ME-405L Mechanical Vibrations Lab

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Experiment 0. Lab Guidelines

0.1 Course Learning Outcomes (CLOs)

Lab CLOs

Table 0.1-1: Course learning outcomes of ME-405L Mechanical Vibrations Lab

Sr. #	CLO Statement	Domain	Level	PLO
1	**DISPLAY** basic proficiency in operation of the apparatus and **PERFORM** the experiment to determine the solution of the engineering problems related to the subject.	Psychomotor	4	4
2	**Communicate** the learned concepts using different media i.e., verbal and written.	Affective	2	10
3	**Manifest** the professional responsibilities and norms of engineering practice.	Affective	3	8

CLO's mapping with PLO's

Table0.1- 2:Relation of CLOs of Mechanical Vibrations Lab with PLOs

PLO #	PLO Statement	CLO1	CLO2	CLO3
PLO-1	**Engineering Knowledge**			
PLO-2	**Problem Analysis**			
PLO-3	**Design/Development of Solution**			
PLO-4	**Investigation**	✓		
PLO-5	**Modern Tool Usage**			
PLO-6	**The Engineer and Society**			
PLO-7	**Environment and Stability**			
PLO-8	**Ethics**			✓
PLO-9	**Individual and Team Work**			

PLO-10	**Communication**		✓	
PLO-11	**Project Management**			
PLO-12	**Life Long Learning**			

Lab report must be submitted/checked within **7 days effectively** after the experiment is conducted. Lab report may not be accepted/checked after due date and lab report marks may be deducted.

0.1.1 Content

The content contain guidelines about the report structure, the constituent headings and content to be written under the headings.

0.1.1.1 Cover Page

The cover page should contain the followings

- Lab Name
- Experiment Name
- Students' Name
- Group #
- Lab Instructor Name
- Date on which lab Experiment was conducted (See the Lab schedule for it)
- Submission date of Lab Report

The format and Alignment and arrangement of above mentioned is student's own choice.

0.1.1.2 Abstract

The abstract contains summary lab activity done and contains the following main points.

1. Purpose/ objective(s) of the experiment
2. Main results in the experiment
3. Main results of experiment
4. Main conclusion

The abstract should be of one paragraph with words not more than 200 words.

0.1.1.3 Introduction

This section is meant for describing the worth/importance/significance of your work. As a part of arguments for proving your work a useful one it is logical to briefly point out the similar work already done by others but a detailed literature review is not a part of introduction.

As a part of description of the importance of work you may also justify your choice of problem solution methodology. When there are potentially more than one approaches available for the solution of the same problem; it is logical to opt for the best available choice giving due regard to the resource constraints.

Through introduction of the report you try to convince the reader that your work is really useful. According to a researcher "Introduction is setting up the scene".

Wherever necessary there may be a separate section of theory but it must not be dragged into introduction.

0.1.1.4 Theory

It is an optional section and is included to appraise the reader the theory of your work. In the lab reports we normally do not recommend to include this section.

0.1.1.5 Procedure

In this section it is recommended to enlist the sequential steps for taking proper data. Wherever applicable a block diagram of the experimental set up is to be included. The diagrams should be properly labeled.

While writing a lab experiment procedure do not adopt the style of instructor. It is generally recommended to use past tense and passive voice. In technical writings the use of "I" and "We" is generally not appreciated.

0.1.1.6 Observations & calculations

It includes tabulation of observed data and calculations are required to be made for the meaningful analysis of results. Formulae involved in calculations need to be mentioned along with a sample of calculations. Graphical representation is a more effective way (than tabulation) of the presentation of results.

0.1.1.7 Conclusions

The conclusion expresses the main points (one or two) of the final results the lab.

0.1.1.8 Discussion

In this section you are supposed to justify your results. The expected results need to be justified with the help of some standard references. Reasons should be mentioned for the unexpected results. In this case all possible sources of error need to be looked at while giving consideration to the individual contribution of each source of error towards the overall error in the final results. Comparison of results with similar investigations (already made using same or different technique) is an essential component of the discussion section of a report.

0.1.1.9 References

Whatever information (other than own work of present report) has been used in writing of report needs to be properly referred (using a standard format of referring a book, a paper of a journal, a paper of a conference and information on a website). It is not sufficient to put a list of references at the end of a report. These references should also appear as numbers in square brackets in the main body of report.

0.1.2 Format

From **Semester 1** to **semester 4**, the report to be submitted containing the content as mentioned above, should be hand written. For **Semester 5 to Semester 8**, report to be submitted should be written on computer.

The following format should be followed for writing report on computer

Title page should always be documented on computer.

- **Font** should be **Times New Roman** (Whole Report)
- **Line Spacing** = 1.15 (whole report)
- **Title** should be of **font size = 16, Bold,**
- **Heading 1** should be of **font size = 14, Bold**
- **Heading 2** should be of **font size = 13, Bold**
- **Heading 3** should be of **font size = 12, Italic, Bold**
- **Page #** should be added.
- List of figure, List of table and Table of content**.**

0.1.3 Caption

For table: Above the Table aligned in center with table. **Font size: 10**

For Figure: Below the Figure aligned in center with figure. **Font size: 10**

0.1.4 References

Should be added in **IEEE format** using Endnote/word.

0.2 General Guidelines in a Lab for safety

The following guidelines are to be followed in a lab.

- No Laboratory work should be carried out without supervision of the Instructor or Lab technician.
- Do only experiment assigned to you and do not perform unauthorized experiment by yourself.
- Do not play with the equipment that are not part of experimental setup.
- Never leave an in progress experiment unattended.
- Don not exceed voltage limits of devices when plugging them into electrical outlets.
- Don not try to repair or modify any lab equipment.
- Always wear a protective lab coat/overall and safety shoes. Long hair should be tied back.
- Be alert to unsafe conditions and actions and call them to the attention of the instructor immediately.
- Be careful not to touch any heated surfaces as they might cause a burn.
- Don’t touch live conductor or wire with the bare hand.
- Don’t work in lab all alone.
- Report all damages to lab instructor immediately.
- Leave equipment in proper places at the end of your experiments and cleanup.
- After completion of the experiments, return the items borrowed, if any.
- Don’t run or paly in the lab.
- Eating drinking, smoking or chewing of gum is not permitted in the laboratory.
- Don’t use cell phones inside the laboratory.
- Everyone is responsible for housekeeping and cleaning up after themselves. Aisles and doorways, including access to the service hallway and electrical boxes, are to be kept clear for purposes of safe passage.
- Report any cases of vandalism or theft to your instructor or staff member.
- Students should not perform any type of maintenance on equipment in the lab without prior authorization and direct supervision of the lab manager.
- Use appropriate safety equipment for the task at hand (i.e. safety glasses, ear protection, gloves). See your instructor or a staff member for guidance.
- In case of fire or hazardous chemical spill evacuate the premises immediately.

Experiment 1. Mass Spring System

1.1 Objectives

1. To determine the stiffness of a helical spring.
2. To determine natural frequency of mass-spring system

1.2 Apparatus

i. Wall mounted Mass-Spring system,
ii. Springs,
iii. Hangers with weights (50g)

1.3 Theory

The spring-mass system in Figure-1 shows an extension linear helical spring with an initial free length L_i, effective mass m_s, supported vertically from one of its ends; while the other end is free to elongate and attached to a load-carrier of mass m_c. The free length of the spring loaded with the load carrier alone is L_o. Disks each of (m_d = 50g) mass are added to the carrier gradually, and each loading state causes the spring to elongate by the distance δ from its unloaded length L_o to get a total length of L.

