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## THEORY OF MACHINES

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# CONTENTS

# CHAPTER - 1
## *BASIC CONCEPT*

### 1.1. INTRODUCTION
Theory of machine is a study of relative motion between various parts of Machine and forces acting upon them. It can be further divided into the two parts.

#### 1.1.1 Kinematics
Kinematics is study of motion without considering external force acting on the machine parts.

#### 1.1.2 Dynamics
Dynamics is study of motion with effect of some external force acting on the machine parts.
It can further divide into two parts

***1. Statics***
It is a study of forces and their effects on machine and its parts, when it is at rest.

***2. Kinetics***
It is study of combined effect of mass & motion of Machine and its parts

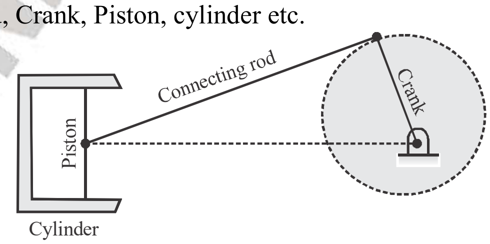
Momentum $\overrightarrow{F_{ext}} = \frac{d}{dt}(m\vec{v})$

#### 1.1.3 Machine
Is a device for transforming and transforming motion and force from one source to another required end to do some desired work.
Input & input force → Desired work and motion.
A machine is made of different parts of member which transmit motion and force & these members are called k. links or elements.

### 1.2 KINEMATIC LINK OR ELEMENT
It is a part of machine which moves relative with respect to some other part of machine. It should be a resistant body so that it is capable of transmitting the motion from one part to other part of machine with negligible deformation.

### 1.3 CLASSIFICATION OF LINKS
The detailed classification of links is described below:

#### 1.3.1. Rigid Link
It is a link which transmits required motion & force without any significant deformation.
**Example.** Connecting rod, Crank, Piston, cylinder etc.




**Slider Crank Chain Mechanism**

# IAS OBJ QUESTIONS

**1.** For one degree of freedom planar mechanism having 6 links, which one of the following is the possible combination?

**[IAS - 2007]**

(a) Four binary links and two ternary links
(b) Four ternary links and two binary links
(c) Three ternary links and three binary links
(d) One ternary link and five binary links

**2.** Consider the following statements in respect of four bar mechanism:

1. It is possible to have the length of one link greater than the sum of length of the other three links.
2. If the sum of the lengths of the shortest and the longest links is less than the sum of lengths of the other two, it is known as the Grashoff's linkage.
3. It is possible to have the sum of the lengths of the shortest and the longest links greater than that of the remaining two links.

Which of these statements is/are correct?

**[IAS - 2003]**

(a) 1, 2 and 3 (b) 2 and 3
(c) 2 only (d) 3 only

**3. Assertion (A):** The kinematic mechanism shown in figure 1 and figure 2 below are the kinematic inversion of the same kinematic chain.

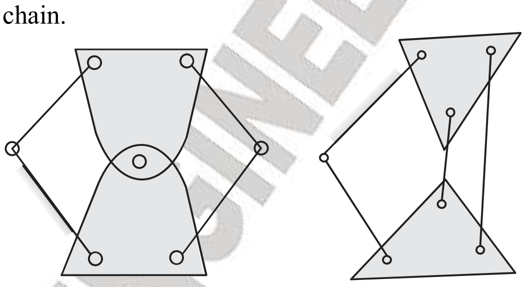


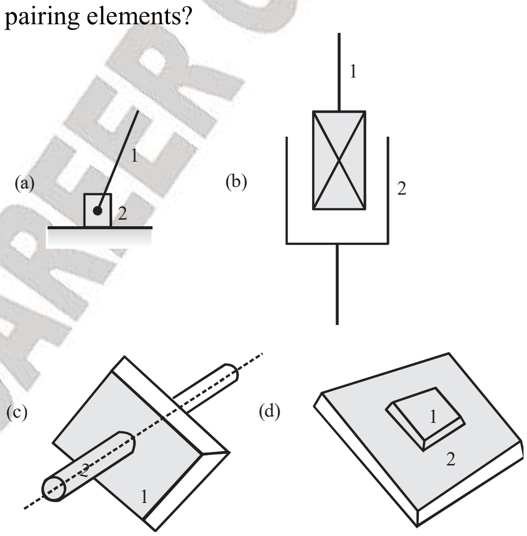
Figure 1 Figure 2

**Reason (R):** Both the kinematic mechanisms have equal number of links and revolute joints, but different fixed links.

**[IAS - 2002]**

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

**4.** Which one of the following "Kinematic pairs" has 3 degrees of freedom between the pairing elements?




**[IAS - 2002]**

**5.** In a four-link kinematic chain, the relation between the number of links (L) and number of pairs (j) is

**[IAS - 2000]**

(a) L = 2j + 4 (b) L = 2j – 4
(c) L = 4j + 2 (d) L = 4j – 2

**6.** The given figure shows a/an

# ESE OBJ QUESTIONS



**1.** Consider the following statements:
1. A kinematic chain is the combination of kinematic pairs joined in such a way that the relative motion between them is completely constrained.
2. The degree of freedom of a kinematic pair is given by the number of independent coordinates required to completely specify the relative movements.
Which of the above statements is/are correct?
**[ESE - 2018]**
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

**2.** Which of the following mechanisms are examples of forced closed kinematic pairs?
(i) Cam and roller mechanism
(ii) Door-closing mechanism
(iii) Slider-crank mechanism
Select the correct answer using the code given below.
**[ESE - 2017]**
(a) (i) and (ii) only (b) (i) and (iii) only
(c) (ii) and (iii) only (d) (i), (ii) and (iii)

**3. Assertion (A)**: Hook's joint connects two non-parallel non–intersecting shafts to transmit motion with a constant velocity ratio.
**Reason (R)**: Hooke's joint connects two shafts the axes of which do not remain in alignment while in motion.
**[ESE - 2015]**
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not correct explanation of A
(c) A is true but R is false
(d) A is false but R is true.

