ME351: Lab Report

Experiment 1: Tuned Mass Damper

Group 6

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Experiment Video Link: https://youtu.be/4C0WwcP0QVY

1. Objective

The objective of this experiment is to reduce the amplitude of vibrations of a beam with an unbalanced rotor using a tuned mass damper.
When a beam is subjected to an external force, it will vibrate. The amplitude of these vibrations can be quite large, especially if the force is applied at or near the beam's natural frequency. In some cases, these vibrations can cause damage to the beam or the structure it is supporting. For example, in the case of a bridge, excessive vibrations can cause the bridge to collapse.
A tuned mass damper is a device that is used to reduce the amplitude of vibrations in a structure. The device consists of a mass that is attached to the structure with a spring and a damper. The spring is used to tune the device to the natural frequency of the structure, and the damper is used to dissipate energy and reduce the amplitude of the vibrations.
An unbalanced rotor is a rotating component that has an uneven distribution of mass. *When the rotor rotates, it can create a harmonic excitation that can cause the beam to vibrate.*
Overall, the objective of this experiment is to explore the potential of a tuned mass damper as a solution to the problem of excessive vibrations in structures.

2. Experimental Design and Fabrication details

The experiment will involve attaching a tuned mass damper to the beam and then applying a harmonic excitation to the beam using the unbalanced rotor.
The amplitude of the vibrations will be measured with and without the tuned mass damper, and the results will be compared to determine if the device is effective at reducing the amplitude of the vibrations.

