MECHANICS OF MACHINERY

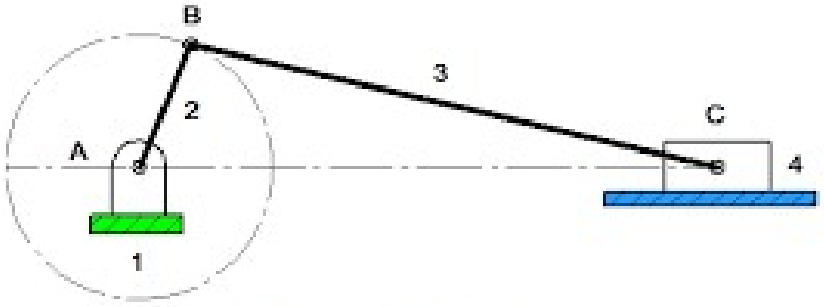
Dynamics

Kinematics:

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

Kinetics:

- *Studies the forces on the system which is in motion.*
- *It deals with inertia forces which arises from the combined effect of mass and motion of the machine parts*



Slider-Crank Mechanism

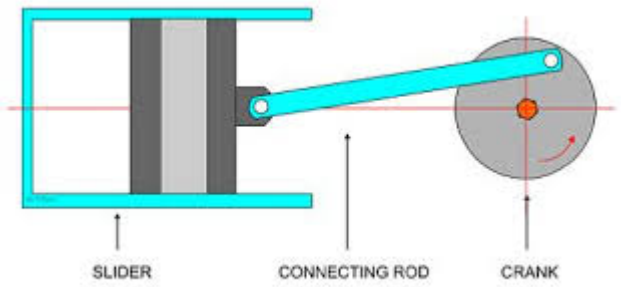
Kinematics

Kinetics

Mechanism and Machine

Mechanism (a fundamental unit for kinematic study)

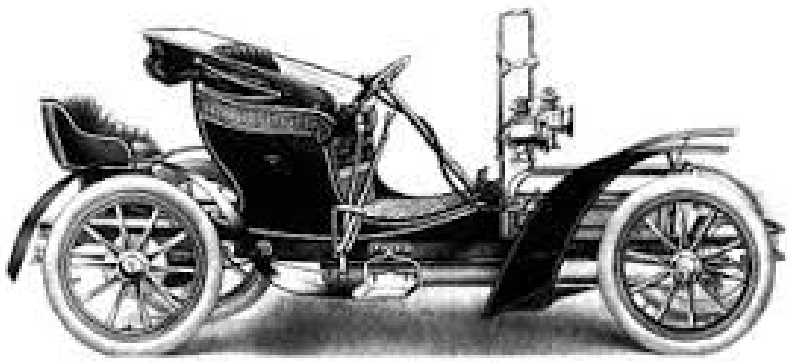
- *If a number of bodies are assembled in such a way that the motion of one causes constrained and predictable motion to the others, it is known as a mechanism.*
- *A mechanism transmits and modifies a motion.*



Mechanism and Machine

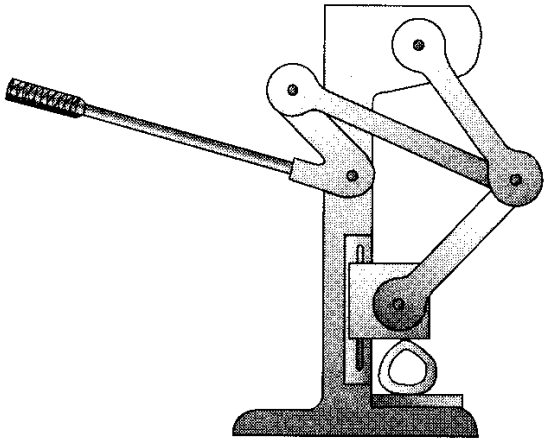
Machine

- *A machine is a mechanism or a combination of mechanisms which, apart from imparting definite motions to the parts, also transmits and modifies the available mechanical energy into some kind of desired work.*

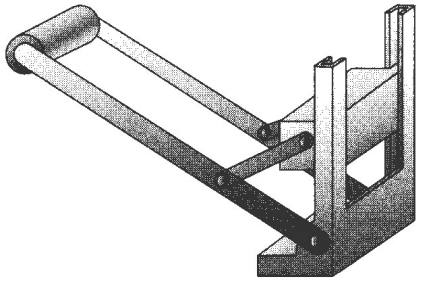


Mechanism and Machine

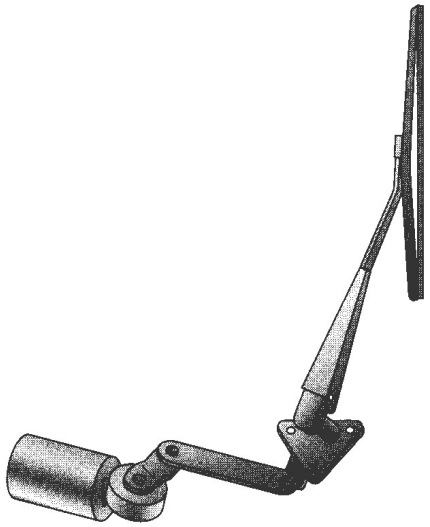
Mechanisms



Simple press



Can crusher



Rear-window wiper

Machines

Bulldozer

Amusement Park Ride

Mechanism and Machine

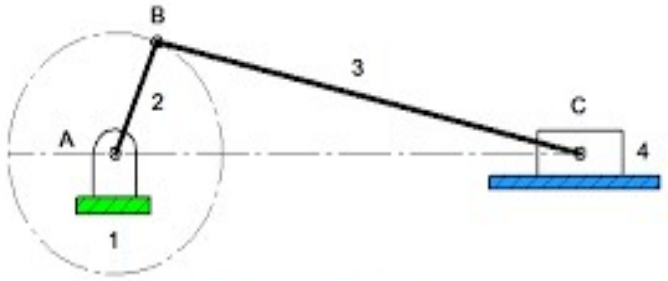
Machine	Mechanism
Machine modifies mechanical work	Mechanism transmits and modifies motion
A machine is a practical development of any mechanism	A mechanism is a part of a machine
A machine may have number of mechanism for transmitting mechanical work or power	A mechanism is a skeleton outline of the machine to produce motion between various links.

Terms and definitions

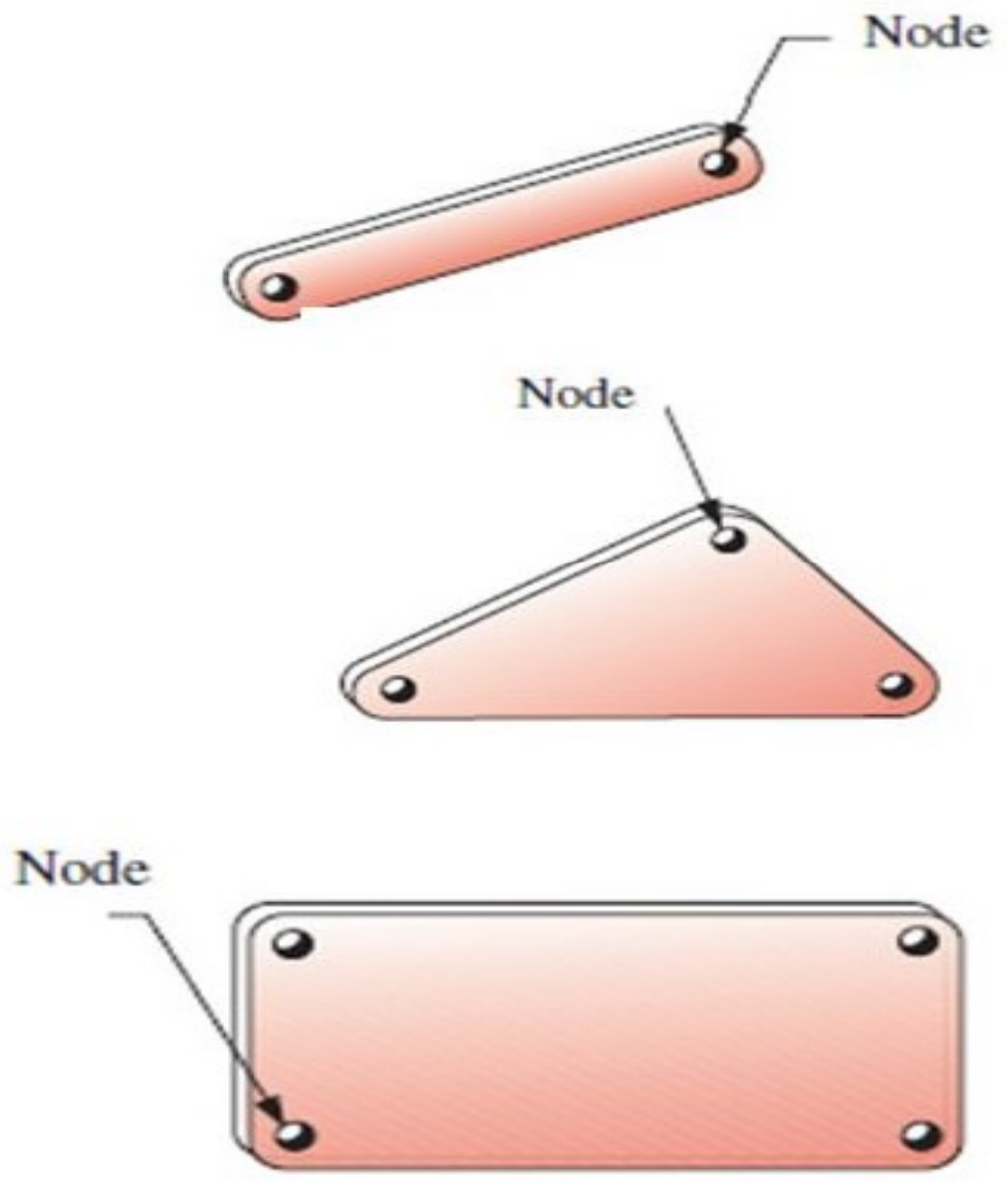
- Rigid body
  - A body is said to be rigid if it under the action of forces, it does not suffer any distortion.
  - i.e , the distance between any points on the body remains constant

- Semi rigid body
  - Normally are flexible
  - Under loading condition acts as rigid body for limited purpose
  - Also called as *resistant bodies*
  - *Eg. Belt under tension, fluid on compression*

- Kinematic link
  - A resistant body or a group of resistant bodies with rigid connections preventing their relative movement is known as a link.
  - It can be also defined as a member or a combination of members of a mechanism, connecting other members and having motion relative to them
  - Links can be classified into *binary, ternary and quaternary* depending upon their ends on which revolute or turning pairs can be placed
  - It must contain two or more nodes



Slider-Crank Mechanism

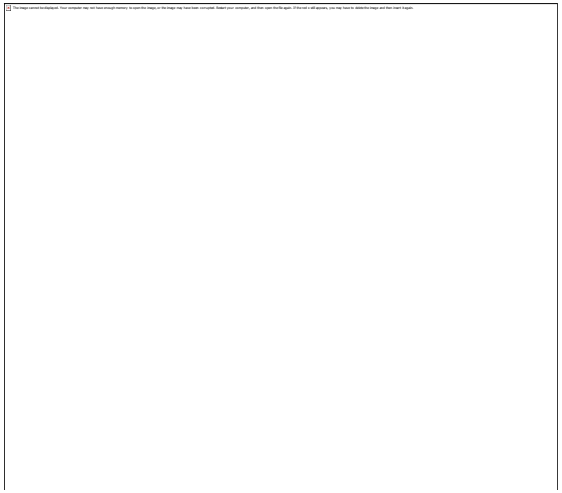

Node
Node
Node

Terms and definitions

- Joint
  - It is the connection between two or more links which allows some motion between the connecting links.

- Kinematic pair
  - The two links or elements of a machine, when in contact with each other, are said to form a pair.

  - If the relative motion between them is completely or partially constrained (*i.e. in a definite* direction), the pair is known as *kinematic pair.*



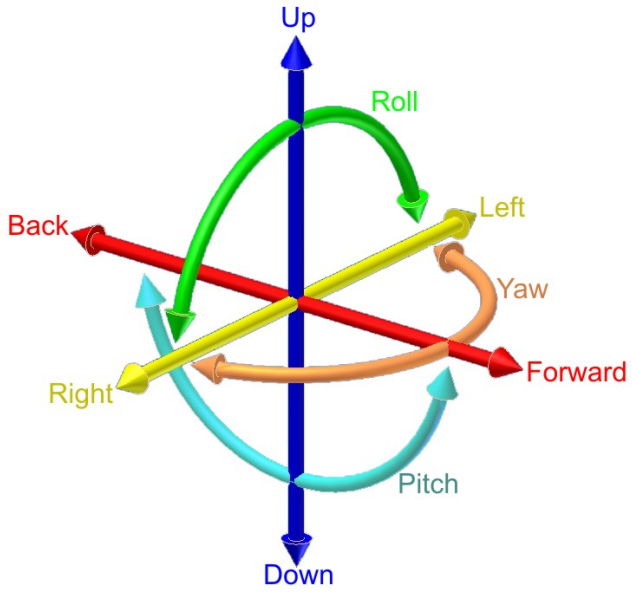
Constrained motion (or relative motion) can be broadly classified into three types.

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

- Completely constrained motion is a type of constrained motion in which relative motion between the links of a kinematic pair occurs in a definite direction by itself, irrespective of the external forces applied.
- In incompletely constrained motion, the relative motion between the links depend on the direction of external forces acting on them.
  - 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 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.
  - Piston reciprocating inside a cylinder in an internal combustion engine.

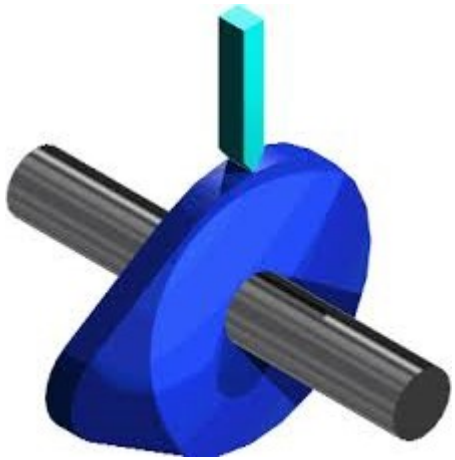
- Degree of freedom
  - Number independent motions(translational or rotary) required to completely specify the relative movement of a pair.
  - If DOF = + ve (mechanism)
  - If DOF = zero (structure)

- Structure(statics)
- Mechanism (kinematics)
- Machine (kinetics)



Classification of kinematic pair

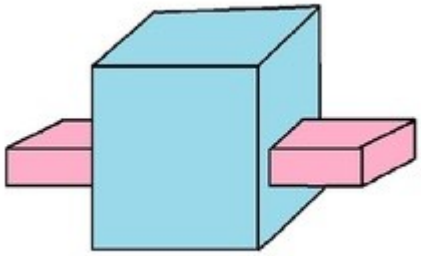
- Based on type of contact between the elements
  - Point, line, surface

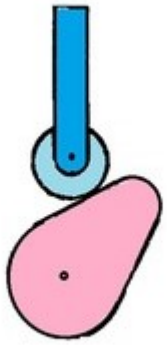


  - If the type contact is point or line type they are called as the *higher pair*
  - If the contact type is area or surface , they are called as *lower pair*

Classification of kinematic pair

- Based on the nature of mechanical constraints
  - Closed pair- When the elements of a pair are held together mechanically.
  - Unclosed pair- When two links of a pair are in contact due to the force of gravity or spring force

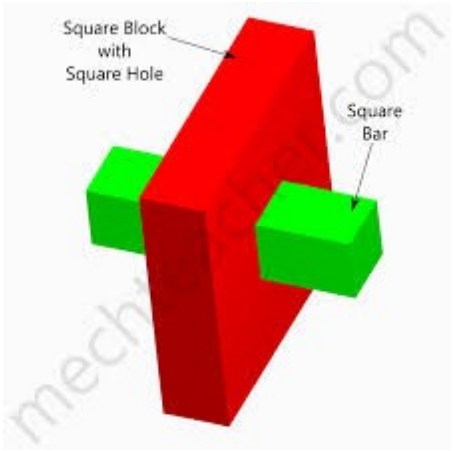




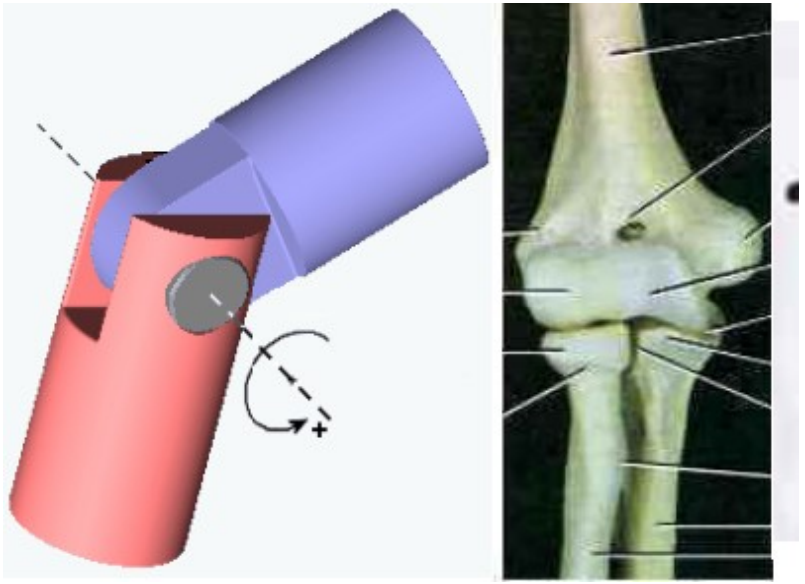
  - All lower pair and some higher pairs are closed pair

Classification of kinematic pair

- According to nature of relative motion



Sliding pair



Turning pair

Classification of kinematic pair

- According to nature of relative motion

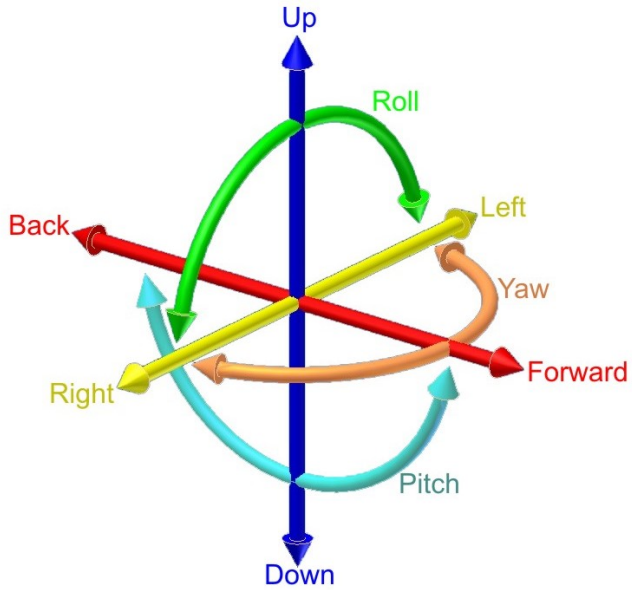
Rolling pair

Screw pair

Spherical pair

Classification of kinematic pair

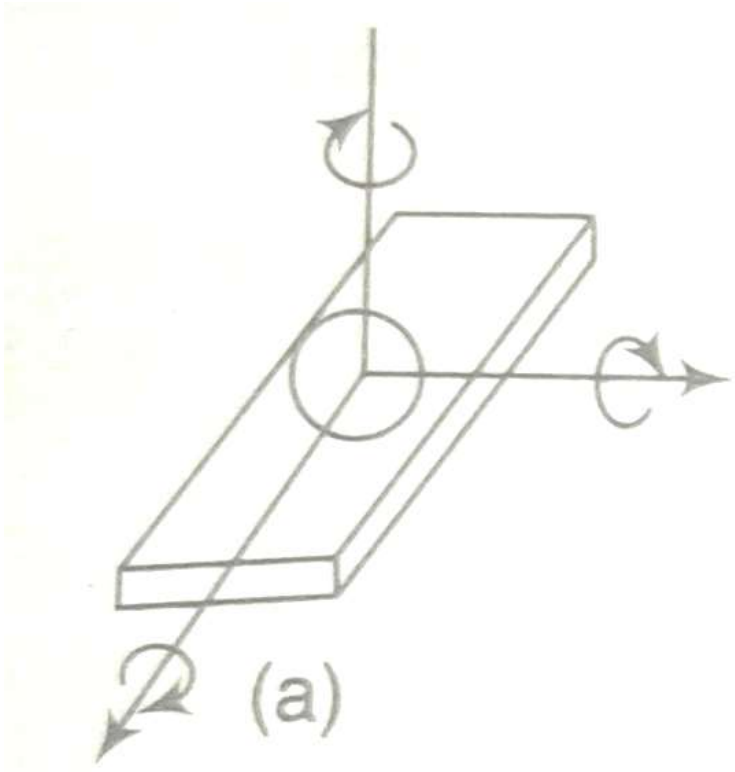
- Based on degree of freedom
  - Degree of freedom of a pair is defined as the number of independent relative motion, both translational and rotational



