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

First Edition : 2020
Second Edition : 2021

Third Edition : 2022

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Theory of Machines

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VOLUME IV

General Engineering

Theory of Machines

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.

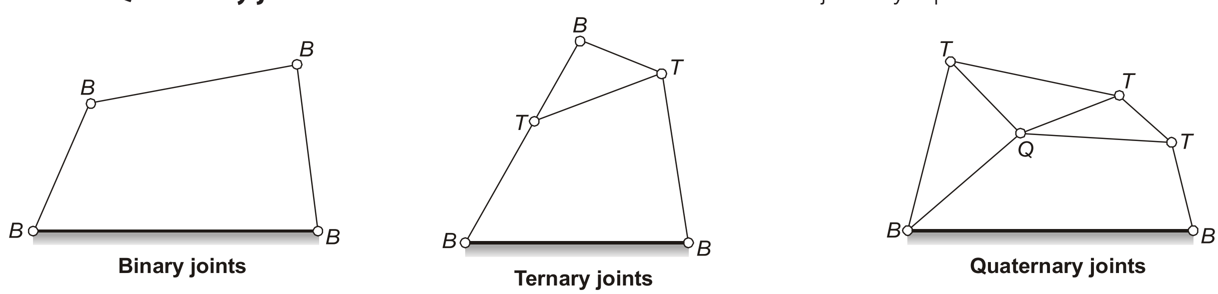
(iii) Fluid link : It is formed by having a fluid in a receptacle and the motion is transmitted through the fluid by pressure or compression only. e.g., hydraulic presses, jacks and brakes.

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.

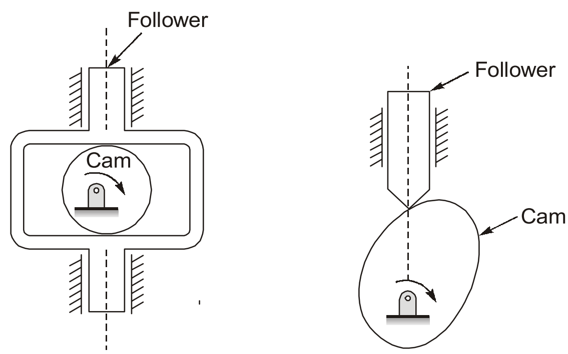
e.g. nut turning on a screw, shaft rotating in a bearing, all pairs of a slider-crank mechanism, universal joint, etc.

(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.

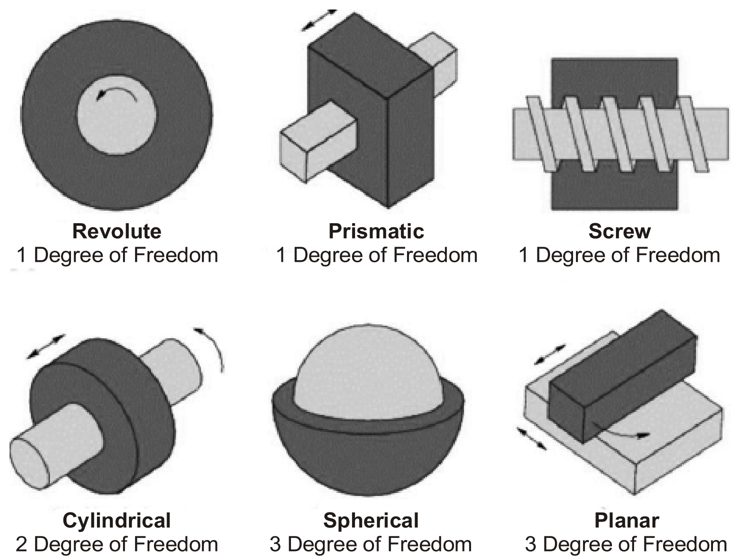
(ii) **Turning pair :** When one link has a turning or revolving motion relative to the other, they constitute a turning or revolving pair. e.g., In a slider-crank mechanism, all pairs except slider and guide pair are turning pairs. A circular shall revolving inside a bearing is a turning pair.

(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.

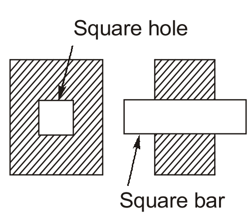
(iv) **Screw pair (helical pair) :** If two mating links have a turning as well as sliding motion between them, they form a screw pair. This is achieved by cutting matching threads on the two links. e.g. lead screw and the nut of a lathe.

