Experiment 9: Forced Vibration and Vibration Absorber

Section D (S4), Group 1

Arnav Kalgutkar (210100025)
Aryan Bhosale (210040024)
Nayantara Ramakrishnan (210100099)
Saukhya Telge (210100135)
Vora Jay Bhaveshbhai (21D100023)

Objectives:

- The primary objective of this experiment is to analyse how the single DOF spring-mass system responds to external forcing.
- By subjecting the system to periodic forcing generated by a motor loaded with an eccentric mass, we aim to observe the changes in vibration amplitude and frequency response.

Introduction:

Forced vibration phenomena play a crucial role in understanding the dynamic behaviour of mechanical systems subjected to external forces. In engineering applications, it is essential to comprehend how systems respond to periodic external forcing to ensure their efficient and safe operation. One of the fundamental systems used to study forced vibrations is the single DOF spring-mass system. This system exhibits unique characteristics during free and forced vibration, offering insights into resonance, damping effects, and methods for vibration control.

In this lab experiment, we focus on investigating the forced vibration response of a single DOF spring-mass system. Degree of freedom is defined as the number of independent variables required to completely define the state of a system. We can understand it as the number of independent motions possible in a system.Let's analyse the equation of motion of the system.

Force balance: $Mx'' + Kx = me\omega^2 sin(\omega t)$
Where,
$M =$ mass of the system
$K = K_1 + K_2$ equivalent stiffness
K_1 and K_2 are spring constants of individual springs (connected in parallel)
$m =$ eccentric mass
$e =$ eccentricity
$\omega =$ rotational frequency

$me\omega^2 sin(\omega t)$ is the force generated by eccentrically loaded motor in vertical direction (assuming ω is constant with respect to time).

Homogeneous solution: The homogeneous solution is obtained by setting the RHS of the equation to zero, i.e.,

$me\omega^2 sin(wt) = 0$

This simplifies the equation to $Mx'' + Kx = 0$, which is a classic homogeneous differential equation for undamped harmonic motion. The general form of the homogeneous solution can be written as:

$x_h(t) = A\, cos(\omega_n t) + B\, sin(\omega_n t)$

where A and B are constants to be determined, and $\omega_n = \sqrt{K/M}$ is the natural frequency of the system.

Particular Solution: To find the particular solution, we assume the form of the solution to be similar to the forcing function, i.e., $x_p(t) = C\, sin(\omega t)$, where C is a constant to be determined. Now, substitute $x_p(t)$ into the original differential equation:

$M(-\, C\omega^2 sin(\omega t)) + K(Csin(\omega t)) = me\omega^2 sin(\omega t)$

Solving for C, we get:

$C = me\omega^2/(M(\omega_n^2 - \omega^2))$

Therefore, the particular solution is:

$x_p(t) = (me\omega^2/(M(\omega_n^2 - \omega^2)))\, sin(\omega t)$

General Solution: The general solution is the sum of the homogeneous and particular solutions

$x(t) = x_h(t) + x_p(t) = A\, cos(\omega_n t) + B\, sin(\omega_n t) + (me\omega^2/(M(\omega_n^2 - \omega^2)))sin(\omega t)$

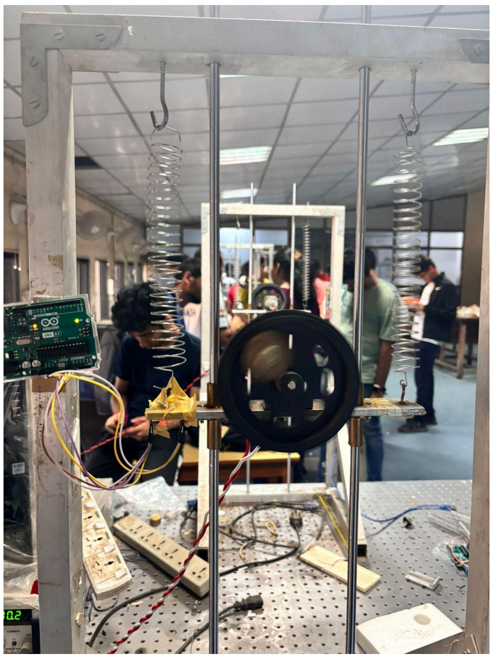
To derive the equation at steady-state, we need to consider the particular solution $x_p(t)$ when the system has reached a steady-state response. In forced vibration analysis, the steady-state solution occurs when the effects of transients have died out, and the system's response becomes periodic and stable. At steady-state, the system's response matches the frequency of the external forcing. Therefore, the equation at steady-state can be represented as:

