THEORY OF MACHINE S – II

LAB MANUAL

SR. NO.	NAME OF EXPERIMENT
01	To determine whirling speed of shaft theoretically and experimentally.
02	To determine the position of sleeve against controlling force and speed of a Hartnell governor and to plot the characteristic curve of radius of rotation.
03	To determine the natural frequency of undamped torsional vibration of a single rotor shaft system.
04	**To determine the natural frequency of undamped torsional vibration of two rotor shaft system.**
05	To analyse the motion of a motorized gyroscope when the couple is applied along its spin axis.
06	To determine the frequency of undamped free vibration of an equivalent spring mass system.
07	To determine the frequency of damped force vibration of a spring mass system.
08	To study the static and dynamic balancing using rigid blocks.

EXPERIMENT - 1

AIM: To determine whirling speed of shaft theoretically and experimentally.

APPARATUS: Apparatus for the demonstration of whirling speed of shaft.

THEORY:

At certain speed, a rotating shaft or rotor has been found to exhibit excessive lateral vibrations (transverse vibrations). The angular velocity of the shaft at which this occurs is called a critical speed or whirling speed or whipping speed. At a critical speed, the shaft deflection becomes excessive and may cause permanent deformation or structural damage. Therefore it is important to note that the machine should never be operated for any length of time at a speed close to a critical speed.

FIGURE:

PROCEDURE:

1. Decide the support end condition of the shaft in bearings.
2. Increase the speed of the shaft by varying voltage.
3. Observe the transverse vibrations in the shaft.
4. Measure the speed of the rotating shaft with tachometer at the maximum deflection of the shaft.
5. Repeat the operation two-three times.
6. Since both the ends have double ball bearing hence both the ends are assumed fixed.

SPECIFICATIONS:

Length of shaft, L	=	0.9m
Diameter of the shaft, D	=	6.4 mm
Young's modulus, E	=	$2.06 * 10^{10}$ kg/m^2
Moment of inertia of the shaft, I	=	$79.91 * 10'^{12} m^4$
Weight of the shaft, W	=	0.28 kg/m

OBSERVATIONS:

Sr. No.	Support end condition	Length of shaft	Whirling speed

Three various values for k are given below:

End Condition	Value of k	
	1stmode	2nd mode
Supported, supported	1.57	6.28
Fixed, supported	2.45	9.8
Fixed, fixed	3.56	14.24

CALCULATIONS:
The frequency of vibration for the various mode is given by the equation.

$$f = k^* \frac{E^*I^*g}{W^*L^4} \text{ rps}$$

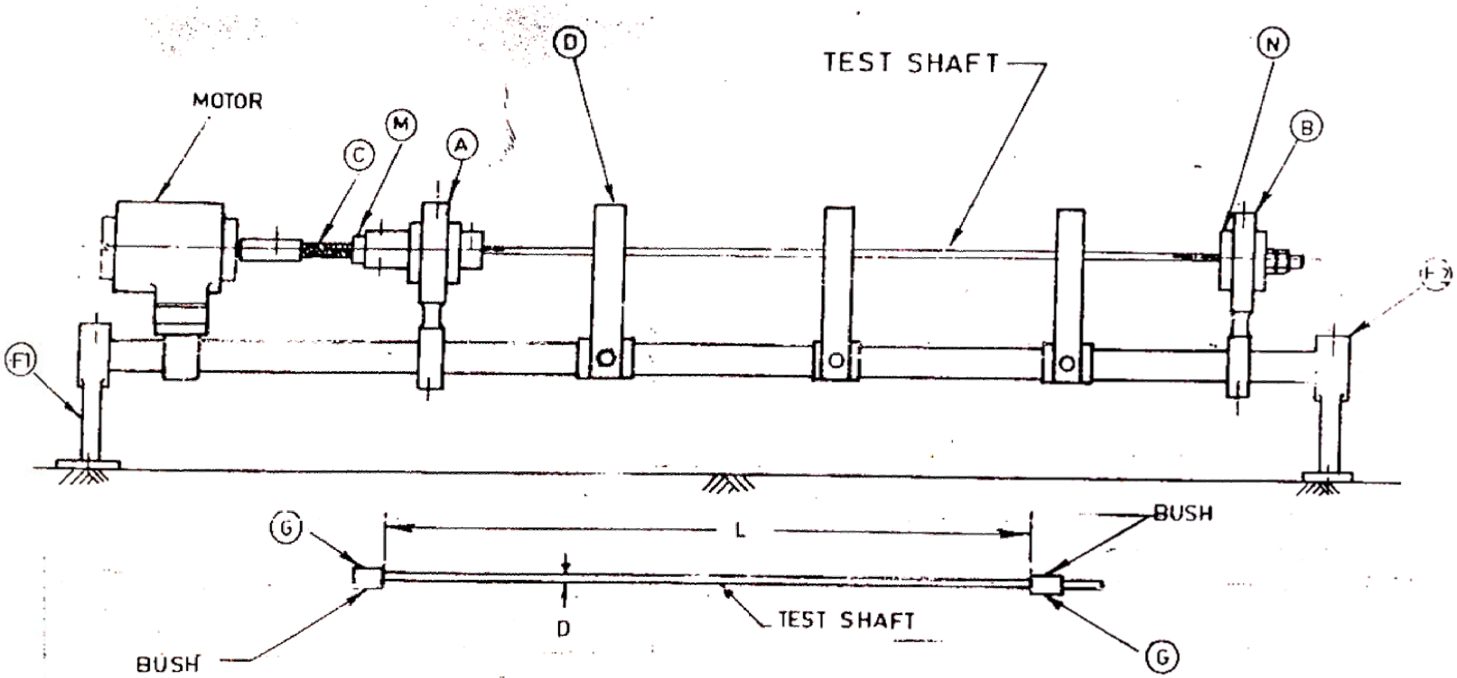
CONCLUSION:
1. The theoretical speed fot the 1st mode is rps.
2. The experimental speed for the 1st mode is rps.
The above two are quite close to each other.

The theoretical speed fot the 2nd mode is rps

The speed of the 2nd mode could not be determined experimentally, as it is very high and beyond the speed limit/range of motor of the apparatus.

PRECAUTIONS:
1. The speed of the shaft should be increased gradually.
2. If the speed of the shaft increased large it may lead to violent instability.

Experiment No. 1



F - Side supports
G - Bushes at the shaft ends
C - Flexible shaft
MN-Ball bearing shaft
D - Guards
AB-Stand for fixing
M - Motor side free block.
N - Tail side free block.

Whirling of shaft apparatus.

