Theory of Machine

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Inversion of Mechanism

Absolute motion is measured with respect to a stationary frame. Relative motion is measured for one point or link with respect to another link.

We have already stated that when one of links is fixed in a kinematic chain, it is called a mechanism. So we can obtain as many mechanisms as the number of links in a kinematic chain by fixing, in turn, different links in a kinematic chain. This method of obtaining different mechanisms by fixing different links in a kinematic chain, is known as **inversion of the mechanism.**

1.16. Inversion of Mechanism

It may be noted that the relative motions between the various links is not changed in any manner through the process of inversion, but their absolute motions (those measured with respect to the fixed link) may be changed drastically.

1.16. Inversion of Mechanism

Note:

The part of a mechanism which initially moves with respect to the frame or fixed link is called **driver** and that part of the mechanism to which motion is transmitted is called **follower.**

Most of the mechanisms are reversible, so that same link can play the role of a driver and follower at different times. For example, in a reciprocating steam engine, the piston is the driver and flywheel is a follower while in a reciprocating air compressor, the flywheel is a driver.

1.16. Inversion of Mechanism

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,**
3. **Double slider crank chain.**

These kinematic chains are discussed, in detail, in the following articles.

1.16. Inversion of Mechanism

1. Four Bar Chain or Quadric Cycle Chain

We have already discussed that the kinematic chain is a combination of four or more kinematic pairs, such that the relative motion between the links or elements is completely constrained.

The simplest and the basic kinematic chain is a four-bar chain or quadric cycle chain, as shown in Fig. 1. 32.

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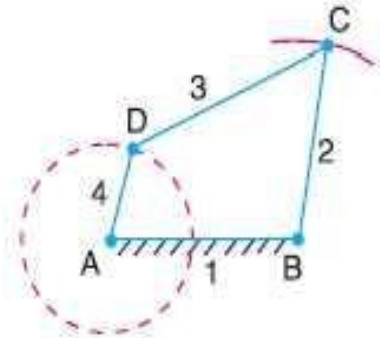


Fig. 1.32 Four bar chain

It consists of four links, each of them forms a turning pair at A, B, C and D. The four links may be of different lengths.

1.16. Inversion of Mechanism

In a four bar chain, one of the links, in particular the shortest link, will make a complete revolution relative to the other three links, if it satisfies the Grashof's law. Such a link is known as **crank or driver.**

In **Fig. 1.32**, AD (link 4) is a crank. The link BC (link 2) which makes a partial rotation or oscillates is known as **lever or rocker or follower** and the link CD (link 3) which connects the crank and lever is called **connecting rod or coupler.** The fixed link AB (link 1) is known as **frame** of the mechanism.

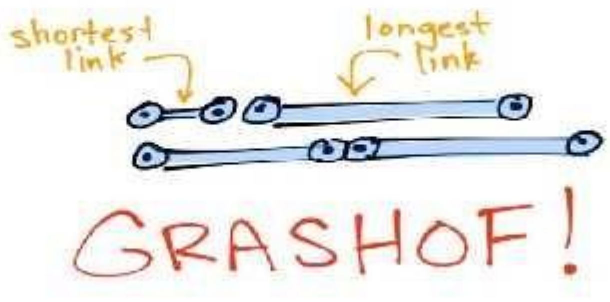
When the crank (link 4) is the driver, the mechanism is transforming rotary motion into oscillating motion.

1.16. Inversion of Mechanism

A very important consideration in designing a mechanism is to ensure that the input crank makes a complete revolution relative to the other links. The mechanism in which no link makes a complete revolution will not be useful in such applications. For the four-bar linkage there is a very simple test of whether this is the case.

Grashof's law for four-bar mechanism.

If one of the links can perform a full rotation relative to another link, the linkage is called a **Grashof mechanism. Grashof's law** states that for a planar four-bar mechanism (linkage), the sum of the shortest and longest link lengths can not be greather than the sum of the other two link lengths if there is to be continuous relative motion between two members.



1.16. Inversion of Mechanism

This is illustrated in Fig. 1.33, where the longest link has length l, the shortest link has length s , and the other two links have lengths p and q. Grashof's law states that one of the links , in particular the shortest link, will rotate continuously relative to the other three links if only if

$$s + l \leq p + q$$

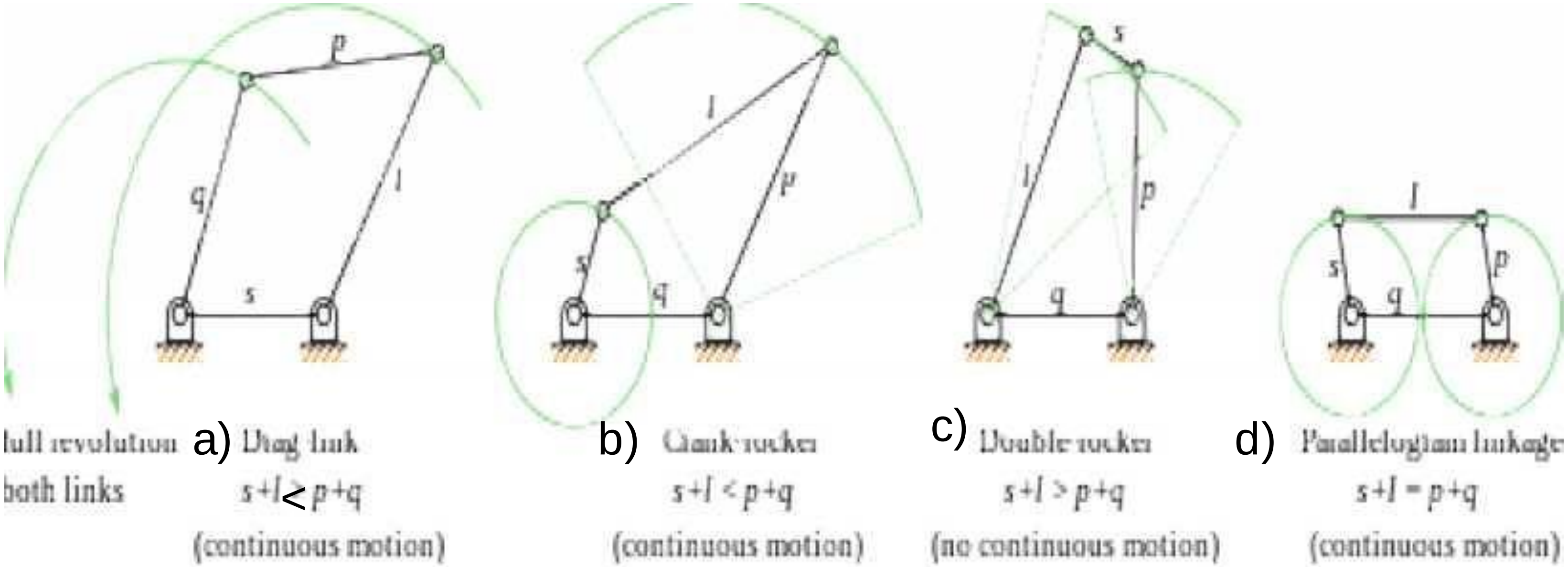
or

$$L_{max} + L_{min} < L_a + L_b$$

where L_{max} and L_{min} are the longest and shortest links, L_a and L_b are each links of intermediate length. If this inequality is not satisfied no link will make a complete revolution relative to another.

1.16. Inversion of Mechanism

Fig. 1.33. Four inversions of the Grashof chain



https://youtu.be/mwPIB89V-L8 https://youtu.be/9D0IBiM4_1M

https://youtu.be/Tjr2c4d09wQ https://youtu.be/eojqAbhdg_w

1.16. Inversion of Mechanism

It should be notted that nothing in Grashof's law specifies the order in which the links are connected or which link of the four –bar chain is fixed. Hence, by fixing any of the four links, we create four inversions of the four –bar mechanism shown in Fig.1.33.

The drag-link mechanism is obtained by fixing the shortest link s as the frame, as shown in Fig. 1.33a. In this inversion, both links adjacent to s can rotate continously, and both are properly described as cranks: the shortest of the two is generally used as the input

If the shortest links is adjacent to the fixed link, as shown in Figs.1.33b, a crank-rocker mechanism is obtained. Link s, the crank, since it is able to rotate continously , and link p, which can only oscilate between limits, is the rocker.

1.16. Inversion of Mechanism

By fixing the link opposite to s we obtain the the third inversion, the double-rocker mechanism of Fig. 1.33c. Note that although link s is able to make a complete revolution , neither link adjacent to the frame can do so; both must oscilate between limits and are therefore rockers.

If $L_{max} + L_{min} < Lp + Lq$ i.e. or s=p and l=q then, the forth inversion, the parallelogram or change-point or crossover-position mechanism is optained as shown in Fig.1.33d.

In each of these inversions , the shortest link s is adjacent to the longest link l . However, exactly the same types of linkages inversions will occur if the longest link l is opposite the shortest links.

1.16. Inversion of Mechanism

AI-Inversions of Four Bar Chain

Though there are many inversions of the four bar chain, yet the following are important from the subject point of view :

1. **Beam engine (crank and lever(rocker) mechanism).**
2. **Coupling rod of a locomotive (Double crank mechanism).**
3. **Watt's indicator mechanism (Double lever(rocker) mechanism).**

1.16. Inversion of Mechanism

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

https://youtu.be/1e8ZWsOzun4 https://youtu.be/bmh0a2OI0u8

A part of the mechanism of a beam engine (also known as crank and lever mechanism) which consists of four links, is shown in Figs. 1.34 and 1.35.

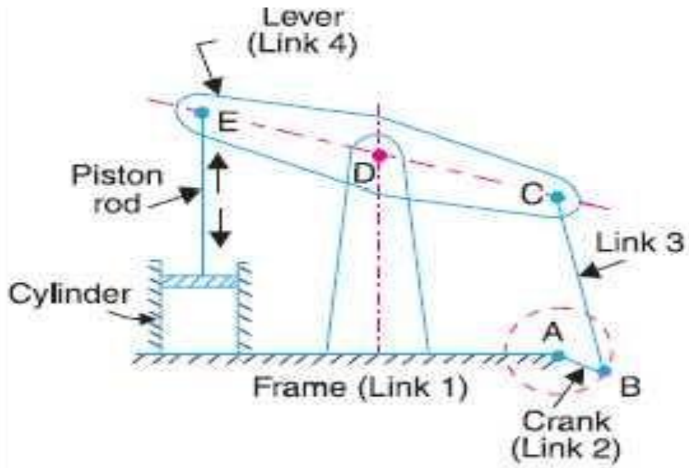


Fig. 1.34 Beam engine **Fig.1.35 Beam engine mechanism**

In this mechanism, when the crank rotates about the fixed centre A, the lever oscillates about a fixed centre D. The end E of the lever CDE is connected to a piston rod which reciprocates due to the rotation of the crank. In other words, the purpose of this mechanism is to convert rotary motion into reciprocating motion.