$x_{steady-state}(t) = (me\omega^2/(M(\omega_n^2 - \omega^2)))\, sin(\omega t)$

This equation describes the amplitude of the system's response at steady-state as a function of time t.

Methodology:

1. The spring constants for the springs were calculated using linear fit for mass suspended vs extension.
2. The motor was attached to the spring. The motor had an eccentric mass as its load.
3. Accelerometer MMA7361 was connected to the system and connections were made with the Arduino board.



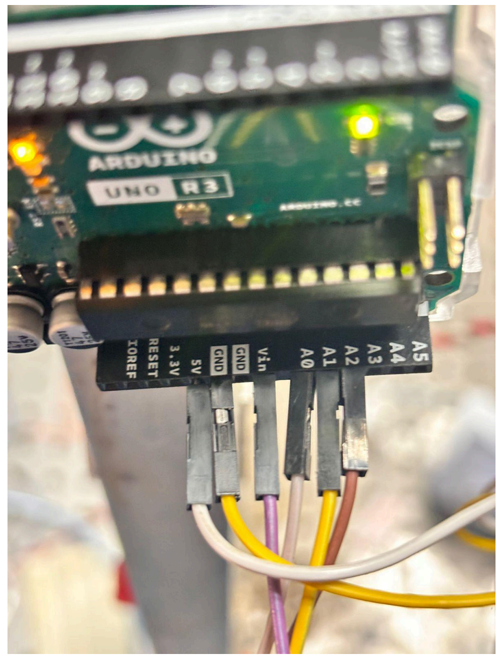
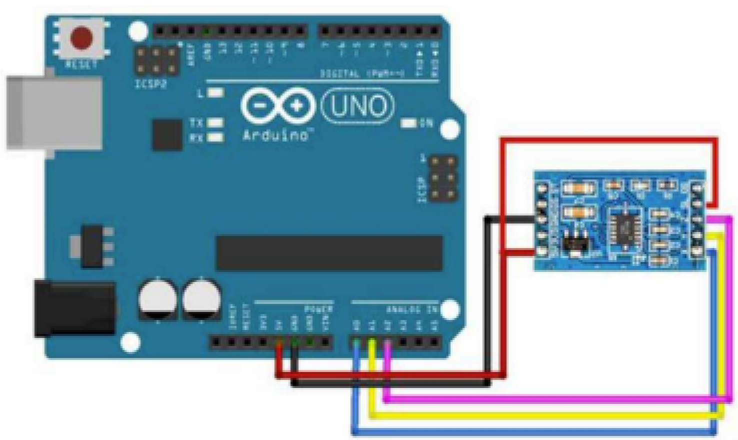