EXPERIMENT 2

AIM : To determine the position of sleeve against controlling force and speed of a Hartnell governor and to plot the characteristic curve of radius of rotation.

APPARATUS:
Hartnell governor, scale, graph sheet.

THEORY:
The Hartnell governor is shown in figure. It consists of two bell crank levers hinged in the frame at *A.* The levers carry balls at *B* on the vertical arm and a spherical head contact point at C at the other end. These spherical head points press against the sleeve *D* that compresses the spring *E* from the bottom. The compression varies with the different positions of the sleeve. The initial force in the spring is controlled by the nut *F.* The speed of rotation can be varied by the electric motor and the voltage regulator.

SPECIFICATIONS:

Vertical length of bell-crank lever, *a*	=	70mm
Horizontal length of bell-crank lever, *b*	=	116mm
Weight of balls, *W*	=	650 gm
Initial radius of rotation, r_0	=	125mm

where *a,* = vertical and horizontal arms of the bell crank lever respectively
b = speed in rpm
N = Spring stiflhess
P = Force
F = Radius of rotation
r = Sleeve displacement
x

PROCEDURE:
1. Measure initial compression of the spring.
2. Go on increasing the speed gradually and take the readings of speed of rotation 'N' and corresponding sleeve displacement 'x'. Radius of rotation 'r' at any position could be found.
3. Following graphs can be plotted to study governor characteristics,
   a. Force Vs Radius of rotation,
   b. Speed Vs Sleeve displacement.

OBSERVATION TABLE:

Sr. No.	Speed, *N rpm*	Sleeve Displacement, *x m*	Radius of rotation, *r m*	Force, *F N*

CALCULATIONS:

1. Radius of rotation, $r = \left\{ r_0 + x\,(a/b) \right\}$
2. Force, $F = \dfrac{W}{S}\,\omega^2 r$

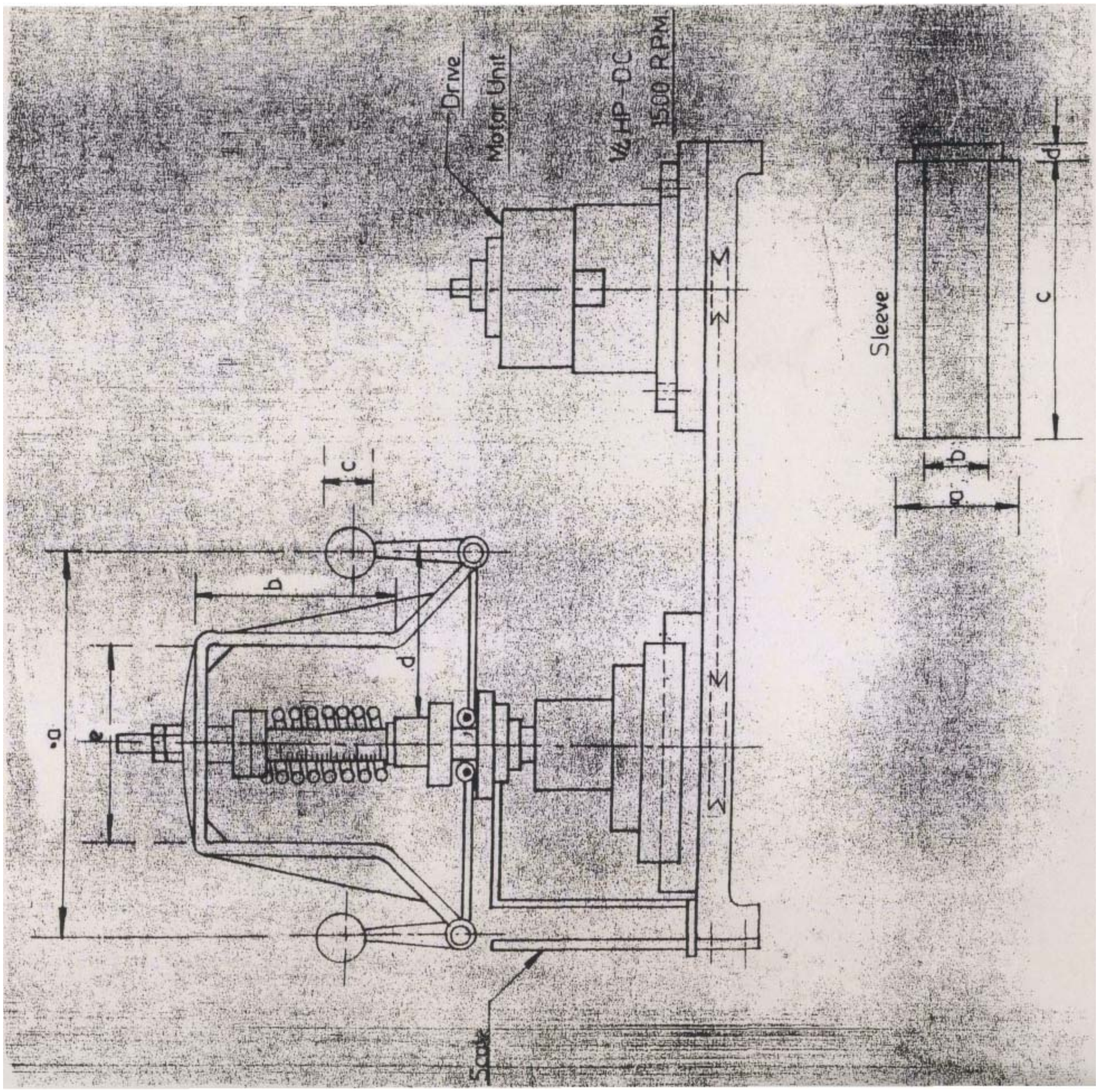
CONCLUSION:

Plot the graph of:

1. Speed Vs Sleeve displacement and .
2. Force Vs Radius of rotation. Comment on the relation between the variables from the graph.

PRECAUTIONS:

1. Check the electrical connections properly.
2. Use of safety guard is compulsory.
3. Increase the speed of motor gradually.



Hartnell Governor

EXPERIMENT 3

AIM: To determine the natural frequency of undamped torsional vibration of a single rotor shaft system.

APPARATUS:

THEORY:

When the particles of the shaft or disc move in a circle about the axis of the shaft, then the vibrations are known as torsional vibrations. The shaft is twisted and untwisted alternatively and the torsional shear stresses are induced in the shaft. Since there is no damping in the system these are undamped vibrations. Also there is no external force is acting on the body after giving an initial angular displacement then the body is said to be under free or natural vibrations. Hence the given system is an undamped free torsional vibratory system.

