



LABORATORY MANUAL
DYNAMICS OF MACHINE LAB

Sr. No	Experiment Title
1	To Perform Experiment On Watt And Porter Governors To Prepare Performance Characteristic Curves, And To Find Stability & Sensitivity
2	To Perform Experiment On Proell Governor To Prepare Performance Characteristic Curves, And To Find Stability & Sensitivity.
3	To Perform Experiment On Hartnell Governor To Prepare Performance Characteristic Curves, And To Find Stability & Sensitivity.
4	To study gyroscopic effects through models.
5	To determine gyroscopic couple on Motorized Gyroscope.
6	To perform the experiment of Balancing of rotating parts and find the unbalanced couple and forces.
7	To study Dynamically Equivalent System.
8	Determine the moment of inertial of connecting rod by compound pendulum method and trifilar suspension pendulum.
9	To study the various types of dynamometers.
10	To study various types of gear- Helical, cross helical, worm, bevel gear.

EXPERIMENT No. 1

AIM:-To Perform Experiment On Watt And Porter Governors To Prepare Performance Characteristic Curves, And To Find Stability & Sensitivity.

APPARATUS USED:- Universal Governor Apparatus & Tachometer.

INTRODUCTION & THEORY :- The function of a governor is to regulate the mean speed of an engine, when there are variations in loads e.g. when load on an engine increase or decrease, obviously its speed will, respectively decrease or increase to the extent of variation of load. This variation of speed has to be controlled by the governor, within small limits of mean speed. This necessitates that when the load increase and consequently the speed decreases, the supply of fuel to the engine has to be increased accordingly to compensate for the loss of the speed, so as to bring back the speed to the mean speed. Conversely, when the load decreases and speed increases, the supply of fuel has to be reduced.

The function of the governor is to maintain the speed of an engine within specific limit whenever there is a variation of load. The governor should have its mechanism working in such a way, that the supply of fuel is automatically regulated according to the load requirement for maintaining approximately a constant speed. This is achieved by the principle of centrifugal force. The centrifugal type governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force, known as the controlling force.

Governors are broadly classified as:

- a) Centrifugal Governors.
- b) Inertia Governors.

The centrifugal governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force, known as controlling force.

In Inertia governors the position of the balls are affected by the forces set by an angular acceleration or deceleration of the given spindle in addition to centrifugal forces on the balls.

DESCRIPTION:

The apparatus is designed to exhibit the characteristics of the spring-loaded governor and centrifugal governor. The experiments shall be performed on following centrifugal type governors:

1. Watt governor
2. Porter governor
3. Proell governor
4. Hartnell governor

WATT GOVERNOR

It is the simplest form of a centrifugal governor, which is known as Watt Governor. It is the original form of the governor used by Watt on early steam engines. It consists of two balls which are attached to the spindle with the helps of links or arms. 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 :

- The pivot P, may be on the spindle axis.
- The pivot P, may be offset from the spindle axis and the arms when produced intersect at O.
- 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 pre-determined level.

PROCEDURE:

Starting Procedure:

1. Assemble the governor to be tested.
2. Complete the electrical connections.
3. Switch ON the main power.
4. Note down the initial reading of pointer on the scale.
5. Switch On the rotary switch.
6. Slowly increase the speed of governor until the sleeve is lifted from its initial position by rotating Variac.
7. Let the governor be stabilized.
8. Increase the speed of governor in steps to get the different positions of sleeve lift at different RPM.
9. Increase the speed of governor in steps to get the different positions of sleeve lift at different RPM.

Closing Procedure:

1. Decrease the speed of governor gradually by bringing the Variac to zero position and then switch off the motor.
2. Switch OFF all switches.
3. Disconnect all the connections.
4. Draw the graph for governor as stated further in manual.
5. Repeat the experiment for different type of governor.

