

LABORATORY MANUAL

DYNAMICS OF MACHINES

ME-313-F

## LIST OF EXPERIMENTS

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4.	To study gyroscopic effects through models.		
5.	To determine gyroscopic couple on Motorized Gyroscope.		
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8.	Determine the moment of inertial of connecting rod by compound pendulum method and tri-flair suspension pendulum.		
9.	To study Dynamically equivalent system.		
10.	To study various types of dynamometer.		

**Note : 1. Ten experiments are to be performed in the Semester.**

**2. At least seven experiments should be performed from the above list. Remaining Three experiments should be performed as designed & set by the concerned institution as per the scope of the syllabus.**

## EXPERIMENT No.- 1

**AIM :-To perform experiment on watt and Porter Governors to prepare performance characteristic Curves, and to find stability & sensitivity.**

**APPARATUS USED:-** Watt and Porter Governors.

**INTRODUCTION & THEORY :-** The function of a governor is to regulate the mean speed of an engine, when there are variations in the load e.g. when the load on an engine increases, its speed decreases, therefore it becomes necessary to increase the supply of working fluid. When the load on the engine decreases, its speed increases and thus less working fluid is required. The governor automatically controls the supply of working fluid to the engine with the varying load conditions and keeps the mean speed within certain limits.

The governors may, broadly, be classified as

1. Centrifugal governor
2. Inertia governor

The centrifugal governors, may further be classified as follows :

1. Pendulum type (Watt governor )
2. Loaded type
  - (i) Dead weight governor (Porter governor and Proell governor)
  - (ii) Spring controlled governors (Hartnell governor, Hartung governor, Wilson-Hartnell governor and Pickering governor)

**Watt Governor :-** The simplest form of a centrifugal governor is a Watt governor. It is basically a conical pendulum with links attached to a sleeve of negligible mass. The arms of the governor may be connected to the spindle in the following three ways :

1. The pivot P, may be on the spindle axis.
2. The pivot P, may be offset from the spindle axis and the arms when produced intersect at O.
3. The pivot P, may be offset, but the arms crosses the axis at O.

**Porter Governor :-** The porter governor is a modification of a Watt's governor, with central load attached to the sleeve. The load moves up down the central spindle. This additional downward force increases the speed of revolution required to enable the balls to rise to any to any pre-determined level.

**OBSERVATION :-**

- Mass of the ball (m) = -----kg.
- Weight of the ball (w)=-----Newtons
- Height of the governor (h) = ----- metres
- Minimum equilibrium speed ( $N_1$ ) = ----- r.p.m.
- Minimum equilibrium speed ( $N_2$ ) = ----- r.p.m.
- Frictional force (F) = ----- Newtons

- Mean equilibrium speed (N) =  $(N_1 + N_2)/2$  in r.p.m
- Mass of the central load = -----kg.
- Weight of the central load (W) = -----N
- Angle of inclination of the arm to the vertical ( $\alpha$ ) = -----
- Angle of inclination of the link to the vertical ( $\beta$ ) = -----

**CALCULATION :-**

- $N^2 = 895/h$  (For watt governor)
- $N^2 = \frac{m + M(1+q)/2}{m} \times \frac{895}{h}$  (For porter governor ), where,  $q = \tan \beta / \tan \alpha$
- Sensitiveness of the governor =  $2(N_1 - N_2) / N_1 + N_2 = 2 (\omega_2 - \omega_1) / \omega_2 + \omega_1$
- A governor is said to be stable when for every speed within the working range there is a definite configuration i.e; there is only one radius of rotation of the governor balls at which the governor is in equilibrium. For a stable governor, if the equilibrium speed increases, the radius of governor balls must also increase.

**PRECAUTIONS :-**

1. Take reading carefully.
2. Measure the angle very carefully.
3. Measure the height of governor carefully.
4. Speed of governor measure accurate.

**VIVA – QUESTIONS :-**

- What is the function of a governor ? How does it differ from that of a flywheel ?
- State the different types of governors. What is the difference between centrifugal and inertia type governors ?
- Explain the term height of the governor. What are the limitations of a Watt governor ?
- What is the stability of a governor ?
- Define the Sensitiveness of governor.
- Which of the governor is used to drive a gramophone ?
- The power of a governor is equal to-----.
- What is hunt?

## EXPERIMENT No.- 2

**AIM :-To perform experiment on Proell Governor to prepare performance characteristic Curves, and to find stability & sensitivity.**

**APPARATUS USED:-** Proell Governor.

**INTRODUCTION & THEORY :-** The function of a governor is to regulate the mean speed of an engine, when there are variations in the load e.g. when the load on an engine increases, its speed decreases, therefore it becomes necessary to increase the supply of working fluid. When the load on the engine decreases, its speed increases and thus less working fluid is required. The governor automatically controls the supply of working fluid to the engine with the varying load conditions and keeps the mean speed within certain limits.

