- How many degrees of freedom do you have each time you introduce a moving link? How many degrees of freedom do you take away when you add a simple joint? How many degrees of freedom would you take away by adding a half joint? Do the different terms in equation make sense in light of this knowledge?

1.3.1 Grashoff's law:

- **Grashoff 4-bar linkage:** A linkage that contains one or more links capable of undergoing a full rotation. A linkage is Grashoff if: S + L < P + Q where: S = shortest link length, L = longest, P, Q = intermediate length links. Both joints of the shortest link are capable of 3 60 degrees of rotation in a Grashoff linkages. This gives us 4 possible linkages: crank-rocker input rotates 360), rocker -crank-rocker coupler rotates 360), rocker -crank follower; double crank all links rotate 360). Note that these mechanisms are si mply the possible inversions (section 2.11, Figure 2-16 of a Grashoff mechanism.
- **Non Grashoff 4 bar:** No link can rotate 360 if: S + L > P + Q

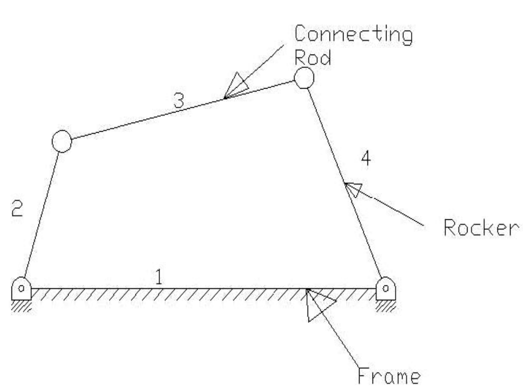
Let's examine why the Grashoff condition works:

- Consider a linkage with the shortest and longest sides joined together. Examine the linkage when the shortest side is parallel to the longest side 2 positions possible, folded over on the long side and extended away from the long side. How long do P and Q have to be to allow the linkage to achieve these positions?
- Consider a linkage where the long and short sides are not joined. Can you figure out the required lengths for P and Q in this type of mechanism

1.4 Kinematic Inversions of 4-bar chain and slider crank chains:

- ***Types of Kinematic Chain:*** 1) Four bar chain 2) Single slider chain 3) Double Slider chain
- **Four bar Chain:**

The chain has four links and it looks like a cycle frame and hence it is also called *quadric cycle chain*. It is shown in the figure. In this type of chain all four pairs will be turning pairs.



- **Inversions:**

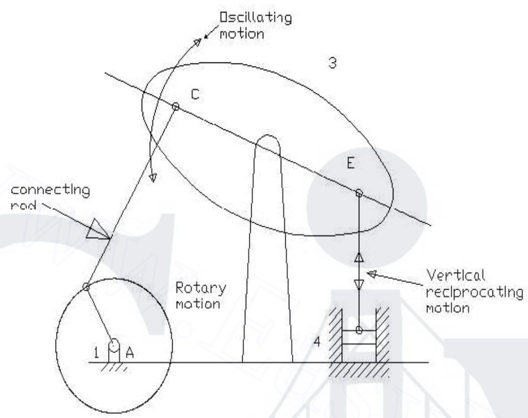
By fixing each link at a time we get as many mechanisms as the number of links, then each mechanism is called 'Inversion' of the original Kinematic Chain.

Inversions of four bar chain mechanism:

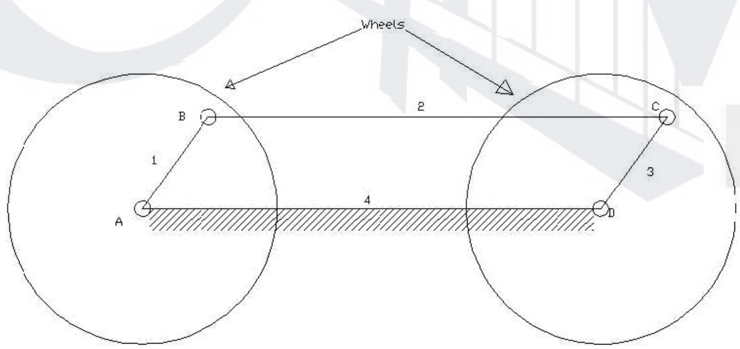
There are three inversions: 1) Beam Engine or Crank and lever mechanism. 2) Coupling rod of locomotive or double crank mechanism. 3) Watt's straight line mechanism or double lever mechanism.