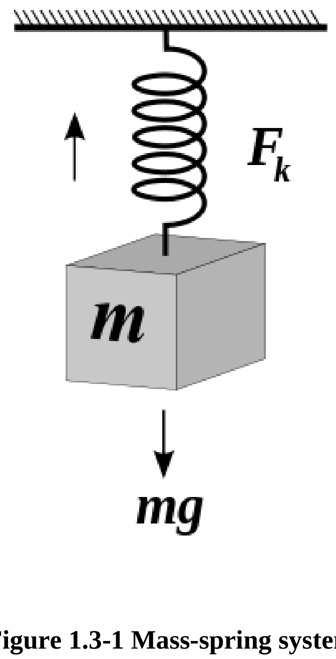

Figure 1.3-1 Mass-spring system

For the spring-mass system shown in Figure-1, in the case of free vibration in the vertical direction Y, the equation of motion of the system is given by:

➢ $M\ddot{y} + Ky = 0$ (1)

Where:

M is the total mass of the system, and equals to:

$$M = m + m_C + m_S$$

m is the total mass of the disks:

$$m = \sum m_d$$

From the equation of motion, we can find that:

- Natural frequency (Theoretical)= $\omega_n = \sqrt{\frac{k_{th}}{M}}$ (2)
- Natural Frequency (Experimental)= $\omega_n = {2\pi}/{\tau}$ (3)
- Period of oscillation= $\tau = \frac{2\pi}{\omega_n} = 2\pi\sqrt{\frac{M}{k}} = 2\pi\sqrt{\frac{m + m_C + m_S}{k}}$ (4)

For a helical spring, the theoretical formula for stiffness is as below:

- $K = \frac{Gd^4}{8ND^3}$ (5)

1.4 Mass Spring System

1.4.1 Procedure

1. Hang the spring vertically with the load carrier attached to its end, and then measure the total length of the spring L_o.
2. Add one disk to the carrier ($m = m_d$), and measure the total length of the spring after elongation L.
3. With this loading, stretch the spring downward, then leave it to oscillate freely and record the time needed to complete ten oscillations T.
4. Add another disk so that ($m = 2m_d$), and repeat steps-2 & 3.
5. Continue by adding a disk each time, and each time measure the parameters L and T.

1.5 Observations and Calculations

Table 1.5-1: Load and corresponding Deflections

Trial	m (kg)	Deflection L (mm)	
		Loading	Unloading
1			
2			
3			
4			
5			

Table 1.5-2: Load and corresponding time period

Trial	m (kg)	Time for __ Oscillations (Sec)	
		Loading	Unloading
1			
2			
3			
4			
5			

Table 1.5-3: Spring Parameters

Parameters	Value
N (turns)	
D (mm)	
d (mm)	
L_o (cm)	

Table 1.5-4: Load, time period and its square values

Trial	m (kg)	τ (second)	τ^2
1			
2			
3			
4			

5			
6			
7			
8			
9			
10			

Table 1.5-5: Theoretical and experimental values of ωn

Trial	**m (kg)**	**ω_n (experimental) (cps)**	**ω_n (Theoretical) (cps)**	**Percent Error (%)**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

1.6 Graphs

1.7 Results

Table 1.7-1: 'k' values

Spring Stiffness k			
K (theoretical) = ………………….. (N/m)			
From:	**Slope**	**k (N/m)**	**Percent Error (%)**
Graph-1			
Graph-2			

1.8 Springs in Series and Parallel Combination

1.8.1 Objective

1. To determine the stiffness of a helical spring.
2. To determine natural frequency of mass-spring system

1.9 Theory

1.9.1 Springs in Series

Springs are said to be in series when they are connected end to end or point to point. In this combination each spring experiences the same pull from the weight of the mass it supports. Therefore each spring extends the same amount as an individual spring would do. The combination therefore is more 'stretchy' and the effective spring constant for the combination will be half that of a single spring for two in series, a third for three in series etc.

For two springs, formula for Equivalent Stiffness (K_{eq}) is:

$$K_{eq} = (1/k_1 + 1/k_2 + 1/k_3 + \ldots\ldots + 1/k_n)^{-1} \quad (6)$$

Figure 1.9-1: Series Spring configuration

1.9.2 Springs in Parallel

Springs are said to be in parallel when they are connected side-by-side. The weight is supported by the combination. They share the load and therefore are not stretched as much as they would be if they were on their own supporting the load. The combination therefore is less stretchy and the effective spring constant for the combination will be twice that of a single spring for two in parallel, a three times for three in parallel etc.

For ‘n’ number of springs, formula for Equivalent Stiffness (K_{eq}) is:

$$K_{eq} = k_1 + k_2 + k_3 + \ldots\ldots + k_n \quad (7)$$

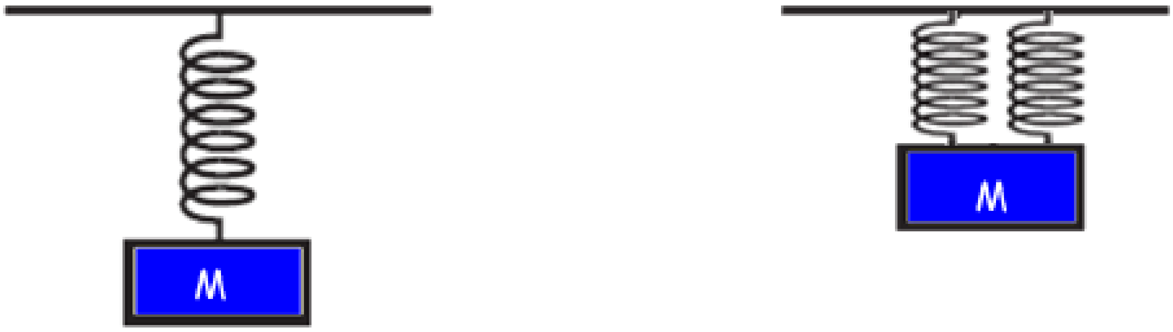

Figure 1.9-2: Parallel Springs Configuration

1.10 Springs in Series Combination

1.10.1 Procedure

Same as in above experiment.

1.10.2 Observations and Calculations

Table 1.10-1: Load and Corresponding deflections

Trial	m (kg)	Deflection L (mm)	
		Loading	Unloading
1			
2			
3			
4			
5			

Table 1.10-2: Load and corresponding time period

Trial	m (kg)	Time for ___ Oscillations (sec)	
		Loading	Unloading
1			
2			
3			
4			
5			

Table 1.10-3: Spring parameters

Parameter	Value
N (turns)	
D (mm)	
d (mm)	
L_o (cm)	

Table 1.10-4: Load and time period values

Trial	m (kg)	τ (second)	τ^2
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Table 1.10-5: Theoretical and experimental values of ωn

Trial	m (kg)	ω_n (experimental) (cps)	ω_n (Theoretical) (cps)	Percent Error (%)
1				
2				

3				
4				
5				
6				
7				
8				
9				
10				

1.10.3 Graphs

1.10.4 Results

Table 1.10-6: 'k' values

Spring Stiffness k			
K (theoretical) = ………………….. (N/m)			
From:	Slope	k (N/m)	Percent Error (%)
Graph-1			
Graph-2			

1.11 Springs in Parallel Combination

1.11.1 Procedure

Same as in above experiment.