The governors may, broadly, be classified as

1. Centrifugal governor
2. Inertia governor

The centrifugal governors, may further be classified as follows :

1. Pendulum type (Watt governor )
2. Loaded type
  - (a) Dead weight governor (Porter governor and Proell governor)
  - (b) Spring controlled governors (Hartnell governor, Hartung governor, Wilson-Hartnell governor and Pickering governor)

**Proell Governor :-** The porter governor is known as a Proell governor if the two balls (masses) are fixed on the upward extensions of the lower links which are in the form of bent links DFB and EGC (show in fig.).

**OBSERVATION :-**

- Mass of the ball (m) = -----kg.
- Weight of the ball (w)=-----Newtons
- Height of the governor (h) = ----- metres
- Minimum equilibrium speed ( $N_1$ ) = ----- r.p.m.
- Minimum equilibrium speed ( $N_2$ ) = ----- r.p.m.
- Frictional force (F) = ----- Newtons
- Mean equilibrium speed ( $N$ ) =  $(N_1 + N_2)/2$  in r.p.m
- Mass of the central load = -----kg.
- Weight of the central load (W) = -----N
- Angle of inclination of the arm to the vertical ( $\alpha$ ) = -----
- Angle of inclination of the link to the vertical ( $\beta$ ) = -----

### **CALCULATION :-**

- $N^2 = \frac{FM}{BM} \times \left[ \frac{m + [M(1+q)]/2}{m} \right] \times \frac{895}{h}$  (For porter governor ) where,  $q = \tan \beta / \tan \alpha$
- Sensitiveness of the governor =  $2(N_1 - N_2) / N_1 + N_2 = 2(\omega_2 - \omega_1) / \omega_2 + \omega_1$
- A governor is said to be stable when for every speed within the working range there is a definite configuration i.e; there is only one radius of rotation of the governor balls at which the governor is in equilibrium. For a stable governor, if the equilibrium speed increases, the radius of governor balls must also increase.

### **PRECAUTIONS :-**

- Take reading carefully.
- Measure the angle very carefully.
- Measure the height of governor carefully.
- Speed of governor measure accurate.

### **VIVA – QUESTIONS :-**

- What is the function of a governor ? How does it differ from that of a flywheel ?
- State the different types of governors. What is the difference between centrifugal and inertia type governors ?
- Explain the term height of the governor. What are the limitations of a Watt governor ?
- What is the stability of a governor ?
- Define the Sensitiveness of governor.
- Which of the governor is used to drive a gramophone ?
- The power of a governor is equal to-----.
- What is hunt?

## EXPERIMENT No.- 3

**AIM :-To perform experiment on Hartnell Governor to prepare performance characteristic Curves, and to find stability & sensitivity.**

**APPARATUS USED:-** Hartnell Governor.

**INTRODUCTION & THEORY :-** The function of a governor is to regulate the mean speed of an engine, when there are variations in the load e.g. when the load on an engine increases, its speed decreases, therefore it becomes necessary to increase the supply of working fluid. When the load on the engine decreases, its speed increases and thus less working fluid is required. The governor automatically controls the supply of working fluid to the engine with the varying load conditions and keeps the mean speed within certain limits.

The governors may, broadly, be classified as

1. Centrifugal governor
2. Inertia governor

The centrifugal governors, may further be classified as follows :

1. Pendulum type (Watt governor )
2. Loaded type
  - i. Dead weight governor (Porter governor and Proell governor)
  - ii. Spring controlled governors (Hartnell governor, Hartung governor, Wilson-Hartnell governor and Pickering governor)

**Hartnell Governor :-** A Hartnell governor is a spring loaded governor as shown in fig.-A. It consists of two bell crank levers pivoted at the points O,O to the frame. The frame is attached to the governor spindle and therefore rotates with it. Each lever carries a ball at the end of the vertical arm OB and a roller at the end of the horizontal arm OR. A helical spring in compression provides equal downward forces on the two rollers through a collar on the sleeve. The spring force be adjusted by screwing at nut up or down on the sleeve.

**OBSERVATION :-**

- Mass of the each ball (m) = -----kg.
- Mass of the sleeve (M)=-----Newtons
- Minimum radius of rotation ( $r_1$ ) = ----- metres
- Maximum radius of rotation ( $r_2$ ) = ----- metres
- Angular speed of the governor at minimum radius ( $\omega_1$ ) = -----rad./s
- Angular speed of the governor at maximum radius ( $\omega_2$ ) = -----rad./s
- Spring force exerted on the sleeve at  $\omega_1$  ( $S_1$ ) = ----- Nt.
- Spring force exerted on the sleeve at  $\omega_2$  ( $S_2$ ) = ----- Nt.
- Length of the vertical or ball arm of the lever (x) = ----- metres.
- Length of the horizontal or sleeve arm of the lever (y) = ----- metres.

