ANNAMALAI UNIVERSITY

DEPARTMENT OF MECHANICAL ENGINEERING

Mechanical Engineering Laboratory

Instruction Manual cum Observation Note book

(Machine Dynamics Lab)

VI Semester B.E., Mechanical Engineering

2014-2015

Name : …………………………………………………….

Roll No: …………………………………………………….

Batch :……………………………………………………….

DEPARTMENT OF MECHANICAL ENGINEERING

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VI SEM .BE MECHANICAL 2014-2015.

MECHANICAL ENGINEERING LABORATORY - II

A. I C Engines Lab [VENUE: I C Engines Laboratory Main]

1. Study & Performance test on Kaeser air compressor test rig.
2. Load test on Batliboi Engine.
3. Heat balance test on Field Marshal 6 HP Engine.
4. Load test on Kirloskar AV I engine (Double arm type).
5. Load test on PSG 5 HP Engine.

B. DYNAMICS Lab

1. Determine the characteristic curves of

   Watt Governor

   Hartnell governor

2. (i) Study and experiments on static and dynamic balancing of rotating masses.

   (ii) Whirling of shaft - Determination of critical speed

3. (i) Study and experiments on Cam Analyzer.
   (ii) Experimental verification of natural frequency of un-damped

   Free vibration of equivalent spring mass system.

4. Determination of mass moment of Inertia of Fly wheel.
5. Determination of mass moment of Inertia of connecting rod with flywheel.

PROPERTIES OF FUEL

Calorific value of Diesel	: 42,000 kJ/kg.
Specific Gravity of Diesel	: 0.835
Density of water	: 1000 kg/m^3

Instructions to the students

1. Be regular and be punctual to classes

2. Come in proper uniform stipulated

3. Ensure safety to your body organs and laboratory equipment

   – SAFETY FIRST DUTY NEXT

4. Read in advance the contents of the instruction manual pertaining to the experiment due and come prepared. Understand the related basics principles.

5. Maintain separate observation and record note books for each laboratory portion of the course wherever justified.

6. Though you work in a batch to conduct experiment, equip yourself to do independently. This will benefit you at the time of mid semester tests and university examinations.

7. Independently do the calculations and sketching. If there is difficulty, consult your batch mate, classmate, teacher(s) and Laboratory in –Charge.

   Do not attempt to simply copy down from others. You may fulfill the formalities but you stand to loose learning and understanding

8. Obtain the signature of teacher (s) in the laboratory observation note book and record note book then and there during class hours (with in a week subsequent to experimentation).This will relieve the teacher (s) from giving reminder.

9. Help to maintain neatness in the laboratory.

10. Students are advised to retain the bonafide record notebook till they successfully complete the laboratory course

Sl No	Date	Name of the Experiment	Signature

Expt. No:

Date:

DETERMINE THE CHARACTERISTIC CURVES OF WATT GOVERNOR

Aim: To determine the characteristic curves, sensitiveness and range of speed of Watt governor.

Introduction:

The function of a governor is to maintain the mean speed of a machine/prime mover, by regulating the input to the machine/prime mover automatically, when the variation of speed occurs due to fluctuation in the load.

SPECIFICATIONS:

Length of each link '*l*' = 195 mm

Initial height of governor (h_0) = 125 mm

Mass of each ball (m) = 0.306 kg

Maximum speed of the governor (N_2) = 1100 rpm

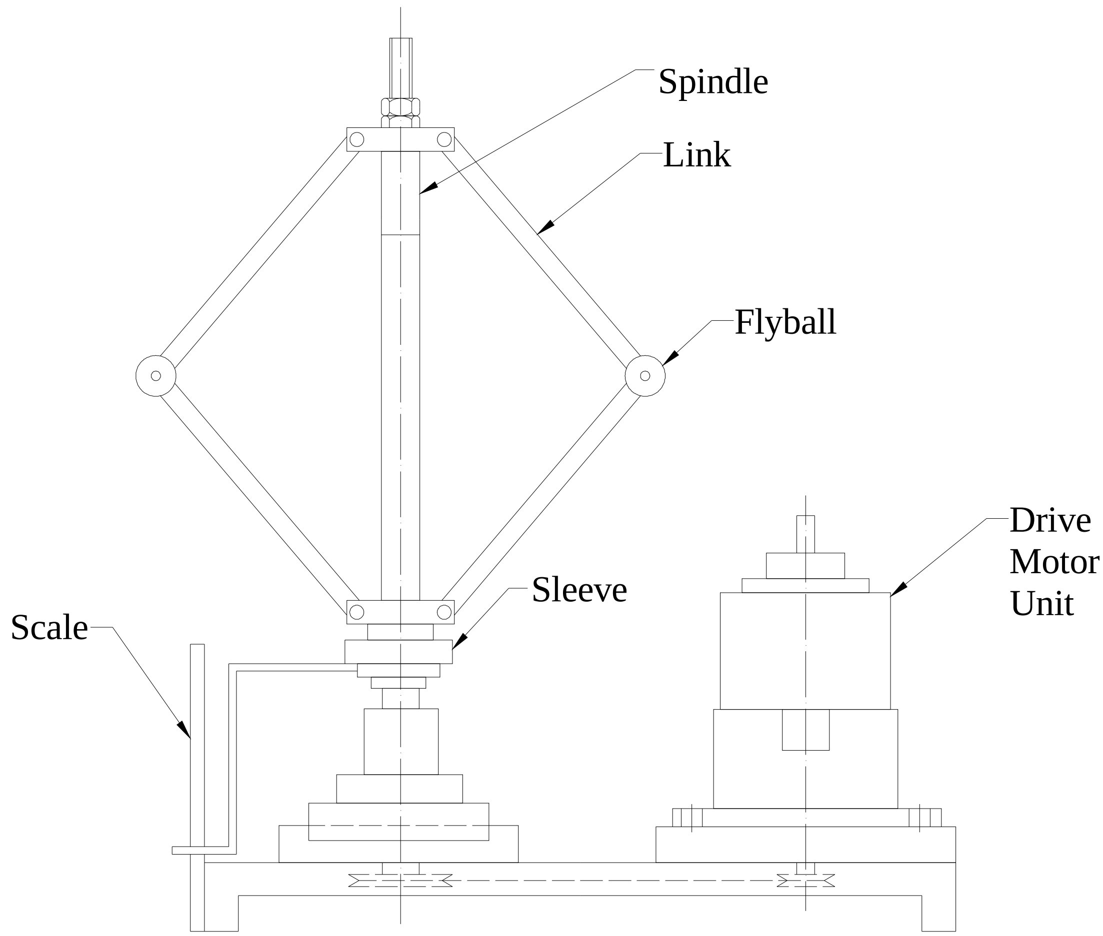
Description:

The drive unit consists of a small electric motor connected through the belt and pulley arrangement. A DC variac effects precise speed control and an extension of the spindle shaft allows the use of hand held tachometer to find the speed of the governor spindle. A graduated scale is fixed to the sleeve and guided in vertical direction.