(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.

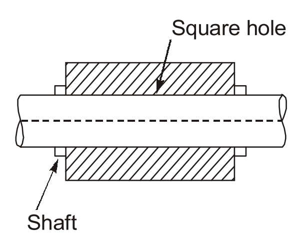


4.4 Types of Constraint Motion

(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.

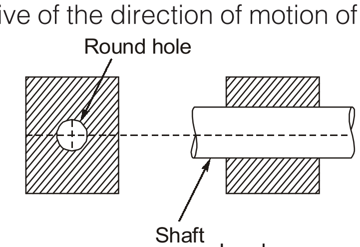


Motion of a square bar in a square hole



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.

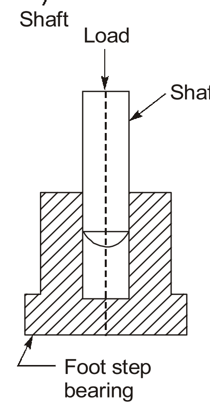


(ii) **Incompletely constrained motion :** When motion between a pair can take place in more than one direction, then motion is called incompletely constrained motion. The change in the direction of impressed force may alter the direction of relative motion between the pair.

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.

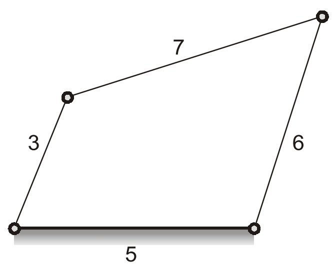
Note : These both motions have no relationship with the other.

(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.



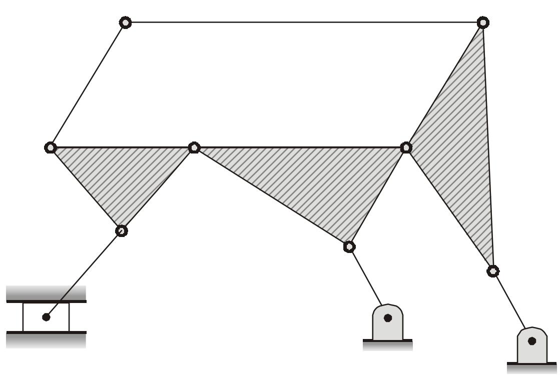
Student's Assignments 1

Q.1 Figure shows four bar link mechanism in which the figures indicate the figures dimensions in standard units of length. Indicate the type of mechanism formed.



(a) Crank rocker (b) Double crank
(c) Double rocker (d) None the above

Q.2 What is the degree of freedom of the following linkage?

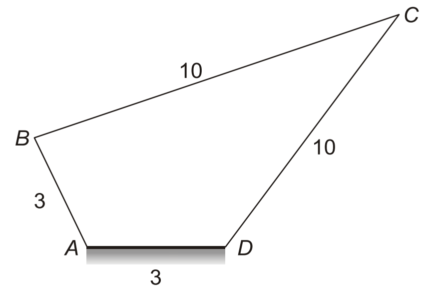


(a) 0 (b) 1
(c) 2 (d) –1

Q.3 Size of cam depends on
(a) Pitch circle (b) Prime circle
(c) Base circle (d) Pitch curve

Q.4 The condition of isochronism can be realized in which of the following governor?
(a) Watt (b) Porter
(c) Proell (d) Hartnell

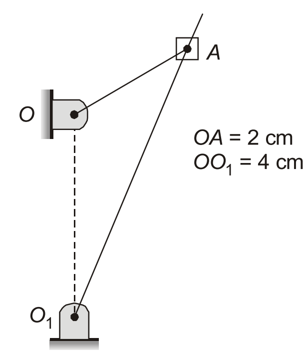
Q.5 The sum of maximum and minimum transmission angle of the following linkage is _____ degree.



Q.6 In whitworth quick-return mechanism, length of fixed link is 150 mm and crank length is 250 mm. The ratio of cutting time and return time is ______.

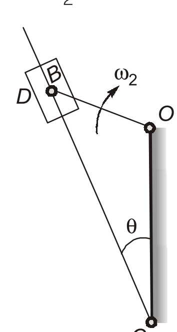
Q.7 In whitworth mechanism, length of extension link on which tool is pivoted is 150 mm, find the length of stroke in mm

Q.8 In a quick return mechanism shown below, cranks *OA* rotates clockwise. The ratio of time for return motion to that of forward motion is ______.