Classification of kinematic pairs

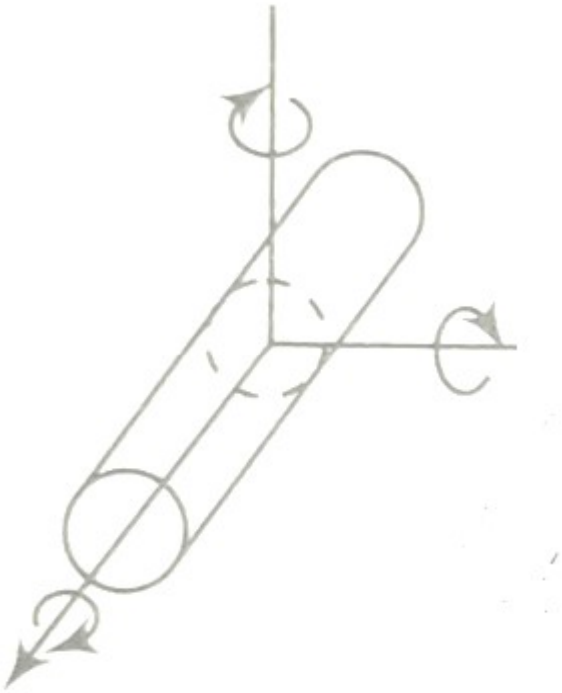
a) Sphere- plane

No. of restraints= 1



Restraints on	
Translatory motion= 1	Rotary motion=0

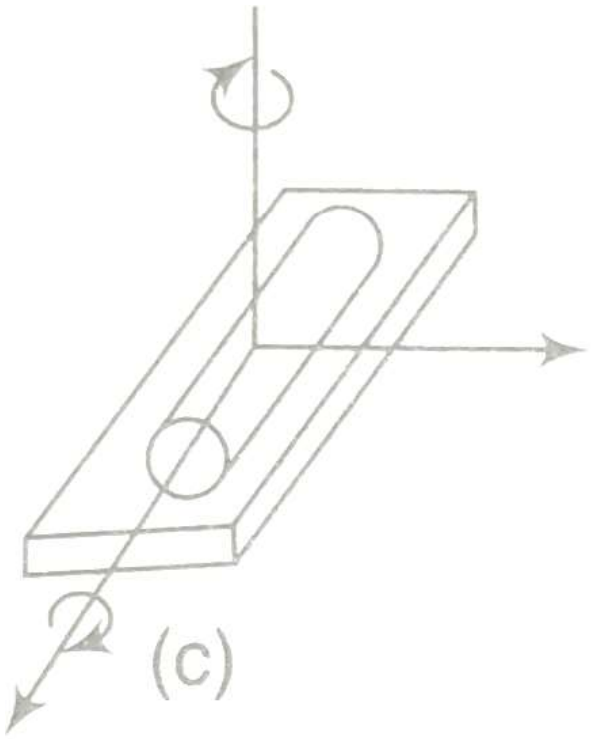
b) Sphere- cylinder



No. of restraints= 2

Restraints on	
Translatory motion= 2	Rotary motion=0

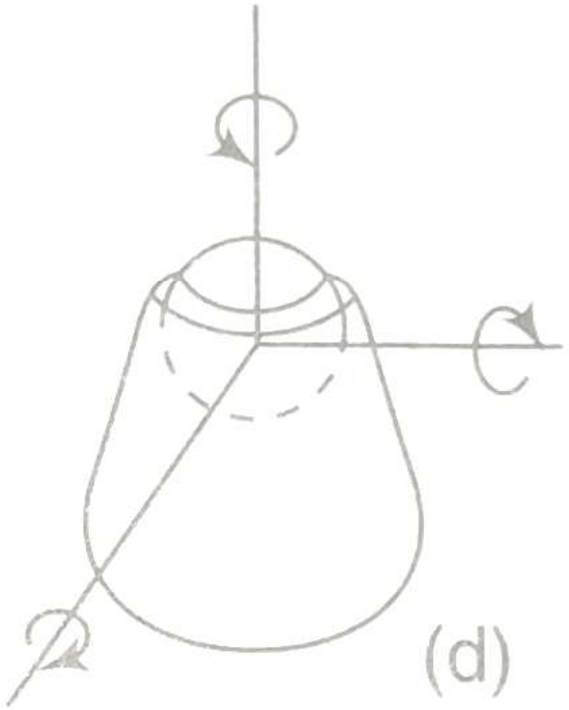
c) Cylinder- plane



No. of restraints= 2

Restraints on	
Translatory motion= 1	Rotary motion=1

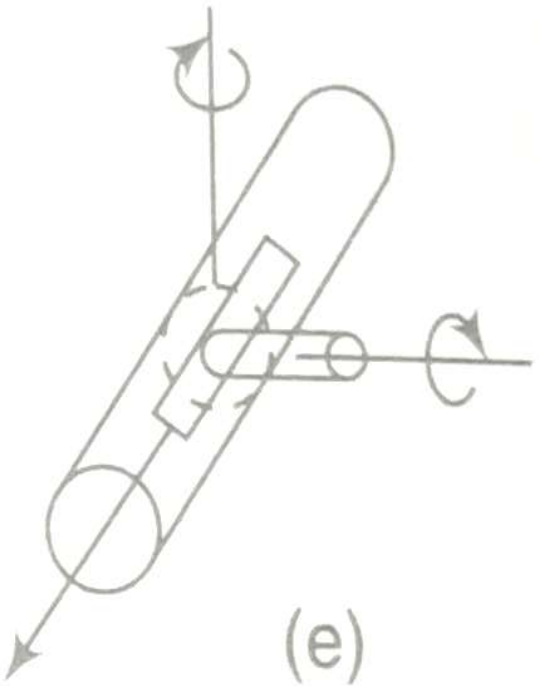
d) Spheric



No. of restraints= 3

Restraints on	
Translatory motion= 3	Rotary motion=0

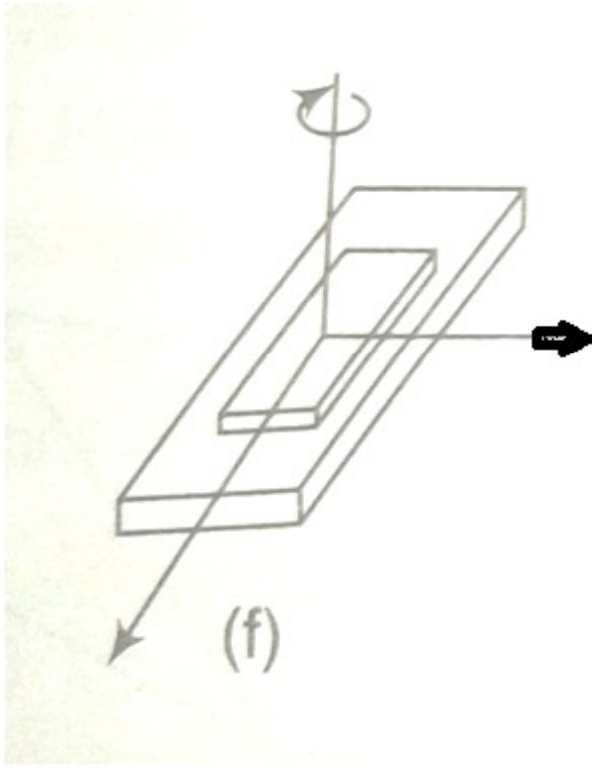
e) Sphere- slotted cylinder



No. of restraints= 3

Restraints on	
Translatory motion= 2	Rotary motion=1

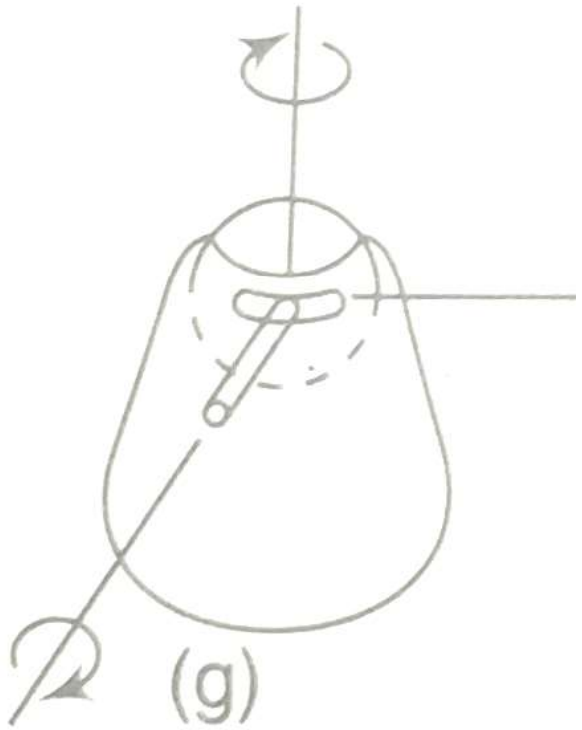
f) Prism- plane



No. of constraints=3

Restraints on	
Translatory motion= 1	Rotary motion=2

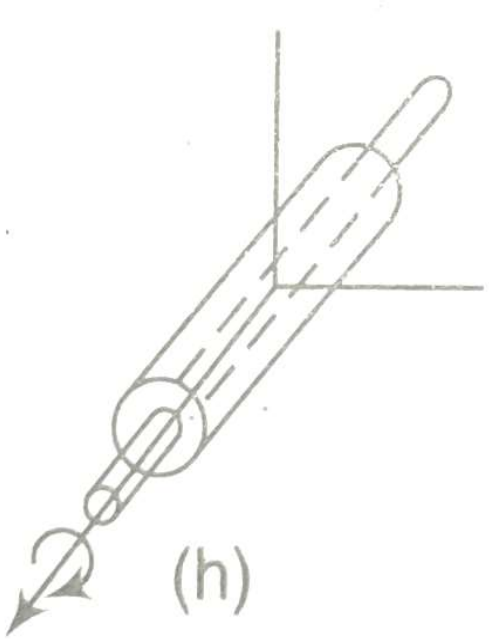
g) Slotted- spheric



No. of constraints=4

Restraints on	
Translatory motion= 3	Rotary motion=1

h) Cylinder



No. of restraints=4

Restraints on	
Translatory motion= 2	Rotary motion=2

Degree of freedom for various joints

Type of joint	Nature of motion	DOF
Hinges(Revolute)	Turning	1
Slider	Pure sliding	1
Cylindrical, cam , gear, ball bearing	Turning and sliding Turning and rolling	2
Rolling contact	Pure rolling	1
Spheric		3

- Kinematic chain

  - An assemblage of links and joints, interconnected in a way to provide a controlled output motion in response to a supplied input motion.
  - Motion of one link will create relative and definite motion on other link.
  - A redundant chain does not allow any motion of a link relative to the other.
  - A kinematic chain with one link fixed is called as mechanism
  - A redundant chain having one link fixed to ground is called structure

In short…..

- *A kinematic link is defined as a resistant body or a group of resistant bodies with rigid connections preventing their relative movement.*

- *A kinematic pair is a joint of two links having relative motion between them.*

- *A kinematic chain is an assembly of links in which the relative motions of the links are possible and the motion of each relative to the other is definite.*

- *If one of the links of a kinematic chain is fixed to the ground and the motions of any of the movable links results in definite motions of others, then it is known as mechanism.*

- A mechanism may consist of a number of pairs belonging to diff. classes having different no. of restraints
- Ranging from single order mechanism (one restraints) to fifth order(with five restraint)
- Sixth order mechanism is impossible
- Mobility of a mechanism defines the number of degrees of freedom a mechanism posses.
- For space mechanism
  - $F= 6(N-1) - 5 P_1 - 4P_2 - 3P_3 - 2P_4 – P_5$

- Most of mechanism are 2-D (i.e , translational along two direction, and rotation about an axis)
- So, eqn becomes,
  - $F= 3(N-1) - 2P_1 – P_2$
- Known as *Gruebler's criterion for dof of planar mechanism*
- For linkages with only turning pair,$P_2 = 0$
- So eqn becomes,
  - $F= 3(N-1) - 2P_1$
- Known as *Kutzback's criterion*

- For most of the mechanism the dof of the mechanism is one.

- So $1 = 3(N-1) - 2P_1$

  i.e, $2P_1 = 3N - 4$

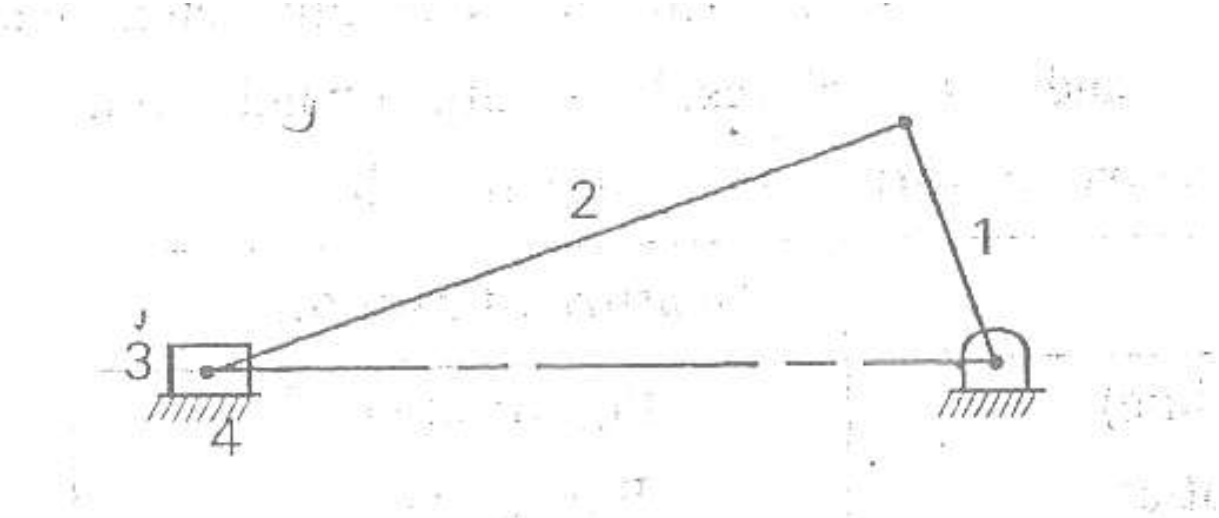
- If N = 4, then $P_1 = 4$ (no excess turning pair)

- If N = 6, then $P_1 = 7$ (one excess turning pair)

- If N = 8, then $P_1 = 10$ (two excess turning pair)

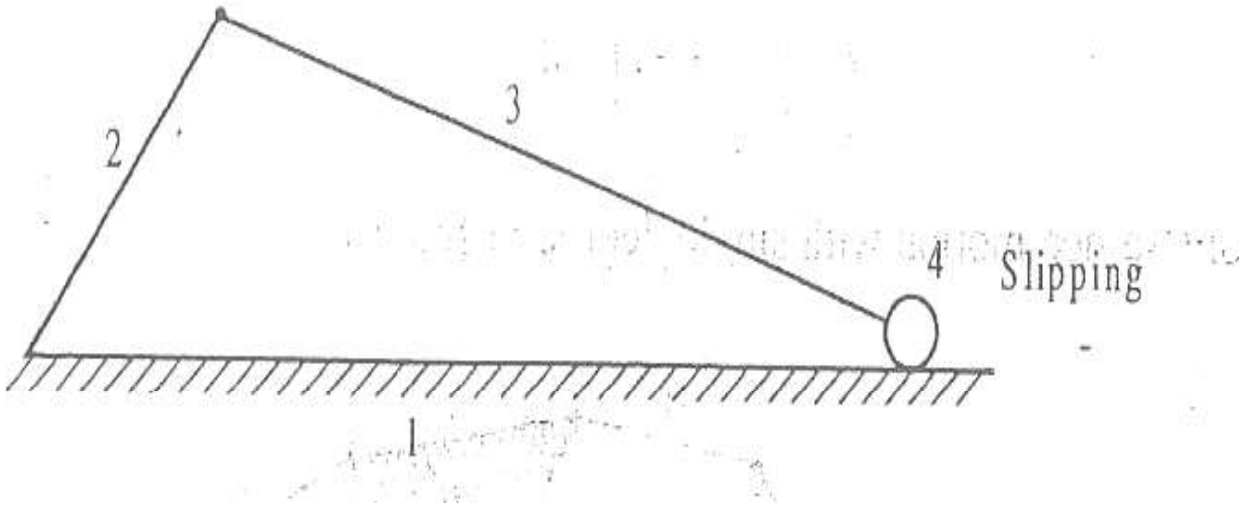
- So as no. of links increases, excess turning pair is req.

- So instead of binary link use of ternary or quaternary link is encouraged



- N=4
- P1=4
- P2=0
- $F=3(N-1)- 2P_1-1P_2 \quad = \quad 3(3)- 2(4)-1(0)= 1$

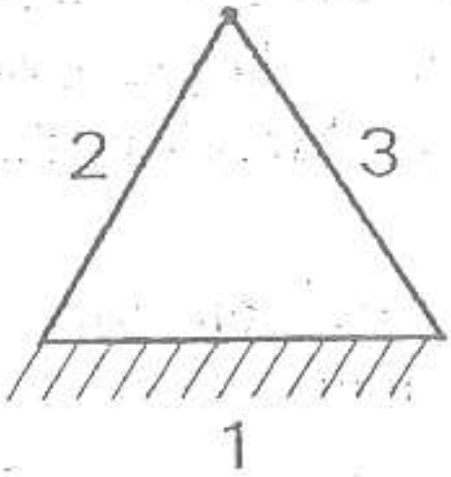
- Therefore the mechanism has 1 DOF



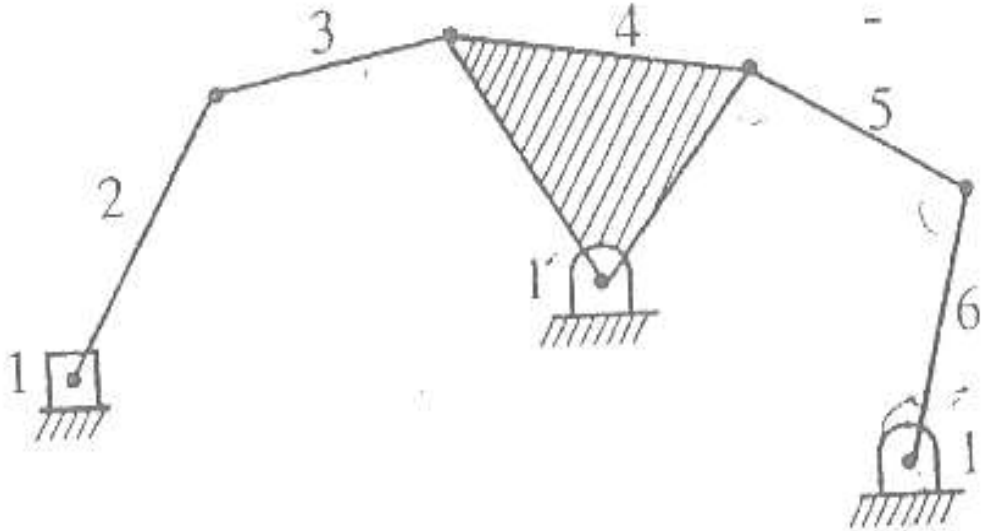
- N=4
- P1=3
- P2=1
- $F=3(N-1)- 2P_1-1P_2 = 3(3)- 2(3)-1(1)= 2$