**4.** Which of the following are associated with Ackerman steering mechanism used in automobiles?
1. Has both sliding and turning pairs
2. Less friction and hence long life.
3. Mechanically correct in all positions
4. Mathematically not accurate except in three positions
5. Has only turning pairs
6. Controls movement of two front wheels
**[ESE - 2015]**
(a) 2, 4, 5 and 6 (b) 1, 2, 3 and 6
(c) 2, 3, 5 and 6 (d) 1, 2, 3 and 5

**5.** The minimum number of links in a constrained planer mechanism involving revolute pairs and two higher pairs is
**[ESE - 2013]**
(a) 3 (b) 4
(c) 5 (d) 6

**6.** Consider the following statements pertaining to an example for a cylindrical pair
1. Piston and cylinder of an IC engine
2. Shaft supported by a foot step bearing
3. Doctor's injection syringe
4. A screw driver operating on a screw
Which of these statements are correct?
**[ESE - 2011]**
(a) 1 and 4 (b) 2 and 3
(c) 1and 3 (d) 3 and 4

**7.** The number of degrees of freedom of an epicyclic gear train is
**[ESE - 2011]**
(a) Zero (b) One
(c) Two (d) Three

**8.** Consider the following statements:
1. Lower pairs are more resistant than the higher pair in a plane mechanism.
2. In a 4-bar mechanism (with 4 turning pairs), when the link opposite to the shortest link is fixed, a double rocker mechanism results.
Which of the statements given is/are correct?
**[ESE - 2006]**
(a) Only 1 (b) Only 2
(c) Both 1 and 2 (d) Neither 1 nor 2

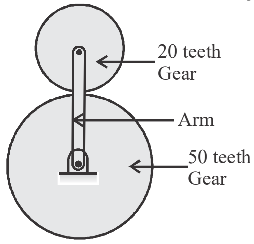
# GATE QUESTIONS

**1.** The number of degrees of freedom in a planner mechanism having n links and j simple hinge joints is

**[GATE - 2016]**

(a) 3(n – 3) – 2j (b) 3(n – 1) – 2j
(c) 3n-2j (d) 2j–3n+4

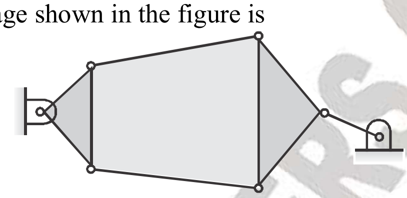
**2.** The number of degrees of freedom of the planetary gear train shown in the figure is




**[GATE - 2015]**

(a) 0 (b) 1
(c) 2 (d) 3

**3.** The number of degrees of freedom of the linkage shown in the figure is



**[GATE - 2014]**

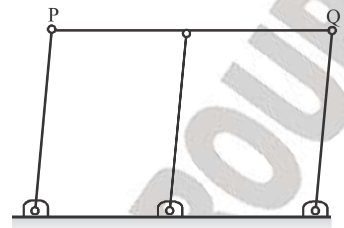
(a) –3 (b) 0
(c) 1 (c) 2

**4.** In a statically determinate plane truss, the number of joints (j) and the number of members (m) are related by

**[GATE - 2014]**

(a) j = 3m–3 (b) m = 2j + 1
(c) m = 2j – 3 (d) m = 2j –1

**5.** A double-parallelogram mechanism in the figure. Note that PQ is a single link. The mobility of the mechanism is




**[GATE - 2011]**

(a) –1 (b) 0
(c) 1 (d) 2

**6.** Mobility of a statistically indeterminate structure is

**[GATE - 2010]**

(a) ≤–1 (b) 0
(c) 1 (d) ≥ 2

**7.** A planar mechanism has 8 links and 10 rotary joints. The number of degrees of freedom of the mechanism, using Grubler's criterion, is

**[GATE - 2008]**

(a) 0 (b) 1
(c) 2 (d) 3

**8.** Match the items in **List-I** and **List-II**

**List-I**
A. Higher kinematic pair
B. Lower kinematic pair
C. Quick return mechanism
D. Mobility of a linkage

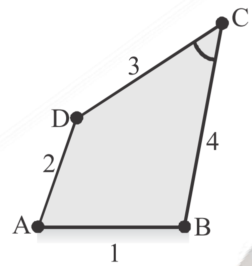
**List-II**
(i)Grubler's equation
(ii)Line contact
(iii)Euler's equation
(iv)Planer
(v)Shaper
(vi)Surface contact

**[GATE - 2006]**

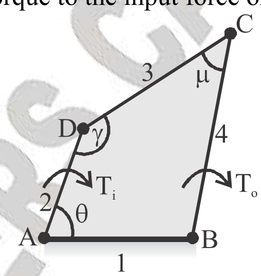
**Codes:**
(a) A-ii, B-vi, C-iv, D-iii
(b) A-vi, B-ii, C-iv, D-i

# CHAPTER - 2
## *INVERSION OF KINEMATIC CHAINS*

### 2.1 INTRODUCTION
The method of obtaining different mechanism by fixing different links in a kinematic chain is known as in version of mechanism. Through process of inversion the relative motion between various link is not changed in any manner.

### 2.2 FOUR BAR CHAIN OR QUADRIC CYCLE CHAIN



As name suggested that, the chain is combination of four kinematic pairs i.e. four Revolute Pair such that the relative motion between the links is completely constrained.
The link AD which is adjacent to the link AB or frame (which is usually fixed) is called as driver (crank) and link BC to which motion is transferred is known as follower (rocker) and link DC which transmits motion from link AD to link BC is known as coupler (connecting rod).