- **Beam Engine:**

When the crank AB rotates about A, the link CE pivoted at D makes vertical reciprocating motion at end E. This is used to convert rotary motion to reciprocating motion and vice versa. It is also known as Crank and lever mechanism. This mechanism is shown in the figure below.

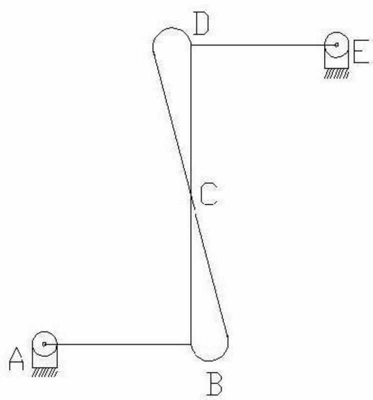


2. Coupling rod of locomotive: In this mechanism the length of link AD = length of link C. Also length of link AB = length of link CD. When AB rotates about A, the crank DC rotates about D. this mechanism is used for coupling locomotive wheels. Since links AB and CD work as cranks, this mechanism is also known as double crank mechanism. This is shown in the figure below.



3. **Watt's straight line mechanism or Double lever mechanism:** In this mechanism, the links AB & DE act as levers at the ends A & E of these levers are fixed. The AB & DE are parallel in the mean position of the mechanism and coupling rod BD is perpendicular to the levers AB & DE. On any small displacement of the mechanism the tracing point 'C' traces the shape of number '8', a

portion of which will be approximately straight. Hence this is also an example for the approximate straight line mechanism. This mechanism is shown below.



- **2. Slider crank Chain:**

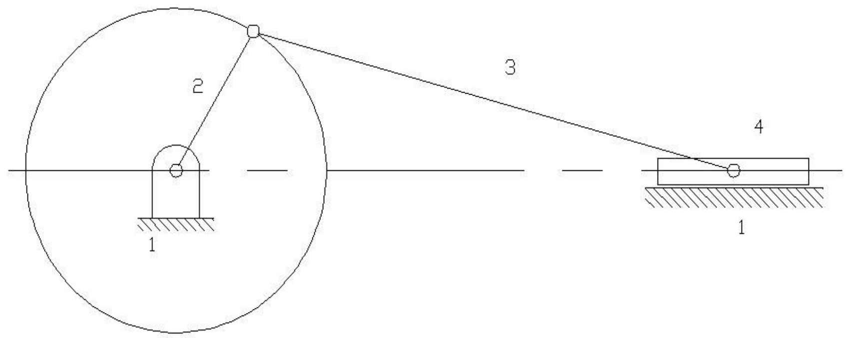
It is a four bar chain having one sliding pair and three turning pairs. It is shown in the figure below the purpose of this mechanism is to convert rotary motion to reciprocating motion and vice versa.
Inversions of a Slider crank chain:

There are four inversions in a single slider chain mechanism. They are:

1) Reciprocating engine mechanism (1st inversion)
2) Oscillating cylinder engine mechanism (2nd inversion)
3) Crank and slotted lever mechanism (2nd inversion)
4) Whitworth quick return motion mechanism (3rd inversion)
5) Rotary engine mechanism (3rd inversion)
6) Bull engine mechanism (4th inversion)
7) Hand Pump (4th inversion)

- **1. Reciprocating engine mechanism :**

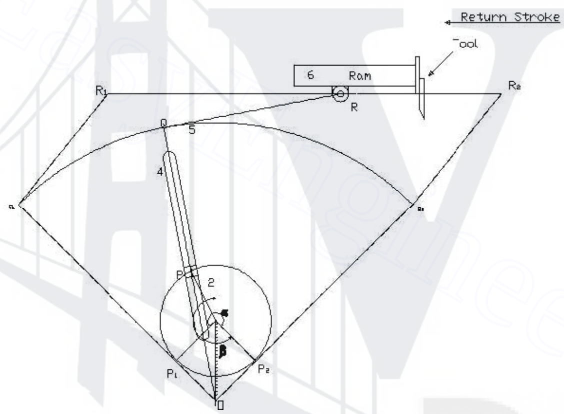
In the first inversion, the link 1 i.e., the cylinder and the frame is kept fixed. The fig below shows a reciprocating engine.



