Theory of machine

If you have a smart project, you can say "I'm an engineer"

Lecture 2

Instructor

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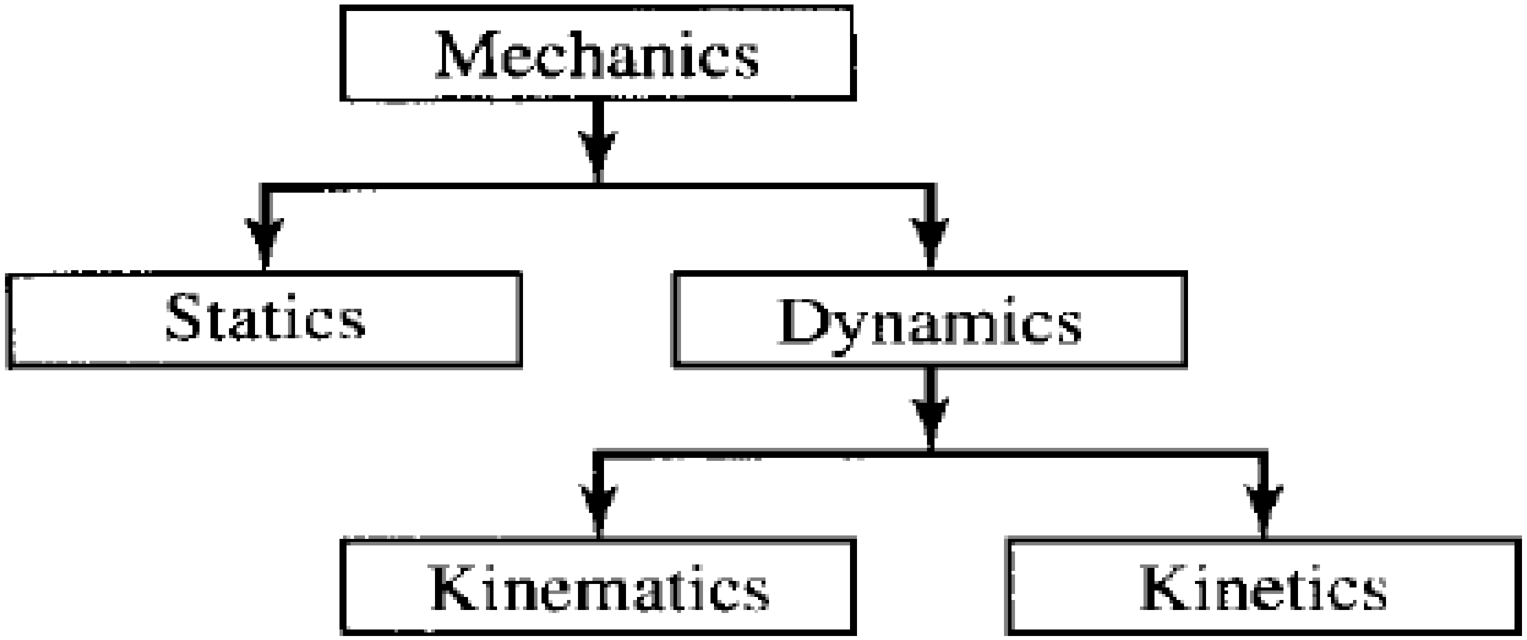
Theory of machine
MDP 234

- **Lecture aims:**
  - Understand the motion types.
  - Understand the mechanism components and types.
  - Identify the Grashof's theorm

THE SCIENCE OF MECHANICS



Analysis of mechanisms

- **<u>Mechanical System, definition</u>:**

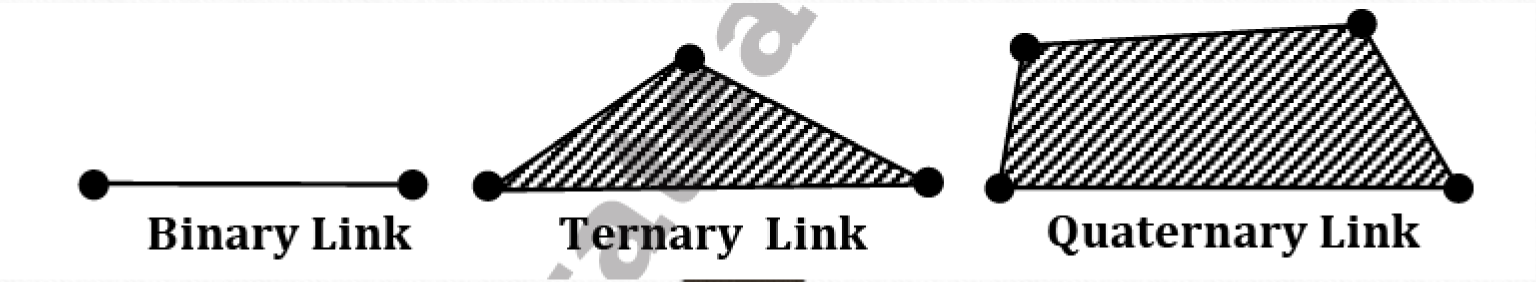
  –A collection of interconnected rigid **bodies that can move relative to one another, consistent with joints that limit relative motions of pairs of bodies**

- **<u>What type of analysis can one speak of in conjunction with a mechanical system?</u>**

  –Kinematics analysis
  –Dynamics analysis
  –Inverse Dynamics analysis
  –Equilibrium analysis

Links

- A **mechanism** is made of a number of resistant bodies out of which some may have motions relative to the others.
- A resistant body or a group of resistant bodies with rigid connections preventing their relative movement is known as a **link**.
- **Links** can be classified into binary, ternary and quaternary depending upon their ends on which revolute or turning pairs can be placed. The links shown in figures given above are rigid links and there is no relative motion between the joints within the link.



Types of Joints

- **Binary Joint:** If two links are joined at the same connection; it is called a binary joint. For example. Fig. 1.17 shows a chain with two binary joints named B.
- **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. In Fig. 1.17 ternary links are mentioned as T.
- **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. Figure 1.17 shows one quaternary joint.

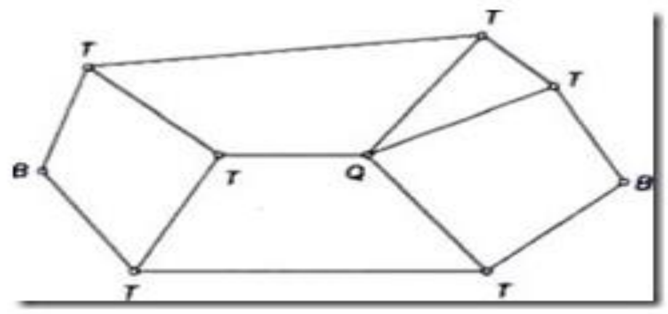


Fig 1.17

Kinematic chains, mechanisms, machines, link classification

- **Kinematic chain**: links **joined** together **for motion**
- **Mechanism**: **grounded kinematic chain**
- **Machine**: mechanism designed to **do work**

Kinematic chains, mechanisms, machines, link classification

Link classification:

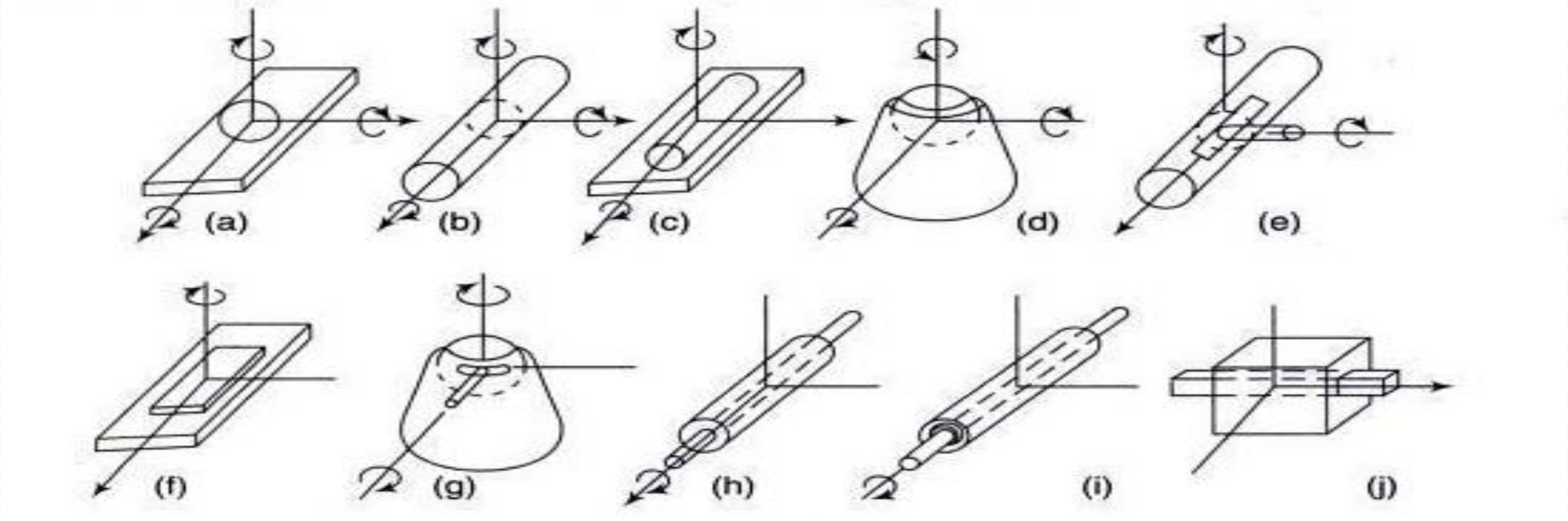
- **Ground**: any link or links that are fixed, **nonmoving** with respect to the reference frame
- **Crank**: **pivoted** to ground, makes complete **revolutions**
- **Rocker**: **pivoted** to ground, has **oscillatory** motion
- **Coupler**: link has **complex** motion, **not attached** to ground

Kinematic Pairs

Types of Kinematic Pairs: Kinematic pairs can be classified according to following points,

- **Nature of contact**
- **Nature of mechanical constraint**
- **Nature of relative motion**

Classification of kinematic pairs



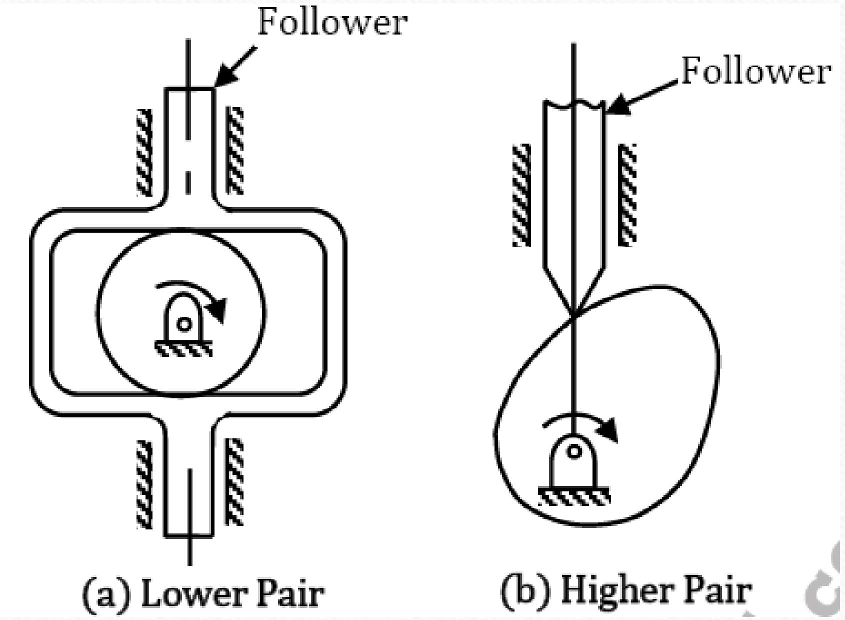
Kinematic Pairs According to Nature of Contact

a. 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, uni joint, etc.

b. 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

Depending upon the nature of mechanical constraint, the kinematic pair is classified into following in to two categories

a. Closed Pair: When the elements of a pair are held together mechanically, it is known as a closet the two elements are geometrically identical, one is solid and full and the other is hollow or open. The latter not only envelops the former but also encloses it. The contact between the two can be broken only by destruction of at least one of the members.

- All the **lower** pairs and some of the higher pairs are **closed** pairs. A cam and follower pair (higher pair) shown in given below and a screw pair (lower pair) belong to the closed pair category.

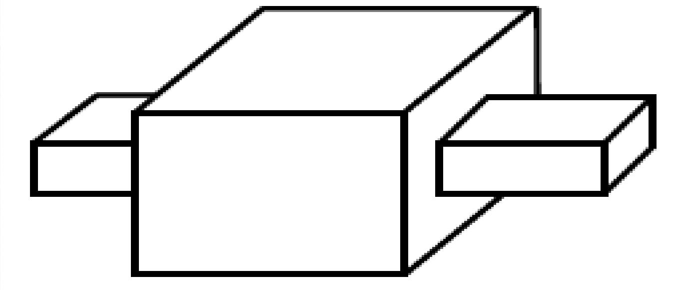
b. Unclosed Pair: When two links of a pair are in contact either due to force of **gravity** or some **spring action**, they constitute an unclosed pair. In this, the links are **not held together** mechanically, e.g., cam and follower pair of figure given above.

Kinematic Pairs according to Nature of Relative Motion

a. Sliding Pair: If two links have a sliding motion relative to each other, they form a sliding pair.

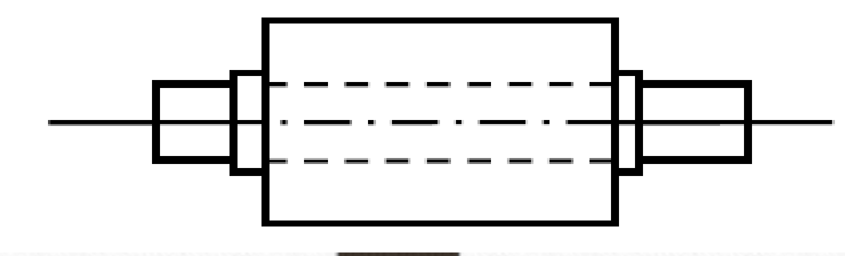
- A rectangular rod in a rectangular hole in a prism is a

sliding pair in the figure



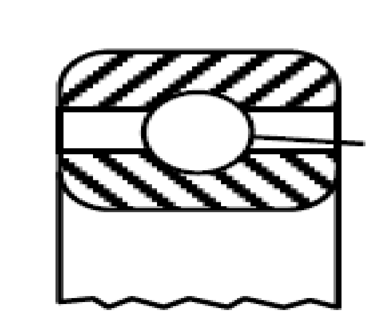
Kinematic Pairs according to Nature of Relative Motion

- **b. Turning Pair**: When one link has a turning or revolving motion relative to the other, they constitute a turning or revolving pair in the figure.
- In a slider-crank mechanism, all pairs except the slider and guide pair are turning pairs. A circular shaft revolving inside a bearing is a turning pair.



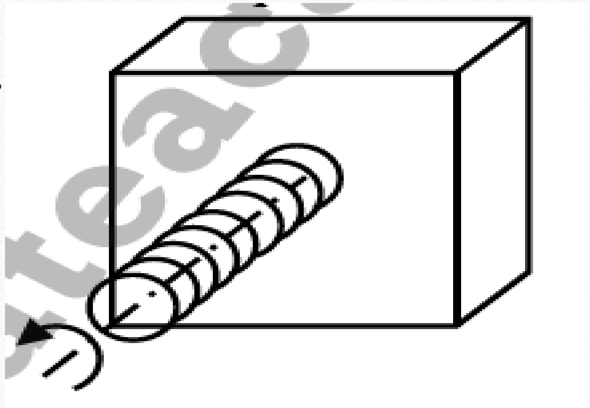
Kinematic Pairs according to Nature of Relative Motion

- **c. Rolling Pair**: When the links of a pair have a rolling motion relative to each other, they form a rolling pair, Eg: a rolling wheel on a flat surface, ball and roller bearings, etc. In a ball bearing in the above figure the ball and the shaft constitute one rolling pair whereas the ball and the bearing is the second rolling pair.