#### 2.2.1 Mechanical Advantage (M.A)
It is the ratio of the output force or torque to the input force or torque at any instant.



From Principle of conservation of energy, we know that:
Power Input = Power output
If $T_i$ is torque applied by input link 2 with angular speed $\omega_i$ and $T_o$ is torque obtained by the output link 4 with angular speed $\omega_o$ respectively.
Then, $T_i\omega_i = T_o\ \omega_o$ $(\therefore\ P = T\ \omega)$

$$M.A = \frac{T_o}{T_i} = \frac{\omega_i}{\omega_o}$$

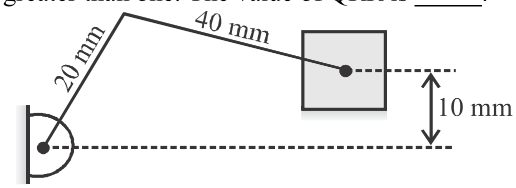
To achieve M.A. to be infinite, the angular velocity $\omega_0$ of the output link 4 becomes zero at extreme positions.
Two extreme condition can be obtained at $\gamma = 0°$ or $\gamma = 180°$. In both conditions the link 2 and link 3 will be in the same line.
These such extreme positions of the mechanism are called as Toggle Position.

# GATE QUESTIONS

**1.** A four bar mechanism has links of length 100mm, 200mm, 300mm and 350 mm. If 350 mm link is fixed, number of links that can fully rotate are?

**[GATE - 2018]**

**2.** An offset slider-crank mechanism is shown in the figure at an instant. Conventionally, the Quick Return Ratio (QRR) is considered to be greater than one. The value of QRR is _____.




**[GATE - 2014]**

**3.** A 4-bar mechanism with all revolute pairs has link lengths $l_f$ = 20 mm, $l_{in}$ = 40 mm, $l_{co}$ = 50 mm and $l_{out}$ = 60 mm. The suffixes 'f', '*in*', 'co' and 'out' denote the fixed link, the input link, the coupler and output link respectively. Which one of the following statements is true about the input and output links?

**[GATE - 2014]**

(a)Both links can execute full circular motion
(b)Both links cannot execute full circular motion
(c)Only the output link cannot execute full circular motion
(d)Only the input link cannot execute full circular motion

**4.** A planar closed kinematic chain is formed with rigid links PQ = 2.0 m, QR = 3.0 m, RS = 2.5 m and SP = 2.7 n with all revolute joints. The link to be fixed to obtain a double rocker (rocker-rocker) mechanism is

**[GATE - 2013]**

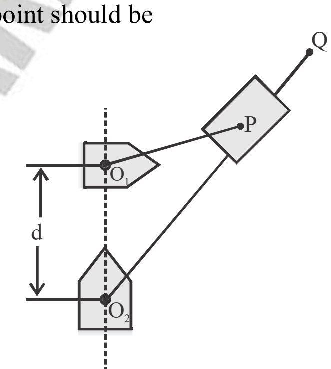
(a) PQ (b) QR
(c) RS (d) SP

**5.** Which of the following statements is INCORRECT?

**[GATE - 2010]**

(a) Grashof's rule states that for a planar crank-rocker four bar mechanism, the sum of the shortest and longest link lengths cannot be less than the sum of the remaining two link lengths.
(b)Inversions of a mechanism are created by fixing different links one at a time.
(c)Geneva mechanism is an intermittent motion device.
(d)Gruebler's criterion assumes mobility of a planar mechanism to be one

**6.** A simple quick return mechanism is shown in the figure. The forward to return time ratio of the quick mechanism is 2:1. If the radius of crank $O_1P$ is 125 mm, then the distance 'd' (in mm) between the crank centre to lever pivot centre point should be




**[GATE - 2010]**

(a) 144.3 (b) 216.5
(c) 240.0 (d) 250.0

**Linked Statement for Q.7 & Q.8**

A quick return mechanism is shown below the crank OS is driven at 2 rad/s in counter clockwise direction.

# CHAPTER - 3
# *KINEMATICS OF MACHINE*

### 3.1 INTRODUCTION
Kinematics deals with study of relative motion between the various parts of machine. The motion leads to concept of displacement, velocity and acceleration.

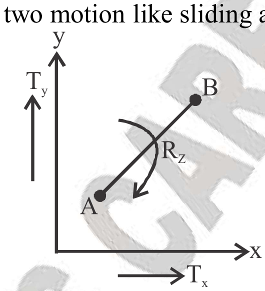
Velocity, $v = \frac{d\vec{s}}{dt}$

Acceleration, $a = \frac{d\vec{v}}{dt}$

$J = \frac{d\vec{a}}{dt}$

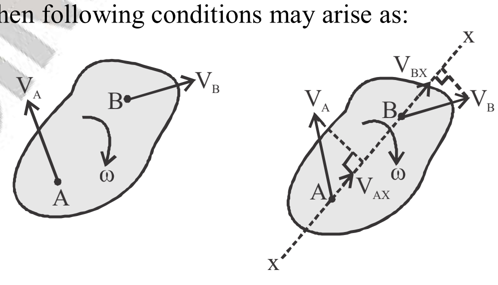
### 3.2 VELOCITY IN MECHANISM
Velocity analysis of a mechanism can be carried out by following methods:
(i) Relative velocity method
(ii) Instantaneous centre method

#### 3.2.1 Relative Velocity Method
In the planar motion, rigid body has two motion like sliding an rotation as shown in figure




Consider a rigid link AB, which translate in X & Y direction as $T_x$ & $T_y$ respectively. Thus, both end of rigid link translate with same velocity and acceleration along the same path.
Now, consider a link AB, which has rotation along Z direction as $R_z$. thus, both end of rigid link rotate with same angular velocity and angular acceleration.