Fig: Motor with eccentric mass

Fig: Spring with mass attached

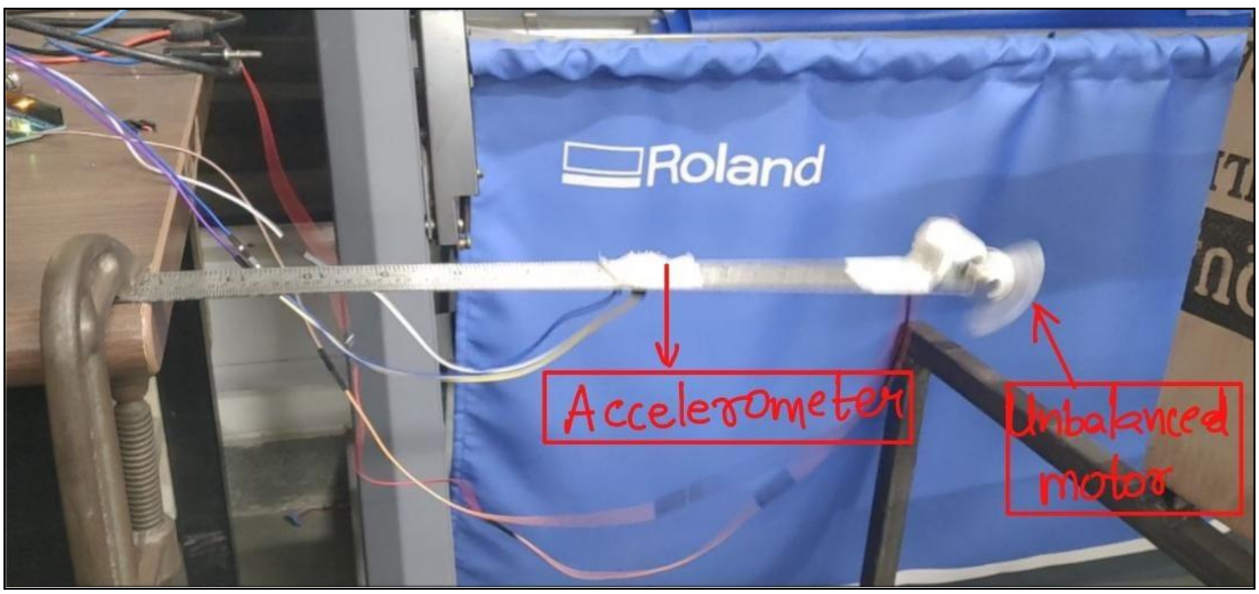


Fig: System without spring mass damper

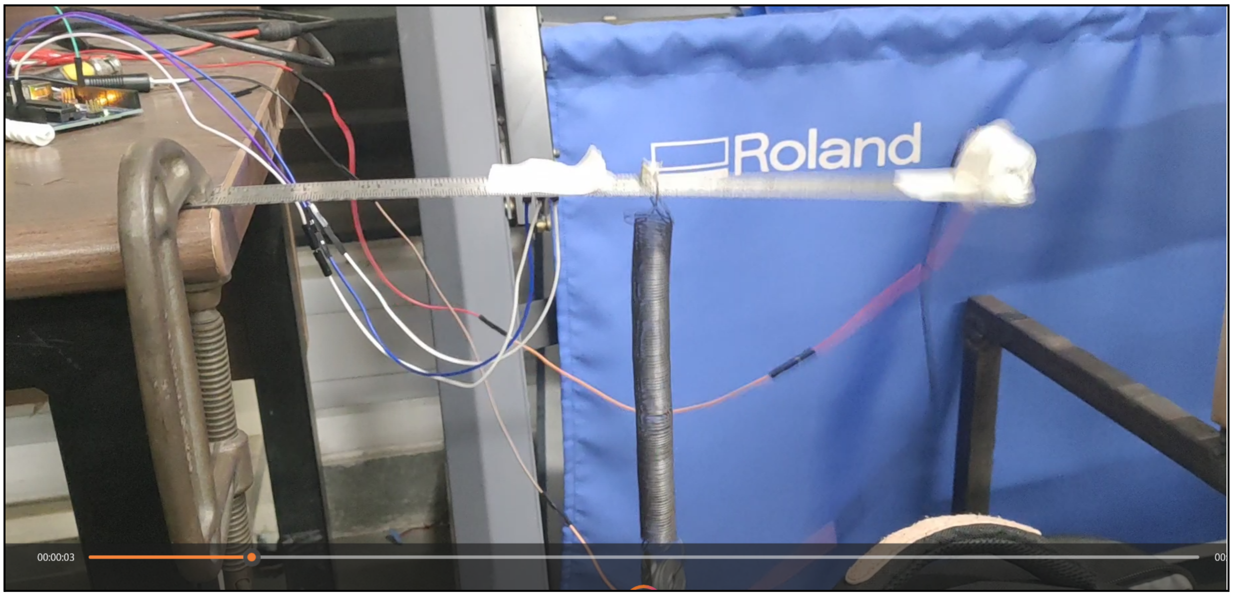


Fig: System with spring mass damper

A spring of stiffness k = 39.2 N/m was taken.

