Production & Industrial Engineering

General Engineering Vol. IV : Theory of Machines

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Theory of Machines

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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.

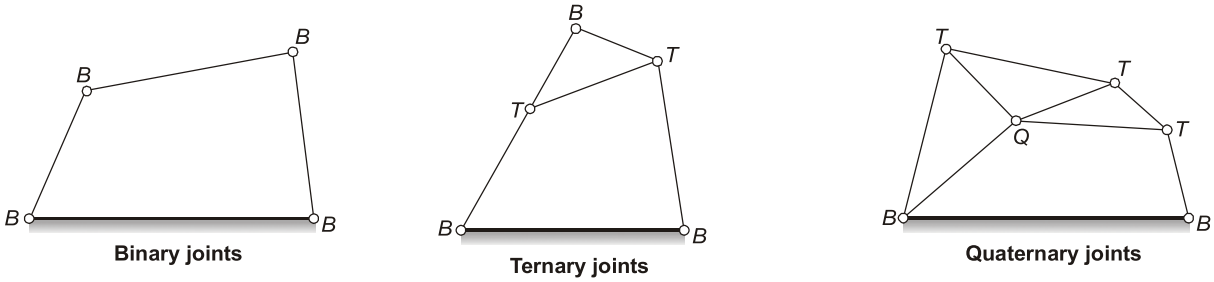
(iii) **Fluid link :** It is formed by having a fluid in a receptacle and the motion is transmitted through the fluid by pressure or compression only. e.g., hydraulic presses, jacks and brakes.

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.

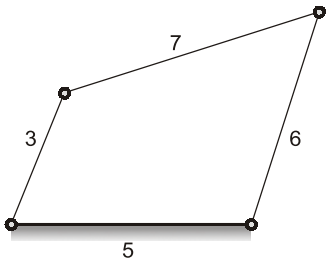
Type of Kinematic Pair

(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.

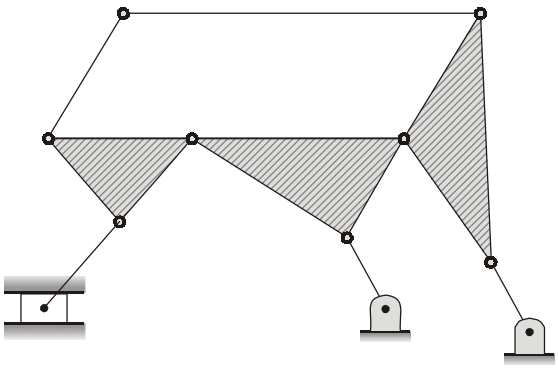
Student's Assignments 1

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?

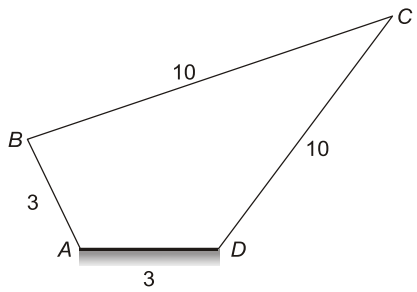


(a) 0 (b) 1
(c) 2 (d) –1

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

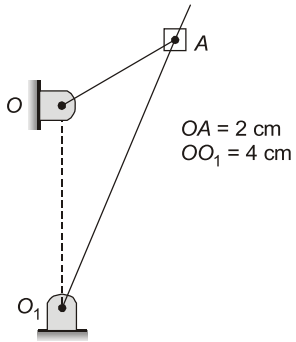
Q.5 The sum of maximum and minimum transmission angle of the following linkage is _____ degree.



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 _____.

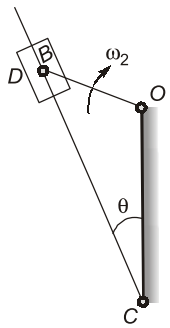
Q.7 In whitworth mechanism, length of extension link on which tool is pivoted is 150 mm, find the length of stroke in mm

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.11 A flywheel is used to given up 18 kJ of energy in reducing its speed from 100 rpm to 98 rpm, then its kinetic energy at 140 rpm will be _____ kJ. (Correct upto two decimal places)