- Distance of fulcrum 'O' from the governor axis or the radius of rotation when the governor is in mid-position ( r ) = ----- metres.
- Minimum equilibrium speed (N<sub>1</sub>) = ----- r.p.m.
- Minimum equilibrium speed (N<sub>2</sub>) = ----- r.p.m.
- Frictional force (F) = ----- Newtons
- Angle of inclination of the arm to the vertical ( α ) = -----
- Angle of inclination of the link to the vertical ( β ) = -----

#### CALCULATION :-

- $F_c = F_{c1} + (F_{c2} - F_{c1}) \times \frac{(r - r_1)}{(r_2 - r_1)} = F_{c2} - (F_{c2} - F_{c1}) \times \frac{(r_1 - r)}{(r_2 - r_1)}$  (when friction is taken)
- $N^2 = F_c \times 3600 / 4\pi^2 m.r$
- Sensitiveness of the governor =  $2(N_1 - N_2) / N_1 + N_2 = 2(\omega_2 - \omega_1) / \omega_2 + \omega_1$
- A governor is said to be stable when for every speed within the working range there is a definite configuration i.e; there is only one radius of rotation of the governor balls at which the governor is in equilibrium. For a stable governor, if the equilibrium speed increases, the radius of governor balls must also increase.

#### PRECAUTIONS :-

- Take reading carefully.
- Measure the angle very carefully.
- Measure the height of governor carefully.
- Speed of governor measure accurate.

#### VIVA – QUESTIONS :-

- What is the function of a governor ? How does it differ from that of a flywheel ?
- State the different types of governors. What is the difference between centrifugal and inertia type governors ?
- Explain the term height of the governor. What are the limitations of a Watt governor ?
- What is the stability of a governor ?
- Define the Sensitiveness of governor.
- Which of the governor is used to drive a gramophone ?
- The power of a governor is equal to-----.
- What is hunt?

## **EXPERIMENT No.- 4**

**AIM :- To study gyroscopic effects through models.**

**APPARATUS USED:-** Models of Aero plane and ship.

**THEORY :-** The earliest observation and studies on gyroscopic phenomenon carried out during Newton's time. These were made in the context of the motion of our planet which in effect is a massive gyroscope. The credit of the mathematical foundation of the principles of gyroscopic motion goes to Euler who derived a set of dynamic equations relating applied mechanics and moment of inertia, angular acceleration and angular velocity in many machines, the rotary components are forced to turn about their axis other than their own axis of rotation and gyroscopic effects are thus setup. The gyroscopes are used in ships to minimize the rolling & pitching effects of water.

### **Effect of the Gyroscopic Couple on an Aeroplane :-**

1. When the aeroplane takes a right turn under similar conditions. The effect of the reactive gyroscopic couple will be to dip the nose and raise the tail of the aeroplane.
2. When the engine or propeller rotates in anticlockwise direction when viewed from the rear or tail end and the aeroplane takes a left turn, then the effect of reactive gyroscopic couple will be to dip the nose and raise the tail of the aeroplane.
3. When the aeroplane takes a right turn under similar conditions as mentioned in note 2 above, the effect of reactive gyroscopic couple will be to raise the nose and dip the tail of the aeroplane.
4. When the engine or propeller rotates in clockwise direction when viewed from the front and the aeroplane takes a left turn, then the effect of reactive gyroscopic couple will be to raise the tail and dip the nose of the aeroplane.
5. When the aeroplane takes a right turn under similar conditions as mentioned in note 4 above, the effect of reactive gyroscopic couple will be to raise the nose and dip the tail of the aeroplane.

The effect of gyroscopic couple on the naval ship in the following three cases :

1- Steering    2- Pitching    and 3- Rolling

### **Effect of the Gyroscopic Couple on a Naval ship during Steering :-**

1. When the ship steers to the right under similar conditions as discussed above, the effect of the reactive gyroscopic couple will be to raise the stern and lower the bow.
2. When the rotor rotates in the anticlockwise direction, when viewed from the stern and the ship is steering to the left, then the effect of reactive gyroscopic couple will be to lower the bow and raise the stern.

3. When the ship is steering to the right under similar conditions as discussed in note 2 above, then the effect of reactive gyroscopic couple will be to raise the bow and lower the stern.
4. When the rotor rotates in the clockwise direction when viewed from the bow or fore end and the ship is steering to the left, then the effect of reactive gyroscopic couple will be to raise the stern and lower the bow.
5. When the ship is steering to the right under similar conditions as discussed in note 4 above, then the effect of reactive gyroscopic couple will be to raise the bow and lower the stern.
6. The effect of the reactive gyroscopic couple on a boat propelled by a turbine taking left or right turn is similar as discussed above.