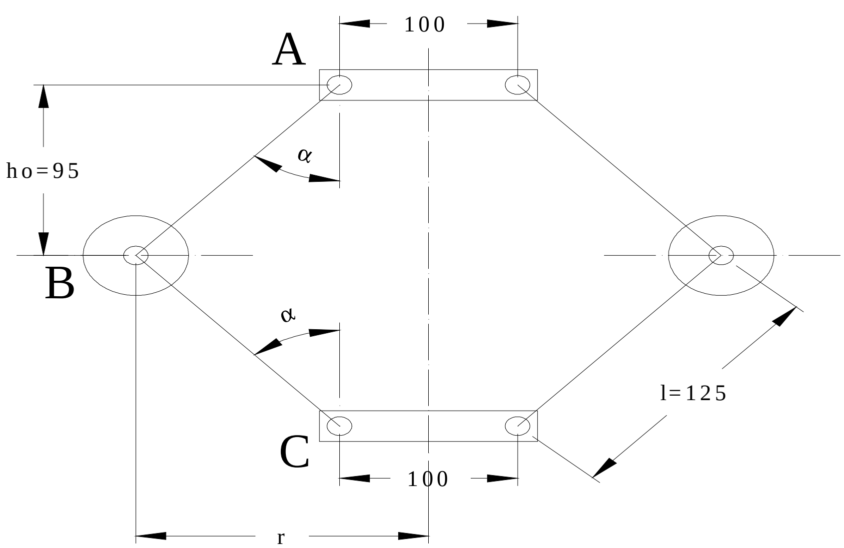
Procedure:

Mount the watt governor mechanism on the drive unit of the governor apparatus. Vary the governor spindle speed by adjusting the variac. The speed can be determined by the hand tachometer.

Increase the speed of the governor spindle gradually by adjusting the variac and note down the speed at which the sleeve just begins to move up. Take four or five sets of readings by increasing the governor speed in steps and note down the corresponding sleeve displacement within the range of the governor and tabulate the observations.



EXPERIMENTAL SETUP OF WATT GOVERNOR



All dimensions are in mm

WATT GOVERNOR CONFIGURATION

Observation Table:

Sl.No.	Speed in rpm N	Sleeve displacement (X) in	
		cm	Meter
1			
2			
3			
4			
5			

Calculation :

Let N_1 = Min equili. speed in Rpm (Corresponding to Initial displacement of the sleeve)

N_2 = Max equili. speed in Rpm (Corresponding to maximum displacement of the sleeve)

N = Mean equilibrium speed = $\frac{N_2+N_1}{2}$

Given max. equilibrium speed, N_2 = 1050 Rpm

$$Sensitiveness = \frac{N_2-N_1}{N}$$

Range of speed = N_2 - N_1

Specimen calculation: (for ___________reading)

Height of the governor, $h = [h_o - (x/2)]$

$=$

$=$ m

From the figure we can write

$$\cos\alpha = h / l$$

$$\therefore \quad \alpha \approx \cos^{-1}(h / l) \text{ in degree}$$

$=$ ....

The controlling force $F_c = m\,\omega^2 r$

Where m = mass of fly ball in kg =0.306kg.

ω = Angular velocity of the spindle in rad/sec

$= 2\pi N / 60$

$=$

ω = ... rad/sec

r = radius of rotation of the balls.

`r' $= l \sin\alpha + 50$ in mm

$=$

r = ... m

The controlling force $F_c = m\,\omega^2 r$

$F_C =$

$=$

F_C = ...N

Result tabulation:

Sl.No.	Speed in rpm N	Radius of rotation (r) in meter.	Controlling force F_C in N
1			
2			
3			
4			
5			

Graph: Draw Speed Vs Displacement

Radius Vs Controlling force

Result:

Expt. No:

Date:

DETERMINE THE CHARACTERISTIC CURVES OF HARTNELL GOVERNOR

Aim : To determine the characteristic curves, sensitiveness and range of speed of Hartnell Governor

Introduction:

This governor comes under the spring loaded type centrifugal governors. The control of the speed is affected either wholly or in part by means of springs. The centrifugal 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. It consists of two balls of equal mass, which are attached to the arms as shown in fig. These balls are known as governor balls or fly balls. The balls revolve with a spindle, which is driven by the engine through bevel gears. The upper ends of the arms are pivoted to the spindle, so that the balls may rise up or fall down as they revolve about the vertical axis. The arms are connected by the links to a sleeve, which is keyed to the spindle. This sleeve revolves with the spindle but can slide up & down. The balls and the sleeve rise when the spindle speed increases and falls when the speed decreases. The sleeve is connected by a bell crank lever to a throttle valve. The supply of the working fluid decreases when the sleeve rises and increases when it falls.

Description:

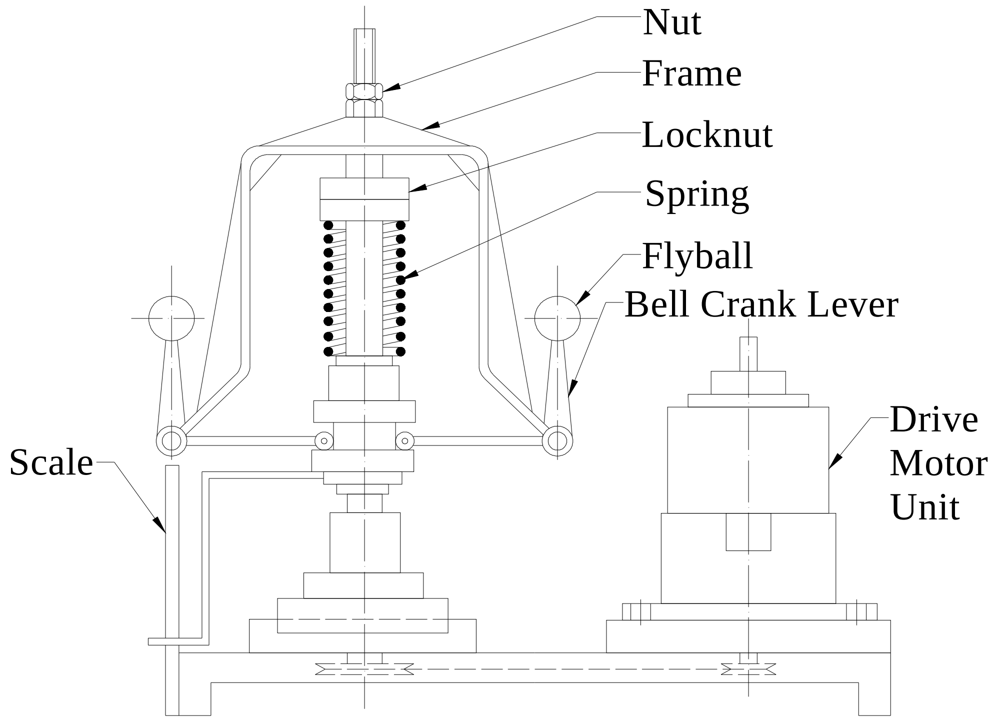
The drive unit of the governor consists of a small electric motor connected through a belt and pulley arrangement. A D.C. Variac effects precise speed control. A photoelectric pick up is used to find speed of the governor spindle. The set up is designed to produce pulses proportional to rpm of shaft using phototransistor as the sensing element. A graduated scale is fixed to the sleeve and guided in vertical direction.