- Therefore the mechanism has 2 DOF

1



2



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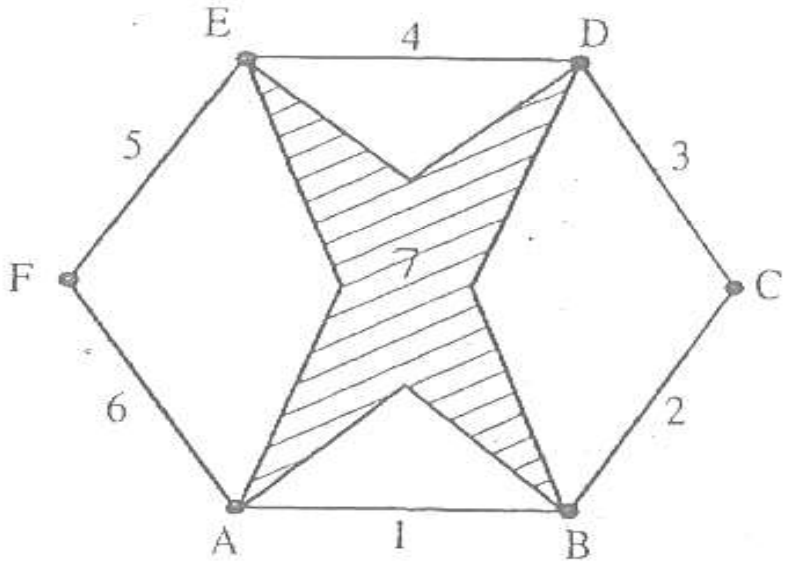
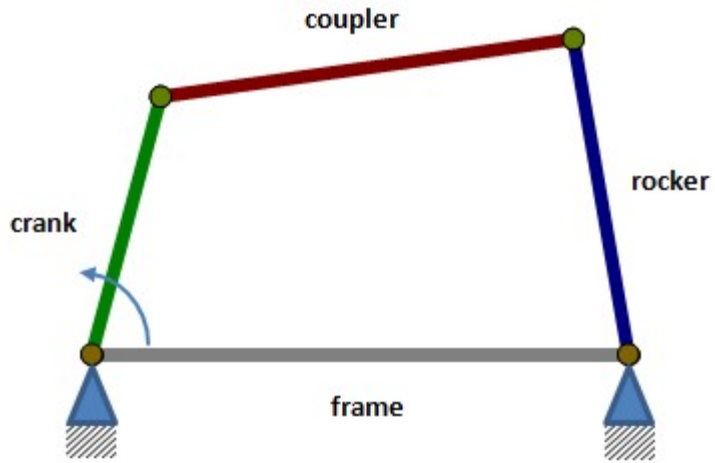


Four bar (link) mechanism

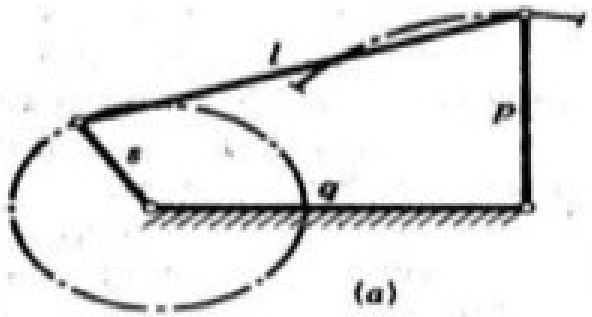
- Simple and versatile
- Necessaties
  - *The length of longest link must be less than the sum of lengths of other three links.*
- Grashof's condition
  - If $(s + l) \leq (a+b)$
  - Then the linkage is grashof and at least one link may be capable of complete revolution.
  - This is *Class I Kinematic chain*
  - If not , its non- grashof known as
  - *Class II Kinematic chain*



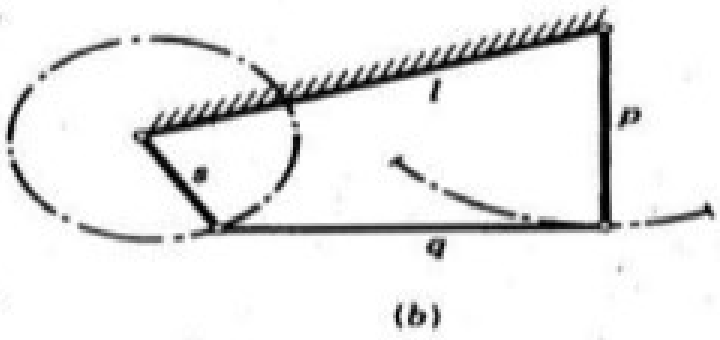
- Kinematic Inversions – Process of choosing different links of a kinematic chain to be fixed or ground to obtain new mechanisms

- No of kinematic inversions is equal to no of links in the kinematic chain

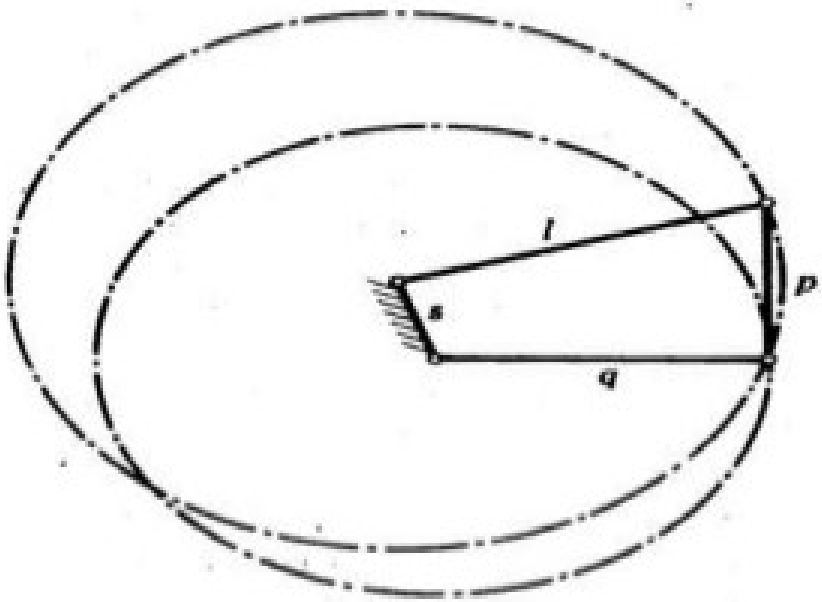
Inversions of four link mechanism



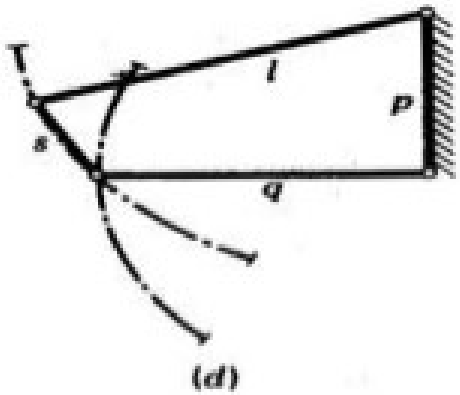
(a)



(b)



(c)



(d)

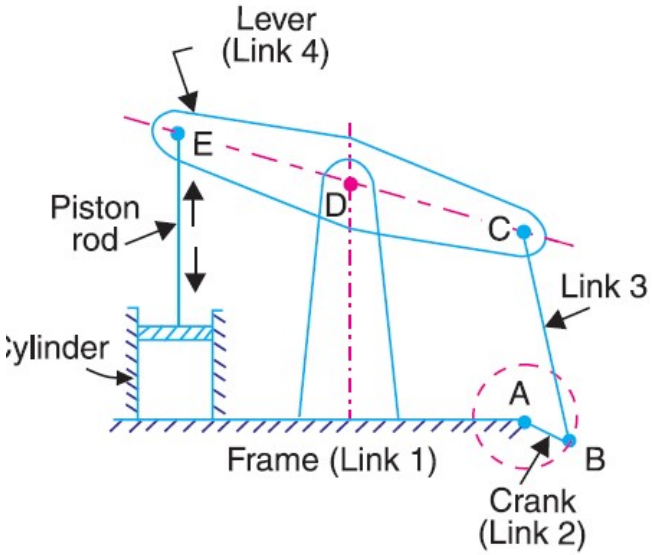
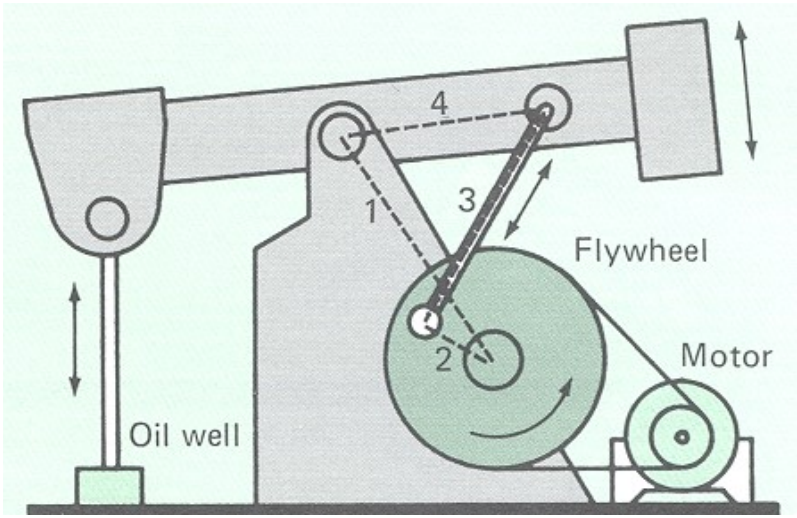
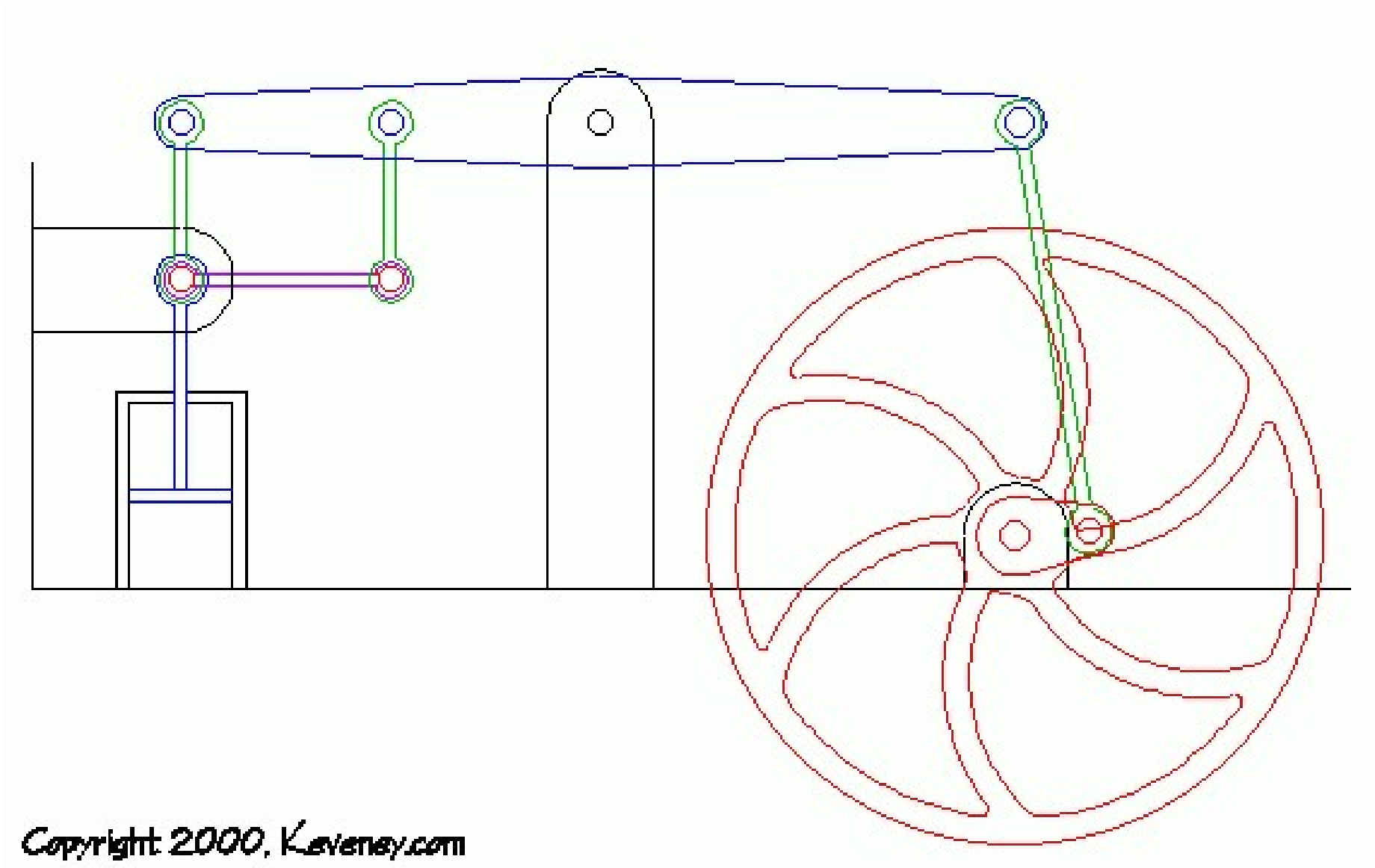


Fig. 5.19. Beam engine.



Oil pump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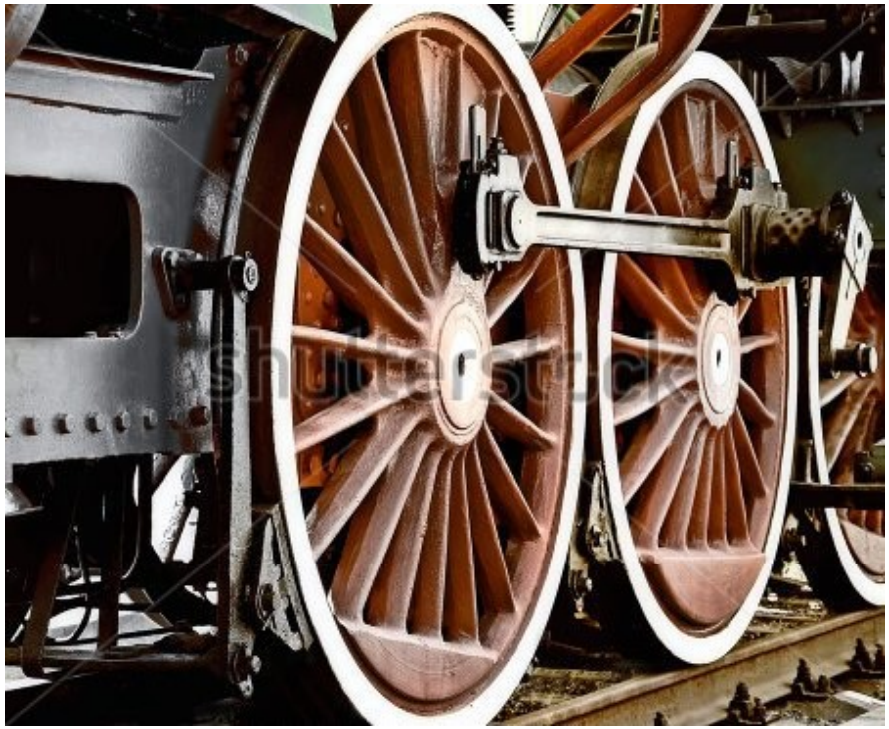
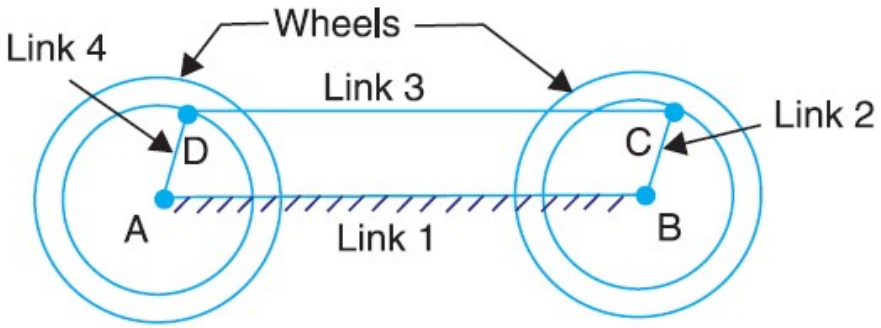
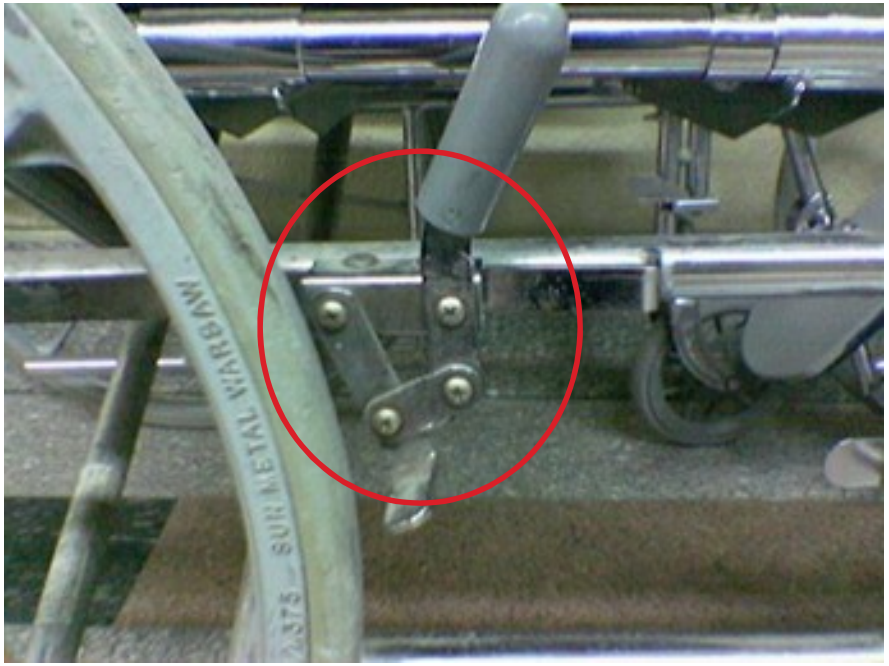
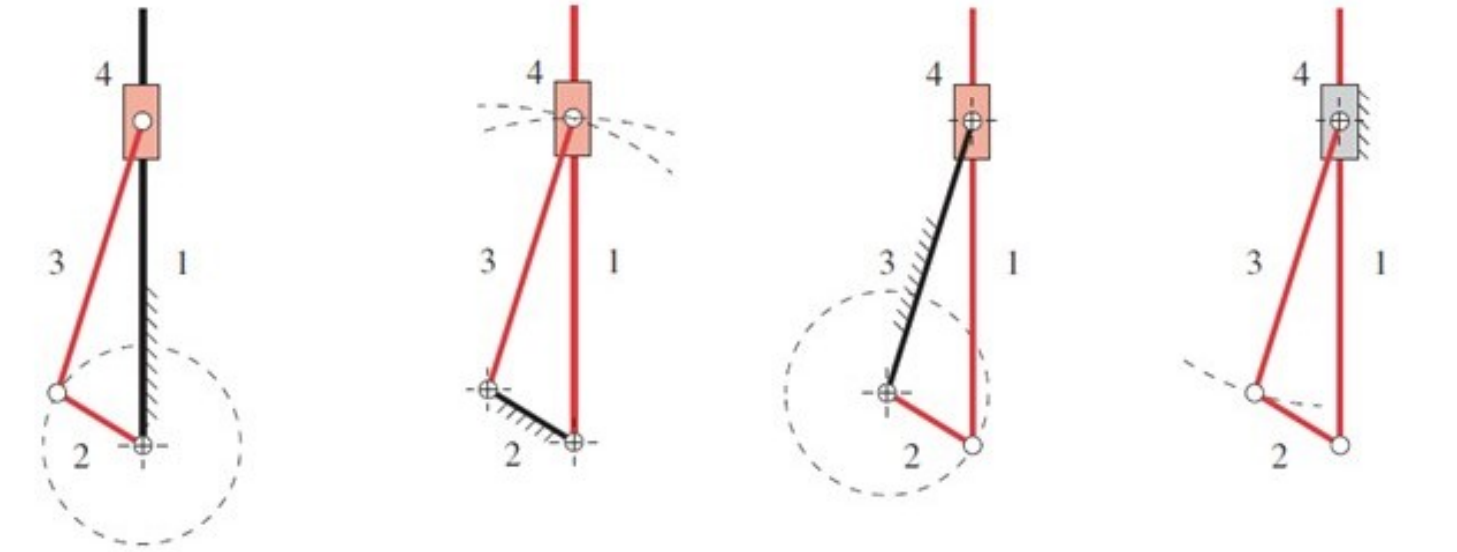



Wheels
Link 4
Link 3
Link 2
D
C
A
B
Link 1



Slider crank mechanism

- Kinematic Inversions – Process of choosing different links of a kinematic chain to be fixed or ground to obtain new mechanisms



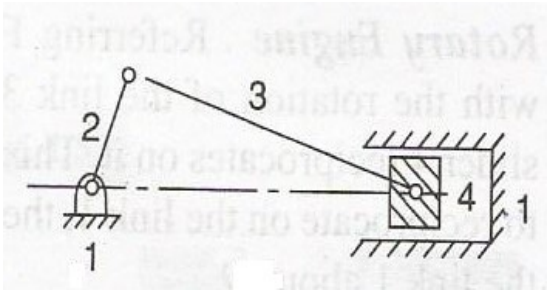
(a) Inversion # 1 slider block translates