1.16. Inversion of Mechanism

2. Coupling rod of a locomotive (Double crank mechanism).

The mechanism of a coupling rod of a locomotive (also known as double crank mechanism) which consists of four links, is shown in Fig. 1.36.

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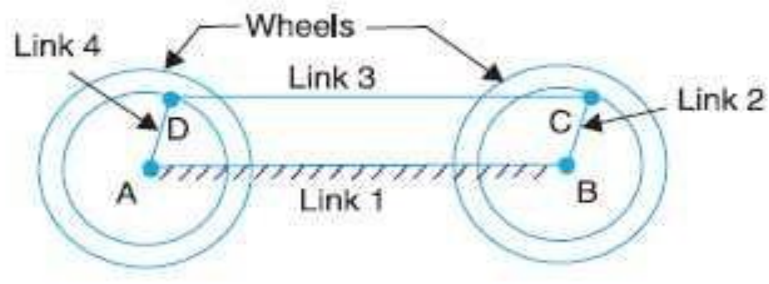


Fig. 1.36. Coupling rod of a locomotive

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.

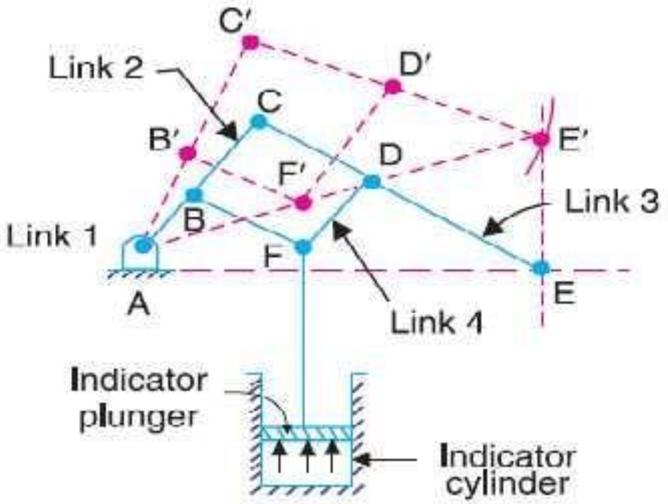
This mechanism is used for transmitting rotary motion from one wheel to the other wheel.

1.16. Inversion of Mechanism

3. Watt's indicator (Double rocker) mechanism.

A Watt's indicator mechanism (also known as Watt's straight line mechanism or double lever mechanism) which consists of four links, is shown in Fig. 1.37.

Fig.1.37. Watt's indicator mechanism



The four links are : fixed link at A, link AC, link CE and link BFD. It may be noted that BF and FD form one link because these two parts have no relative motion between them. The links CE and BFD act as levers. The displacement of the link BFD is directly proportional to the pressure of gas or steam which acts on the indicator plunger. On any small displacement of the mechanism, the tracing point E at the end of the link CE traces out approximately a straight line.

The initial position of the mechanism is shown in Fig. 1.37 by full lines whereas the dotted lines show the position of the mechanism when the gas or steam pressure acts on the indicator plunger.

1.16. Inversion of Mechanism

B. Single Slider Crank Chain

A single slider crank chain is a modification of the basic four bar chain. It consist of one sliding pair and three turning pairs. It is, usually, found in reciprocating steam engine mechanism. This type of mechanism converts rotary motion into reciprocating motion and vice versa.

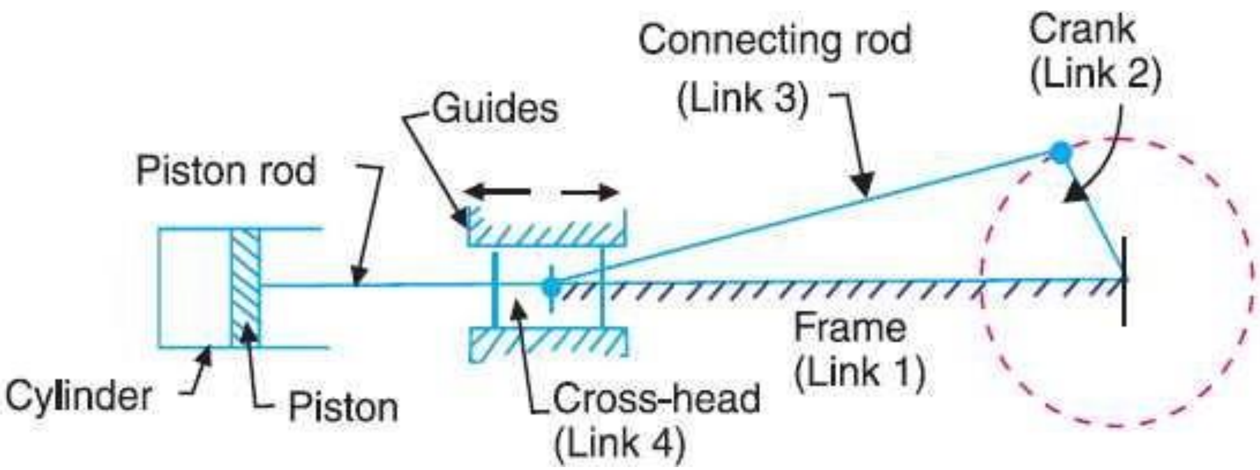


Fig. 1.38. Single slider crank chain

1.16. Inversion of Mechanism

In a single slider crank chain, as shown in Fig. 1.38, the links 1 and 2, links 2 and 3, and links 3 and 4 form three turning pairs while the links 4 and 1 form a sliding pair.

The link 1 corresponds to the frame of the engine, which is fixed. The link 2 corresponds to the crank ; link 3 corresponds to the connecting rod and link 4 corresponds to cross-head. As the crank rotates, the cross-head reciprocates in the guides and thus the piston reciprocates in the cylinder.

1.16. Inversion of Mechanism

BI: Inversions of Single Slider Crank Chain

We have seen in the previous article that a single slider crank chain is a four-link mechanism. We know that by fixing, in turn, different links in a kinematic chain, an inversion is obtained and we can obtain as many mechanisms as the links in a kinematic chain. It is thus obvious, that four inversions of a single slider crank chain are possible. These inversions are found in the following mechanisms.

1.16. Inversion of 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.
1.39. 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, as shown in Fig.

1.16. Inversion of Mechanism

1.39.

1.16. Inversion of Mechanism

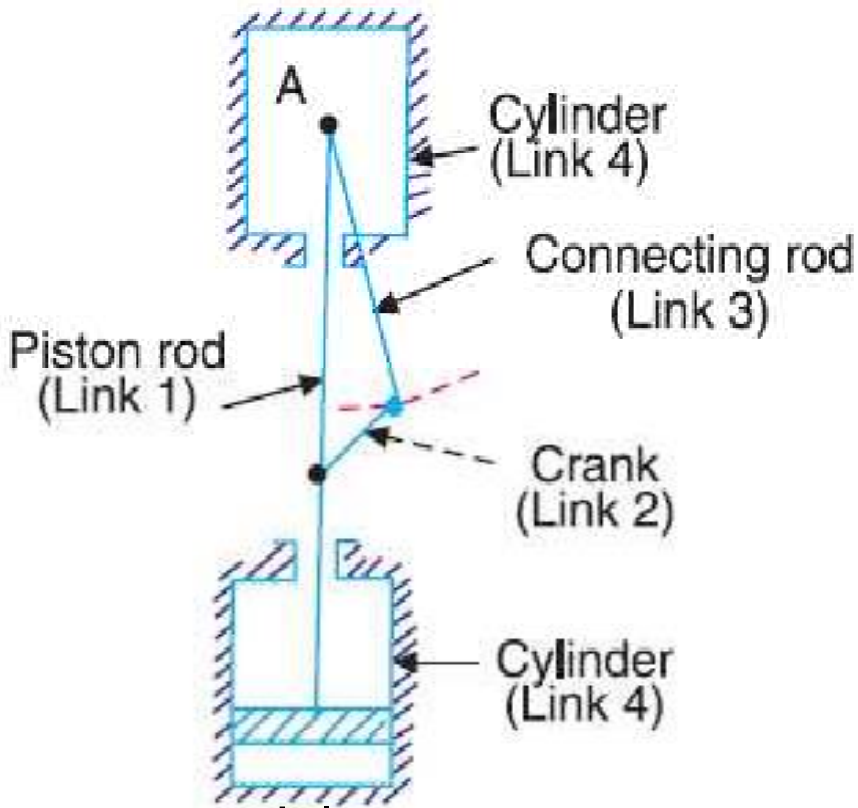


Fig. 1.39 Pendulum pump

https://youtu.be/mxgPTsXpB6k

1.16. Inversion of Mechanism

***2.* Oscillating cylinder engine.** The arrangement of oscillating cylinder engine mechanism, as shown in Fig. 1.40, is used to convert reciprocating motion into rotary motion. In this mechanism, the link 3 forming the turning pair is fixed. The link 3 corresponds to the connecting rod of a reciprocating steam engine mechanism. 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.

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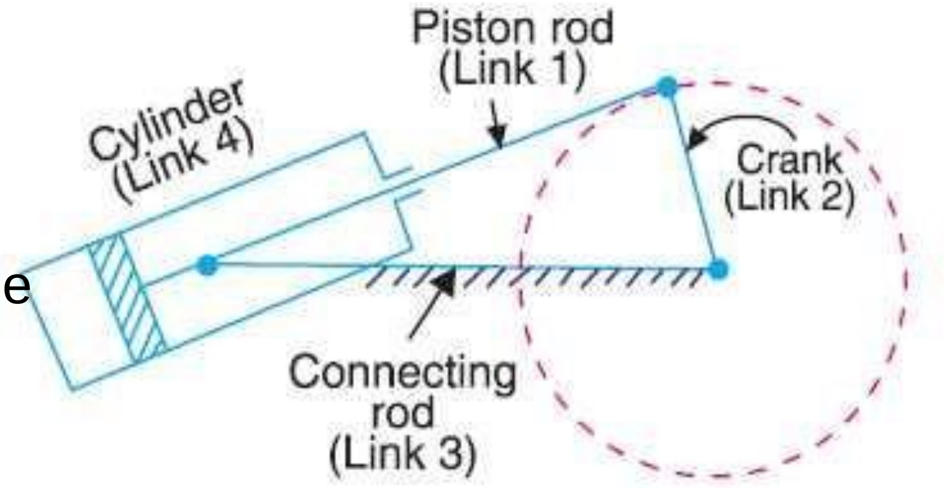


