Theory of Machines

For

Mechanical Engineering

By

THE GATE ACADEMY

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Syllabus for Theory of Machines

Displacement, Velocity and Acceleration Analysis of Plane Mechanisms, Dynamic Analysis of Linkages, CAMs, Gears and Gear Trains, Flywheels and Governors, Balancing of Reciprocating and Rotating Masses, Gyroscope.

Vibrations: Free and Forced Vibration of Single Degree of Freedom Systems, Effect of Damping, Vibration Isolation, Resonance, Critical Speeds of Shafts.

Analysis of GATE Papers

Year	Percentage of Marks	Overall Percentage
2015	8.66	8.5%
2014	11.00	
2013	8.00	
2012	4.00	
2011	7.00	
2010	9.00	
2009	10.00	
2008	4.67	
2007	8.67	
2006	14.00	

Contents

"Your imagination is your preview of life's coming attractions."
... Albert Einstein

CHAPTER 1

Mechanisms

Learning Objectives

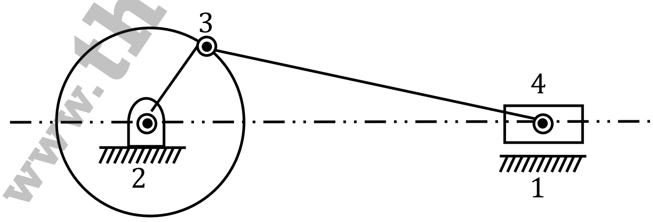
After reading this chapter, you will know:

1. Kinematic Link, Relative Motions,
2. Completely Constrained Motion incomplete Constrained Motion, Successfully Constrained Motion
3. Kinematic Pair Lower and Higher Pair, Kinematic Chain, Degree of Freedom
4. Four Bar Mechanism, Grashof's Law, Inversion of Four Bar Mechanism
5. Single Slider Crank Mechanism, Inversion of Single Slider Crank Mechanism
6. Double Slider Crank Mechanism and its Inversions

Mechanism and Machine

A combination of a number of bodies (usually rigid) assembled in such a way that the motion of one causes constrained and predictable motion to the others is known as a mechanism. Thus, the function of a mechanism is to transmit and modify a motion.

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. It is neither a source of energy nor a producer of work but helps in proper utilization of the same. The motive power has to be derived from external sources.



Slider Crank Mechanism

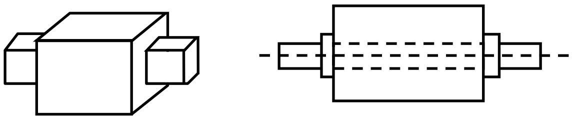
A slider-crank mechanism (figure show above) converts the reciprocating motion of a slider into rotary motion of the crank or vice-versa. However, when it is used as an automobile engine by adding valve mechanism etc. it becomes a machine which converts the available energy (force on the piston) into the desired energy (torque of the crank-shaft). The torque is used to move a vehicle, reciprocating pumps, reciprocating compressors and steam engines are other examples of machines derived from the slider-crank mechanism.

Some other examples of mechanisms are typewriters, clocks, watches, spring toys, etc. In each of these, the force or energy provided is not more than what is required to overcome the friction of the parts and which is utilized just to get the desired motion of the mechanism and not to obtain any useful work.

Types of Constrained Motions

There are three types of constrained motion,

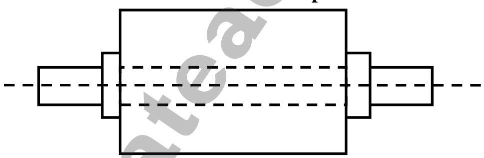
1. **Completely Constrained Motion:** When the motion between two elements of a pair is in a definite direction irrespective of the direction of the force applied, it is known as completely constrained motion. The constrained motion may be linear or rotary. The sliding pair of fig. (a) and the turning pair of fig. (b) are the examples of the completely constrained motion.