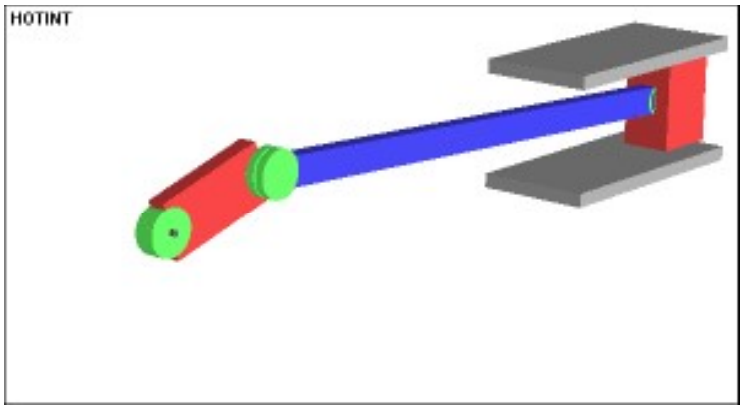
(b) Inversion # 2 slider block has complex motion

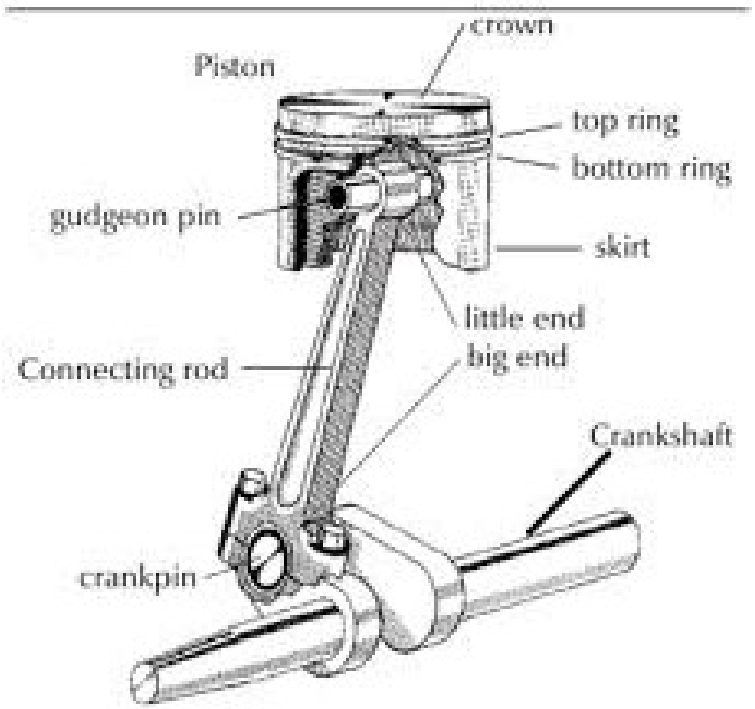
(c) Inversion # 3 slider block rotates

(d) Inversion # 4 slider block is stationary

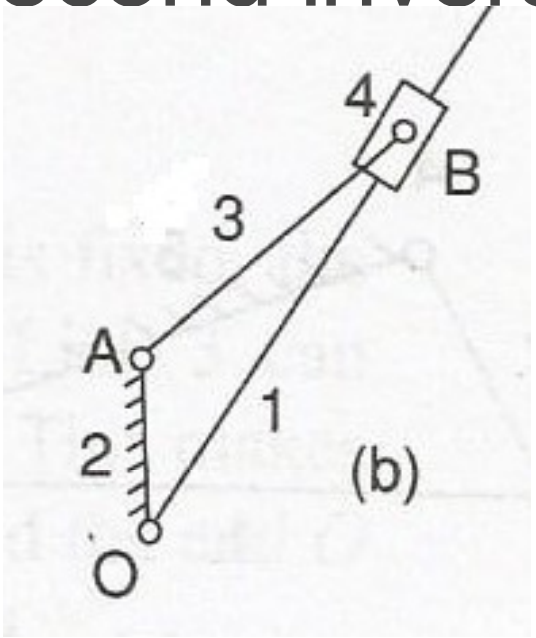
First Inversion

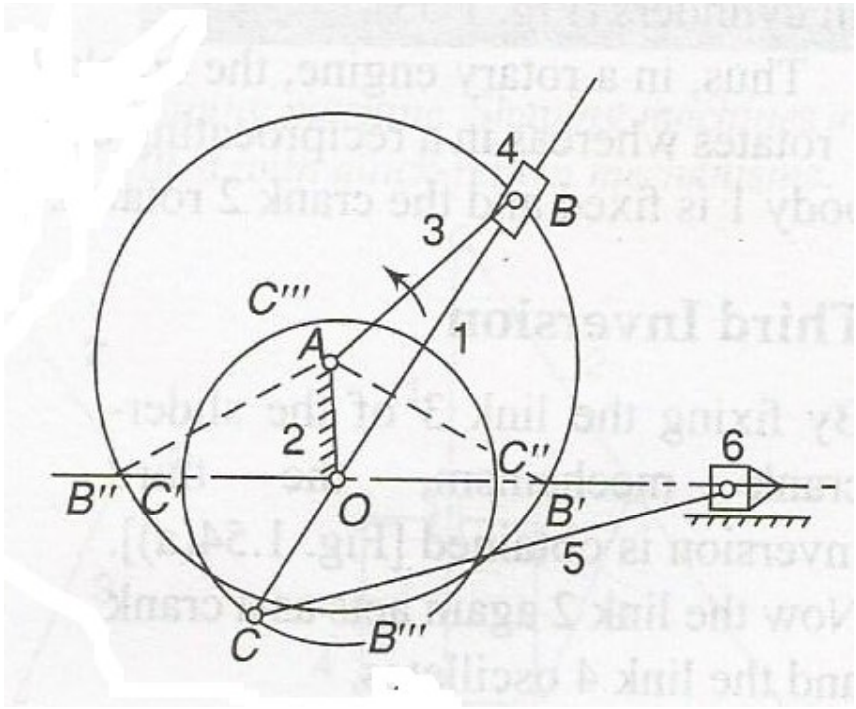






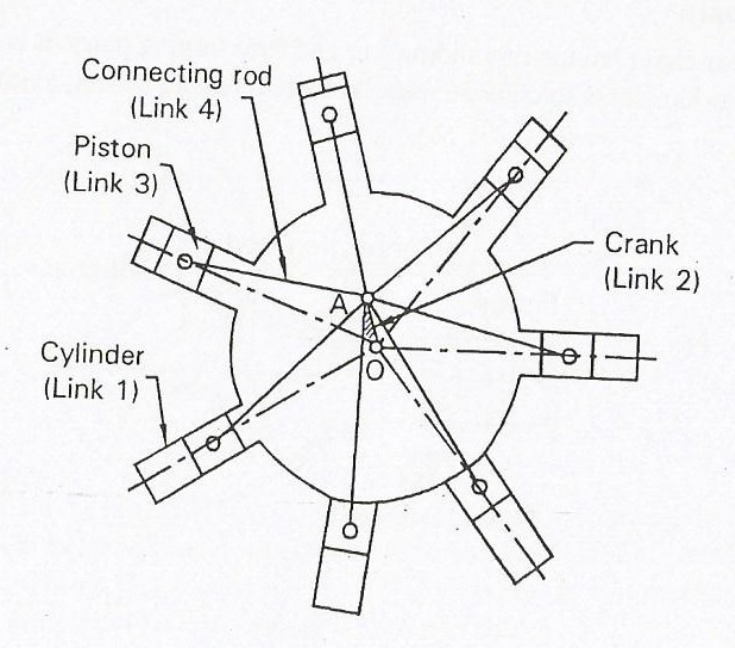
Second inversion

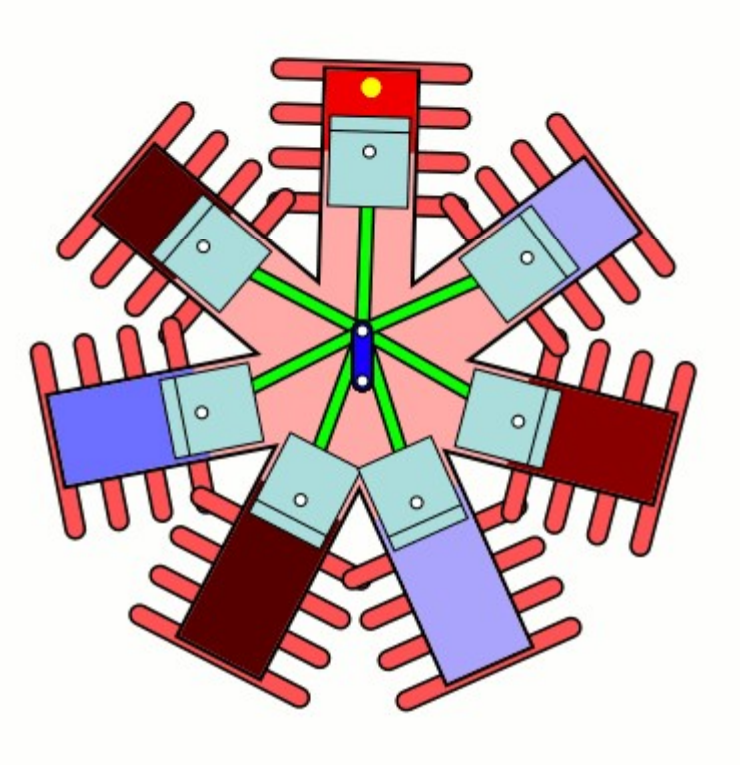




- Applications -
  - Whitworth Quick Return Mechanism
  - Rotary Engine

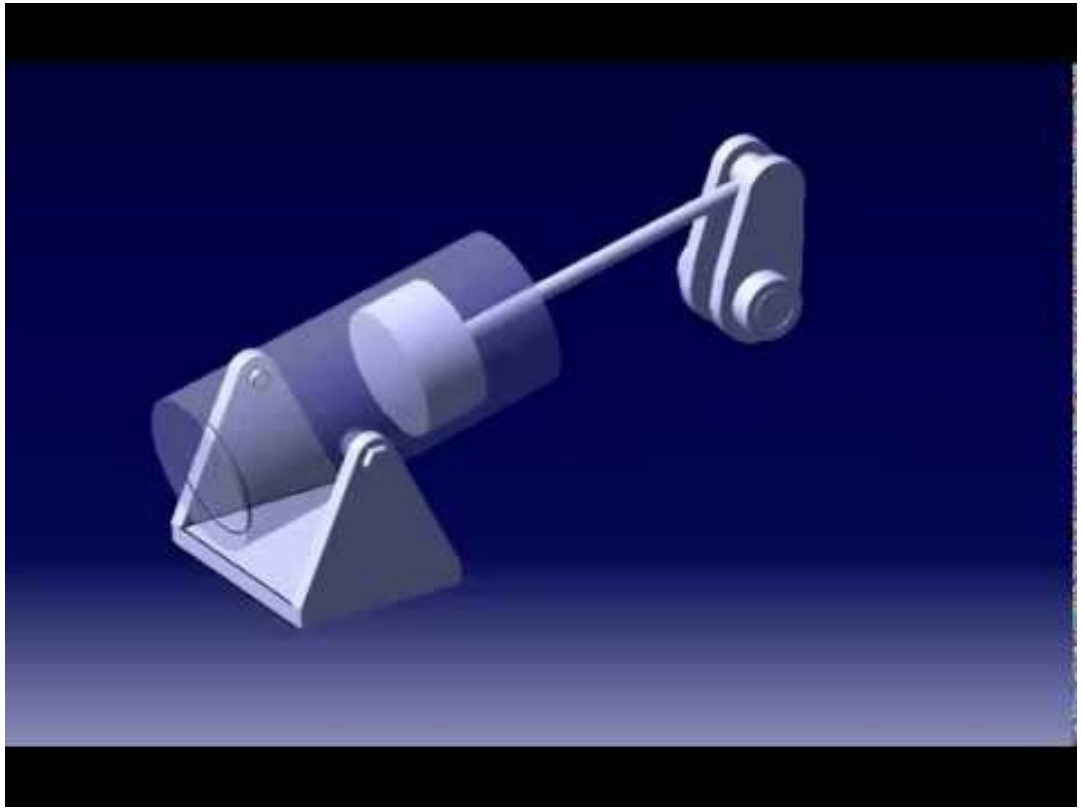
- Rotary Engine





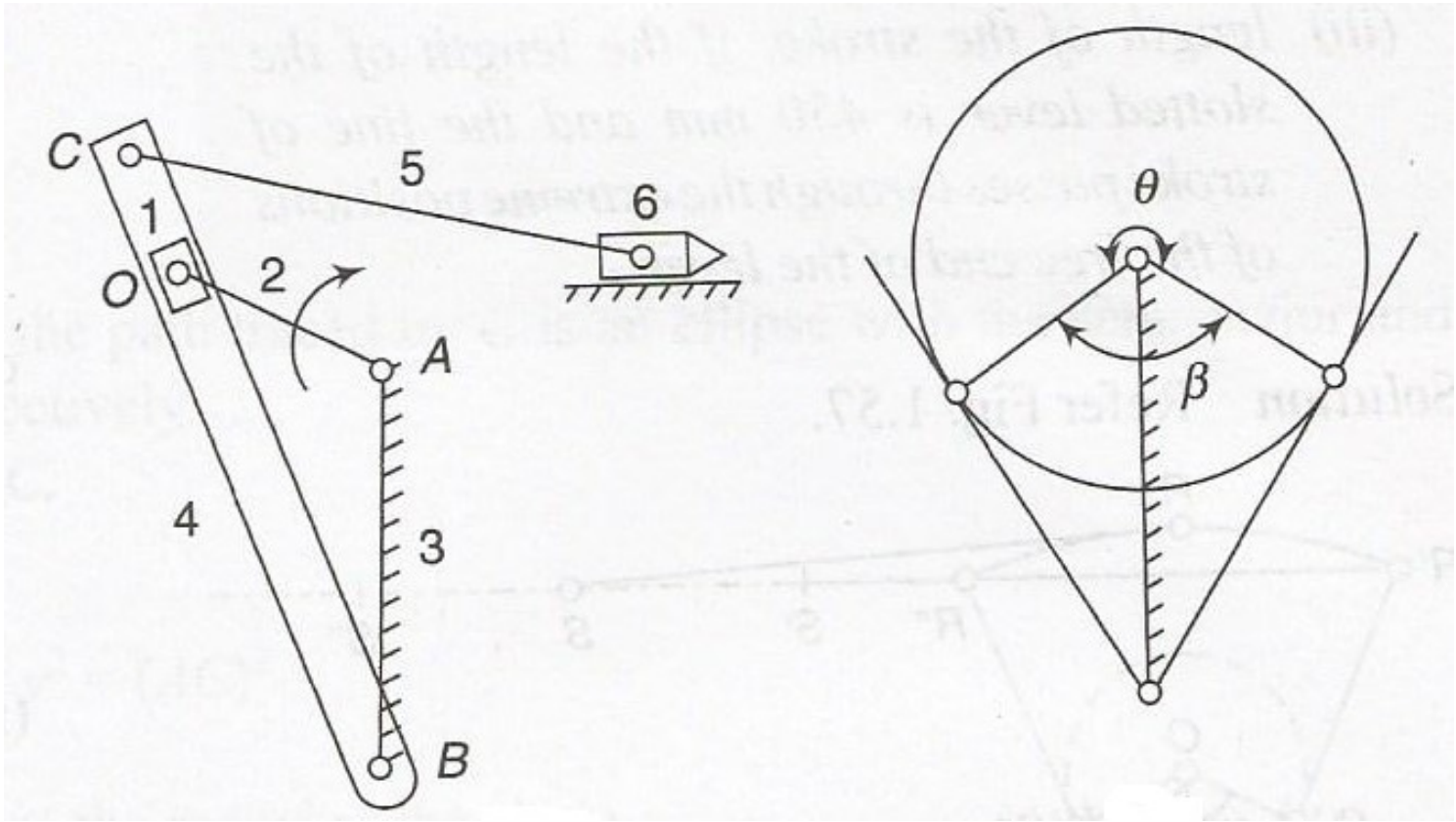
Third inversion

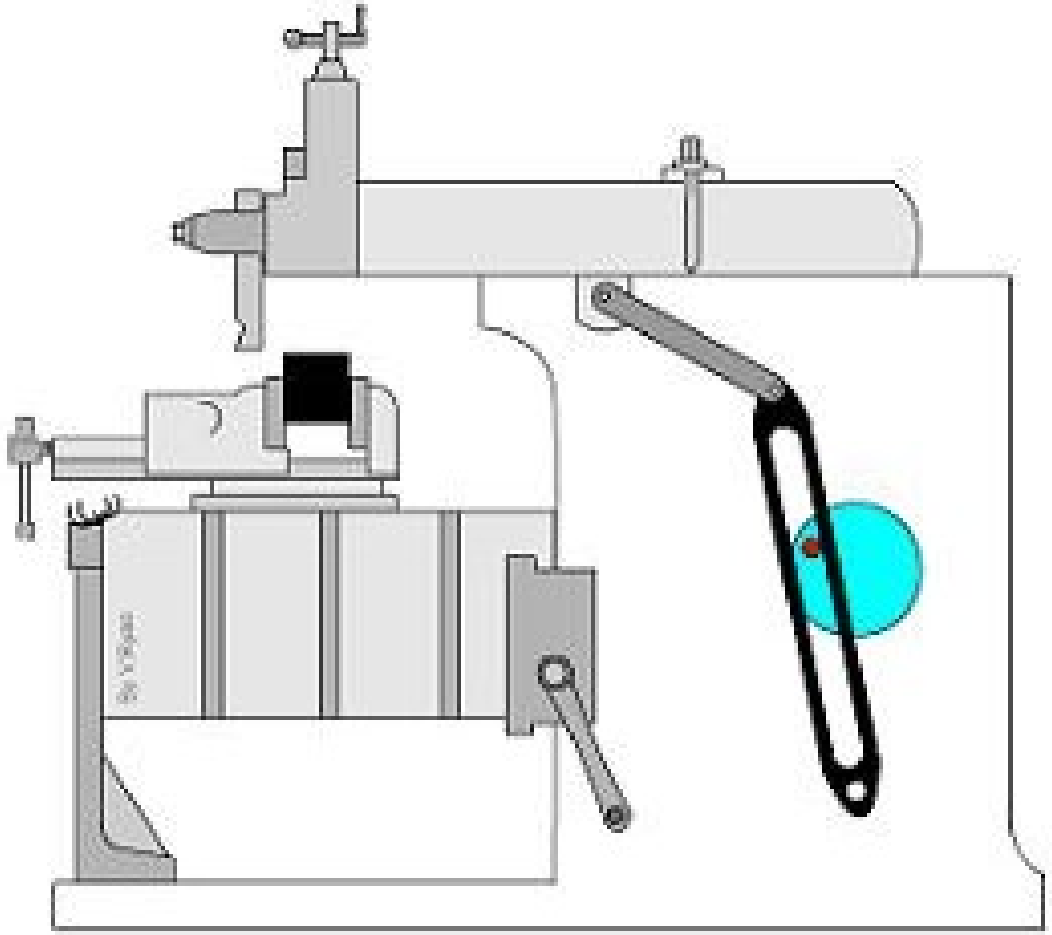
- Oscillating cylinder
  - Link 4 is made in the form of cylinder and a piston fixed to a rod as link 1



Crank & slotted lever quick return mechanism

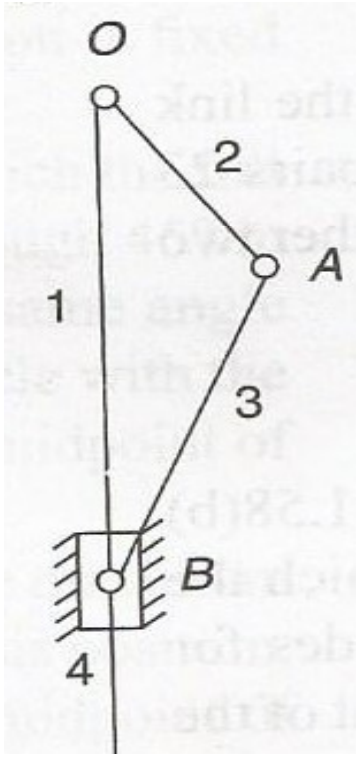
- Cylinder of oscillating cylinder is replaced by link made in the form of guide
- Piston and link replaced by slider