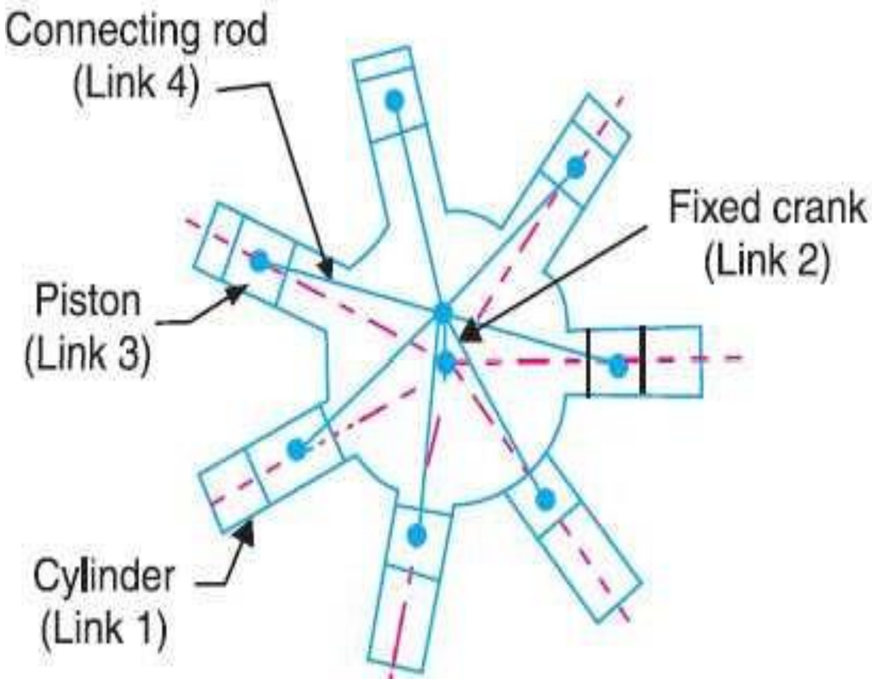
Fig.1.40 Oscilating cylinder engine

1.16. Inversion of Mechanism

3. Rotary internal combustion engine or Gnome engine.

Sometimes back, rotary internal combustion engines were used in aviation. But presently gas turbines are used in its place. It consists of seven cylinders in one plane and all revolves about fixed centre D, as shown in Fig. 1.41, 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.

1.16. Inversion of Mechanism



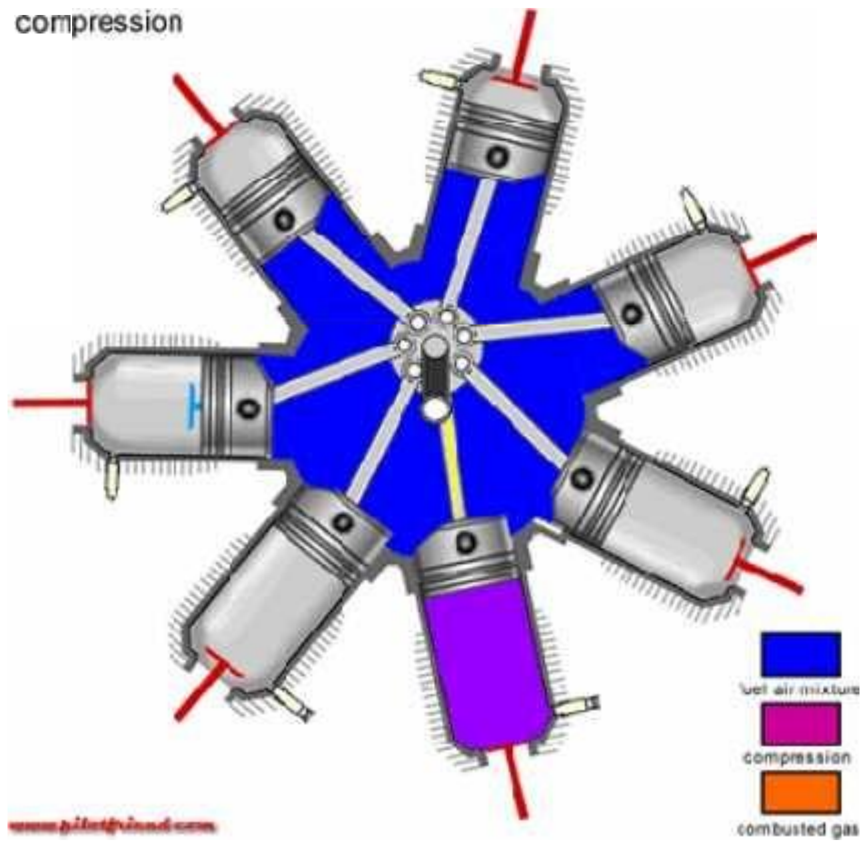


Fig. 1.41

https://youtu.be/W3elogQimk4 https://youtu.be/0jHRuEkvO8E

1.16. Inversion of Mechanism

4. Crank and slotted lever quick return motion mechanism. *This mechanism is mostly used* in shaping machines, slotting machines and in rotary internal combustion engines.

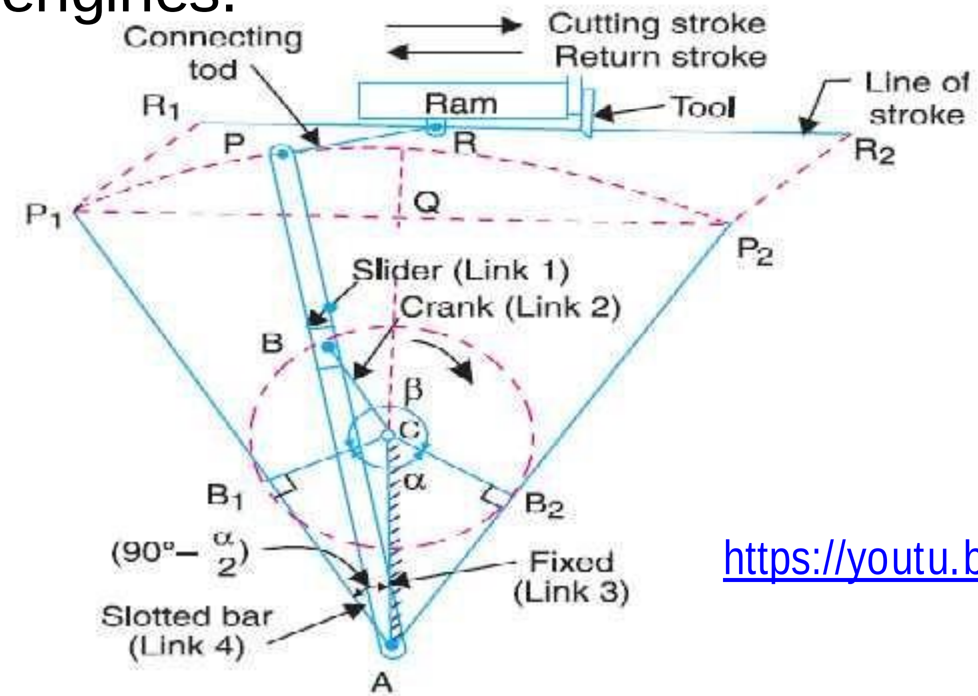


Fig.1.42

https://youtu.be/ESBYdJx8X7k

https://youtu.be/s3TiMedJKds

1.16. Inversion of Mechanism

In this mechanism, the link AC (i.e. link 3) forming the turning pair is fixed, as shown in Fig. 1.42. The link 3 corresponds to the connecting rod of a reciprocating steam engine. The driving crank CB revolves with uniform angular speed about the fixed centre C. A sliding block attached to the crank pin at B slides along the slotted bar AP and thus causes AP to oscillate about the pivoted point A. A short link PR transmits the motion from AP to the ram which carries the tool and reciprocates along the line of stroke R1R2. The line of stroke of the ram (i.e. R1R2) is perpendicular to AC produced.

1.16. Inversion of Mechanism

Whitworth quick return motion mechanism

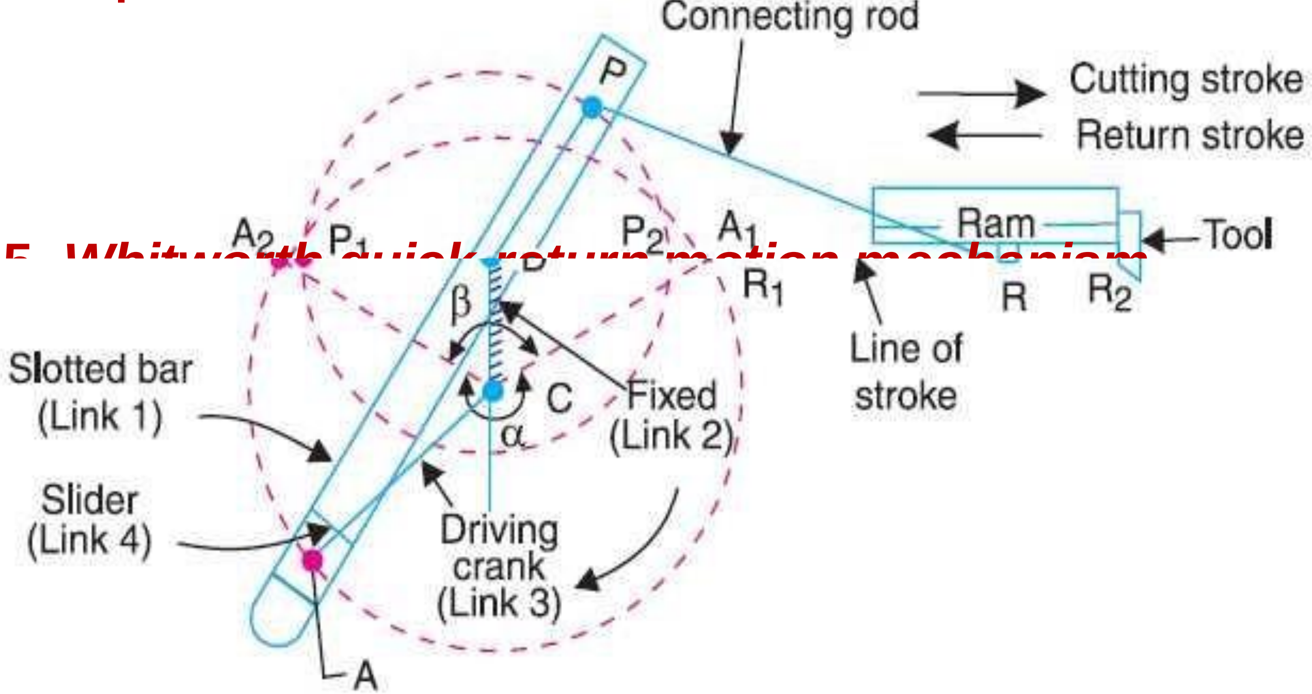
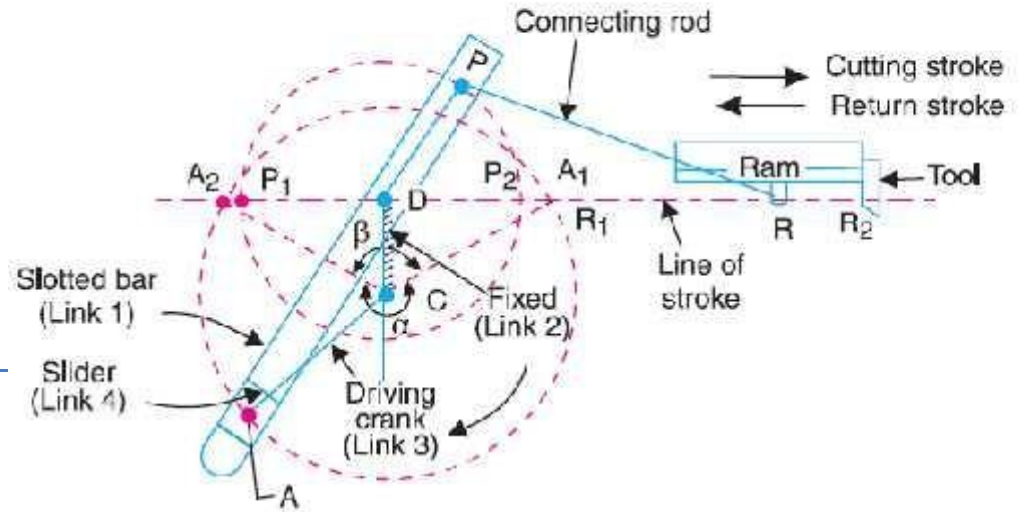