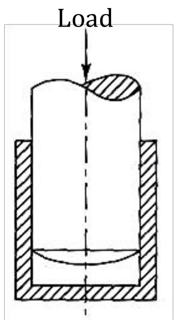
(a) (b)

In sliding pair, the inner prism can only slide inside the hollow prism. In case of a turning pair, the inner shaft can have only rotary motion due to collars at the ends. In each case the force has to be applied in particular direction for the required motion.

2. **Incompletely Constrained Motion:** When the motion between two elements of a pair is possible in more than one direction and depends upon the direction of the force applied it is known as incompletely constrained motion. For example, if the turning pair of figure given below does not have collars, the inner shaft may have sliding or rotary motion depending upon the direction of the force applied. Each motion is independent of the other.



3. **Successfully Constrained Motion:** When the motion between two elements of a pair is possible in more than one direction but is made to have motion only in one direction by using some external load means, it is a successfully constrained motion. For example, a shaft in a footstep bearing may have vertical motion apart from rotary motion.



Footstep Bearing

But due to load applied on the shaft it is constrained to move in that direction and thus it is a successfully constrained motion. Similarly, a piston in a cylinder of an internal combustion engine is made to have only reciprocating motion and no rotary motion due to constrain of the piston pin. Also, the valve of an IC engine is kept on the seat by the force of a spring and thus has successfully constrained motion.

Rigid and Resistant Bodies

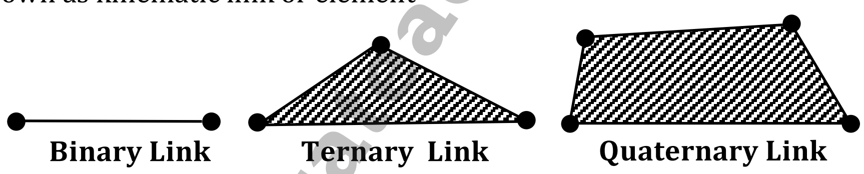
A body is said to be rigid if under the action of forces, it does not suffer any distortion or the distance between any two points on it remains constant.

Resistant bodies are those which are rigid for the purposes they have to serve. Apart from rigid bodies, there are some semi-rigid bodies which are normally flexible, but under certain loading conditions act as rigid bodies for the limited purpose and thus are resistant bodies. A belt is rigid when subjected to tensile forces. Therefore, the belt-drive acts as a resistant body. Similarly, fluids can also act as resistant bodies when compressed as in case of a hydraulic press. For some purposes, springs are also resistant bodies.

Links

A mechanism is made of a number of resistant bodies out of which some may have motions relative to the others. A resistant body or a group of resistant bodies with rigid connections preventing their relative movement is known as a link. A link may also be defined as a member or a combination of members of a mechanism, connecting other members and having motion relative to them. Thus, a link may consist of one or more resistant bodies. A slider-crank mechanism consists of four links, frame and guides, crank, connecting-rod and slider. However, the frame may consist of bearings for the crankshaft. The crank link may have a crankshaft and flywheel also, forming one link having no relative motion of these.

A link is also known as kinematic link or element



Links can be classified into binary, ternary and quaternary depending upon their ends on which revolute or turning pairs can be placed. The links shown in figures given above are rigid links and there is no relative motion between the joints within the link.

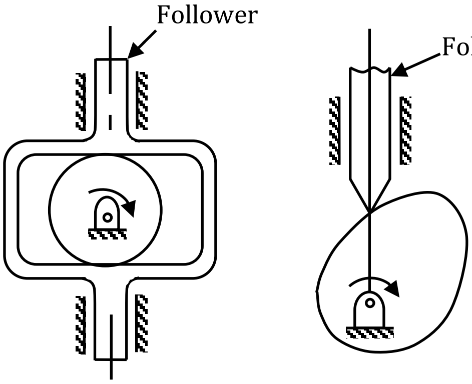
Kinematic Pair

A kinematic pair or simply a pair is a joint of two links having relative motion between them. A pair is said to be kinematic pair if the relative motion between all the links are constrained motion. In a slider-crank mechanism, the link 2 rotates relative to the link 1 and constitutes a revolute or turning pair. Similarly, links 2, 3 and 3, 4 constitute turning pairs. Link 4 (slider) reciprocates relative to the link 1 and is a sliding pair.(Refer figure lower pair and higher pair)