***1. Direction of Velocity***
Consider a rigid body rotating with angular speed (ω) and it has two points A & B on it. The velocity of point A & B are $V_A$ & $V_B$ respectively shown in the figure. Since, the velocity component $V_{AX}$ & $V_{BX}$ parallel to connecting line should be equal if $V_{AX}$ & $V_{BX}$ are if velocity component are different then following conditions may arise as:



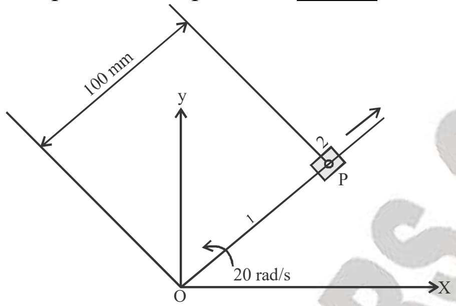
# GATE QUESTIONS

**1.** Which of the statement is correct regarding Oldham coupling?
1. Torsional load is transferred along shaft axis
2. A velocity ratio of 1 : 2 between shaft is obtained without using gears
3. Bending load is transferred perpendicular to shaft axis
4. Rotational movement is transferred along shafts axis

**[GATE - 2018]**

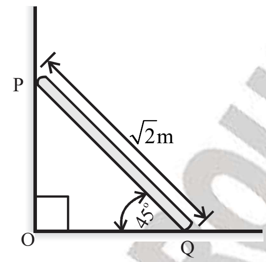
(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

**2.** Block 2 slides on link 1 at a uniform of 6 m/s as shown in the figure. Link 1 is rotating at a constant angular velocity f 20 radian/s counterclockwise. The magnitude of the total acceleration (in $m/s^2$) if point P of the block with respect to fixed point O is______



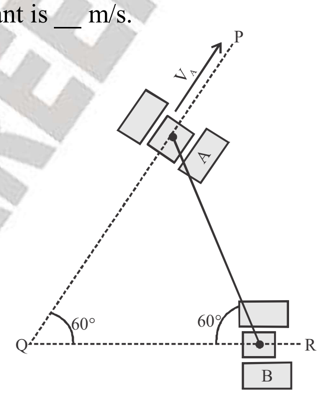

**[GATE - 2017]**

**3.** The rod PQ of length $L = \sqrt{2}m$, and uniformly distributed mass of M = 10 kg, is released from rest at the position shown in the figure. The ends slide along the frictionless faces OP and OQ. Assume acceleration due to gravity, $g = 10\ m/s^2$. The mass moment of inertia of the rod about its centre of mass and an axis perpendicular to the plane of the figure is $(ML^2/12)$. At this instant, the magnitude of angular acceleration (in $radian/s^2$) of the rod is ________.



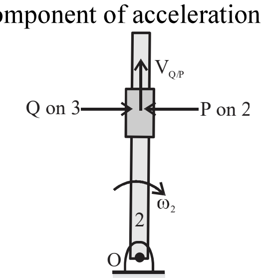

**[GATE - 2017]**

**4.** The rod AB, of length 1 m, shown in the figure is connected to two sliders at each end through pins. The sliders can slide along QP and QR. If the velocity $V_A$ of the slider at A is 2 m/s, the velocity of the midpoint of the rod at this instant is __ m/s.




**[GATE - 2016]**

**5.** In the figure, link 2 rotates with constant angular velocity $\omega_2$. A slider link 3 moves outwards with a constant relative velocity $V_{Q/P}$, where Q is a point on slider 3 and P is a point on link 2. The magnitude and direction of Corioli's component of acceleration is given by

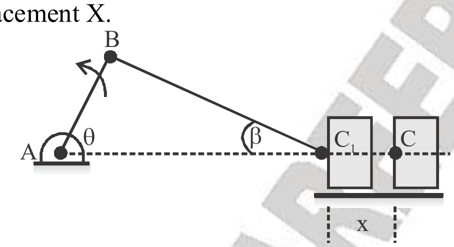


# CHAPTER - 4
## *DYNAMICS OF MACHINE*

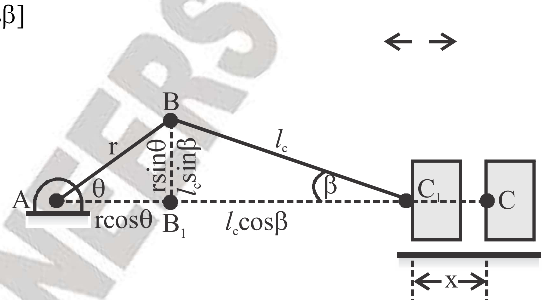
### 4.1 INTRODUCTION
Dynamic deals with study of forces acting upon the various parts of machine while working order accelerating masses. Dynamic forces are always present when machines working under full or part load condition.

#### 4.1.1 D'Alembert's Principle
It states that, the inertia force and couples, and the external force and torques on a body together gives statically equilibrium.
Thus, $\Sigma F + F_i = 0$
and $\Sigma T + C_i = 0$

### 4.2 SLIDER-CRANK MECHANISM
Let, the crank AB has turned through angle θ from inner dead centre (IDC) and slider changes its position C to $C_1$ with displacement X.