Fig. 1.43

https://youtu.be/UuTNtg7-Bwg

1.16. Inversion of Mechanism

This mechanism is mostly used in shaping and slotting machines. In this mechanism, the link CD (link 2) forming the turning pair is fixed, as shown in Fig. 1.43. The link 2 corresponds to a crank in a reciprocating steam engine. The driving crank CA (link 3) rotates at a uniform angular speed. The slider (link 4) attached to the crank pin at A slides along the slotted bar PA (link 1) which oscillates at a pivoted point D. The connecting rod PR carries the ram at R to which a cutting tool is fixed. The motion of the tool is constrained along the line RD produced, i.e. along a line passing through D and perpendicular to CD.



1.16. Inversion of Mechanism

When the driving crank CA moves from the position CA1 to CA2 (or the link DP from the position DP1 to DP2) through an angle α in the clockwise direction, the tool moves from the left hand end of its stroke to the right hand end through a distance 2 PD. Now when the driving crank moves from the position CA2 to CA1 (or the link DP from DP2 to DP1) through an angle β in the clockwise direction, the tool moves back from right hand end of its stroke to the left hand end.

A little consideration will show that the time taken during the left to right movement of the ram (i.e. during forward or cutting stroke) will be equal to the time taken by the driving crank to move from CA1 to CA2. Similarly, the time taken during the right to left movement of the ram (or during the idle or return stroke) will be equal to the time taken by the driving crank to move from CA2 to CA1.

1.16. Inversion of Mechanism

Since the crank link CA rotates at uniform angular velocity therefore time taken during the cutting stroke (or forward stroke) is more than the time taken during the return stroke. In other words, the mean speed of the ram during cutting stroke is less than the mean speed during the return stroke. The ratio between the time taken during the cutting and return strokes is given by

Time of cutting stroke/ Time of return stroke

$= \alpha / \beta = \alpha / (360° - \alpha)$ or $= (360° - \beta) / \beta$

Note. In order to find the length of effective stroke R1 R2, mark P1 R1 = P2 R2 = PR. The length of effective stroke is also equal to 2 PD.

1.16. Inversion of Mechanism

C-Double Slider Crank Chain

A kinematic chain which consists of two turning pairs and two sliding pairs is known as double slider crank chain, as shown in Fig. 1.44. We see that the link 2 and link 1 form one turning pair and link 2 and link 3 form the second turning pair. The link 3 and link 4 form one sliding pair and link 1 and link 4 form the second sliding pair.

https://youtu.be/iMYiM8I__vE

1.16. Inversion of Mechanism

C. Inversions of Double Slider Crank Chain

The following three inversions of a double slider crank chain
Are important from the subject point of view:

1. **Elliptical trammels.** It is an instrument used for drawing ellipses. This inversion is obtained by fixing the slotted plate (link 4), as shown in Fig. 1.44. The fixed plate or link 4 has two straight grooves cut in it, at right angles to each other. The link 1 and link 3, are known as sliders and form sliding pairs with link 4. The link AB (link 2) is a bar which forms turning pairs with links 1 and 3.

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1.16. Inversion of Mechanism

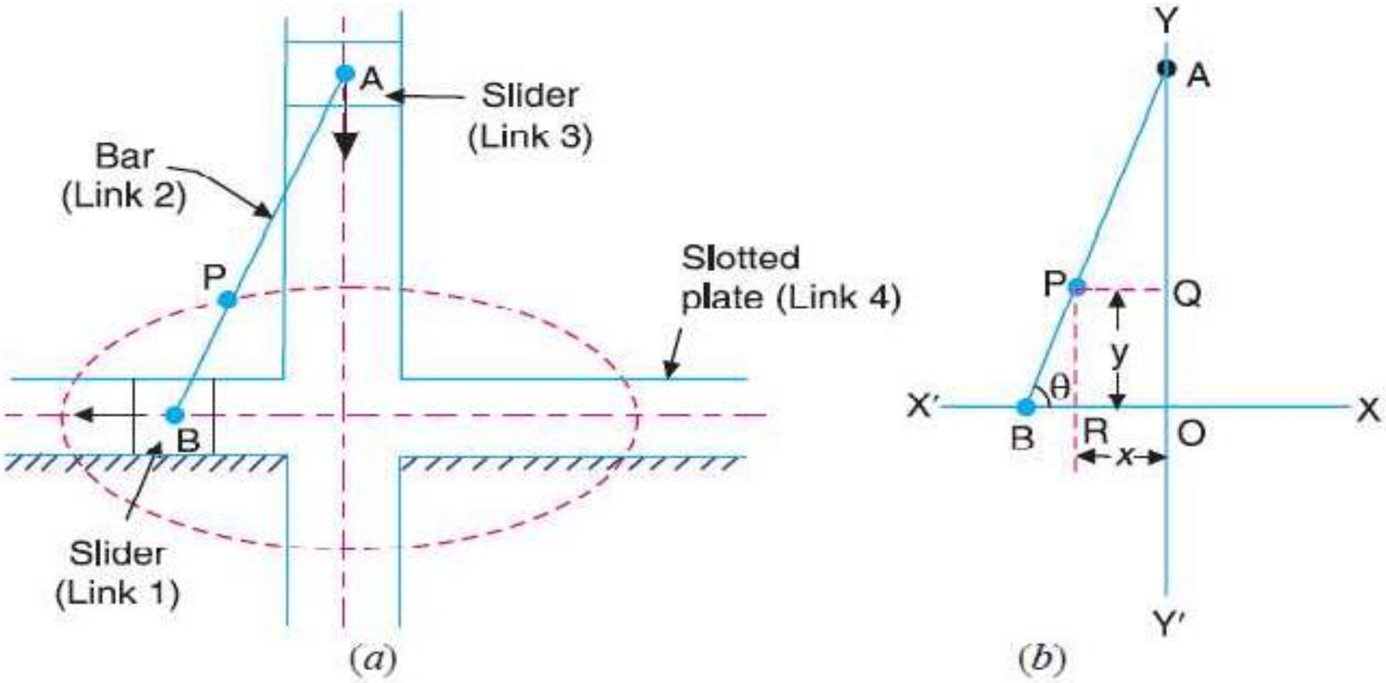


Fig.1.44 Elipticaltrammels

1.16. Inversion of Mechanism

When the links 1 and 3 slide along their respective grooves, any point on the link 2 such as P traces out an ellipse on the surface of link 4, as shown in Fig. 1.44 (a). A little consideration will show that AP and BP are the semi-major axis and semi-minor axis of the ellipse respectively.

1.16. Inversion of Mechanism

2. Scotch yoke mechanism.

https://youtu.be/hsaoTo1vuY4

https://youtu.be/HhX-8RyP214

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. In Fig. 1.45, link 1 is fixed. In this mechanism, when the link 2 (which corresponds to crank) rotates about B as centre, the link 4 (which corresponds to a frame) reciprocates. The fixed link 1 guides the frame.

1.16. Inversion of Mechanism

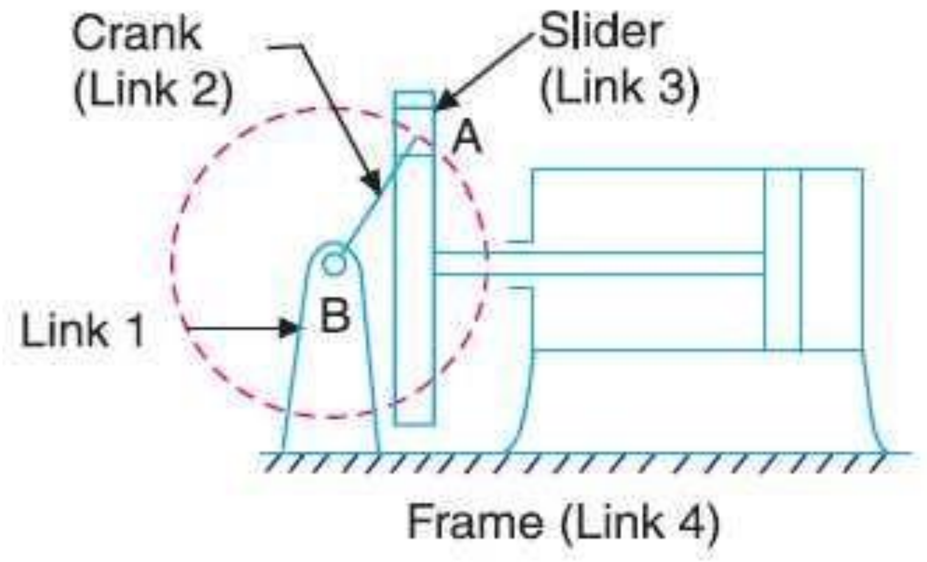


Fig 1.45 Scotch yoke mechanism.

1.16. Inversion of Mechanism

***3.* Oldham's coupling.** https://youtu.be/XvaDAbdZCyU

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. This inversion is obtained by fixing the link 2, as shown in Fig. 1.46 (a). The shafts to be connected have two flanges (link 1 and link 3) rigidly fastened at their ends by forging.

The link 1 and link 3 form turning pairs with link 2. These flanges have diametrical slots cut in their inner faces, as shown in Fig. 1.46 (b). The intermediate piece (link 4) which is a circular disc, have two tongues (i.e. diametrical projections) T1 and T2 on each face at right angles to each other, as shown in Fig. 1.46 (c). The tongues on the link 4 closely fit into the slots in the two flanges (link 1 and link 3). The link 4 can slide or reciprocate in the slots in the flanges.