Procedure:

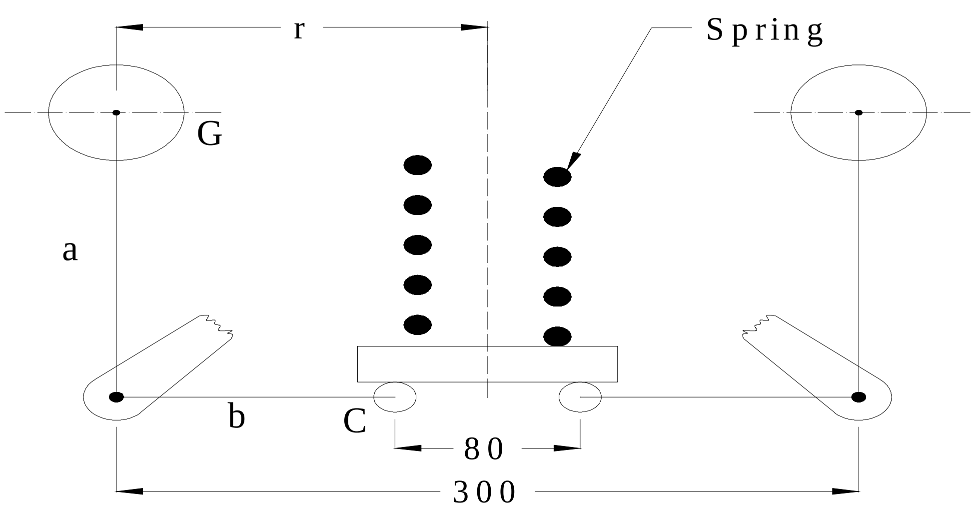
Mount the Hartnell governor mechanism on the drive unit of the governor apparatus. Vary the governor spindle speed by adjusting the variac. Increase the speed of the governor spindle gradually by adjusting the variac and note down the speed at which the sleeve just begins to move up. Take four or five sets of readings by increasing the governor speed gradually in steps and note down the corresponding sleeve movement within the range of the governor.

Specifications:

Mass of the fly ball	= 0.700 kg
Length of ball arm (a)	= 75 mm
Length of sleeve arm (b)	= 115.5 mm
Initial radius r_0	= 165 mm
Maximum speed of the governor (N_2)	= 1050 rpm



EXPERIMENTAL SETUP OF HARTNELL GOVERNOR



HARTNELL GOVERNOR CONFIGURATION

Observation table:

Sl.No.	Speed in rpm N	Sleeve displacement (x) in	
		cm	Meter
1			
2			
3			
4			
5			

Calculation :

Let N_1 = Min equili. speed in Rpm (Corresponding to Initial displacement of the sleeve)

N_2 = Max equili. speed in Rpm (Corresponding to maximum displacement of the sleeve)

N = Mean equilibrium speed = $\frac{N_2+N_1}{2}$

Given max. equilibrium speed, N_2 = 1050 Rpm

$$Sensitiveness = \frac{N_2 - N_1}{N}$$

Range of speed = $N_2 - N_1$

Specimen calculation:

The controlling force $F_c = m\,\omega^2\,r$

Where m = mass of fly ball in kg

ω = Angular velocity of spindle in rad/sec

= $2 \pi N / 60$

=

= .... rad/sec

Radius of rotation (r) = $r_o + (a / b) x$ in mm

=

= .... m

The controlling force $F_c = m \omega^2 r$

F_C =

F_C = ... N

Result Tabulation:

Sl. No.	Speed in rpm N	Radius of rotation (r) in meter.	Controlling force F_c in N
1			
2			
3			
4			
5			

Graph: Draw Speed Vs Displacement

Radius Vs controlling force

Result:

Expt. No:
Date:

STUDY AND EXPERIMENTS ON STATIC AND DYNAMIC BALANCING OF ROTATING MASSES

AIM:

To check experimentally the method of calculating the position of counter balancing weight in rotating mass system.

THEORY

If the centre of gravity of the rotating disc does not lie on the axis of rotation but at a distance away from it, we say that the disc is out of balance. When such a disc rotates, a centrifugal force $F_c = m\omega^2 r$ is setup in which, `m' the mass of the disc, `r' the distance of the center of gravity of the disc from the axis of rotation and `ω' the angular velocity. This rotating centrifugal force acts on the bearing in a constantly changing directions and results in a vibrating load. The process of providing or removing the mass to counteract the out of balance is called balancing.

Generally all rotating machine elements such as pulleys, flywheels, rotors etc. are designed to rotate about a principal axis of inertia and theoretically require no balancing. However, lack of material homogeneity and inaccuracies in machining and assembly may cause an unintentional shifting of the centre of gravity of the rotor from the axis of rotation.

The centrifugal forces resulting from the unbalance increase as the square of the rotational speed and hence it is important that all revolving and reciprocating parts should be completely balanced as far as possible.

DESCRIPTION:

The apparatus basically consists of a steel shaft mounted in ball bearings in a stiff rectangular main frame. A set of four blocks of different weights are provided and may be clamped in any position on the shaft, they can also be easily detached from the shaft.

A disc carrying a circular protractor scale is fitted to one side of the rectangular frame, shaft carries a disc and rim of this disc is grooved to take a light cord provided with two cylindrical metal containers of exactly the same weight. A scale is fitted to the lower member of the main frame and when used in conjunction with the circular protractor scale, allows the exact longitudinal and angular position of each adjustable block to be determined.

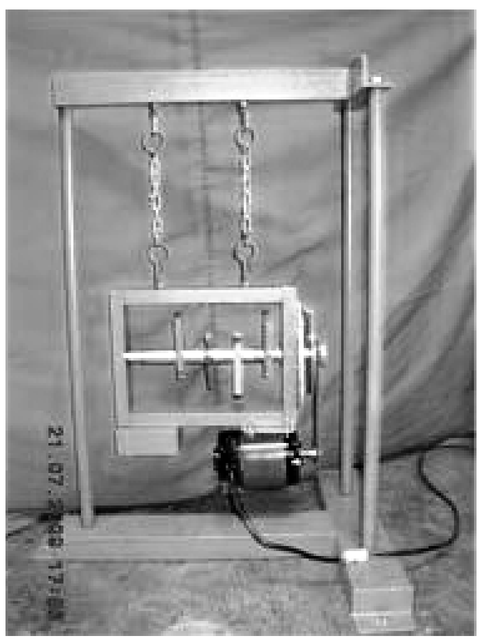
The shaft is driven by a 230 volts single phase 50 cycles electric motor, mounted under the main frame, through a round section rubber belt. For static balancing of individual weights the main frame is rigidly attached to the support frame by nut-bolts and in this position the motor driving belt is removed.

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 the supporting frame are in the same plane.

For balancing of rotating masses, the centrifugal force for each block should be therefore instead of finding centrifugal force, it is enough to find the value determined. We know that the centrifugal force $F_c = m\,\omega^2\,r$. But the angular velocity `$\omega$' remains same, because all the blocks are clamped on the same shaft for balancing. of `mr' which is the product of the mass of each block and the distance of the centre of gravity of each block from the axis of rotation.

STATIC BALANCING:

The main frame is rigidly fixed at right angles to the support frame and the drive belt is removed. The value of ‘mr’. 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 comes to stationery horizontal position, the number of balls "N" will give the value of `mr' for the block.



PROCEDURE:

For finding out `mr' during static balancing proceed as follows:

1. Remove the belt and attach the mainframe to support frame rigidly
2. Screw the combined hook to the pulley with groove (This pulley is different than the belt pulley).
3. Attach the cord-ends of the pans to the above combined hook.
4. Attach block No.1 to the shaft at any convenient position.
5. Put steel balls in one of the pans to make the block horizontal.
6. Number of balls give the `mr' of block 1
7. Repeat the procedure for other three blocks.