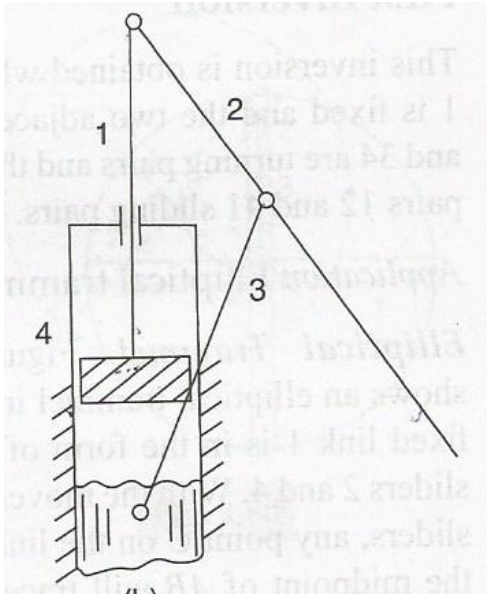


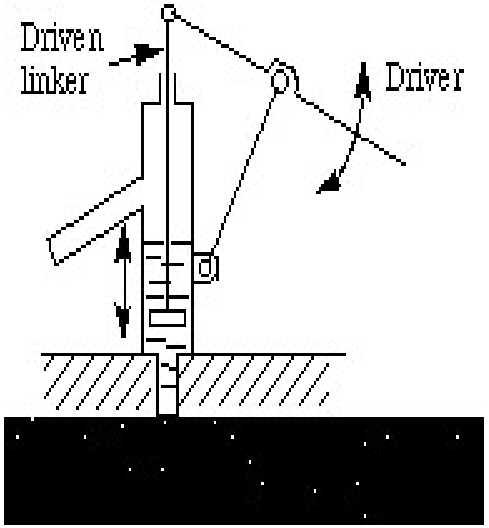


Fourth inversion

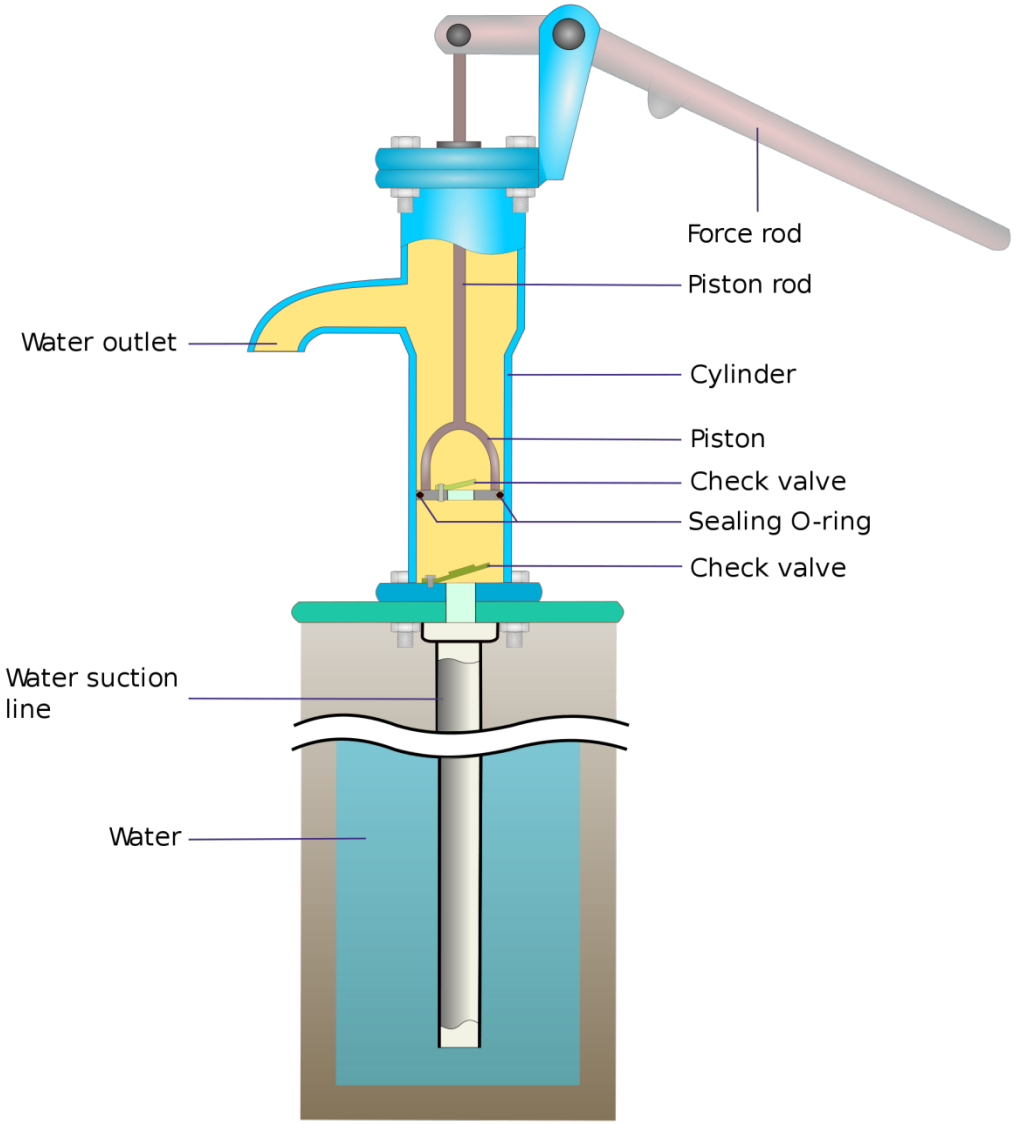
Fourth inversion is obtained by fixing link 4 of slider crank mechanism

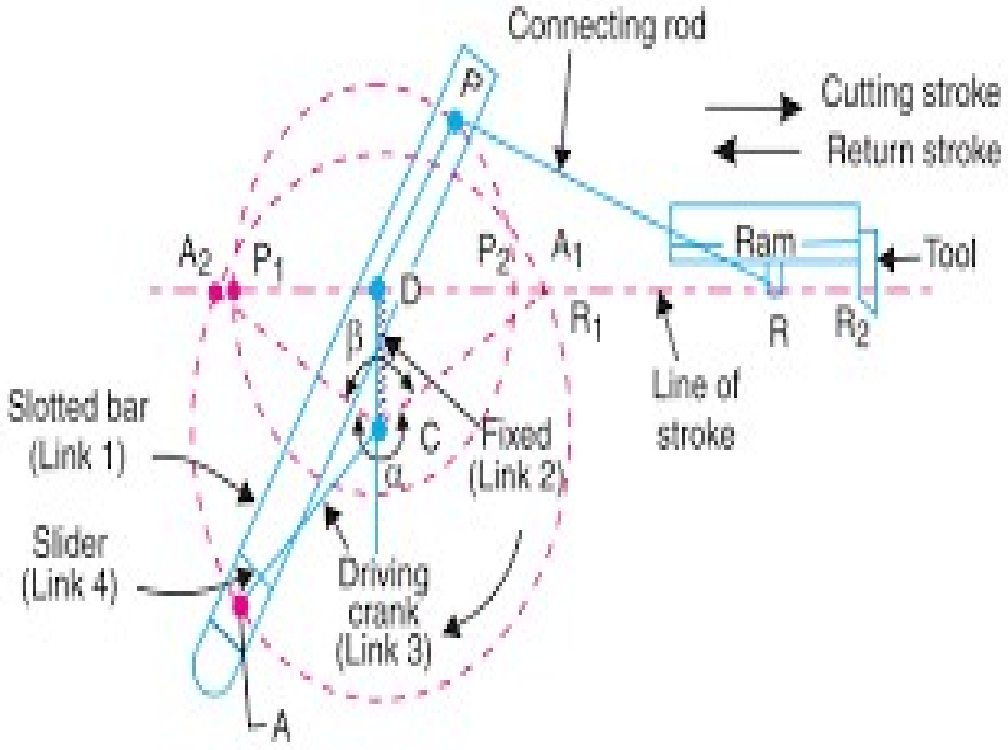


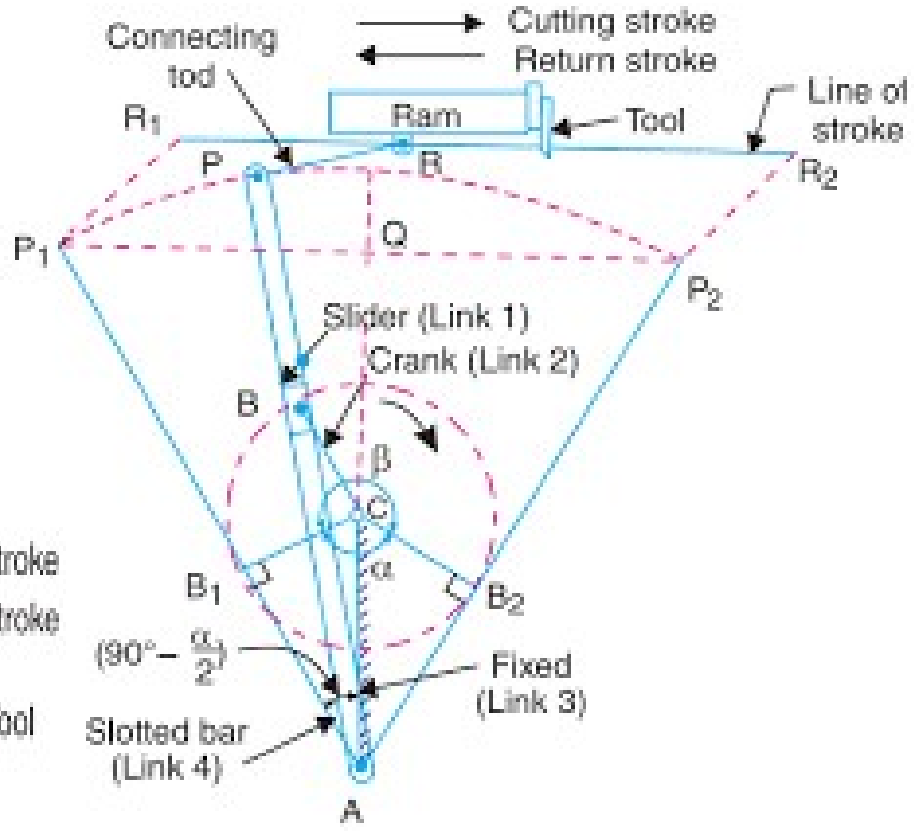




Application: Hand pump


Force rod
Piston rod
Water outlet
Cylinder
Piston
Check valve
Sealing O-ring
Check valve
Water suction line
Water

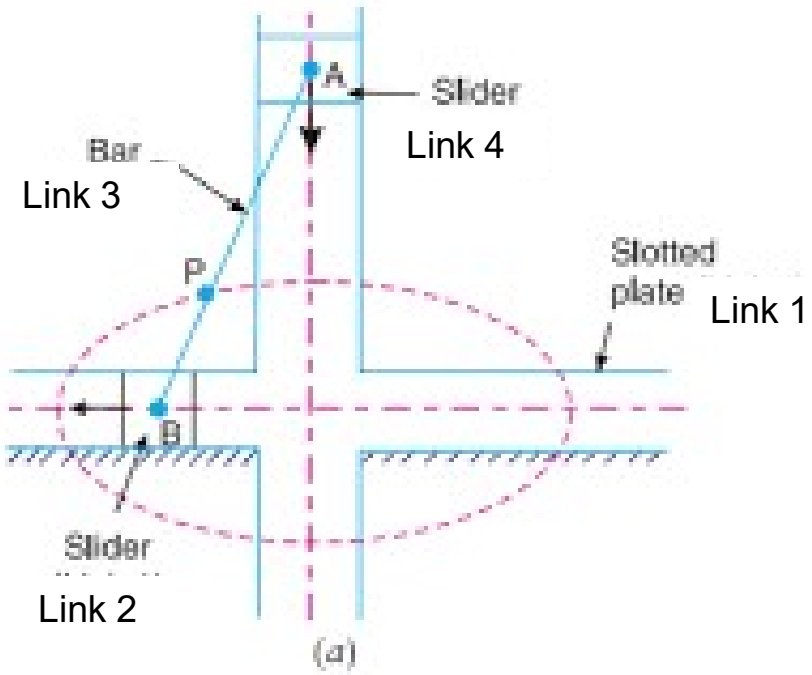

Connecting rod
P
Cutting stroke
Return stroke
Ram
Tool
A2
P1
D
P2
A1
R1
R
R2
β
C
α
Line of stroke
Slotted bar (Link 1)
Fixed (Link 2)
Slider (Link 4)
Driving crank (Link 3)
A


Connecting tod
Cutting stroke
Return stroke
R1
Ram
Tool
Line of stroke
R2
P
R
Q
P1
P2
Slider (Link 1)
Crank (Link 2)
B
β
C
α
B1
B2
(90° – α/2)
Fixed (Link 3)
Slotted bar (Link 4)
A

Whitworth quick return mechanism	Crank and slotted lever mechanism
1. Crank of whitworth is longer than fixed link	1. Fixed link is longer than crank
2.The coupler link makes complete rotation about the pivot joint of fixed link	2. Coupler link oscillates about the pivot
3. For same dislacement, Coupler link connected to tool post is connected at the **other side** of main coupler link with respect to slider	3. Coupler link connected to tool post is connected at the **same side** of main coupler link with respect to slider, but after the extreme position of slider

Double slider crank mechanism

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



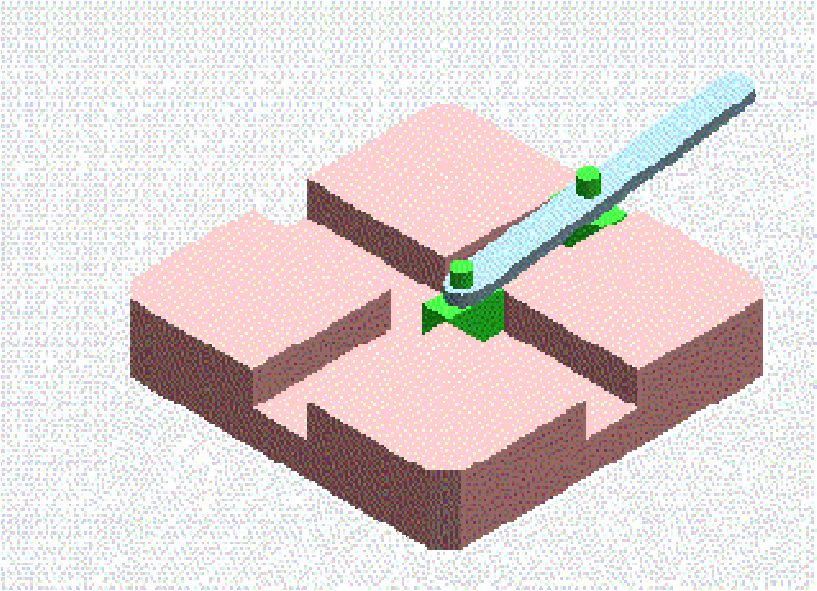
First inversion

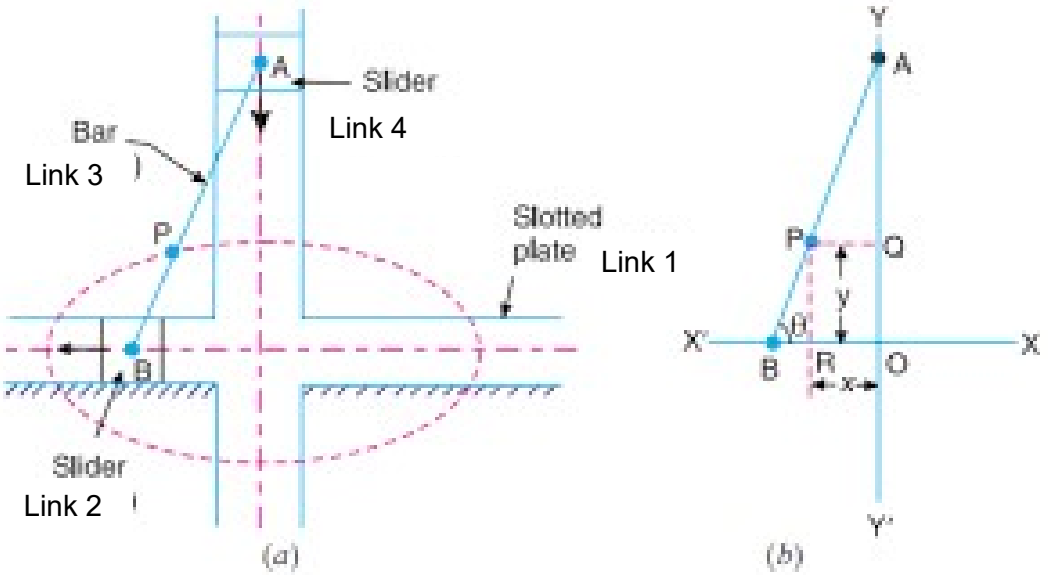
Application- Elliptical trammel

Link 1- fixed

Adjacent pairs link 2&3, link3&4– turning pairs

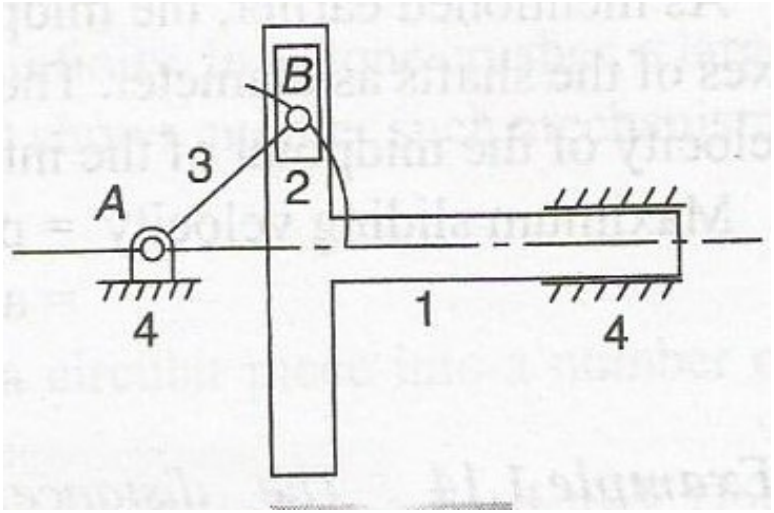
Adjacent pairs link 1&2, link1&4– sliding pairs

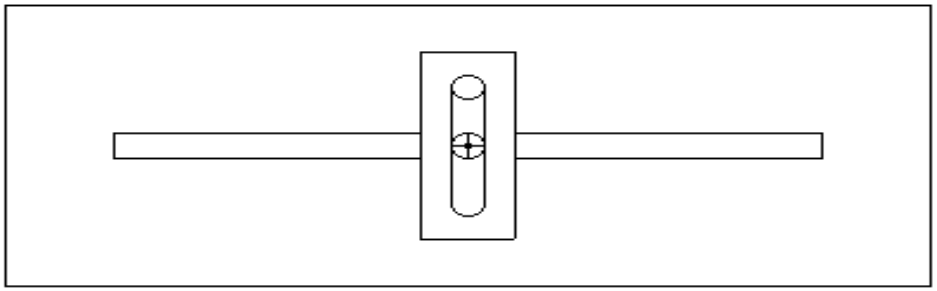




Scotch yoke (Second Inversion)

- A scotch- yoke mechanism is used to convert the rotary motion to sliding motion.
- If any slide blocks of the first inversion is fixed second inversion is obtained
- As the crank 3 rotates the horizontal portion of the link 1 slides in the fixed link 4
- Used in control valve actuators in high pressure oil and gas pipe lines