1.11.2 Observations and Calculations

Table 1.11-1: Load and corresponding deflections

Trial	m (kg)	Deflection L (mm)	
		Loading	Unloading
1			
2			
3			
4			
5			

Table 1.11-2: Load and corresponding time period

Trial	m (kg)	Time for ___ Oscillations (Sec)	
		Loading	Unloading
1			
2			
3			
4			
5			

Table 1.11-3: Spring parameters

Parameter	Value
N (turns)	
D (mm)	
d (mm)	
L_o (cm)	

Table 1.11-4: Load and time period values

Trial	m (kg)	τ (second)	$τ^2$
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Table 1.11-5: Theoretical and experimental values of ωn

Trial	m (kg)	$ω_n$ (experimental) (cps)	$ω_n$ (Theoretical) (cps)	Percent Error (%)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

1.11.3 Graphs

1.12 Results

Table 1.12-1: 'k' values

Spring Stiffness k			
K (theoretical) = ………………….. (N/m)			
From:	**Slope**	**k (N/m)**	**Percent Error (%)**
Graph-1			
Graph-2			

1.13 Discussion and Conclusion

Experiment 2.

2.1 Objective

To study the torsional oscillations and to determine the natural frequency of single and double rotor system experimentally and theoretically.

2.2 Theory

A torsional spring is one of the many types of springs used in mechanical devices. Unlike extension and compression springs, which work with pushing and pulling types of forces, torsional springs are used when a twisting force is involved. These work by storing rotational mechanical energy when a force is applied, and exert a torque in the opposite direction of said force. Some of the examples of torsion springs are: sway bar in vehicles, lids, door hinges, hatches, clocks etc. Similar to extension springs, a release in applied force causes the spring to oscillate; twisting and untwisting till the spring loses energy to friction. This experiment is designed to analyze this very behavior by calculating the resonant frequency of the spring experimentally as well as theoretically. The values are subsequently compared to verify the theory.

2.3 Apparatus

Figure 2.3-1: Torsional Oscillation apparatus.

Procedure

1. Fix one or two disc of the shaft and fit the shaft in the bearing.
2. Deflect the disc in opposite direction by hand and then release.
3. Note down the time required for particular number of oscillations.
4. Repeat the procedure note down the time**.**
5. Perform the necessary calculations from data obtained.

2.4 Observations and Calculations

2.4.1 Moment of Inertia

$$I = \frac{1}{2} m r^2$$

Where,

- m = Mass of the disc(s) involved (kg)
- r = Radius of disk (m)

2.4.2 Stiffness of Spring

$$K_t = \frac{Ed^4}{64ND}$$

Where,

- E = Modulus of elasticity
- d = Wire diameter
- D = Spring nominal diameter
- N = Number of active turns

2.4.3 Natural Frequency of Spring

$$\omega_{Theory} = \sqrt{\frac{k_T}{I}}$$

From time measurements, the natural frequency is equal to:

$$\omega_n = \frac{2\pi}{\tau}$$

2.5 Single Rotor System

Calculations of I, K_{th} and theoretical natural frequency.

4.

Table 2.5-1: For single rotor

Serial No.	Time for 10 Oscillations	Time Period (Seconds)	Experimental Natural Frequency	Percent Error
1.				
2.				
3.				
4.				
5.				

2.6 Double Rotor System

Calculations of I, K_{th} and theoretical natural frequency.

Table 2.6-1: For double rotor system

Serial No.	Time for 10 Oscillations	Time Period (Seconds)	Experimental Natural Frequency	Percent Error
1.				
2.				
3.				
4.				
5.				

2.7 Discussion and Conclusion

Experiment 3. Torsional Oscillations-Wire

3.1 Apparatus

i. Wire
ii. Disk
iii. Stopwatch
iv. Hanger

3.2 Introduction

A torsional pendulum, or torsional oscillator, consists of a disk-like mass suspended from a thin rod or wire. When the mass is twisted about the axis of the wire, the wire exerts a torque on the mass, tending to rotate it back to its original position. If twisted and released, the mass will oscillate back and forth, executing simple harmonic motion. This is the angular version of the bouncing mass hanging from a spring. This lab will give you a better grasp of the meaning of moment of inertia.

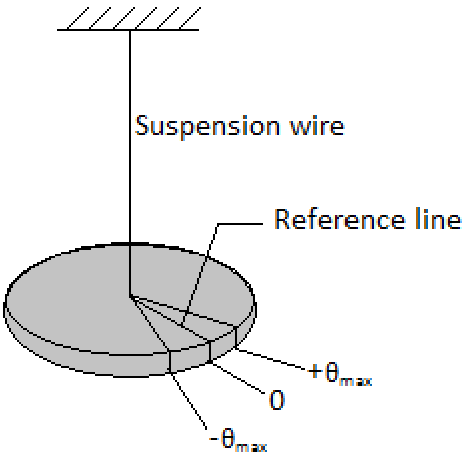

Figure 3.2-1: Torsional Apparatus

3.3 Theory and Mathematical Formulas

Consider a thin rod with one end fixed in position and the other end twisted through an angle θ about the rod's axis.

If the angle θ is sufficiently small that the rod is not plastically deformed, the rod exerts a torque τ proportional to the angle θ

$\tau = -\kappa\theta$ ------------- (1) (like $F = -k\,x$ for a spring)

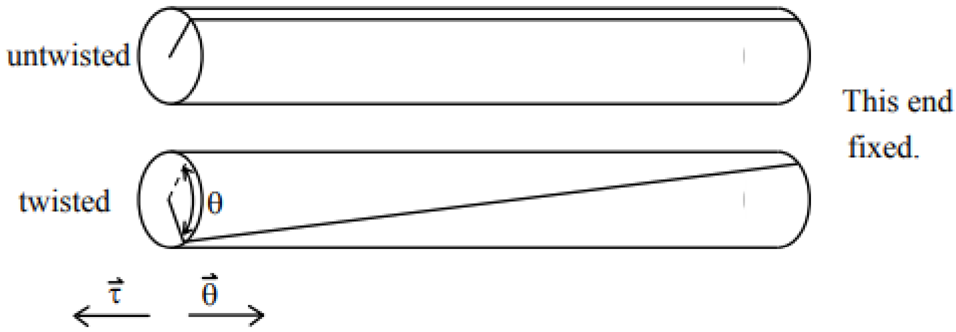

Figure 3.3-1

Where κ (Greek letter kappa) is called the torsion constant. The minus sign indicates that the direction of the torque vector G, τ is opposite to the angle vector G θ, so the torque tends to undo the twist. This is just like Hooke's Law for springs. If a mass with moment of inertia I is attached to the rod, the torque will give the mass an angular acceleration α according to

$$\tau = I\alpha = I\frac{d^2\theta}{dt^2} \text{------------- (2)} \qquad \left(\text{like } = ma = m\frac{d^2x}{dt^2}\right)$$

Combining (1) and (2) yields the equation of motion for the torsional pendulum,

$$-\kappa\theta = I\frac{d^2\theta}{dt^2} \text{------------- (3)} \qquad \left(\text{like } = ma = m\frac{d^2x}{dt^2}\right)$$

$$-\frac{\kappa\theta}{I} = \frac{d^2\theta}{dt^2} \text{------------- (4)}$$

The solution to this differential equation is

$$\theta(t) = \theta m\cos(\omega t + \varphi) \text{ ---------- (5)} \qquad (\text{like } x\,(t) = xm\cos(\omega t + \varphi))$$

$$\omega = \left(\frac{\kappa}{I}\right)^{\frac{1}{2}} \text{ ---------- (6)} \qquad \left(\text{like } \omega = \left(\frac{k}{m}\right)^{\frac{1}{2}}\right.$$

Where θ_m and ϕ are constants which depend on the initial position and angular velocity of the mass. (The equation of motion is a second order differential equation so its solution must have two constants of integration.) θ_m is the maximum angle; θ oscillates between $+\theta_m$ and $-\theta_m$.

