Kinematics of Machines

Course Owner
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Machines

- Machine is a device for trnsmitting and transforming Motion and Force (Power) from source to the load is called a machine


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Kinematics

The subject which deals only with **Geometric Aspects** (constraints) of motion without any consideration of forces is known as Kinematics

For the study of kinematics a machine maybe referred to as a mechanism which is a combination of interconnected rigid bodiess capable of **Relative Motion**

Basic Building Block of a Mechanism

Kinematic Link

Types of Kinematic Link

- Rigid Link
- Flexible Link
- Fluid Link

Basic Structure of Machine

Kinematic Link

↓

Kinematic Pair

↓

Mechanism

↓

Machines

Identification of Kinematic Pairs

- Degees of Freedom
- Pair Variables
- Classification: Lower, Higher, Wrapping
- Classification: Form Closed, Force Closed
- Schematic Representation

Kinematic Pair

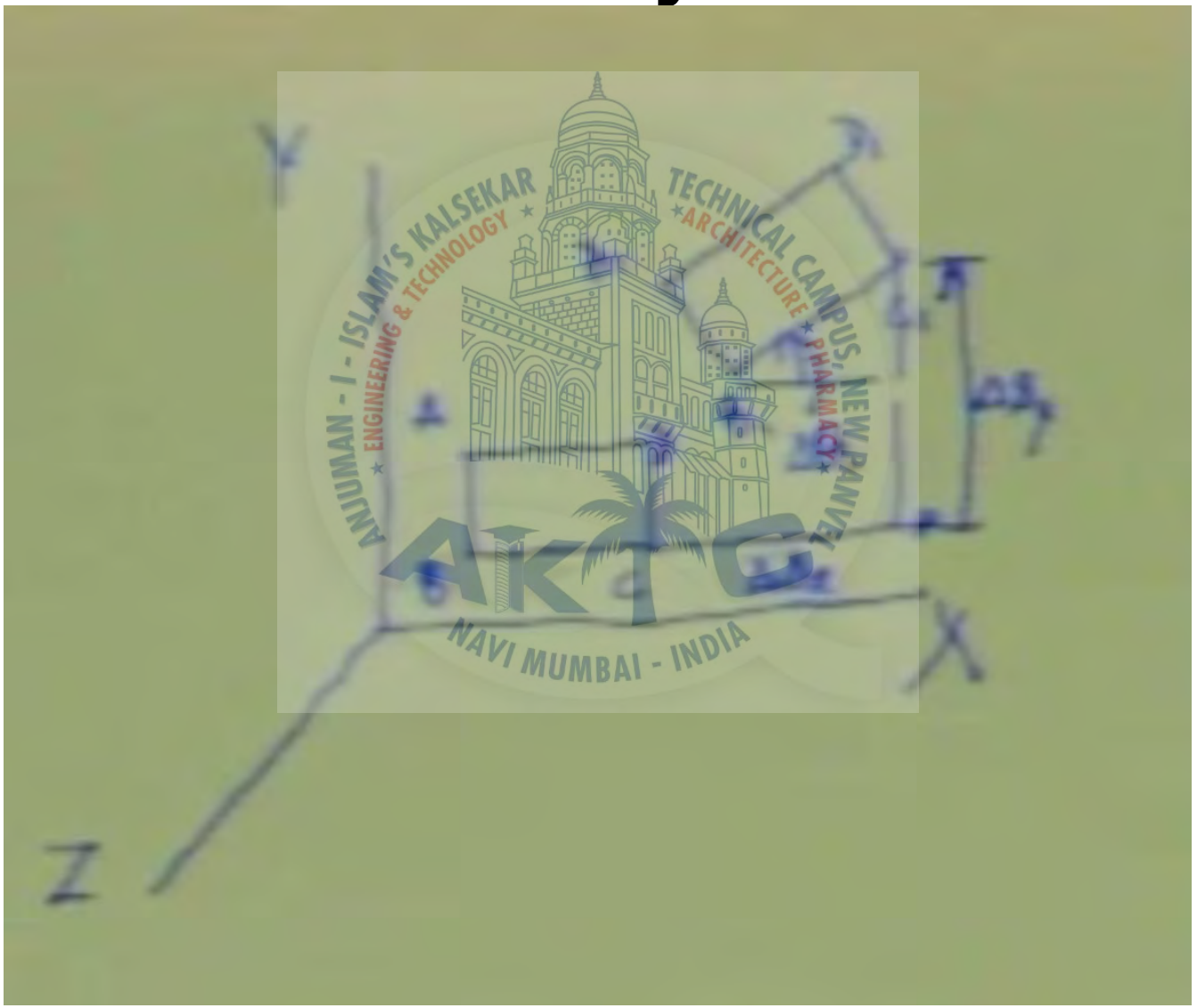
- Degree of Freedom
- Pair Variable
- Classification

DoF

- No. of independent coordinates to completely specify the relative movement permitted in a kinematic pair is called DoF

- in every pair there is some relative moment and to describe that the coordinates used are pair variables

PLANAR 3-DOF System



Kinematic Pairs

- Acc. to nature of relative motion
- Acc. to Nature of contact
- Acc. to Nature of Mechanical Arrangements

Acc. to Nature of Relative Motion

1. Sliding/ Prismatic
2. Revolute/ Turning
3. Screw/ Helical
4. Rolling
5. Cyllendric
6. Spherical/ Globular

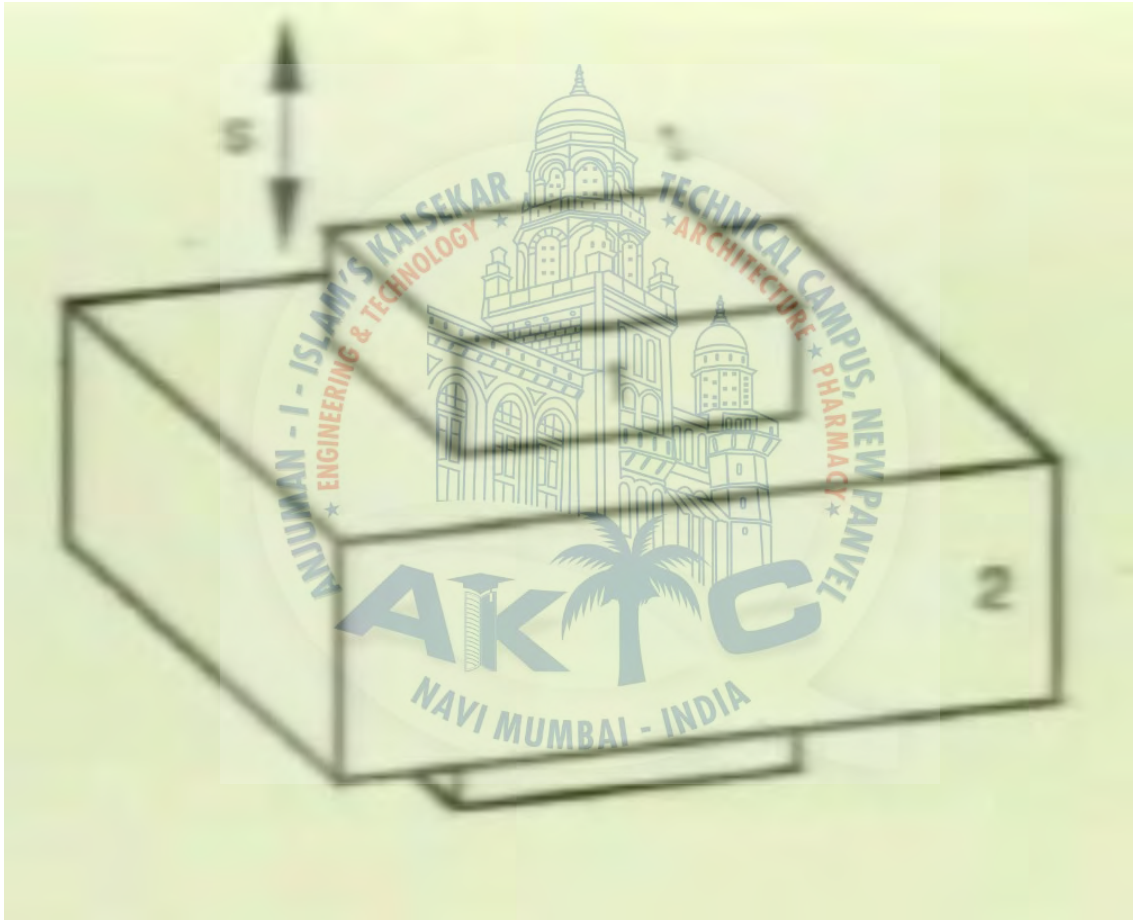
Acc. to Nature of Contact

- Lower Pair
- Higher Pair

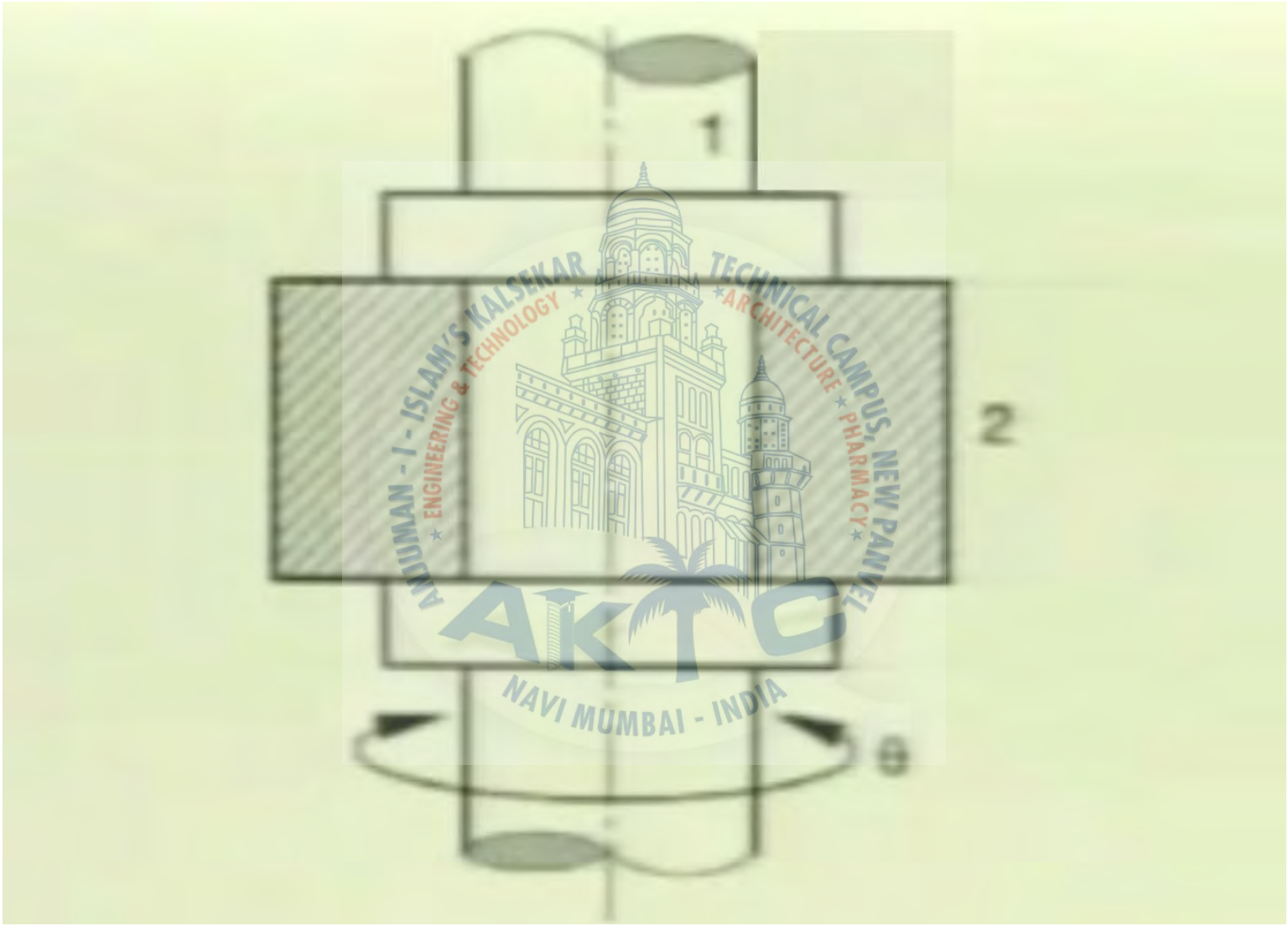
Acc. to Nature of Mechanical Arrangements