A slotted link 1 is fixed. When the crank 2 rotates about O, the sliding piston 4 reciprocates in the slotted link 1. This mechanism is used in steam engine, pumps, compressors, I.C. engines, etc.

- **2. Crank and slotted lever mechanism:**

It is an application of second inversion. The crank and slotted lever mechanism is shown in figure below.

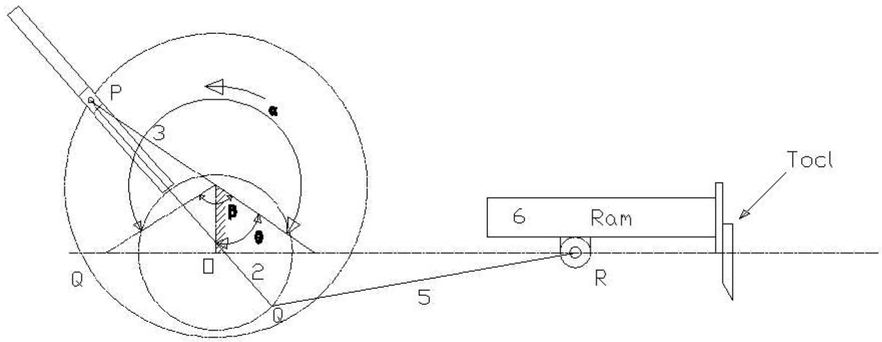


In this mechanism link 3 is fixed. The slider link 1) reciprocates in oscillating slotted lever link 4) and crank link 2) rotates. Link 5 connects link 4 to the ram link 6). The ram with the cutting tool reciprocates perpendicular to the fixed link 3. The ram with the tool reverses its direction of motion when link 2 is perpendicular to link 4. Thus the cutting stroke is executed during the rotation of the crank through angle α and the return stroke is executed when the crank rotates through angle β or 360 – α. Therefore, when the crank rotates uniformly, we get

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

This mechanism is used in shaping machines, slotting machines and in rotary engines.

1.4 . 1 Whitworth quick return motion mechanism:



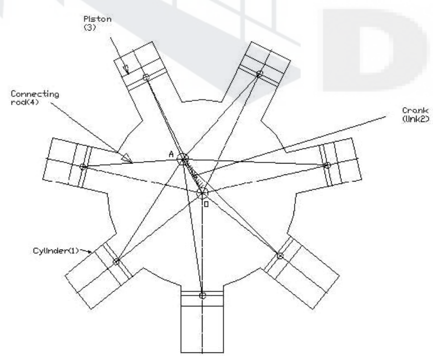
Third inversion is obtained by fixing the crank i.e. link 2. Whitworth quick return mechanism is an application of third inversion. This mechanism is shown in the figure below. The crank OC is fixed and OQ rotates about O. The slider slides in the slotted link and generates a circle of radius CP. Link 5 connects the extension OQ provided on the opposite side of the link 1 to the ram link 6). The rotary motion of P is taken to the ram R which reciprocates. The quick return motion mechanism is used in shapers and slotting machines. The angle covered during cutting stroke from P1 to P2 in counter clockwise direction is α or 360 -2θ. During the return stroke, the angle covered is 2θ or β.

Therefore, Time to cutting = 360 -2θ = 180 – θ

Time of return 2θθ = α = α . β 360 – α

1. Rotary engine mechanism or Gnome Engine:

Rotary engine mechanism or gnome engine is another application of third inversion. It is a rotary cylinder V – type internal combustion engine used as an aero – engine. But now Gnome engine has been replaced by Gas turbines. The Gnome engine has generally seven cylinders in one plane. The crank OA is fixed and all the connecting rods from the pistons are connected to A. In this mechanism when the pistons reciprocate in the cylinders, the whole assembly of cylinders, pistons and connecting rods rotate about the axis O, where the entire mechanical power developed, is obtained in the form of rotation of the crank shaft. This mechanism is shown in the figure below.