The constant ω is related to the frequency f and the period T of the simple harmonic motion by

$$\omega = 2\pi f = \frac{2\pi}{T} \qquad \text{--------------- (7)}$$

So, from (6) and (7), the period T is given by

$$T = 2\pi\left(\frac{I}{\kappa}\right)^{\frac{1}{2}} \qquad \text{------------------- (8)}$$

The torsion constant can be determined from measurements of T if I is known

$$\kappa = 4\pi^2\frac{I}{T} \qquad \text{------------------ (9)} \qquad \text{(experimental)}$$

$\kappa = \frac{JG}{L}$ ------------------- (10)

Where J= Second polar moment of area

G= Shear modulus

L= Length of wire

3.4 Procedure

1. Clamp wire from one end that is fixed end.
2. Suspend the rigidly attached disk to the wire from other end.
3. Measure the length and diameter of wire.
4. Measure diameter and thickness of disk.
5. Rotate the disk slightly. And allow it to oscillate.
6. Using stopwatch measure time period of 6-7 oscillations and evaluate of time period of one vibration. And repeat this step 4-5 times
7. Take average time period
8. Calculate mass of disk.
9. Calculate moment of inertia I of disk.
10. Calculate polar moment of area of disk.
11. Calculate theoretical and experimental torsional spring constant and compute.

3.5 Observation and Calculations

Diameter of Wire =

Diameter of Disk =

Thickness of Disk =

Length of Wire =

Density of Material of Disk =

Average Time period (T) =

Theoretical Torsional Spring Constant (κ) =

Experimental Torsional Spring Constant (κ) =

Percentage Error =

Table 3.5-1:

Sr.No	Time Period of 7 oscillations	Time Period of one oscillation

3.6 Precautions

i. Do not twist wire beyond elastic limit
ii. Do not allow the system to rotate like a simple pendulum
iii. Good reflexes for handling stopwatch.

3.7 Results and Discussion

Experiment 4. Transverse Vibrations of a beam with one or more bodies attached

4.1 Objectives

1. To determine the natural frequency ω_n of the simply supported beam
2. To compare ω_n with the theoretical value

4.2 Abstract

4.3 Introduction

Forced vibration occurs, when an external force continuously acts on a body. During forced vibration, at a certain value of frequency, the frequency of the source combines with the natural frequency of the body and this causes the system to vibrate with the maximum amplitude. This phenomenon is termed as "Resonance", and can be very dangerous in mechanical systems. Thus systems are designed to operate at a frequency, different from the natural frequency of the vibrating body to avoid resonance.

In this experiment the external force was provided by the motor which rotated a circular disk with eccentric mass at different RPMs, to induce vibrations in the system. We were provided with all systems parameters which included the beam's length, width, thickness, Young's Modulus and mass (motor, beam and accelerometer). Auxiliary masses *(disks)* may be added to the system. A general layout of the system is shown in Figure 1.

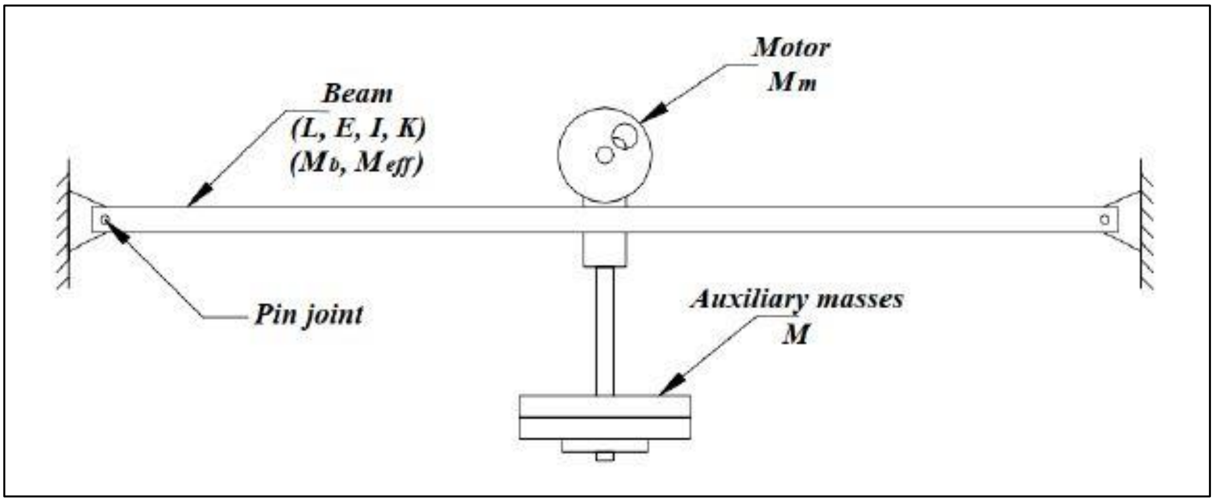

Figure 4.3-1: Experimental setup layout

For the system shown in Figure 1, the equation of motion is given by:

$$(M + M_{Eff})\ddot{Y} + KY = 0$$

From which the natural frequency of the whole system ω_{ns} is found as:

$$\omega_{ns} = \sqrt{\frac{K}{M + M_{Eff}}}$$

Square and take inverse of this equation to get:

$$\frac{1}{{\omega_{ns}}^2} = \frac{M}{K} + \frac{M_{Eff}}{K}$$

$$\frac{1}{{\omega_{ns}}^2} = \frac{1}{{\omega_{nm}}^2} + \frac{1}{{\omega_{nb}}^2}$$

This equation is known as the "*Dunkerley's Equation*", where:

ω_{ns} is the natural frequency of the whole system.
ω_{nm} is the natural frequency of the motor and added weights.
ω_{nb} is the natural frequency of the beam.

4.4 Procedure

1. Start with the system shown without any additional masses, and activate the motor to initiate vibrations on the beam.
2. Note the reading of analyser for every one-volt increase.
3. Plot the results until voltage is 3.0 volts.
4. Identify N_R at which resonance is taking place (shown as peak point).
5. Add a mass of 100 g to the beam and repeat.
6. Identify N_R, speed at which resonance occurs.
7. Repeat another four times to get total six pairs of M and N_R.
8. Draw a graph of obtained ω_n using $1/{\omega_n}^2$ for each mass added plus the motor mass.
9. Extrapolate the graph backwards to cut the Y-axis. This is the real value of ω_n.
10. Compare this value with the analytical ω_n value to find the error.