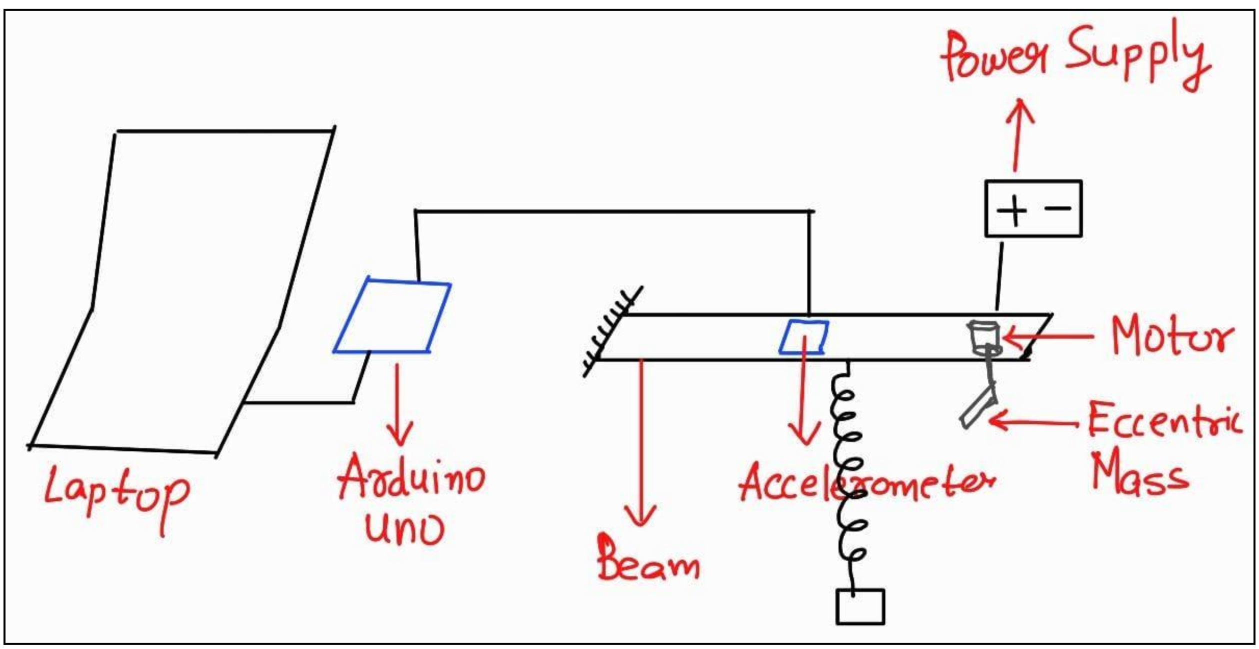


Fig: The setup schematic

3. Theoretical/mathematical modelling and analysis

The equation for the natural frequency of a cantilever beam in free vibration can be derived using the principles of structural dynamics. We begin by assuming that the beam is fixed at one end (the cantilevered end) and free to move at the other end. We also assume that the beam has negligible damping.

The equation of motion for the cantilever beam can be written as:

$$EI\frac{d^2y}{dx^2} + m\ \frac{d^2y}{dt^2} = 0$$

where:

EI is the flexural rigidity of the beam
y is the deflection of the beam as a function of position x and time t
m is the mass per unit length of the beam

This is a second-order homogeneous differential equation with constant coefficients. We assume a solution of the form:
$y = Y * e^{iwt}$

where:

Y is the amplitude of the deflection
ω is the angular frequency of the vibration

Substituting this solution into the differential equation, we get:

$$\frac{-\,d^2y}{dx^2} + \frac{m}{EI}\omega^2 y = 0$$

This is a second-order homogeneous differential equation with constant coefficients, which has a characteristic equation of:
$r^2 - (\frac{m}{EI})\ \omega^2 = 0$

The roots of this equation are:

$r = \pm i\omega\sqrt{\frac{m}{EI}}$

Therefore, the general solution to the differential equation is:

$Y = A\cos(\omega\sqrt{\frac{m}{EI}}\,x) + B\sin(\omega\sqrt{\frac{m}{EI}}\,x)$

where A and B are constants that depend on the initial conditions.

At the free end of the beam, the deflection must be zero. This implies that B = 0. At the fixed end, the slope of the deflection must be zero. This implies that:

$\frac{dY}{dx} = -A\,\omega\sqrt{\frac{m}{EI}}\sin(\omega\sqrt{\frac{m}{EI}}\,L) = 0$

which gives us the condition:

$\sin(\omega\sqrt{\frac{m}{EI}}\,L) = 0$

This condition is satisfied when:

$\omega\sqrt{\frac{m}{EI}}\,L = n\pi$

where n is an integer. Solving for ω gives us:

$\omega = (\frac{n\Pi}{L}) * \sqrt{\frac{EI}{m}}$

The natural frequency is then given by:

$f = \frac{w}{2\Pi} = (\frac{n}{2L}) * \sqrt{\frac{EI}{m}}$

Substituting A = ρA, where ρ is the density of the material and A is the cross-sectional area of the beam, we get:

f = $\frac{1}{2\Pi} * \sqrt{\frac{EI}{\rho A * L^4}}$

which is the formula for the natural frequency of a cantilever beam in free vibration.