PRECAUTIONS :-

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

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 (α) = -----
- Angle of inclination of the link to the vertical (β)
=-----

OBSERVATION TABLE:

Initial reading of pointer on scale, X' = mm

Selected ball weight, w = kg

S. No.	Sleeve displacement, X' mm	Speed, N _{act} RPM

Plot the graph for following curves: -

1. Sleeve (X) vs. N_{tho}
2. Sleeve (X) vs N_{act}.

CALCULATION :-

- $N^2 = 895/h$ (For watt governor)
- $N^2 = \frac{m + M(1+q)/2}{m} \times 895/h$ (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.

RESULT :-

- Sensitiveness of the governor is = -----

EXPERIMENT No. 2

AIM :-To Perform Experiment On Proell Governor To Prepare Performance Characteristic Curves, And To Find Stability & Sensitivity.

APPARATUS USED:- Universal Governor Apparatus & Tachometer.

INTRODUCTION & THEORY :- The function of a governor is to regulate the mean speed of an engine, when there are variations in loads e.g. when load on an engine increase or decrease, obviously its speed will, respectively decrease or increase to the extent of variation of load. This variation of speed has to be controlled by the governor, within small limits of mean speed. This necessitates that when the load increase and consequently the speed decreases, the supply of fuel to the engine has to be increased accordingly to compensate for the loss of the speed, so as to bring back the speed to the mean speed. Conversely, when the load decreases and speed increases, the supply of fuel has to be reduced. The function of the governor is to maintain the speed of an engine within specific limit whenever there is a variation of load. The governor should have its mechanism working in such a way, that the supply of fuel is automatically regulated according to the load requirement for maintaining approximately a constant speed. This is achieved by the principle of centrifugal force. The centrifugal type governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force, known as the controlling force.

Governors are broadly classified as:

- a) Centrifugal Governors.
- b) Inertia Governors.

The centrifugal governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force, known as controlling force.

In Inertia governors the position of the balls are affected by the forces set by an angular acceleration or deceleration of the given spindle in addition to centrifugal forces on the balls.

Proell Governor :- Proell governor is similar to the porter governor having a heavy central load at sleeve. But it differs from porter governor in the arrangement of balls. The balls are carried on the extension of the lower arms instead of at the junction of upper and lower arms.

The center sleeve of the Porter and Proell governors incorporates a weight sleeve to which weights can be added. The Hartnell governor consists of a frame, spring and bell crank lever. The spring tension can be increased or decreased to study the governor.

PROCEDURE:

Starting Procedure:

1. Assemble the governor to be tested.
2. Complete the electrical connections.
3. Switch ON the main power.
4. Note down the initial reading of pointer on the scale.
5. Switch On the rotary switch.
6. Slowly increase the speed of governor until the sleeve is lifted from its initial position by rotating Variac.
7. Let the governor be stabilized.
8. Increase the speed of governor in steps to get the different positions of sleeve lift at different RPM.
9. Increase the speed of governor in steps to get the different positions of sleeve lift at different RPM.

Closing Procedure:

1. Decrease the speed of governor gradually by bringing the Variac to zero position and then switch off the motor.
2. Switch OFF all switches.
3. Disconnect all the connections.
4. Draw the graph for governor as stated further in manual.
5. Repeat the experiment for different type of governor.

PRECAUTIONS :-

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

OBSERVATION :-

- Mass of the ball (m) = -----kg.
- Weight of the ball (w)=-----Newtons
- Height of the governor (h) = ----- metres
- Minimum equilibrium speed (N₁) = ----- r.p.m.
- Minimum equilibrium speed (N₂) = ----- r.p.m.
- Frictional force (F) = ----- Newtons
- Mean equilibrium speed (N) = (N₁ + N₂)/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 (α) = -----
- Angle of inclination of the link to the vertical (β) = -----

OBSERVATION TABLE:

Initial reading of pointer on scale, X' = mm

Selected ball weight, w = kg

S. No.	Sleeve displacement, X' mm	Speed, N _{act} RPM

Plot the graph for following curves: -

1. Sleeve (X) vs. N_{tho}
2. Sleeve (X) vs N_{act}.

CALCULATION :-

$$N^2 = \frac{FM}{BM} \times \left[\frac{m}{m} + \frac{M(1+q)}{2} \right] \times \frac{895}{h} \text{ (For porter governor) where, } q = \tan \beta / \tan \alpha$$

- 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.