FIGURE:

SPECIFICATIONS:

Shaft diameter, d = 3 mm

Diameter of disc, D = 225 mm

Weight of the disc, W = 2.795 kg

Modulus of rigidity for shaft, C = $7.848 * 10^{10}$ N/m^2

PROCEDURE:

1. Fix the brackets at convinent position along the lower beam.
2. Grip one end of the shaft at the bracket by chuck.
3. Fix the rotor on the other end of the shaft.
4. Twist the rotor through some angle and release.
5. Note down the time required for 10 to 20 oscillations.
6. Repeat the procedure for different length of the shaft.

OBSERVATIONS:

Sr. No.	Length of shaft, L met	Number of oscillations, n	Time for n oscillations, t	Periodic time, T=t/n (expt)	Frequency, f = 1 / T (theo)	Frequency, f = 1 / T (expt)

CALCULATIONS:

Polar moment of inertia of shaft = $\pi * d^4 / 32$

Moment of inertia of disc, I = $(W/g)*(D^2/8)$

1. Torsional stiffness Kt

   $Kt = (G * I_p)/L$

2. Periodic time, T (theoretically)

$$T = 2\pi\sqrt{\frac{I}{K_t}}$$

3. Periodic time, T (expt)

   $T = t / n$

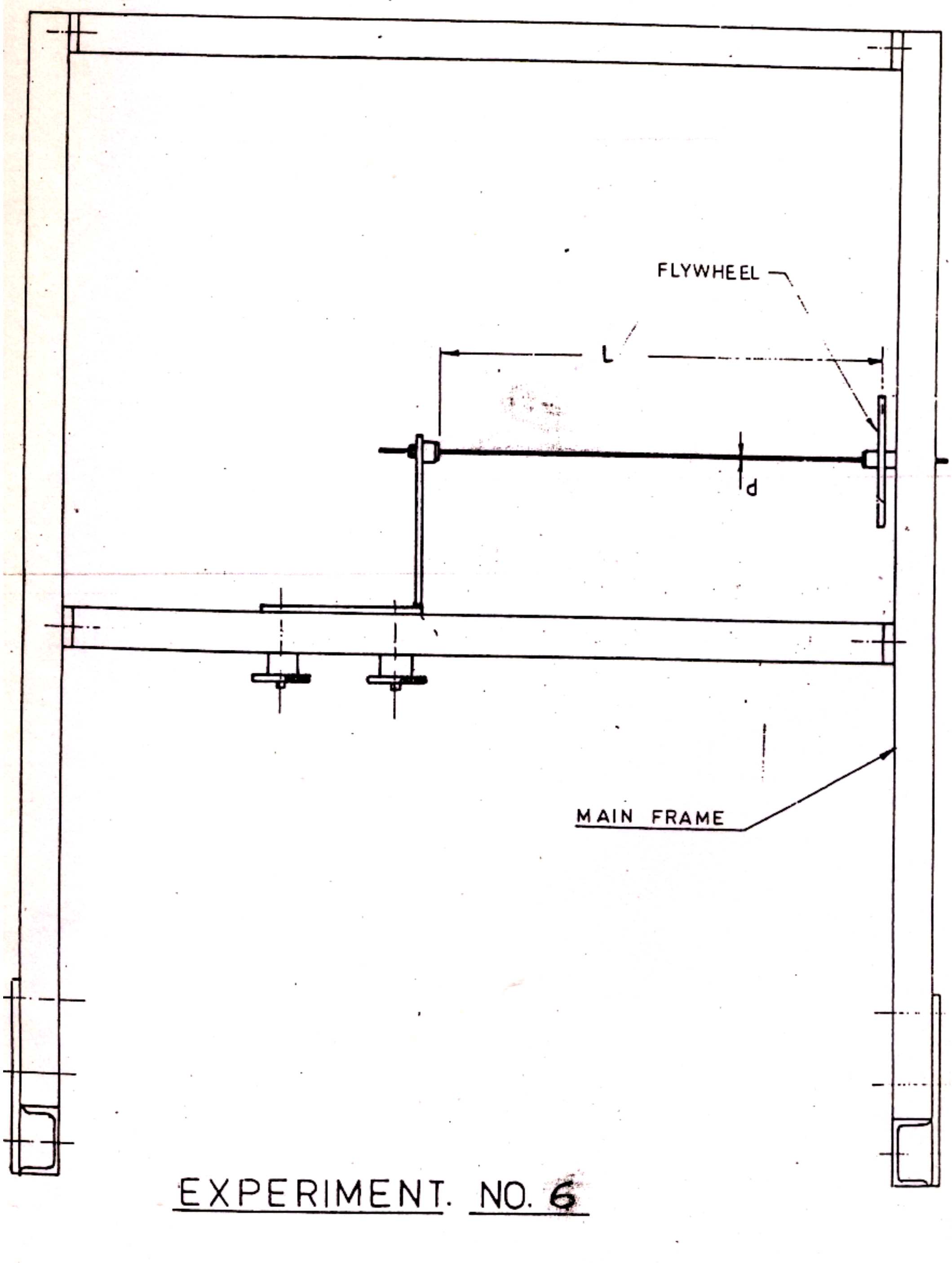
4. Frequency, f (expt) = 1 / T
5. Frequency, f (theo) = / = $\frac{1}{2\pi}\sqrt{\frac{C*J}{I*L}}$

RESULT TABLE:

Sr. No.	Length of shaft, L met	THEORETICAL VALUES				EXPERIMENTAL VALUES			
		m kg	I	T_{th}	f_{th}	No. of oscillations selected, n	Time required for n oscillations, t sec	T_{exp} = t / n	f_{exp} = n / t

CONCLUSION:

1. The natural frequency of undamped free torsional vibration (theo)
2. The natural frequency of undamped free torsional vibration (expt)



EXPERIMENT. NO. 6

Vib. Lab Apparatus

EXPERIMENT - 4

AIM:

To determine the natural frequency of undamped torsional vibration of two rotor shaft system.

APPARATUS:

Figure shows the general arrangement for carrying out the experiment. Two discs having different mass moment of inertia are clamped one at each end of the shaft by means of collets chucks. Mass moment of inertia of any disc can be changed by attaching the cross lever masses. Both disc are free to oscillate in the ball bearings. This provides negligible damping during experiment.

THEORY:

The system which requires two co-ordinates independently to describe its motion completely is called a two degree of freedom system. The system having two degree of freedom has two natural frequencies.

The two rotor system consists of a shaft having torsional stiffness K and two rotors having their inertias as Ii and L? at its two ends. Torsional vibration occurs only when the rotor 1 and rotor 2 rotates in the opposite direction. If the rotor 1 and rotor 2 rotates in the same direction then it has zero frequency. When the rotors rotate in the opposite direction then the amplitude of vibration at the two ends will be in the opposite direction and there exists a point on the shaft having zero amplitude is called node point.