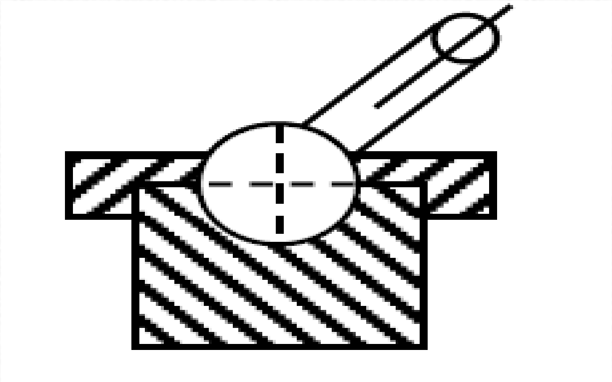
Kinematic Pairs according to Nature of Relative Motion

- **d. Screw Pair (Helical Pair):** If two mating links have a turning as well as sliding motion between them, they from 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 in the figure.



Kinematic Pairs according to Nature of Relative Motion

- **e. 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 in the figure.



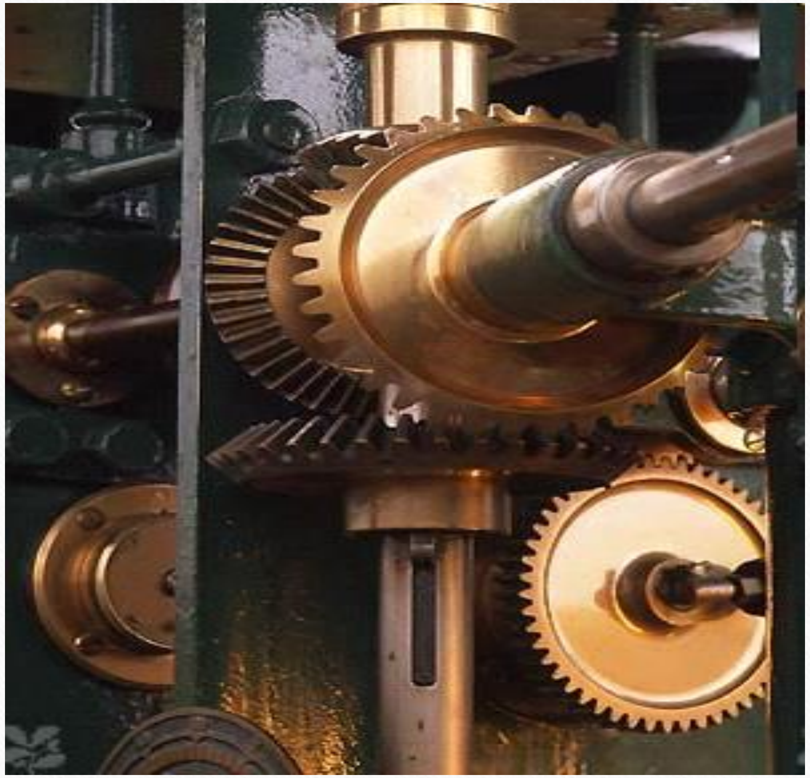
Types of motion

A mechanism is something which transforms (changes);

- An input force and motion into
- An output force and motion

There are 4 types of motion (or movement), these are;

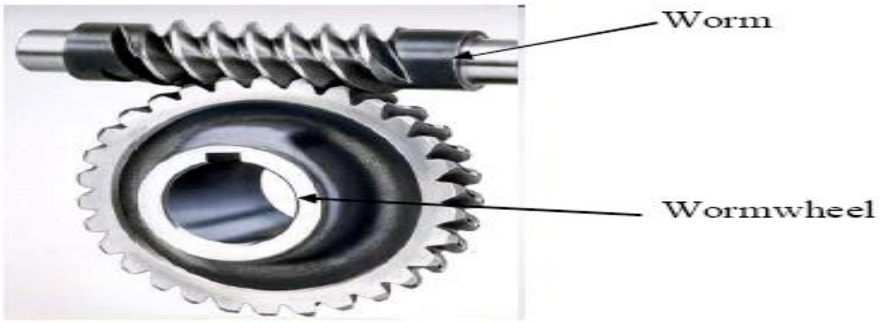
1. Rotary Motion -this is motion in a circle
2. Linear Motion – this is motion in a straight line
3. Reciprocating Motion – this is motion backwards and forwards
4. Oscillating Motion – this is motion in an arc (like a child's swing)



Mechanisms - Changing Motion Through 90 Degrees

- 1. Turning motion through a right angle.

This is achieved by using a BEVEL GEAR or a WORM and WORMWHEEL.



A wormwheel. These can give huge reductions in speed as the worm only has 1 tooth. So if the wormwheel had 40 teeth a speed reduction of 40 times is created.

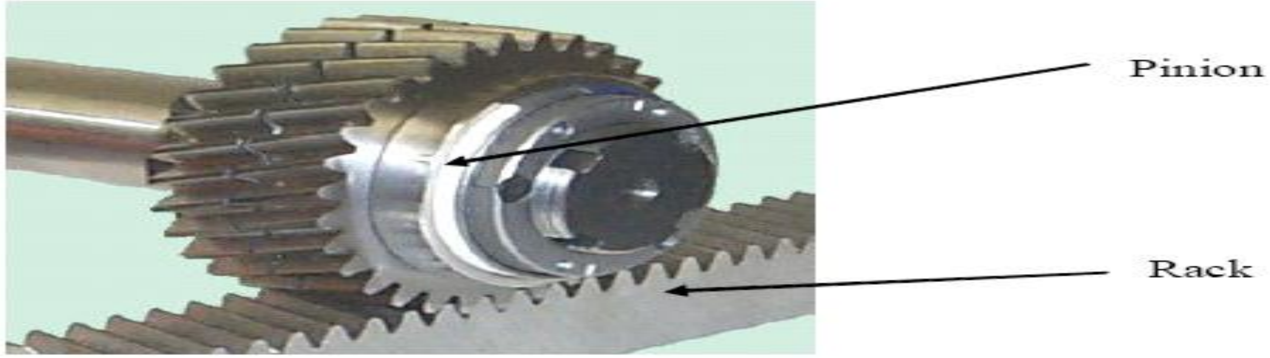
A bevel gear. This can also speed up rotation if the gears have different numbers of teeth. For example if the small gear had 10 teeth and the large gear had 40 teeth the small gear would rotate 4 times as fast.

Mechanisms – Reversing Direction

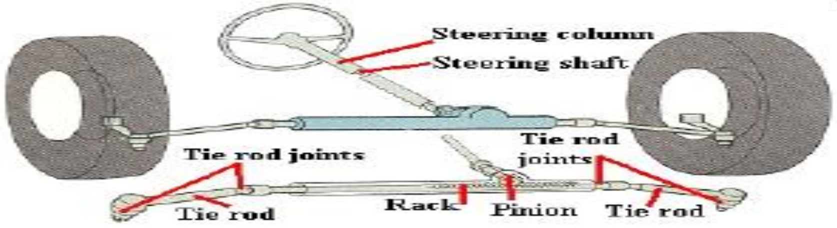
If two gears touch each other (also called meshing) the gears will rotate in opposite directions. This can also speed up rotation if the gears have different numbers of teeth. For example if the small gear had 15 teeth and the large gear had 30 teeth the small gear would rotate 2 times as fast.