1.16. Inversion of Mechanism

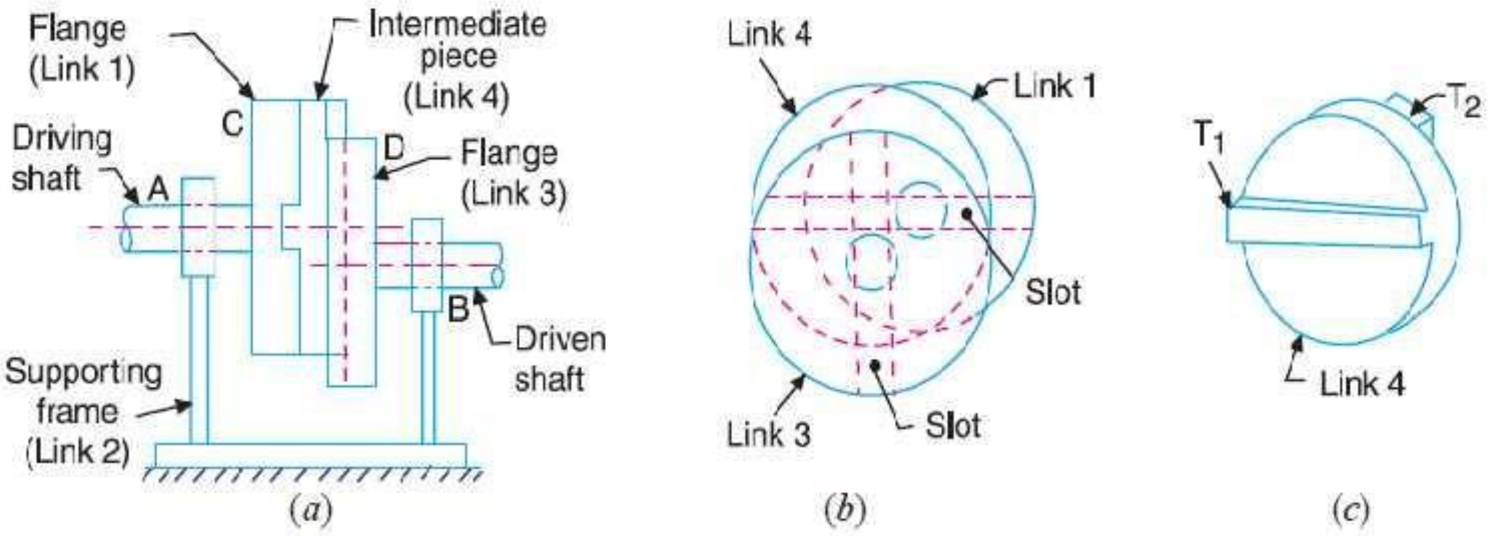


Fig. 1.46 Oldham's coupling.

1.16. Inversion of Mechanism

When the driving shaft A is rotated, the flange C
(link 1) causes the intermediate piece (link 4) to rotate at the same angle through which the flange has rotated, and it further rotates the flange D (link 3) at the same angle and thus the shaft B rotates. Hence links 1, 3 and 4 have the same angular velocity at every instant. A little consideration will
show, that there is a sliding motion between the link 4 and each of the other links 1 and 3.

1.16. Inversion of Mechanism

If the distance between the axes of the shafts is constant, the centre of intermediate piece will describe a circle of radius equal to the distance between the axes of the two shafts. Therefore, the maximum sliding speed of each tongue along its slot is equal to the peripheral velocity of the centre of the disc along its circular path.

Let ω = Angular velocity of each shaft in rad/s, and

r = Distance between the axes of the shafts in metres.

∴ Maximum sliding speed of each tongue (in m/s),

$v = \omega . r$

1.16. Inversion of Mechanism

Non Grashof mechanisms

Four bar linkages that do not satisfy the Grashof criterion are called double rocker mechanisms of the second kind or triple-rocker mechanisms. If $L_{max} + L_{min} > L_p + L_q$ no link can rotate through 360°. A computer program based on the flowchart of Figure 1.47 may be used to classify four-bar linkages by characteristics of their motion.

1.16. Inversion of Mechanism

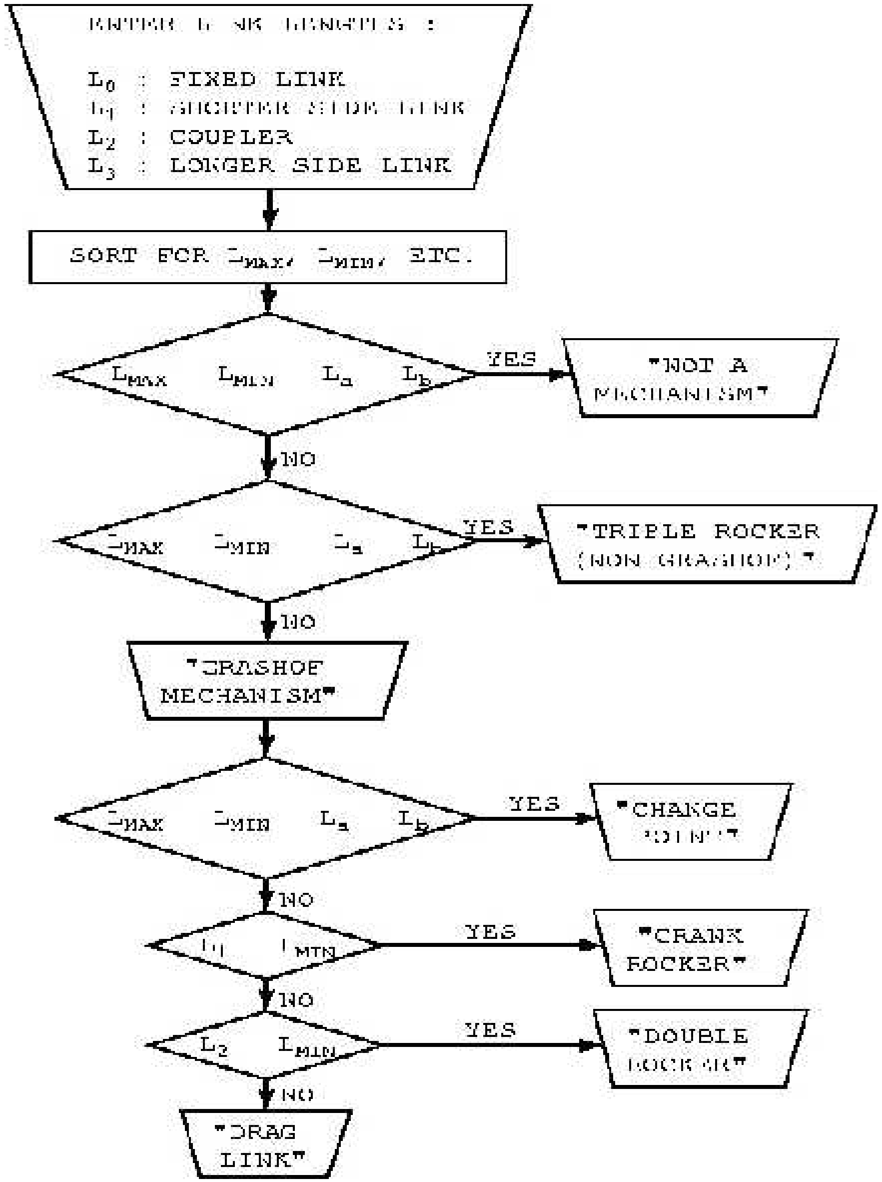


FIGURE 1. 47 Flowchat for classifying four-bar linkages according to the characteristics of theirmotion.

HOMEWORK PROBLEM 1

The Grashof Criterion

This problem concerns the classification of four-bar linkages. Link lengths: L_0, fixed link; L_1, dri-ver crank; L_2, coupler; L_3, follower crank; $L_1 = 100$ mm, $L_2 = 200$ mm, $L_3 = 300$ mm. Find the ranges of values for L_0, if the linkage can be classified as follows:

a. Grashof mechanism
b. Crank-rocker mechanism
c. Drag link mechanism
d. Double-rocker mechanism
e. Change –point mechanism
f. Triple-rocker mechanism

1.17. Mechanical Advantage

Mechanical advantage:- Mechanical advantage of a linkage is the ratio of output torque exerted by the driven link to the necessary input torque required at the driver. The mechanical advantage of the four-bar linkage shown in Fig. 1. 48 is directly proportional to the sine of the angle γ between the coupler and the follower and inversely proportional to the sine of the angle β between the coupler and the driver. When the sign of the angle β becomes zero, the mechanical advantage becomes infinite; thus, at such a position, only a small input torque is necessary to overcome a large output torque load. This is the case when the driver AB of Fig. 1.48 is directly in line with the coupler BC; it occurs when the crank is in position AB_1 and again when the crank is in position AB_4. Note that these also define extreme positions of travel of the rocker DC_1 and DC_4.When the four-bar linkage is in either of these positions, mechanical advantage is infinite and the linkage is said to be in a **toggle position**.

1.17. Mechanical Advantage

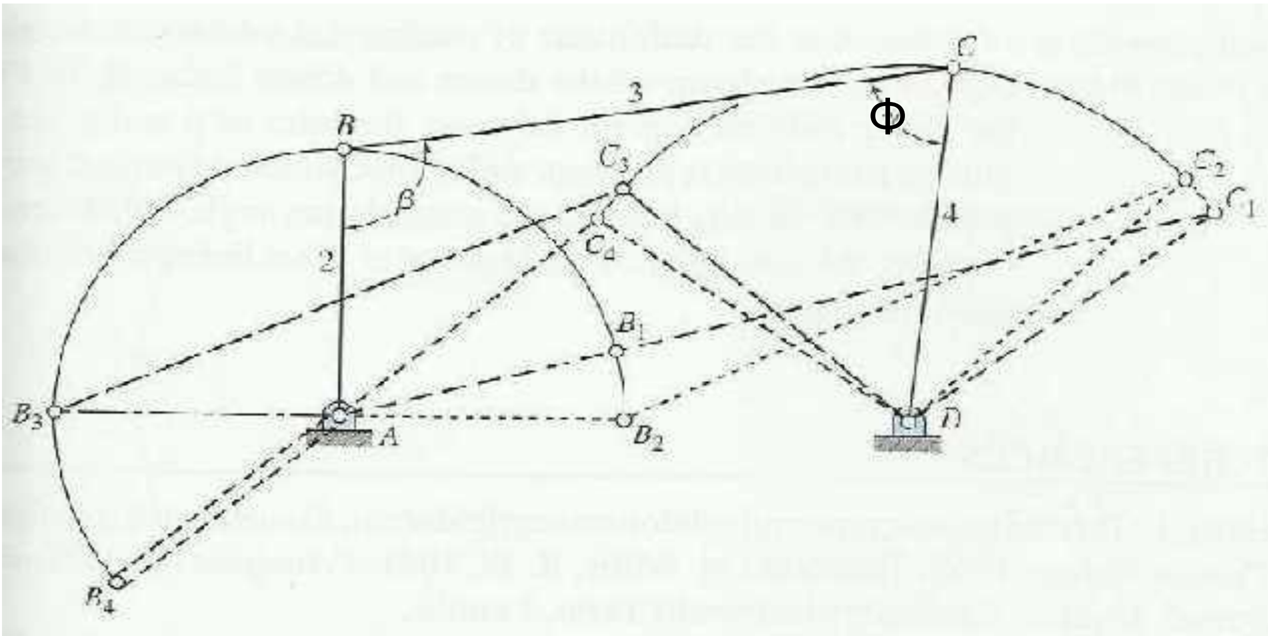


Fig.1.48 Toggle positions

1.17. Mechanical Advantage

Transmission angle : The angle γ between the coupler and the follower is called **transmission angle**. As this angle becomes small, the mechanical advantage decreases and even a small amount of friction will cause the mechanism to lock or jam. A common rule of thumb is that a four- bar linkage should not be used in the rigion where the transmission angle is less than 40^o or 45^o and no great than 135^o or 140^o is usually satisfactory. The extreme values of the transmission angle occur when the crank AB lies along the line of the frame AD. In Fig.1.47 the transmission angle is minimum when the crank is position AB_2 and maximum when the crank has position AB_3.