FIGURE:

SPECIFICATIONS:

Diameter of disc A, D_A	=	190 mm
Diameter of disc B, D_B	=	225 mm
Mass of disc A, m_A	=	2.015 kg
Mass of disc B, me	=	2.795 kg
Mass of arm with bolts, m	=	0.166 kg
Length of cross arm, R	=	0.165 m
Diameter of shaft, d	=	3 mm
Length of shaft between rotors, L	=	1.03 m
Moment of inertia of disc A, I_A	=	kg-m^2
Moment of inertia of disc B, I_B	=	kg-m^2
Modulus of rigidity of the shaft, C	=	$7.848 * 10^{10}$ N/m^2

PROCEDURE:

1. Fix two discs to the shaft and fit the shaft in bearings.
2. Turn the disc in angular position in opposite direction by hand and release.
3. Note down the time required for particular number of oscillations.
4. Fit the cross arm to one of the disc say A and again note down the time.
5. Repeat the procedure with different equal masses attached to the ends of the cross arm and note down the time.

OBSERVATIONS:

Sr. No.	Mass attached on arm m_{A1} kg	Theoretical values						Experimental values			
		I_A	I_B	L_A	L_B	T_{th}	f_{th}	Number of oscillations selected, n	Time for n oscillations	T_{exp}=t/n	f_{exp}=1/T
1											
2											
3											
1											
2											
3											

CALCULATIONS:

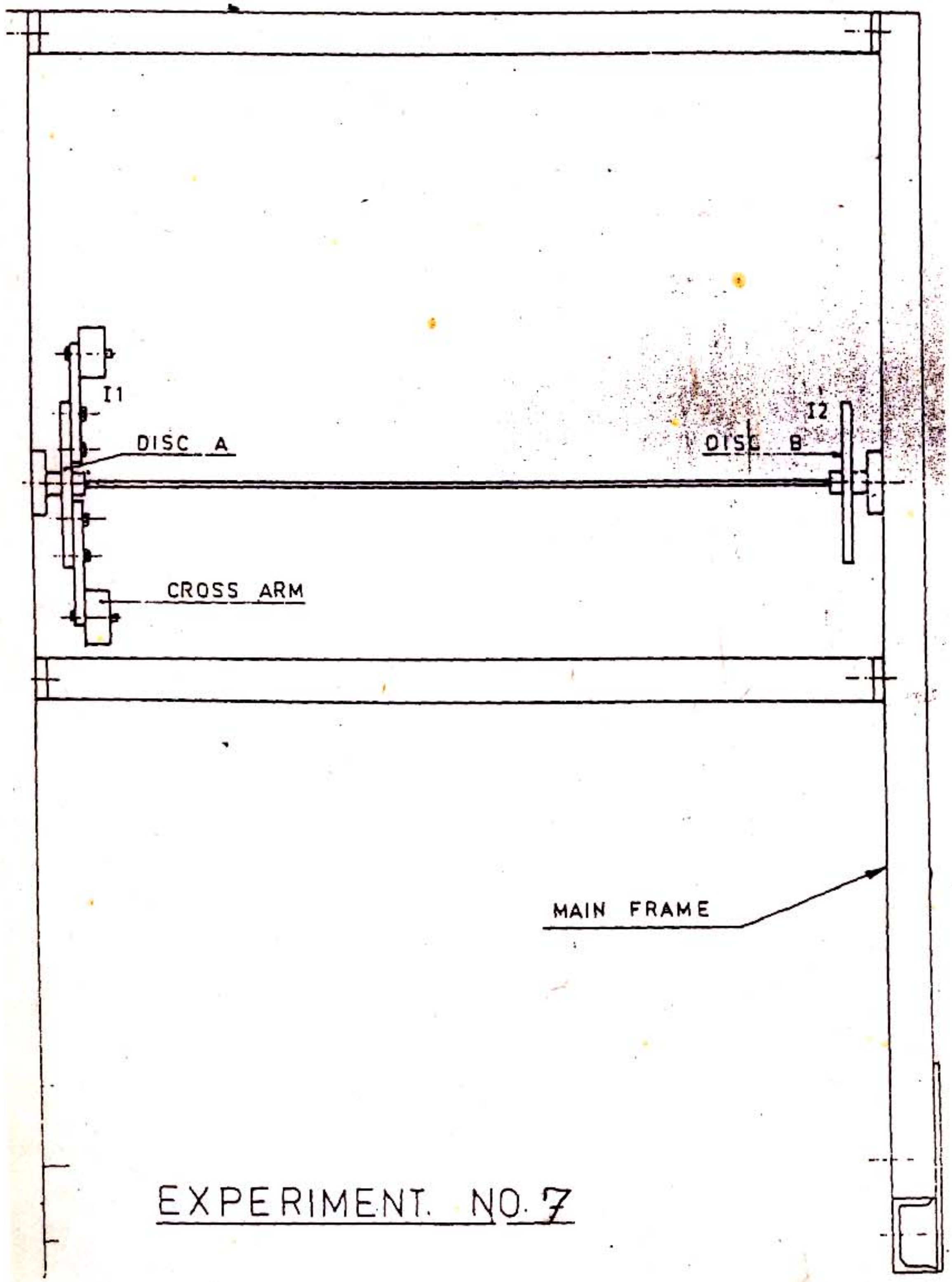
1. $I_A = (m_A D_A^2 / 8) + (2m_{A1} R^2 / 8)$
2. $I_B = (m_B D_B^2 / 8)$
3. $J = (\pi d^4 / 32)$
4. Natural frequency of torsional vibration (theoretical)

$$f_{th} = \frac{1}{2\pi}\sqrt{\frac{C * J}{I_A * L_A}} = \frac{1}{2\pi}\sqrt{\frac{C * J}{I_B * L_B}}$$

$I_A * L_A = I_B * L_B$

CONCLUSION:

The experimental and theoretical values of natural frequency of torsional vibration should be same.



EXPERIMENT. NO. 7

Vib. Lab Apparatus

EXPERIMENT - 5

AIM: To analyse the motion of a motorized gyroscope when the couple is applied along its spin axis.

APPARATUS:
Motorised gyroscope, weights, and voltage regulator.

THEORY:
The angular velocity is a vector quantity and change in its magnitude can be caused by acceleration. To create this angular acceleration a torque or couple is required. To keep this angular velocity constant in magnitude due to the angular acceleration caused by the couple the spinning mass of the gyroscope undergoes a change called the angle of precession. This cause the gyroscopic couple to incline to a certain degree so that it can retain its angular velocity. This angle of precession for different torques and couple can be analysed by this experiment.