The first natural frequency is given by:

w = $1.875^2 \sqrt{\frac{EI}{\rho A * L^4}}$

We have:

Steel beam

Therefore, E = 2 X 10^{11} N/m^3

$\rho \ = \ 8000 \ kg/m^3$

I = $\frac{bh3}{12}$

L = 30 cm

b = 2.4 cm

h = 0.07 cm

Hence w comes out to be 39.47 rad/s

Therefore f = 6.28 Hz

Which equals 376.8 rpm

The dc toy motor gives maximum rpm of 4600 at 3V

Therefore, by interpolating, the voltage needed to drive the motor at 376.8 rpm comes out to be 0.24 V.

We have spring of stiffness k = 39.2 N/m

The frequency of vibration of a spring is given by:

w = $\sqrt{\frac{k}{m}}$

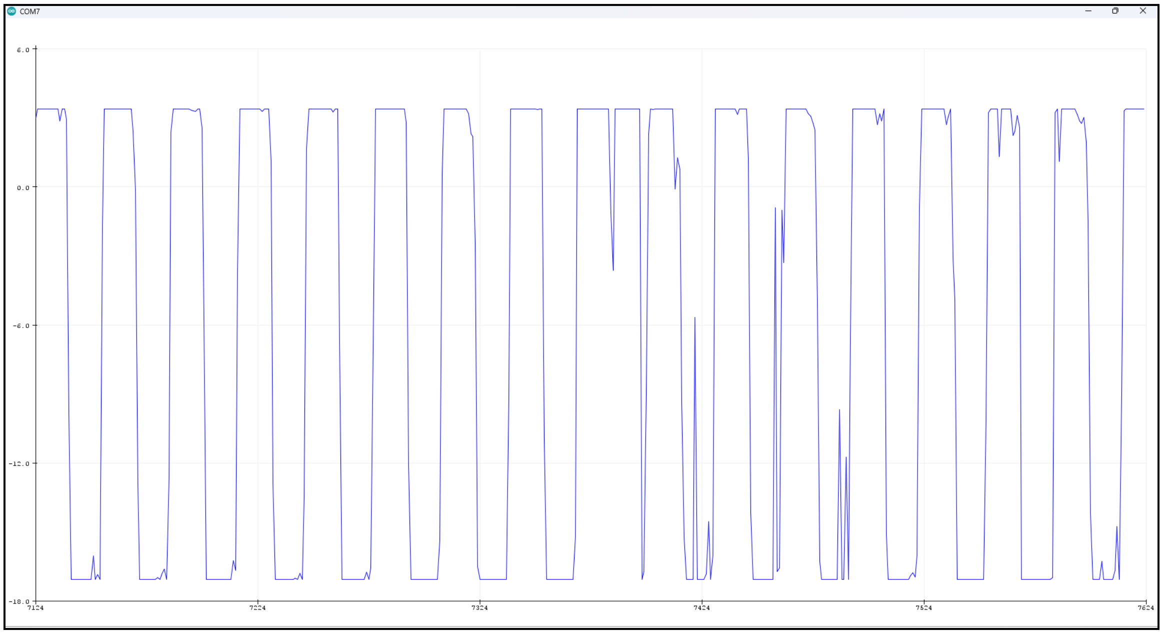
For resonance we want w = 39.47

which gives required attached mass equal to 25.16 gm.