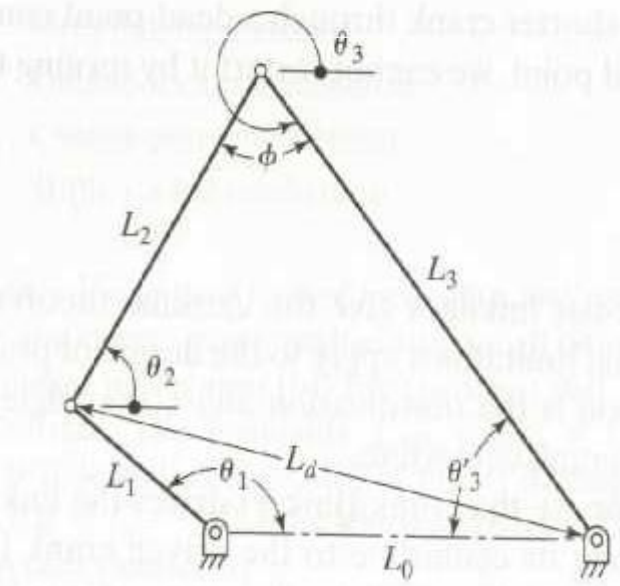
1.17. Mechanical Advantage

Consider the four-bar linkage whose links form a quadrilateral, as in Figure 1.49. For crank angle

$$L_d^2 = L_0^2 + L_1^2 - 2\, L_0\, L_1 \cos \theta_1$$

Using the law of cosines for the triangle formed by the diagonal and links 2 and 3

$$L_d^2 = L_2^2 + L_3^2 - 2\, L_2\, L_3 \cos \phi$$



Rearranging the cosine law equation:

$$\cos\phi = \frac{L_2^2 + L_3^2 - L_d^2}{2L_2L_3}.$$

FIGURE 1.49 Determination of transmission angle.

HOMEWORK PROBLEM 2

Given the driver crank length L_1 = 100mm, coupler length L_2 = 200 mm, and follower length L_3 = 300 mm, and considering the transmission angle, find the range of values for the fixed link L_0 if the linkage is to be a crank rocker. Make the design decision to limit the transmission angle to $45° \leq \phi \leq 135°$.

1.18. Actuators and Drivers

In order to operate a mechanism, an actuator, or driver device, is required to provide the input motion and energy. To precisely operate a mechanism, one driver is required for each degree of freedom exhibited. Many different actuators are used in industrial and commercial machines and mechanisms. Some of the more common ones are given in the following section.

1.18. Actuators and Drivers

Electric motors (DC) produce continuous rotary motion. The speed and direction of the motion can be readily altered, but they require power from a generator or a battery. DC motors can achieve extremely high speeds——up to 30,000 rpm. These motors are most often used in vehicles, cordless devices, or in applications where multiple speeds and directional control are required.

1.18. Actuators and Drivers

Engines also generate continuous rotary motion. The speed of an engine can be throttled within a range of approximately 1000 to 8000 rpm. They are a popular and highly portable driver for high-power applications. Because they rely on the combustion of fuel, engines are used to drive machines that operate outdoors.

1.18. Actuators and Drivers

Servomotors are motors that are coupled with a controller to produce a programmed motion or hold a fixed position. The controller requires sensors on the link being moved to provide feedback information on its position, velocity, and acceleration. These motors have lower power capacity than non-servomotors and are significantly more expensive, but they can be used for machines demanding precisely guided motion, such as robots.

1.18. Actuators and Drivers

Electric motors (AC) provide the least expensive way to generate continuous rotary motion. However, they are limited to a few standard speeds that are a function of the electric line frequency. Single-phase motors are used in residential applications and are available from. Three-phase motors are more efficient, but mostly limited to industrial applications because they require three-phase power service.

1.18. Actuators and Drivers

Air or hydraulic motors also produce continuous rotary motion and are similar to electric motors, but have more limited applications. This is due to the need for compressed air or a hydraulic source. These drive devices are mostly used within machines, such as construction equipment and aircraft, where high pressure hydraulic fluid is available.

1.18. Actuators and Drivers

Hydraulic or pneumatic cylinders are common components used to drive a mechanism with a limited linear stroke. Figure 1.50a illustrates a hydraulic cylinder. Figure 1.50b shows the common kinematic representation for the cylinder unit. The cylinder unit contains a rod and piston assembly that slides relative to a cylinder. For kinematic purposes, these are two links (piston/rod and cylinder), connected with a sliding joint. In addition, the cylinder and rod end usually have provisions for pin joints.

1.18. Actuators and Drivers

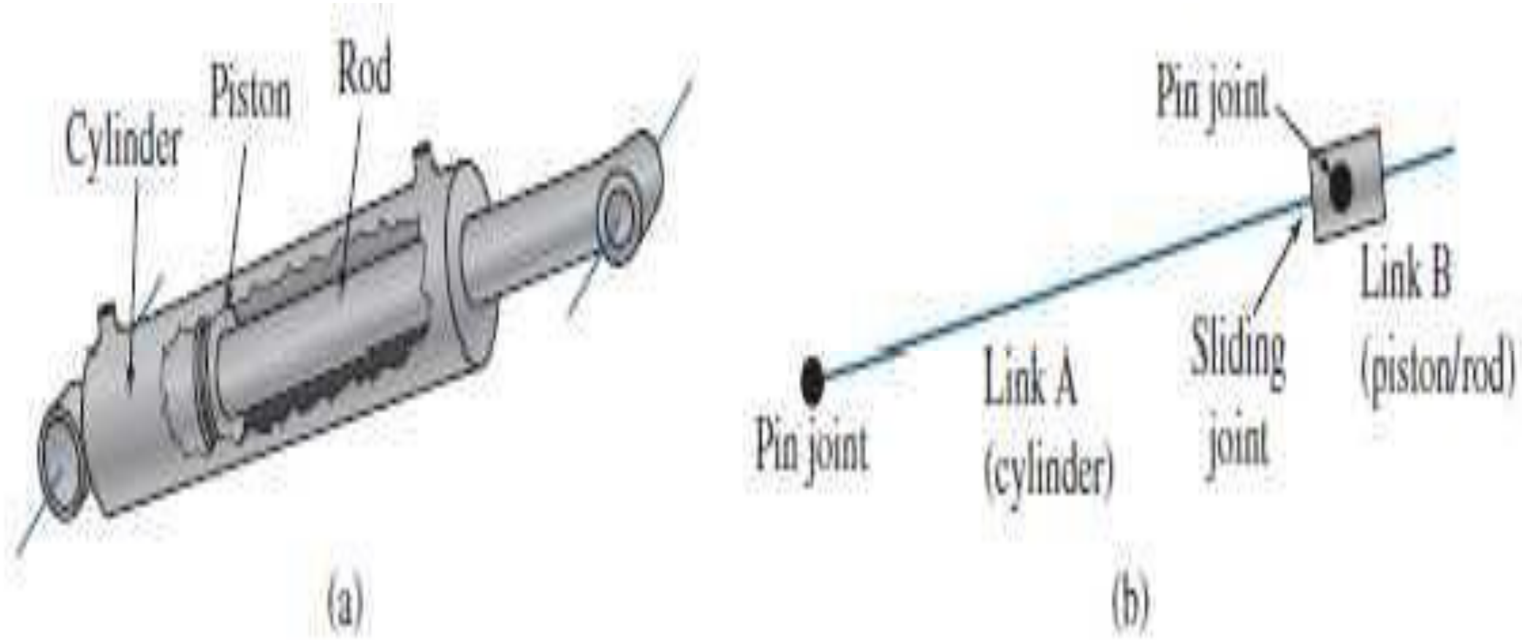


Fig. 1.50 Hydrolic cylinder

1.18. Actuators and Drivers

Screw actuators also produce a limited linear stroke. These actuators consist of a motor, rotating a screw. A mating nut provides the linear motion. Screw actuators can be accurately controlled and can directly replace cylinders. However, they are considerably more expensive than cylinders if air or hydraulic sources are available. Similar to cylinders, screw actuators also have provisions for pin joints at the two ends. Therefore, the kinematic diagram is identical to Figure 1.50b.

1.18. Actuators and Drivers

Manual, or hand-operated, mechanisms comprise a large number of machines, or hand tools. The motions expected from human "actuators" can be quite complex. However, if the expected motions are repetitive, caution should be taken against possible fatigue and stain injuries

1.18. Actuators and Drivers

Example 1.10: Figure 1.51 shows an outrigger foot to stabilize a utility truck. Draw a kinematic diagram, using the bottom of the stabilizing foot as a point of interest. Also compute the degrees of freedom.

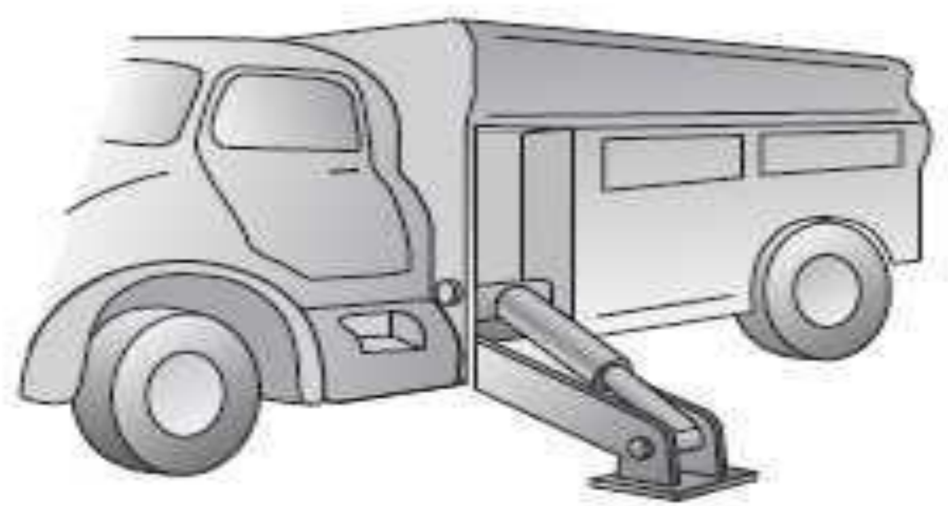


Fig. 1.51 Outrigger foot

1.18. Actuators and Drivers

SOLUTION:

1. Identify the Frame

During operation of the outriggers, the utility truck is stationary. Therefore, the truck is designated as the frame. The motion of all other links is determined relative to the truck. The frame is numbered as link 1.