FIGURE:

SPECIFICATIONS:

Moment of inertia of disc, I	= $0.8 * 10^{-2}$ kg-m^2
Distance of point of application of load from center of disc, L	= 0.22 m
Maximum speed of motor	= 6000 rpm

PROCEDURE:
1. Set the rotating disc of the gyroscope in motion.
2. Increase the speed of motor from 1000 rpm to 3500 rpm gradually in steps.
3. Put weights in pan from 50 gm to 2500 gm for creating couple at defined speed in steps.
4. Observe the axis of spin will precess to a certain degree to retain the angular velocity.
5. Measure the angle of precession for the respective speed and weight.
6. Take the readings for the change in angle of precession in constant period say 15°.

OBSERVATIONS:

Sr. No.	Speed	ω rad/sec	Weight in pan W kg	$\delta\theta$ in deg	δt in sec	$\omega_p = \delta\theta / \delta t$	Torque kg-m (theoretical) W*L	Gyroscopic couple $I * \omega * \omega_p$

CALCULATIONS:

1. Theoretical torque = W * L kg-m

   Where, L is distance of point of application of load from the center of disc

   is 0.22 m

   W is weight in pan in kg

2. Gyroscopic couple = I* $\omega * \omega_p$ kg-m

   Where, I is moment of inertia of disc = 0.8 * 1^{-2} kg-m^2

   ω is angular velocity of disc in rad/sec

   ω_p is velocity of precession rad/sec

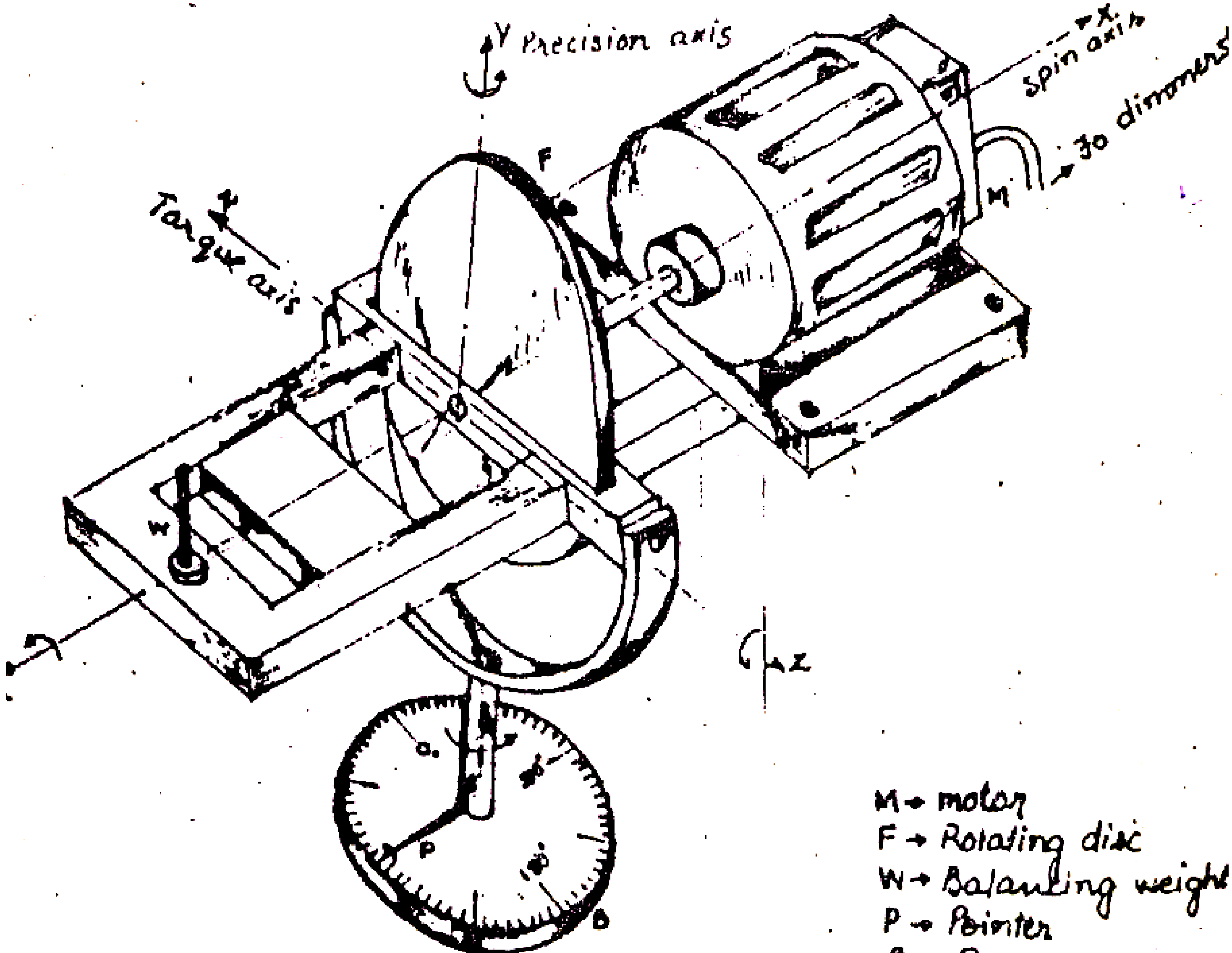
CONCLUSION:

1. Theoretical torque / couple is kg-m
2. Gyroscopic couple is kg-m

From the above results it can be concluded that the theoretical and practical couples produced conform to the principle of gyroscope.

PRECAUTIONS:

1. Increase the speed of the motor gradually in the range given.
2. Do not add large weight on the weight pan.
3. Always maintain safe distance from the apparatus.



M → motor
F → Rotating disc
W → Balancing weight
P → Pointer
B → Base

EXPERIMENT - 6

AIM: To determine the frequency of undamped free vibration of an equivalent spring mass system.

/

THEORY:

The vibrations the system executes under no damping condition is known as undamped vibrations. Neglecting damping is also considered as undamped situation. When no external force is acts on the body after giving an initial displacement then the body is said to be under free or natural vibrations. The frequency of the free vibrations is called free or natural frequency and denoted by f_n. simple pendulum is an example of undamped free vibrations.

FIGURE:

PROCEDURE:

1. Support one end of the beam in the slot of trunion and clamp it by means of screw.
2. Attach the other end of the beam to the lower end of the spring.
3. Set the beam in the horizontal position.
4. Measure the distance LI of the assembly from pivot.
5. Allow the system to vibrate.
6. Measure the time for say 10 oscillations and find the periodic time and natural • frequency of vibration.
7. Repeat the experiment by varying L_1.