### **Effect of the Gyroscopic Couple on a Naval ship during Pitching :-**

1. The effect of the gyroscopic couple is always given on specific position of the axis of spin, i.e. whether it is pitching downwards or upwards.
2. The pitching of a ship produces forces on the bearings which act horizontally and perpendicular to the motion of the ship.
3. The maximum gyroscopic couple tends to shear the holding-down bolts.
4. The angular acceleration during pitching.

$$\alpha = d^2\theta/dt^2 = -\Phi(\omega_1)^2 \sin \omega_1 t \quad (\text{Differentiating } d\theta/dt \text{ with respect to } t)$$

The angular acceleration is maximum, if  $\sin \omega_1 t = 1$

Therefore Maximum angular acceleration during pitching,

$$\alpha_{\max} = \Phi(\omega_1)^2$$

**Effect of the Gyroscopic Couple on a Naval ship during Rolling:-** We know that, for the effect of gyroscopic couple to occur, the axis of precession should always be perpendicular to the axis of spin. If, however, the axis of precession becomes parallel to the axis of spin, there will be no effect of the gyroscopic couple acting on the body of the ship.

In case of rolling of a ship, the axis of precession (i.e. longitudinal axis) is always parallel to the axis of spin for all positions. Hence, there is no effect of the gyroscopic couple acting on the body of a ship.

**APPLICATIONS :-** The gyroscopic principle is used in an instrument or toy known as gyroscope. The gyroscopes are installed in ships in order to minimize the rolling and pitching effects of waves. They are also used in aeroplanes, monorail cars, gyrocompasses etc.

### **VIVA – QUESTIONS :-**

- Write a short note on gyroscope.
- What do you understand by gyroscopic couple ? Derive a formula for its magnitude.
- Explain the application of gyroscopic principles to aircrafts.
- Discuss the effect of the gyroscopic couple on a two wheeled vehicle when taking a turn.
- When the pitching of a ship is upward, the effect of gyroscopic couple acting on it will be to move the ship towards port side or to move the ship towards star-board.

## EXPERIMENT No.- 5

**AIM :- To determine gyroscopic couple on Motorized Gyroscope.**

**APPARATUS USED:-** Four wheeler & two wheeler vehicle.

**THEORY :-** When a body moves along a curved path with a uniform linear velocity, a force in the direction of centripetal acceleration (known as centripetal force) has to be applied externally over the body, so that it moves along the required curved path. This external force applied is known as active force. When a body, itself, is moving with uniform linear velocity along a circular path, it is subjected to the centrifugal force radially outwards. This centrifugal force is called reactive force.

The change in angular momentum is known as active gyroscopic couple ( $I_w \omega_w \omega_p$ ). When the axis of spin itself moves with angular velocity  $\omega_p$ , the disc is subjected to reactive couple whose magnitude is same (i.e.  $I_w \omega_w \omega_p$ ) but opposite in direction to that of active couple.

**OBSERVATION :-**

- Mass of the vehicle (m) = ----- kg.
- Weight of the vehicle (W) = ----- Newtons.
- Radius of the wheels ( $r_w$ ) = ----- metres.
- Radius of curvature ( R ) = ----- meters.
- Distance of centre of gravity, vertically above the road surface(h) = ----- metres,
- Width of track (x) = -----metres,
- Mass moment of inertia of one of the wheels(  $I_w$  ) = -----kg-m<sup>2</sup>
- Angular velocity of the wheels or velocity of spin( $\omega_w$ ) = -----rad/sec
- Mass moment of inertia of the rotating parts of the engine( $I_E$ ) = ----- kg-m<sup>2</sup>
- Angular velocity of the rotating parts of the engine ( $\omega_E$ ) = -----rad/sec
- Gear ratio =  $\omega_E / \omega_w$
- Linear velocity of the vehicle (v) =  $r_w \omega_w$
- Angle of heel ( $\theta$ ) = ----- rad.

**CALCULATION :-**

**For 4-wheel drive:**

- Gyroscopic couple due to 4 wheels,  $C_w = 4 I_w \omega_w \omega_p$  where, ( $\omega_p = v/R$ )
- Gyroscopic couple due to the rotating parts of the engine,  $C_E = I_E \omega_E \omega_p = I_w \cdot G \cdot \omega_w \cdot \omega_p$
- Net Gyroscopic couple,  $C = C_w \pm C_E$

**For 2-wheel drive:**

- Gyroscopic couple,  $C_1 = v (2 I_w \pm I_E \cdot G) \cos\theta / R \cdot r_w$

**PRECAUTIONS :-**

- When rotating parts of the engine rotate in opposite directions, then negative sign is used.
- When  $C_E > C_w$ , then  $C$  will be negative. Thus the reaction will be vertically downwards on the outer wheels and vertically upwards on the inner wheels.
- The gyroscopic couple will act over the vehicle outwards i.e. in the anticlockwise direction when seen from the front of the vehicle. The tendency of this couple is to overturn the vehicle in outward direction.

**RESULT :-**

- Gyroscopic couple of four wheel drive is = -----N-m.
- Gyroscopic couple of two wheel drive is = -----N-m.