Mechanisms – Changing Rotary into Linear Motion

3. Changing rotary motion into linear motion.

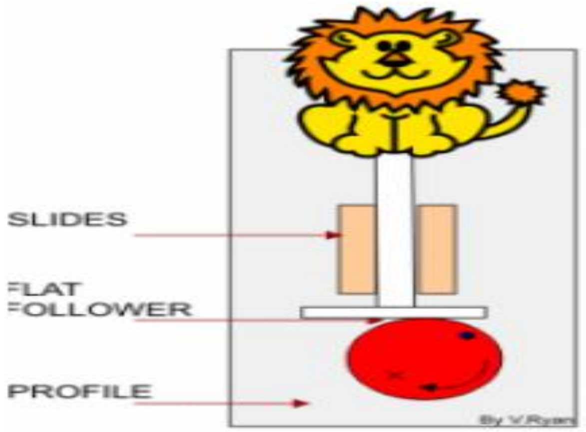


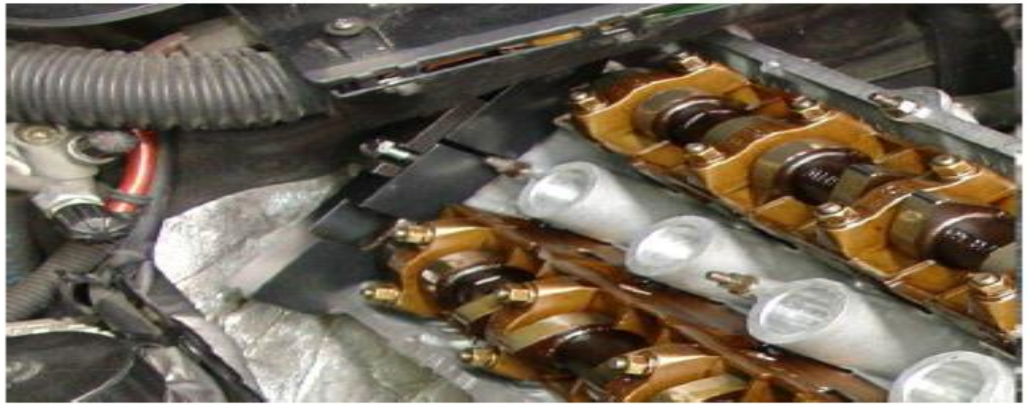
As the pinion rotates the rack (which is a straight piece of metal with teeth on one side) has linear motion. Common uses are on a pillar drill (you rotate the handle and the drill moves up and down) and car steering (you turn the steering wheel and the wheels move).



Mechanisms – Changing Rotary into Reciprocating Motion

4. Changing rotary motion into reciprocating motion.



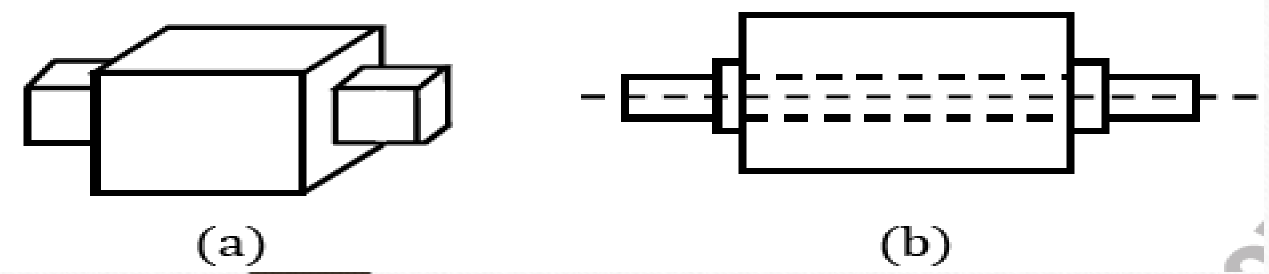


As the cam rotates the follower moves up and down, in other words it reciprocates. The cam can have different shapes (or profiles) which change the way the follower moves up and down. Here as the cam rotates the lion moves up and down. The 'slides' simply keep the follower in place.

The picture above shows how cams are used in a car engine. This example is of a double (two sets of cams) overhead cam shaft. In engines the cams open and close 'poppet' valves which in turn open and close the intake and exhaust valves in the engine.

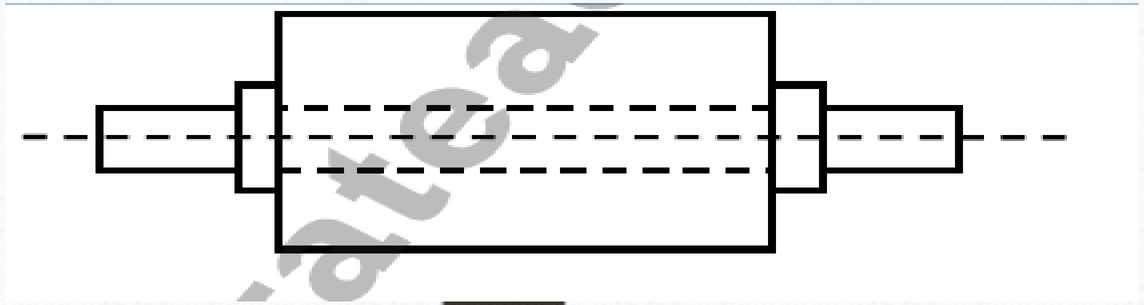
Types of Constrained Motions

- **1. Completely Constrained Motion:** When the motion between two elements of a pair is in a definite direction **irrespective of the direction of the force applied**, it is known as completely constrained motion. The constrained motion may be linear or rotary. The **sliding pair** of fig. (a) and the **turning pair** of fig. (b) are the examples of the completely constrained motion.
- In sliding pair, the inner prism can only slide inside the hollow prism. In case of a turning pair, the inner shaft can have only rotary motion due to collars at the ends. In each case the force has to be applied in particular direction for the required motion.



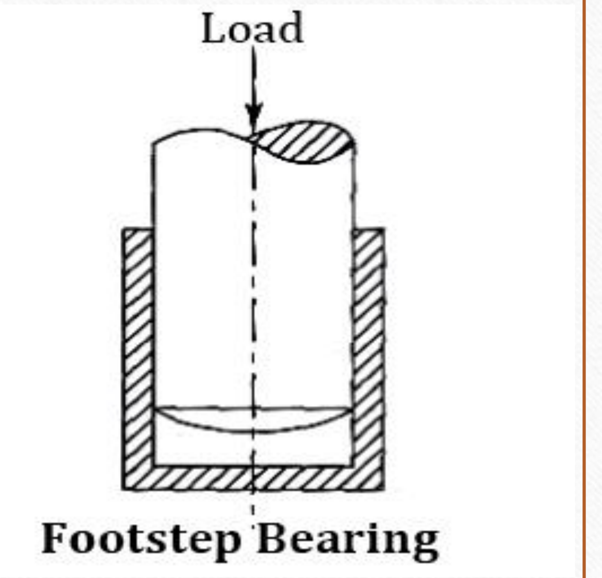
Types of Constrained Motions

- **2. Incompletely Constrained Motion**: When the motion between two elements of a pair is **possible** in **more than one direction** and depends upon the direction of the force applied it is known as incompletely constrained motion. For example, if the turning pair of figure given below does not have collars, the inner shaft may have sliding or rotary motion depending upon the direction of the force applied. Each motion is independent of the other.



Types of Constrained Motions

- **3. Successfully Constrained Motion**: When the motion **between two elements** of a pair is possible in **more than one direction** but is made to have motion only in one direction by using some external load means, it is a successfully constrained motion. For example, a shaft in a footstep bearing may have vertical motion apart from rotary motion.
- But due to load applied on the shaft it is constrained to move in that direction and thus it is a successfully constrained motion. Similarly, a piston in a cylinder of an internal combustion engine is made to have only reciprocating motion and no rotary motion due to constrain of the piston pin. Also, the valve of an IC engine is kept on the seat by the force of a spring and thus has successfully constrained motion.