OBSERVATIONS:

Sr. No.	L1	w	No of oscillations, n	Time for n oscillations, sec	Periodic time, T (theo)	Natural frequency f_n (theo)	Periodic time, (T = t/n) (expt)	Natural frequency f_n (expt) (fn = 1/t)

CALCULATIONS:

1. Periodic time T (theoretical)

$$T = 2\pi\sqrt{\frac{m_e}{K}}$$

where rrie equivalent mass at the spring = m (L_1^2 / L^2)

K = stiffness of the spring 0.3 kg/mm

m = (W + w) / g

w = weight attached to exciter assembly

W = weight of exciter assembly = 4.44 kg

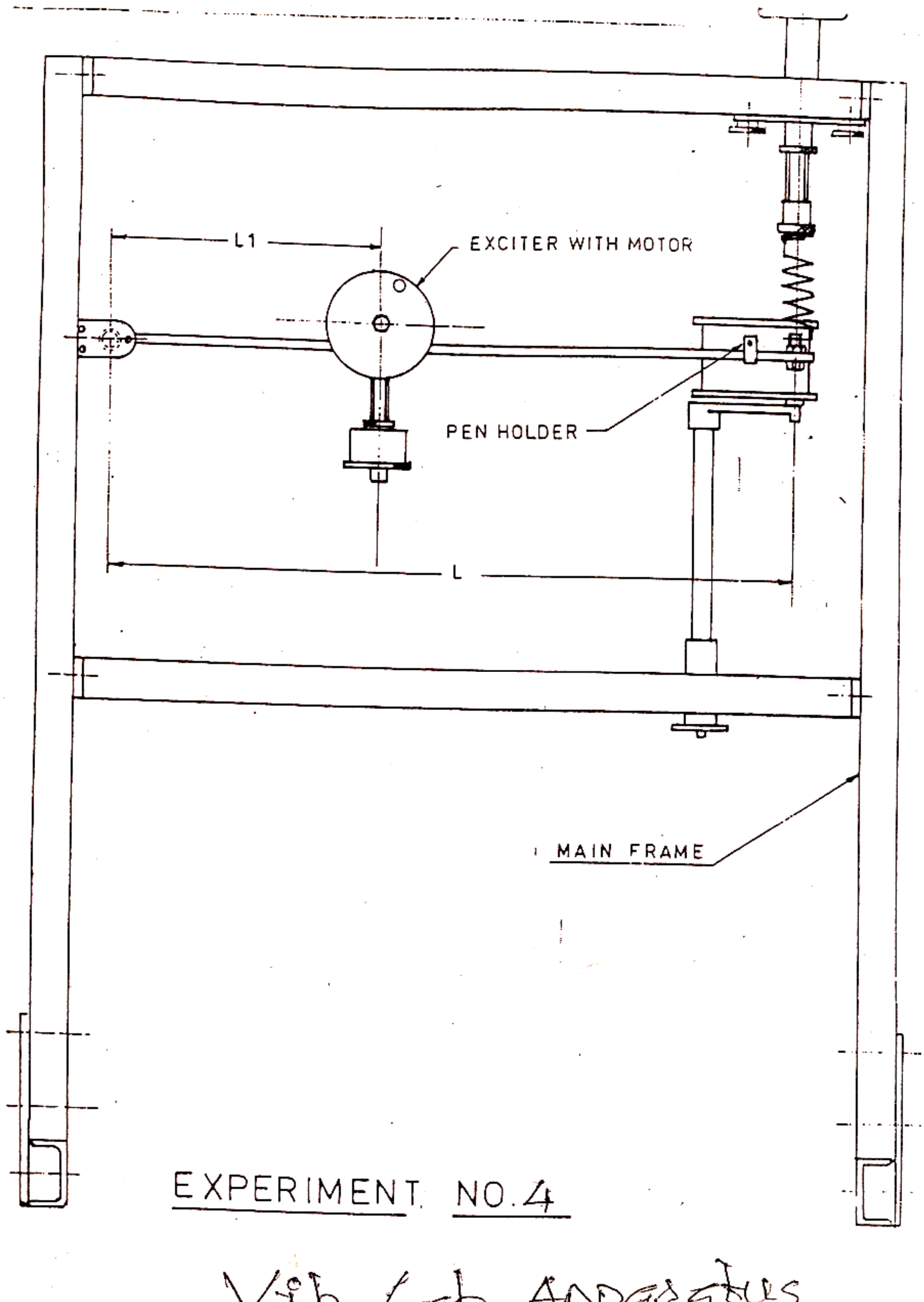
LI distance of W from pivot = 0.25 m

L is distance of spring from pivot 0.94 m

CONCLUSION:

1. The theoretical natural frequency is
2. The experimental natural frequency is

It is to conclude that the theoretical and experimental natural frequency of vibration is almost equal.



EXPERIMENT NO.4

Vib. Lab. Apparatus

EXPERIMENT - 7

AIM:
To determine the frequency of damped force vibration of a spring mass system.

APPARATUS:
Spring mass system, damper, exciter unit, voltage regulator and strip-chart recorder.

THEORY:
The vibration that the system executes under damping system is known as damped vibrations. In general all the physical systems are associated with one or the other type of damping. In certain cases amount of damping may be small in other case large. In damped vibrations there is a reduction in amplitude over every cycle of vibration. This is due to the fact that a certain amount of energy possessed by the vibrating system is always dissipated in overcoming frictional resistances to the motion. The rate at which the amplitude of vibration decays depends upon the type and amount of damping in the system. Damped vibrations can be free vibrations or forced vibrations. Shock absorber is an example of damped vibration. Mainly the following two aspects are important while studying damped free vibrations:

1. The frequency of damped free vibrations and
2. The rate of decay.

FIGURE:

PROCEDURE:

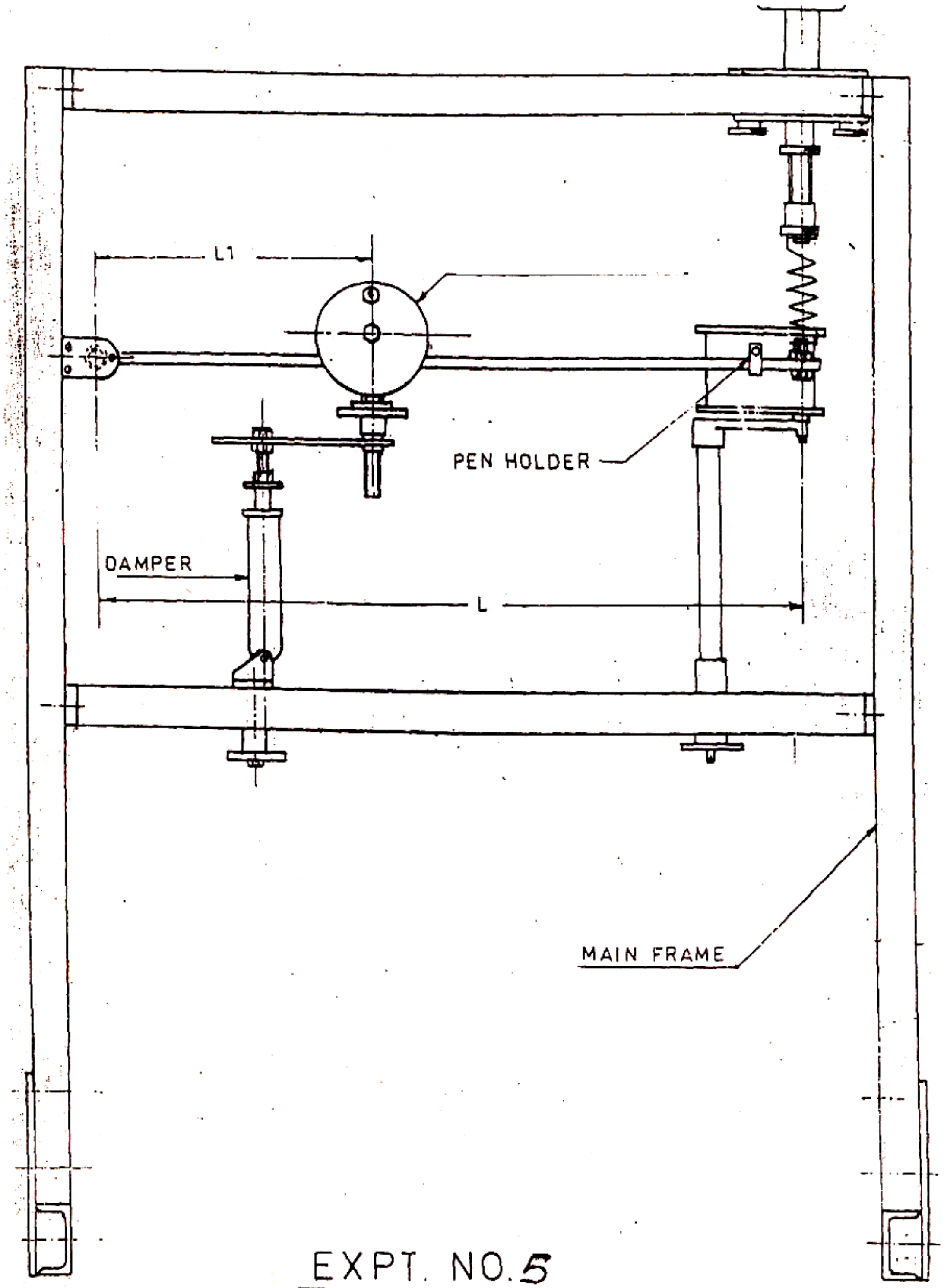
1. Connect the exciter to D.C. motor.
2. Start the motor and allow the system to vibrate.
3. Wait for 3 to 5 minuets for the amplitude to build for particular forcing frequency.
4. Adjust the position of strip-chart recorder. Take the record of amplitude Vs time on the strip-chart.
5. Take record by changing forcing frequency.
6. Repeat the experiment for different damping. Damping can be changed adjusting the position of the exciter.
7. Plot the graph of amplitude Vs frequency for each damping condition.

OBSERVATIONS:

Sr. No.	Number of oscillations, n	Time required for n oscillations, t	Periodic Time, T	Forcing frequency, f = 1/T	Amplitude, mm

CONCLUSION:

1. From the graph it can be observed that the amplitude of vibration decreases with time.
2. Amplitude of vibration is less with damped system as compared to undamped system.



EXPT. NO.5

Vib Lab Apparatus

EXPERIMENT NO – 8

AIM: To study the static and dynamic balancing using rigid blocks.

DYNAMIC BALANCING MACHINE

DESCRIPTION:

The apparatus basically consists of main Steel shaft mounted in ball bearings on either side in a rectangular frame. Set of four blocks of regid different weights are provided and it can be clamped in any position on the shaft: which can also be easily detached.

A protractor scale in fitted to one side of the rectangular frame shaft carries a disc ani rim of this disc is grooved to locate the Weighing, balance card provided with two metal containers of equal weight.

A scale io fired to.the bottom member of the frame and when used along with the circular protractor scale, allows the exact longitudinal and angular position of pa oh adjustable block to be determined.

The shaft ia driven by a fractional IIP AC motor, fixod below the frame with rubber belt,

For Static Balancing of individual weights the frame is rigidly fixed to the support frame by nut bolts and at that position the motor driving belt is disconnected. Wr x No.of balls.

For dynamic balancing of the rotating mass system the frame is suspended by the support-frame by two chains in which the frames are in same place»

STATIC BALANCING

The block is finally fixed at 90° to the frame and the belt is removed. The value of v/r. for each block is determined by fixing block in 90° to 0 position on the shadt. The cord and pan 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. So that the block should come back to original 90°. The number of balls 'N' will give the value the wr for the block.

PROCEDURE OT FIND: UT_wr BY STATIC BALANCING METHOD

Attach the balance frame to main frame firmly. Insert the Card with pan to i he grooved, pulley provided. Set the unit to 0 position.

Values of Static balancing for cull the M sights will be arrived when we are conducting. the experiment on Dynamic Balancing.

Now keep the block in a suitable position as reference and fix the 2nd block in any convenient position say 3 cm to left.

Now draw forco and couple polygons and find out the position of the other 2 bolcks and fix it to get complete balance.

Now hang the frame by chain and couple it with motor and run the motor by suing electric dimmer to a rated speed.

By this way we can balance the machine.

If the calculation is not correct then the unit will vibrate. That indicates there is something calculation mistake at the time of drawing force and couple polygon.

Attach any block to the shaft at any position.
Put steel balls in one of the pans to bring the block to original 90^o position.

Number of balls proportional to the 'Wr' value of block.

Repeat the experiment for other three blocks.
Wr x No. of balls.

TYPICAL RESULTS: (For illustration of Experimental Calculations)

EXPERIMENTS

To statically and dynamically balance a four place rotating mass system, Block No. 2 is to be positioned 90^0 anticlockwise and 3 cms. Along the shaft from block no. 1. Determine the angular and longitudinal positions of blocks 3 to 4 for perfect balance.