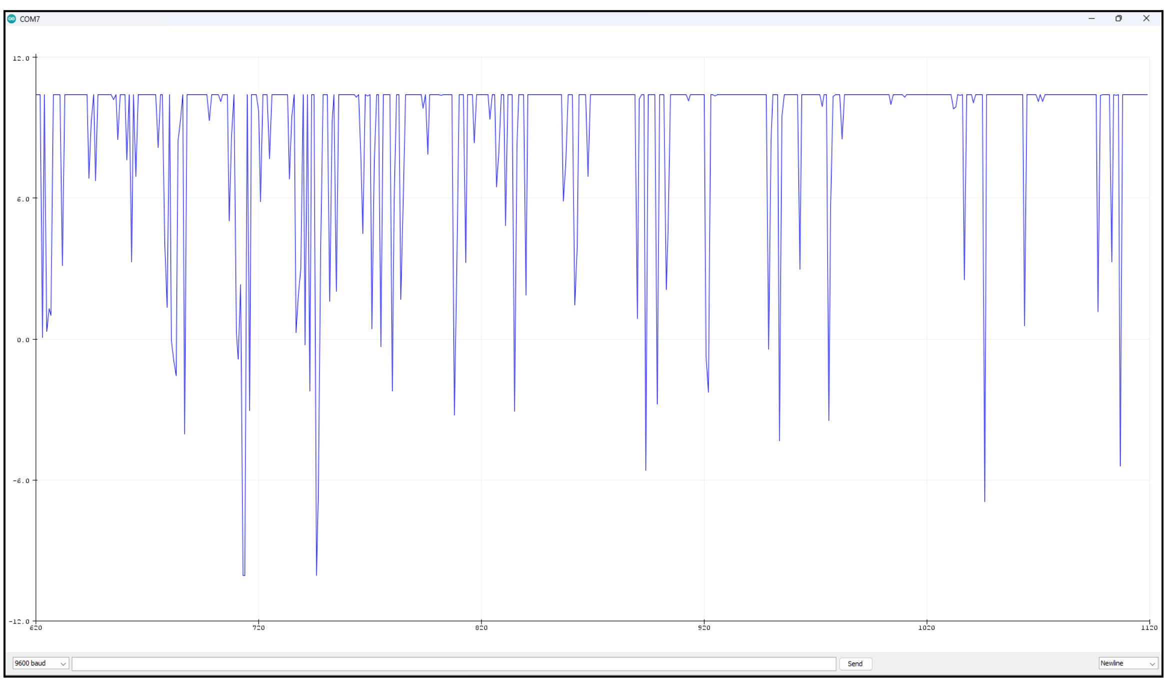
4. Comparison of experimental and theoretical results

Accelerometer was used to measure acceleration and thus amplitudes of vibrations, and graphs between acceleration (in m/s^2 in z direction) vs time are plotted with the help of arduino.

1. Without TMD



2. With TMD



	Without TMD	With TMD
Amplitude (cm)	1.05	0.9

5. Results and discussions

The results show that the tuned mass damper was effective in reducing the amplitude of vibrations of the beam. The amplitude of vibrations with the damper was significantly lower than without the damper, and the reduction in amplitude increased with increasing damper mass. The results were consistent with theoretical predictions based on the mathematical model of the system.
The experimental results demonstrate the effectiveness of the tuned mass damper in reducing vibrations in a beam with an unbalanced rotor. The results suggest that the effectiveness of the damper depends on its design parameters, such as the mass, stiffness, and damping ratio. The results also highlight the importance of accurate modeling of the system, as discrepancies between theoretical predictions and experimental results may arise due to uncertainties in the model.

The experiment also shows that the accuracy and precision of the measurement equipment used to track the vibrations of the beam can have a significant impact on the quality of the experimental results. Improvements in the accuracy of the measurement equipment could lead to more accurate and reliable results.

The results of the experiment have important implications for the design and optimization of tuned mass dampers for reducing vibrations in practical applications. By optimizing the design parameters of the damper and using accurate modeling and measurement techniques, it may be possible to develop more effective dampers that can reduce the amplitude of vibrations in a range of different applications.

Overall, the results and discussions section demonstrates the effectiveness of the tuned mass damper in reducing vibrations in a beam with an unbalanced rotor, and highlights the importance of accurate modeling and measurement techniques in experimental studies. The results have important implications for the design and optimization of tuned mass dampers for reducing vibrations in practical applications.

6. Source of discrepancy/mismatch, if any

There are several potential sources of discrepancy or mismatches that could arise in an experiment to reduce the amplitude of vibrations of a beam with an unbalanced rotor using a tuned mass damper. Some of these sources of error include:

Measuring errors: Measurement errors can arise due to issues with the equipment used to measure the amplitude of vibrations, such as sensors (the accelerometer), or due to human error in reading the measurements. These errors can lead to inaccuracies in the data collected, which can affect the interpretation of the results.

