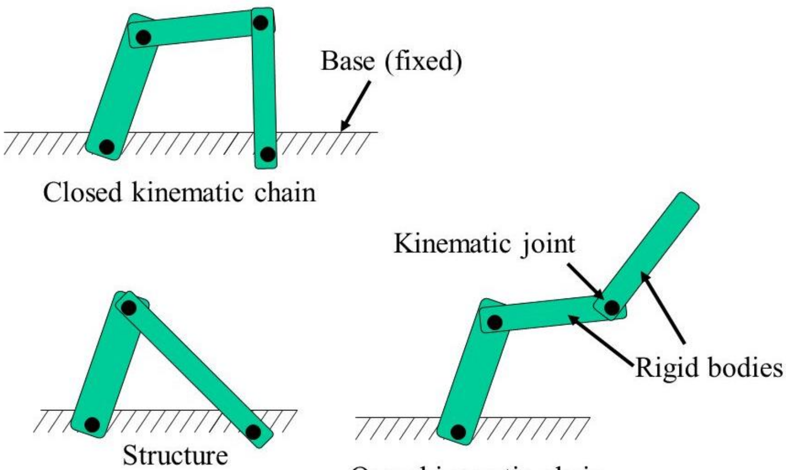
A kinematic pair is said to be force closed if the links in the pair are kept in contact by the application of external forces. A good example of this type of pair is ball and roller bearings



self closed pair force closed pair

2.4 chain:

Is an assemblage of kinematic pairs in which each link forms a pair of two kinematic pairs and the relative motion between the links is eithers completely constrained or successfully constrained, kinematic chain should provide predictable or controlled output motion in response to a supplied input motion. distal segment is fixed and the end of segments are unite to form ring or circuit. when one line moves all the other line will move in a predictable pattern.



When several links are connected together by joints, they are said to form a ***kinematic chine***. In other word when the ***kinematic pairs*** are coupled in such a way that the last link is joined to the first link to transmit definite motion it is called a ***kinematic chain***. For example, the crank shaft of an engine forms a kinematic pair with bearing which are fixed in a pair, the connecting rod with the crank forms a second kinematic pair, the piston with the connecting rod forms a third pair, and the piston with the cylinder forms the fourth pair. The total combination of these links is a ***kinematic chain.***

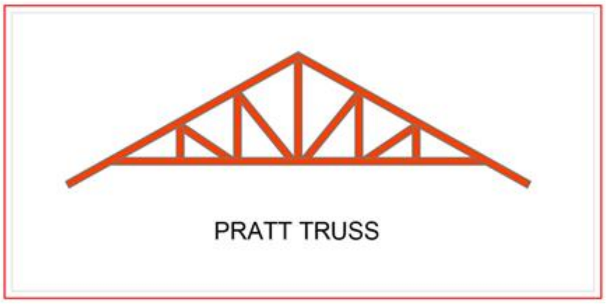
Type of chains.

can be classified into:

1.locked chain

Is also known as structure, locked chain forms a rigid farm (no relative motion between its members, they are mean for carrying load and used in bridges and trusses.

bridge



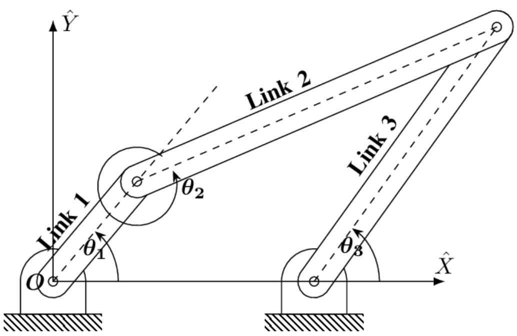
trusse

2.kinematic chain (KC)

Is an assembly of rigid bodies connected by joints to provide constrained (or desired) motion that is the mathematical model for a mechanical system.

In this chain, the relative motion between links well be completely or successfully constrained motion and well provide predictable or controlled output motion in response to a input motion.

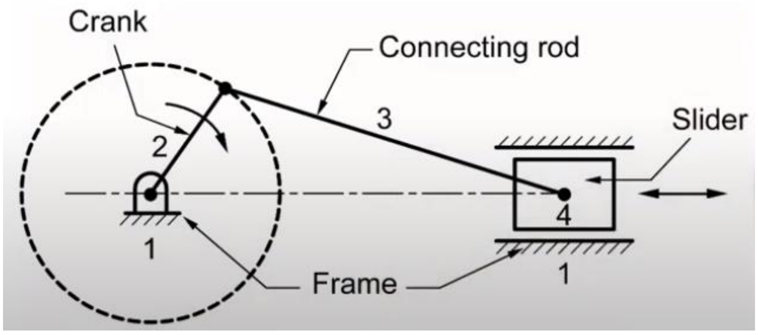
Four link chain forms a kinematic chain



The kinematic chain can be classified into:

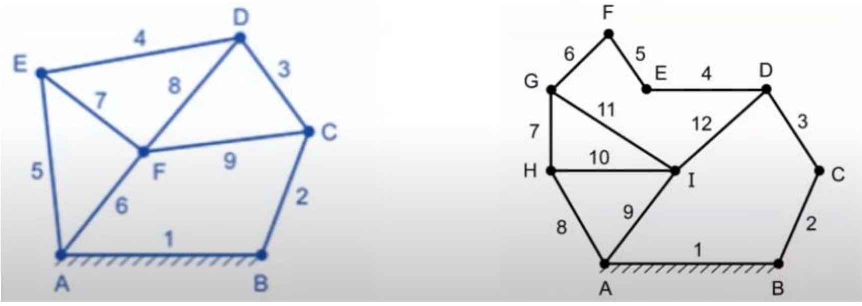
Based on number of links:

a) Simple kinematic chain (having four links)



Simple kinematic chain

b) Compound kinematic chain(having more than four)



Compound kinematic chain

Based on formation loop

a) closed kinematic chain

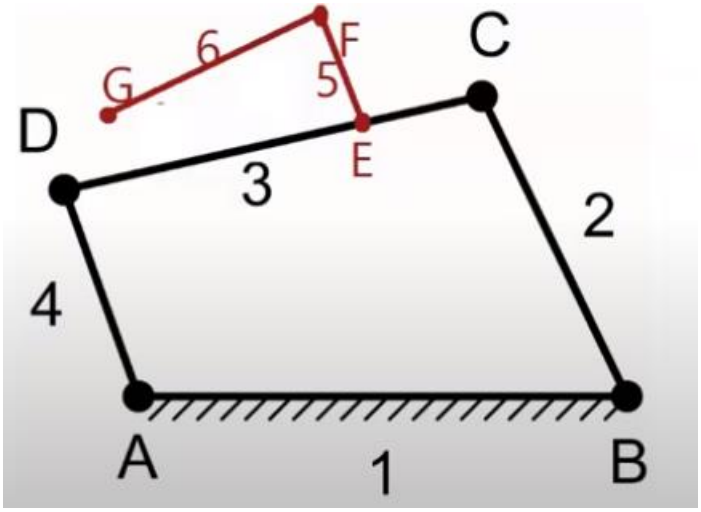
when links are connected in a sequence, with first link connected to the last link (forming a closed loop)

b) open kinematic chain

when links are connected in a sequence, with first link not connected to the last link(forming a closed loop)

c) hybrid kinematic chain.