- Self Closed Pair
- Forced Closed Pair

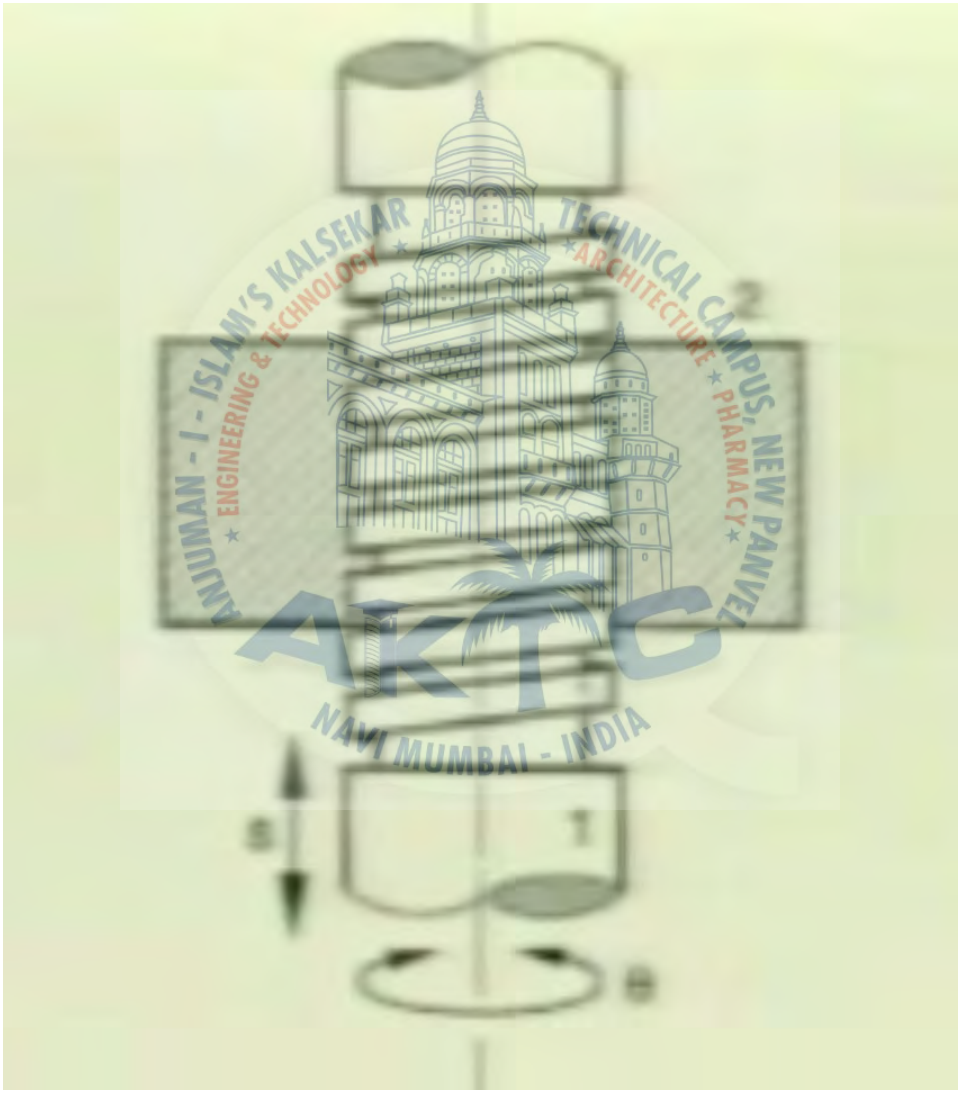
Prismatic Pair



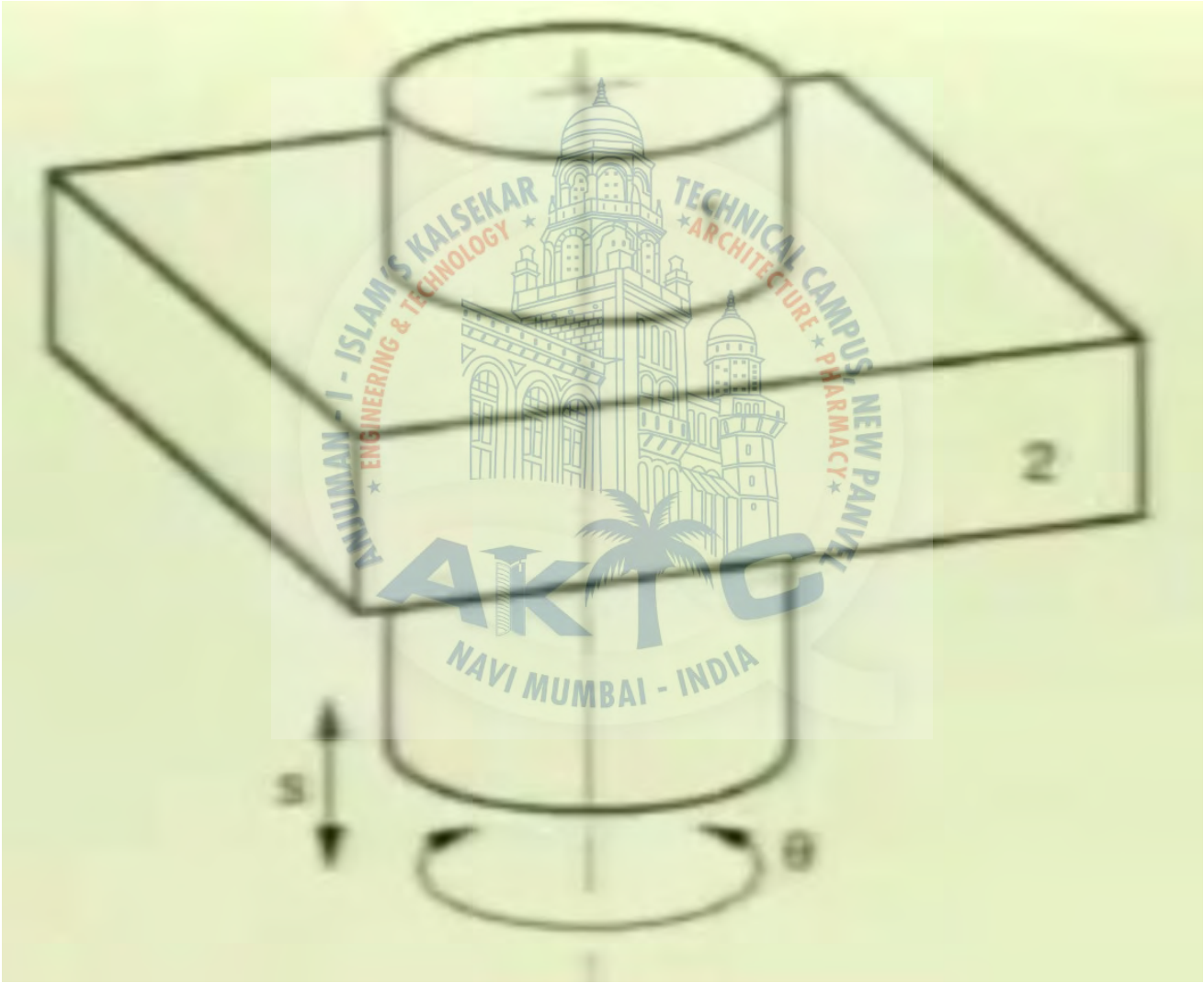
Revolute Pair



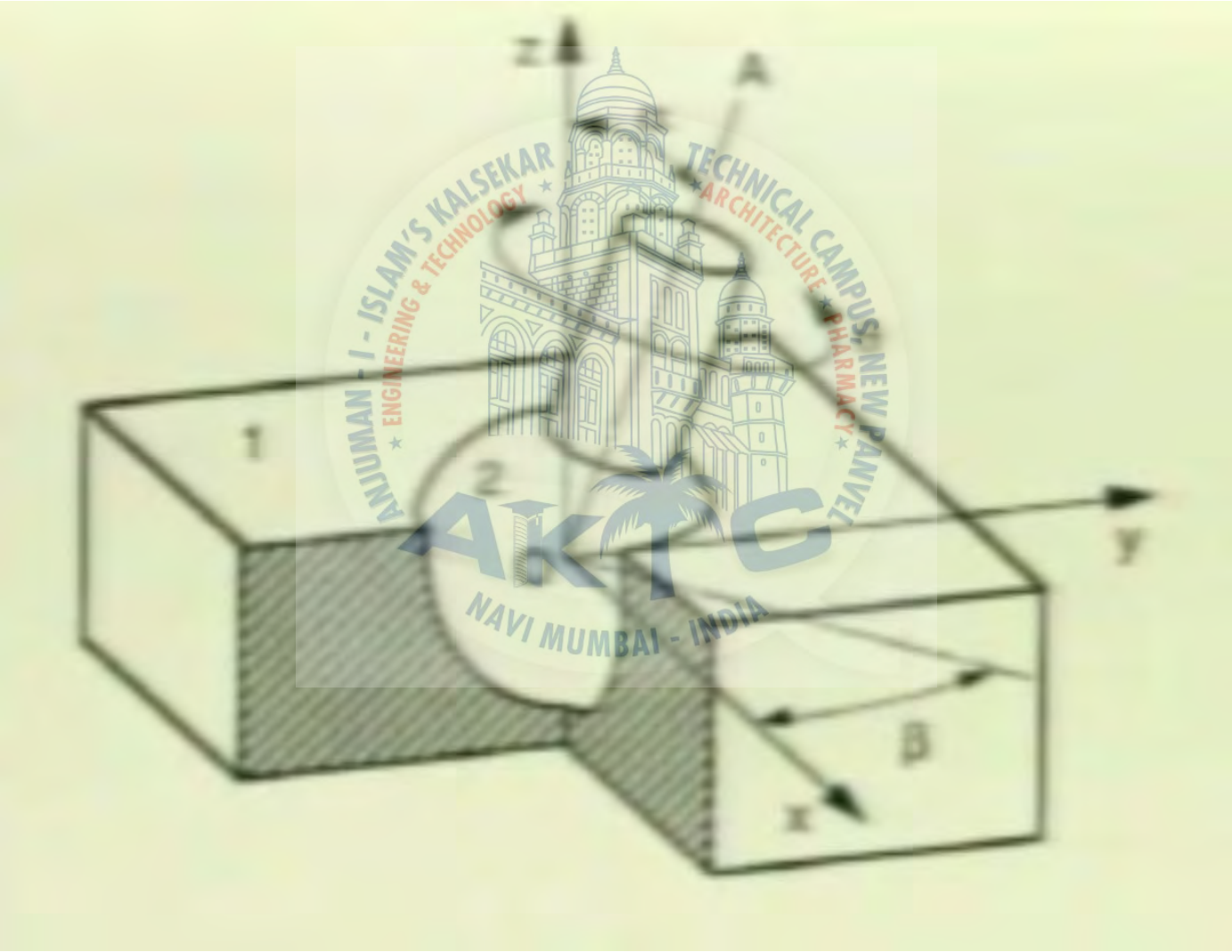
Screw Pair



Cylindric Pair



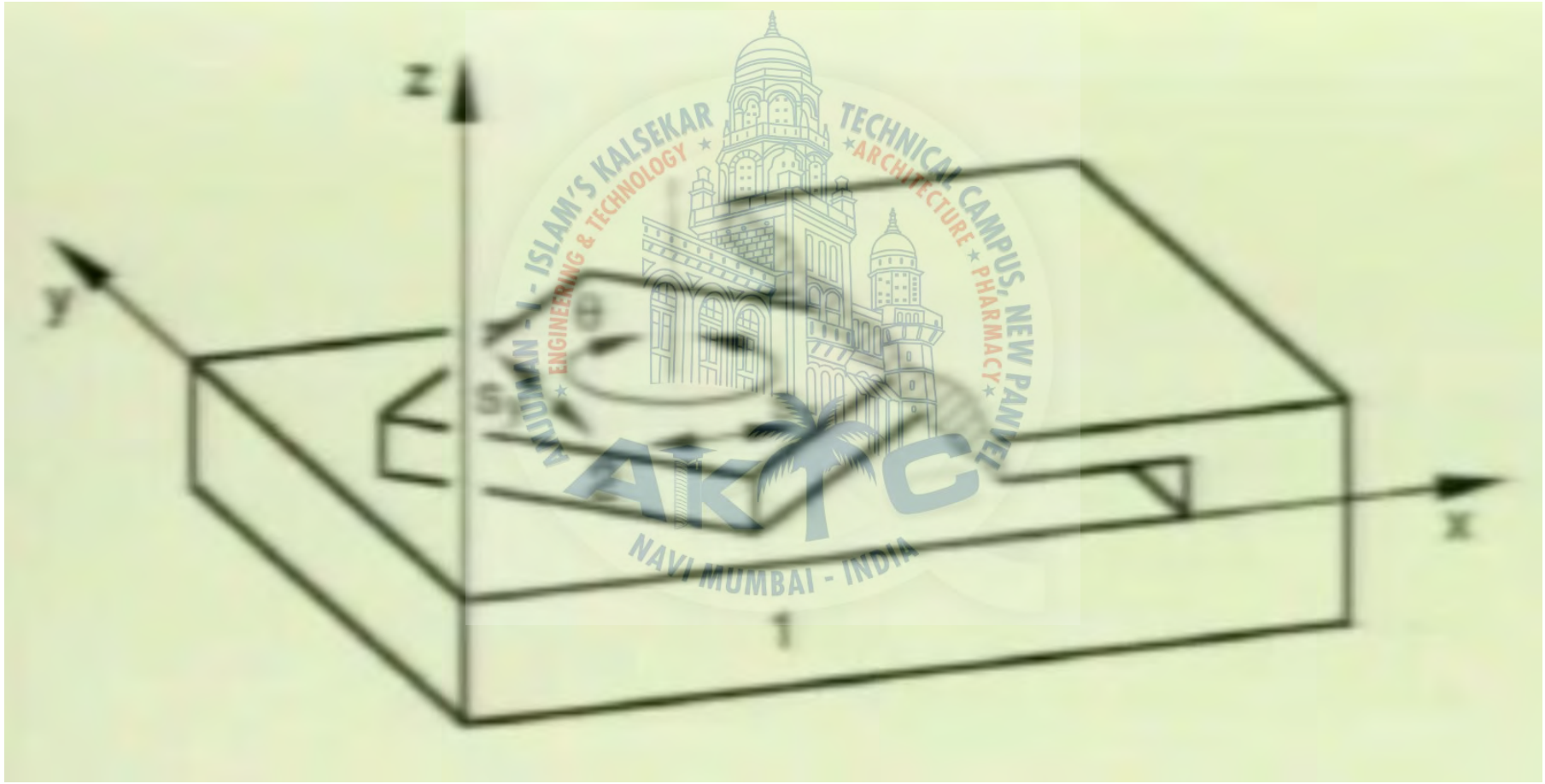
Spheric Pair



Acc. to Nature of contact