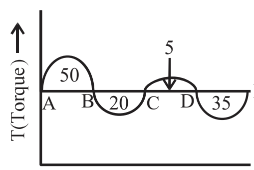

#### 4.2.1 Displacement of Piston
It is a distance travel by piston.
$x = C\,C_1 = CA - C_1A$
$x = (l_c + r) - (r\cos\theta + l_c\cos\beta)$
$= (nr + r) - (r\cos\theta + nr\cos\beta)$ $\quad [\therefore n = l_c/r]$
$= r[n + 1 - \cos\theta - n\cos\beta]$




Where,
$\sin^2\beta + \cos^2\beta = 1$
$$\cos\beta = \sqrt{1-\sin^2\beta}$$
At $BB_1$, $r\sin\theta = l_c\sin\beta$
$$\sin\beta = \sin\theta \times \frac{r}{l_c} = \frac{\sin\theta}{n}$$

# IAS OBJ QUESTIONS

**1.** The crank-effort diagram of an engine running a machine is showing the areas above and below the mean line (in joules). What is the maximum fluctuation of energy in the above diagram?




**[IAS - 2009]**

(a) 0 J (b) 30 J
(c) 50 J (d) 55 J

**2.** Which one of the following does a flywheel control?

**[IAS - 2009]**

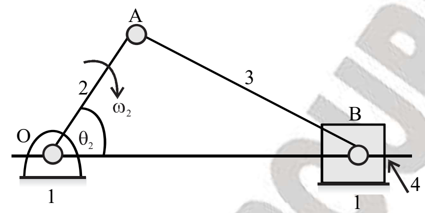
(a)The mean speed of an engine, when load may vary
(b)The cyclic fluctuation of speed with delivering constant output
(c)Variation of load demand of the engine
(d)Mean torque developed by an engine

**3.** Which one of the following statement true for static balancing of a shaft?

**[IAS - 2009]**

(a) The net dynamic force acting on shaft is zero
(b) The net couple due to dynamic acting on the shaft is zero
(c) Both (a) and (b)
(d) Neither (a) nor (b)

**4.** In the figure given below, when is the absolute velocity of end B of the coupler equal to the absolute velocity of the end A of the coupler?




**[IAS - 2007]**

(a) $\theta_2 = 90°$ (b) $\theta_2 = 45°$
(c) $\theta_2 = 0°$ (d) Never

**5.** With usual notations for different parameters involved, the maximum fluctuation of energy for a flywheel is given by

**[IAS - 2002]**

(a) $2EC_s$ (b) $\frac{EC_s}{2}$
(c) $2EC_s^2$ (d) $2E^2C_s$

**6.** Consider the following statements:
If the fluctuation of speed during a cycle is ± 5% of mean speed of a flywheel, the coefficient of fluctuation of speed will
1. Increase with increase mean speed of prime mover
2. Decrease with increase of mean speed of prime mover
3. Remain same with increase of mean speed of prime mover

Which of these statements(s) is/are correct?

**[IAS - 2001]**

(a) 1 and 3 (b) 1 and 2
(c) 3 alone (d) 2 alone

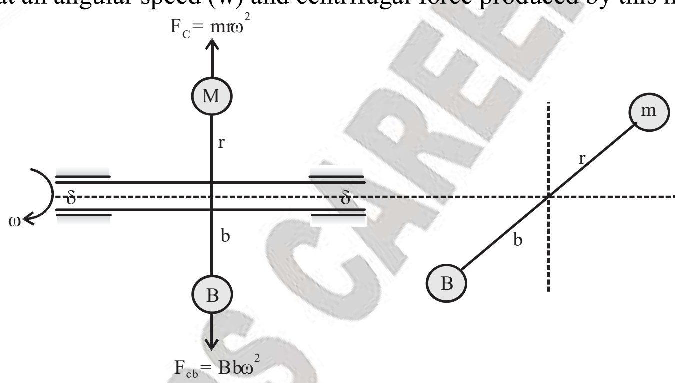
**7.** **Assertion (A):** d' Alembert's principle is known as the principle of dynamic equilibrium.
**Reason (R):** d' Alembert's principle converts a dynamic problem into a static problem.

**[IAS - 2000]**

# CHAPTER - 5
# *BALANCING*

### 5.1 INTRODUCTION
In an every machine there are two types of parts are commonly used as: rotating part and reciprocating part. It is necessary to balance both types of parts in the machines to avoid unbalance force components. These unbalanced focus case excessive noise, vibrations or and fear of the system.
Meanwhile now days high speed engines and other machines are requirement of each every industry. Thus, it is very essential to balance the machines to reduce or eliminate unbalanced forces.

### 5.2 BALANCING OF A SINGLE ROTATING MASS
Whenever a certain mass is attached to a rotating shaft, it exists centrifugal force which tends to bend the shaft and produce vibration and also produce lends on bearings. To eliminate the effect of centrifugal force we should attach an another balanced mass in opposite directions in such a way that it eliminate effect of centrifugal force. Let us consider a mass (m) is attached to the shaft which is rotating at an angular speed (w) and centrifugal force produced by this mass is $F_C$. Thus




$$F_c = F_{cb}$$
$$mr\omega^2 = Bb\omega^2$$
$$mr = Bb$$

1. Product of mass × radius will be remains same for both original mass and balanced mass respectively.
2. Usually radius of balanced mass is taken larger to reduce the balance mass.
3. Both mass will rotate at same angular speed.