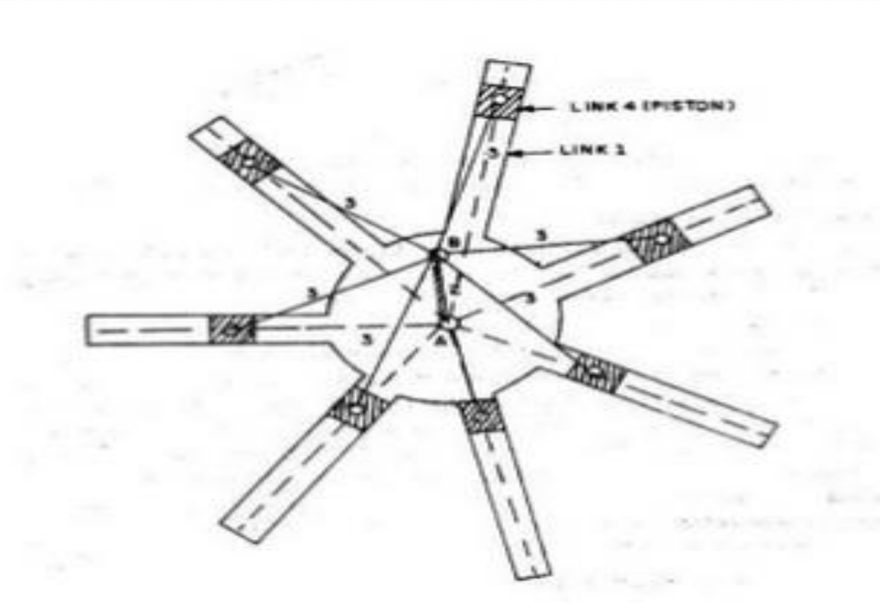


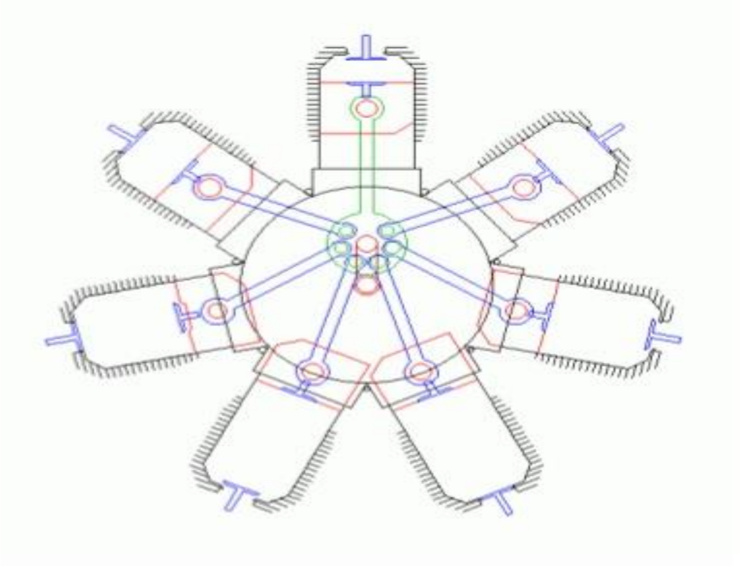
Types of Kinematic Chains

- 1. Four bar chain or quadric cyclic chain,
- 2. Single slider crank chain, and
- 3. Double slider crank chain.