CALCULATION FOR STATIC AND DYNAMIC BALANCE

SCALE : 1 CM = 20 Balls SCALE

Block 1.	$W_1 r_1$ -	148 No of balls	7.4 cm
Block 2.	$W_2 r_2$ -	75 No of balls	3.75 cm
Block 3.	$W_3 r_3$ -	124 No of balls	6.2 cm
Block 4.	$W_4 r_4$ -	168 No of balls	8.4 cm

FORCE POLYGON is drawn to find out the angular position of block 3 & 4. The longitudinal positions of 3 & 4 are l and m from (reference).

Take W_1 r_1 = 3 CM to Reference --------- 0

0 = W_2 r_2

SCALE 40 = 1

CM

W_1 r_1 1_1 ----------- 148 x 3 (CM) = -444. 11. 4

W2 r2 12 -------------------- 0

W3 r3 13 ------------------------ 11. 6 X 4 0 (from couple polygon)

W4 r4 14 ------------------------- 8 . 15 x 4 0 (from couple polygon)

W1 r1 11 = 148 x 3 (fixed) left.

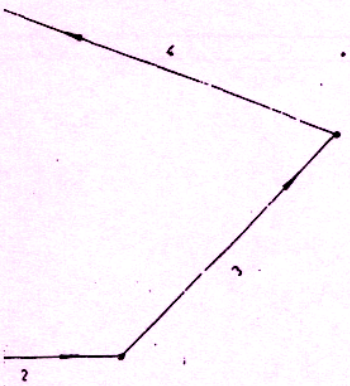
W3 r3 13 = 11 . 6 x 40

$$13 = \frac{11.6 \times 40}{124} = 3.75 \text{ cn} \quad \text{(to the right)}$$

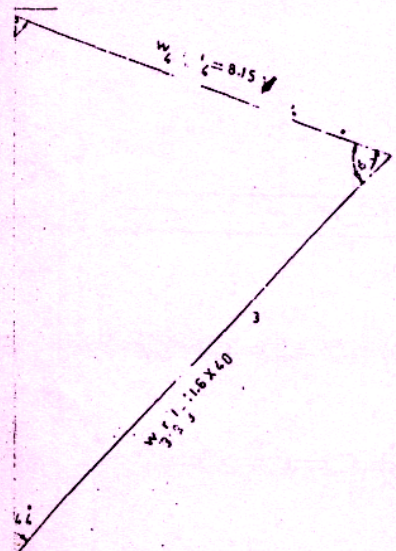
W4r4 14 = 8.15 x 40

$$W4 = \frac{8.15 \times 40}{168} = 1.95 \text{ cm} \quad \text{(to the right)}$$

FORCE POLYGON



COUPLE POLYGON



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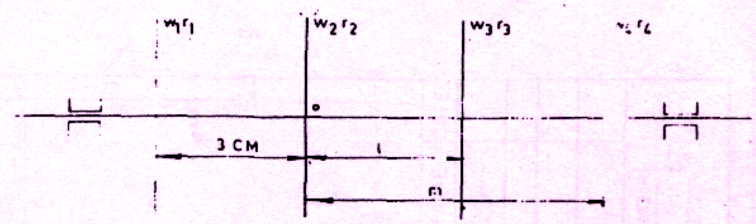

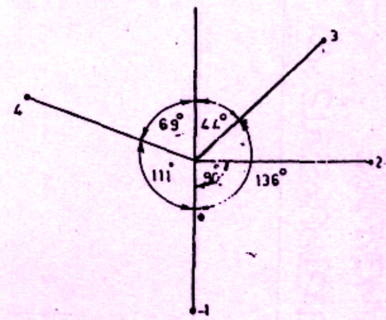

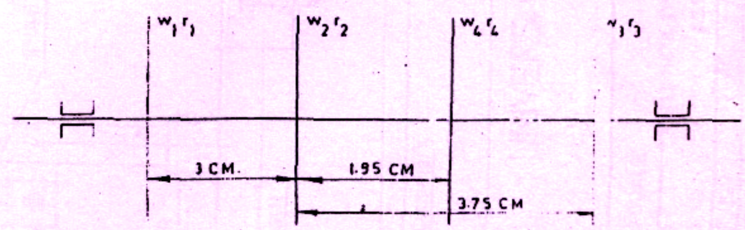

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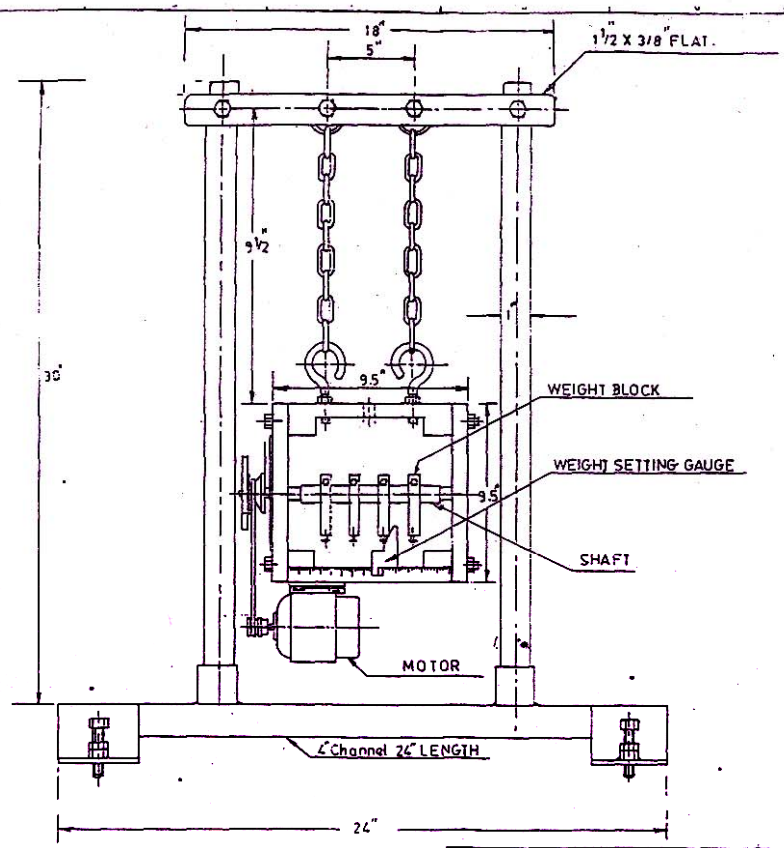

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