2 Double Slider Crank Chain:

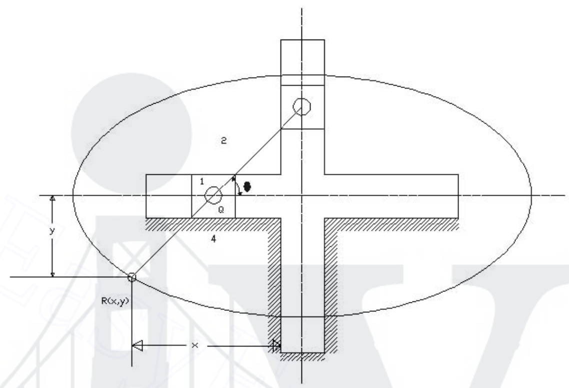
A four bar chain having two turning and two sliding pairs such that two pairs of the same kind are adjacent is known as double slider crank chain.

3 Inversions of Double slider Crank chain:

It consists of two sliding pairs and two turning pairs. They are three important inversions of double slider crank chain. 1) Elliptical trammel. 2) Scotch yoke mechanism. 3) Oldham's Coupling.

4 1. Elliptical Trammel:

This is an instrument for drawing ellipses. Here the slotted link is fixed. The sliding block P and Q in vertical and horizontal slots respectively. The end R generates an ellipse with the displacement of sliders P and Q.

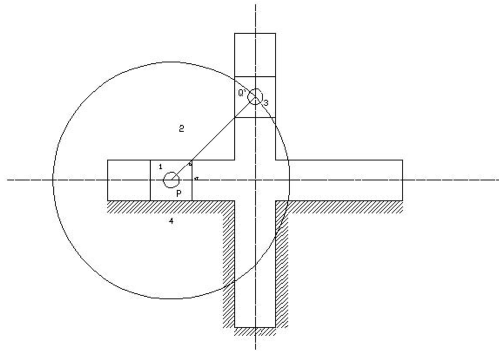


The co-ordinates of the point R are x and y. From the fig. cos θ = x.PR
and Sin θ = y. QR
Squaring and adding (i and (ii we get $\frac{x^2}{PR^2} + \frac{y^2}{QR^2} = \cos^2\theta + \sin^2\theta$

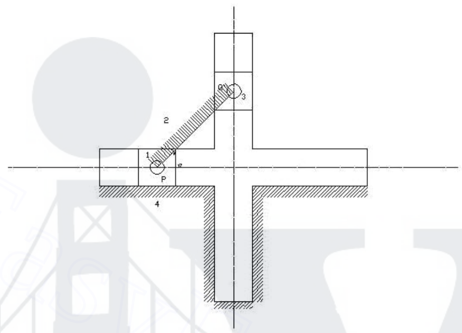
$$\frac{x^2}{PR^2} + \frac{y^2}{QR^2} = 1$$

The equation is that of an ellipse, Hence the instrument traces an ellipse. Path traced by mid-point of PQ is a circle. In this case, PR = PQ and so $x^2 + y^2 = 1$ (PR^2 QR^2)
It is an equation of circle with PR = QR = radius of a circle.

5. Scotch yoke mechanism: This mechanism, the slider P is fixed. When PQ rotates above P, the slider Q reciprocates in the vertical slot. The mechanism is used to convert rotary to reciprocating mechanism.



5.Oldham's coupling: The third inversion of obtained by fixing the link connecting the 2 blocks P & Q. If one block is turning through an angle, the frame and the other block will also turn through the same angle. It is shown in the figure below.