DYNAMIC BALANCING:

After obtaining the values of `mr' for all the four blocks draw a force polygon by assuming suitable values of angular displacement between any two masses (say block 1 and 2 is 40^o). Using the force polygon the angular displacement of other two masses can be obtained. If all the four blocks are arranged on the shaft as per the values of the angular displacement obtained from the force polygon, the system will be statically balanced i.e. sum of all the forces acting on the system will be zero. But there will be unbalanced couple. For complete balance i.e. for dynamic balancing, the blocks should be arranged on the shaft in such a manner, that the sum of all the couple acting on the system is zero. For this, without altering the angular displacement of all the four blocks, the relative axial displacement should be calculated as follows.

To determine the axial distances frame the table as follows:

Mass No.	mr	Axial distance of the masses from m_1 in m	mrl	θ	mrl $\sin\theta$	mrl $\cos\theta$
m_1	m_1r_1	$l_1 = 0$	0	θ_1	$m_1r_1l_1 \sin\theta_1$	$m_1r_1l_1 \cos\theta_1$
m_2	m_2r_2	l_2	$m_2r_2l_2$	θ_2	$m_2r_2l_2 \sin\theta_2$	$m_2r_2l_2 \cos\theta_2$
m_3	m_3r_3	l_3	$m_3r_3l_3$	θ_3	$m_3r_3l_3 \sin\theta_3$	$m_3r_3l_3 \cos\theta_3$
m_4	m_4r_4	l_4	$m_4r_4l_4$	θ_4	$m_4r_4l_4 \sin\theta_4$	$m_4r_4l_4 \cos\theta_4$
		Sum				

For complete dynamic balance (Sum) mrl Sinθ = 0

& (Sum) mrl Cosθ = 0

l_1 & l_2 values are assumed. The above two equations will contain the unknowns namely l_3 & l_4. The value of l_3 & l_4 can be determined by solving the two simultaneous equations.

Having known the axial and angular displacement of the masses, all the blocks can be clamped on the shaft in their appropriate positions. Connect the shaft pulley with the motor using the belt and transfer the frame to its hanging position. Run the motor to verify the complete balance of the system.

<u>Observation table</u>:

Mass no	mr	Axial distance of the masses from m_1 in m (L)	mrl	θ	mrl sin θ	mrl cos θ
m_1						
m_2						
m_3						
m_4						

Take let us assume l_1=0, l_2= 0.12m, θ_1= 0^o, θ_2 = 40^o

Length diagram:

Angular displacement diagram:

Force polygon diagram:

Obtain the values of θ3 & θ4 from force polygon.

Specimen calculation:

For complete dynamic balancing

Net couple = 0 i.e., $\sum mrl \sin\theta = 0$ & $\sum mrl \cos\theta = 0$

Step – 1

$$m_1 r_1 l_1 \sin\theta_1 + m_2 r_2 l_2 \sin\theta_2 + m_3 r_3 l_3 \sin\theta_3 + m\ r_4 l_4 \sin\theta_4 = 0$$

Eqn. 1

Step – 2

$$m_1 r_1 l_1 \cos\theta_1 + m_2 r_2 l_2 \cos\theta_2 + m_3 r_3 l_3 \cos\theta_3 + m\ r_4 l_4 \cos\theta_4 = 0$$

Eqn. 2

Solving the eqn. 1 & 2 find the values of l_3 & l_4

Result Tabulation

Mass no.	mr	Axial distance of the masses from m_1 in m (l)	mrl	θ	mrl sinθ	mrl cosθ
1						
2						
3						
4						

Result:

Expt. No:
Date:

WHIRLING SPEED OF SHAFT – DETERMINATION OF CRITICAL SPEED

Aim :

To determine the whirling speed of shafts with various diameters experimentally and compare it with theoretical values.

Apparatus required :

Rigid frame with motor and supporting ends, shaft 3 nos, Chuck key, A.C Voltage regulator, Digital Tachometer.

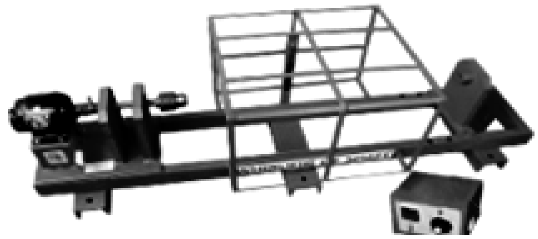
Description :

Critical Speed : The Phenomena is that the "The additional deflection of the shaft from the axis of rotation becomes infinite is known as critical speed".

In normal running conditions the centre of gravity of a loaded shaft will always displace from the axis of rotation, although this amount of displacement may be very less. As a result of this displacement, the centre of gravity is subjected to a centripetal acceleration as soon as the shaft begins to rotate. The inertia force acts radially outwards and bends the shaft. The bending of shaft not only depends upon the value of eccentricity, but also depends upon the speed at which it rotates.

Specification :

Shaft 1	Shaft 2	Shaft 3
m_1 = 0.090 kg	m_2 = 0.195 kg	m_3 = 0.350 kg
d_1 = 0.004 m	d_2 = 0.006 m	d_3 = 0.008 m
l_1 = 0.755 m	l_2 = 0.755 m	l_3 = 0.755 m



Procedure :

1. Fix the shaft properly at both ends.
2. Check the whole apparatus by tightening the screws.
3. First increase the voltage slowly to the level where whirling is observed subsequently reduce the voltage step by step thus reducing the speed.
4. Observe the loops appearing on the shaft and note down the speed at which they are appearing with the help of digital tachometer.
5. Slowly bring the shaft to rest and switch off the supply.
6. Repeat the same procedure for different shafts.

Precautions:

1. The shaft should be straight
2. The shaft should be properly tightened.
3. Voltage should not be very high.

Formula:

Natural frequency of vibration $f_{n} = K \quad \overline{\qquad\qquad}\,{}_{4}$

Where,

K = Constant = 2.45

E = Young's modulus (for steel) 2.06×10^{11} , N / m^2

g = acceleration due to gravity = 9.81 m/sec^2

I = Mass moment of inertia of the shaft = $(\pi / 64) d^4$ m^4

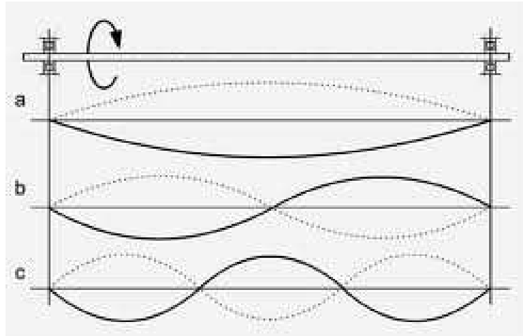
d = diameter of the shaft in m

w = weight of the shaft in N/m = Kg x 9.81

L = Length of the shaft in m

Theoretical whirling speed $Nc_{theo} = f_n \times 60$ rpm

Static Deflection $\delta = W L^3 / 3 EI$ m



a = one mode

b = two mode

c = three mode

Observation :

Sl.no	Shaft No.	Experimental speed in RPM	Deflection in Cm

Specimen Calculation:

Shaft – 4 mm

I = Mass moment of inertia of the shaft = $(\pi / 64)\, d^4$ m^4

=

I = **m^4**

w = weight of the shaft in N/m = Kg x 9.81

=

W = N

Natural frequency of vibration f_n = $K\sqrt{EgI/wL^4}$

=

f_n = **Hz**

Theoretical whirling speed Nc_{theo} = f_n x 60 rpm

=

Nc_{theo} = rpm

Deflection $\delta = W L^3 / 3 EI$ m

$\delta =$ m

<u>Shaft – 6 mm</u>

<u>Shaft – 8 mm</u>

<u>Result Tabulation :</u>

Shaft No	Length of Shaft in m	Diameter of shaft (m)	Weight of the shaft (N/m)	Moment of inertia $I = \pi/64 X d^4$ m^4	Whirling Speed in rpm		Deflection(δ) in m	
					Nc theo	Nc expt	δ theo	δ expt

<u>Result :</u> The whirling speed for the shafts of various diameter are determined experimentally and verified with the theoretical values.