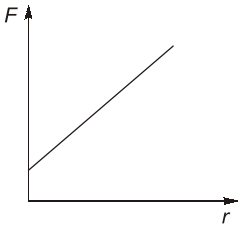
Q.12 The moment of inertia of a flywheel is 2000 kgm^2. Initially at rest, it is moving with uniform acceleration of 0.5 rad/s^2. After 10 seconds, its kinetic energy will be

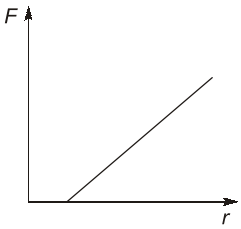
(a) 2500 Nm (b) 500 Nm
(c) 5000 Nm (d) 25000 Nm

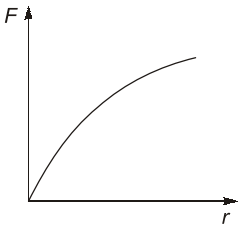
Q.13 A flywheel absorbs energy during those period of crank rotation when

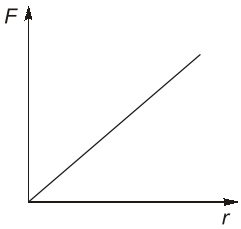
(a) the turning moment is greater than the resisting moment.
(b) the turning moment is equal to the resisting moment.
(c) the turning moment is less than the resisting moment.
(d) absorbs energy during all periods of crank rotation.

Q.14 Which of the following represent an isochronous governor?

(a)


(b)


(c)


(d)


Q.15 The moment of inertia of a flywheel is 4000 kgm^2. Starting from rest, it is moving with a uniform angular acceleration of 0.5 rad/s^2. After 20 seconds from the rest, its kinetic energy in Nm will be

(a) 200000 kNm (b) 100 kNm
(c) 200 kNm (d) 250 kNm

Q.16 If for a flywheel $\frac{\omega_{max}}{\omega_{min}} = 3$, then the value of coefficient of speed fluctuation in percentage is _____.

Student's Assignments 2

Q.17 Which of the statements regarding degree of freedom is not correct?

(a) The connection of a link with another imposes certain constraint on relative motion
(b) Degree of freedom tell how many number of inputs links is required to obtain the constraint motion.
(c) Degree of freedom of a pair is defined as the number of independent relative motion, both translational and rational, a pair can have
(d) The number of restraints may be zero or six.

Q.18 Match **List-I** with **List-II** and select the correct answer using the codes given below:

List-I

A. Rotary engine
B. Scotch yoke
C. Hand pump
D. Oscillating cylinder engine

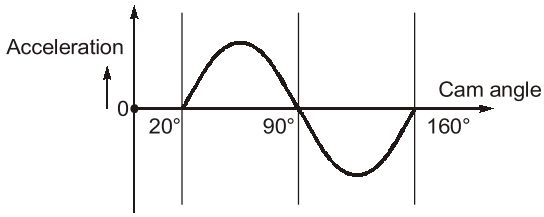
List-II

1. Slider is fixed
2. Fixed link smallest
3. Third inversion of single slider crank
4. Rotary motion to sliding motion

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	2	4	1	3
(c)	2	3	1	4
(d)	3	1	2	4

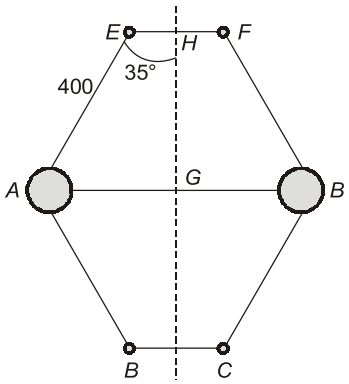
Q.19 Acceleration profile of cam given below shows the following type of cam system



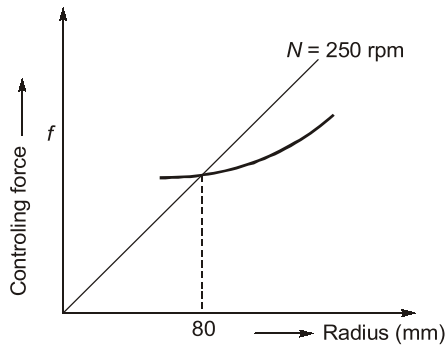
(a) Constant velocity
(b) Cycloidal
(c) Parabolic
(d) Simple harmonic motion (SHM)

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

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