2. Identify All Other Links

Careful observation reveals three other moving parts:

Link 2: Outrigger leg

Link 3: Cylinder

Link 4: Piston/rod

1.18. Actuators and Drivers

3. Identify the Joints

Three pin joints are used to connect these different parts. One connects the outrigger leg with the truck frame. This is labeled as joint A. Another connects the outrigger leg with the cylinder rod and is labeled as joint B. The last pin joint connects the cylinder to the truck frame and is labeled as joint C. One sliding joint is present in the cylinder unit. This connects the piston/rod with the cylinder. It is labeled as joint D.

1.18. Actuators and Drivers

4. Identify Any Points of Interest

The stabilizer foot is part of link 2, and a point of interest located on the bottom of the foot is labeled as point of interest X.

5. Draw the Kinematic Diagram

The resulting kinematic diagram is given in Figure 1.52.

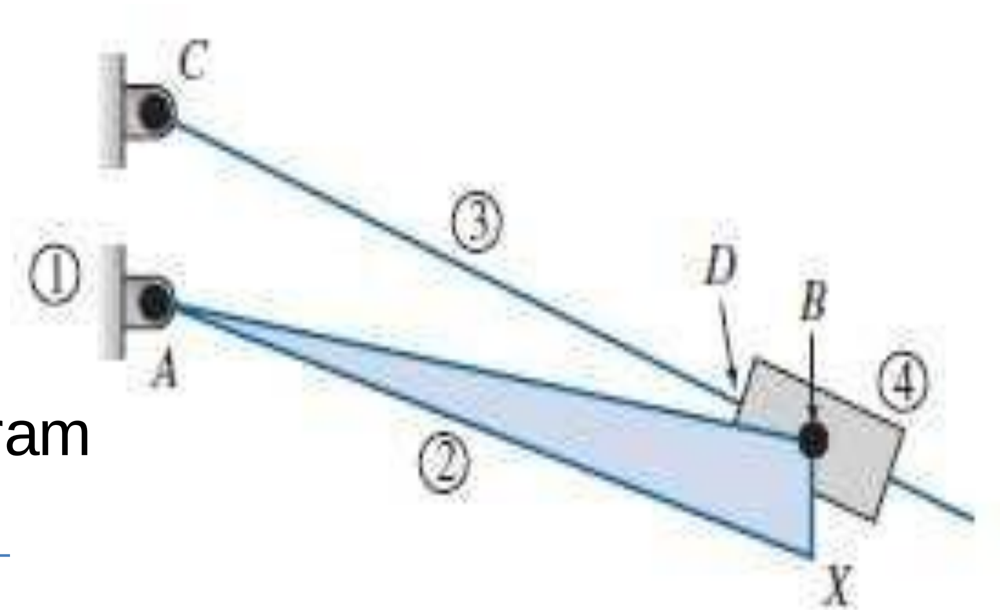


Fig. 1.52 Kinematic Diagram

1.18. Actuators and Drivers

6. Calculate Mobility

To calculate the mobility, it was determined that there are four links in this mechanism, as well as three pin joints and one slider joint. Therefore,

$l = 4$, $jp = (3 \text{ pins} + 1 \text{ slider}) = 4$, $jh = 0$

and

$$n = 3(n - 1) - 2jp - jh = 3(4 - 1) - 2(4) - 0 = 1$$

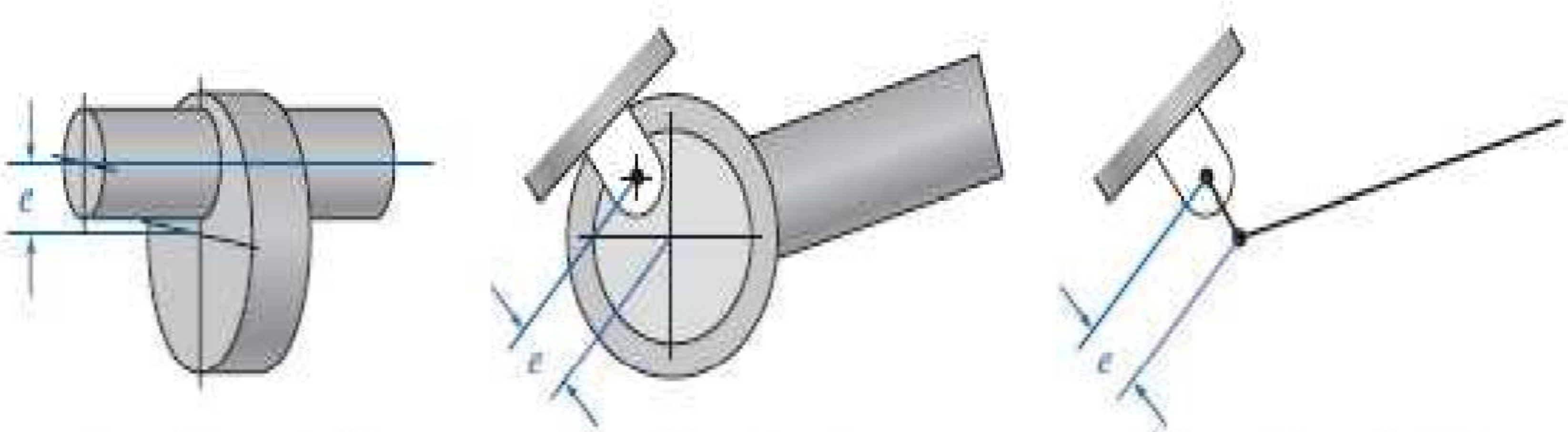
With one degree of freedom, the outrigger mechanism is constrained. Moving only one link, the piston, precisely positions all other links in the outrigger, placing the stabilizing foot on the ground.

1.19. Commonly Used Lınks and Joınts

1. Eccentric Crank

On many mechanisms, the required length of a crank is so short that it is not feasible to fit suitably sized bearings at the two pin joints. A common solution is to design the link as an eccentric crankshaft, as shown in Fig. 1.53a. This is the design used in most engines and compressors. The pin, on the moving end of the link, is enlarged such that it contains the entire link. The outside circumference of the circular lobe on the crankshaft becomes the moving pin joint, as shown in Figure 1.53b. The location of the fixed bearing, or bearings, is offset from the eccentric lobe. This eccentricity of the crankshaft, , is the effective length of the crank. Fig. 1.53c illustrates a kinematic model of the eccentric crank. The advantage of the eccentric crank is the large surface area of the moving pin, which reduces wear.

1.19. Commonly Used Links and Joints



(a) Eccentric crankshaft (b) Eccentric crank (c) Eccentric crank model

Fig.1.53 Eccentric crank.

1.19. Commonly Used Lınks and Joınts

2. Pin-in-a-Slot Joint

A common connection between links is a pin-in-a-slot joint, as shown in Figure 1.54a. This is a higher-order joint because it permits the two links to rotate and slide relative to each other. To simplify the kinematic analysis, primary joints can be used to model this higher-order joint. The pin-in-a-slot joint becomes a combination of a pin joint and a sliding joint, as in Figure 1.54b. Note that this involves adding an extra link to the mechanism. In both cases, the relative motion between the links is the same. However, using a kinematic model with primary joints facilitates the analysis.

1.19. Commonly Used Lınks and Joınts

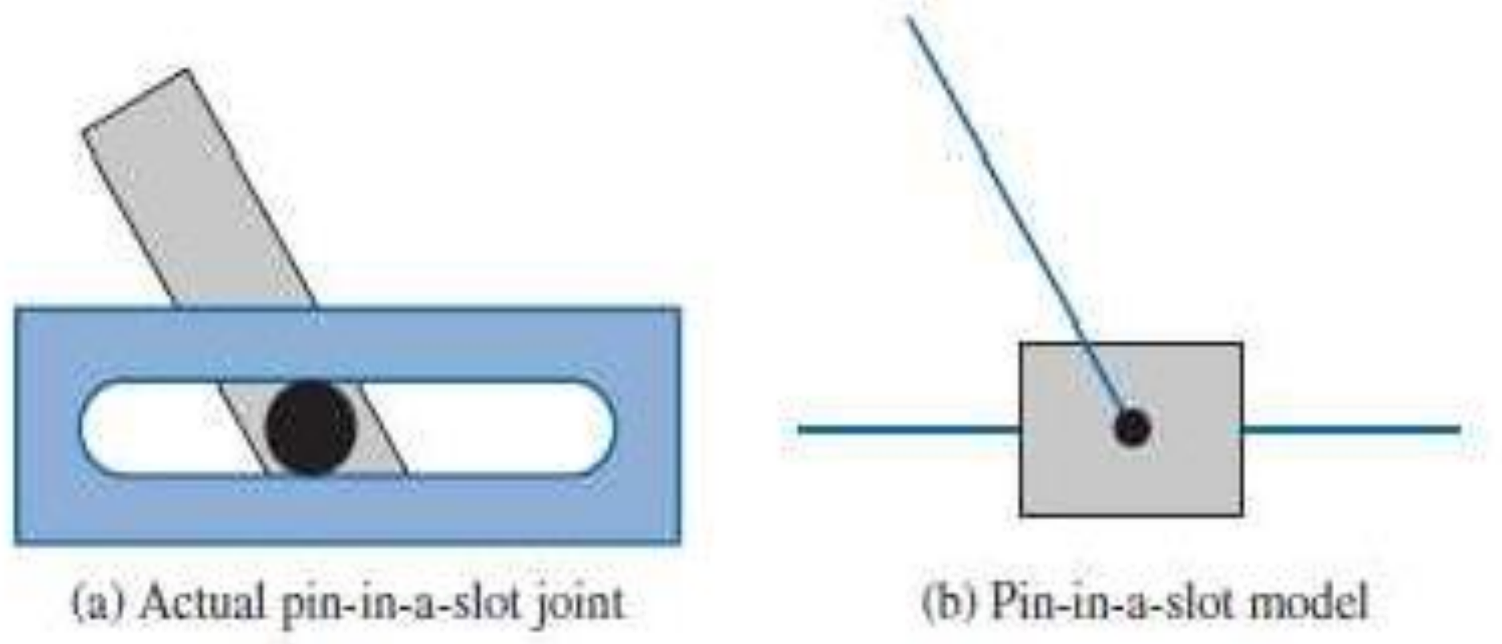


Fig.1.54 Pin-in-a-slot joint.