An application of the third inversion of the double slider crank mechanism is Oldham's coupling shown in the figure. This coupling is used for connecting two parallel shafts when the distance between the shafts is small. The two shafts to be connected have flanges at their ends, secured by forging. Slots are cut in the flanges. These flanges form 1 and 3. An intermediate disc having tongues at right angles and opposite sides is fitted in between the flanges. The intermediate piece forms the link 4 which slides or reciprocates in flanges 1 & 3. The link two is fixed as shown. When flange 1 turns, the intermediate disc 4 must turn through the same angle and whatever angle 4 turns, the flange 3 must turn through the same angle. Hence 1, 4 & 3 must have the same angular velocity at every instant. If the distance between the axis of the shaft is x, it will be the diameter if the circle traced by the centre of the intermediate piece. The maximum sliding speed of each tongue along its slot is given by

$v = x\omega$ where, ω = angular velocity of each shaft in rad/sec v = linear velocity in m/sec

1.6 Mechanical Advantage, Transmission angle:

1The mechanical advantage MA is defined as the ratio of output torque to the input torque. or ratio
of load to output.

2 Transmission angle.

3 The extreme values of the transmission angle occur when the crank lies along the line of frame.

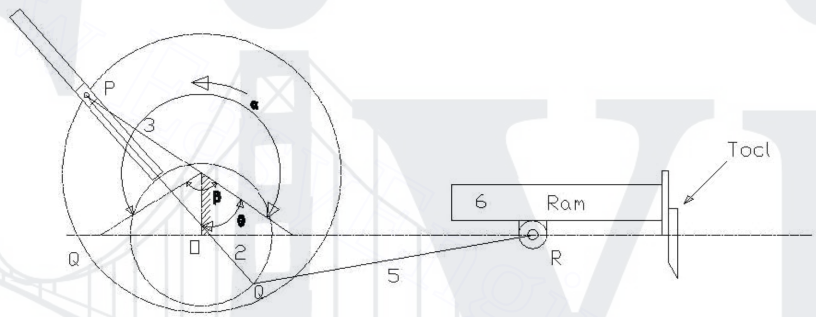
1.7Description of common mechanisms-Single, Double and offset slider mechanisms - Quick return mechanisms:

1.Quick Return Motion Mechanisms:

Many a times mechanisms are designed to perform repetitive operations. During these operations for a certain period the mechanisms will be under load known as working stroke and the remaining period is known as the return stroke, the mechanism returns to repeat the operation without load. The ratio of time of working stroke to that of the return stroke is known a time ratio. Quick return mechanisms are used in machine tools to give a slow cutting stroke and a quick return stroke. The various quick return mechanisms commonly used are i Whitworth ii Drag link. iii Crank and slotted lever mechanism

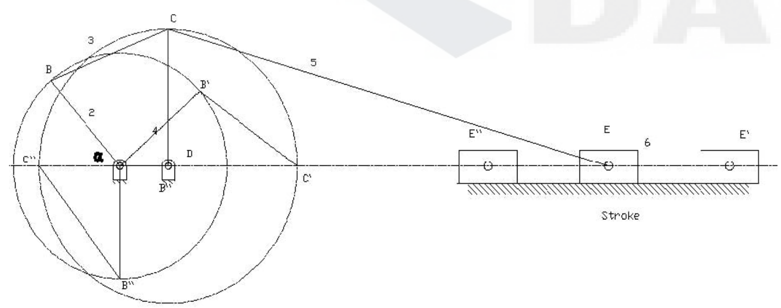
2. Whitworth quick return mechanism:

Whitworth quick return mechanism is an application of third inversion of the single slider crank chain. This mechanism is shown in the figure below. The crank OC is fixed and OQ rotates about O. The slider slides in the slotted link and generates a circle of radius CP. Link 5 connects the extension OQ provided on the opposite side of the link 1 to the ram link 6. The rotary motion of P is taken to the ram R which reciprocates. The quick return motion mechanism is used in shapers and slotting machines.



The angle covered during cutting stroke from P1 to P2 in counter clockwise direction is α or 360 -2θ. During the return stroke, the angle covered is 2θ or β.

3. Drag link mechanism :



This is four bar mechanism with double crank in which the shortest link is fixed. If the crank AB rotates at a uniform speed, the crank CD rotate at a non-uniform speed. This rotation of link CD is transformed to quick return reciprocatory motion of the ram E by the link CE as shown in figure.