**VIVA – QUESTIONS :-**

- Write a short note on gyroscope.
- What do you understand by gyroscopic couple ? Derive a formula for its magnitude.
- Explain the application of gyroscopic principles to aircrafts.
- Discuss the effect of the gyroscopic couple on a two wheeled vehicle when taking a turn.
- When the pitching of a ship is upward, the effect of gyroscopic couple acting on it will be to move the ship towards port side or to move the ship towards star-board.

## EXPERIMENT No.- 6

**AIM :- To perform the experiment for static balancing on static balancing machine.**

**APPARATUS USED:-** Static Balancing m/c.

**THEORY :-** A system of rotating masses is said to be in static balance if the combined mass centre of the system lies on the axis of rotation. Whenever a certain mass is attached to a rotating shaft, it exerts some centrifugal force, whose effect is to bend the shaft and to produce vibrations in it. In order to prevent the effect of centrifugal force, another mass is attached to the opposite side of the shaft. The process of providing the second mass in order to counteract the effect of the centrifugal force of the first mass, is called balancing of rotating masses.

The following cases are important from the subject point of view :

1. Balancing of a single rotating mass by a single mass rotating in the same plane.
2. Balancing of a single rotating mass by two masses rotating in different planes.
3. Balancing of different masses rotating in the same plane.
4. Balancing of different masses rotating in different planes.

**PROCESURE :-** Remove the belt, the value of weight for each block is determined by clamping each block in turn on the shaft and with the cord and container system suspended over the protractor disc, the number of steel balls, which are of equal weight are placed into one of the containers to exactly balance the blocks on the shaft. When the block becomes horizontal, the number of balls N will give the value of wt. for the block.

For finding out  $W_r$  during static balancing proceed as follow:

1. Remove the belt.
2. Screw the combined hook to the pulley with groove. This pulley is diff. than the belt pulley.
3. Attached the cord end of the pans to above combined hook.
4. Attached the block no.-1 to the shaft at any convenient position and in vertical downward direction.
5. Put steel balls in one of the pans till the blocks starts moving up. (upto horizontal position).
6. Number of balls give the  $W_r$  value of block-1. repeat this for 2-3 times and find the average no. of balls.
7. Repeat the procedure for other blocks.

**OBSERVATION :-**

S.no	Plane	Mass (m) kg.	Radius ® m	Cent. Force ÷ $\omega^2$ (m.r) kg-m	Distance from plane x(l) m	Couple ÷ $\omega^2$ (m.r.l) kg- m <sup>2</sup>

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**CALCULATION :-** The balancing masses and angular positions may be determined graphically as given below :-

1. First of all, draw the couple polygon from the data which are calculated in table to some suitable scale. The vector distance represents the balanced couple. The angular position of the balancing mass is obtained by drawing, parallel to vector distance. By measurement will be find the angle.
2. Then draw the force polygon from the data, which are calculated in table to some suitable scale. The vector distance represents the balanced force. The angular position of the mass is obtained by drawing, parallel to vector distance. By measurement will be find the angle in the clockwise direction from mass.

**PRECAUTIONS :-**

1. Couple should be represented by a vector drawn perpendicular to the plane of the couple.
2. Angular position measure carefully in clockwise direction.
3. Vector diagram should be represent with suitable scale.

**VIVA-QUESTIONS :-**

- Why is balancing of rotating parts necessary for high speed engines ?
- Explain the terms 'static balancing' and 'dynamic balancing'. State the necessary conditions to achieve them.
- Discuss how a single revolving mass is balanced by two masses revolving in different planes.
- How the different masses rotating in different planes are balanced ?
- Explain the method of balancing of different masses revolving in the same plane.

## **EXPERIMENT No.- 7**

**AIM :- To perform the experiment for dynamic balancing on dynamic balancing machine.**

**APPARATUS USED:-** Dynamic balancing m/c.

**THEORY :-** When several masses rotate in different planes, the centrifugal force, in addition to being out of balance, also forms couples. A system of rotating masses is in dynamic balance when there does not exist any resultant centrifugal force as well as resultant couple.

### **Pivoted-cradle Balancing M/C :-**

In this type of m/c., the rotor to be balanced is mounted on half-bearing in a rigid carriage and is rotated by a drive motor through a universal joint. Two balancing planes A and B are chosen on the rotor. The cradle is provided with pivots on left and right sides of the rotor which are purposely adjusted to coincide with the two correction planes. Also the pivots can be put in the locked or unlocked position. Thus, if the left pivot is released, the cradle and the specimen are free to oscillate about the locked (right) pivot. At each end of the cradle, adjustable springs and dashpots are provided to have a single degree of freedom system. Usually, their natural frequency is tuned to the motor speed.