Single slider crank chain mechanisms

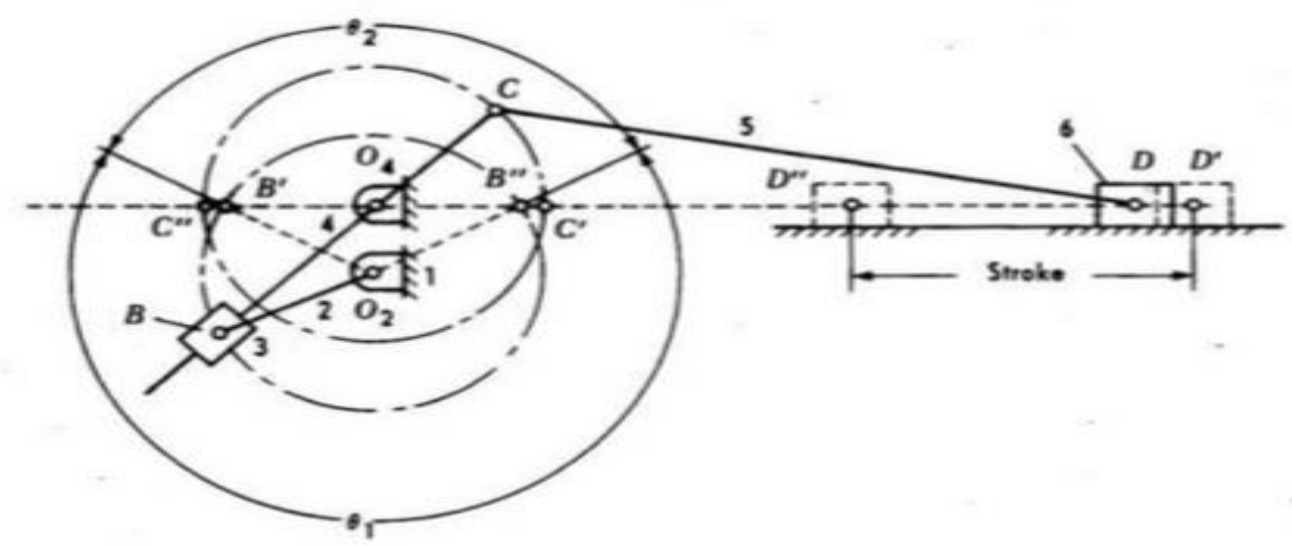
1- Rotary IC engine



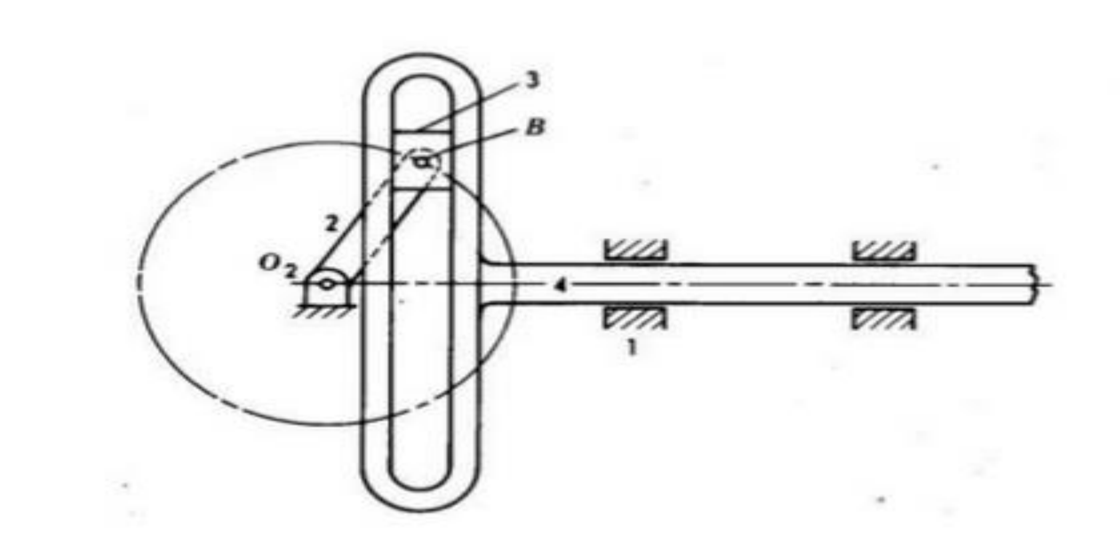


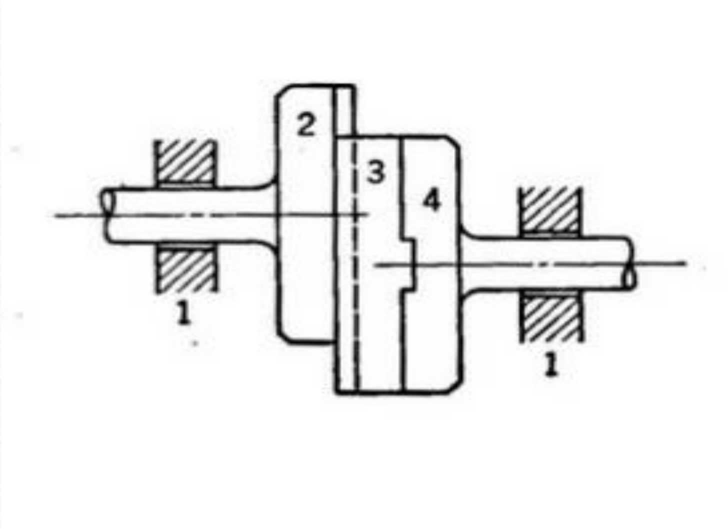
Single slider crank chain mechanisms

2- with worth quick return mechanism



Double slider crank chain mechanisms





Inversion mechanism

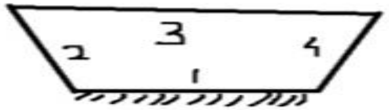


fig. 1

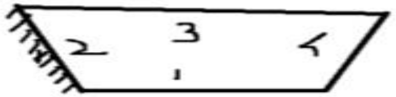


fig. 2

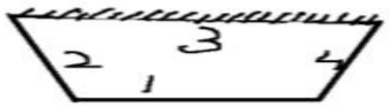


fig. 3

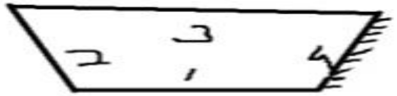


fig. 3

Inversion is the method of obtaining different mechanism from single kinematic chain by fixing different links in turn.

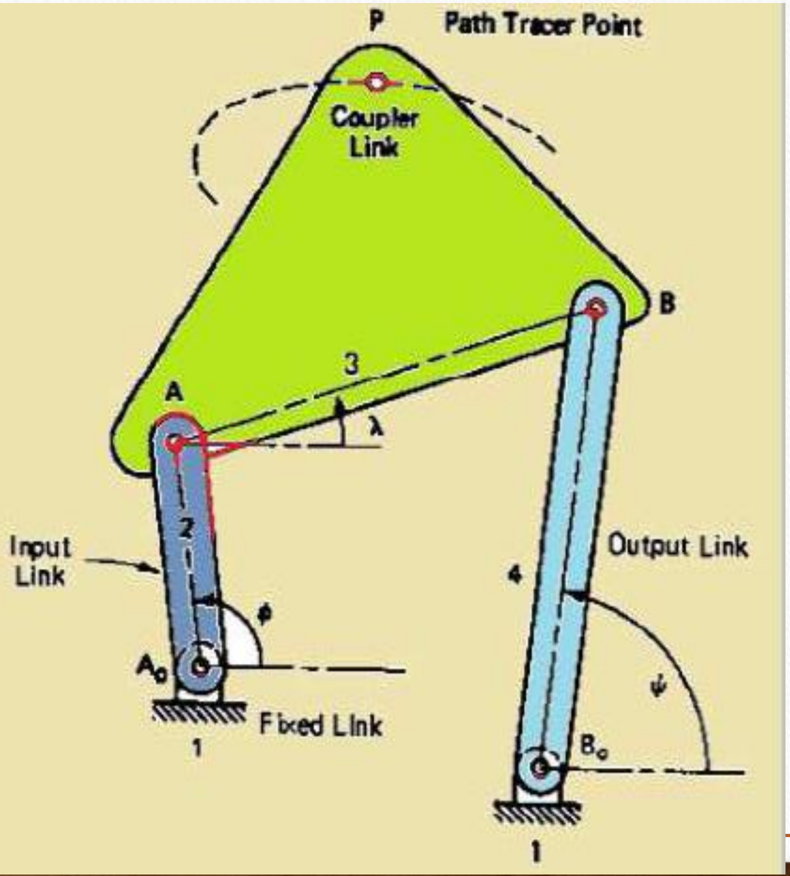
FOUR-BAR LINCKAGE

- Very simple but very versatile.
- First option for design.
- Classification depending on the task:

►Function Generator. Output rules

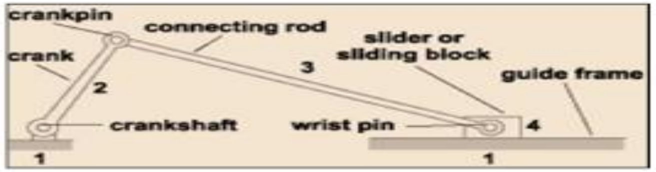
►Path Generator. Path rules

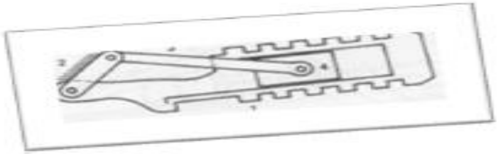
►Motion Generator. All important

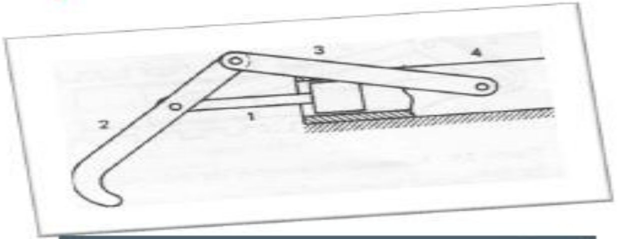


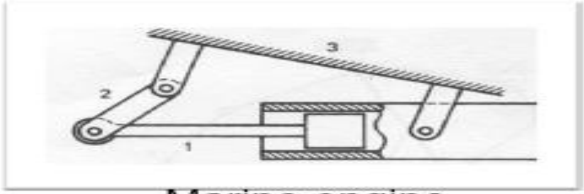
4 BAR KINEMATIC INVERSIONS

- It is the method of obtaining different mechanisms by fixing different links of the same kinematic chain. POWERFUL TOOL. See that with the slider-crank example:



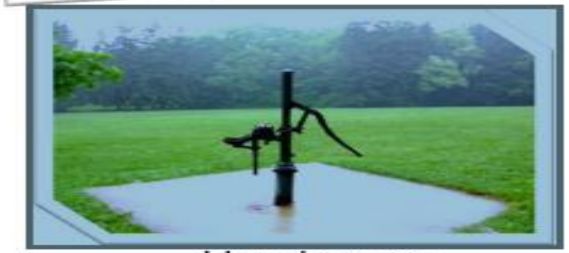






Marine engine

Whitworth mechanism. Gnome engine



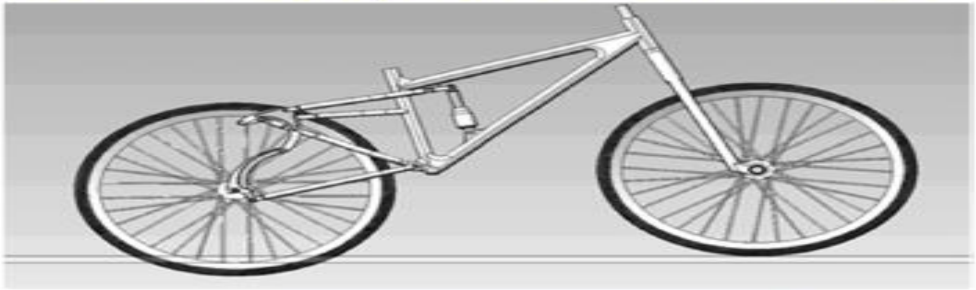
Hand pump

REAL MECHANISMS

FOUR BAR MECHANISM

UCI XGR gravity racer

SIX BAR MECHANISM: to maintain a constant distance between the axle and bottom bracket. It is a Stephenson III six-bar linkage



Brake pedal

GRASHOF CRITERIA

- Simple relation that describes the behavior of the kinematic inversions of a four-bar mechanism.

