Production & Industrial Engineering

General Engineering

Vol. IV : Theory of Machines

Comprehensive Theory

with Solved Examples and Practice Questions

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General Engineering : Vol. IV – Theory of Machines

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INTRODUCTION

Theory of Machines may be defined as that branch of engineering science, which deals with the study of relative motion between the various parts of machine, and forces which act on them. The knowledge of this subject is very essential for an engineer in designing the various parts of a machine.

Theory of Machines may be classified into the following four branches:

1. **Kinematics :** It is that branch of theory of machines which is responsible to study the motion of bodies without reference to the forces which are cause this motion, i.e., it's relate the motion variables (displacement, velocity, acceleration) with the time.
2. **Kinetics :** It is that branch of theory of machines which is responsible to relate the action of forces on bodies to their resulting motion.
3. **Dynamics :** It is that branch of theory of machines which deals with the forces and their effects, while acting upon the machine parts in motion.
4. **Statics :** It is that branch of theory of machines which deals with the forces and their effects, while the machine parts are rest.

4.1 Kinematic Links and Joints

Each part of a machine, which moves relative to some other part, is called kinematic link (or simply link) or element.

A link or element need not to be a rigid body, but it must be a resistant body. A body is said to be a resistant body if it is capable of transmitting required forces with negligible deformation. Thus a link should have the following two characteristics :

(i) It should have relative motion.

(ii) It must be a resistant body.

Type of Links

In order to transmit motion, driver and the follower may be connected by the following three types of links:

(i) **Rigid link :** A rigid link is one which does not undergo any deformation while transmitting motion. Rigid links do not exist. However, as the deformation of a connecting rod, crank etc. of a reciprocating steam engine is not appreciable, they can be considered as rigid links.

(ii) **Flexible link :** It is partly deformed in a manner not to affect the transmission of motion. e.g., belts, ropes, chains and wires are flexible links and transmit tensile forces only.

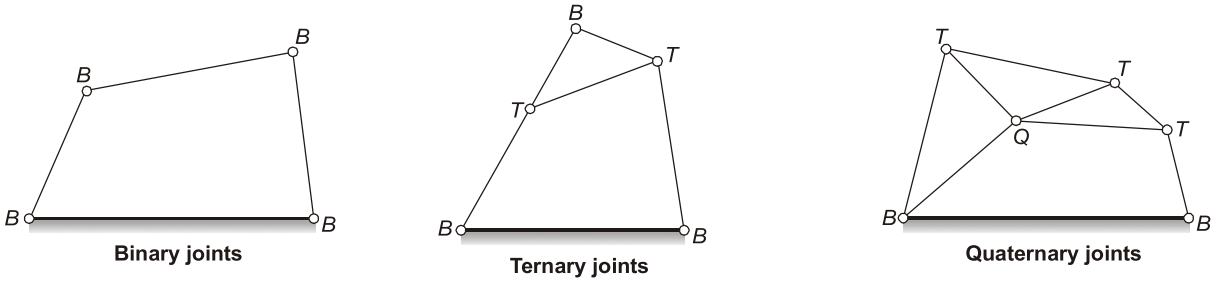
(iii) **Fluid link :** It is formed by having a fluid in a receptacle and the motion is transmitted through the fluid by pressure or compression only. e.g., hydraulic presses, jacks and brakes.

Kinematic Joint

A kinematic joint is the connection between two links by a pin. There is ample clearance between the pin and the hole in the ends of the links being connected to provide free motion of the links.

The usual types of joints in a chain are as shown in figure.

- **Binary joint** : Two links are connected at the same joint by a pin.
- **Ternary joint** : Three links are connected at the same joint by a pin.
- **Quaternary joint** : Four links are connected at the same joint by a pin.



Type of Kinematic Joints

4.2 Structure

It is an assemblage of a number of resistant bodies (known as members) having no relative motion between them and meant for carrying loads having straining action, e.g., railway bridge, a roof truss, machine frames etc.

Difference between Machine and Structure

(i) Parts of a machine move relative to one another, whereas members of a structure do not move relative to one another.

(ii) Machine transforms available energy into some useful work, whereas in structure no energy is transformed into useful work.

(iii) Link of a machine may transmit both power and motion, while members of a structure transmit forces only.

4.3 Kinematic Pair

The two links or elements of a machine, when in contact with each other, are said to form a pair. If relative motion between them is completely or successfully constrained (i.e., in a definite direction), the pair is called kinematic pair.

Type of Kinematic Pair

(1) According to nature of contact.

(i) **Lower pair :** A pair of links having surface or area contact between members is called a lower pair. Contact surfaces of the two links are similar.