RESULT :-

- Sensitiveness of the governor is = -----

EXPERIMENT No. 3

AIM:-To Perform Experiment On Hartnell Governor To Prepare Performance Characteristic Curves, And To Find Stability & Sensitivity.

APPARATUS USED:- Universal Governor Apparatus & Tachometer.

INTRODUCTION & THEORY :- The function of a governor is to regulate the mean speed of an engine, when there are variations in loads e.g. when load on an engine increase or decrease, obviously its speed will, respectively decrease or increase to the extent of variation of load. This variation of speed has to be controlled by the governor, within small limits of mean speed. This necessitates that when the load increase and consequently the speed decreases, the supply of fuel to the engine has to be increased accordingly to compensate for the loss of the speed, so as to bring back the speed to the mean speed. Conversely, when the load decreases and speed increases, the supply of fuel has to be reduced.

The function of the governor is to maintain the speed of an engine within specific limit whenever there is a variation of load. The governor should have its mechanism working in such a way, that the supply of fuel is automatically regulated according to the load requirement for maintaining approximately a constant speed. This is achieved by the principle of centrifugal force. The centrifugal type governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force, known as the controlling force.

Governors are broadly classified as:

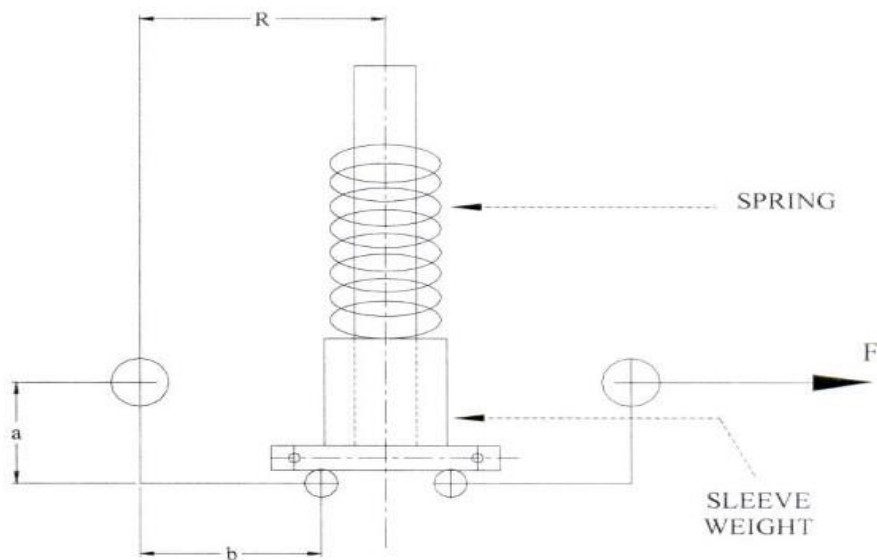
- a) Centrifugal Governors.
- b) Inertia Governors.

The centrifugal governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force, known as controlling force.

In Inertia governors the position of the balls are affected by the forces set by an angular acceleration or deceleration of the given spindle in addition to centrifugal forces on the balls.

HARTNELL GOVERNOR

Hartnell governor is spring controlled governor. Two bell crank levers, each carrying a ball at on one end and a roller on the other end. The roller fit into a groove in the sleeve. The frame is attached to the governor spindle and hence rotates with it. A helical spring in compression provides equal downward forces on the two rollers through a collar on the sleeve.



PROCEDURE:

Starting Procedure:

1. Assemble the governor to be tested.
2. Complete the electrical connections.
3. Switch ON the main power.
4. Note down the initial reading of pointer on the scale.
5. Switch On the rotary switch.
6. Slowly increase the speed of governor until the sleeve is lifted from its initial position by rotating Variac.
7. Let the governor be stabilized.
8. Increase the speed of governor in steps to get the different positions of sleeve lift at different RPM.
9. Increase the speed of governor in steps to get the different positions of sleeve lift at different RPM.