Expt. No:
Date:

STUDY AND EXPERIMENTS ON CAM ANALYZER

Aim: To study various types of cams & followers and to draw displacement diagram of the follower for the given two cam profiles.

Description:

The cam is a reciprocating, oscillating or rotating body, which imparts reciprocating or oscillating motion to a second body called the follower with which it is in contact.

The cam mechanisms are commonly used in printing machinery, in automatic machines, machine tools, internal combustion engines, control mechanisms etc.,

There are at least three members in a cam mechanism

1. The cam, which has a contact surface either curved or straight.
2. The follower whose motion is produced by contact with the cam surface.
3. The frame which supports and guides the follower and cam

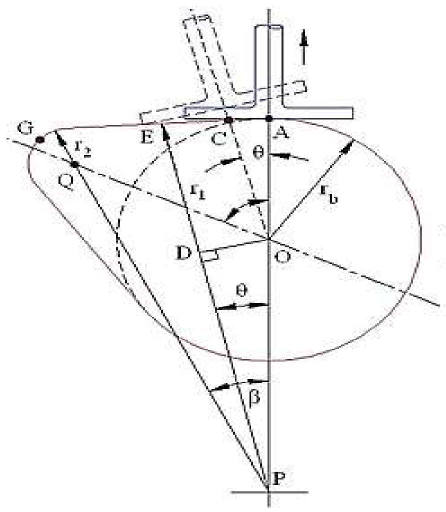
The cam rotates usually at constant angular velocity and drives the follower whose motion depends upon the shape of the cam.

The apparatus consists of roller follower and provision for mounting disc cams. The different cams are mounted one after another and rotated through the handle. The translator motion of the follower can be determined by the arm attached to the follower.

The displacement of the follower at various angular position of the cam is determined by attaching a paper over the plate. (On which the projecting arm moves). Using this observation the displacement diagram of the follower for the given cam can be drawn.

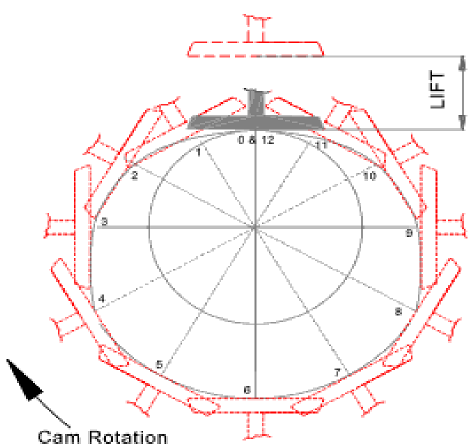
Procedure:

Mount one of the cam profiles (say Circular Arc Cam) on the apparatus. Fix a white paper on the plate (on which the projecting arm moves). Rotate the cam using the handle through a known angular displacement (i.e., coinciding the follower with the division made on the cam). Now the position of the projecting arm on the paper can be marked. Similarly subsequent positions of the follower at other known angular positions can be determined for one full rotation of the cam. The same procedure has to be repeated for other cams. Tabulate the observations.



Circular arc cam

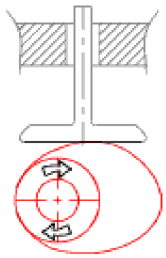
When the flanks of the cam connecting the base circle and nose are of convex circular arcs,then the cam is known as circular arc cam



Offset cam

when the motion of the cam is along an axis away from the axis centre, it is called the off-set cam.

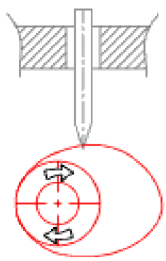
TYPES OF FOLLOWERS



FLAT FACE

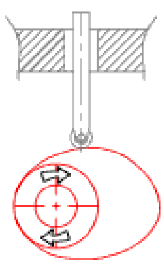
When the contacting end of the follower is a perfectly flat face, it is called a flat face follower, .The flat faced followers are generally used where space is limited such as in cams which operate the valves automobile engines.

e.g automobile engines



KNIFE EDGE

When the contacting end of the follower has a sharp knife edge is called a knife edge follower, because the small area of contacting surface results in excessive wear. In knife edge followers, a considerable side thrust exists between the follower and the guide.



ROLLER

When the contacting end of the follower is a roller, it is called a roller follower, The roller followers are extensively used where more space is available.

e.g stationary gas ,oil engines and aircraft engines.

Observation table

Angular displacement of cams in degree	Linear displacement of the follower in Cm	
	Circular Arc Cam	Offset Cam
0		
20		
40		
60		
80		
100		
120		
140		
160		
180		
200		
220		
240		
260		
280		
300		
320		
340		
360		

Graph: To draw angular displacements of the cam Vs the linear displacements of the Follower by graphical and Polar chart.

Result:

Expt. No :

Date:

EXPERIMENTAL VERIFICATION OF NATURAL FREQUENCY OF UNDAMPED FREE VIBRATION OF EQUIVALENT SPRING MASS SYSTEM

Aim:

To verify the un-damped free vibration of equivalent spring mass system

Description of set up:

The arrangement is shown in Fig. It is designed to study free, forced damped and un-damped vibrations. It consists of M.S. rectangular beam supported at one end by a trunnion pivoted in ball bearing. The other end of the beam is supported by the lower end of helical spring. Upper end of spring is attached to the screw.

The weight platform unit can be mounted at any position along the beam. Additional known weights may be added to the weight platform.

Procedure:

1. Support one end of the beam in the slot of trunnion and clamp it by means of screw.
2. Attach the other end of beam to the lower end of spring
3. Adjust the screw to which the spring is attached such that beam is horizontal in the above position.
4. Weigh the platform unit
5. Clamp the weight platform at any convenient position.
6. Measure the distance L_1 of the weight platform from pivot. Allow system to vibrate freely.
7. Measure the time for any 20 oscillations and find the periodic time and natural frequency of vibrations.
8. Repeat the experiment by varying L_1 and by also putting different weights on the platform.

Note: It is necessary to clamp the slotted weights to the platform by means of nut so that weights do not fall during vibrations.