Fig: The setup

Fig: Connections made with Arduino

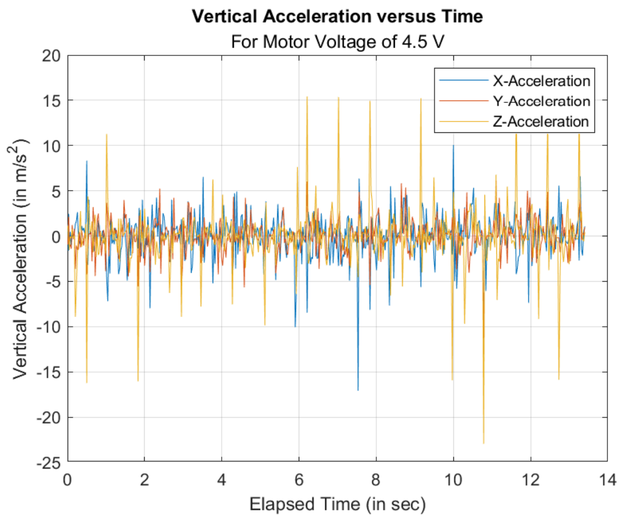
4. The following circuit diagram was referred:

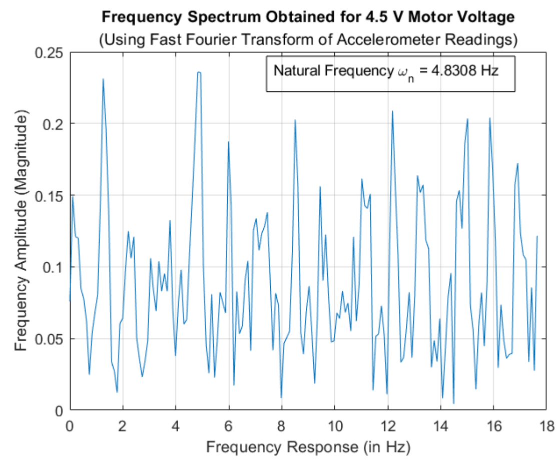


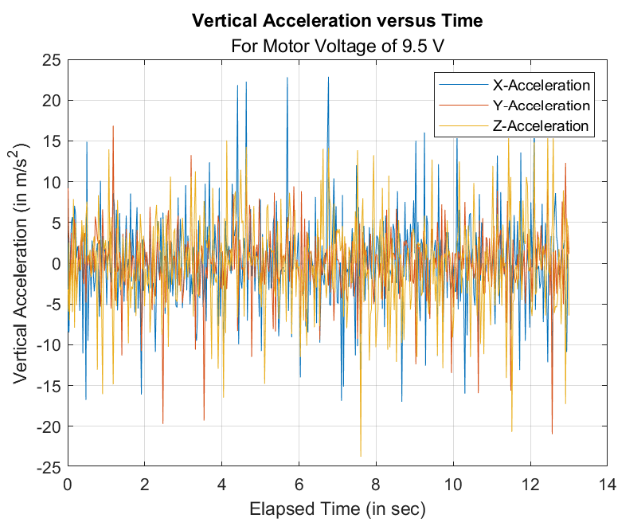
5. Arduino was connected to the laptop via USB cable and code was flashed via COM port 11. Putty was used for data logging
6. Voltage was varied from 0.5V to 17V. Motor started at 1.5V, and hence we have taken readings at 0.5V intervals from 1.5 to 12V. From 12V to 17V we have taken readings at 1V intervals
7. Voltage was held constant for around 15 seconds

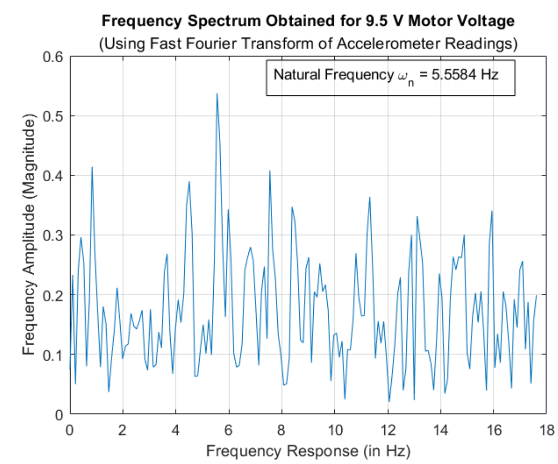
8. FFT was performed on the data to get amplitude and frequency of oscillations at each voltage value. The reading with maximum amplitude is the resonance value.