Closing Procedure:

1. Decrease the speed of governor gradually by bringing the Variac to zero position and then switch off the motor.
2. Switch OFF all switches.
3. Disconnect all the connections.
4. Draw the graph for governor as stated further in manual.
5. Repeat the experiment for different type of governor.

PRECAUTIONS :-

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

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 (ω_1) = -----rad./s
- Angular speed of the governor at maximum radius (ω_2) = -----rad./s
- Spring force exerted on the sleeve at ω_1 (S_1) = ----- Nt.
- Spring force exerted on the sleeve at ω_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_1) = ----- r.p.m.
- Minimum equilibrium speed (N_2) = ----- 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) = -----

OBSERVATION TABLE:

Initial reading of pointer on scale, X' = mm

Selected ball weight, w = kg

S. No.	Sleeve displacement, X'' mm	Speed, N _{act} RPM

Plot the graph for following curves: -

1. Sleeve (X) vs. N_{tho}
2. Sleeve (X) vs N_{act}.

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.

RESULT :-

EXPERIMENT No. 4

AIM :- To Study Gyroscopic Effects Through Models.

APPARATUS USED:- Models of Aeroplane 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 gyroscopic. 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 :-

- 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.
- 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.
- When the aeroplane takes a right turn under similar conditions as mentioned in note above, the effect of reactive gyroscopic couple will be to raise the nose and dip the tail of the aeroplane.
- 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.
- When the aeroplane takes a right turn under similar conditions as mentioned in note 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 :-

- 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.
- 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.
- When the ship is steering to the right under similar conditions as discussed in note above, then the effect of reactive gyroscopic couple will be to raise the bow and lower the stern.
- 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.
- 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.
- 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 :-

- 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.
- The pitching of a ship produces forces on the bearings which act horizontally and perpendicular to the motion of the ship.
- The maximum gyroscopic couple tends to shear the holding-down bolts.
- 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.

EXPERIMENT No. 5

AIM :- To determine gyroscopic couple on Motorized Gyroscope.

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 ($I\omega\omega_p$). When the axis of spin itself moves with angular velocity ω_p , the disc is subjected to reactive couple whose magnitude is same (i.e. $I\omega\omega_p$) but opposite in direction to that of active couple.

APPARATUS USED:- Motorized Gyroscope Apparatus, weights, tachometer.

EXPERIMENTAL SET UP: The set up consists of heavy disc mounted on a horizontal shaft, rotated by a variable speed motor. The rotor shaft is coupled to a motor mounted on a trunion frame having bearing in a yoke frame, which is free to rotate about vertical axis. A weight pan on other side of disc balances the weight of motor. Rotor disc can be move about three axis. Weight can be applied at a particular distance from the center of rotor to calculate the applied torque. The Gyroscopic couple can be determined with the help of moment of inertia, angular speed of disc and angular speed of precession.

RULE NO. 1

“The spinning body exerts a torque or couple in such a direction which tends to make the axis of spin coincides with that of precession”.

To study the rule of gyroscopic behavior, following procedure may be adopted:

Balance the initial horizontal position of the rotor. Start the motor by increasing the voltage with the autotransformer, and wait until it attains constant speed.

Presses the yoke frame about vertical axis by an applying necessary force by hand to the same (in the clockwise sense seen from above).

It will be observed that the rotor frame swings about the horizontal AXIS Y Y. Motor side is seen coming upward and the weight pan side going downward.

Rotate the vertical yoke axis in the anticlockwise direction seen from above and observe that the rotor frame swing in opposite sense (as compared to that in previous case following the above rule).

RULE NO. 2

“The spinning body precesses in such a way as to make the axis of spin coincide with that of the couple applied, through 90° turn axis”.

Balance the rotor position on the horizontal frame. Start the motor by increasing the voltage with the autotransformer and wait until the disc attains constant speed.

Put weights in the weight pan, and start the stopwatch to note the time in seconds required for precession, through 90° or 180° etc.

The vertical yoke precesses about OZ axis as per the rule No. 2.