Observation Table-I

Length of beam (L) = 94 cm

Mass of the weight platform = 3.785 kg

Mass of the beam (m) = 2.440 kg

Sl. No.	Mass attached to the beam including weight platform (m_1) (kg)	L_1 (m)	Time for 20 oscillations, (s)				Periodic time (s)	Natural frequency (Hz)
			t_1	t_2	t_3	t_{ave}		f_n (expt)
1	3.785+5.000 =8.785	0.65						
2	3.785+7.000 =10.785							
3	3.785+9.000 =12.785							
4	3.785+5.000 =8.785	0.85						
5	3.785+7.000 =10.785							
6	3.785+9.000 =12.785							

SPECIMEN CALCULATION:

Considering the M.I. of the beam:

The equation of motion is

$$I\left(\frac{d^2x}{dt^2}\right)+\left(\frac{mL^2}{3}\right)\left(\frac{d^2x}{dt^2}\right)+kL^2x=0$$

Where

I is the mass moment of inertia of the mass attached to the beam from the pivot = $m_1 L_1^2$

m_1 is the mass attached to the beam

L_1 is the distance of the mass from the pivot

m is the mass of the beam

L is the effective length of the beam

k is the stiffness of the spring

The equation can be rewritten as

$$\left(\frac{d^2x}{dt^2}\right)\left[I+\left(\frac{mL^2}{3}\right)\right]+kL^2x=0$$

$$\left(\frac{d^2x}{dt^2}\right)\left[m_1L_1^2+\left(\frac{mL^2}{3}\right)\right]+kL^2x=0$$

$$\frac{d^2x}{dt^2}+\frac{kL^2}{\left[m_1L_1^2+\left(\frac{mL^2}{3}\right)\right]}x=0$$

Comparing the equation of motion with S.H.M

$$\frac{d^2x}{dt^2}+\varpi^2x=0$$

$$\omega^2=\frac{kL^2}{\left[m_1L_1^2+\left(\frac{mL^2}{3}\right)\right]}$$

Time period of oscillation $T = 2\pi / \omega$

Frequency of oscillation $f_n = 1/T = \omega / 2\pi$

Therefore $f_n = \left[\frac{1}{2\pi}\right]\left[\frac{kL^2}{\left[m_1L_1^2 + \left(\frac{mL^2}{3}\right)\right]}\right]^{\frac{1}{2}}$

Where $m_e = \left[\frac{m_1L_1^2 + \left(\frac{mL^2}{3}\right)}{L^2}\right]$

=

=

m_e =

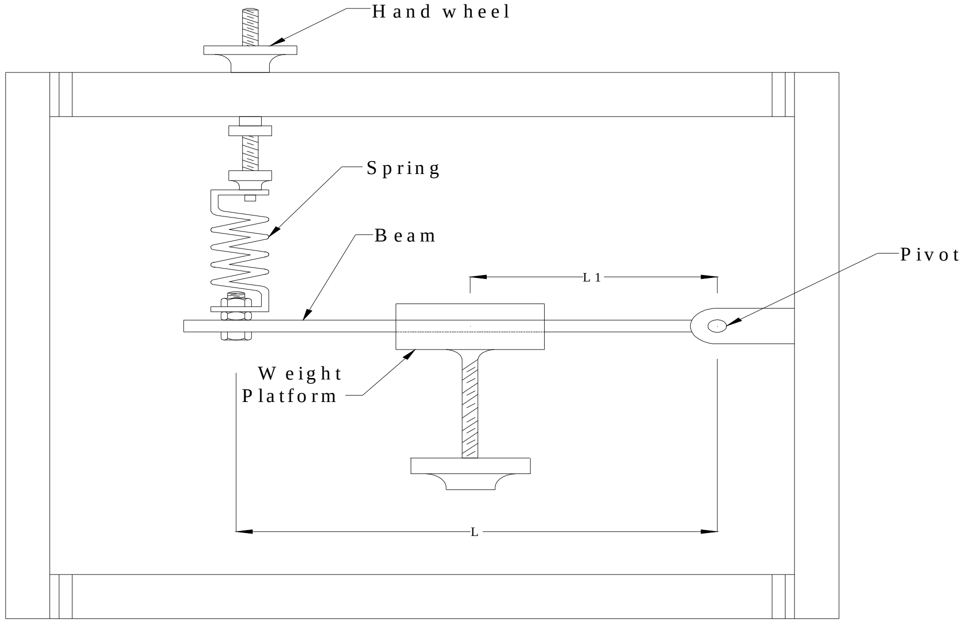
$f_n = \left[\frac{1}{2\pi}\right]\left[\frac{k}{m_e}\right]^{\frac{1}{2}}$

=

=

f_n = Hz

The unit of frequency is Hz or CPS (cycles/sec)



EXPERIMENTAL SETUP OF UNDAMPED FREE VIBRATION
OF EQUIVALENT SPRING MASS SYSTEM

<u>Stiffness of the spring</u> (k):

The stiffness of the given spring can be found as follows:

1. Remove the beam and the weight platform from the experimental set up
2. Fix one end of the helical spring to the upper screw which engage with

   Screwed hand wheel.
3. Determine the free length of the spring
4. Attach a weight platform
5. Put some known weight to the weight platform and note down the deflection and repeat for different weights.

Observation Table - II

Free length of the spring = cm

Mass of the platform = 0.360 kg.

Sl. No.	Mass attached kg	Length of spring		Elongation(m) (Free length – Length of spring)	Stiffness(K) = Weight / elongation N/m
		cm	m		
1	5.360				
2	7.360				
3	9.360				
				Average	

Result:

	1	2	3	4	5	6
f_n Expt						
f_n Theo.						

Expt. No :

Date:

DETERMINATION OF MASS MOMENT OF INERTIA OF FLY WHEEL

Aim:

Experimentally determine the mass moment of inertia of the flywheel along with the shaft and verify the same theoretically.

Theory:

Let the mass descend under the force of gravity starting from rest with uniform acceleration. As per Newton's second law of motion of the falling mass

$$M g - T = M a \qquad (1)$$

Where M = Mass of the falling body

T = tension in the string

a = acceleration of the falling mass

therefore

$$T = M g - M a$$

$$= M (g - a) \qquad (2)$$

Considering the motion of the flywheel the equation of motion is

Net torque acting on the flywheel = M.M.I. $\times$ angular acceleration

Net torque = $I / \propto$

But net torque = Torque due to tension T - Frictional torque

$$= (T \times r) - (F_f \times r)$$

$$= (T - F_f)\, r$$

Where F_f is Frictional force in Newton

Therefore $(T - F_f)\, r = I \propto \qquad (3)$

Substituting the value of T in equation (3)

$$[M (g - a) - F_f]\, r = I \propto$$

But $\propto = a / r$

Therefore $[M (g - a) - F_f]\, r = I \times (a/r)$

or $I = (r^2 / a) [M(g - a) - F_f]$ (4)

To find \` a':

Let \`t' is the time taken by the falling mass to travel the distance \`h"