### **PROCEDURE :-**

1. First either of the two pivots say left is locked so that the readings of the amount and the angle of location of the correction in the right hand plane can be taken. These readings will be independent of any unbalance in the locked plane as it will have no moment about the fixed pivot.
2. A trial mass at a known radius is then attached to the right hand plane and the amplitude of oscillation of the cradle is noted.
3. The procedure is repeated at various angular positions with the same trial mass.
4. A graph is then plotted of amplitude Vs angular positions of the trial mass to know the optimum angular position for which amplitude is minimum. Then at this position, the magnitude of the trial mass is varied and the exact amount is found by trial and error which reduces the unbalance to almost zero.
5. After obtaining the unbalance in one plane, the cradle is locked in the right hand pivot and released in the left hand pivot. The above procedure is repeated to obtain the exact balancing mass required in that plane.
6. Usually, a large number of test runs are required to determine the exact balance masses in this type of machine. However, by adopting the following procedure, the balance masses can be obtained by making only four test runs :

First make a test run without attaching any trial mass and note down the amplitude of the cradle vibrations. Then attach a trial mass  $m$  at some angular position and note down the amplitude of the cradle vibrations by moving the rotor at the same speed. Next detach the trial mass and again attach it at  $90^\circ$  angular position relative to the first position at the same radial distance. Note down the amplitude by rotating the rotor at the same speed. Take the last reading in the same manner by fixing the trial mass  $180^\circ$ . Let the four reading be

**OBSERVATION :-**

S.No.	Trial Mass	Amplitude
1.	0	$X_1$
2.	$m$ at $0^\circ$	$X_2$
3.	$m$ at $90^\circ$	$X_3$
4.	$m$ at $180^\circ$	$X_4$

**CALCULATION & CONSTRUCTION :-**

Draw a triangle OBE by taking  $OE = 2 X_1$ ,  $OB = X_2$  and  $BE = X_4$ . Mark the mid-point A on OE. Join AB.

Now,  **$OB = OA + AB$**

Where,  $OB =$  Effect of unbalance mass + Effect of the trial mass at  $0^\circ$

$OA =$  Effect of unbalanced mass

Thus, AB represents the effect of the attached mass at  $0^\circ$ . The proof is as follows:

Extend BA to D such that  $AD = AB$ . Join OD and DE. Now when the mass  $m$  is attached at  $180^\circ$  at the same radial distance and speed, the effect must be equal and opposite to the effect at  $0^\circ$  i.e. if AB represents the effect of the attached mass at  $0^\circ$ , AD represents the effect of the attached mass at  $180^\circ$ .

Since,  **$OD = OA + AD$**

OD must represent the combined effect of unbalance mass and the effect of the trial mass at  $180^\circ$  ( $X_4$ ).

Now, as the diagonals of the quadrilateral OBED bisect each other at A, it is a parallelogram which means BE is parallel and equal to OD. Thus, BE also represents the combined effect of

unbalance mass and the effect of the trial mass at  $180^\circ$  or  $X_4$  which is true as it is made in the construction.

Now as OA represents the unbalance, the correction has to be equal and opposite of it or AO. Thus, the correction mass is given by

$$m_c = m.OA/AB \text{ at an angle } \theta \text{ from the second reading at } 0^\circ.$$

For the correction of the unbalance, the mass  $m_c$  has to be put in the proper direction relative to AB which may be found by considering the reading  $X_3$ .

Draw a circle with A as centre and AB as the radius. As the trial mass as well as the speed of the test run at  $90^\circ$  is the same, the magnitude must equal to AB or AD and AC or AC' must represent the effect of the trial mass. If OC represents  $X_3$ , then angle is opposite to the direction of angle measurement. If OC' represents  $X_3$ , then angle measurement is in taken in the same direction.

**PRECAUTIONS :-**

1. Measure the amplitude carefully.
2. Draw the triangle and parallelogram in correct scale.
3. Vector diagram should be represent with suitable scale.

**VIVA-QUESTIONS :-**

- Why is balancing of rotating parts necessary for high speed engines ?
- Explain the terms 'static balancing' and 'dynamic balancing'. State the necessary conditions to achieve them.
- Discuss how a single revolving mass is balanced by two masses revolving in different planes.
- How the different masses rotating in different planes are balanced ?
- Explain the method of balancing of different masses revolving in the same plane.

## EXPERIMENT No.- 8

**AIM :-**Determine the moment of inertial of connecting rod by compound pendulum method and tri-filar suspension pendulum.

**APPARATUS USED:-** Compound Pendulum and tri-filar suspension system setup.

### **THEORY :-**

**Compound Pendulum :-** When a rigid body is suspended vertically, and it oscillates with a small amplitude under the action of the force of gravity, the body is known as compound pendulum.

**Trifilar Suspension (Torsional Pendulum) :-** It is also used to find the moment of inertia of a body experimentally. The body (say a disc or flywheel) whose moment of inertia is to be determined is suspended by three long flexible wires A, B and C, as shown in fig.-b. When the body is twisted about its axis through a small angle  $\theta$  and then released, it will oscillate with simple harmonic motion.