S= lenght of the shortest link

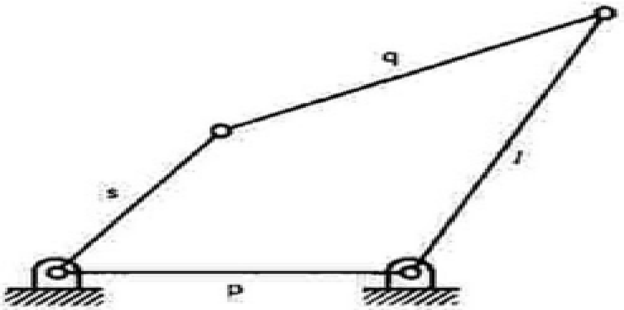
L= lenght of the longest link.

P and Q are the other links.

$$S+L \leq P+Q$$

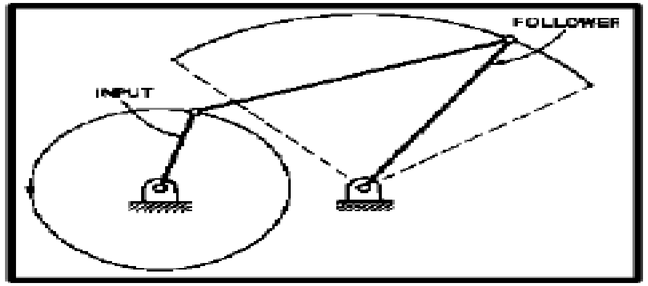
CONTINOUS MOTION IS ALLOWED

If my condition is satisfied, at least one link would be able to do a full revolution with respect to another link.

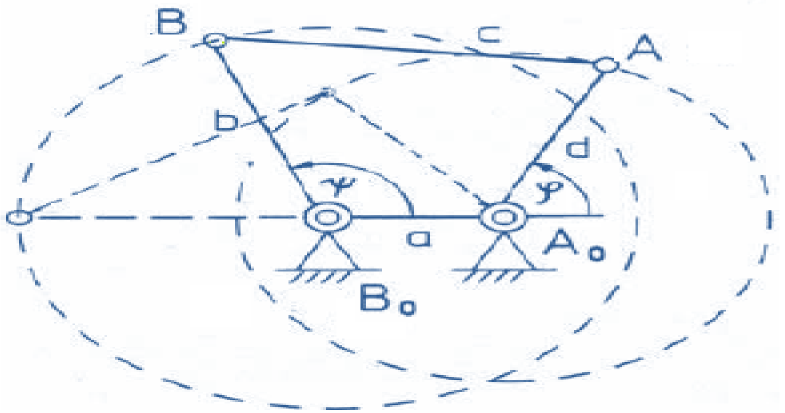


GRASHOF CRITERIA

- **If s + l < p + q: Four possibilities of Grashof mechanism**:
  - **Crank-rocker**: Shortest link is the crank. Frame is adjacent

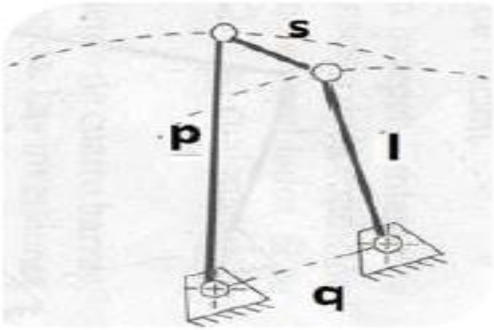


  - **Rocker-Crank**: The shortest link is the follower.
  - **Double Crank** or drag-link: Shortest link is the frame.



GRASHOF CRITERIA

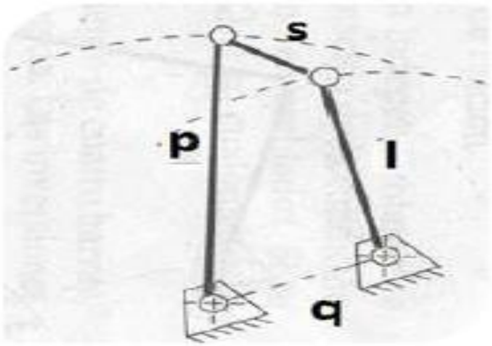
- **Double rocker**: The link opposite the shortest is the frame.



Where is the full rotation of a link?

GRASHOF CRITERIA

- **Double rocker**: link opposite the shortest is the frame



Where is the full rotation of a link? → The Coupler¡¡

No GRASHOF mechanisms

- **If s + l > p + q:** All the kinematic inversions will be double rocker. No continous relative motion is posible.

Special GRASHOF mechanisms.

- **If s + l = p + q. Grashof Special Mechanisms.**
- All inversions are double-crank or crank-rocker.
- These mechanisms suffer from the change-point condition.
  - **All links become collinear creating momentarily a second DOF.** OUTPUT RESPONSE IS UNDETERMINED.

Special GRASHOF mechanisms.

the **parallelogram and antiparallelogram configurations** of the **special-case Grashof linkage.**

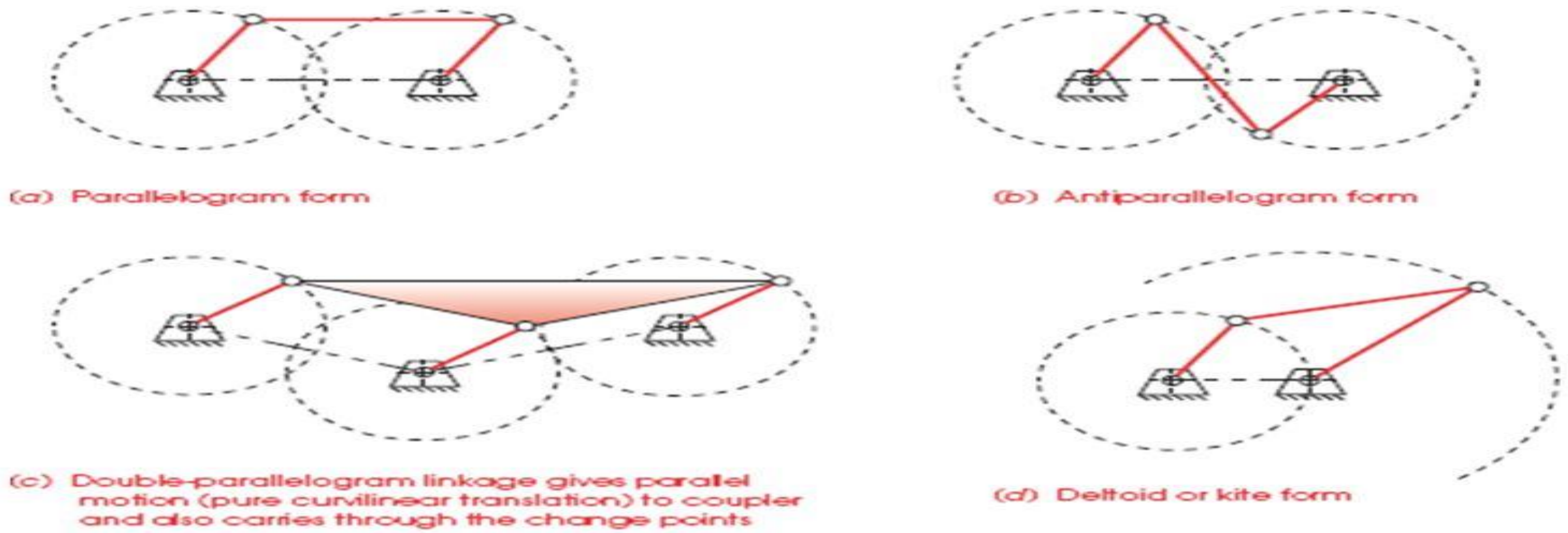


TABLE 2-4 Barker's Complete Classification of Planar Fourbar Mechanisms

Adapted from ref. (10). s = shortest link, l = longest link, Gxxx = Grashof, RRRx = non-Grashof, Sxx = Special case