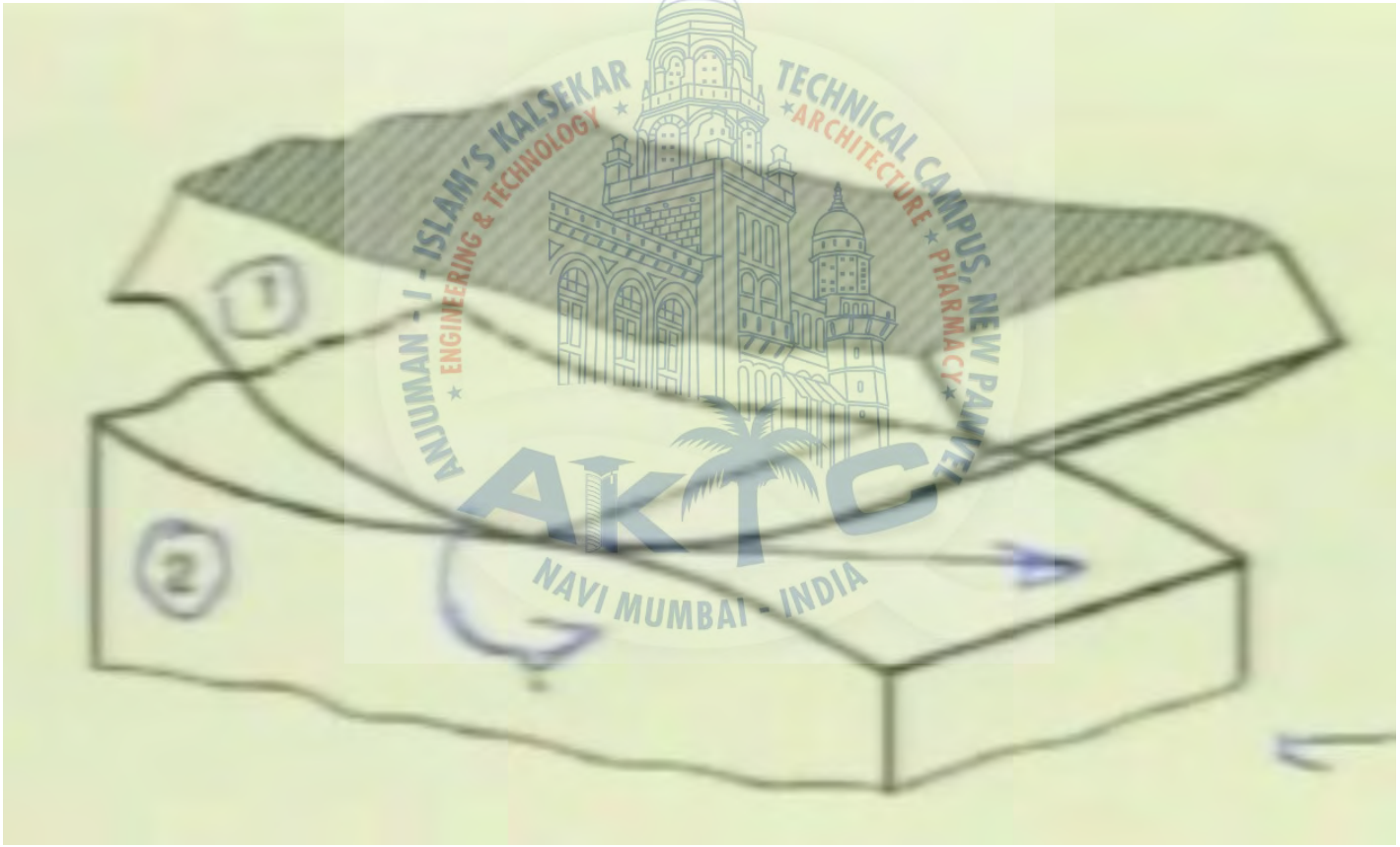
- Lower Pair
- Higher Pair

Planer Pair

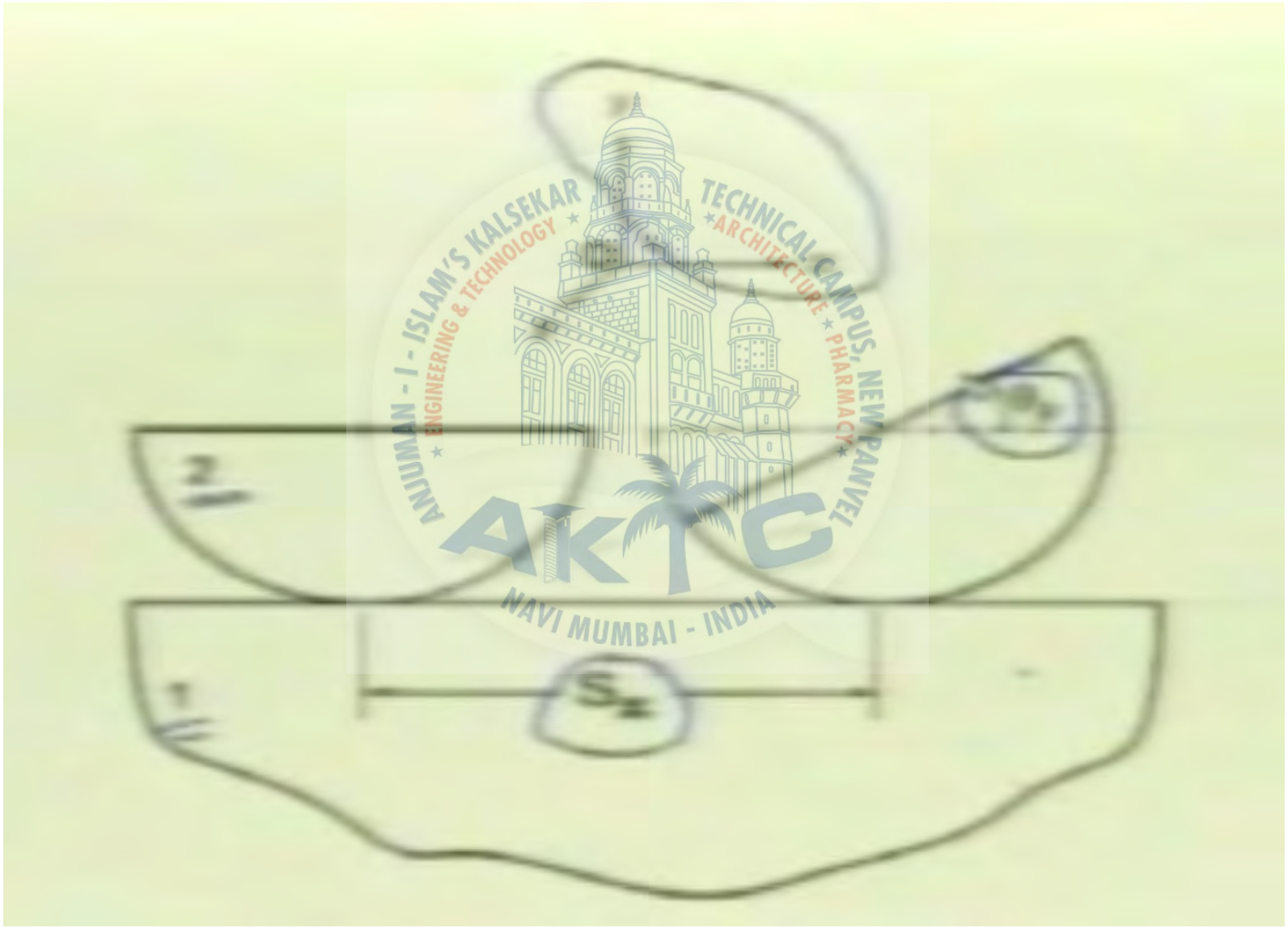


Type	Symbol	DOF	Pair Variable
Revolute (Hinge)	R	1	θ
Prismatic (Sliding)	P	1	s
Screw (Helix)	H	1	θ or s
Cylindric	C	2	θ and s
Spheric (Globular)	G	3	α, β, Φ
Planar	E	3	Sx, Sz, and θy