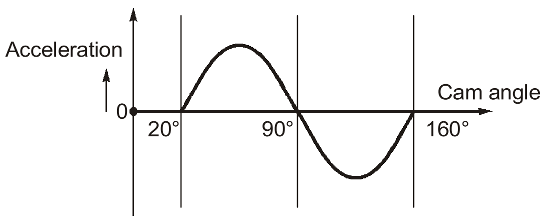


Q.9 In a single slider mechanism, the length of connecting rod and crank is 150 mm and 30 mm. Crank rotates at 1500 rpm and it is at 60° from top dead centre. The magnitude of acceleration of connecting rod will be _______ rad/s^2.

Q.10 For the crank and slotted lever quick return shown below, the Coriolis acceleration of slider at θ = 30° will be _______ m/s. [Given data: *OD* = 2 cm, *OC* = 4 cm, ω_2 = 2 rad/sec]



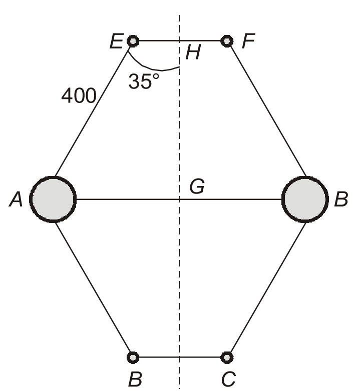
Q.19 Acceleration profile of cam given below shows the following type of cam system



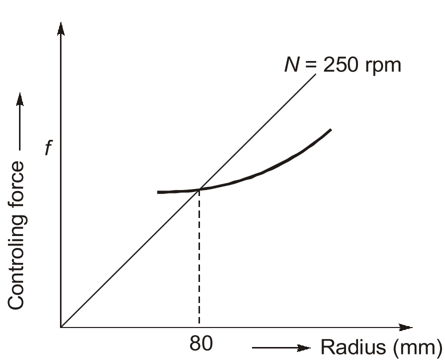
(a) Constant velocity
(b) Cycloidal
(c) Parabolic
(d) Simple harmonic motion (SHM)

Q.20 The energy-released by a flywheel having a mass of 2 kN and radius of gyration of 1.2 m when its speed decreases from 460 rpm to 435 rpm is ________ kJ.

Q.21 In an open arm type governor shown below, AE = 400 mm, EF = 50 mm, and angle q = 35°. The percentage change in speed when q decreases to 30° is ________ %.



Q.22 In porter governor for the controlling force diagram shown below, the mass of each ball is 5 kg, the controlling force is __________ Newton.



Q.23 The controlling force F in Newton and r the radius of rotation in mm for a spring loaded governor are related by the expression

$$F = 3r - 60$$

If the extreme radii of rotation are 120 mm and 190 mm and friction of governor mechanism is equivalent to a force of 30 N at each ball, then what will be the coefficient of insensitiveness of the governor at extreme radius?

(a) 10% at upper extreme radii and 6.25% at lower extreme radii
(b) 6.25% at upper extreme radii and 10% at lower extreme radii
(c) 11.76% at upper extreme radii and 20% at lower extreme radii
(d) 12.5% at upper extreme radii and 20% at lower extreme radii

Q.24 The following data related to a cam profile in which the follower moves with uniform acceleration and deceleration during ascent and descent.
Lift = 25 mm
Offset of follower axis = 12 mm towards right
Angle of ascent = 60°
Angle of descent = 90°
Dwell angle between ascent and descent = 45°
Speed of the cam = 300 rpm
The ratio of uniform acceleration of the follower during the outstroke and return stroke will be_________. (Correct upto two decimal places)

ANSWERS

1. (a)	**2.** (c)	**3.** (c)	**4.** (d)
5. (34.92)	**6.** (2.38)	**7.** (300)	**8.** (0.5)
9. (4294.53)	**10.** (0)	**11.** (890.91)	**12.** (d)
13. (a)	**14.** (d)	**15.** (c)	**16.** (100)
17. (d)	**18.** (b)	**19.** (b)	**20.** (36)
21. (3.44)	**22.** (274.155)	**23.** (b)	**24.** (2.25)

HINTS

2. (c)