1.19. Commonly Used Lınks and Joınts

3. Screw Joint

A screw joint, as shown in Figure 1.55a, is another common connection between links. To start with, a screw joint permits two relative, but dependent, motions between the links being joined. A specific rotation of one link will cause an associated relative translation between the two links. For example, turning the screw one revolution may move the nut along the screw threads a distance of 0.1 in. Thus, only one independent motion is introduced. A screw joint is typically modeled with a sliding joint, as shown in Figure 1.55b. It must be understood that out-of plane rotation occurs. However, only the relative translation between the screw and nut is considered in planar kinematic analysis.

1.19. Commonly Used Lınks and Joınts

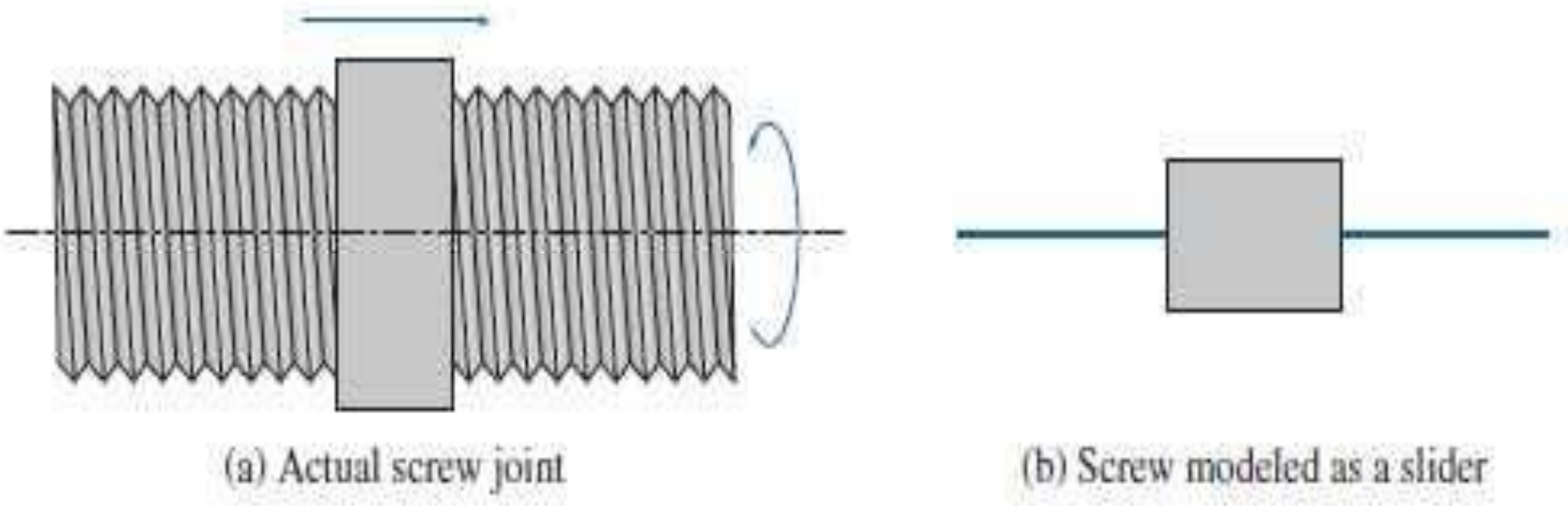


Fig.1.55 Screwjoint.

1.19. Commonly Used Lınks and Joınts

Example 1. Figure 1.56 presents a lift table used to adjust the working height of different objects. Draw a kinematic diagram and compute the degrees of freedom.

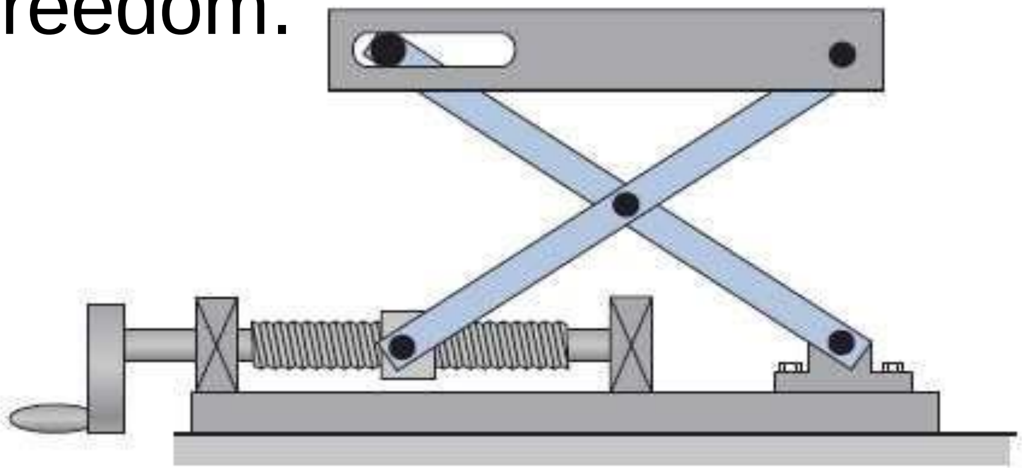


Fig.1. 56 Lift table

1.19. Commonly Used Lınks and Joınts

Solution:

1. **Identify the Frame:**

The bottom base plate rests on a fixed surface. Thus, the base plate will be designated as the frame. The bearing at the bottom right of Figure 1.56 is bolted to the base plate. Likewise, the two bearings that support the screw on the left are bolted to the base plate.

From the discussion in the previous section, the out-of-plane rotation of the screw will not be considered. Only the relative translation of the nut will be included in the kinematic model. Therefore, the screw will also be considered as part of the frame. The motion of all other links will be determined relative to this bottom base plate, which will be numbered as link 1.

1.19. Commonly Used Lınks and Joınts

_2._ Identify All Other Links

Careful observation reveals five other moving parts:

Link 2: Nut

Link 3: Support arm that ties the nut to the table

Link 4: Support arm that ties the fixed bearing to the slot in the table

Link 5: Table

Link 6: Extra link used to model the pin in slot joint with separate pin and slider joints

1.19. Commonly Used Lınks and Joınts

3. Identify the Joints

A sliding joint is used to model the motion between the screw and the nut. A pin joint, designated as point A, connects the nut to the support arm identified as link 3. A pin joint, designated as point B, connects the two support arms—link 3 and link 4. Another pin joint, designated as point C, connects link 4 to link 6. A sliding joint joins link 6 to the table, link 5. A pin, designated as point D, connects the table to the support arm, link 3. Lastly, a pin joint, designated as point E, is used to connect the base to the support arm, link 4.

1.19. Commonly Used Lınks and Joınts

5. ***Draw the Kinematic Diagram***
The kinematic diagram is given in Figure 1.57.

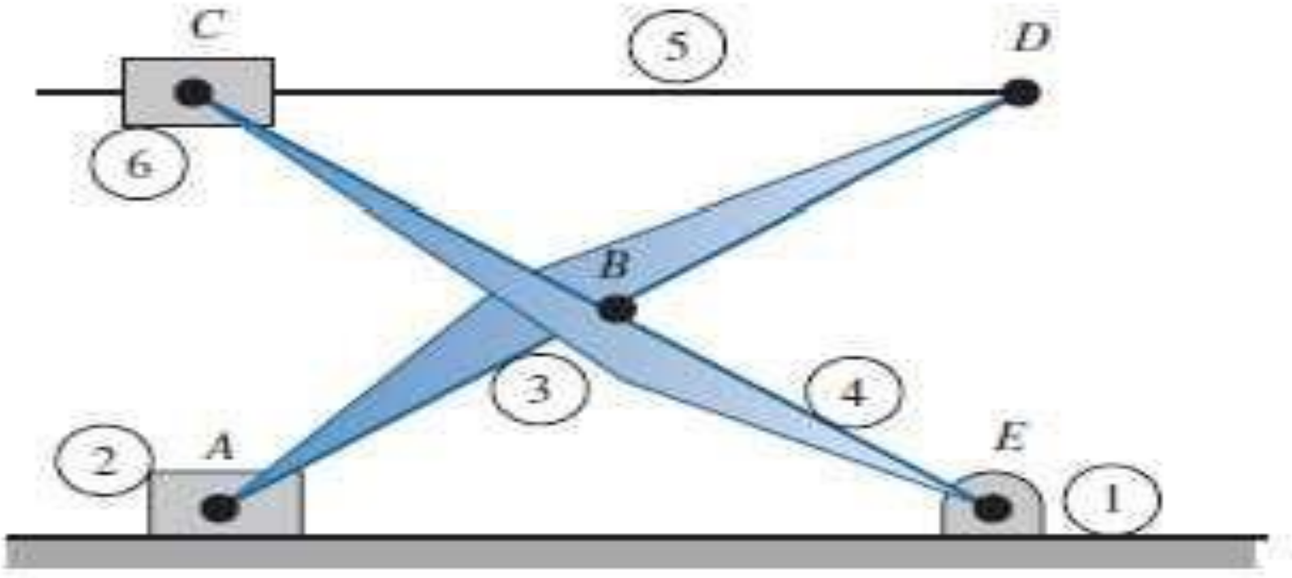


Fig.1.57 Kinematic diagram

1.19. Commonly Used Lınks and Joınts

5. **Calculate Mobility**

To calculate the mobility, it was determined that there are six links in this mechanism. There are also five pin joints and two slider joints. Therefore,

$l = 6$, $j_p = (5 \text{ pins} + 2 \text{ sliders}) = 7$, $j_h = 0$

and

$$n = 3(l - 1) - 2j_p - j_h = 3(6 - 1) - 2(7) - 0 = 15 - 14 = 1$$

With one degree of freedom, the lift table has constrained motion. Moving one link, the handle that rotates the screw, will precisely position all other links in the device, raising or lowering the table.

1.20. Analysis and Syntesis

There are two different aspects of the study of mechanical systems: **design** and **analysis.**

The concept embodied in the word “ design” might be more properly termed **syntesis,** the process of contriving a scheme or a method of accomplishing a given purpose.

Design is the process of prescribing the sizes, shapes material compositions, and arrangements of parts so that the resulting machine will perform the prescribed task. It calls for imagination, intuition, creativity, judgments and experience.

Design process is by its very nature as much an art as a science. The role of science in the design process is merely to provide tools to be used by the designers as that practise their art.

1.20. Analysis and Syntesis

The process of evaluating the various interacting alternatives that designers find usually requires a large collection of mathematical and scientific tools. These tools , when applied properly , can provide more accurate and more reliable information for use in judging a design than one can achive through intuition or estimation. Thus, they can provide tremendous help in deciding among alternatives.

Hovever, scientific tools can not make decisions for designer.

Designers have every right to exert their imaginations and creative abilities.

1.20. Analysis and Syntesis

The largest collection of scientific methods at the designer's disposal fall into the category called **analysis.** These are the techniques which allow the designer to critically examine an already existing or proposed design in order to judge its suitability and rating of things already conceived.

We should always bear in mind that although most of our effort may be spent on analysis, real goal is synthesis, design of a machine or system. Analysis is simply a tool. It is, however a vital tool and will inevitable be used as one step in the design process.

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