HIGHER PAIR



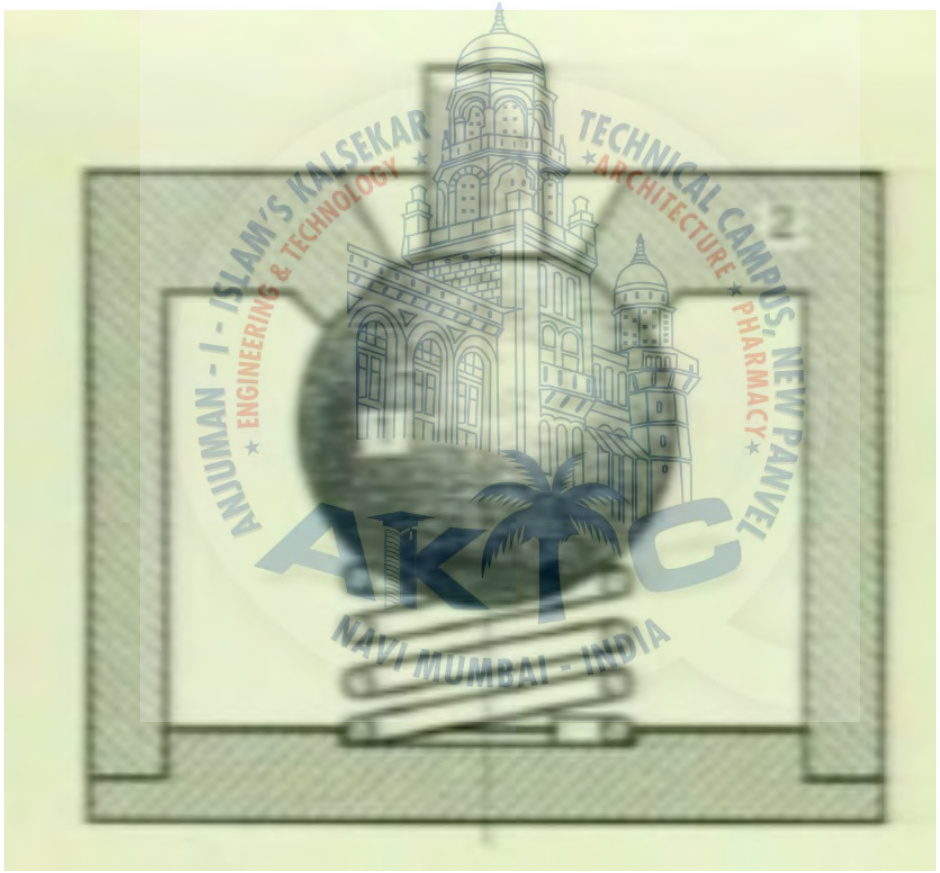
Higher Pair



Acc. to Nature of Mechanical Arrangements

- Self Closed Pair
- Forced Closed Pair

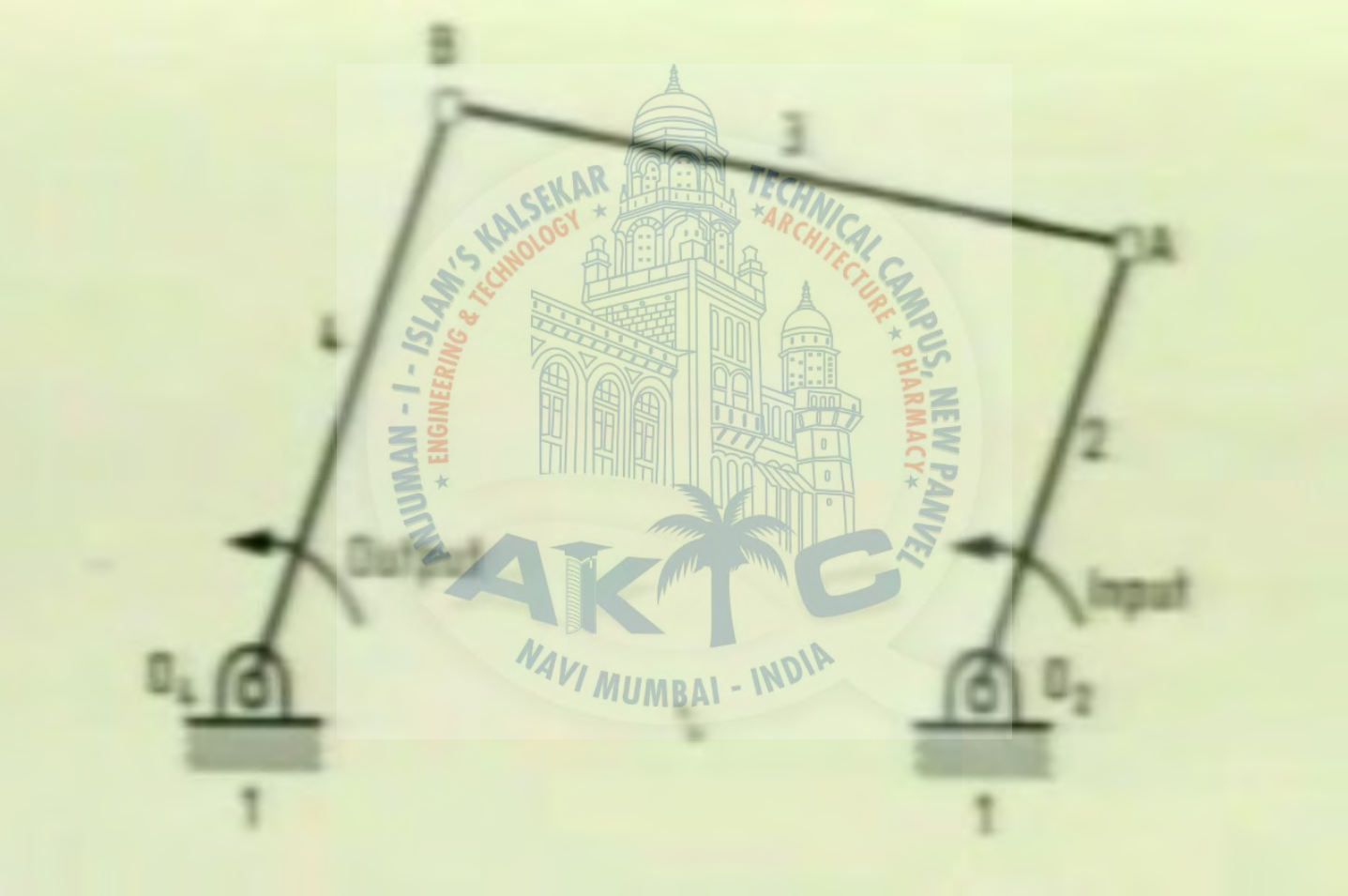
Spheric Forced Pair



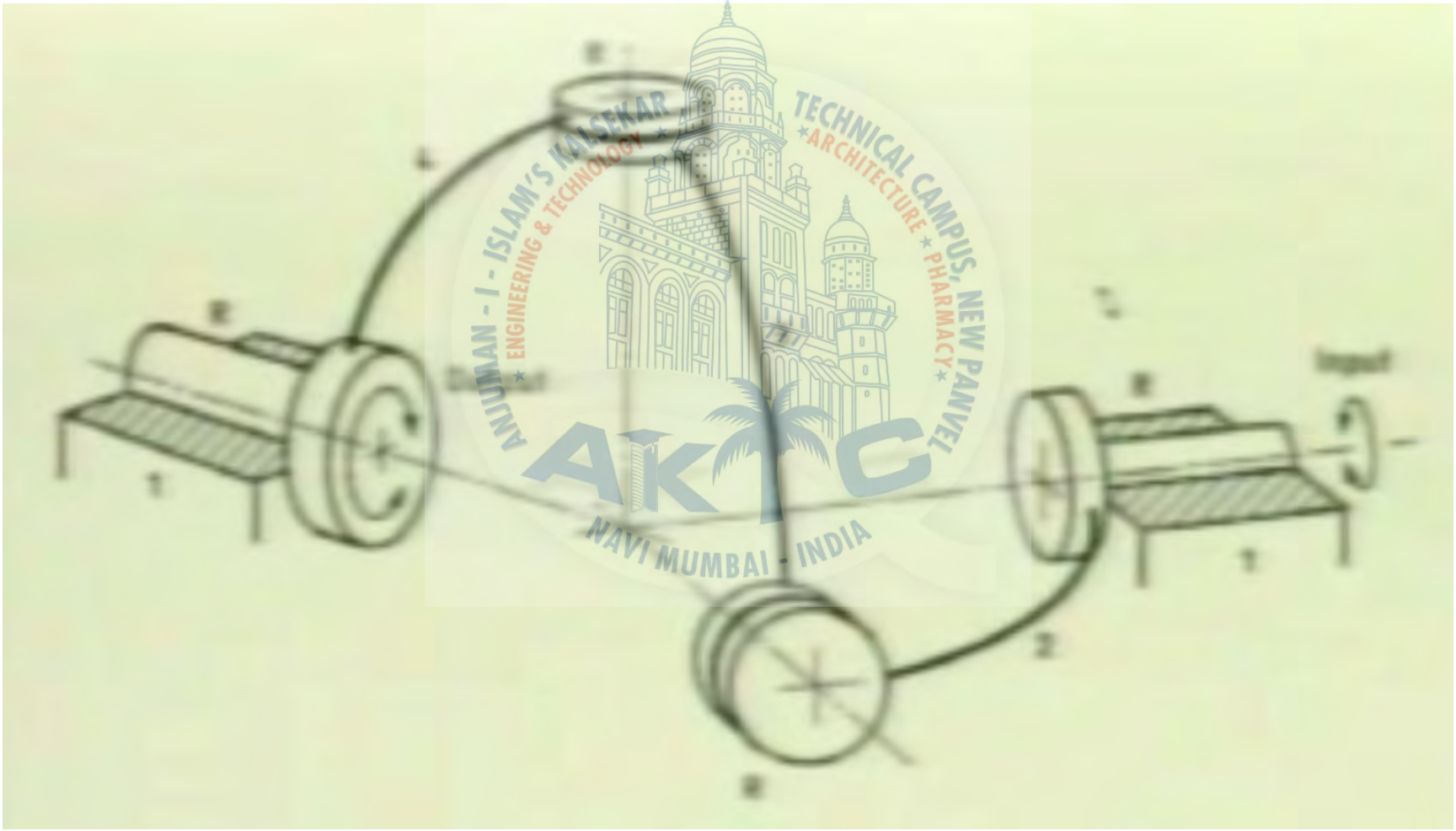
Classification of Different Mechanisms

- Planar
- Spherical
- Spacial

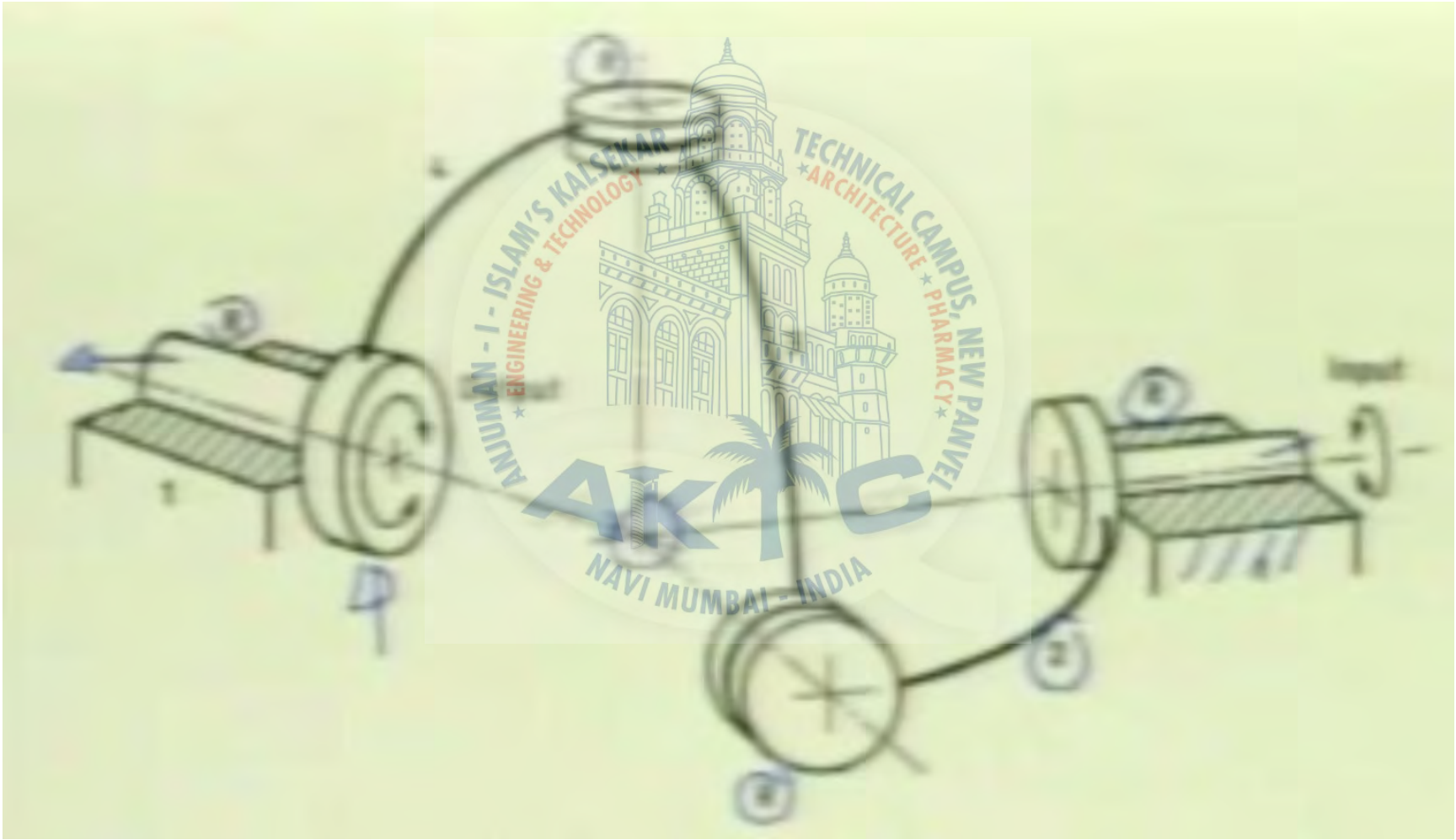
4R- Planar Linkages



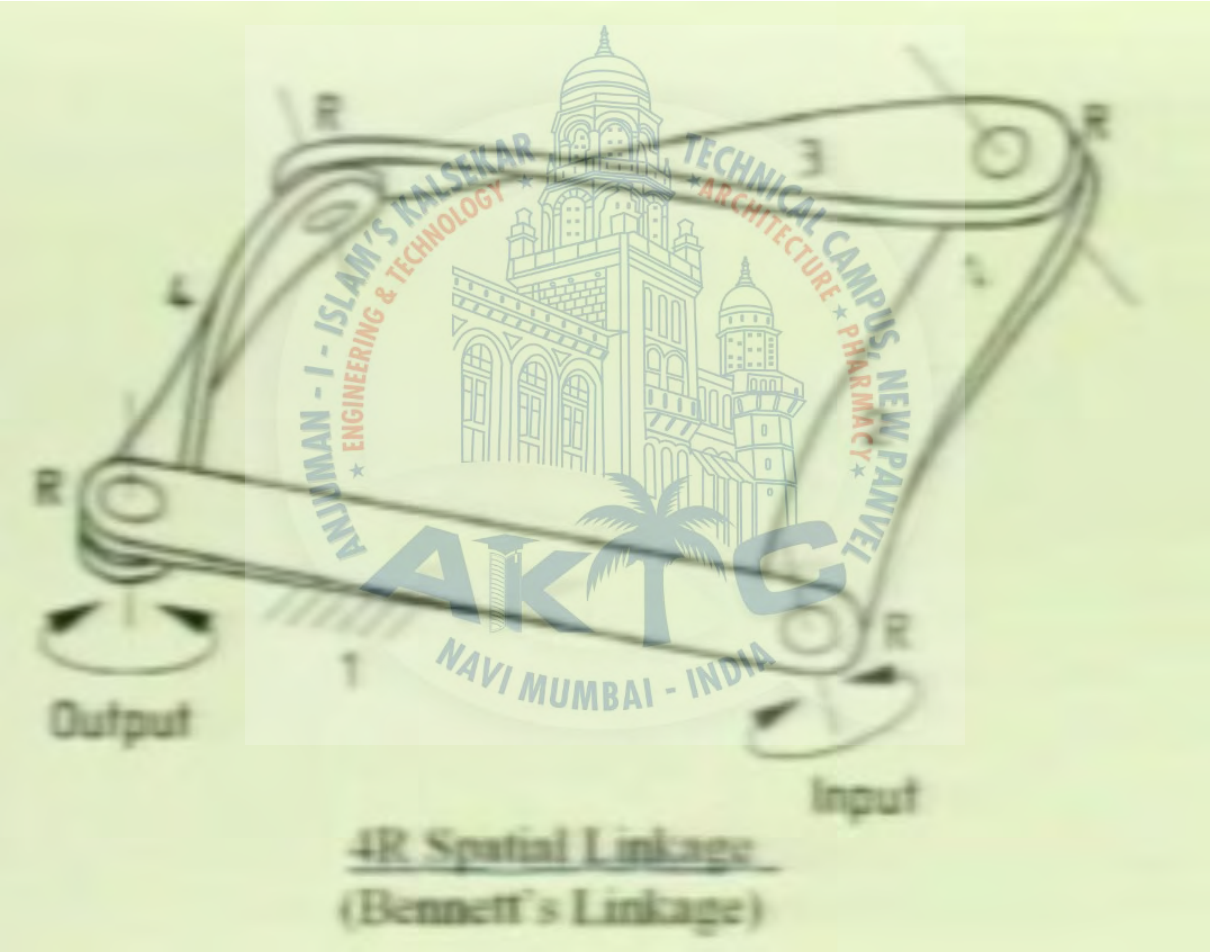
4R Spherical Linkage Hooks Joint



4R Spherical Linkage Hook's Joint



4R Spatial Linkage



Types Of Problems in **KINEMATICS**

1. **Analysis**
2. **Synthesis**

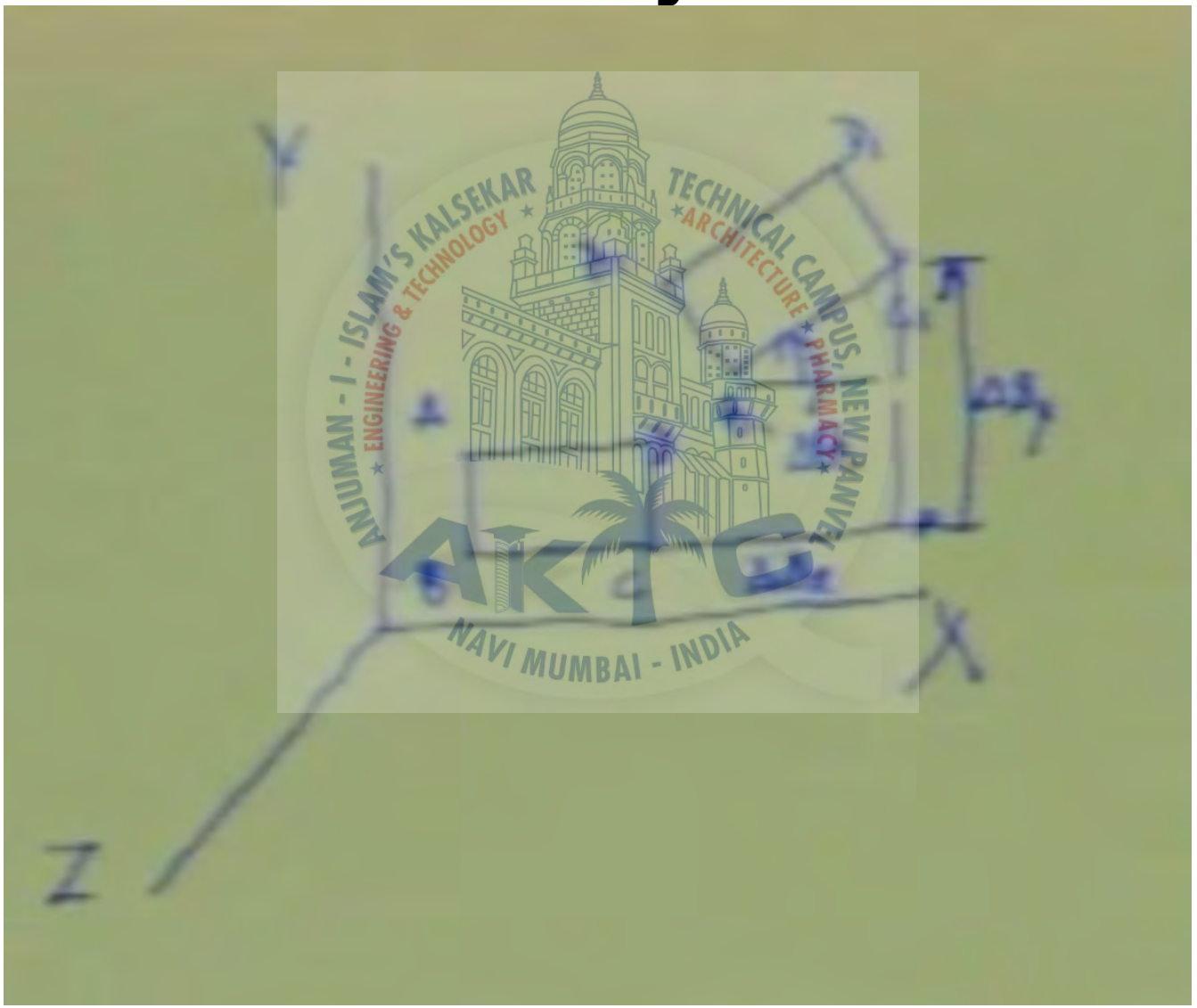
- In **Kinematic Analysis** one is given a mechanism and the task is to determine the various relative motions that can take place in that mechanism

In **Kinematic Synthesis** one has to come up with a design of a mechanism to generate prescribed required relative motion characterstic