Contains both open KC and closed KC.

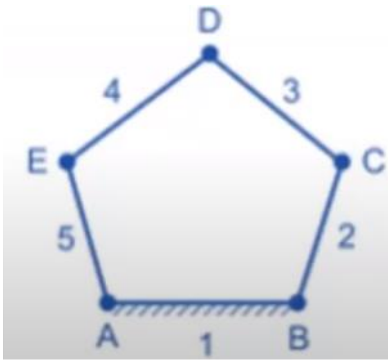


hybrid kinematic chain

3.non-kinematic chain (unconstrained chain)

Relative motion between links well be unconstrained motion, this type chain well not provide predictable or controlled output motion in response to a input motion.

Five link chain forms a non-kinematic chain



A.W.Klien's criterion of constrain to determine nature of chain

The required condition to form KC:

$$j + \frac{h_p}{2} = \frac{3}{2} \cdot l - 2$$

$$j = j_1 + 2 \cdot j_2 + 3 \cdot j_3$$

Where is : ***j*** is a total join in kinematic chain, $\boldsymbol{j_1}$ is binary joint in the kinematic chain, $\boldsymbol{j_2}$ is ternary joint in the kinematic chain, $\boldsymbol{j_3}$ is a quaternary joint in the kinematic chain, ***l*** number of link, **hp** number of higher pair

A.W.Klien's criterion of constrain is used to determine the nature of chain i.e. whether the chain is:

A locked chain (i.e. structure), or a constrained (i.e. kinematic) chain or an unconstrained chain.

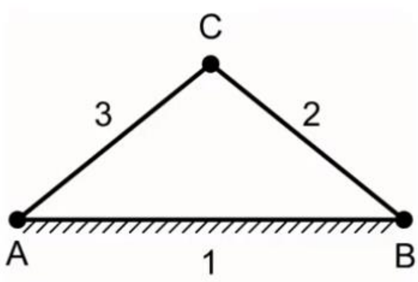
$$if\ L.H.S > R.H.S\ then\ given\ chain\ is\ called\ locked\ chainor\ structure$$

$$if\ L.H.S = R.H.S\ then\ given\ chain\ is\ called\ constrained\ or\ kinematic\ chain$$

$$if\ L.H.S < R.H.S\ then\ given\ chain\ is\ called\ unconstrained\ or\ non - kinematic\ chain$$

Examples

1. The arrangement of three links shown with pin joint

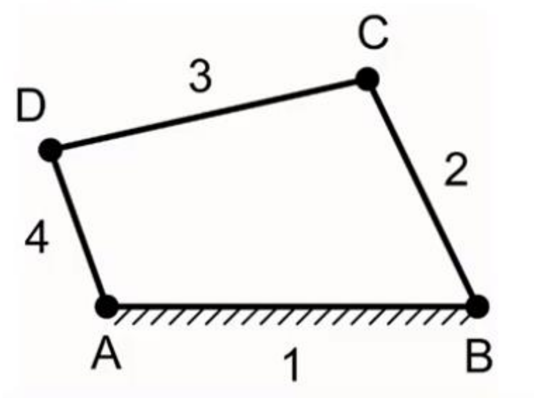


as A, B, C
Solution:
l= 3, hp=0, j=3
from kinematic equations

$$j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 3 + 2 \cdot 0 + 3 \cdot 0 = 3$$
$$j + \frac{h_p}{2} = \frac{3}{2} \cdot l - 2 \xrightarrow{yields} 3 + 0 = \frac{3}{2} \cdot 3 - 2$$
$$3 \neq 2.5 \xrightarrow{yields} L.H.S > R.H.D$$

Since L.H.D>R.H.S then given chain is called locked chain or structure

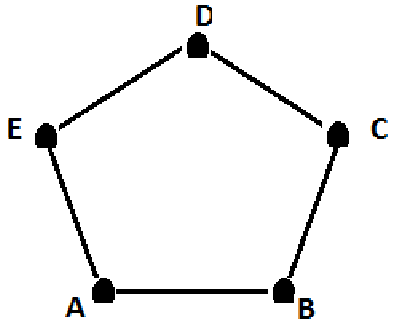
2.The arrangement of four link with pin joint A, B, C, D as shown:



Solution:
l= 4, hp=0, j=4

$$j + \frac{h_p}{2} = \frac{3}{2} \cdot l - 2 \xrightarrow{yields} 4 + 0 = \frac{3}{2} \cdot 4$$
$$4 = 4 \xrightarrow{yields} L.H.S = R.H.D$$

Since L.H.D=R.H.S then given chain is a constrained or kinematic chain.
3.The arrangement of five links with pin joint A, B, C, D, and E as shown:



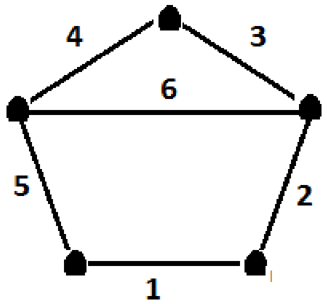
Solution:
l= 5, hp=0, j=5

$$j + \frac{h_p}{2} = \frac{3}{2} \cdot l - 2 \xrightarrow{yields} 5 + 0 = \frac{3}{2} \cdot 5 - 2$$

$$5 < 5.5 \xrightarrow{yields} L.H.S = R.H.D$$

Since L.H.D<R.H.S then given chain is a unconstrained or non-kinematic chain.