PROCEDURE:

1. Set the rotor at zero position.
2. Start the motor with the help of rotary switch.
3. Increase the speed of rotor with dimmer state & stable it & measure the rpm with the help of tachometer (optional).
4. Put the weight on weight pan than yoke rotate at anticlockwise direction.
5. Measure the rotating angle (30° , 40°) with the help of stopwatch.
6. Repeat the experiment for the various speeds and loads.
7. After the test is over set dimmer to zero position and switch off main supply.

FORMULAE:

$$T_{\text{theo}} = I\omega \omega_p$$

$$I = W r^2 / 4g \text{ Kgm sec}^2$$

$$\omega = 2 \pi N / 60 \text{ rad/sec}$$

$$\omega_p = d\theta \times \pi / 180 \text{ dt rad/sec}$$

$$T_{\text{act}} = wL$$

PRECAUTIONS

1. Before start the motor dimmer state at zero position
2. Increase the speed gradually.
3. Do not run the motor at low voltage i.e. less than 180 volts.

OBSERVATION & CALCULATION:

DATA:

Density of Rotor = 7817 Kg/m³
Rotor Diameter = 300 mm = 0.3m
Rotor Thickness = 10 mm = 0.001 m
Weight of disc = 5.42 kg
Weights = 0.500 kg, 1.0 kg, 2.0 kg

Distance of bolt of Weight pan from disc Center = 225 mm = 0.225 m

OBSERVATION TABLE:

S. No.	Speed (RPM)	Weight (Kg)	dθ (degree)	Dt (Sec)

CALCULATION:

S. No.	I Kg.-m.-sec ²	ω rad/sec	ω_p rad/sec	T _{act} (Kg.m)	T _{th} (Kg.m)

NOMENCLATURE:

- I = Mass Moment of inertia of disc, Kg.-m.-sec²
 ω = Angular velocity of disc
 W = Weight of rotor disc, in kg
 R = Radius of disc, in meter
 G = Acceleration due to gravity, in m/sec²
 N = RPM of disc spin
 ω_p = Angular velocity of precession of yoke about vertical axis.
 $d\theta$ = Angle of precession
 dt = Time required for this precessions.
 T = Gyroscopic couple, Kg. M
 W = Weight of pan
 L = Distance of weight

RESULT: Compared experimentally the gyroscopic couple on Motorized Gyroscope with applied couple.

Experiment No.-6

Aim: To perform the experiment of Balancing of rotating parts and find the unbalanced couple and forces.

THEORY:

Conditions for Static and Dynamic Balancing:

If a shaft carries a number of unbalanced masses such that center of mass of the system lies on the axis of rotation, the system is said to statically balance. The resultant couple due to all the inertia forces during rotation must be zero. These two conditions together will give complete dynamic balancing. It is obvious that a dynamically -balanced system is also statically balanced, but the statically balanced system is not dynamically balanced.