### 5.3 EXTERNAL BALANCING OF SINGLE ROTATING MASS
If in any case balancing mass cannot possible to place just equal and opposite to original mass then external balancing of mass can be used. In such case, balanced mass to be placed in different

# CHAPTER - 6
# *GOVERNORS*

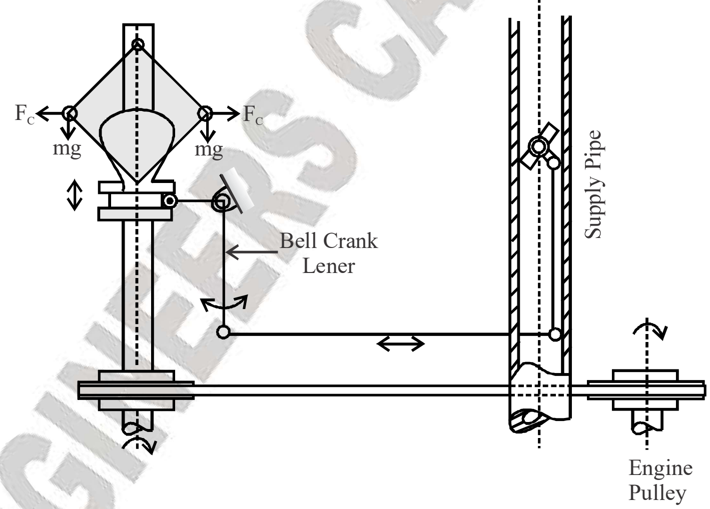
## 6.1 INTRODUCTION

The flywheel which minimizes fluctuations of speed within the cycle but it cannot minimize fluctuations due to load variation. This means flywheel does not exercise any control over mean speed of the engine. To minimize fluctuations in the mean speed which may occur due to load variation, governor is used. The governor has no influence over cyclic speed fluctuations but it controls the mean speed over a long period during which load on the engine may vary.

When there is change in load, variation in speed also takes place then governor operates a regulatory control and adjusts the fuel supply to maintain the mean speed nearly constant. Therefore, the governor automatically regulates through linkages, the energy supply to the engine as demanded by variation of load so that the engine speed is maintained nearly constant.

The sketch of a governor along with linkages which regulates the supply to the engine. The governor shaft is rotated by the engine shown in the figure. If load on the engine increases the engine speed tends to reduce, as a result of which governor balls move inwards. This causes sleeve to move downwards and this movement is transmitted to the valve through linkages to increase the opening and, thereby, to increase the supply.

On the other hand, reduction in the load increases engine speed. As a result of which the governor balls try to fly outwards. This causes an upward movement of the sleeve and it reduces the supply. Thus, the energy input (fuel supply in IC engines, steam in steam turbines, water in hydraulic turbines) is adjusted to the new load on the engine. Thus the governor senses the change in speed and then regulates the supply instantaneously. Due to this type of action it is simple example of a mechanical feedback control system which senses the output and regulates input accordingly.




**Governor and Linkages**

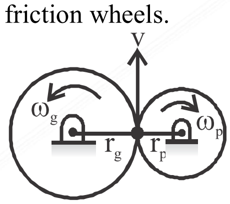
## 6.2 CLASSIFICATION OF GOVERNORS

The broad classification of governor can be made depending on their operation.

1. Centrifugal governors
2. Inertia and flywheel governors
3. Pickering governors

# CHAPTER - 7
## *GEARS & GEAR TRAINS*

### 7.1 INTRODUCTION
Gears are toothed wheels which are used to transmit rolling and a sliding motion along the tangent at the point of contract. It can be successfully possible by the engagement of teeth.
The concept of gears has been derived from the rolling of two friction cylinders or disc. If there is no slip to be assumed in such case, that can definitely transit motion of one to another and vice-versa. The rotating discs are known as friction wheels.




At a point of contact, the same linear velocity can be obtained as

$$v = \omega_g.r_g = \omega_p.r_p$$

$$v = 2\pi N_g r_g = 2\pi N_p r_p$$

or $\frac{N_g}{N_p} = \frac{r_p}{r_g}$

or $\frac{\omega_g}{\omega_p} = \frac{r_p}{r_g}$

It gives that, the speed of the two rolling discs without slipping is always proportional to the radii of the discs.
The friction wheels can be used to transmit motion at lower speeds. At high speeds it is not possible to transmit continuous motion without slipping. Thus, the concept of gear has been introduced to transmit motion and power at smaller centre distance. This lead to the formation of teeth on the discs and the motion between the surface changes from rolling to sliding. The disc with teeth are called as gear or gear wheel.
To obtain large reduction in velocity sometimes, two or more pair of gears may be used which is called as gear trains.

### 7.2 ADVANTAGES OF GEARS
Gear has many advantage over belt & chain drive.
1. It can transmit exact velocity ratio with positive drive. (No Slip)
2. It is capable of transmitting higher power.
3. It require less space, which gives compact layout. For large V.R.
4. It gives reliable service with high efficiency. (Tear & wear in less)
5. Can't use when distance between shaft is more.
6. Costly
7. Special manufacturing m/c required

### 7.3 CLASSIFICATION OF GEARS
Gear can be classified according to their relative position of axes of the shaft as:

# CHAPTER - 8
# *GYROSCOPE*

**Gyroscope**

If the axis of a spinning or rotating body is given an angular motion about an axis perpendicular to the axis of spin, an angular acceleration acts on the body about third perpendicular axis.

The torque required to produce this acceleration is known as the active gyroscope couple or gyroscopic torque.

A reactive gyroscope couple torque or couple also acts similar to the concept of centripetal and centrifugal forces on a body.

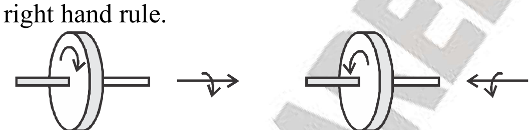
The effect produced by the reactive gyroscope couple is known as gyroscopic effect.

Thus, airplanes, ships, automobiles etc. that have rotating parts in the form of wheel or rotors of engines experience this effect while taking a turn.

**Angular Velocity**

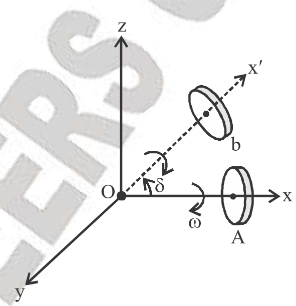
It is defined by Magnitude, direction of axis of rotation (x, y or z) and sense of motion (clockwise (c.c.) or counter clockwise(c.c.w.).