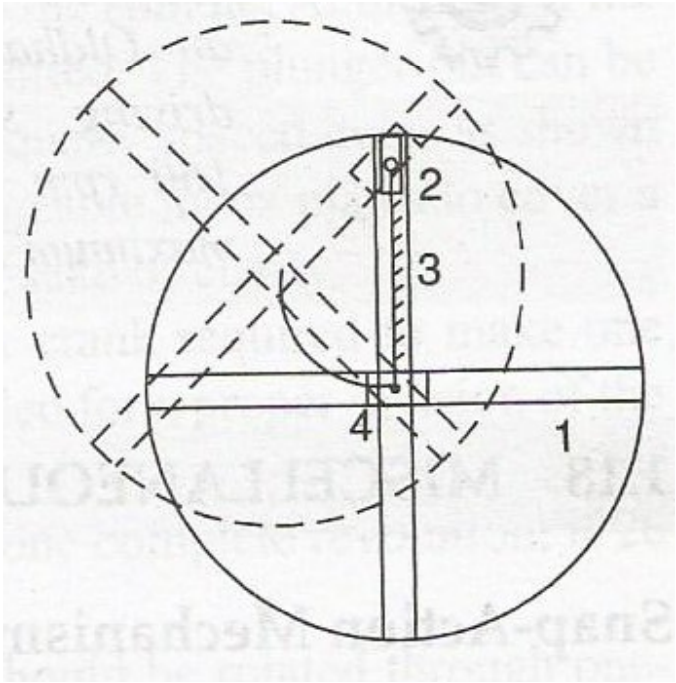




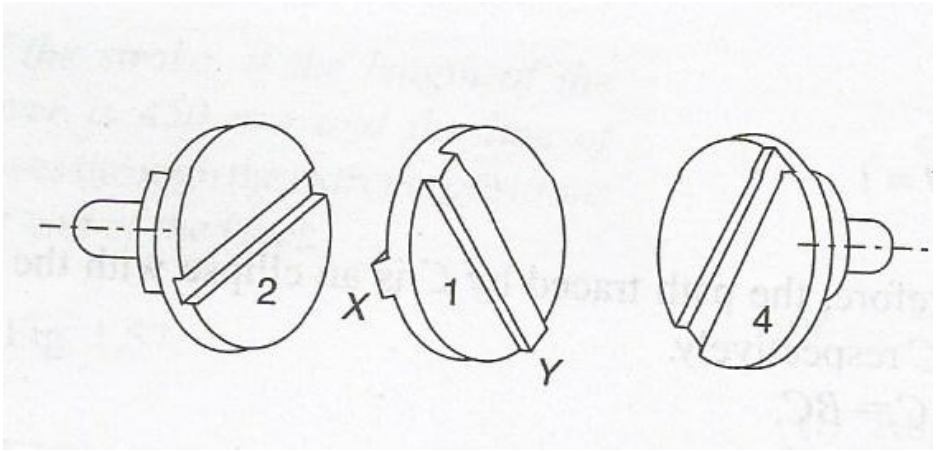
Third inversion

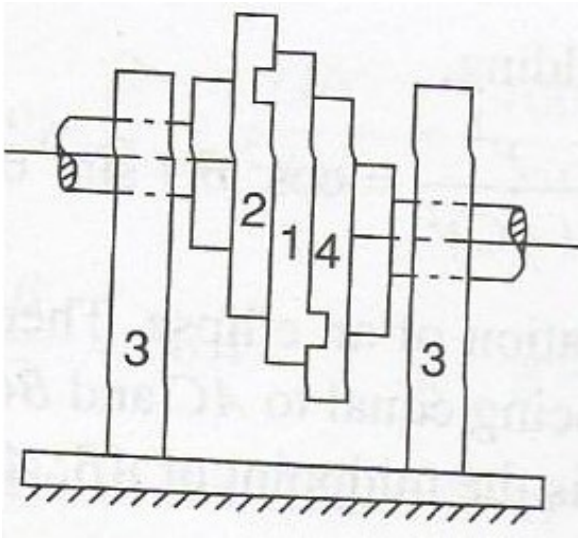
Application- Oldham's coupling

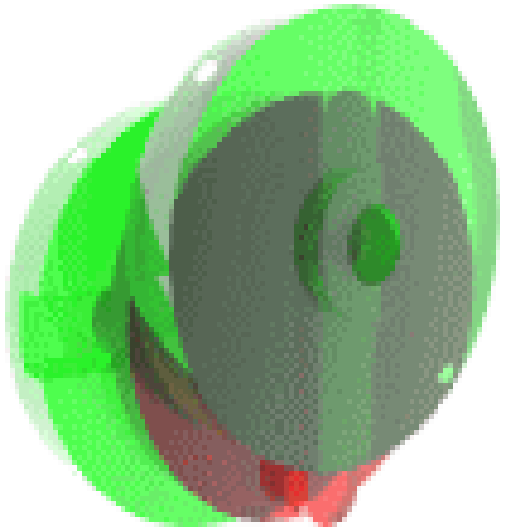
- Link 3 of the first inversion is fixed and link 1 is free to move



Oldham's coupling

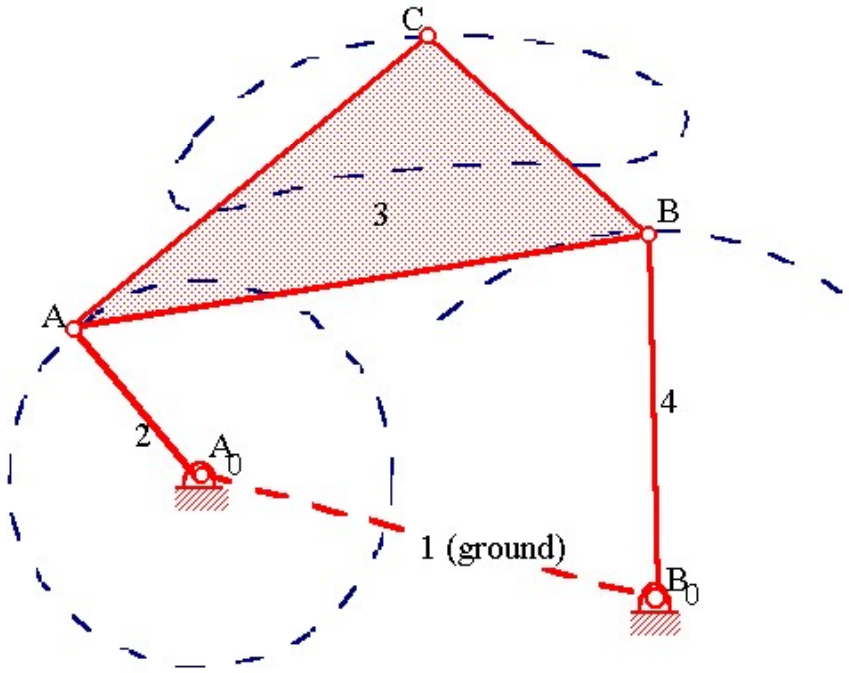


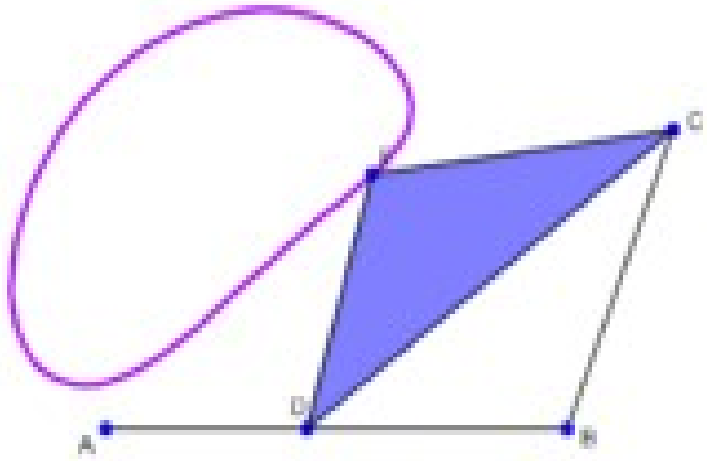




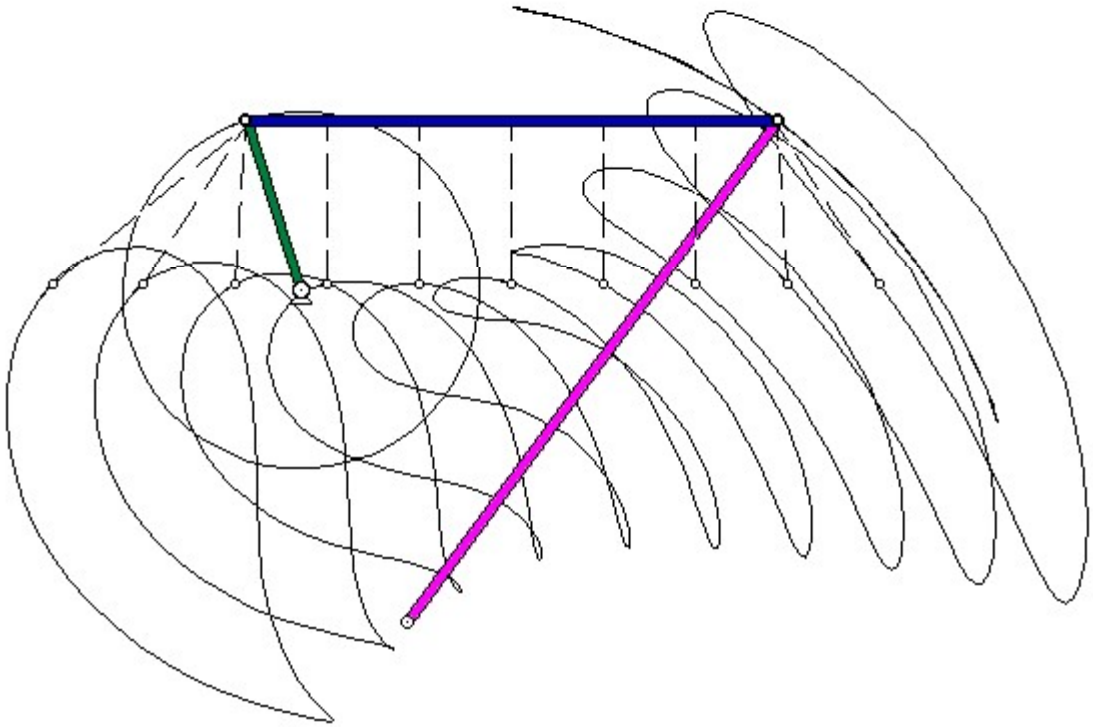
Couplers curves

- For most of the mechanisms, output obtained from path traced by points on coupler link.



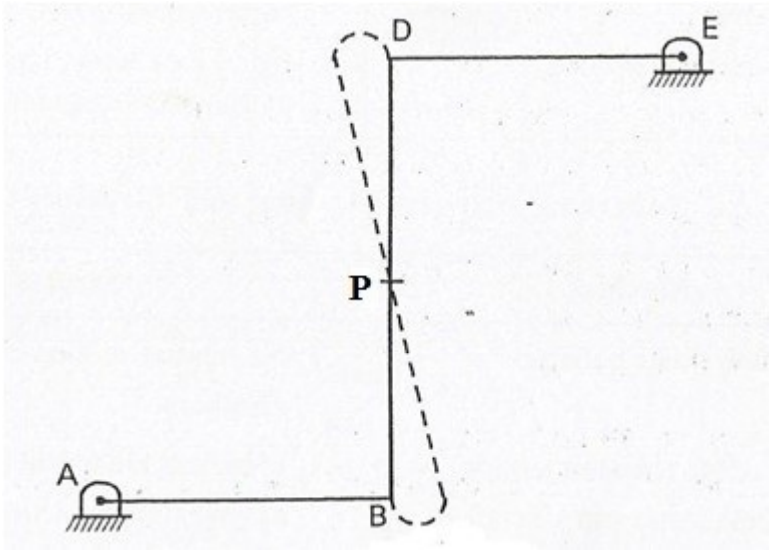


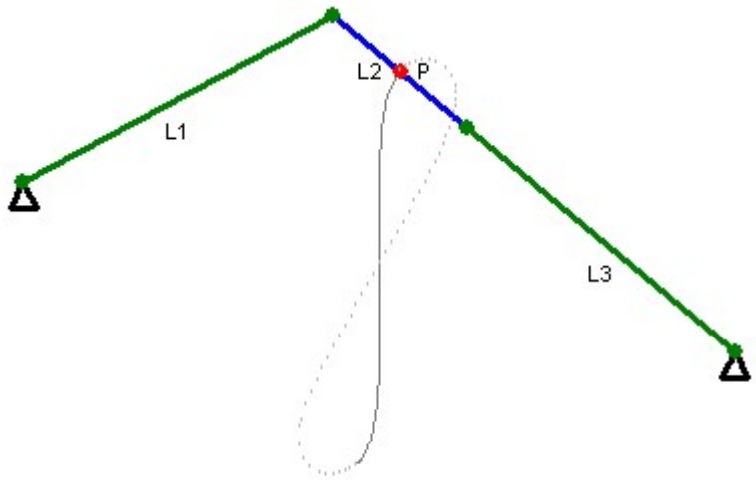
Couplers curves



APPROXIMATE STRAIGHT LINE MECHANISM

(a) **Watt's Straight Line Mechanism (1784)**

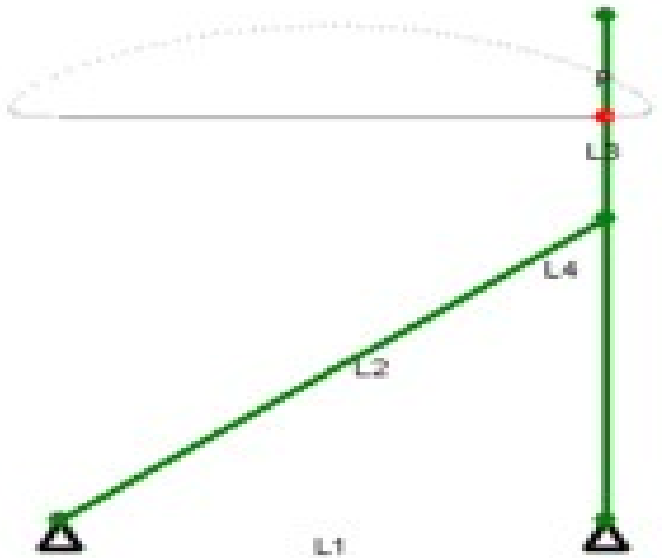




L1:L2:L3 = 2:1:2

- Link AB & DE act as levers and ends A & E are fixed.
- On small displacement of the mechanism, the tracing point P traces the shape of number **8 ,** a portion of which will be approximately straight , and hence also an example for approximate straight line mechanism

(b) **Chebyshev linkage**

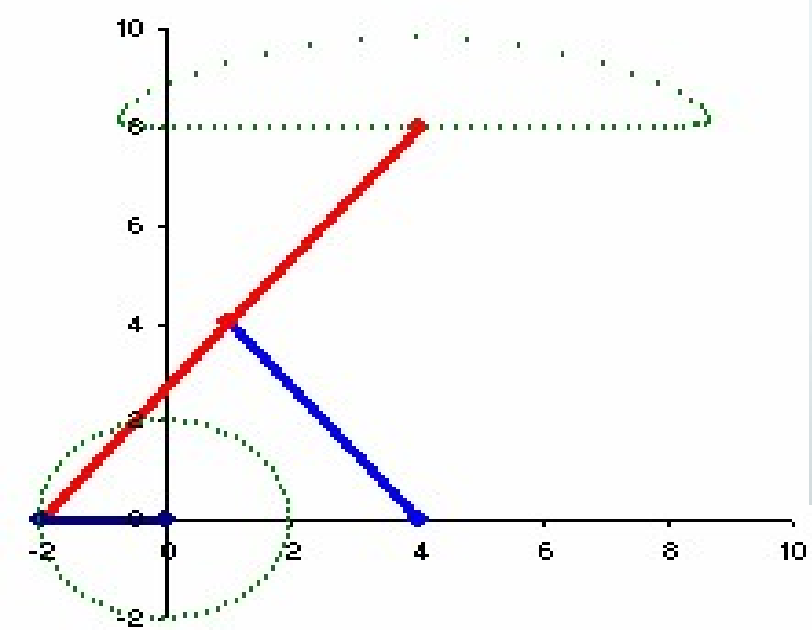


L1:L2:L3:L4 = 4:5:2:5

•The **Chebyshev linkage** is a mechanical linkage that converts rotational motion to approximate straight-line motion

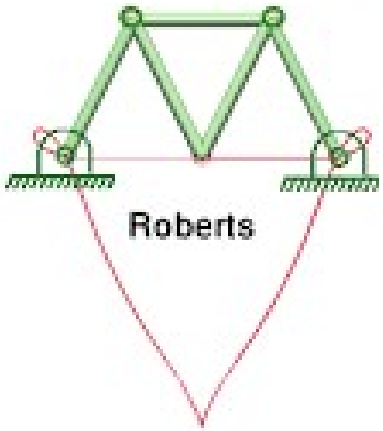
•It was invented by the 19th century mathematician Pafnuty Chebyshev who studied theoretical problems in kinematic mechanisms

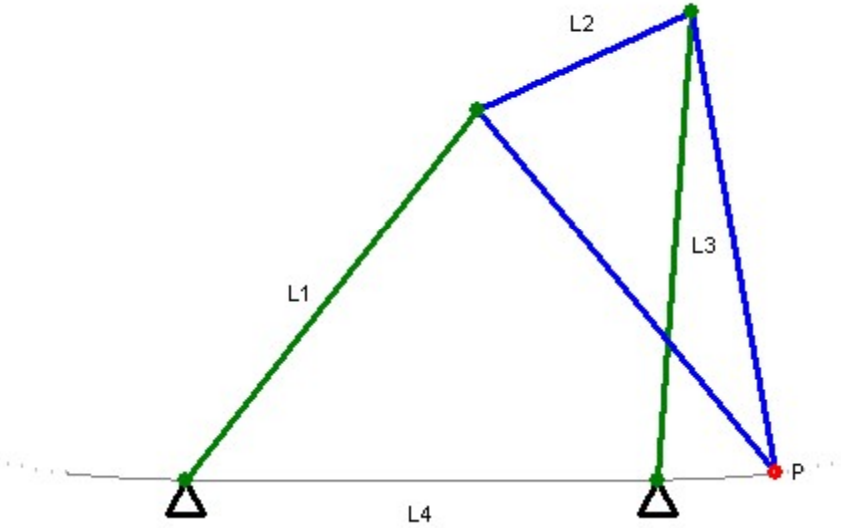
(c) Hoekens linkage

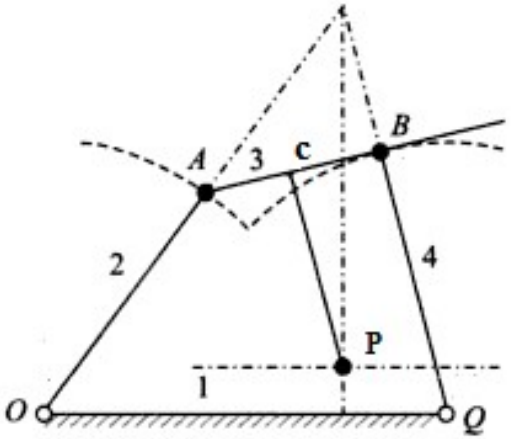


•The **Hoekens linkage** is a four-bar mechanism that converts rotational motion to approximate straight-line motion with approximate constant velocity.