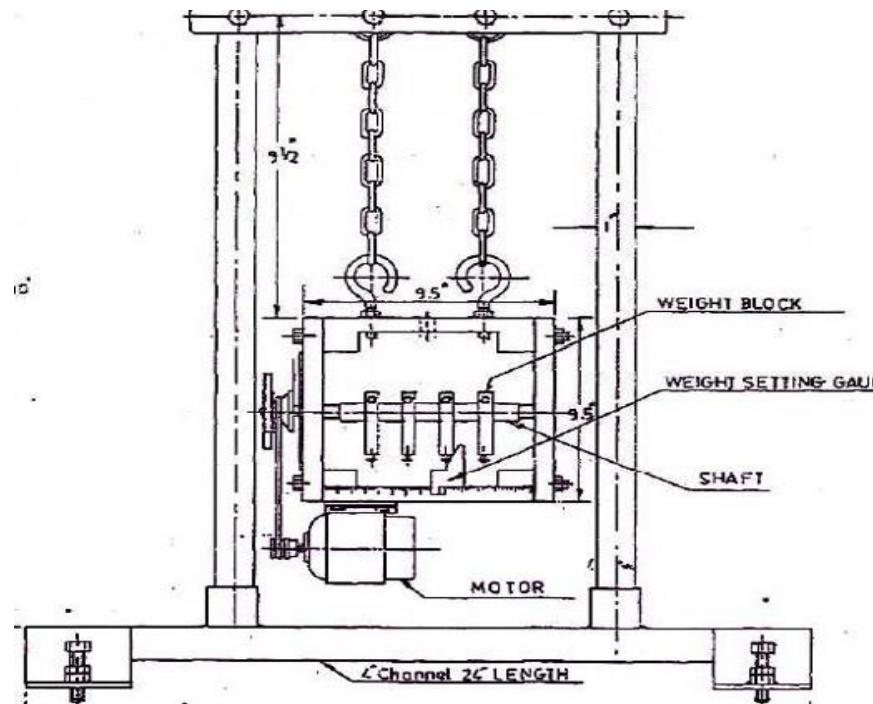


Figure: Dynamic balancing apparatus

Balancing of Several Masses Rotating in Different Planes:

When several masses revolve in different planes, they may be transferred to a reference plane (written as RP), which may be defined as the plane passing through a point on the axis of rotation and perpendicular to it. The effect of transferring a revolving mass (in one plane) to a reference plane is to cause a force of magnitude equal to centrifugal force of the revolving mass to act in the reference plane, together with a couple of magnitude equal to the product of the force and the distance between the plane of rotation and the reference plane. In order to have a complete balance of the several revolving masses in different planes, the following conditions must be satisfied:

1. The forces in the reference plane must balance i.e. the resultant force must be zero.
2. The couple about the reference plane must balance, i.e. the resultant couple must be zero.

Let us now consider four masses m_1 , m_2 , m_3 and m_4 revolving in plane 1, 2, 3 and 4 shown in fig. The relative angular position and position of the balancing mass m_1 in plane may be obtained as discussed below:

1. Take one of the plane, say 1 as the reference plane (R.P). The distance of all the other planes to the left of the reference plane may be regarded as negative, and those to the right as positive.
2. Tabulate the data as in table. The planes are tabulated in the same order i.e. 1, 2,

Plane	Weight No.	Mass (m)	Radius r	Angle (θ)	Mass moment Mr	Distance from plane 1 (L)	Couple mrL

1. The position of plane 4 from plane 2 may be obtained by drawing the couple polygon with the help of data given in column no. 8.
2. The magnitude and angular position of mass m_1 may be determined by drawing the force polygon from the given data of column no.5 & column no.6 to some suitable scale. Since the masses are to be completely balanced, therefore the force polygon must be closed figure. The closing side of force polygon is proportional to the m_1r_1 .

The angular position of mass m_1 must be equal to the angle in anticlockwise measured from the R.P. to the line drawn in the fig. Parallel to the closing side of the polygon.

Description

The apparatus consists of a steel shaft mounted in ball bearings in a stiff rectangular main frame. A set of four blocks of different weights is provided and may be detached from the shaft.

A disc carrying a circular protractor scale is fitted to one side of the rectangular frame. A scale is provided with the apparatus to adjust the longitudinal distance of the blocks on the shaft. The circular protractor scale is provided to determine the exact angular position of each adjustable block.

The shaft is driven by 230 volts, single phase, 50 cycles electric motor mounted under the main frame, through a belt.

For static balancing of weights the main frame is suspended to support frame by chains then rotate the shaft manually after fixing the blocks at their proper angles. It should be completely balanced. In this position, the motor driving belt is removed. For dynamic balancing of the rotating mass system the main frame is suspended from the support frame by two short links such that the main frame and supporting frame are in the same plane. Rotate the statically balanced weights with the help of motor. If they rotate smoothly and without vibrations, they are dynamically balanced.