4. The arrangement of six links with pin joint 1-6 as shown:

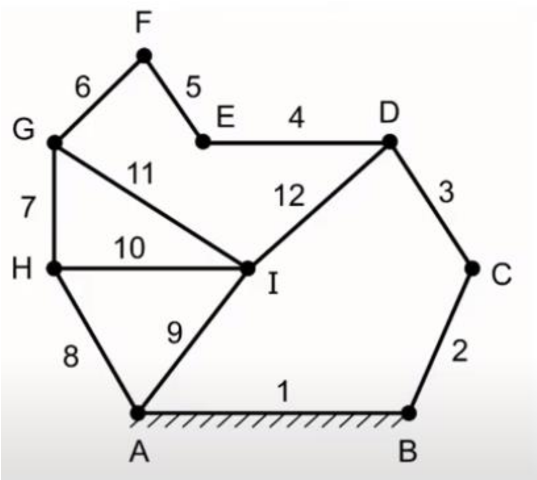


Solution:
l= 6, hp=0, j= 7

$$j + \frac{h_p}{2} = \frac{3}{2} \cdot l - 2 \xrightarrow{yields} 7 + 0 = \frac{3}{2} \cdot 6 - 2$$

$$7 = 7 \xrightarrow{yields} L.H.S = R.H.D$$

Since L.H.S=R.H.S then given chain is a constrained or kinematic chain.
*5.*The arrangement of 12 links with pin joint 1-12 as shown:



Solution:
l= 12, hp=0,
number of binary joints is=4(at B, C,E,F) points
number of ternary joints =4(at D,G,H,A)
number of quaternary joints =1(at I)

$$j = 4 + 4 \cdot 2 + 3 = 15$$

$$j + \frac{h_p}{2} = \frac{3}{2} \cdot l - 2 \xrightarrow{yields} 15 + 0 = \frac{3}{2} \cdot 12 - 2$$

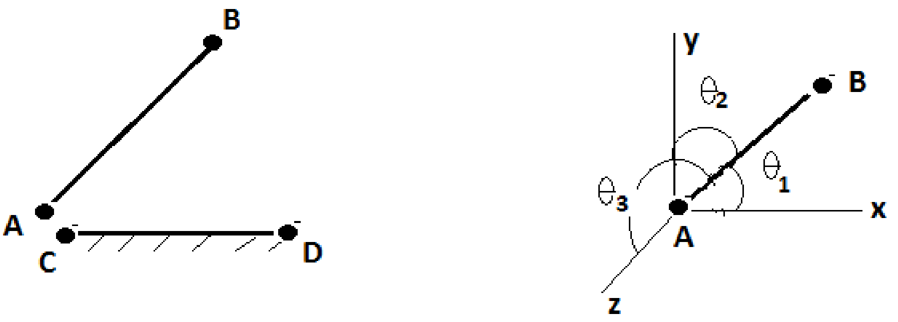
$$15 < 16 \xrightarrow{yields} L.H.S < R.H.D$$

Since L.H.D<R.H.S then given chain is a unconstrained or non-kinematic chain.

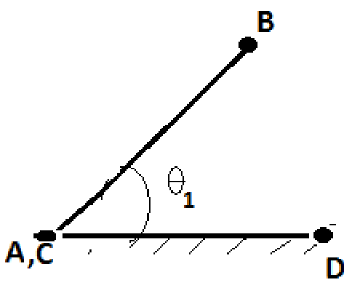
2.5 Mobility or Number of Degrees of freedom for plane Mechanisms:

In the design or analysis of mechanism, one of the most important concern is the number of degrees of freedom (also called move-ability) of the mechanism. It is defined *as number of input parameters(pair) which must be independently controlled in order to bring the mechanism into a useful engineering purpose*.

Each link of mechanism has three degrees of freedom before it is connected to any other link, as shown in figure below:



(a) Before connected
3DOF



(b) After conncted o
1 DOF

From above we see that when a link is connected to a fixed link by a turning pair two degree of freedom are destroyed.

Generally, the number of degrees of freedom can be calculated from (Kutzbach criterion) as:

$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p$$

where:

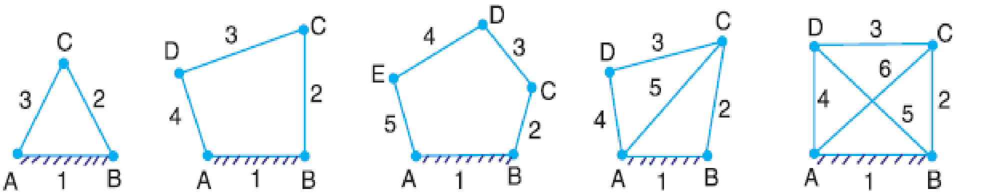
n numbers of degree of freedom.
l numbers of links.
L_p *numbers of lower pair=j(number of the binary joints.*
h_p *numbers of higher pair.*

If there is no higher pair (h_p) so, equation (3) can be written as:

$$n = 3 \cdot (l - 1) - 2 \cdot L_p$$

If n=0 , the drives is statically determinate structure.
If n>=1, the drives is a mechanism having constrained motion.
If n<0, the drives is statically indeterminate structure.

Ex1: A number of degrees of freedom (n) for some simple mechanisms having no higher pair (h_p=0) can be shown as following:



(*a*) Three-bar mechanism. (*b*) Four bar mechanism. (*c*) Five bar mechanism. (*d*) Five bar mechanism. (*e*) Six bar mechanism.

Figure (3) Plan Mechanism

a) l=3, L_p=3

$$n = 3(3-1) - 2 \cdot 3 = 0$$

This mechanism forms a structure.

b) l=4, L_p =4

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

It can be driven by single input motion.

c) l=5, L_p =5

$$n = 3(5-1) - 2 \cdot 5 \ = \ 2$$

Two independent input motion are necessary to produce useful motion.

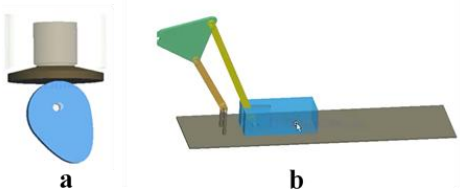
d) l=5, L_p =6

$$n = 3(5-1) - 2 \cdot 6 \ = \ 0$$

e) l=6, L_p =8

$n = 3(6-1) - 2 \cdot 8 \ = \ -1$ (*It mean that the mechanism is redundant constraint in the chain.)*

Ex2: A number of degrees of freedom for mechanism with higher pair ($h_p \neq 0$).



a) l=3, L_p =2, h_p =1

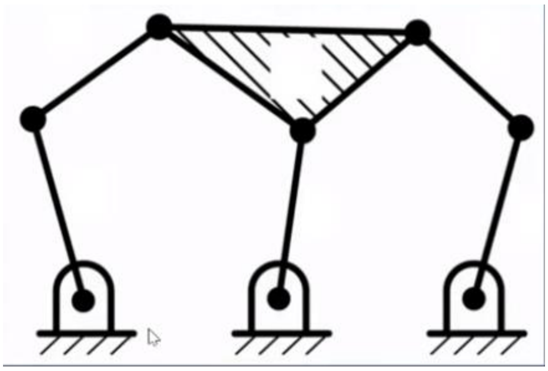
$$n = 3 \cdot (l-1) - 2 \cdot L_p - h_p$$
$$n = 3(3-1) - 2 \cdot 2 - 1 = \ 1$$

Ex3: A number of degrees of freedom for mechanism with higher pair (h_p =0).