Kinematic Analysis

Kinematic Synthesis

PLANAR 3-DOF System



Kinematic Link

Types of Kinematic Link

- Rigid Link
- Flexible Link
- Fluid Link

Kinematic chain: it is series of links connected by kinematic pairs

Closed Chain: Every link is connected to at least two other links

No of D.O.F. for Planar Mech

- Unconnected rigid body in planar mechanism have 3- DOF
- R-1
- P-1
- H (Screw)- 1

- C (Cylindrical Pair)-2
- H (higher pair)-2

Degree of Freedom

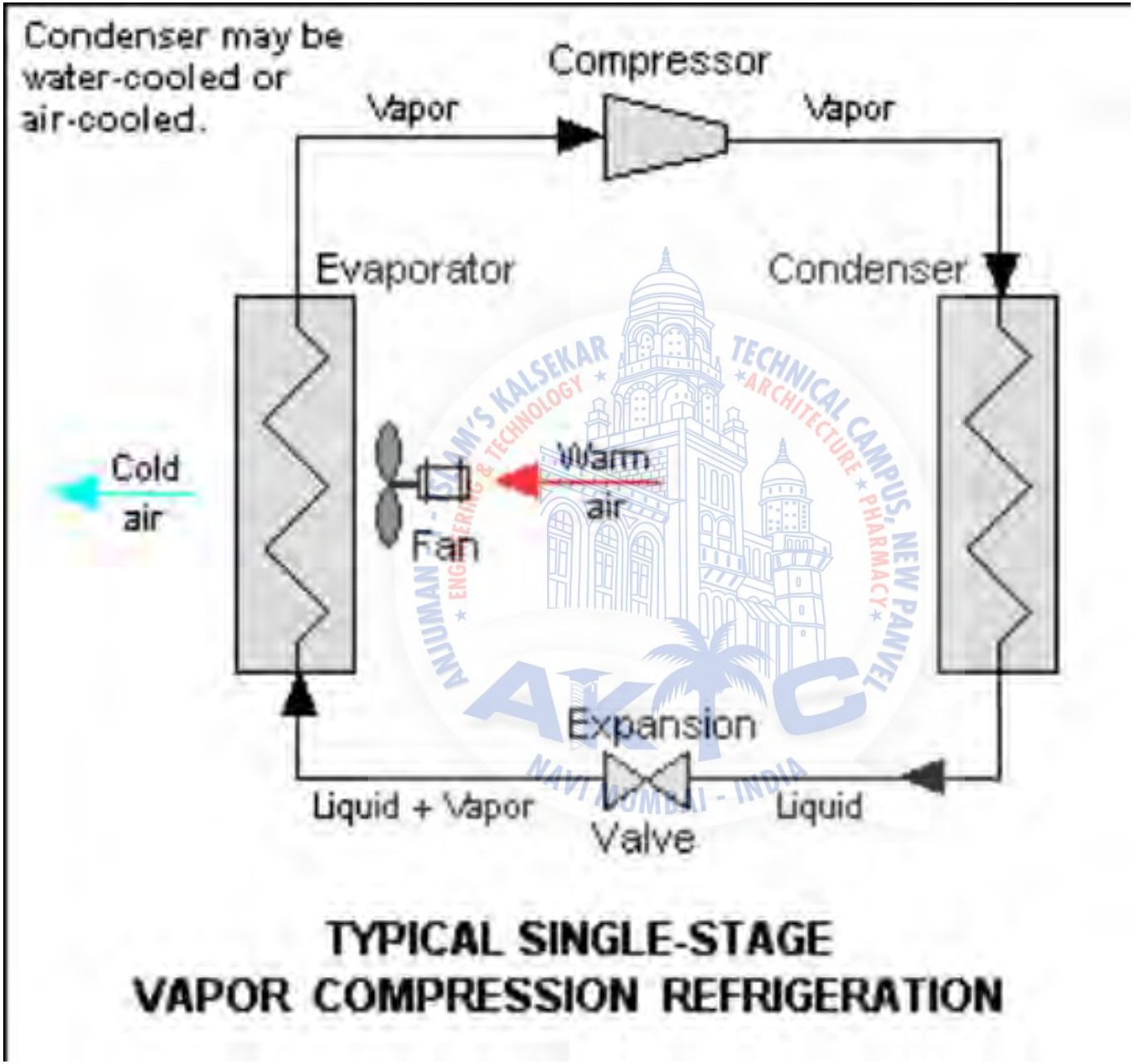
- Mechanism: A closed kinematic chain with one link fixed

- The DoF of mechanism is gven by no. of independent pair variables needed to completely define the relative movements between all its linkages

- Mechanism is said to be constrained when no. of inputs equals to degree of freedom of mechnism

- Constrained mechanism means O/P of mechanism can move in unique fashion

- Non constrained Mechanism in Differential Gear Box of an Automobile



TYPICAL SINGLE-STAGE VAPOR COMPRESSION REFRIGERATION

Kinematic Chain

A *kinematic chain* is a series of links connected by kinematic pairs.

The chain is said to be *closed chain* if every link is connected to at least two other links, otherwise it is called an *open chain*.

- Singular Link- Connected to one other link
- Binary Links- Connected to two other links
- Tertiary Links- Connected to three other links

Conditions to form a Kinematic Chain

- *l= 2p-4*
- *j= 3l/2-2*
- *j+ H/2= 3l/2-2*

l= no. of links

p= no. of. lower pairs

j= no. of joints

H= no. of higher pairs

Kutzbach criterion for the mobility of a mechanism having plane motion

- $n = 3 (l – 1) – 2 j – h$

- *n = number of degrees of freedom*
- *j = number of binary joints or lower pairs*
- *l = number of links*
- *h = number of higher pairs*

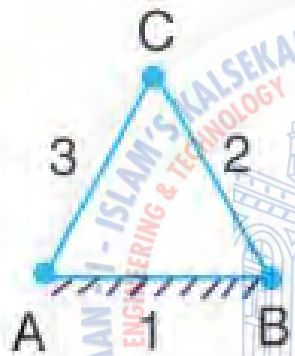
(*a) When n = 0, then the mechanism forms a structure and no relative motion between the* links is possible

(*b) When n = 1, then the mechanism can be driven by a single input motion*

(*c) When n = 2, then two separate input motions are necessary to produce constrained* motion for the mechanism,

(*d) When n = – 1 or less, then there are redundant constraints in the chain and it forms a* statically indeterminate structure

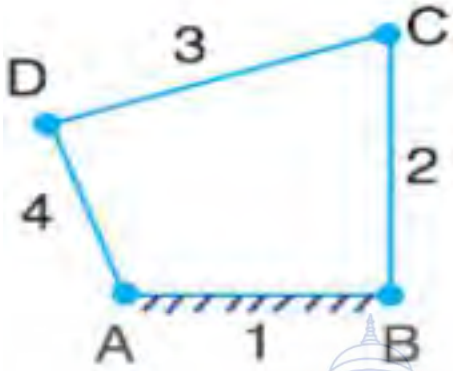
Application of Kutzbach Criterion to Plane Mechanisms



(*a*) Three-bar mechanism

three links and three binary joints, i.e. l = 3 and j = 3.

∴ n = 3 (3 – 1) – 2 × 3 = 0



(*b*) Four bar mechanism

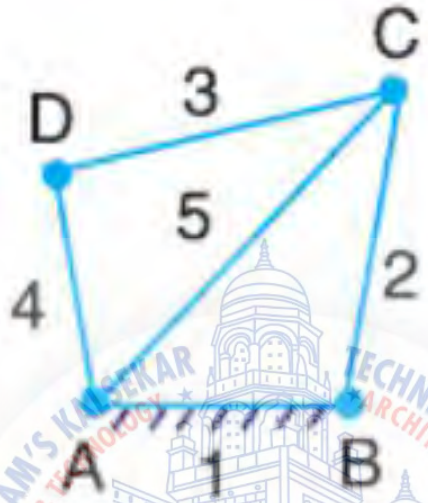
four links and four binary joints, *i.e. l = 4 and j = 4.*

∴ *n = 3 (4* *= 1*

(*c*) Five bar mechanism

five links and five binary joints, *i.e. l = 5, and j = 5.*

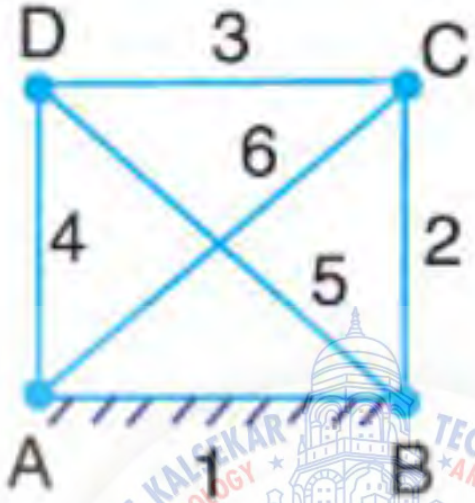
∴ *n = 3 (5 – 1) – 2 × 5 = 2*



(*d*) Five bar mechanism.

five links and six equivalent binary joints (because there are two binary joints at B and D, and two ternary joints at A and C), i.e. l = 5 and j = 6.

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



(e) Six bar mechanism

six links and eight equivalent binary joints (because there are four ternary joints at A, B, C and D), i.e. l = 6 and j = 8.

$\therefore n = 3 (6 - 1) - 2 \times 8 = -1$

Grubler's Criterion for Plane Mechanisms

The Grubler's criterion applies to mechanisms with only single degree of freedom joints where the overall movability of the mechanism is unity. Substituting *n = 1 and h = 0 in Kutzbach* equation, we have

$3(l-1)-2j=1$ or $\mathbf{3l-2j-4=0}$

a plane mechanism with a movability of 1 and only single degree of freedom joints can not have odd number of links

KINEMATIC INVERSION

The process of fixing different links of a kinematic chain one at a time to produce distinct mechanisms is called kinematic inversion.

Here the relative motions of the links of the mechanisms remain unchanged.

Types of Kinematic Chains important for this Subject:

The most important kinematic chains are those which consist of four lower pairs, each pair being a sliding pair or a turning pair. The following three types of kinematic chains with four lower pairs are important from the subject point of view :

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

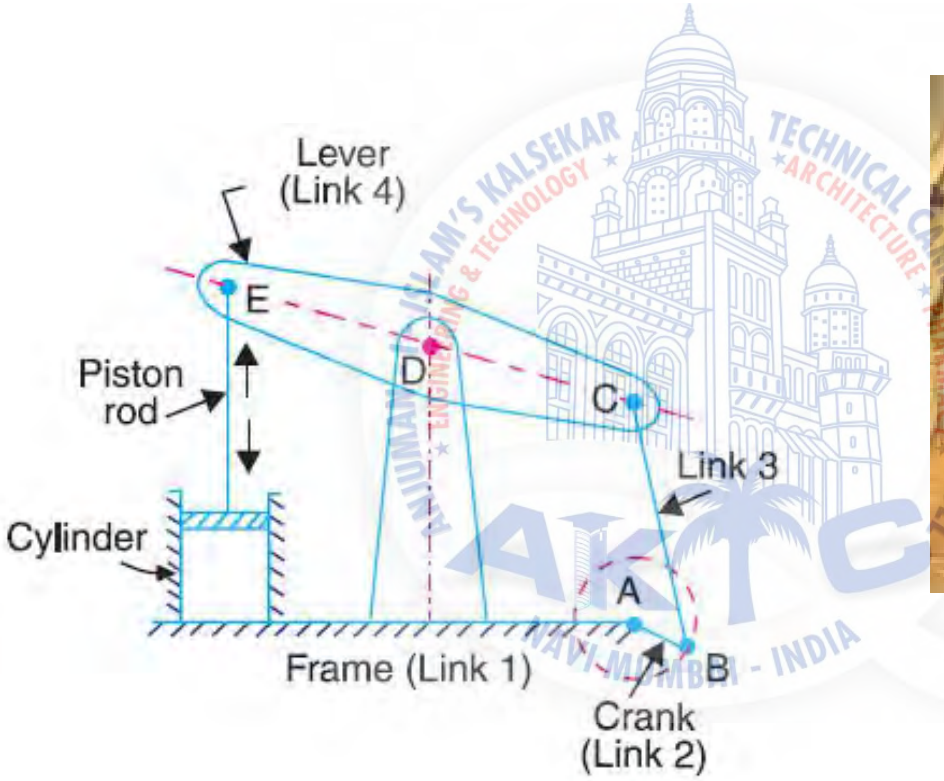
Grashof's law for a four bar mechanism,

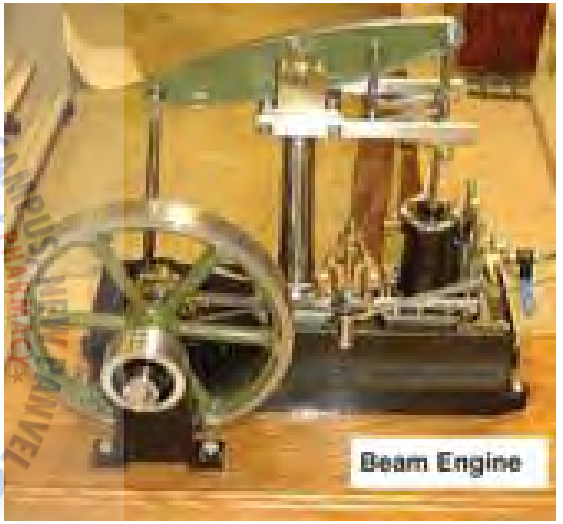
the sum of the shortest and longest link lengths should not be greater than the sum of the remaining two link lengths if there is to be continuous relative motion between the two links.

A very important consideration in designing a mechanism is to ensure that the input crank makes a complete revolution relative to the other links.