PROCEDURE:

1. Insert all the weights in sequence 1-2-3-4 from pulley side.
2. Fix the pointer and pulley on shaft.
3. Fix the pointer on 0° (θ_2) on the circular protractor scale.
4. Fix the weight no.1 in horizontal position.
5. Rotate the shaft after loosening previous position of pointer and fix it on θ_3 .
6. Fix the weight no. 2 in horizontal position.
7. Loose the pointer and rotate the shaft to fix pointer on θ_4 .
8. Fix the weight no.3 in horizontal position.
9. Loose the pointer and rotate the shaft to fix pointer on θ_1 .

RESULT:

Statically and dynamically balanced the rotating parts.

VIVA-VOCE

1. Why balancing is necessary for high speed engine
2. What is difference between Static & Dynamic Balancing?
3. What are effects of partial balancing in locomotives?
4. What are the practical applications of balancing?
5. Secondary balancing force is given by relation

EXPERIMENT No. 7

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),

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

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 arbitrarily 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

$$L = [(k_G)^2 + h^2] / h = [(k_G)^2 + l_{12}] / l$$

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

Therefore $L = [l_1 \cdot l_2 + l_{12}] / l_1 = l_1 + l_2$

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. 8

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

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 θ and then released, it will oscillate with simple harmonic motion.

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

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, $n = 1/ t_p$

$$t_p = \frac{1}{2\pi} \sqrt{\frac{gh}{K_G + h^2}}$$

- $I = m.(k_G)^2$ in kg.-m²

For tri-filar suspension :

- Frequency of oscillation, $n = 1/ t_p$

$$t_p = \frac{1}{2\pi} \sqrt{\frac{gh}{K_G + h^2}}$$

- $I = m.(k_G)^2$ in kg.-m²

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 the various types of dynamometers.

APPARATUS USED : - 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

Power $P = 2\pi N \cdot T/60$ in N-m/s

$= 2\pi N \cdot W \cdot l/60 \cdot 1000$ 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 = $F \cdot r$

Balancing torque = $W \cdot l$

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

Power = $2\pi N \cdot T/60$ in N-m/s

$= 2\pi N \cdot W \cdot l/60 \cdot 1000$ in kW

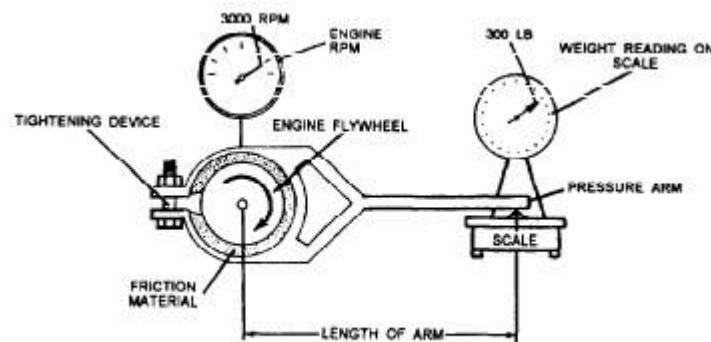


Figure: Prony brake dynamometer

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.

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

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

D = dia. Of drum

d = rope dia.

S = spring balance reading

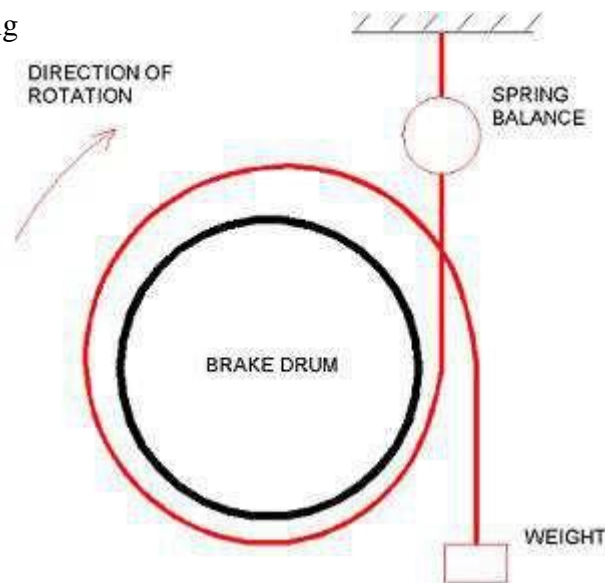


Figure: Rope brake dynamometer

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.