### **PROCEDURE :-**

#### **For compound pendulum :**

- Measure the mass of the body.
- Lift the pendulum from the mean position till for suitable height (h).
- Release the pendulum and note down the number of oscillations and time period taken to complete the number of oscillation.
- Repeat the above steps for more readings.

#### **For tri-filar suspension :**

- Measure the mass of the disc and connecting rod.
- Lift the connecting rod from the mean position till for suitable height (h).
- Release the connecting rod and note down the number of oscillations and time period taken to complete the number of oscillation.
- Repeat the above steps for more readings.

### **OBSERVATION :-**

#### **For compound pendulum :**

- Mass of the body (m) = -----kg.
- Distance of point of suspension 'O' from the C.G. of the body (h) = -----metres.
- Frequency of oscillation (n) = -----Hz.

S.No.	Number of oscillations	Time period taken

**For tri-filar suspension :**

- Mass of the body (m) = -----kg.
- Distance of each wire from the axis of the disc (r) = -----metres.
- Length of each wire (l) = -----metres.

S.No.	Number of oscillations	Time period taken

**CALCULATION :-**

**For compound pendulum :**

- Frequency of oscillation,  $n = 1/t_p = \frac{1}{2\pi} \times \sqrt{g.h / k_G + h^2}$
- $I = m.(k_G)^2$  in kg.-m<sup>2</sup>
- 

**For tri-filar suspension :**

- Frequency of oscillation,  $n = 1/t_p = \frac{r}{2\pi k_G} \times \sqrt{g./ l}$
- $I = m.(k_G)^2$  in kg.-m<sup>2</sup>

**VIVA-QUESTIONS :-**

- Explain the meaning of S.H.M. and give an example of S.H.M.
- Define the terms amplitude, periodic time and frequency as applied to S.H.M.
- What is a simple pendulum ? under what conditions its motion is regarded as simple harmonic.
- What do you understand by centre of percussion ?
- What is a torsional pendulum ?

## EXPERIMENT No.- 9

**AIM :- To study Dynamically Equivalent System.**

**APPARATUS USED:-** Models of different rigid masses.

**THEORY :-** In order to determine the motion of a rigid body, under the action of external forces, it is usually convenient to replace the rigid body by two masses placed at a fixed distance apart, in such a way that,

1. the sum of their masses is equal to the total mass of the body;
2. the centre of gravity of the two masses coincides with that of the body; and
3. the sum of mass moment of inertia of the masses about their centre of gravity is equal to the mass moment of inertia of the body.

When these three conditions are satisfied, then it is said to be an equivalent dynamical system. Consider a rigid body, having its centre of gravity at G,

Let,  $m$  = Mass of the body,

$K_G$  = Radius of gyration about its centre of gravity G.

$m_1$  and  $m_2$  = Two masses which form a dynamical equivalent system,

$l_1$  = Distance of mass  $m_1$  from G

$l_2$  = Distance of mass  $m_2$  from G

$L$  = Total distance between the masses  $m_1$  and  $m_2$

Thus for the two masses to be dynamically equivalent,

$$m_1 + m_2 = m \text{ ----- (i)}$$

$$m_1 l_1 = m_2 l_2 \text{ -----(ii)}$$

and  $m_1 (l_1)^2 = m_2 (l_2)^2 = m (k_G)^2 \text{ -----(iii)}$

From equations (i) and (ii),

$$m_1 = l_2 m / l_1 + l_2 \text{ -----(iv)}$$

$$\text{and } m_2 = l_1 m / l_1 + l_2 \text{-----(v)}$$

Substituting the value of  $m_1$  and  $m_2$  in equation (iii), we have

$$l_1.l_2 = (k_G)^2 \text{-----(vi)}$$

This equation gives the essential condition of placing the two masses, so that the system becomes dynamical equivalent. The distance of one of the masses (i.e. either  $l_1$  or  $l_2$ ) is arbitrary chosen and the other distance is obtained from equation (vi).

When the radius of gyration  $k_G$  is not known, then the position of the second mass may be obtained by considering the body as a compound pendulum. We have already discussed, that the length of the simple pendulum which gives the same frequency as the rigid body (i.e. compound pendulum) is

$$L = [(k_G)^2 + h^2] / h = [(k_G)^2 + l_1^2] / l_1$$

We also know that,  $l_1.l_2 = (k_G)^2$

Therefore  $L = [l_1.l_2 + l_1^2] / l_1 = l_1 + l_2$

This means that the second mass is situated at the centre of oscillation or percussion of the body which is at a distance of  $l_2 = (k_G)^2 / l_1$

#### **APPLICATIONS :-**

- In Connecting rod of engine.
- In Crank shaft.
- In slider crank mechanism.
- In steam engine.

#### **VIVA – QUESTIONS :-**

- Define the ‘inertia force’ and ‘inertia torque’.
- What are the requirements of an equivalent dynamical system ?
- Given acceleration image of a link. Explain how dynamical equivalent system can be used to determine the direction of inertia force on it
- How are velocity and acceleration of the slider of a single slider crank chain determined analytically ?