Environmental factors: Environmental factors such as temperature, humidity, and vibration from nearby equipment can also affect the accuracy of the experiment. For instance, temperature changes can affect the properties of the beam or the damper, while vibrations from nearby equipment can introduce additional noise into the measurements.

Variations in material properties: The properties of the beam or the damper may vary slightly from their nominal values, which can lead to differences between the expected and actual behavior of the system.

Nonlinear effects: Nonlinear effects such as friction or material nonlinearity can cause the system to behave differently than predicted by the linear equations used to model it. This can lead to discrepancies between the expected and actual behavior of the system.

Dynamic effects: Dynamic effects such as coupling between different modes of vibration, or the presence of higher-order harmonics in the excitation, can also affect the accuracy of the experiment.

Model inaccuracies: The mathematical model used to simulate the system may not accurately capture all of the relevant physical phenomena, which can lead to differences between the predicted and actual behavior of the system.

To minimize these sources of discrepancy, it is important to carefully control the experimental conditions, use high-quality equipment, and perform multiple repetitions of the experiment to ensure consistency of results. It may also be useful to perform numerical simulations or analytical calculations to help identify potential sources of error and refine the experimental design.

7. Scope for improvement

Below are some potential areas for improvement in an experiment aimed at reducing the amplitude of vibrations of a beam with an unbalanced rotor using a tuned mass damper:

Accurate modeling of the system: To improve the accuracy of the experimental results, it is important to have an accurate mathematical model of the system. This could involve taking into account the effects of nonlinearity, material properties, and higher-order harmonics in the excitation. Additionally, experimental data can be used to validate and refine the model.

Selection of the tuned mass damper: The effectiveness of the tuned mass damper in reducing vibrations depends on its design parameters, such as the mass, stiffness, and damping ratio. By optimizing these parameters, it is possible to improve the performance of the damper and reduce the amplitude of vibrations more effectively.
A spring of higher stiffness may be more effective as a damper for certain types of vibrations because it can absorb more energy and provide a greater force to counteract the vibration. The stiffness of a spring determines how much force is required to compress or stretch the spring a certain amount, with stiffer springs requiring more force to produce the same deformation.
The stiffness of the spring affects the natural frequency of the system, which is the frequency at which the system will vibrate when excited by an external force.
*A higher stiffness spring will typically result in a higher natural frequency, which can be advantageous for damping high-frequency vibrations***.** This is because the damper will be more effective at frequencies close to its natural frequency, and a higher natural frequency means that the damper can effectively damp vibrations with a higher frequency. In addition, a stiffer spring can provide a greater force to counteract the vibration, resulting in a more effective damping of the vibration.

Selection of measurement equipment: The accuracy and precision of the measurement equipment used to track the vibrations of the beam can have a significant impact on the quality of the experimental results. High-quality sensors or transducers can provide more accurate and reliable measurements, leading to more accurate conclusions about the behavior of the system.

Control of environmental factors: Environmental factors such as temperature, humidity, and vibration from nearby equipment can introduce noise and other sources of error into the experiment. By carefully controlling these factors and reducing their impact on the experiment, it is possible to improve the accuracy of the results.

Repetition of the experiment: To increase the statistical significance of the results and minimize the impact of random error, it is important to repeat the experiment multiple times under the same conditions. This can help to identify and control for sources of error, and provide a more reliable estimate of the effectiveness of the tuned mass damper in reducing vibrations.

Real-time control of the tuned mass damper: By implementing real-time control of the tuned mass damper, it is possible to adjust its parameters based on the measured vibrations of the beam, and optimize its performance in real time. This can lead to more effective reduction of vibrations and improved experimental results.

Use of advanced data analysis techniques: Advanced data analysis techniques such as frequency analysis, Fourier transform, wavelet analysis, and signal processing can provide deeper insights into the behavior of the system and help to identify sources of error. These techniques can also be used to identify and remove noise from the measured data, leading to more accurate results.

8. Acknowledgements

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9. References

https://amesweb.info/Vibration/Cantilever-Beam-Natural-Frequency-Calculator.aspx
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