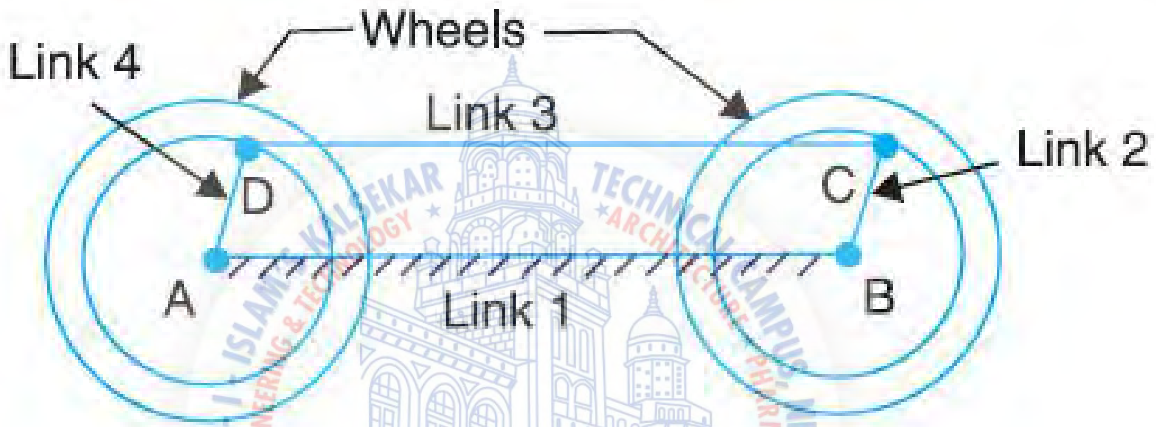
Inversions of Four Bar Chain

1. *Beam engine (crank and lever mechanism).*



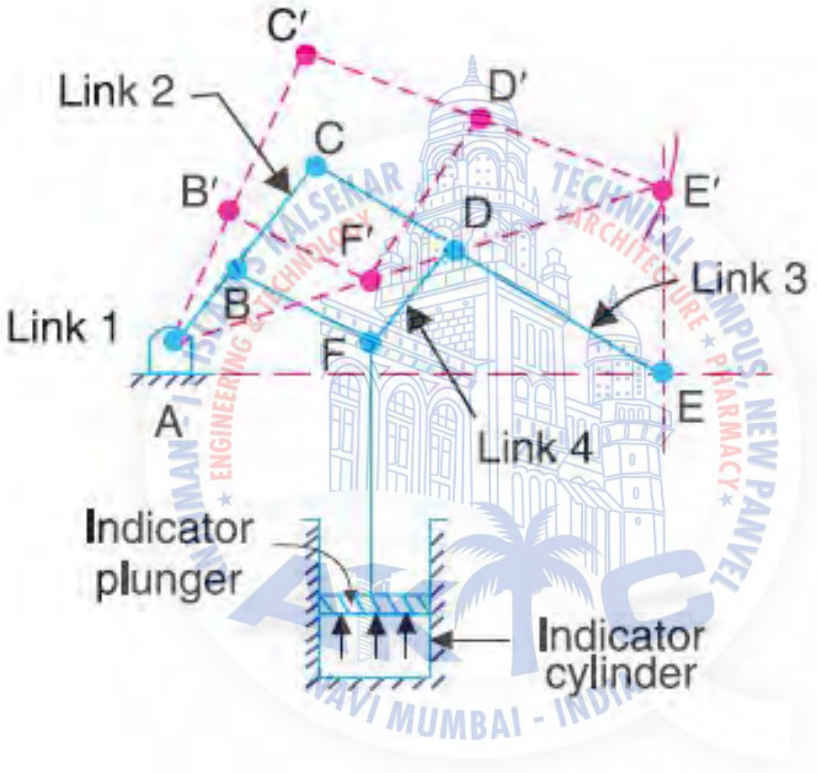


Coupling rod of a locomotive (Double crank mechanism)

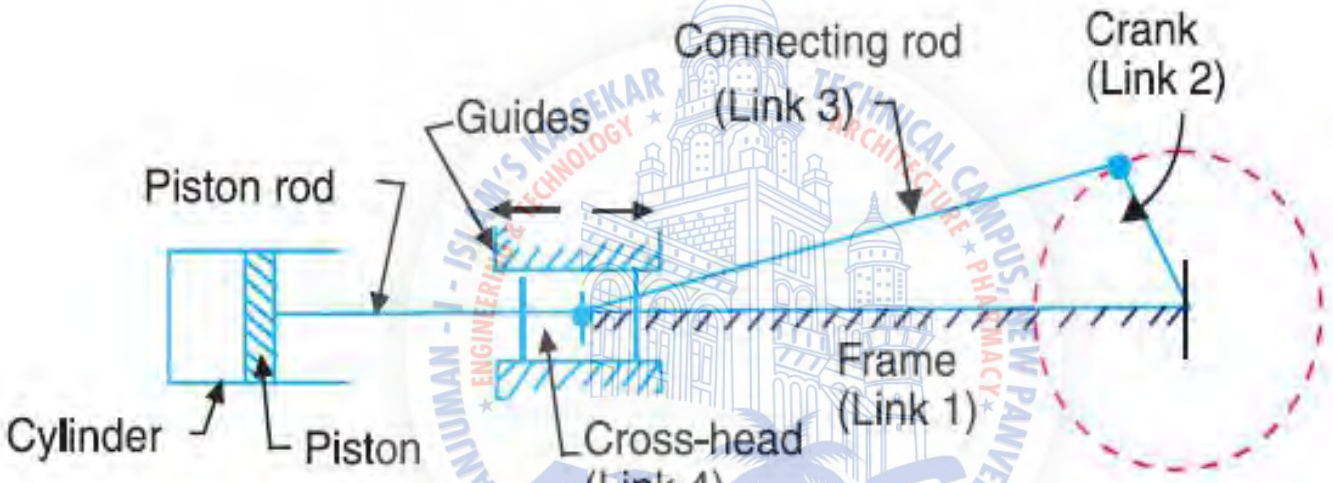


In this mechanism, the links *AD and BC (having equal length) act as cranks and are connected* to the respective wheels. The link *CD acts as a coupling rod and the link AB is fixed in order* to maintain a constant centre to centre distance between them. This mechanism is meant for transmitting rotary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

Watt's indicator mechanism (Double lever mechanism)



Single Slider Crank Chain

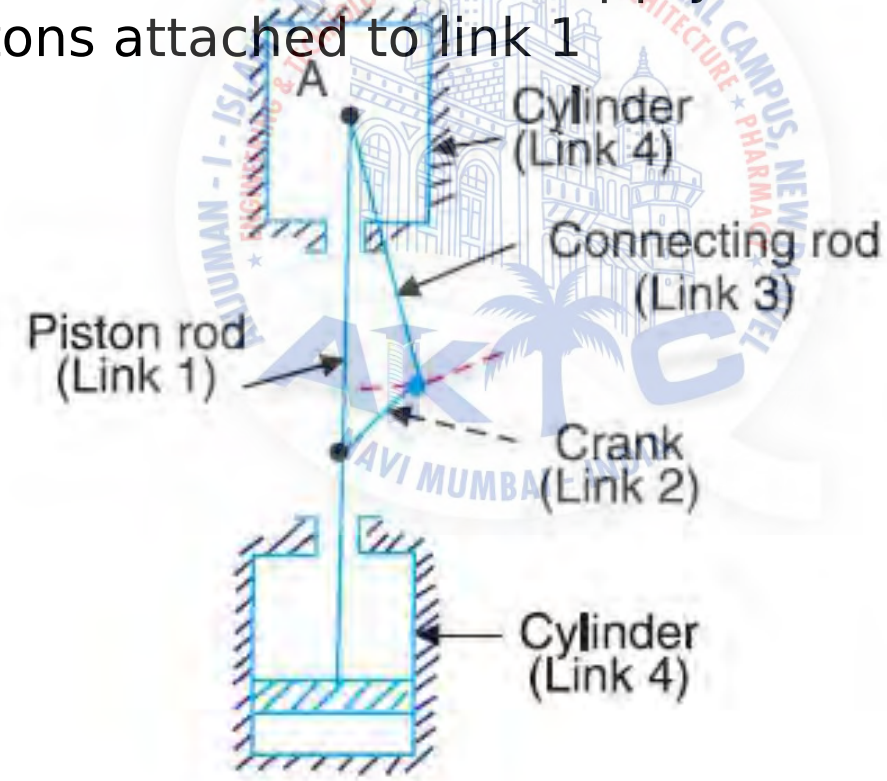


Inversions of Single Slider Crank Chain

1. *Pendulum pump or Bull engine*
2. *Oscillating cylinder engine*
3. *Rotary internal combustion engine or Gnome engine*
4. *Crank and slotted lever quick return motion mechanism*
5. *Whitworth quick return motion mechanism*

1. Pendulum pump or Bull engine

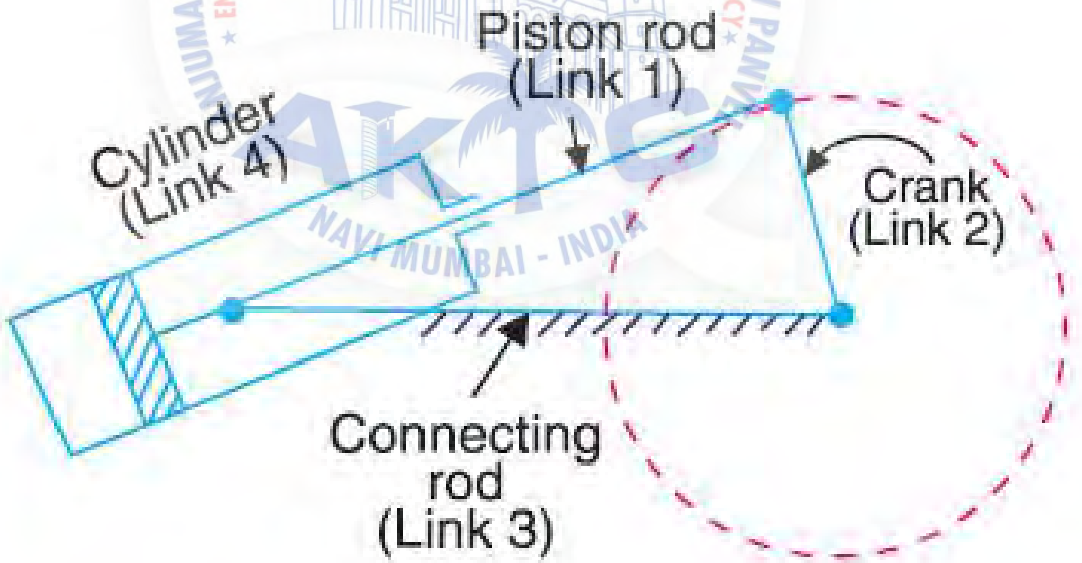
In this mechanism, the inversion is obtained by fixing the cylinder or link 4 (*i.e. sliding pair), as shown in Fig. 5.23. In this case, when the crank (link 2) rotates,* the connecting rod (link 3) oscillates about a pin pivoted to the fixed link 4 at *A and the piston* attached to the piston rod (link 1) reciprocates. The duplex pump which is used to supply feed water to boilers have two pistons attached to link 1



2. Oscillating cylinder engine

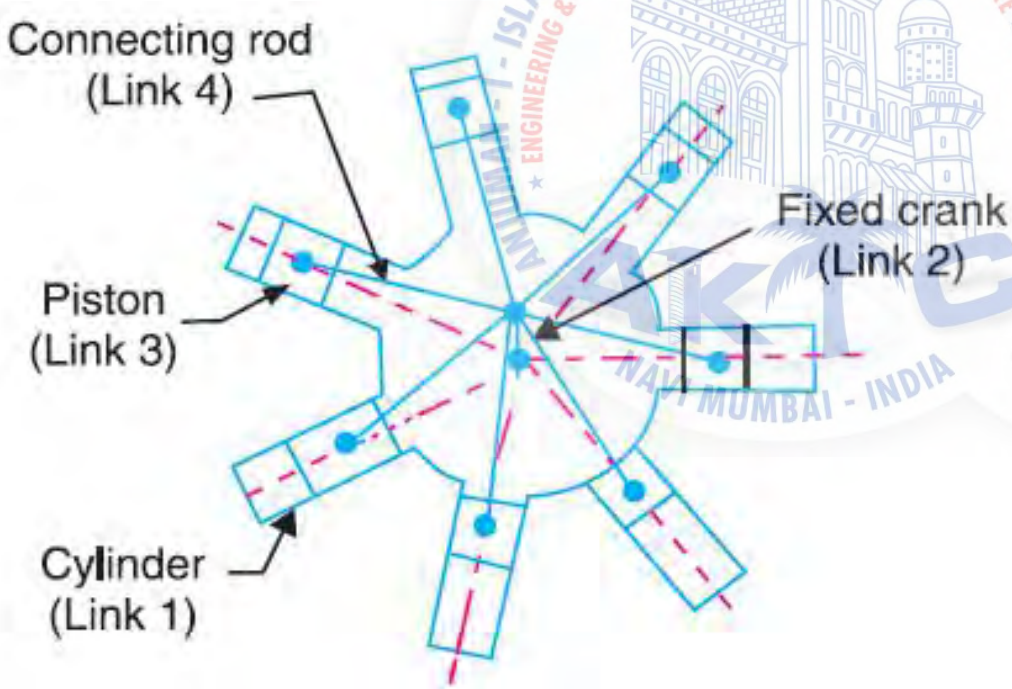
Is used to convert reciprocating motion into rotary motion. In this mechanism, the link 3 forming the turning pair is fixed.

When the crank (link 2) rotates, the piston attached to piston rod (link 1) reciprocates and the cylinder (link 4) oscillates about a pin pivoted to the fixed link at *A*.



3. *Rotary internal combustion engine or Gnome engine.*

It consists of seven cylinders in one plane and all revolves about fixed centre *D, as shown in* Fig. 5.25, while the crank (link 2) is fixed. In this mechanism, when the connecting rod (link 4) rotates, the piston (link 3) reciprocates inside the cylinders forming link 1.