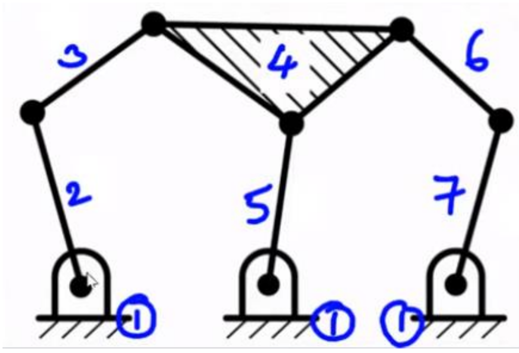
b) l=5, L_p =5, h_p =0

$$n = 3 \cdot (l-1) - 2 \cdot L_p - h_p$$
$$n = 3(5-1) - 2 \cdot 5 = \ 2$$

Ex4. Determine DOF follow system drive:



Solution



l= 7,

$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 8 + 2 \cdot 0 + 3 \cdot 0 = 8$$

$$L_p = 8$$

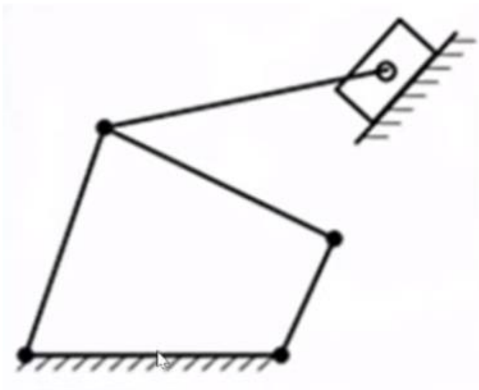
$$h_p = 0$$

$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p$$

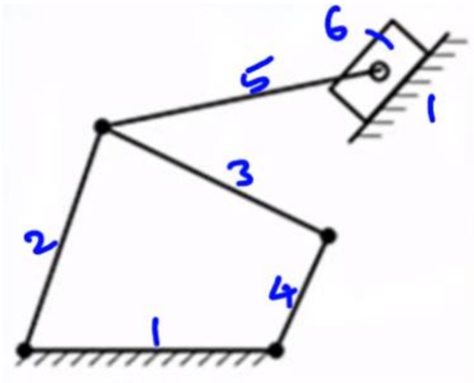
$$n = 3 \cdot (7 - 1) - 2 \cdot 8 - 0 = 18 - 16 = 2$$

$n = 2$(the drives is a mechanism having constrained motion)

Ex5. Determine DOF follow system drive:



Solution



l= 6,

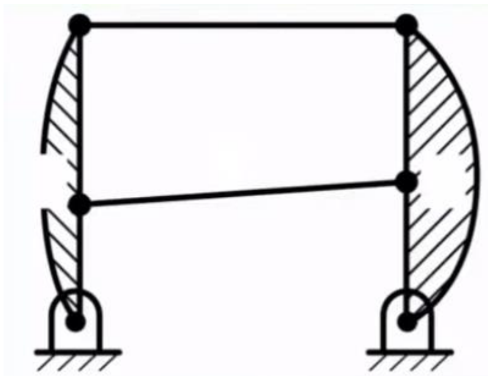
$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 5 + 2 \cdot 1 + 3 \cdot 0 = 7$$

hp=0

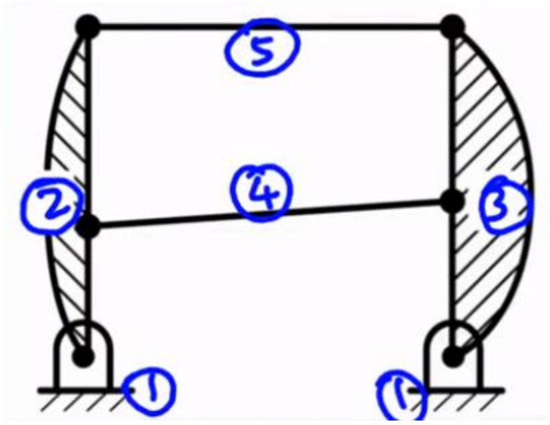
$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (6 - 1) - 2 \cdot 7 - 0 = 1$$

$n = 1$(the drives is a mechanism having constrained motion)

Ex6. Determine DOF follow system drive:



Solution



l= 5,

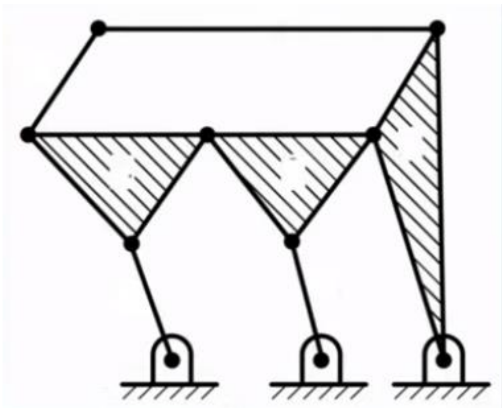
$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 6 + 2 \cdot 0 + 3 \cdot 0 = 6$$

hp=0

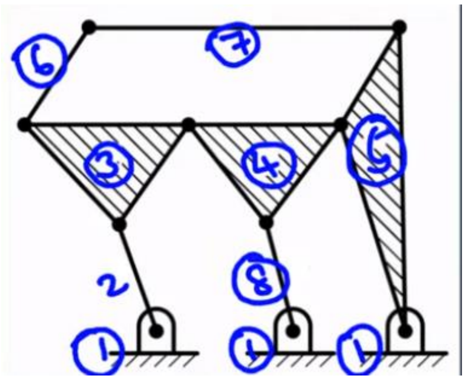
$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (5 - 1) - 2 \cdot 6 - 0 = 0$$

n =0(the drives is statically determinate structure)

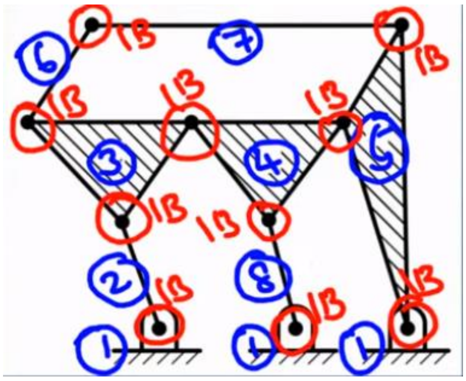
Ex7. Determine DOF follow system drive:



Solution



l= 8,



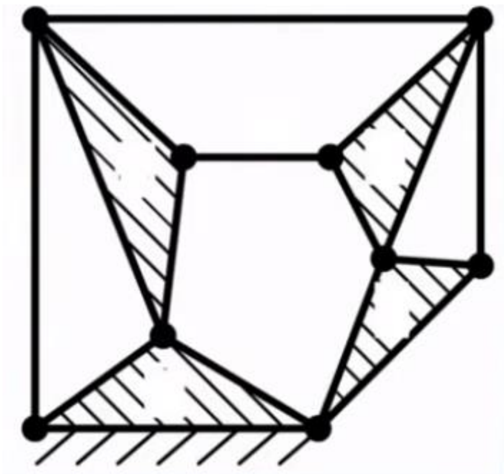
$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 10 + 2 \cdot 0 + 3 \cdot 0 = 10$$

hp=0

$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (8 - 1) - 2 \cdot 10 - 0 = 1$$

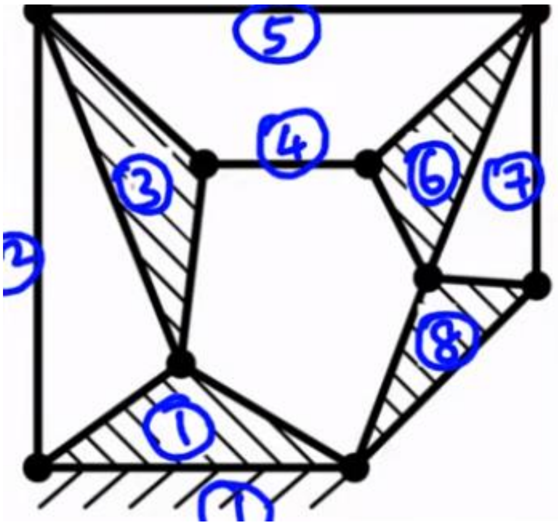
n =1(the drives is a mechanism having constrained motion)

Ex8. Determine DOF follow system drive:



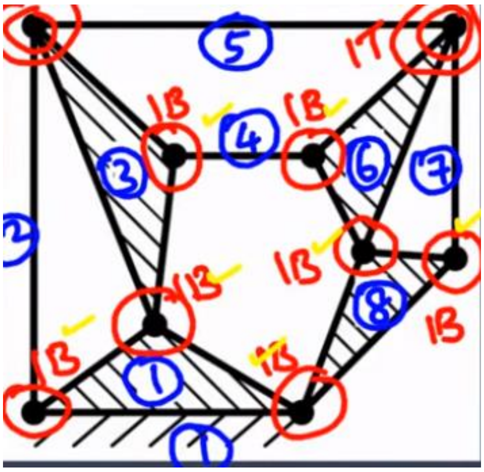
Solution

l= 8,

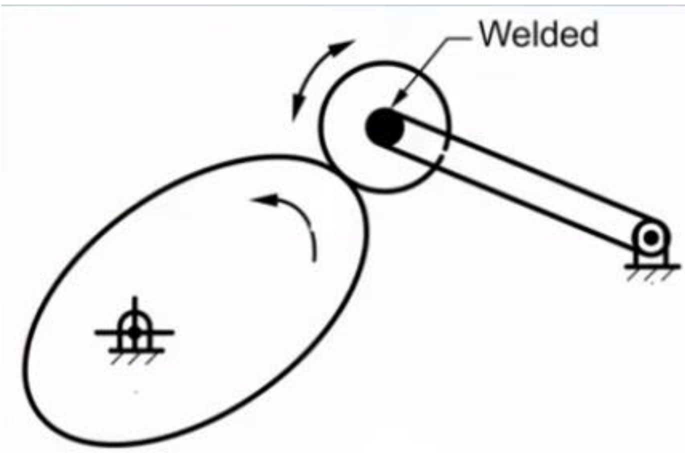


$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 7 + 2 \cdot 2 + 3 \cdot 0 = 11$$

$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (8 - 1) - 2 \cdot 11 - 0 = -1$ (the drives is statically indeterminate structure.)

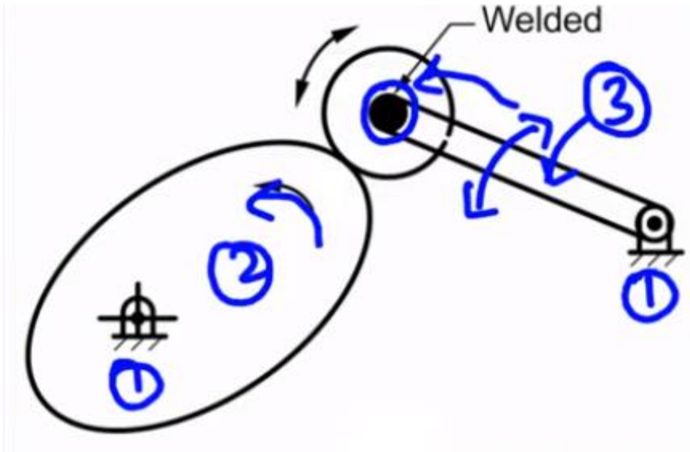


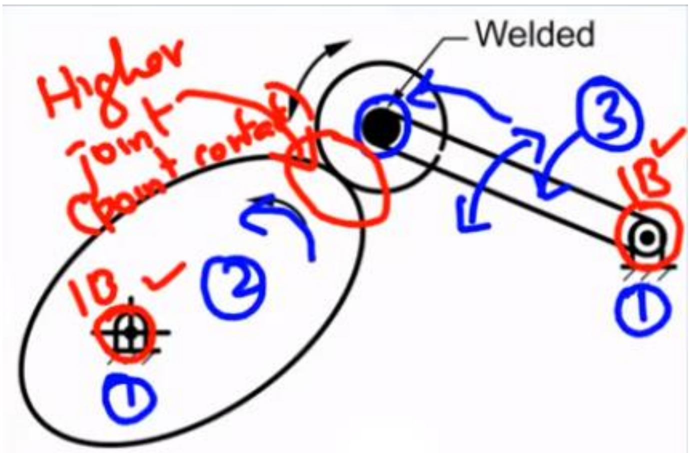
Ex9. Determine DOF follow system drive:



Solution

l= 3,



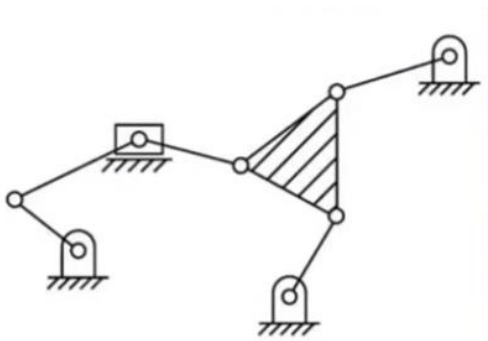


$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 2 + 2 \cdot 0 + 3 \cdot 0 = 2$$

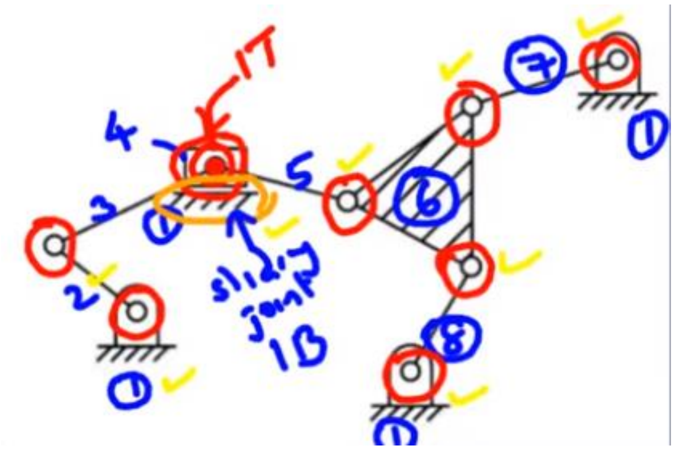
$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (3 - 1) - 2 \cdot 2 - 1 = 1$$

$n = 1$, (the drives is a mechanism having constrained motion)

Ex10. Determine DOF follow system drive:



l= 8,

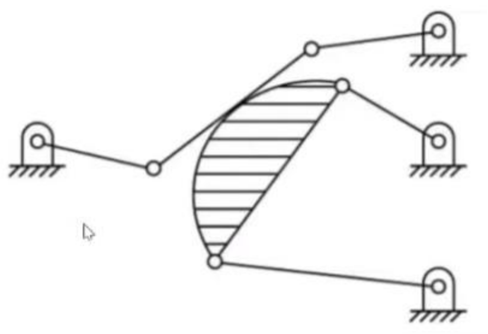


$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 8 + 2 \cdot 1 + 3 \cdot 0 = 10$$

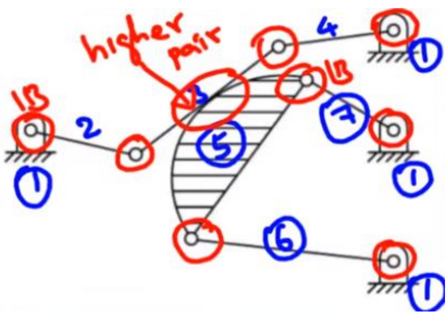
$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (8 - 1) - 2 \cdot 10 = 1$$

$n = 1$, (the drives is a mechanism having constrained motion)

Ex11. Determine DOF follow system drive:



l= 7,

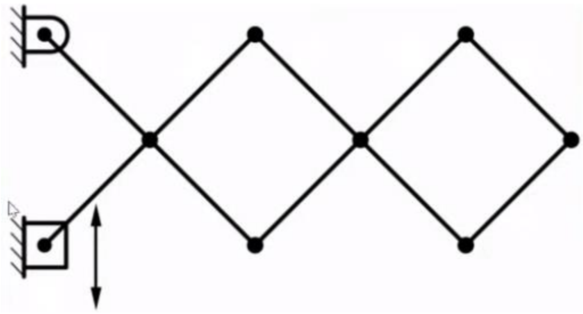


$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 8 + 2 \cdot 0 + 3 \cdot 0 = 8$$

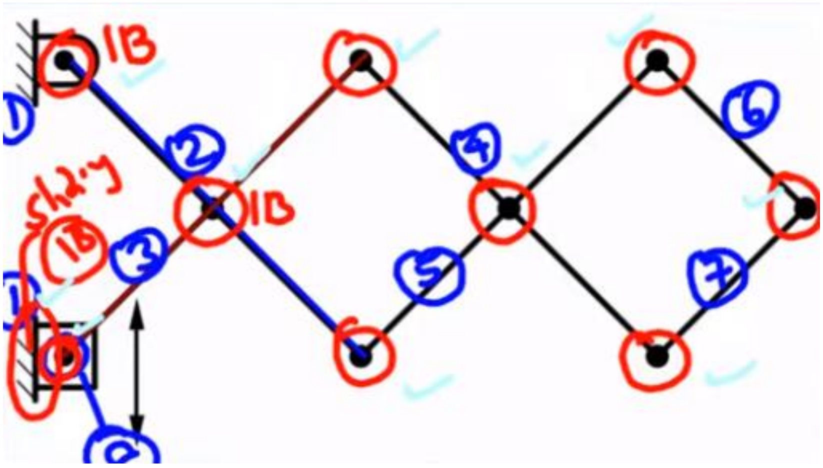
$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (7 - 1) - 2 \cdot 8 - 1 = 1$$

$n = 1$, (the drives is a mechanism having constrained motion)

Ex12. Determine DOF follow system drive:



l= 8,

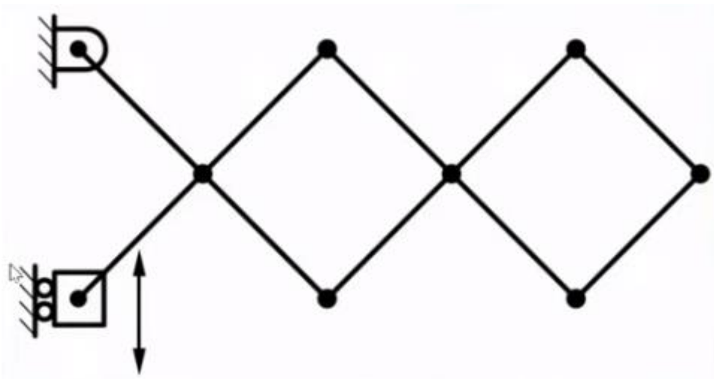


$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 10 + 2 \cdot 0 + 3 \cdot 0 = 10$$