The magnitude of velocity is represented by length of the vector. The direction axis of rotor is represented by drawing a vector parallel to axis of rotor and sense of rotation velocity direction of vector is represented by right hand rule.

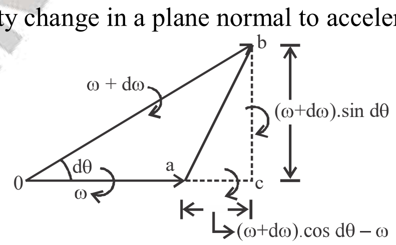


**Angular Acceleration**

Let a rotor is spinning about horizontal axis OX at a speed ω rad/sec in c.c.w. direction. If the magnitude of the angular velocity changes to (ω + δω) from ω and direction of axis of spin to OX′ in dt time.




1. ac represents angular velocity change in a plane normal to acceleration or x-axis.




2. cb representing angular velocity change in a plane normal to cb or y-axis

⇒ change in angular velocity w.r.t. time (dt).

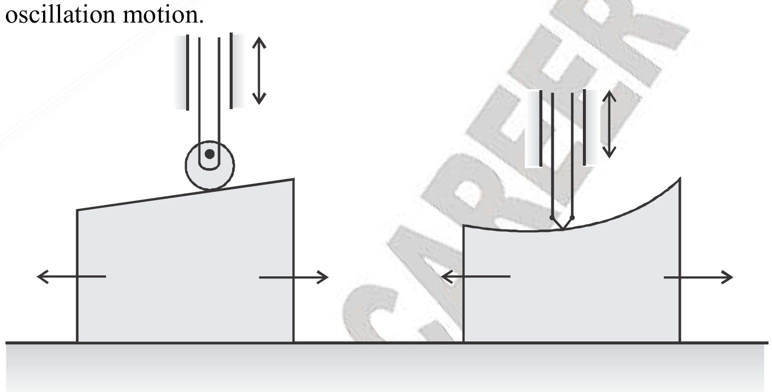
# CHAPTER - 9
## *CAMS*

### 1.1 CAM
Cam is the machine part which is used to impact desired motion to follower by direct contact. The cam may be rotating or reciprocating, while follower can have reciprocating or oscillating motion.

### 1.2 PARTS OF A CAM
1.Cam-It is driver member in mechanism
2.Follower-It is driven member in mechanism
3.Frame-It supplied cam and guides the follower.

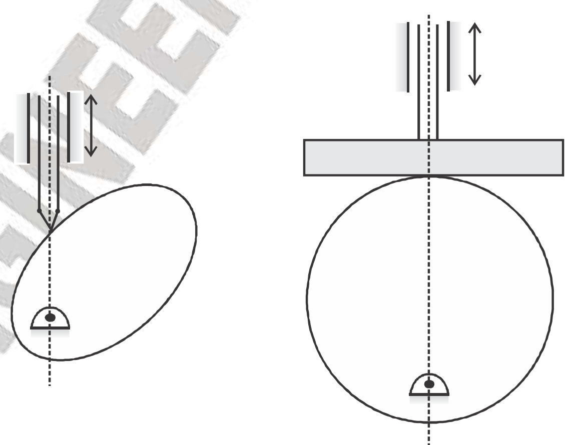
#### 1.2.1 Classifications of Cam
***1. On the Basic of Shape***

***(i) Wedge or Flat Cam-*** It wedge or flat cam has a translation motion and follower can have either translation or oscillation motion.



***(ii)Radial or Disc Cam***

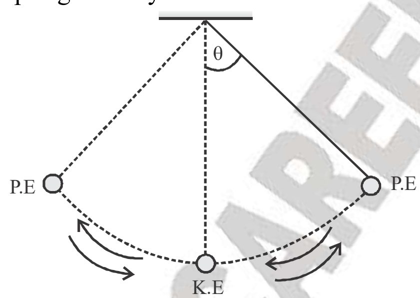
In this type of cam the follower moves radially from the centre rotation of the cam is known as radial disc cam.



# CHAPTER - 10
# *VIBRATION*

### 8.1 INTRODUCTION
All bodies having mass and elasticity are capable of vibration. The mass is inherent of the body and elasticity can relative motion among its parts.
When body particles are displaced by the application of external force, the internal force in the form of elastic energy are present in the body. These forces try to bring the body to its original position.
At equilibrium position, the whole of the elastic energy is converted into kinetic energy and body continues to move in the opposite direction because of it. The whole of the K.E. is again converted into elastic or strain energy due to which the body again returns to the equilibrium position. In this way vibratory motion is repeated indefinitely and exchange of energy takes place.
This, any motion which repeats itself after an internal of time is called vibration or oscillation

**Example.** Simple pendulum, Spring mass system




The main reasons of vibration are as follows
1. Unbalanced centrifugal force in the system. This is caused because of non uniform material distribution in a rotating machine element.
2. Elastic nature of the system
3. External excitation applied on the system
4. Winds may cause vibrations of certain systems such as electricity lines, telephone lines etc.

#### 8.1.1 Advantages of Vibrations
1. Vibration can be used for useful purposes such as vibration testing equipments, vibrations conveyors, hoppers, sieves and compactors.
2. Vibration is found very fruitful in mechanical workshops such as in improving the efficiency of machining, casting, forging and welding techniques, musical instruments and earth quakes for geological research. Etc.
3. It is very useful for propagation of sound.

#### 8.1.2 Disadvantages of Vibration
1. The vibration causes rapid wear of m/c parts such as bearing and gears.
2. Unwanted vibrations may cause loosening of parts from the machine.
3. Many buildings, structures and bridges fall because of vibration.
4. Mechanical failure of the system if the frequency of excitation coincides with one of the natural frequency of the system, a condition of resonance is reached.
5. Sometimes because of heavy vibrations readings of instruments cannot be taken.