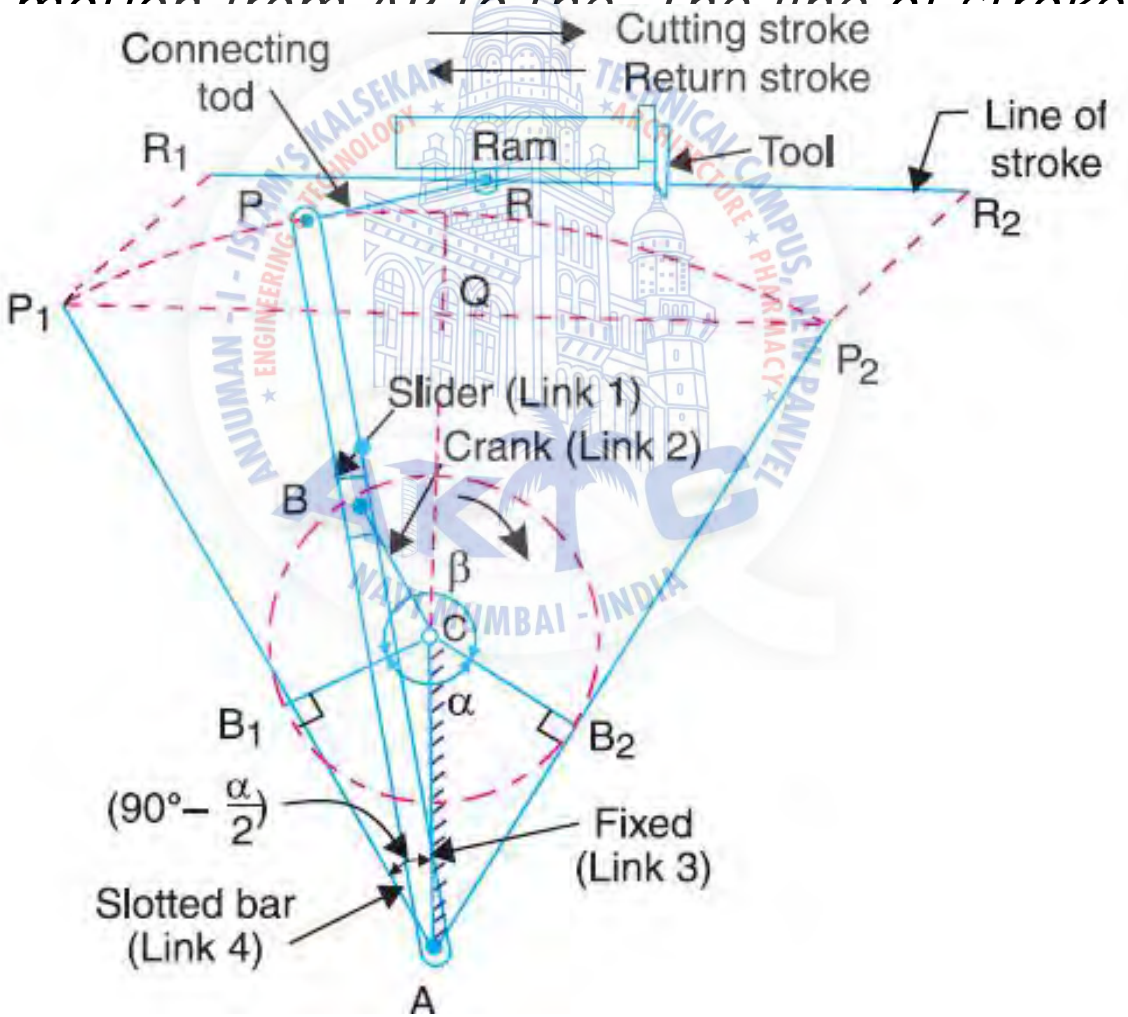
How is the working of a Shaper Machine/ Slotting machines/ IC engines?

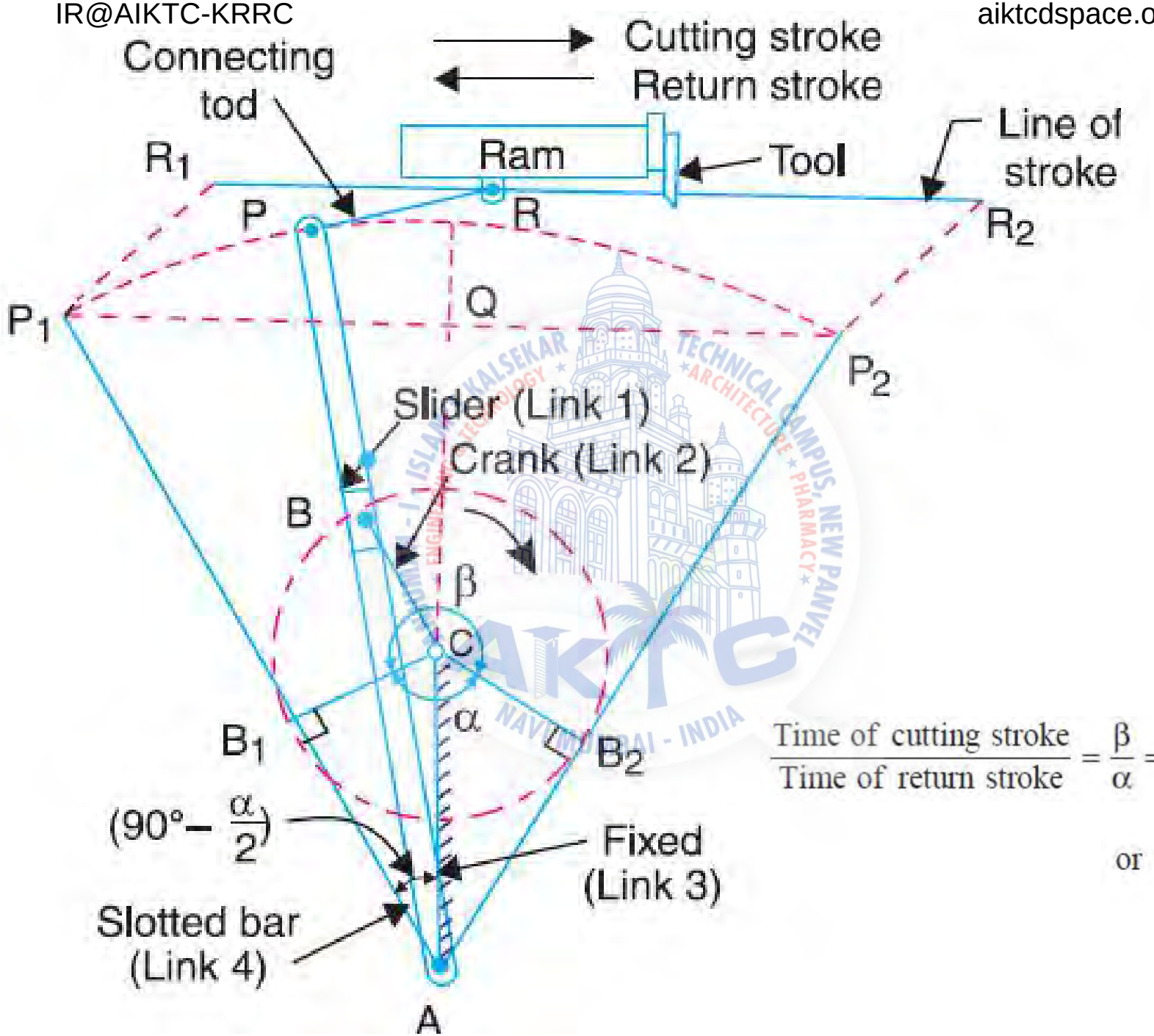
What are Desirable Properties for a Machining Operation?

4. Crank and slotted lever quick return motion mechanism.

(Shaper, Slotting M/C and Rotary ICE)

The driving crank *CB revolves with uniform angular speed about the fixed centre C. B slides along the slotted bar AP,* link *PR transmits the motion from AP to the. The line of stroke of the ram (i.e. R1R2) is*

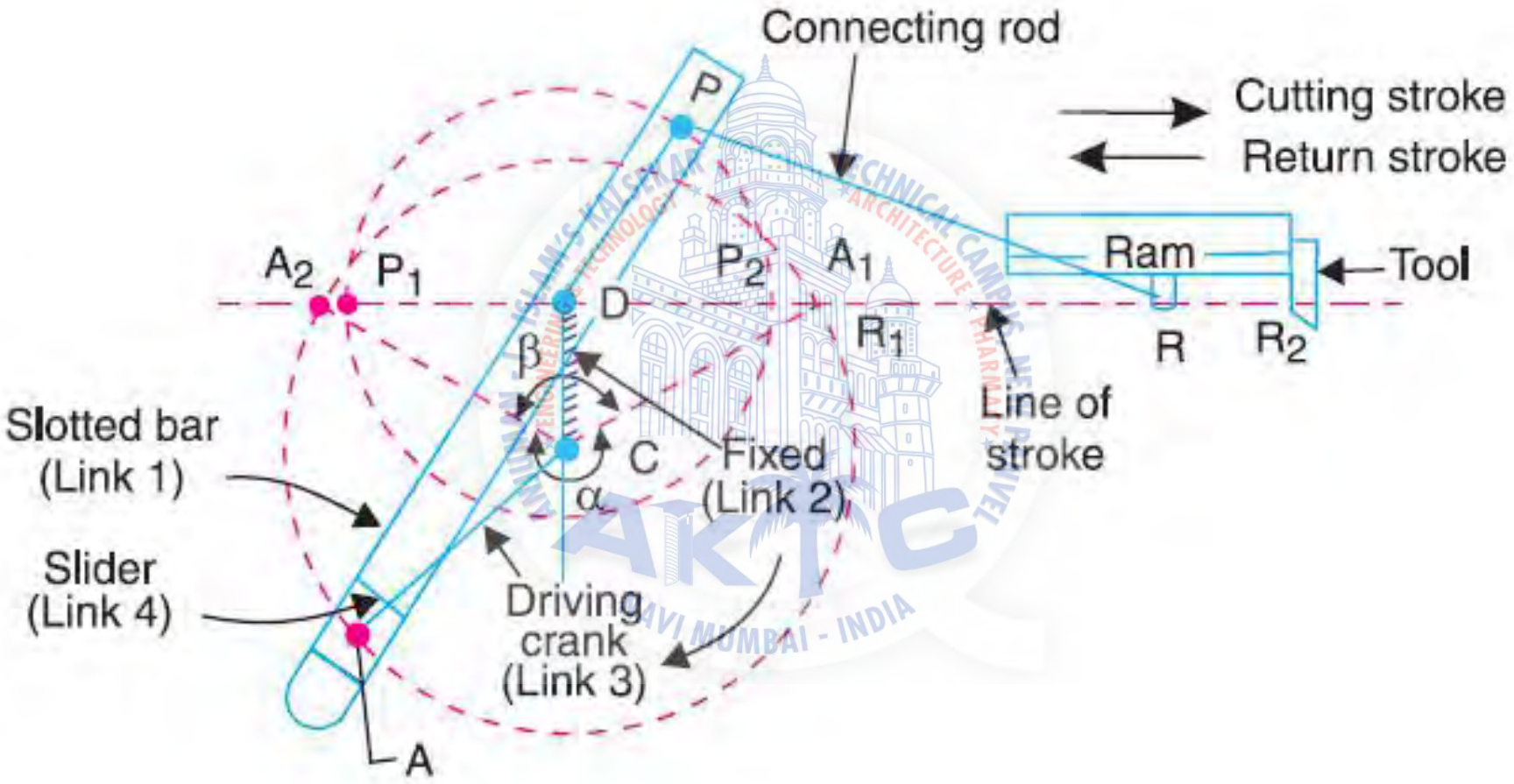




$$\frac{\text{Time of cutting stroke}}{\text{Time of return stroke}} = \frac{\beta}{\alpha} = \frac{\beta}{360° - \beta}$$

$$\text{or} \quad \frac{360° - \alpha}{\alpha}$$

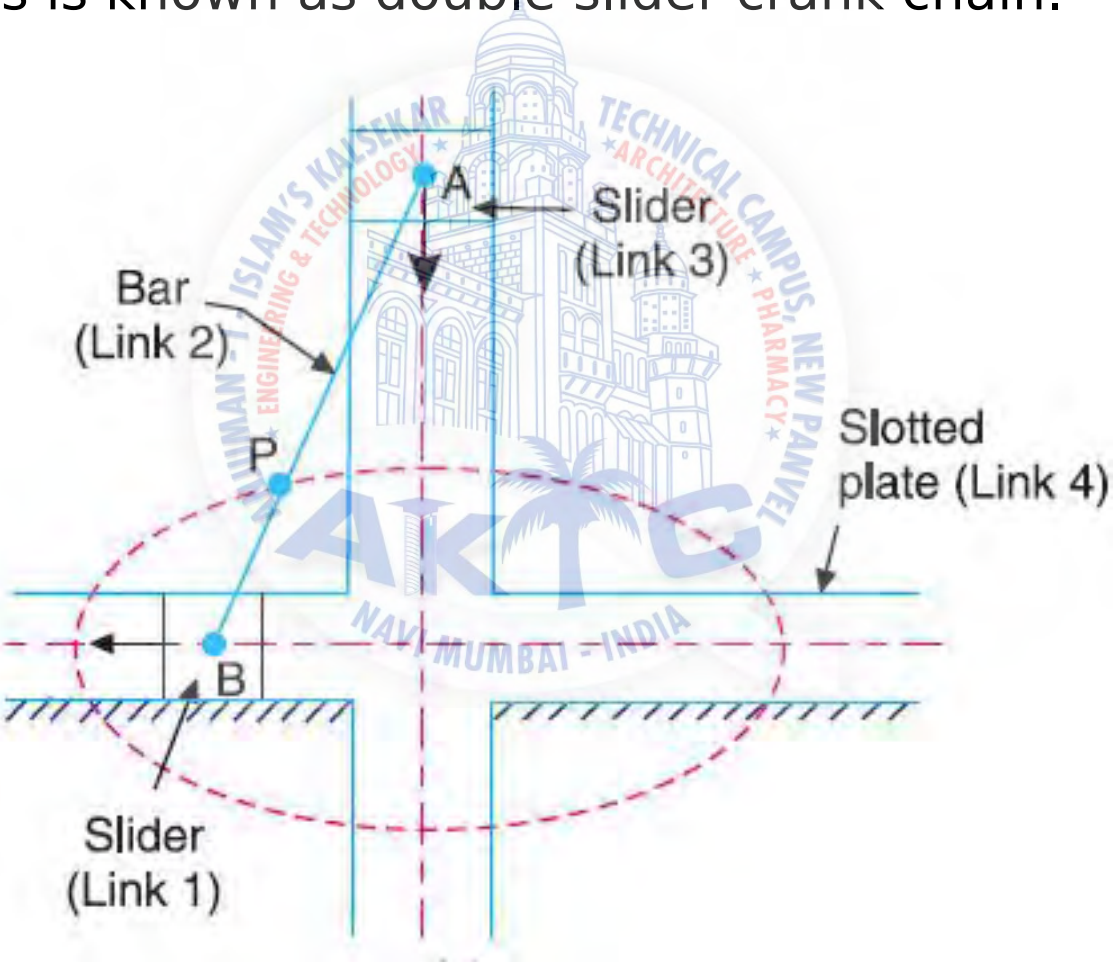
5. Whitworth quick return motion mechanism (shaping and slotting machines)