## **EXPERIMENT NO - 10**

**AIM:** - To study the various types of dynamometers.

**APPARATUS:** - Models of dynamometer.

**THEORY:-** The dynamometer is a device used to measure the torque being exerted along a rotating shaft so as to determine the shaft power.

Dynamometers are generally classified into:

- 1) Absorption dynamometers (i.e. Prony brakes, hydraulic or fluid friction brakes, fan brake and eddy current dynamometers)
- 2) Transmission dynamometers (i.e. Torsion and belt dynamometers, and strain gauge dynamometer)
- 3) Driving dynamometers (i.e. Electric cradled dynamometer)

**PRONY BRAKE:** - The prony and the rope brakes are the two types of mechanical brakes chiefly employed for power measurement. The prony brake has two common arrangements in the block type and the band type. Block type is employed to high speed shaft and band type measures the power of low speed shaft.

**BLOCK TYPE PRONY BRAKE DYNAMOMETER:** - The block type prony brake consists of two blocks of wood of which embraces rather less than one half of the pulley rim. One block carries a lever arm to the end of which a pull can be applied by means of a dead weight or spring balance. A second arm projects from the block in the opposite direction and carries a counter weight to balance the brake when unloaded. When operating, friction between the blocks and the pulley tends to rotate the blocks in the direction of the rotation of the shaft. This tendency is prevented by adding weights at the extremity of the lever arm so that it remains horizontal in a position of equilibrium.

Torque,  $T = W \cdot l$  in Nm

$$\text{Power } P = 2\pi N * T/60 \text{ in N-m/s}$$

$$= 2\pi N * W * l / 60 * 1000 \text{ in kW}$$

Where, W= weights in Newton

l = Effective length of the lever arm in meter and

N = Revolutions of the crankshaft per minute.

**BAND TYPE PRONY BRAKE DYNAMOMETER:** - The band type prony brake consists of an adjustable steel band to which are fastened wooden block which are in contact with the engine brake-drum. The frictional grip between the band the brake drum can be adjusted by tightening or loosening the clamp. The torque is transmitted to the knife edge through the torque arm. The knife edge rests on a platform or communicates with a spring balance.

**Frictional torque at the drum = F\*r**

**Balancing torque = W\*l**

**Under equilibrium conditions, T = F\*r = W\*l in Nm.**

$$\text{Power} = 2\pi N * T/60 \text{ in N-m/s}$$

$$= 2\pi N * W * l / 60 * 1000 \text{ in kW}$$

**ROPE BRAKE DYNAMOMETERS:** - A rope brake dynamometers consists of one or more ropes wrapped around the fly wheel of an engine whose power is to be measured. The ropes are spaced evenly across the width of the rim by flywheel. The upward ends of the rope are connected together and attached to a spring balance, and the downward ends are kept in place by a dead weight. The rotation of flywheel produces frictional force and the rope tightens. Consequently a force is induced in the spring balance.

Effective radius of the brake  $R = (D + d)/2$

Brake load or net load = (W-S) in Newton

Braking torque  $T = (W-S) R$  in Nm.

$$\text{Braking torque} = 2\pi N * T/60 \text{ in N-m/s}$$

$$= 2\pi N * (W-S)R/60 * 1000 \text{ in kW}$$

D= dia. Of drum

d = rope dia.

S = spring balance reading

**FLUID FRICTION (HYDRAULIC DYNAMOMETER):-** A hydraulic dynamometer uses fluid-friction rather than friction for dissipating the input energy. The unit consists essentially of two elements namely a rotating disk and a stationary casing. The rotating disk is keyed to the driving shaft of the prime-mover and it revolves inside the stationary casing. When the brake is operating, the water follows a helical path in the chamber. Vortices and eddy-currents are set-up in the water and these tend to turn the dynamometer casing in the direction of rotation of the engine shaft. This tendency is resisted by the brake arm and balance system that measure the torque.

$$\text{Brake power} = W \cdot N / k,$$

Where W is weight as lever arm, N is speed in revolutions per minute and k is dynamometer constant.

Approximate speed limit = 10,000rpm

Usual power limit = 20,000kW

**BEVIS GIBSON FLASH LIGHT TORSION DYNAMOMETER:** - This torsion dynamometer is based on the fact that for a given shaft, the torque transmitted is directly proportional to the angle of twist. This twist is measured and the corresponding torque estimated the relation:

$$T = I_p \cdot C \cdot \theta / l$$

Where  $I_p = \pi d^4 / 32$  = polar moment of inertia of a shaft of diameter d

$\theta$  = twist in radians over length l of the shaft

C = modulus of rigidity of shaft material

#### **APPLICATIONS:-**

- i) For torque measurement.
- ii) For power measurement.

#### **VIVA-QUESTIONS:-**

- (i)
- (ii)
- (iii)