d) Robert's mechanism



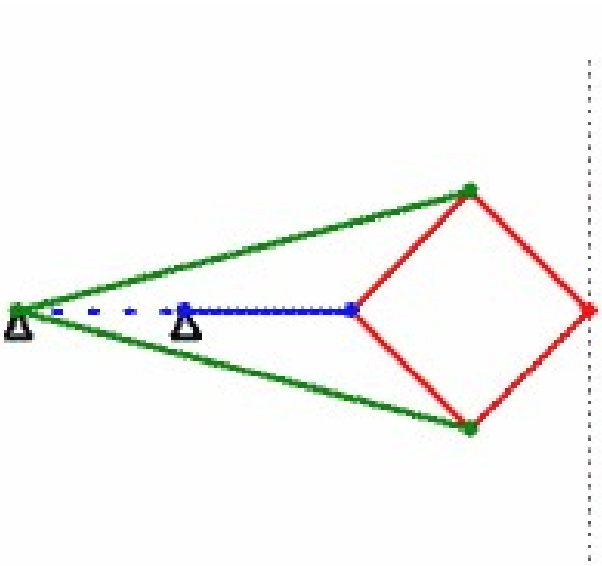


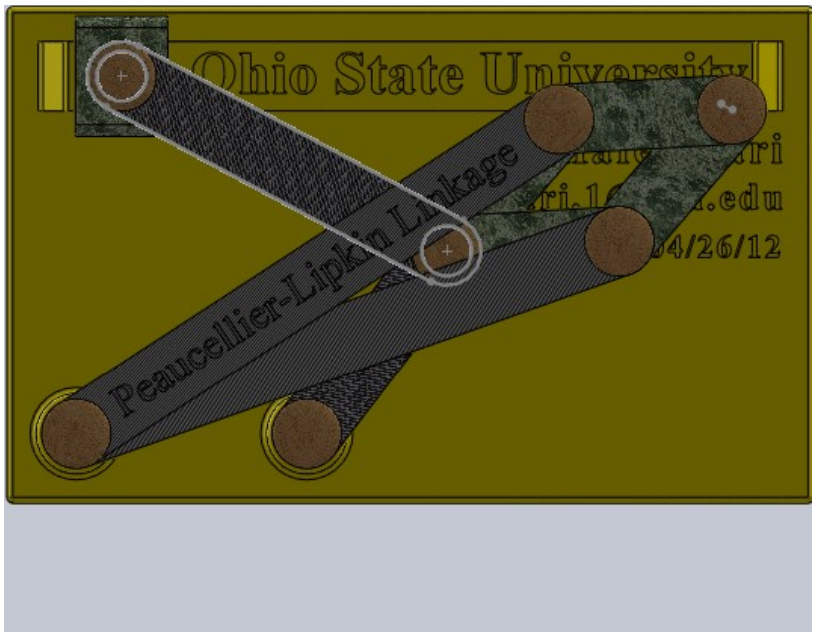


AO=BQ, AC=BC
CP perpendicular to AB
P is the tracing point

ACCURATE STRAIGHT LINE MECHANISM

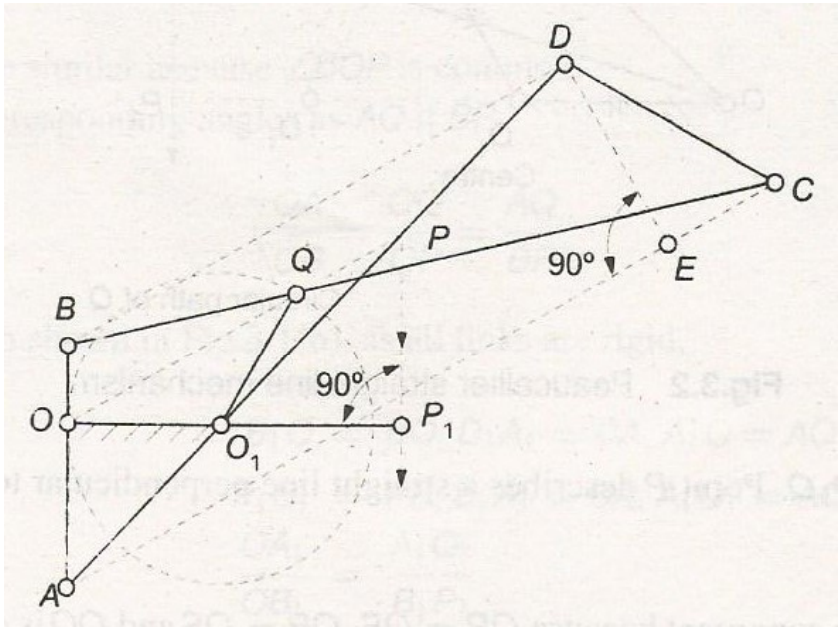
Peaucellier–Lipkin linkage





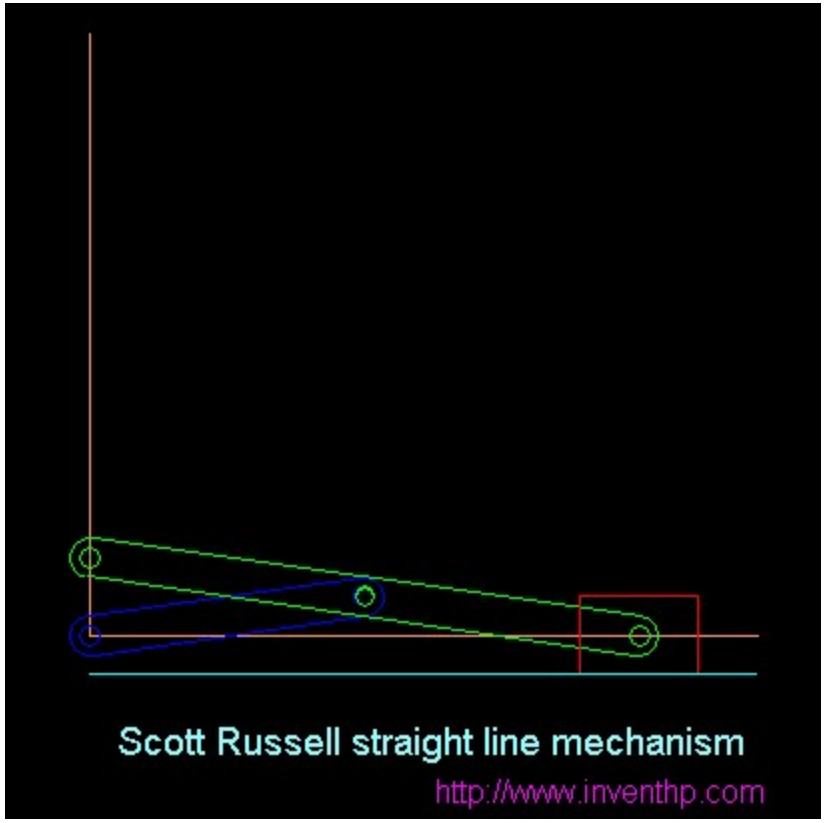
The **Peaucellier–Lipkin linkage** invented in 1864, was the first planar linkage capable of transforming rotary motion into perfect straight-line motion and vice versa

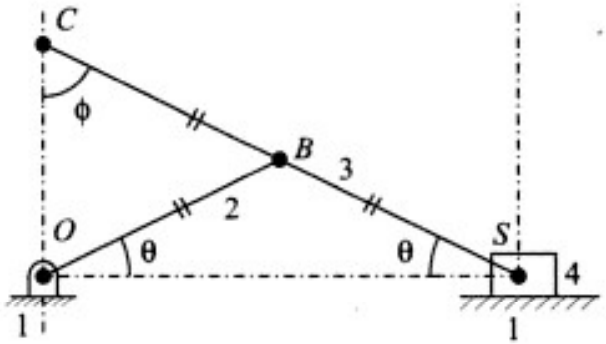
Hart Mechanism



- O O_1 is the fixed link
- O_1Q is the rotating link
- Point Q moves in a circle with O_1 and radius O_1Q
- ABCD is a trapezium so that AB=CD; BD parallel to AC
- BO/BA= BQ/BC=DP/DA
- Point P describes the straight line perpendicular to OO_1

Scott- Russel Mechanism





OB=BS=BC
CO perpendicular to OS
S moves in a straight line along OS

INTERMITTENT MOTION MECHANISM

Ratchets and Escapements

•There are different forms of ratchets and escapements used in engineering practices

•They are used in locks, clock works, jacks and many other mechanism requiring some form of intermittent motion

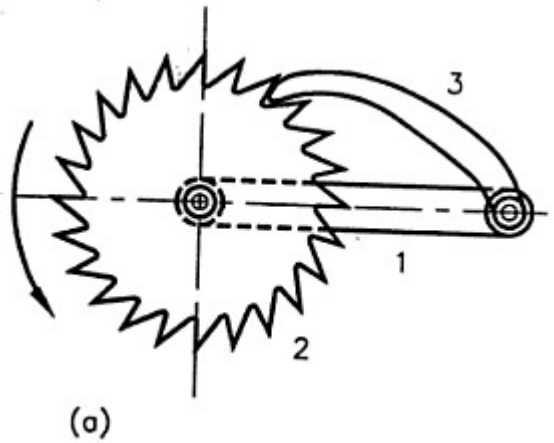
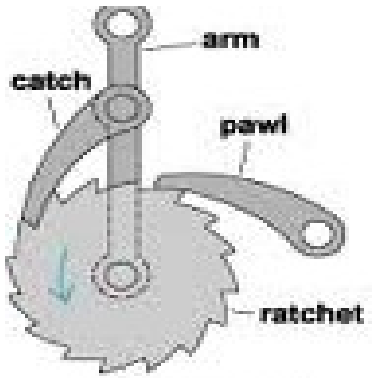
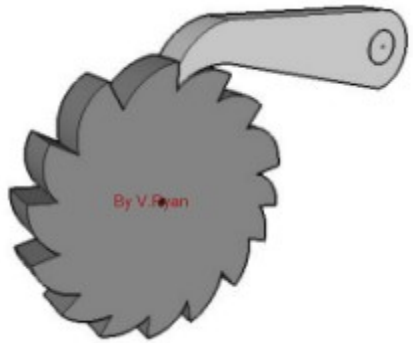
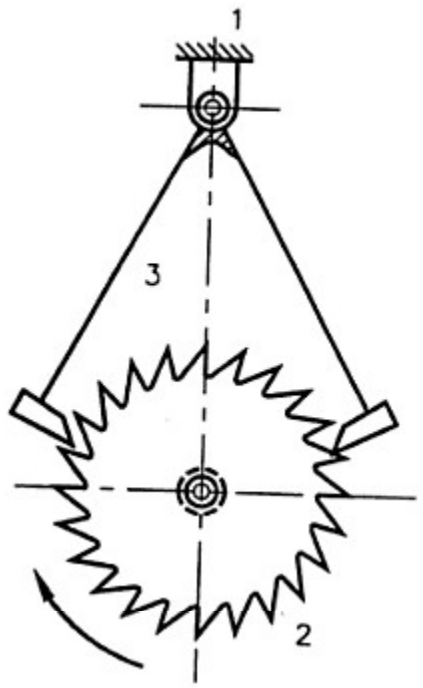


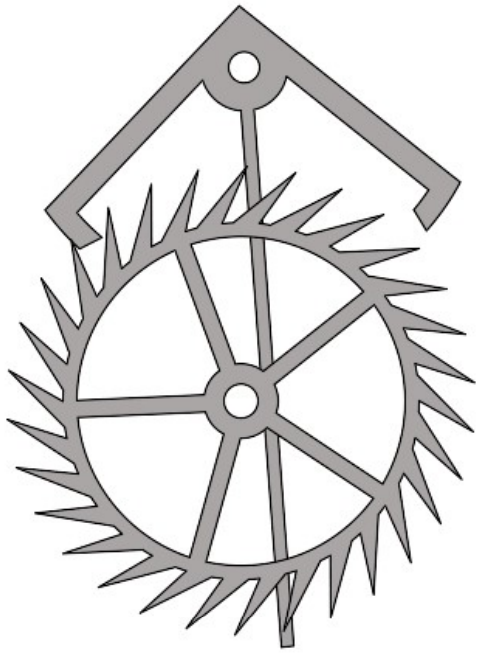
Fig (a) shows one kind of ratchets which allows the motion of the gear in one direction



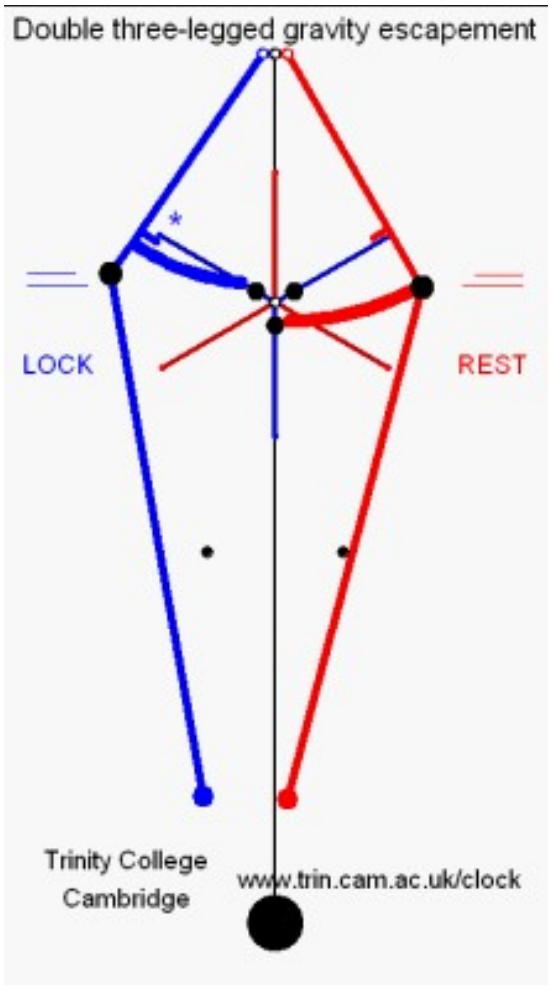
toothed ratchet





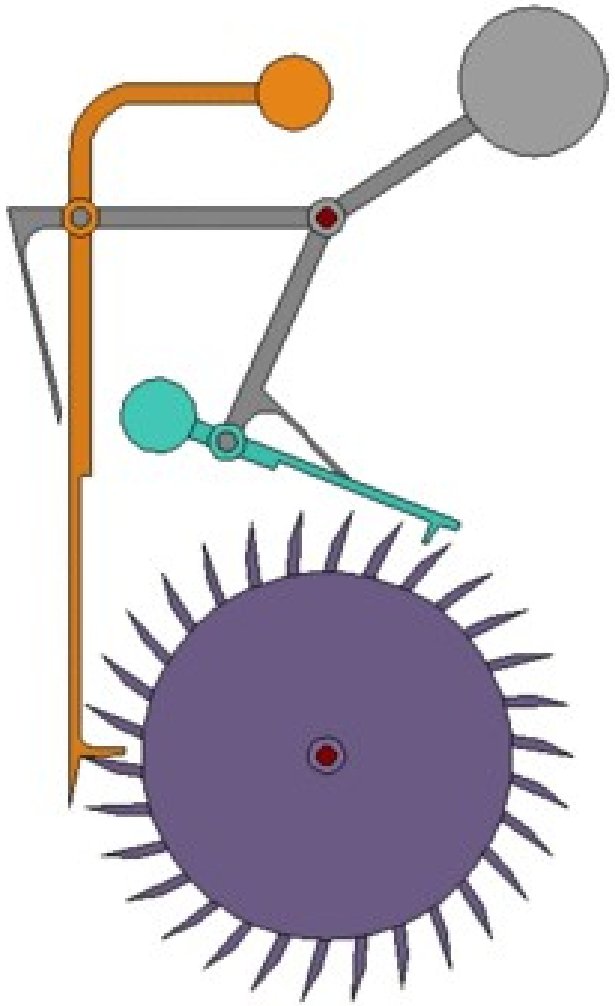


Above figure is an example for deadbeat escapement used commonly in pendulum clocks

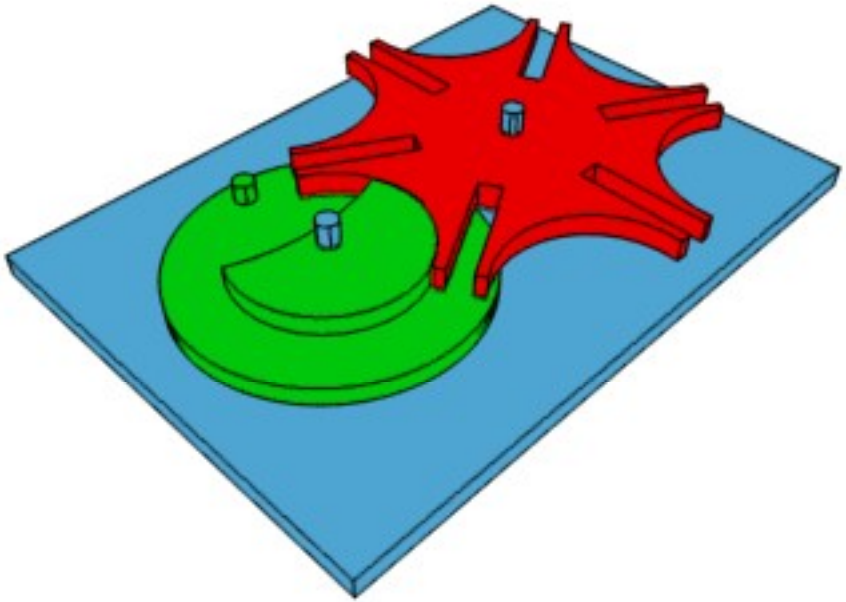


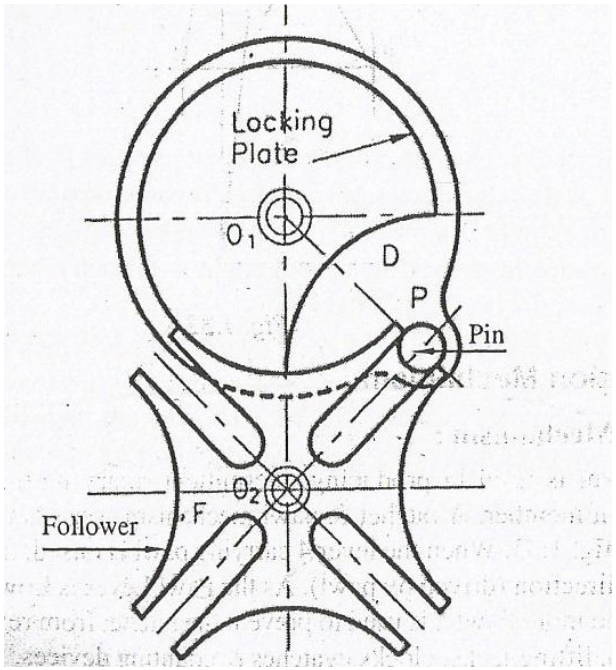
A gravity escapement uses a small weight or a weak spring to give an impulse directly to the pendulum

Grass hopper escapement



Geneva mechanism

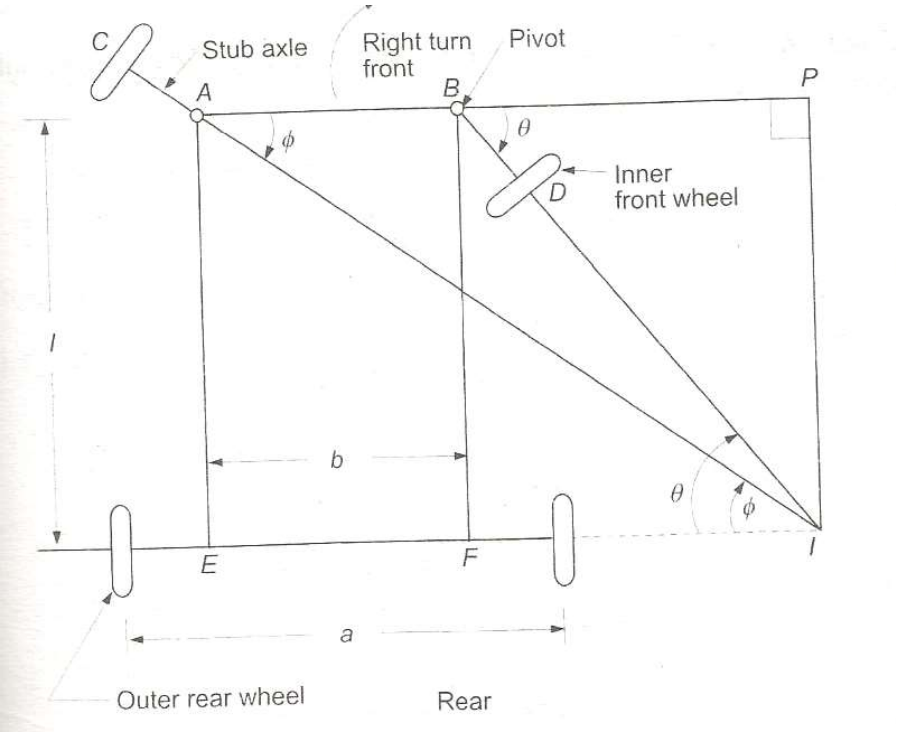




•It is an intermittent motion mechanism
•Consists of a driving wheel D carrying a pin P which engages in a slot of the follower F
•During one quarter revolution of the driving plate, the pin and follower remain in contact and hence the follower is turned by one quarter turn
•During the remaining time of one revolution of the driver , the follower remains at rest locked in position by the circular arc