$$u = 0 \qquad S = u\,t + \frac{1}{2}\,a\,t^2$$

$$S = h \qquad h = 0 + \frac{1}{2}\,a\,t^2$$

$$t = t$$

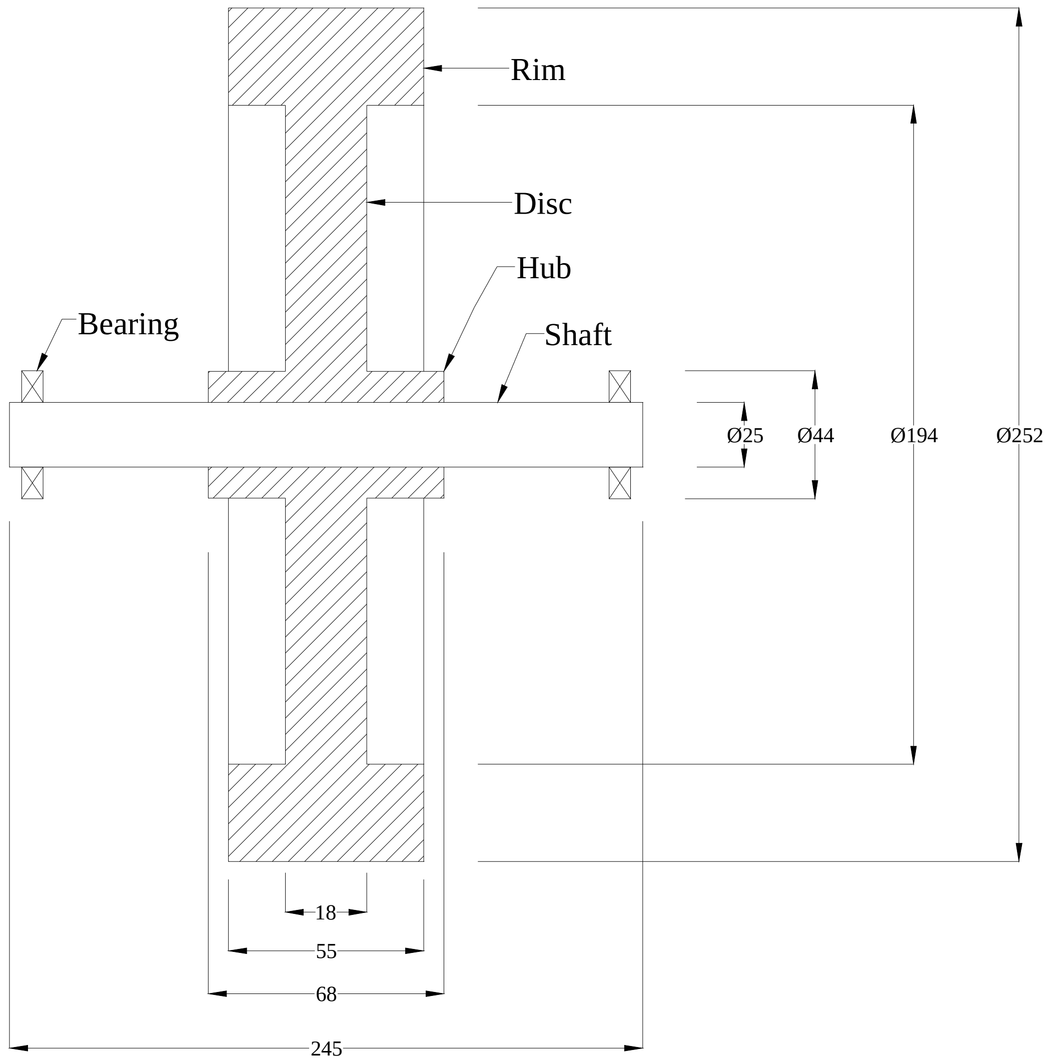
Therefore $a = \frac{2h}{t^2}$

Moment of inertia of the flywheel 'I' can be found by substituting the value of 'a' in eqn. (4)

Procedure:

First of all find out the force needed to overcome the friction present on the bearings when it just begins to rotate by gradually adding the weight to the weight pan which is attached to the one end of the string.

Then some more known weight is added and allow the mass to fall under the force of gravity. Note down the time for first 10 revolutions of the flywheel starting from rest. Conduct the experiment two or three times with the same mass and take the average time value. Repeat the experiment with different masses and tabulate the observations.



All Dimensions are in mm

SECTIONAL FRONT VIEW OF FLYWHEEL

Observations:

Mass needed to overcome friction on the shaft, m_f =

Frictional force F_f $= m_f \times g$

=

= in N

Sl.No.	Mass of falling body (m) in Kg		Time for 10 revolutions in seconds			
	grams	Kg.	t_1	t_2	t_3	t_{ave}
1						
2						
3						

<u>Specimen Calculations:</u>

m - mass added

r - radius of the shaft in mtrs.

h - distance travelled for 10 revolutions

= $10 \times \pi \times d$ in meter

Where d is diameter of the shaft

h =

h = m

a = $\frac{2h}{t^2}$

=

= ……….. m/s^2

Therefore

$$I = \frac{r^2}{a}\left[m(g-a) - F_f\right] \quad kgm^2$$

=

=

= kgm^2

Determine the Mass Moment Of Inertia of Flywheel (Theoretically)

Sl. No.	Name of the part	Outer radius R_o (m)	Inner radius R_i (m)	Area of c/s (m^2)	Width (m)	Volume (m^3)	Mass (Kg)	$I=mk^2$ Kg m^2
1	Shaft							
2	Hub							
3	Disk							
4	Rim							
							Total	

SPECIMEN CALCULATION:

Mass Density of the material (ms) of the flywheel and shaft = 6840 kg/m^3

Mass moment of Inertia of Shaft:

Mass Density of the flywheel and shaft material (ms) = 6840 kg/m^3

Cross sectional Area of the shaft `d' $a_s = (\pi/4)\, d^2$

$a_s = \pi/4\, (d)^2$

= m^2

Volume $_s$ = Area $\times$ width $_s$

=

V_S = m^3

Mass (m) = Volume $\times$ mass density

M_S = kg

Radius of gyration k:

k^2 for solid cylinder of diameter. `d' = $d^2 / 8$

K^2 = m^2

$\therefore$ Mass moment of Inertia $I_{shaft} = m k^2$

I_{shaft} = kgm^2

Mass moment of Inertia of Hub:

d_o = m

d_I = m

area = $\pi/4\ (d_o^2 - d_I^2)$

a_H = m^2

$V_H = a_H \times w_H$ (Hub width as per specification = 0.068 m)

V_H = m^3

$m_H = V_H$ x Mass density

(Mass Density of the flywheel and shaft as per specification= 6840 kg/m^3)

m_H = kg

Radius of gyration $K^2 = \dfrac{(d_o^2 + d_I^2)}{8}$

=

K_{HUB} = m^2

∴ Mass moment of Inertia $I_{HUB} = m\ k^2$

= Kg m^2

Mass moment of Inertia of Disc:

Mass Density of the material (ms) of the flywheel and shaft = 6840 kg/m^3

Area = $\pi/4\ (d_o^2 - d_I^2)$

a_D = m^2

Volume = a x width of the Disc

V_D = m^3

Mass = Volume x mass density

=

M_D = Kg

Radius of gyration $k^2 = (d_o^2 + d_I^2) / 8$

K^2_D = m^2

∴ Mass moment of Inertia $I_{DISC} = m\ k^2$

I_D = Kg m^2

Mass moment of Inertia of Rim:

$a_{RIM} = \pi/4\ (d_o^2 - d_I^2)$

$= \qquad m^2$

$V_R = a_R \times w_R$

$= \qquad m^3$

$m_R = V_R$ x Mass density

$= \qquad$ Kg.

Radius of gyration $K^2_{RIM} = \dfrac{d_o^2 + d_I^2}{8}$

$K^2_{RIM} = \qquad m$

$\therefore$ Mass moment of Inertia $I_{RIM} = m\ k^2$

$= \qquad$ Kg m^2

Result:

Expt. No :

Date:

Determination of mass moment of Inertia of connecting rod with flywheel

Aim : To determine the mass moment of inertia of the given connecting rod.

Apparatus : Connecting rod with flywheel setup and stop watch

Procedure :

- Measure the center to center distance of connecting rod. Also measure inner diameter of the small and big end of the connecting rod.
- Measure the weight of connecting rod and flywheel.
- Attach small end of the connecting to the shaft.
- Oscillate the connecting rod
- Measure the time for five oscillations and calculate the time period (t_{p1})
- Remove the connecting rod from the shaft and attach the big end to the shaft
- Again measure the time for five oscillations and calculate the time period (t_{p2})
- Calculate the moment of inertia of the connecting rod.
- Repeat the same procedure for two more times and take mean of it.
- Attach flywheel to the other side of the shaft and repeat the same procedure as above and see the effect of it on the oscillations of the connecting rod.