# ESE OBJ QUESTIONS

**1.** Which of the following are the basic building block elements for a mechanical system where forces and straight line displacements are involved without any rotation ?
1. Spring 2. Dashpot
3. Mass 4. Moment of inertia
Select the correct answer using the code given below.
**[ESE - 2018]**
(a) 1, 2 and 4 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 3

**2.** The equation of motion for a single degree of freedom system is $4\ddot{x}+9\ddot{x}+15x=0$
The critical damping coefficient for the system is
**[ESE - 2018]**
(a) $4\sqrt{2}$ (b) 4
(c) $16\sqrt{2}$ (d) 16

**3.** The mass of a single degree damped vibrating system is 7.5 kg and it makes 24 free oscillations in 14s when disturbed from its equilibrium position. The amplitude of vibration reduces to 0.25 of its initial value after five oscillations. Then the logarithmic decrement will be
**[ESE - 2018]**
(a) $\frac{2}{5}\log_e 4$ (b) $\frac{1}{5}\log_e 6$
(c) $\frac{1}{5}\log_e 4$ (d) $\frac{2}{5}\log_e 6$

**4.** A 20 kg mass is suspended form a spring which deflects 15mm under this load. The value of the critical damping coefficient to make the motion aperiodic will be
**[ESE - 2018]**
(a) 1010 N/m/s (b) 1013 N/m/s
(c) 1018 N/m/s (d) 1023 N/m/s

**5.** Consider the following statements:
1. The whirling (critical) speed of a shaft is that rotational speed at which the shaft so runs that the deflection of the shaft from the axis of rotation tends to become infinite.
2. Critical speed is equal to the frequency of transverse vibration of a shaft when the shaft carries a point load or a uniformly distributed load or a combination of both such loads.
3. The whirling of a shaft results from causes such as mass unbalance, hysteresis damping in the shaft, gyroscopic forces and fluid friction in the bearing
Which of the above statements are correct ?
**[ESE - 2018]**
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

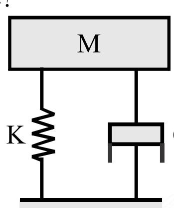
**6.** A simple spring- mass vibrating system has a natural frequency of N. If the spring stiffness is halved and the mass doubled, then the natural frequency will be
**[ESE - 2017]**
(a) 0.5 N (b) N
(c) 2 N (d) 4 N

**7.** A car of mass 1450 kg is constructed on a chasis supported by four springs. Each spring has a force constant of 40000 N m. The combined mass of the two people occupying the car is 150 kg. What is the period of execution of two complete vibrations?
**[ESE - 2017]**
(a) 0.63 s (b) 1.59 s
(c) 4.96 s (d) 1.26 s

**8.** Consider the following statements:
Artefacts to prevent harmful effects resulting from vibrations of an unbalanced machine fixed on its foundation include
(i)Mounting the machine on springs thereby minimizing the transmission of forces.
(ii)Using vibration isolating materials to prevent or reduce the transmission of forces.

# GATE QUESTIONS

**1.** In a single degree of freedom underdamped spring-mass-damper system as shown in the figure, an additional damper, is added in parallel such that the system still remains underdamped. Which one of the following statements is ALWAYS true?




**[GATE - 2018]**

(a) Transmissibility will increase

(b) Transmissibility will decrease

(c) Time period of free oscillations will increase

(d) Time period of free oscillations will decrease

**2.** The equation of motion for a spring-mass system excited by a harmonic force is

$$M\ddot{x} + Kx = F\cos(\omega t)$$

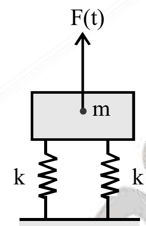
where M is the mass, K is the spring stiffness, F is the force amplitude and ω is the angular frequency of excitation occurs when ω is equal to

**[GATE - 2018]**

(a) $\sqrt{\frac{M}{K}}$ (b) $\frac{1}{2\pi}\sqrt{\frac{K}{M}}$

(c) $2\pi\sqrt{\frac{K}{M}}$ (c) $\sqrt{\frac{K}{M}}$

**3.** A machine of mass m = 200 kg is supported on two mounts, with two springs of stiffness k = 10 kN/m and subjected to a harmonic force F(t) = 50 cos 5t kN. Find the magnitude of dynamic force transmitted from each mounting to the ground




**[GATE - 2018]**

**4.** The damping ratio for a viscously damped spring mass system, governed by the relationship

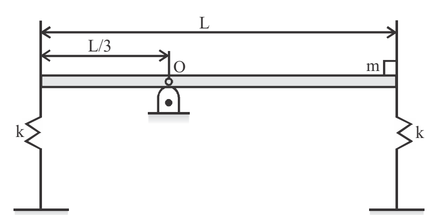
$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F(t)$, is given by

**[GATE - 2017]**

(a) $\sqrt{\frac{c}{mk}}$ (b) $\frac{c}{2\sqrt{km}}$

(c) $\frac{c}{\sqrt{km}}$ (d) $\sqrt{\frac{c}{2mk}}$

**5.** A thin uniform rigid bar of length L and mass M is hinged at point O, located at a distance of $\frac{L}{3}$ from one of its ends. The bar is further supported using springs, each of stiffness k, located at the two ends. A particle of mass m = $\frac{M}{4}$ is fixed at one end of the bar, as shown in the figure. For small rotations of the bar about O, the natural frequency of the system is




**[GATE - 2017]**

(a) $\sqrt{\frac{5k}{M}}$ (b) $\sqrt{\frac{5k}{2M}}$