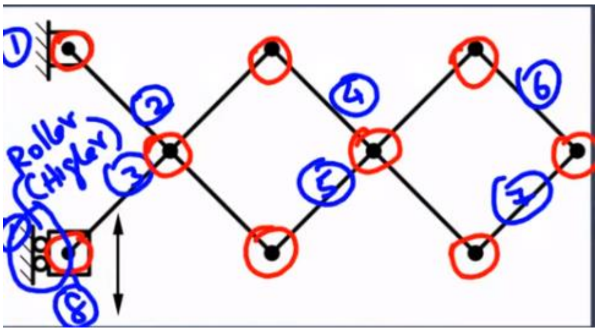
$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (8 - 1) - 2 \cdot 10 - 0 = 1$$

$n = 1$, (the drives is a mechanism having constrained motion)

Ex13. Determine DOF follow system drive:



l= 8,



$$L_p = j = j_1 + 2 \cdot j_2 + 3 \cdot j_3 \xrightarrow{yields} j = 9 + 2 \cdot 0 + 3 \cdot 0 = 9$$

$$n = 3 \cdot (l - 1) - 2 \cdot L_p - h_p = 3 \cdot (8 - 1) - 2 \cdot 9 - 1 = 2$$

n =2, (the drives is a mechanism having constrained motion)

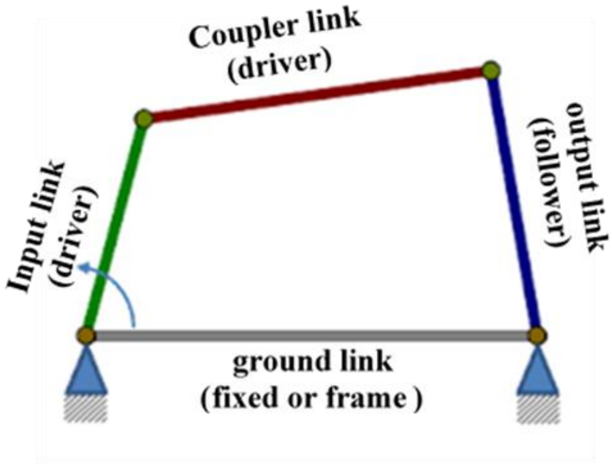
2.6 **Grashof criteria**

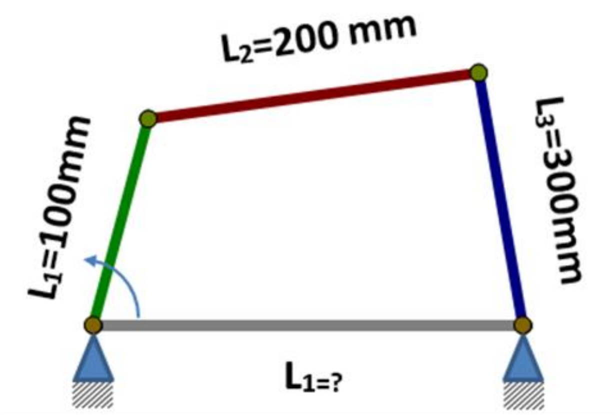
Grashof's criterion states that for a basic four bar mechanism if the sum of lengths of the shortest and the longest link is less than the sum of the other two link lengths then all types of inversions are possible.

Type mechanism	***Shortest mechanis***	***Relation***	Four bar mechani
Crank rocker	driver	$L_{min} + L_{max} < L_a +$	
Double crank (Drag link)	fixed		
Double rocker	coupler		
Cross position	Any link	$L_{min} + L_{max} = L_a +$	
Triple rocker	Any link	$L_{min} + L_{max} > L_a +$	

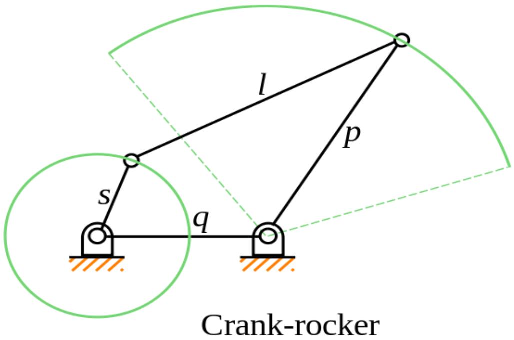
Example1:

From basic four bar mechanism (Figure below), depending on the **Grashof criteria**, Analyze and determine the value L_0 for all cases.





a) *crank rocker* (condition is driver to be shortness'**)**



Crank-rocker
$s+l < p+q$
(continuous motion)

1- If $L_0=L_{max}$ than

$$L_1 + L_0 < L_2 + L_3$$

$$100 + L_0 < 200 - 300 \xrightarrow{yields} L_0 < 400\, mm$$

Then crank rocker mechanism can be performed and continuous motion.

2- If L_0 intermediate

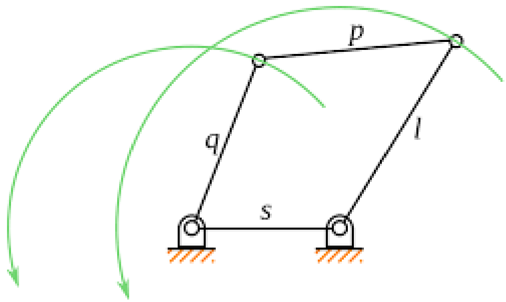
$L_0=L_2$ or L_3 (L_1 may be minimum because it is driver)

$$L_1 + L_3 < L_0 + L_3$$

$$100 + 300 < L_0 + 200 \xrightarrow{yields} L_0 > 200\, mm$$

Then crank rocker mechanism can be performed and continuous motion.

b) ***drag-link mechanism*** (The condition to be fixed link shortest ($L_0=L_{min}$))



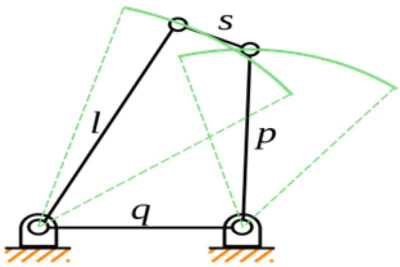
full revolution both links

Drag-link $s+l > p+q$ (continuous motion)

$$L_0 + 300 < 200 + 100 \xrightarrow{yields} L_0 < 0\ mm$$

Then NO change drag link mechanism can be performed and NO continuous motion

C) ***Double rocker mechanism*** (condition is coupler to be shortness



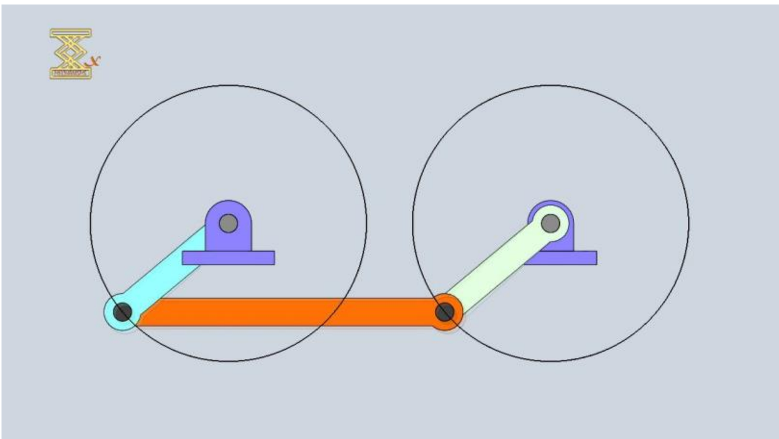
Double-rocker

$s+l > p+q$

(no continuous motion)