4.5 Precautions

i. During experiment on universal vibration apparatus, cover should be drop down to avoid any damage due to rotating parts at high speed.
ii. At Resonance the apparatus should be operated for short time to protect from damage/over-stress.
iii. This equipment requires hanging of weights, therefore it is important to follow safety requirements such as wearing closed shoes.

4.6 Observations and Calculations

Table 4.6-1: Experimental setup parameters

Parameter	Description	Value (Units)
Length	L	0.86 m
Width	w	0.05 m
Thickness	t	0.005 m
Mass of the Beam	M_b	0.503 Kg
Mass of motor + accelerometer Assembly	M_m	0.606 Kg
Young's Modulus of Beam	E	80 GPa

Formulas:

$$\omega = \sqrt{\frac{K}{M_{Eff}}} \quad \textbf{(1)}$$

$$K = \frac{48EI}{L^3} \quad \textbf{(2)}$$

$$M_{Eff} = \frac{17}{35} M_b = 0.485714\, M_b \quad \textbf{(3)}$$

$$I = \frac{1}{12} bh^3 \quad \textbf{(4)}$$

Table 4.6-2: Values calculated

I	K	M_{Eff}	$\omega_{n-theoretical}$

Table 4.6-3: Data with no additional mass.

Voltage (V)	Frequency (RPM)	Amplitude (μm)
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		
1.7		
1.9		
2.1		
2.3		
2.5		
2.7		
2.9		
3.1		
3.3		

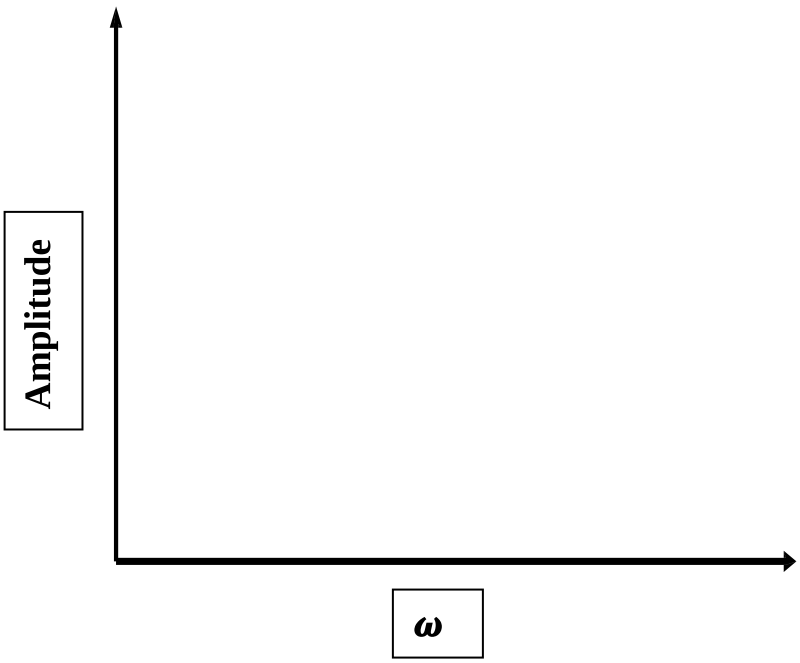

Figure 4.6-1: Amplitude vs frequency from data in Table 4.6-3

Table 4.6-4: Data with 100g additional mass

Voltage (V)	Frequency (RPM)	Amplitude (μm)
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		
1.7		
1.9		
2.1		
2.3		
2.5		
2.7		
2.9		
3.1		
3.3		

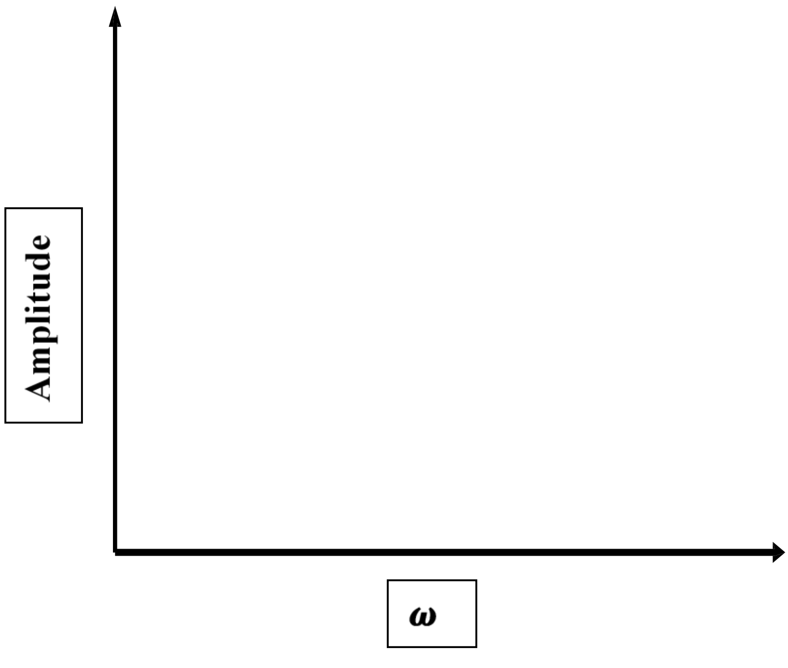

Figure 4.6-2: Amplitude vs frequency from data in Table 4.6-4

Table 4.6-5: Data with 200g additional mass

Voltage (V)	Frequency (RPM)	Amplitude (μm)
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		
1.7		
1.9		
2.1		
2.3		
2.5		
2.7		
2.9		
3.1		
3.3		

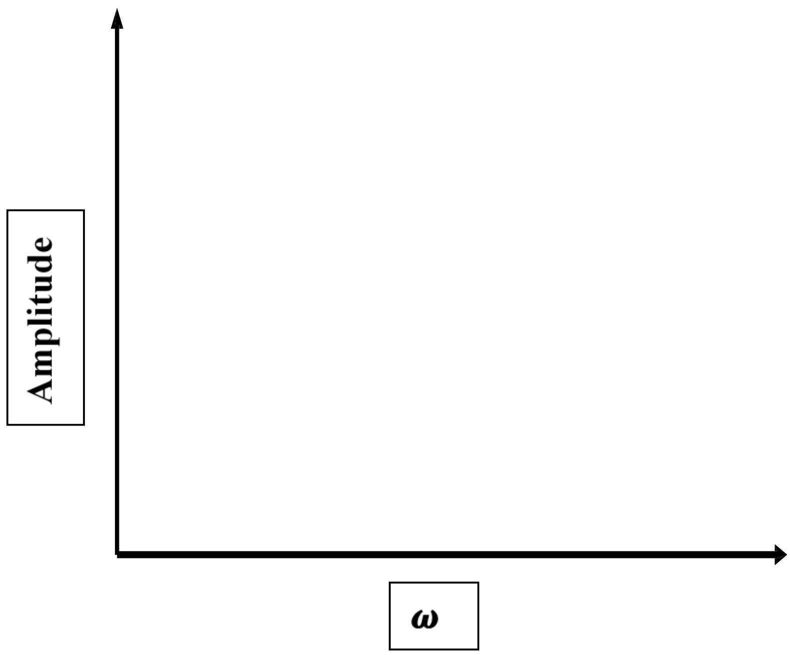

Figure 4.6-3: Amplitude vs frequency from data in Table 4.6-5

Table 4.6-6: Data with 200g additional mass

Voltage (V)	Frequency (RPM)	Amplitude (μm)
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		
1.7		
1.9		
2.1		
2.3		
2.5		
2.7		
2.9		
3.1		
3.3		