Brake power = $W * N/k$,

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:

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

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

1. How many types of method of shaft power measurement ?
2. How many types of mechanical brakes ?
3. Which type mechanical brake use for high speed and low speed shaft ?
4. What is mean by effective radius of the brake drum?
5. Which types of bearing is same as the friction torque transmitted by a disc or plate clutch?

Experiment No.-10

AIM: - To study various types of gear- Helical, cross helical, worm, bevel gear.

APPARATUS USED: - Arrangement of gear system.

THEORY:-

CLASSIFICATION OF GEAR: - Gears can be classified according to the relative position of their shaft axis are follows:

A: PARALLEL SHAFT

- (i) Spur gear
- (ii) Spur rack and pinion
- (iii) Helical gears or Helical spur gear
- (iv) Double- helical and Herringbone gear

B: INTER SECTING SHAFT

- (i) Straight bevel gear
- (ii) Spiral bevel gear
- (iii) Zerol bevel gear

C: SKEW SHAFT

- (i) Crossed- helical gear
- (ii) Worm gears(Non-throated, Single throated, Double throated)

SPUR GEAR:- They have straight teeth parallel to the axes and thus are not subjected to axial thrust due to teeth load. Spur gears are the most common type of gears. They have straight teeth, and are mounted on parallel shafts. Sometimes, many spur gears are used at once to create very large gear reductions. Each time a gear tooth engages a tooth on the other gear, the teeth collide, and this impact makes a noise. It also increases the stress on the gear teeth.

Spur gears are the most commonly used gear type. They are characterized by teeth, which are perpendicular to the face of the gear. Spur gears are most commonly available, and are generally the least expensive.



Figure: Spur gear

HELICAL GEARS:- In helical gears, the teeth are curved, each being helical in shape. Two mating gears have the same helix angle, but have teeth of opposite hands. At the beginning of engagement, contact occurs only at the point of leading edge of the curved teeth. As the gears rotate, the contact extends along a diagonal line across the teeth. Thus the load application is gradual which result in now impact stresses and reduction in noise. Therefore, the helical gears can be used at higher velocities then the spur gears and have greater load - carrying capacity. The teeth on helical gears are cut at an angle to the face of the gear. When two teeth on a helical gear system engage, the contact starts at one end of the tooth and gradually spreads as the gears rotate, until the two teeth are in full engagement. This gradual engagement makes helical gears operate much more smoothly and quietly than spur gears. For this reason, helical gears are used in almost all car transmission. Because of the angle of

the teeth on helical gears, they create a thrust load on the gear when they mesh. Devices that use helical gears have bearings that can support this thrust load.



Figure: Helical gear

DOUBLE HELICAL AND HERRING BONE GEARS :- A- double- helical gear is equivalent to a pair of helical gears secured together, one having a right - hand helix and the other a left hand helix. The tooth of two raw is separated by a grooved used for too run out. If the left and the right inclinations of a double - helical gear meet at a common apex and there is no groove in between, the gear is known as herring bone gear.

CROSSED - HELICAL GEAR :- The used of crossed helical gear or spiral gears is limited to light loads. By a suitable choice of helix angle for the mating gears, the two shaft can be set at any angle.

WORM GEAR :- Worm gear is a special case of spiral gear in which the larger wheel, usually, has a hollow or concave shape such that a portion of the pitch diameter is the other gear is enveloped on it. The smaller of two wheels is called the worm which also has larger spiral angle. **worm gear**: Worm gears are used when large gear reductions are needed. It is common for worm gears to have reductions of 20:1, and even up to 300:1 or greater.



Figure: Worm gear

BEVEL GEAR :- Kinematically, the motion between two intersecting shafts is equivalent to the rolling of two cones, assuming no slipping. The gears, in general, are known as bevel gear. When teeth formed on the cones are straight, the gear are known as straight bevel and when inclined, they are known as spiral or helical bevel.

Result:- Different types of gear have been studied.