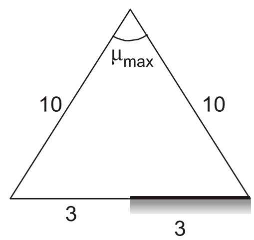
$$l = 9,\ h = 0,\ j = 11$$

By Grubler's criterion

$$f = 3(l - 1) - 2j - h$$

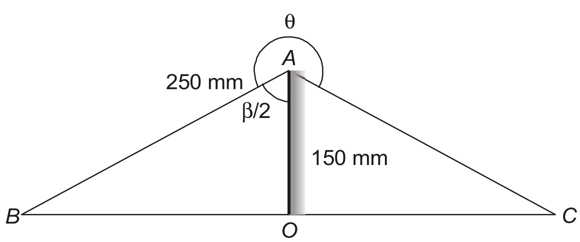
$$= 3(9-1) - 2 \times 11 - 0$$
$$= 24 - 22$$
$$F = 2$$

5. **(34.92) (34.80 to 35.00)**



$$(6)^2 = (10)^2 + (10)^2 - 2 \times 10 \times 10 \times \cos \mu_{max}$$
$$\mu_{max} = 34.92°$$
$$\mu_{min} = 0$$
$$= \mu_{max} + \mu_{min} = 34.92° + 0°$$
$$= 34.92°$$

6. **(2.38) (2.35 to 2.43)**



$$\frac{\text{Time of cutting}}{\text{Time of return}} = \frac{\theta}{\beta}$$
$$\cos\frac{\beta}{2} = \frac{150}{250}; \beta = 106.26°$$
$$\theta = 360° - 106.26°$$
$$\theta = 253.74°$$
$$\text{Ratio} = \frac{253.74}{106.26} = 2.38$$

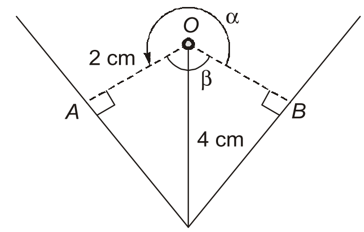
7. **(300) (299 to 301)**

Since, Length of stroke

$$= 2 \times \text{Length of extension link}$$
$$= 2 \times 150 = 300 \text{ mm}$$

8. **(0.5)**

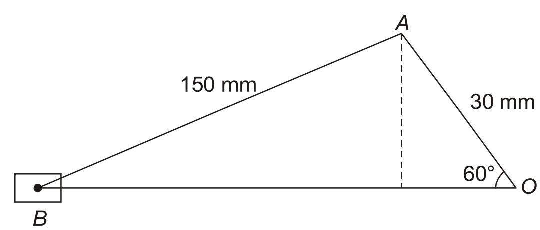
$$\frac{\text{Time for return motion}}{\text{Time for forward motion}} = \frac{\beta}{\alpha}$$
$$\cos\frac{\beta}{2} = \frac{2}{4}$$
$$\Rightarrow \quad \beta = 120°$$
$$\alpha = 360° - 120°$$



$$\alpha = 240°$$
$$\frac{\text{Time for return motion}}{\text{Time for forward motion}} = \frac{120}{240} = \frac{1}{2} = 0.5$$

9. **(4294.53) (4285 to 4300)**

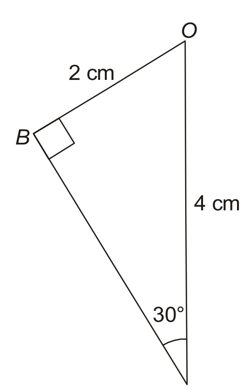
$$n = \frac{l}{r} = \frac{150}{30} = 5$$
$$\alpha_c = -\omega^2 \sin\theta \frac{(n^2 - 1)}{(n^2 - \sin^2\theta)^{3/2}}$$
$$\omega = \frac{2\pi N}{60} = 157.08 \text{ rad/s}$$



$$\alpha_c = -(157.08)^2 \sin 60° \frac{(25-1)}{(25 - \sin^2 60°)^{3/2}}$$
$$\alpha_c = -4294.53 \text{ rad/s}^2$$
$$|\alpha_c| = 4294.53 \text{ rad/s}^2$$

10. **(0)**

Drawing configuration at $\theta = 30°$



At this position $\angle OBC$ will be 90°, velocity of B perpendicular to CD will be zero hence $\omega_{CD} = 0$. So, Coriolis acceleration will be zero.