Type	$s + l$ vs. $p + q$	Inversion	Class	Barker's Designation	Code	Also Known As
1	<	$L_1 = s =$ ground	I-1	Grashof crank-crank-crank	GCCC	double-crank
2	<	$L_2 = s =$ input	I-2	Grashof crank-rocker-rocker	GCRR	crank-rocker
3	<	$L_3 = s =$ coupler	I-3	Grashof rocker-crank-rocker	GRCR	double-rocker
4	<	$L_4 = s =$ output	I-4	Grashof rocker-rocker-crank	GRRC	rocker-crank
5	>	$L_1 = l =$ ground	II-1	Class 1 rocker-rocker-rocker	RRR1	triple-rocker
6	>	$L_2 = l =$ input	II-2	Class 2 rocker-rocker-rocker	RRR2	triple-rocker
7	>	$L_3 = l =$ coupler	II-3	Class 3 rocker-rocker-rocker	RRR3	triple-rocker
8	>	$L_4 = l =$ output	II-4	Class 4 rocker-rocker-rocker	RRR4	triple-rocker
9	=	$L_1 = s =$ ground	III-1	change point crank-crank-crank	SCCC	SC* double -crank
10	=	$L_2 = s =$ input	III-2	change point crank-rocker-rocker	SCRR	SC crank-rocker
11	=	$L_3 = s =$ coupler	III-3	change point rocker-crank-rocker	SRCR	SC double-rocker
12	=	$L_4 = s =$ output	III-4	change point rocker-rocker-crank	SRRC	SC rocker-crank
13	=	two equal pairs	III-5	double change point	S2X	parallelogram or deltoid
14	=	$L_1 = L_2 = L_3 = L_4$	III-6	triple change point	S3X	square

* SC = special case.

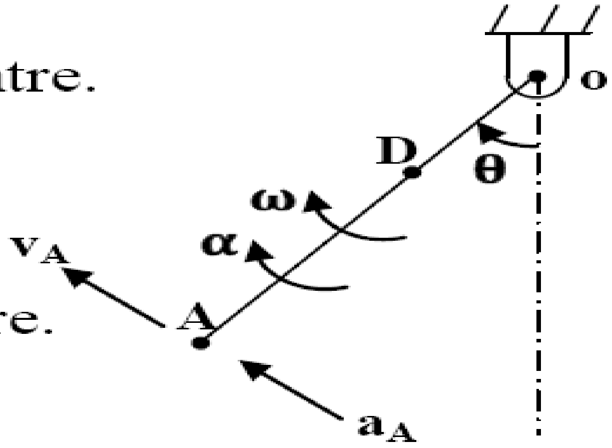
Bodies rotate about fixed point

Consider the link shown which is rotate about the fixed point o, the motion of this link can be analyzed using the principle of absolute motion as follow:

If θ: angular displacement about fixed rotation centre.

ω: angular velocity about fixed rotation centre.

α: angular acceleration about fixed rotation centre.



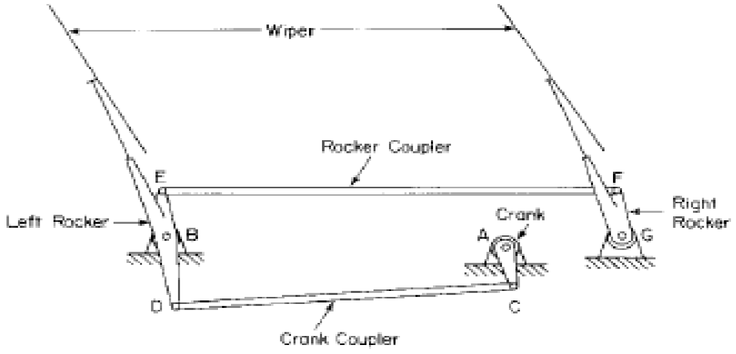
Model Examples

- Walking robot

Thank you

Kinematics analysis

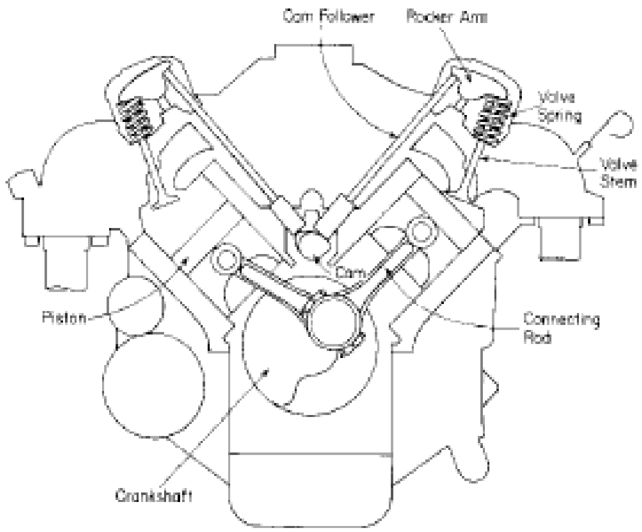
- Concerns the motion of the system **independent** of the forces that produce the motion
- Typically, the time history of one body in the system is prescribed
- We are interested in how the rest of the bodies in the system move
- Requires the solution linear and nonlinear systems of equations



Windshield wiper mechanism

Dynamics analysis

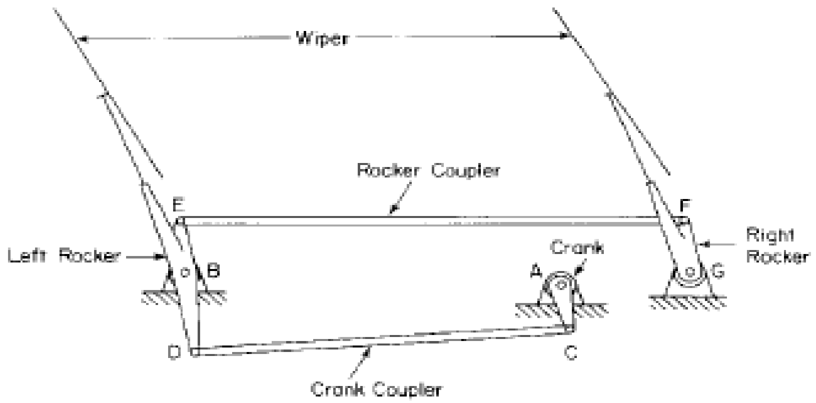
- Concerns the motion of the system that is due to the action of applied forces/torques
- Typically, a set of forces acting on the system is provided. Motions can also be specified on some bodies
- We are interested in how each body in the mechanism moves
- Requires the solution of a combined system of differential and algebraic equations (DAEs)

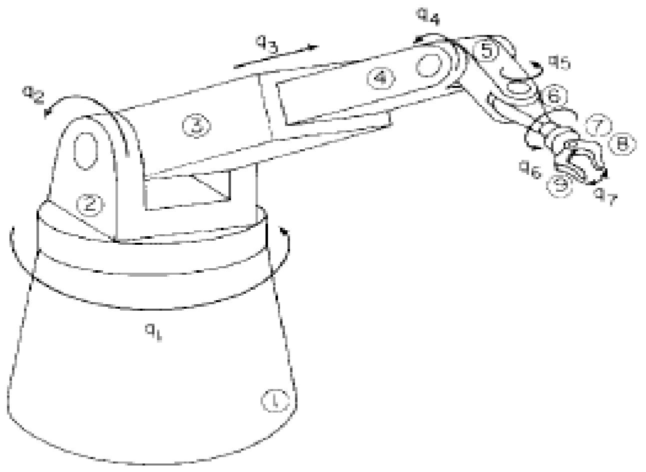


Cross Section of Engine

Inverse Dynamics analysis

- It is a hybrid between Kinematics and Dynamics
- Basically, one wants to find the set of forces that lead to a certain desirable motion of the mechanism
- Your bread and butter in Controls…





Robotic Manipulator