Connecting rod with flywheel

Specification of Connecting rods:

Connecting rod	L - mm	m- Kg	m_f Kg	d_1 - mm	d_2 - mm	No.of Oscillations
1	150	1.4	2	25	54	5
2	225	2.65	2	35	60	5

L = center to center distance of connecting rod
m = weight of connecting rod
m_f = weight of flywheel
d_1 = dia of the small end of the connecting rod
d_2 = dia of the big end of the connecting rod
n = No. of oscillations

Observation :

- L_1 = length of equivalent simple pendulum when suspended from the top of small end bearing.
- L_2 = length of equivalent simple pendulum when suspended from the top of big end of bearing.
- h_1 = distance of center of gravity, G from the top of small end bearing.
- h_2 = distance of center of gravity ,G, from the top of big end bearing.
- Periodic time = $t_{p} = t_{avg} / 5$ in (sec)

Observation table :

Connecting rod		Connecting rod suspension point	Time for '5' Oscillations (t)sec				Time for 1 oscillation (t_p) in sec
			t_1	t_2	t_3	t_{avg}	
Connecting rod -1	With flywheel	Small end					
		Big end					
	Without flywheel	Small end					
		Big end					
Connecting rod - 2	With flywheel	Small end					
		Big end					
	Without flywheel	Small end					
		Big end					

Calculation for Connecting rod - 1

(i) With Flywheel

$t_{p1} = 2\pi\sqrt{L1/g}$ $\quad\quad$ $t_{p2} = 2\pi\sqrt{L2/g}$

$L_1 = g\,(t_{p1}/2\pi)^2$ $\quad\quad$ $L_2 = g\,(t_{p2}/2\pi)^2$

$L_1 =$ m $\quad\quad$ $L_2 =$ m

We know that the length of equivalent of simple pendulum

$$L = \frac{(KG)^2 + h^2}{h}$$

$$(KG)^2 = L.h - h^2$$

$$(KG)^2 = h\,(L - h)$$

When the rod is suspended from the top of small end bearing

$$(KG)^2 = h_1\,(L_1 - h_1) \quad \text{———} \quad 1$$

When the rod is suspended from the top of big end

then $$(KG)^2 = h_2\,(L_2 - h_2) \quad \text{———} \quad 2$$

$$h_1 - h_2 = X$$

$$h_2 = (x - h_1)$$

the eqn. 1 &2

$$h_1\,(L_1 - h_1) = h_2\,(L_2 - h_2)$$

$$h_1\,(L_1 - h_1) = (x - h_1)\left[\,L_2 - (X - h_1)\,\right]$$

$h_1 =$ m

Now from equation 1

$(KG1)^2 = h_1 (L_1 - h_1)$

$=$ m^2

M.I of connecting rod with flywheel = m $(KG)^2$

$=$ Kg m^2

<u>(ii) Without Flywheel</u>

$tp1 = 2\pi\sqrt{L1/g}$

$L_1 = g\,(t_{p1} / 2\pi)^2$

$L_1 =$ m

$tp2 = 2\pi\sqrt{L2/g}$

$L_2 = g\,(t_{p2} / 2\pi)^2$

$L_2 =$ m

We know that the length of equivalent of simple pendulum

$$L = \frac{(KG)^2 + h^2}{h}$$

$(KG)^2 = L.h - h^2$

$(KG)^2 = h\,(L - h)$

When the rod is suspended from the top of small end bearing

$(KG)^2 = h_1 (L_1 - h_1)$ ———————— 1

When the rod is suspended from the top of big end

then $(KG)^2 = h_2 \, (L_2 - h_2)$ ————— 2

$h_1 - h_2 = X$

$h_2 = (x - h_1)$

the eqn. 1 &2

$h_1 (L_1 - h_1) = h_2 \, (L_2 - h_2)$

$h_1 (L_1 - h_1) = (x - h_1) \left[L_2 - (X - h_1) \right]$

$h_1 =$ m

Now from equation 1

$(KG1)^2 = h_1 (L_1 - h_1)$

$=$ m^2

M.I of connecting rod with flywheel = $m \, (KG)^2$

$=$ $Kg \, m^2$

Calculation for Connecting rod - 2

(i) With Flywheel

$tp1 = 2\pi\sqrt{L1/g}$ $tp2 = 2\pi\sqrt{L2/g}$

$L_1 = g\,(t_{p1} / 2\pi)^2$ $L_2 = g\,(t_{p2} / 2\pi)^2$

$L_1 =$ m $L_2 =$ m

We know that the length of equivalent of simple pendulum

$$L = \frac{(KG)^2 + h^2}{h}$$

$$(KG)^2 = L.h - h^2$$

$$(KG)^2 = h\,(L - h)$$

When the rod is suspended from the top of small end bearing

$$(KG)^2 = h_1\,(L_1 - h_1) \quad \text{———} \quad 1$$

When the rod is suspended from the top of big end

$$\text{then } (KG)^2 = h_2\,(L_2 - h_2) \quad \text{———} \quad 2$$

$$h_1 - h_2 = X$$

$$h_2 = (x - h_1)$$

the eqn. 1 &2

$$h_1\,(L_1 - h_1) = h_2\,(L_2 - h_2)$$

$$h_1\,(L_1 - h_1) = (x - h_1)\left[\,L_2 - (X - h_1)\,\right]$$

$h_1 =$ m

Now from equation 1

$(KG1)^2 = h_1 (L_1 - h_1)$

= m^2

M.I of connecting rod with flywheel = m $(KG)^2$

= Kg m^2

<u>(ii) Without Flywheel</u>

$tp1 = 2\pi\sqrt{L1/g}$ $\quad$ $tp2 = 2\pi\sqrt{L2/g}$

$L_1 = g\,(t_{p1} / 2\pi)^2$ $\quad$ $L_2 = g\,(t_{p2} / 2\pi)^2$

$L_1 =$ m $\quad$ $L_2 =$ m

We know that the length of equivalent of simple pendulum

$$L = \frac{(KG)^2 + h^2}{h}$$

$(KG)^2 = L.h - h^2$

$(KG)^2 = h (L - h)$

When the rod is suspended from the top of small end bearing

$(KG)^2 = h_1 (L_1 - h_1)$ ———————— 1

When the rod is suspended from the top of big end

then $(KG)^2 = h_2 (L_2 - h_2)$ ———————— 2

$$h_1 - h_2 = X$$

$$h_2 = (x - h_1)$$

the eqn. 1 &2

$$h_1 (L_1 - h_1) = h_2 (L_2 - h_2)$$

$$h_1 (L_1 - h_1) = (x - h_1)\left[L_2 - (X - h_1) \right]$$

$$h_1 = \qquad m$$

Now from equation 1

$$(KG1)^2 = h_1 (L_1 - h_1)$$

$$= \qquad m^2$$

M.I of connecting rod with flywheel = $m\,(KG)^2$

$$= \qquad Kg\ m^2$$

<u>Result Tabulation</u> :

Connecting Rod	Mass moment of Inertia (**I**) of the connecting rod (Kg m^2)	
	With Fly wheel	With out Fly wheel
1		
2		

<u>Result :</u> Hence the moment of inertia of the given connecting rod was determined with and without flywheel.