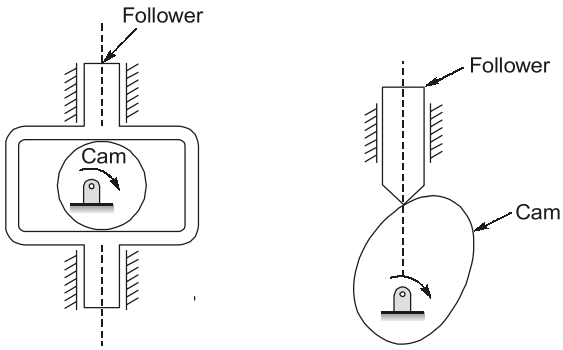
e.g. nut turning on a screw, shaft rotating in a bearing, all pairs of a slider-crank mechanism, universal joint, etc.

(ii) **Higher pair :** When a pair has a point or line contact between the links, it is called 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.

(2) According to nature of mechanical constraint

(i) **Closed pair :** When elements of a pair are held together mechanically, it is called a closed pair. 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 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 and follower pair (higher pair) shown in the figure. Screw pair (lower pair) are closed pairs.



Closed Pair **Unclosed Pair**

(ii) **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 arc not held together mechanically. e.g., cam and pair shown in the figure .

(4) According to nature of relative motion

(i) **Sliding pair :** If two links have a sliding motion relative to each other, they form a sliding pair. e.g., rectangular rod in a rectangular hole in a prism is a sliding pair.

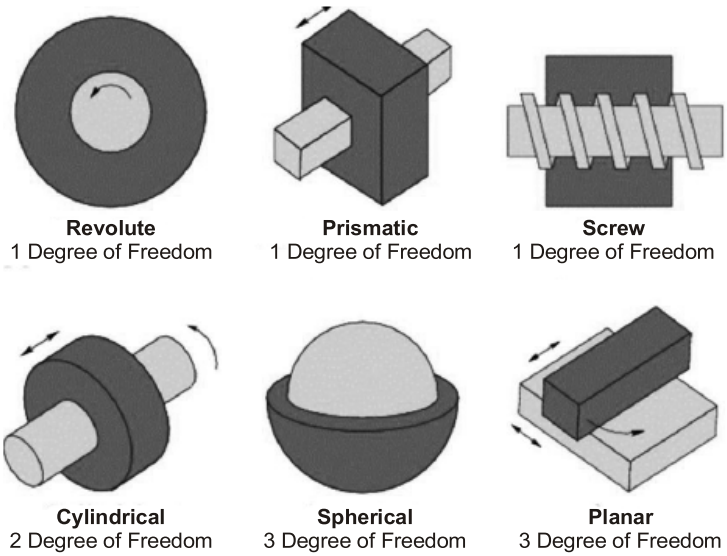
(ii) **Turning pair :** When one link has a turning or revolving motion relative to the other, they constitute a turning or revolving pair. e.g., In a slider-crank mechanism, all pairs except slider and guide pair are turning pairs. A circular shall revolving inside a bearing is a turning pair.

(iii) **Rolling pair :** When links of a pair have a rolling motion relative to each other, they form a rolling pair. e.g., rolling wheel on a flat surface, ball and roller bearings, etc.

In a ball bearing, ball and the shaft constitute one rolling pair whereas ball and the bearing is the second rolling pair.

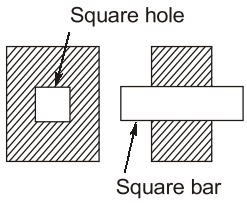
(iv) **Screw pair (helical pair) :** If two mating links have a turning as well as sliding motion between them, they form a screw pair. This is achieved by cutting matching threads on the two links. e.g. lead screw and the nut of a lathe.

(v) **Spherical pair :** When one link in the form of a sphere turns inside a fixed link, it is a spherical pair. e.g., ball and socket joint is a spherical pair.

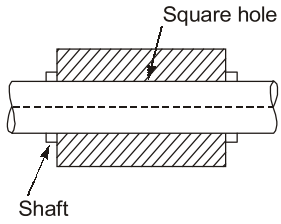


4.4 Types of Constraint Motion

(i) **Completely constrained motion :** When motion between a pair is limited to a definite direction irrespective of the direction of force applied, then motion is called completely constrained motion.



Motion of a square bar in a square hole

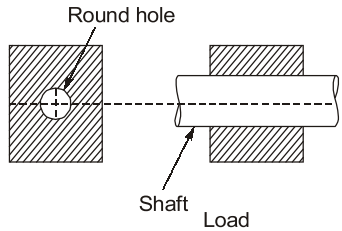


Motion of a shaft with collars at each end in a circular hole

e.g. piston and cylinder (in a steam engine) form a pair. Motion of the piston is limited to a definite direction {i.e. it will only reciprocate) relative to the cylinder irrespective of the direction of motion of the crank.

(ii) **Incompletely constrained motion :** When motion between a pair can take place in more than one direction, then motion is called incompletely constrained motion. The change in the direction of impressed force may alter the direction of relative motion between the pair.

e.g., a circular bar or shaft in a circular hole, as shown in the figure, as it may either rotate or slide in a hole.



Note : These both motions have no relationship with the other.

(iii) **Successfully constrained motion :** When motion between elements, forming a pair, is such that the constrained motion is not completed by itself, but by some other means, then the motion is called successfully constrained motion. e.g. shaft in a foot step bearing.