Types of Kinematic Pairs: Kinematic pairs can be classified according to following points,

- Nature of contact
- Nature of mechanical constraint
- Nature of relative motion

Kinematic Pairs According to Nature of Contact



(a) Lower Pair (b) Higher Pair

a. **Lower Pair:** A pair of links having surface or area contact between the members is known as a lower pair. The contact surfaces of the two links are similar.
E.g.: Nut turning on a screw, shaft rotating in a bearing, all pairs of a slider-crank mechanism, uni joint, etc.

b. **Higher Pair:** When a pair has a point or line contact between the links, it is known as a higher pair. The contact surfaces of the two links are dissimilar.
E.g.: Wheel rolling on a surface, cam and follower pair, tooth gears, ball and roller bearings, etc.

Kinematic Pairs According to Nature of Mechanical Constraint

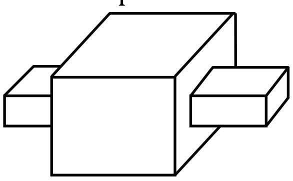
Depending upon the nature of mechanical constraint, the kinematic pair is classified into following in to two categories

a. **Closed Pair:** When the elements of a pair are held together mechanically, it is known as a closet the two elements are geometrically identical, one is solid and full and the other is hollow or open. The latter not only envelops the former but also encloses it. The contact between the two can be broken only by destruction of at least one of the members.
All the lower pairs and some of the higher pairs are closed pairs. A cam ansd follower pair (higher pair) shown in given below and a screw pair (lower pair) belong to the closed pair category.

b. **Unclosed Pair:** When two links of a pair are in contact either due to force of gravity or some spring action, they constitute an unclosed pair. In this, the links are not held together mechanically, e.g., cam and follower pair of figure given above.

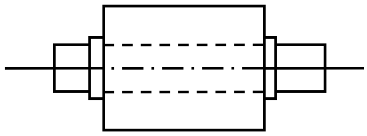
Kinematic Pairs according to Nature of Relative Motion

a. **Sliding Pair:** If two links have a sliding motion relative to each other, they form a sliding pair.
A rectangular rod in a rectangular hole in a prism is a sliding pair in the figure

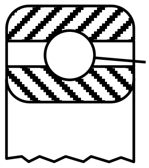


b. **Turning Pair:** When one link has a turning or revolving motion relative to the other, they constitute a turning or revolving pair in the figure.

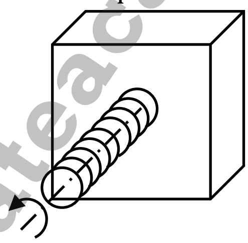
In a slider-crank mechanism, all pairs except the slider and guide pair are turning pairs. A circular shaft revolving inside a bearing is a turning pair.



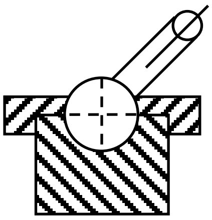
c. **Rolling Pair:** When the links of a pair have a rolling motion relative to each other, they form a rolling pair, Eg: a rolling wheel on a flat surface, ball and roller bearings, etc. In a ball bearing in the above figure the ball and the shaft constitute one rolling pair whereas the ball and the bearing is the second rolling pair.



d. **Screw Pair (Helical Pair):** If two mating links have a turning as well as sliding motion between them, they from a screw pair. This is achieved by cutting matching threads on the two links.
The lead screw and the nut of a lathe is a screw pair in the figure.



e. **Spherical Pair:** When one link in the form of a sphere turns inside a fixed link, it is a spherical pair. The ball and socket joint is a spherical pair in the figure.



Types of Joints

The usual types of joints in a chain are

- Binary joint
- Ternary joint
- Quaternary joint

Binary Joint: If two links are joined at the same connection, it is called a binary joint. For example, below figure shows a chain with two binary joints named B.