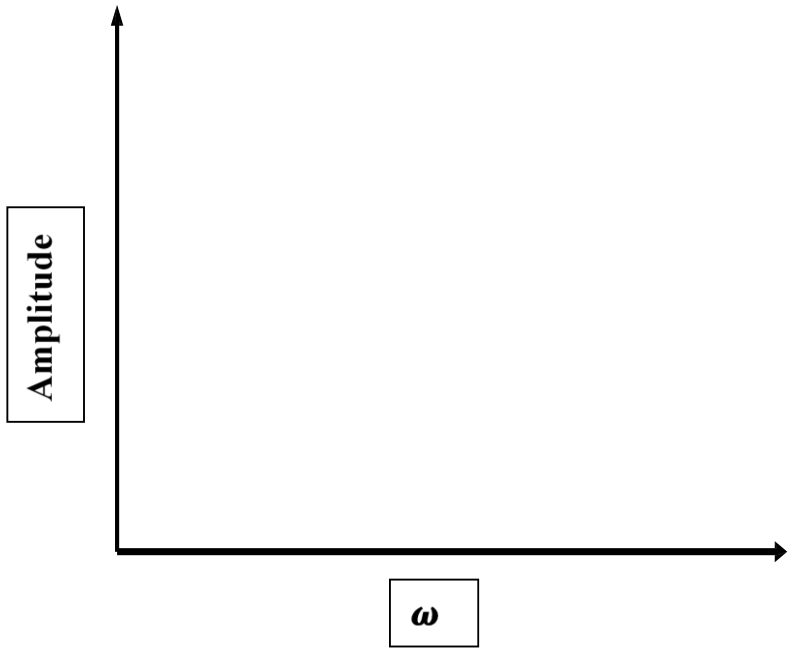

Figure 4.6-4: Amplitude vs frequency from data in Table 4.6-6

Table 4.6-7: Data with 300g additional mass

Voltage (V)	Frequency (RPM)	Amplitude (μm)
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		
1.7		
1.9		
2.1		
2.3		
2.5		
2.7		
2.9		
3.1		
3.3		

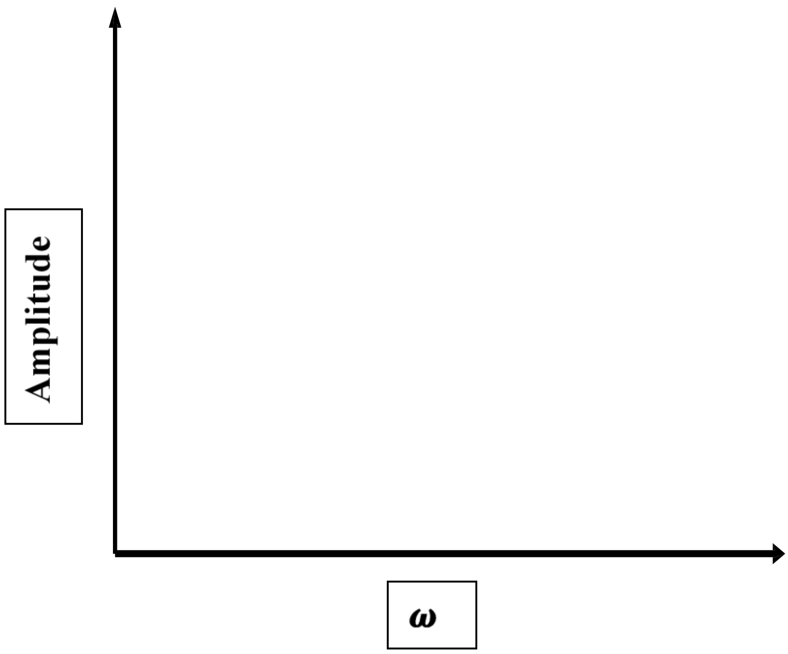

Figure 4.6-5: Amplitude vs frequency from data in Table 4.6-7

Table 4.6-8: Data with 400g additional mass

Voltage (V)	Frequency (RPM)	Amplitude (μm)
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		
1.7		
1.9		
2.1		
2.3		
2.5		
2.7		
2.9		
3.1		
3.3		

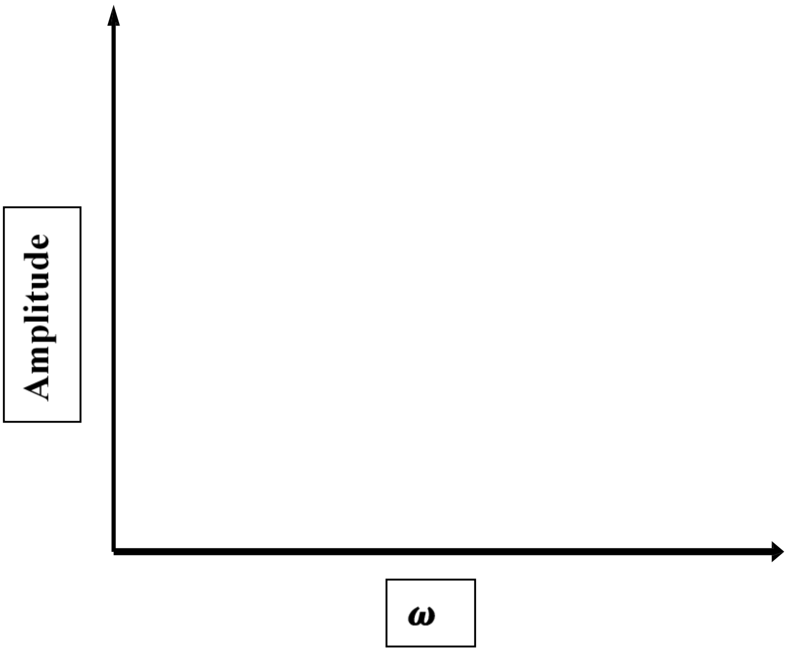

Figure 4.6-6: Amplitude vs frequency from data in Table 4.6-8

Table 4.6-9: Data with 500g additional mass

Voltage (V)	Frequency (RPM)	Amplitude (μm)
0.5		
0.7		
0.9		
1.1		
1.3		
1.5		
1.7		
1.9		
2.1		
2.3		
2.5		
2.7		
2.9		
3.1		
3.3		