Steering gear mechanism

Fundamental Equation of Correct Steering

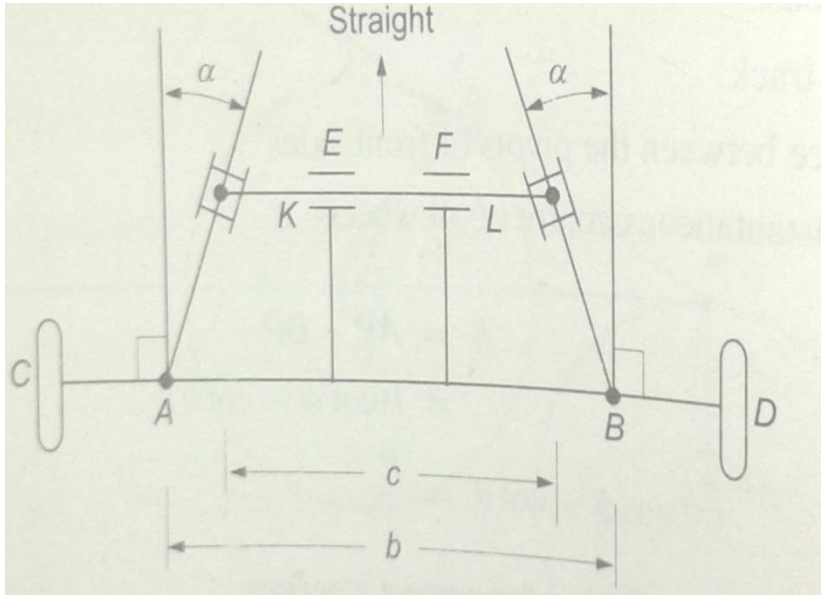


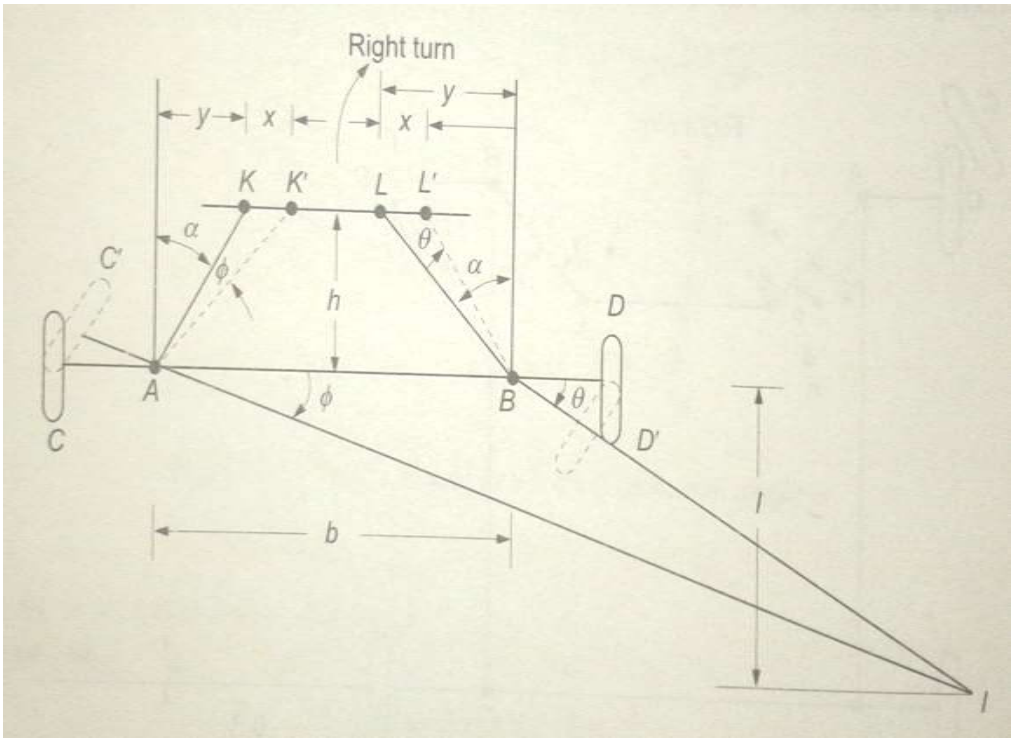
$$\cot\phi - \cot\theta = \frac{b}{l}$$

Types of Steering Gear

- Davis steering gear (which has sliding pairs)
- Ackermann steering gear (which has turning pairs)

Davis steering gear mechanism





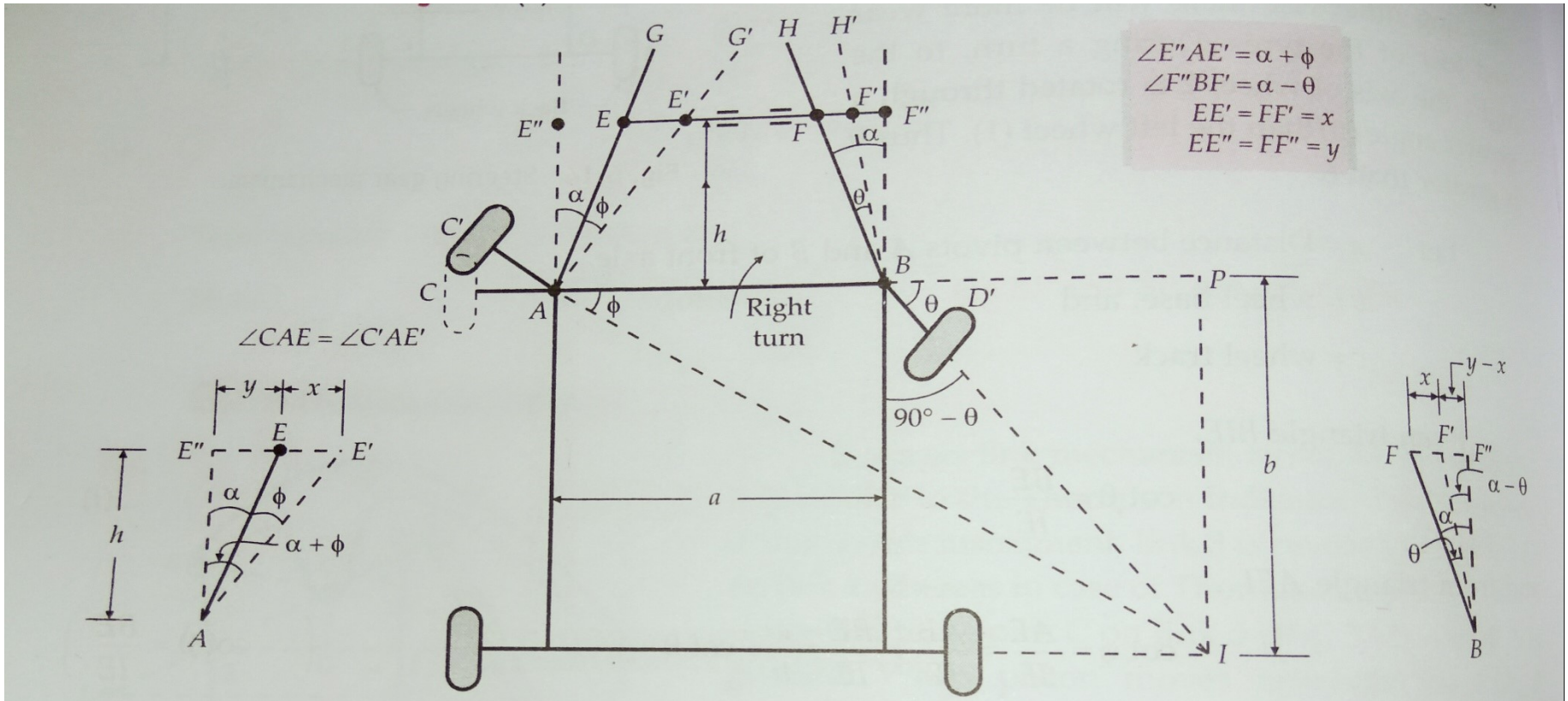


Fig. 5.15 (*b*)

Let a = Distance between the pivots A and B of front axle

h = Vertical distance between AB and EF

x = Distance moved by BH to $BH' = EE' = FF'$

α = Angle subtended by links AG and BH with vertical

b = Wheel base

$$\tan(\alpha - \theta) = \frac{F'F''}{F''B} = \frac{FF'' - FF'}{F''B}$$

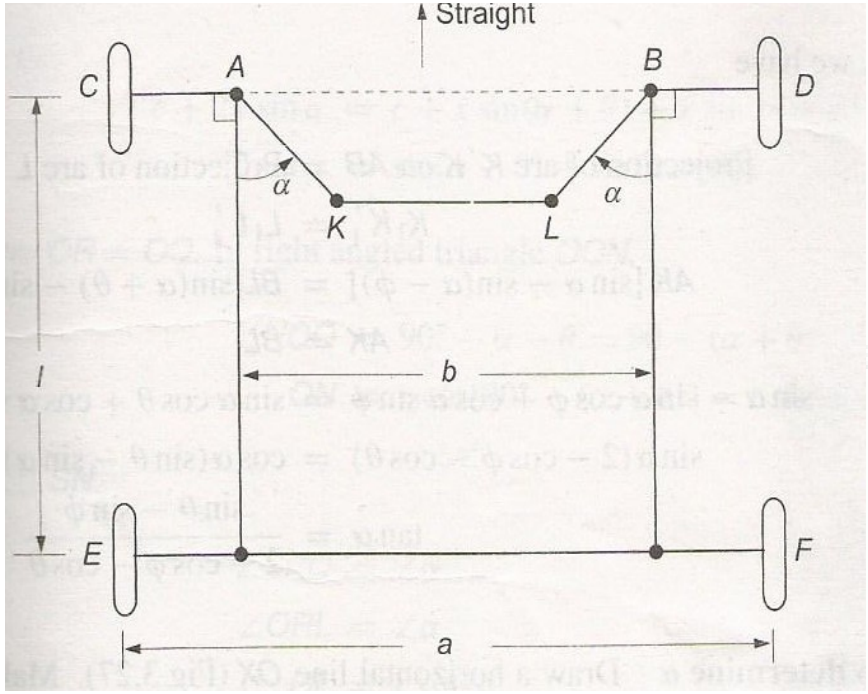
$$\frac{\tan\alpha - \tan\theta}{1 + \tan\alpha \,.\, \tan\theta} = \frac{y - x}{h} \quad \text{and} \quad \tan\alpha = \frac{y}{h} = \frac{EE''}{AE''} = \frac{FF''}{BF''}$$

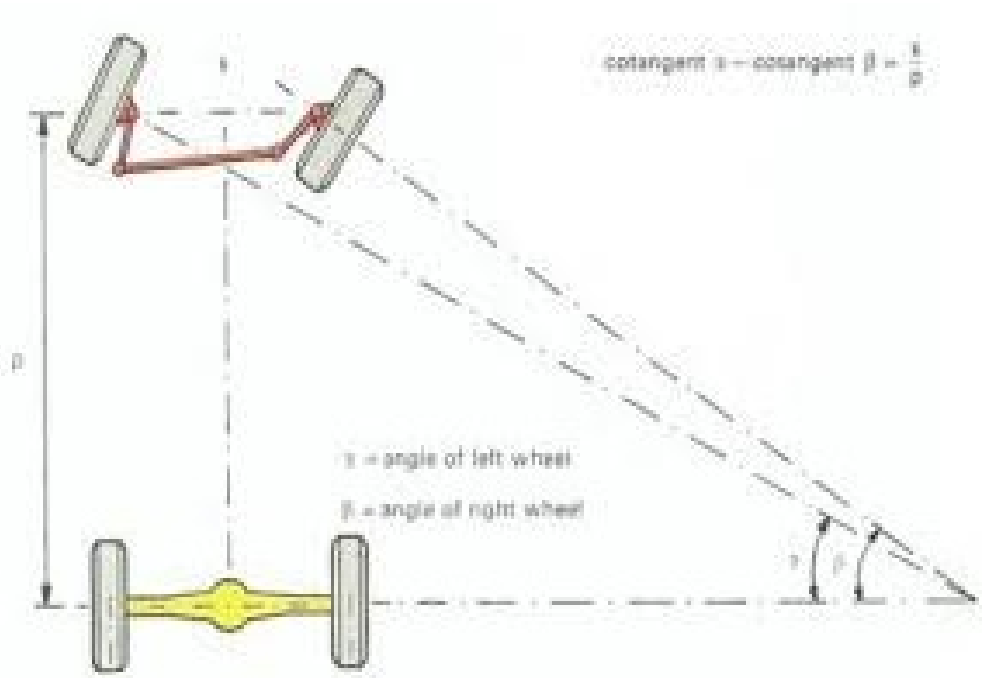
$$\frac{\frac{y}{h} - \tan\theta}{1 + \frac{y}{h} \,.\, \tan\theta} = \frac{y - x}{h}$$

$$\frac{y - h\tan\theta}{h + y \,.\, \tan\theta} = \frac{y - x}{h}$$

$$\tan\theta = \frac{hx}{y^2 - xy + h^2}$$

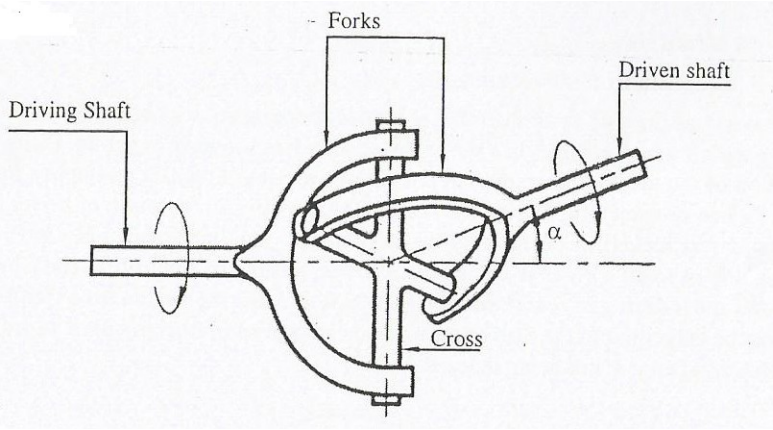
Ackermann steering gear



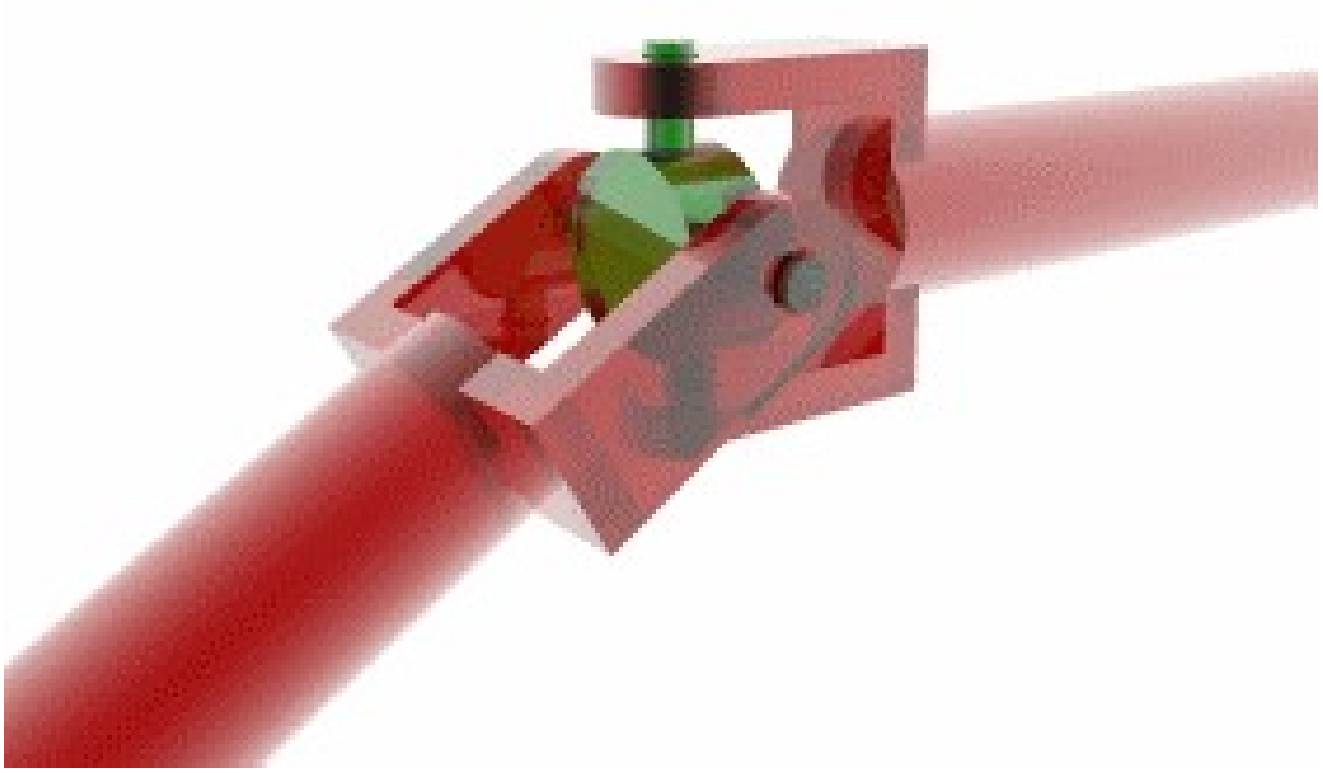


Hooke's joint or Universal coupling

•Hooke's joint is a device that connects two shafts whose axes are neither coaxial nor parallel but intersect at a point
•Used to transmit power from the engine to the rear axle of an automobile
•Transmission of drives to different spindle in multiple drilling machine
•Knee joint in a milling machine
•Transmission of torque in rolling mills



Hooke’s joint or Universal coupling



- When driver shaft rotates with uniform speed,
- The driven shaft rotates at continuously varying speed

$$\tan\theta = \tan\phi . \cos\alpha$$

Let ω_1 = Angular velocity of the driving shaft $= \frac{d\theta}{dt}$

ω_2 = Angular velocity of the driven shaft $= \frac{d\phi}{dt}$

$$\sec^2\theta \frac{d\theta}{dt} = \cos\alpha \sec^2\phi \frac{d\phi}{dt}$$

$$\frac{d\phi}{dt} \Big/ \frac{d\theta}{dt} = \frac{\sec^2\theta}{\cos\alpha . \sec^2\phi}$$

$$\frac{\omega_2}{\omega_1} = \frac{1}{\cos^2\theta . \cos\alpha . \sec^2\phi} = \frac{1}{\cos^2\theta . \cos\alpha . (1 + \tan^2\phi)}$$

$$= \frac{1}{\cos^2\theta . \cos\alpha \left(1 + \frac{\tan^2\theta}{\cos^2\alpha}\right)} \qquad \left(\because \tan\phi = \frac{\tan\theta}{\cos\alpha} \text{ from } (i)\right)$$

$$= \frac{1}{\cos^2\theta . \cos\alpha + \frac{\sin^2\theta}{\cos\alpha}} = \frac{\cos\alpha}{\cos^2\theta \cos^2\alpha + \sin^2\theta}$$

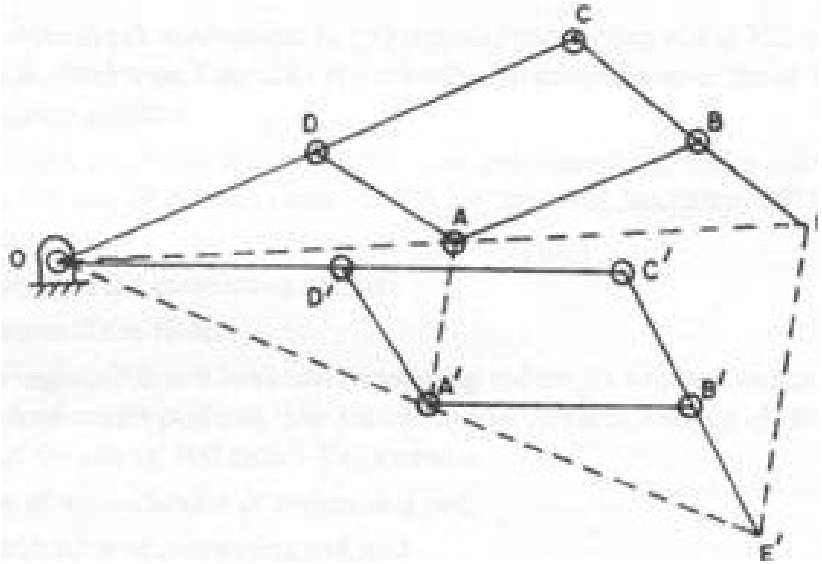
$$= \frac{\cos\alpha}{\cos^2\theta (1 - \sin^2\alpha) + \sin^2\theta} = \frac{\cos\alpha}{\cos^2\theta - \cos^2\theta \sin^2\alpha + \sin^2\theta}$$

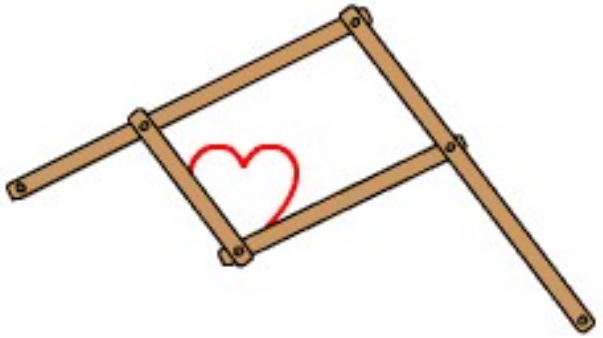
$$= \frac{\cos\alpha}{\cos^2\theta + \sin^2\theta - \cos^2\theta \sin^2\alpha}$$

$$\frac{\omega_2}{\omega_1} = \frac{\cos\alpha}{1 - \cos^2\theta \sin^2\alpha} \qquad \ldots(ii)$$

- *As a mechanism moves over a range of motion its geometry changes. If we are using a mechanisms to transmit torque, or force then we must consider the ratio between the input and output force in various positions.*
- *Mechanical Advantage*
  - The advantage gained by the use of a mechanism in transmitting force
  - The ratio of the force that performs the useful work of a machine to the force that is applied to the machine
- *Transmission angle*
- Transmission angle is the angle between the coupling member and the output member in a mechanism.
- As this angle approaches ±90°, the mechanical advantage of the mechanism typically increases.
- *Toggle position*
- Toggle positions occur when the mechanical advantage has near infinite.
- Mechanisms which utilizes this is position is called as toggle mechanism.
- Used for stone crushers

- PANTOGRAPH





Dwell mechanism