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

Double Slider Crank Chain

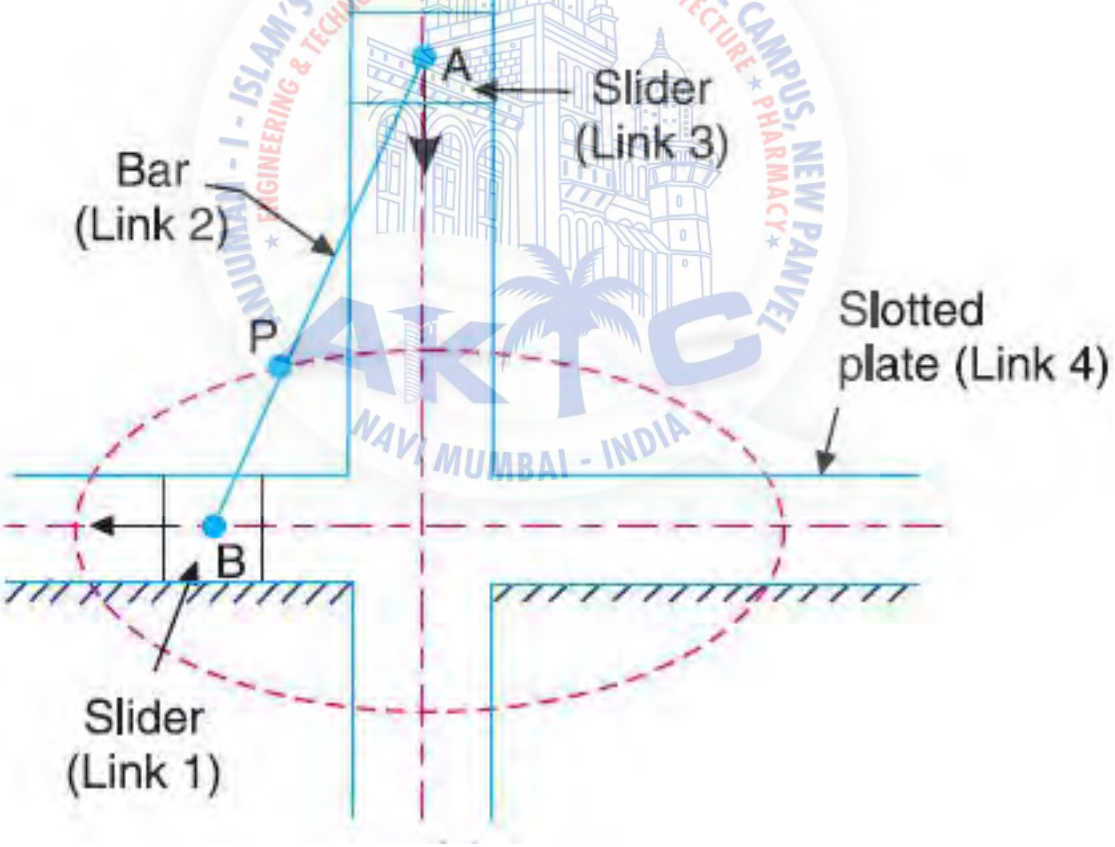
A kinematic chain which consists of two turning pairs and two sliding pairs is known as double slider crank chain.

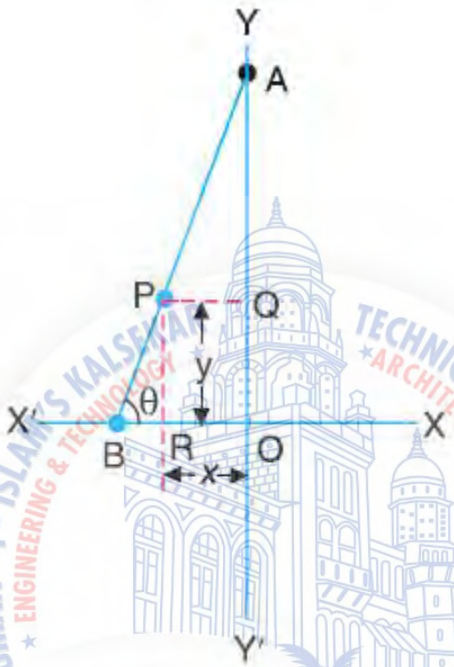


First Inversion of Double Slider Crank Chain

1.Elliptical trammels.

It is an instrument used for drawing ellipses.





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

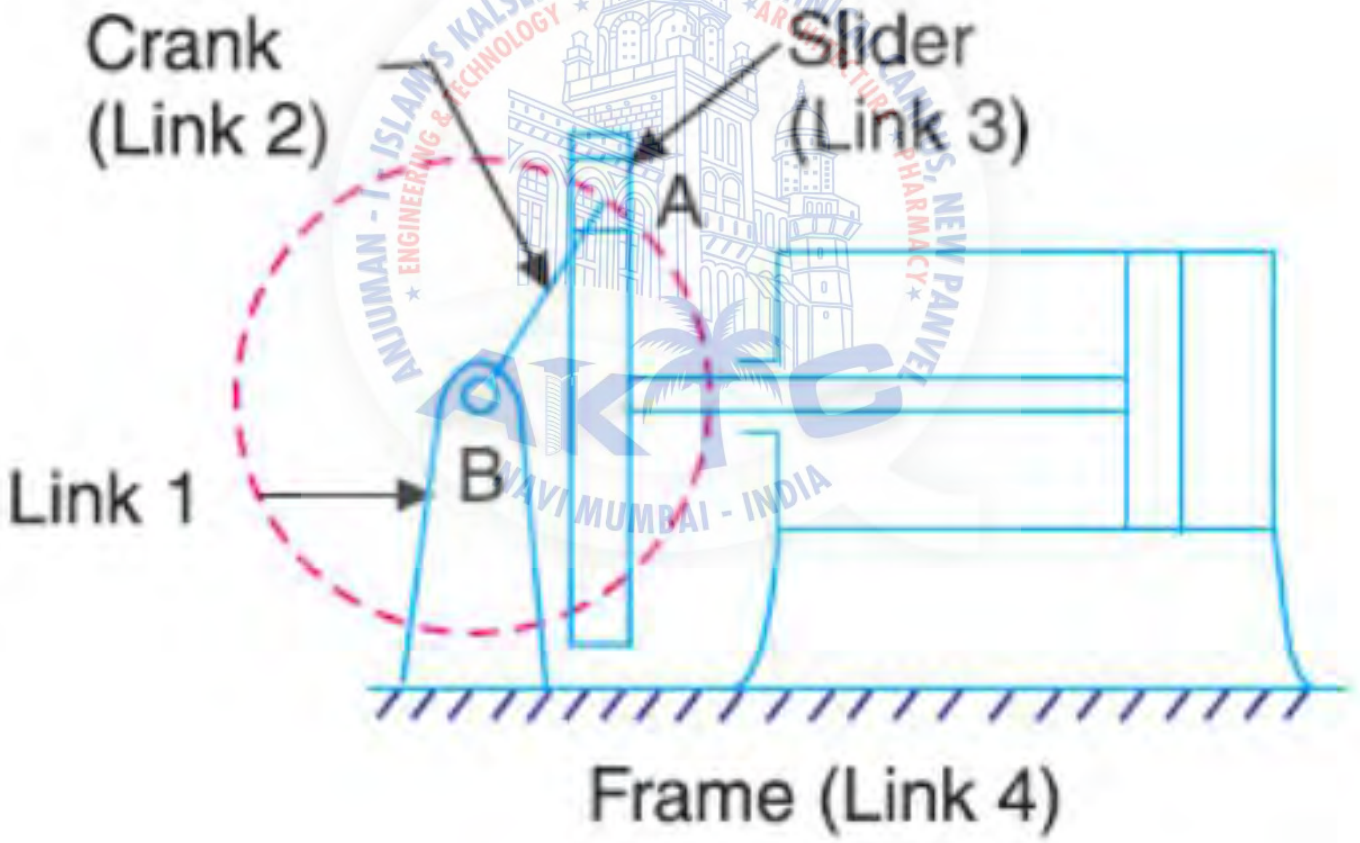
$\frac{x}{AP} = \cos\theta$; and $\frac{y}{BP} = \sin\theta$

Squaring and adding,

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

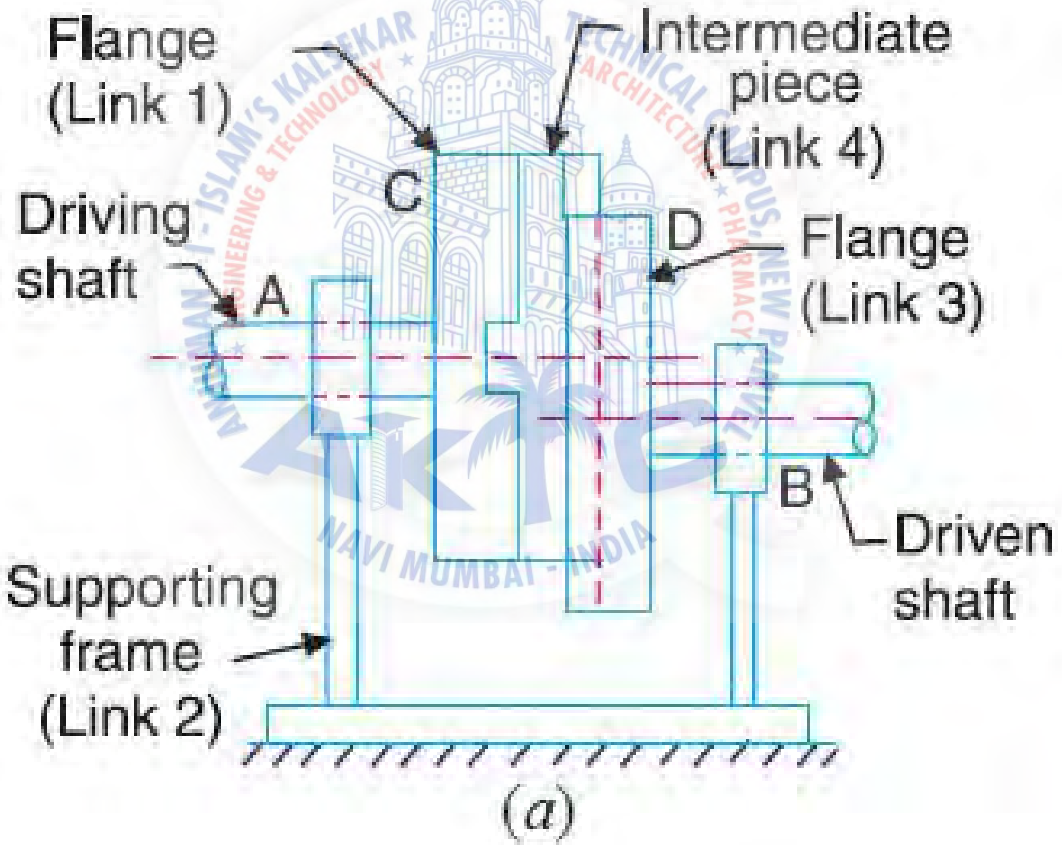
2. Scotch yoke mechanism

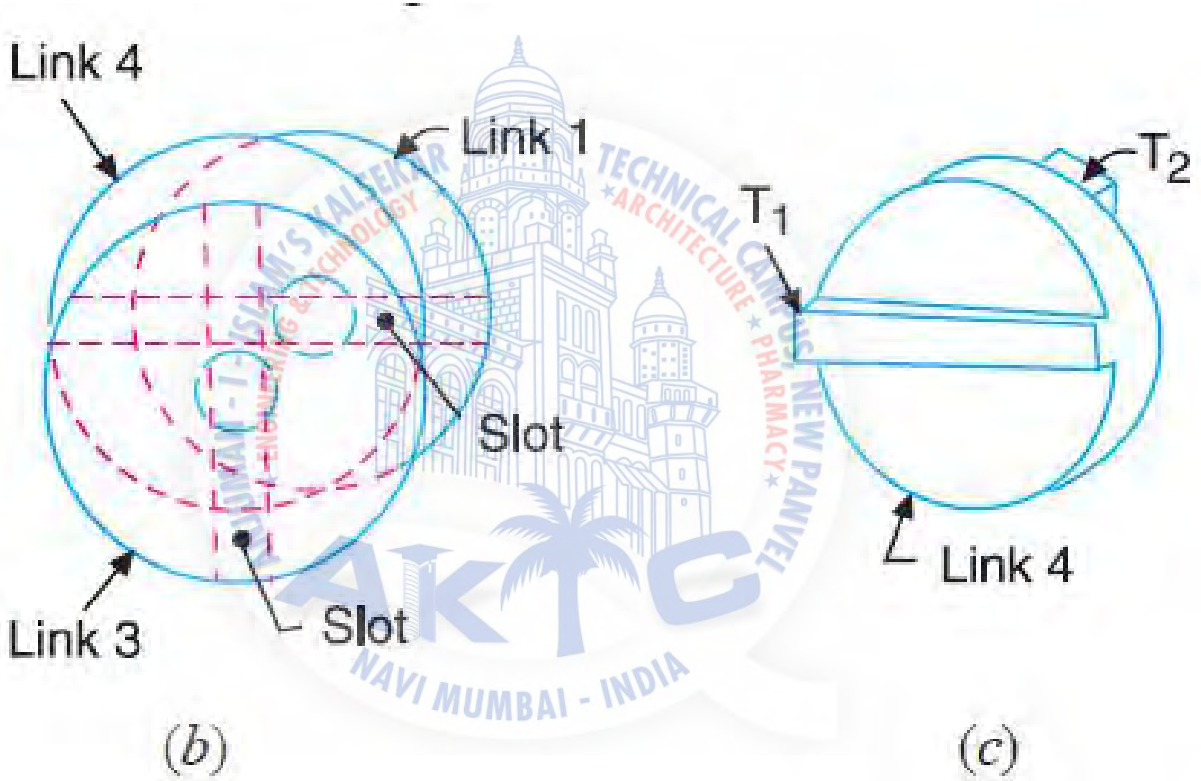
This mechanism is used for converting rotary motion into a reciprocating motion. The inversion is obtained by fixing either the link 1 or link 3.link 1 is fixed. In this mechanism, when the link 2 (which corresponds to crank) rotates about *B as centre.*



3. Oldham's coupling

An oldham's coupling is used for connecting two parallel shafts whose axes are at a small distance apart. The shafts are coupled in such a way that if one shaft rotates, the other shaft also rotates at the same speed.




Link 4
Link 1
Slot
Link 3
Slot
(b)
T_2
T_1
Link 4
(c)