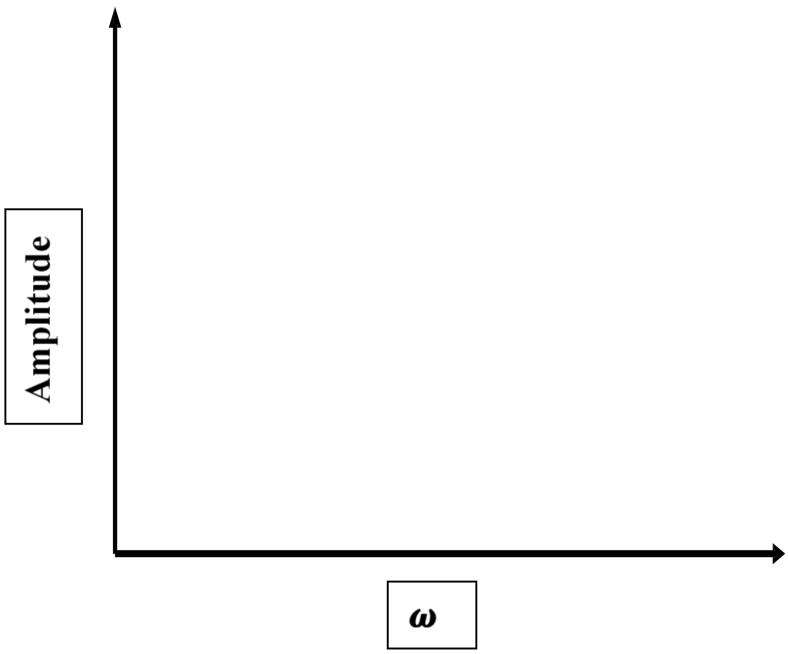

Figure 4.6-7: Amplitude vs frequency from data in Table 4.6-9

Table 4.6-10: Resonance frequency for each added mass.

Additional Mass (g)	**Total Additional Mass (kg)**	$\boldsymbol{\omega_n}$ **Resonance Frequency (rpm)**	$\boldsymbol{\omega_n}$ **Resonance frequency (rad/s)**	$\boldsymbol{\frac{1}{{\omega_n}^2}}$
606	0.606			
100	0.706			
100	0.806			
100	0.906			
100	1.006			
100	1.106			

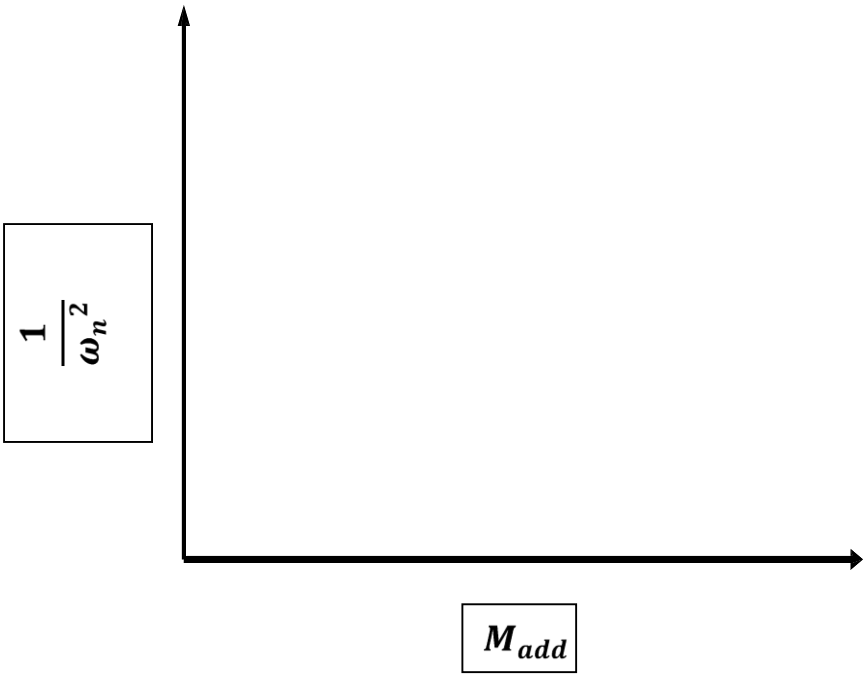

Figure 4.6-8: $\frac{1}{(\omega_n)^2}$ **vs M add from Table 4.6-11**

Table 4.6-11: Percentage error in readings

$\omega_{n-experimental}$	$\omega_{n-analytical}$	%error

4.7 Discussion

Experiment 5. Forced Vibrations – Rigid Body – Mass Spring System

&

Experiment 6. Forced damped Vibrations – Rigid Body – Mass Spring System

6.1 Objectives

1. To determine natural frequency of system without damper
2. To determine natural frequency of system with damper
3. Compare all these frequencies and find relative errors

6.2 Abstract

6.3 Apparatus

i. Rectangular cross-section beam pinned at one end and suspended by helical spring at other end
ii. Motor mounted on the beam
iii. Voltage Supply
iv. Tachometer attached to the beam

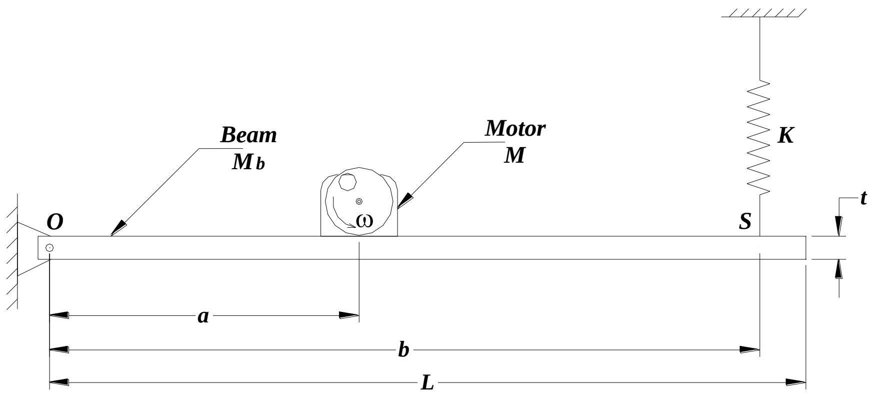

Figure 6.3-1: General Layout of Experimental Setup

6.4 Theory

The system to be used in the experiment is shown in ***Error! Reference source not found.***, which consists of a regular rectangular cross-section beam of mass M_b, length *L*, width *w* and thickness *t*; pinned at one end to the main frame at point *O,* where it is free to rotate about, and suspended from point *S* by a linear helical spring of stiffness *K* at distance *b* from point *O*.

A motor with mass *(M = kg)* is fitted on the beam at distance *a* from pivot point *O*, and drives two circular discs with total eccentric mass *m* at distance *e* from the centre of the disc. The motor induces forced vibrations in the beam when it rotates these discs with speed *ω*. Harmonic excitation is established on the beam, and as a result of that, the beam vibrates in the vertical plane with angle *θ(t)* measured from the horizontal reference direction.

The mechanical system's vibration is given by:

$$I\ddot{\theta} + Kb^2\theta = 0$$

From which the natural frequency is found to be:

$$\omega_n = \sqrt{\frac{Kb^2}{I}}$$

Where:

$$I = \left(Ma^2 + M_h\frac{L^2}{3}\right)$$

For helical springs:

$$K = \frac{Gd4}{8ND3}$$

The damped vibrations frequency is given by

$$\omega_d = \omega_n\sqrt{1-\delta^2}$$

6.5 Forced Vibrations

When the body affected by an outside drive vibrates, the body is said to be under forced vibration. The frequency used for this type of vibration is known as forced frequency. In the experiment, when the motor is in operation, the beam will be imposed to a harmonic excitation due to the eccentric mass in each disk.