Of the data is L1=100 mm < L2 (along coupler), then no change double rocker mechanism can be performed NO continuous motion

d) ***Change point or cross-over position mechanism*** (condition is any link to be shortness)



1- If $L_0 = L_{max}$

$$100 + L_0 = 200 + 300 \xrightarrow{yields} L_0 = 400\ mm$$

Then change point or cross-over position mechanism can be performed and continuous motion

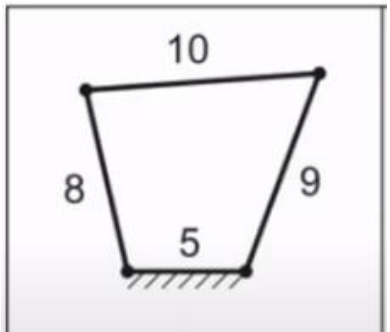
2- If $L_0 = L_{min}$

$$L_0 + 300 = 100 + 200 \xrightarrow{yields} L_0 = 0\, mm$$
then no change point or cross-over position mechanism can be performed NO continuous motion
3- L_0=L_2 or L_3
$$100 + 300 = L_0 + 200 \xrightarrow{yields} L_0 = 200\, mm$$
Than change point or cross-over position mechanism can be performed and continuous motion.
e) ***Triple rocker mechanism*** (condition is any link to be shortness)
$$L_1 + L_0 > L_2 + L_3$$
1) if L_0=L_{min}
$$L_0 + 300 > 100 + 200 \xrightarrow{yields} L_0 > 0\, mm$$
then triple rocker mechanism can be performed and continuous motion

2- If L_0=L_{max}
$$100 + L_0 > 300 + 200 \xrightarrow{yields} L_0 > 400\, mm$$
then triple rocker mechanism can be performed and continuous motion
3- If L_0=L_2 or L_3
$$100 + 300 > L_0 + 200 \xrightarrow{yields} L_0 < 200\, mm$$
Then there are two solutions
$$0 < L_0 < 200\, mm\ or\ L_0 > 400\, mm$$
For both solutions are triple rocker mechanism can be performed and continuous motion.

Ex2

M1 is four bar-mechanism as shown in figure. The figure indicate the respective link lengths I Cm. identify the nature of the mechanism, i.e. whether double-crank, crank-rocker or double-rocker



(a) M1

Solution

Identification of nature of mechanism M1.

s=5 cm (length of shortest link), l=10 cm (length of longest link), p and q =17 cm (length of other two links).

Here is

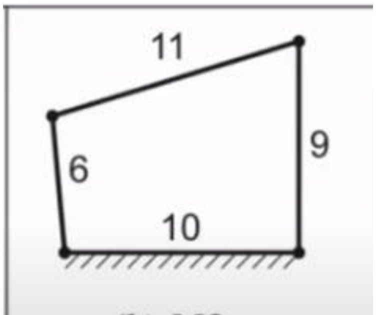
$$s + i = 5 + 10 = 15$$

$$p + q = 8 + 9 = 17$$

1. $s + i < p + q$ $(so\ it\ is\ Groshoff's\ chain)$
2. $shortest\ link\ is\ fixed\ than\ mechanism\ M1\ is\ double\ crank$

Ex3

M2 is four bar-mechanism as shown in figure. The figure indicates the respective link lengths I Cm. identify the nature of the mechanism, i.e. whether double-crank, crank-rocker or double-rocker



(b) M2

Identification of nature of mechanism M2.

s=6 cm (length of shortest link), l=11 cm (length of longest link), p and q =19 cm (length of other two links).

Here is

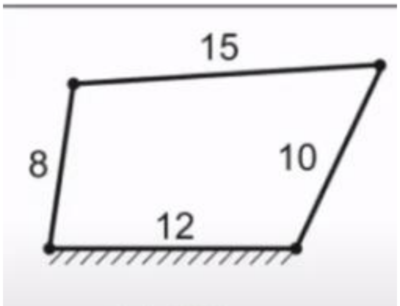
$$s + i = 6 + 11 = 17$$

$$p + q = 9 + 10 = 19$$

1. $s + i < p + q$ $(so\ it\ is\ Groshoff's\ chain)$
2. $shortest\ link\ is\ driver\ than\ mechanism\ M1\ is$ Crank rocker

Ex4

M3 is four bar-mechanism as shown in figure. The figure indicate the respective link lengths I Cm. identify the nature of the mechanism, i.e. whether double-crank, crank-rocker or double-rocker



(c) M3

Identification of nature of mechanism M3.

s=8 cm (length of shortest link), l=15 cm (length of longest link), p and q =22 cm (length of other two links).

Here is

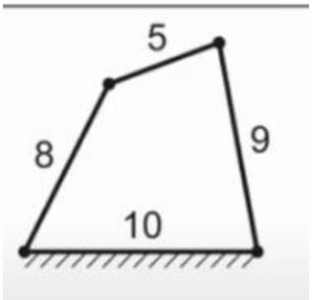
$$s + i = 8 + 15 = 23$$

$$p + q = 10 + 12 = 22$$

1. $s + i > p + q$ ($so\ it\ is\ non - Groshoff's\ chain$)
2. $than\ mechanism\ M3\ is$ Triple rocker

Ex5

M4 is four bar-mechanism as shown in figure. The figure indicate the respective link lengths I Cm. identify the nature of the mechanism, i.e. whether double-crank, crank-rocker or double-rocker



(d) M4

Identification of nature of mechanism M4.

s=5 cm (length of shortest link), l=10 cm (length of longest link), p and q =17 cm (length of other two links).

Here is

$$s + i = 5 + 10 = 15$$

$$p + q = 8 + 9 = 17$$

1. $s + i < p + q$ $(so\ it\ is\ Groshoff's\ chain)$
2. $shortest\ link\ is\ coupler\ than\ mechanism\ M4\ is$ Double rocker