6.6 Damped vibration

When the energy of a vibrating system is gradually dissipated by friction and other resistances, the vibrations are said to be damped. The vibrations gradually reduce or change in frequency or intensity or cease and the system rests in its equilibrium position. In our case we add the damping effect by to our system by attaching the rectangular beam to another immovable beam. Damped frequency will then be:

$$\omega_d = \omega_n \sqrt{1 - \delta^2}$$

6.7 Basic Parameters and Dimensions

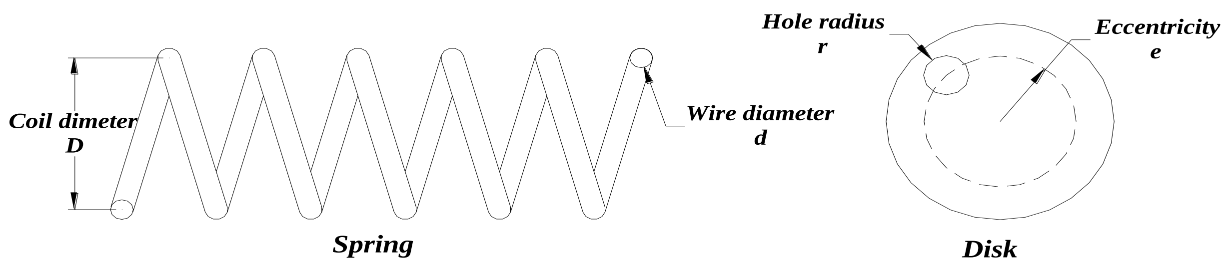

Figure 6.7-1: Spring and Disc Dimensions

According to the Figure 5.3-1 and Figure 5.3-2, the following table consists of some dimensions and parameters of experimental setup.

Table 6.7-1: Dimensions and Parameters of Apparatus

Beam			
Parameter	**Value**	**Parameter**	**Value**
L (cm)		**b (cm)**	
w (mm)		**t (mm)**	

Spring			
Parameter	**Value**	**Parameter**	**Value**
D (mm)		**d (mm)**	
N (turns)			

6.8 Part 1: Forced Vibrations without damper

6.8.1 Procedure

1. Use the system described above while the motor is turned off.
2. Give the beam a small vertical displacement, then release it to oscillate freely for ten oscillations. Record the elapsed time *T*.
3. Now start the motor and increase the speed of the motor slowly by increasing voltage at a step of 1 volt.
4. Take reading of tachometer and analyser at each step.
5. Note the response of the system, and at the same time; try to identify the point at which resonance takes place *(When the largest amplitude of vibrations is noticed)*. Record the speed of the motor at that state N_r. Continue the experiment unto 24 volts. Plot frequency Hz verses amplitude.

6.8.2 Observation and calculations

Table 6.8-1: Forced Vibrations without damper

Voltage (V)	N (rpm)	Amplitude (mm)

6.8.3 Graph 1

The peak of the graph will give natural frequency of the system.

(Graph plotted between frequency and amplitude)

6.9 Part-2: Forced Vibrations with damper

6.9.1 Procedure

1. Now attach the damper with the beam with the help of a screw.
2. Start the motor and slowly increase the voltage at a step of .5 volts.
3. Take reading of tachometer and analyser at each step.
4. Note the response of the system, and at the same time; try to identify the point at which resonance takes place *(When the largest amplitude of vibrations is noticed)*. Record the speed of the motor at that state N_r. Continue the experiment until the first peak is reached. Plot frequency Hz verses amplitude.

6.9.2 Observation and Calculations

Table 6.9-1: Forced Vibrations with damper

Voltage (V)	N (rpm)	Amplitude (mm)

6.9.3 Graph 2

The peak of the graph will give damped natural frequency of the system.

(Graph plotted between frequency and amplitude)

6.10 Results

Table 6.10-1: Comparison of Various Natural Frequencies

Method	**Natural Frequency ω_n (rad/sec)**	**Percent Error (%)**
Theoretical		
Resonance Observation Part- 1		
Resonance Observation Part- 2		

6.11 Discussion and conclusion

Appendix

Appendix A

Program Learning Outcomes (PLOs)

On the basis of the Knowledge Attributes defined in the Washington Accord, twelve (12) Program Learning Outcomes, also known as Graduate Attributes, are listed below:

(i) **Engineering Knowledge**: An ability to apply knowledge of mathematics, science and engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

(ii) **Problem Analysis**: An ability to identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.

(iii) **Design / Development of Solutions**: An ability to design solutions for complex engineering problems and design systems, components, or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.

(iv) **Investigation**: An ability to investigate complex engineering problems in a methodical way including literature survey, design and conduct of experiments, analysis and interpretation of experimental data, and synthesis of information to derive valid conclusions.

(v) **Modern Tool Usage**: An ability to create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to complex engineering activities, with an understanding of the limitations.

(vi) **The Engineer and Society**: An ability to apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solution to complex engineering problems.

(vii) **Environment and Sustainability**: An ability to understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development.

(viii) **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.

(ix) **Individual and Team Work**: An ability to work effectively, as an individual or in a team, on multifaceted and/or multidisciplinary settings.

(x) **Communication**: An ability to communicate effectively, orally as well as in writing on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentations, make effective presentations, and give and receive clear instructions.

(xi) **Project Management**: An ability to demonstrate management skills and apply engineering principles to one's own work, as a member and/or leader in a team to manage projects in a multidisciplinary environment.

(xii) **Lifelong Learning**: An ability to recognize importance of, and pursue lifelong learning in the broader context of innovation and technological developments.

Appendix B

Details of Domains

Cognitive		**Affective**		**Psychomotor**	
Level 1	Knowledge	Level 1	Receiving	Level 1	Perception
Level 2	Comprehension	Level 2	Responding	Level 2	Set
Level 3	Application	Level 3	Valuing	Level 3	Guided Response
Level 4	Analysis	Level 4	Organization	Level 4	Mechanism
Level 5	Synthesis	Level 5	Characterization by value or value complex	Level 5	Complex over response
Level 6	Evaluation			Level 6	Adaption
				Level 7	Organization

Appendix C

Lab Rubrics

CLOs	Criteria	Poor (0 to 4)	Satisfactory (5-6)	Good (7-8)	Excellent (9-10)
CLO-1	**Apparatus Handling, Experiment Performance and Calculations**	No knowledge of apparatus, experiment not performed, nor any calculations done	Knows basic operation of the apparatus, performed the experiment with major errors in calculations	Can handle the apparatus well, experiment completely performed, and calculations have few mistakes	Fully understands the complete operation of the apparatus, experiment performed, and all calculations are correct
	Planning and Execution of an Experiment [OEL]	Experiment not planned for proper execution	Experiment planned but not executed properly	Experiment planned and executed but slight omissions	Experiment correctly planned and executed
CLO-2	**Communication [Report]**	Report neither covers technical details of experiment nor according to format	Correct report submitted according to format but not covering essential technical details	Report well written technically but format not completely followed / slight mistakes	Well-composed flawless report covering technical aspects of experiment
	Communication [Viva]	Either does not understand or cannot communicate concepts related to experiment	Understands the concepts related to experiment but does not communicate in technical terms	Understands and able to communicate the learned concepts but with slight mistakes	Fully understands all the concepts and can express them technically
CLO-3	**Punctuality, Teamwork and Safety**	Arrives too late for experiment with disregard to teamwork or safety	Arrives little late for experiment, somewhat adheres to teamwork and safety	Punctual but slightly lacking in teamwork and safety consciousness	Punctual, works as a team and adheres to safety instructions