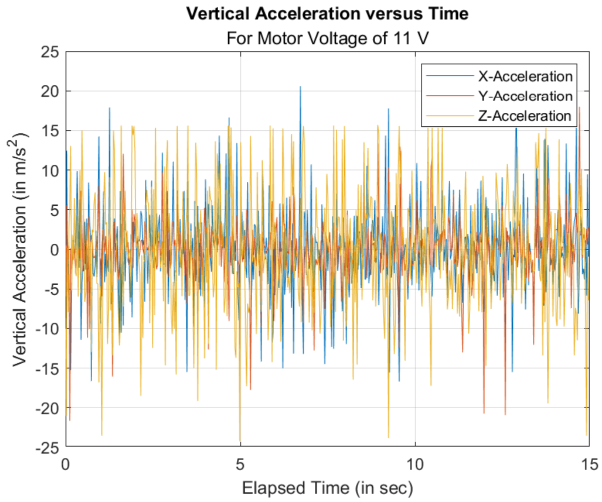
Results:

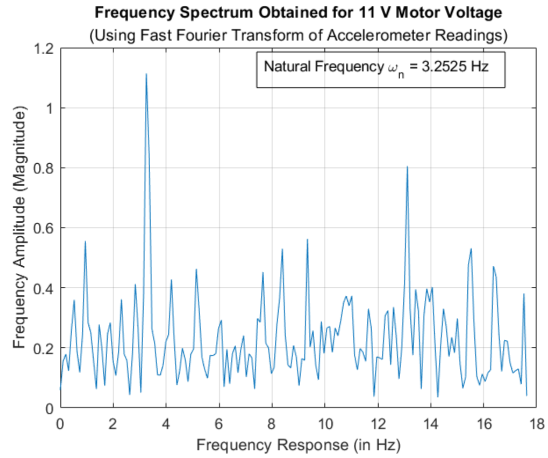


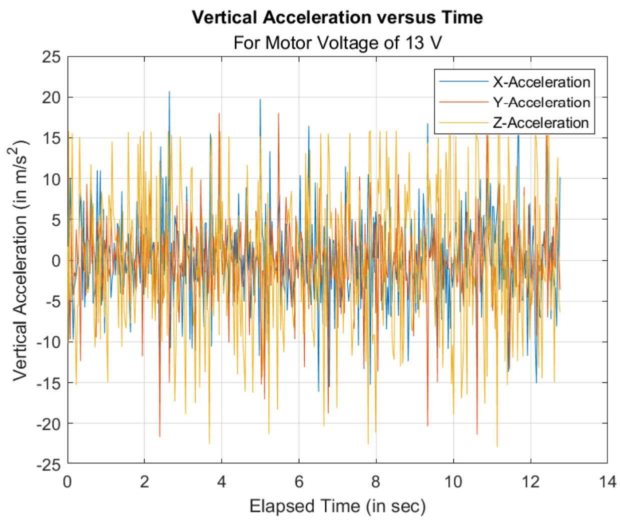


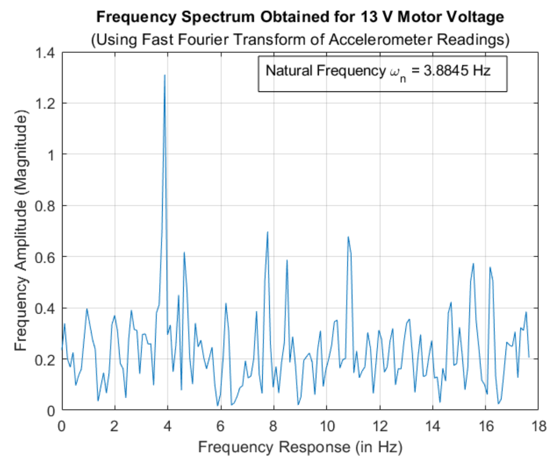


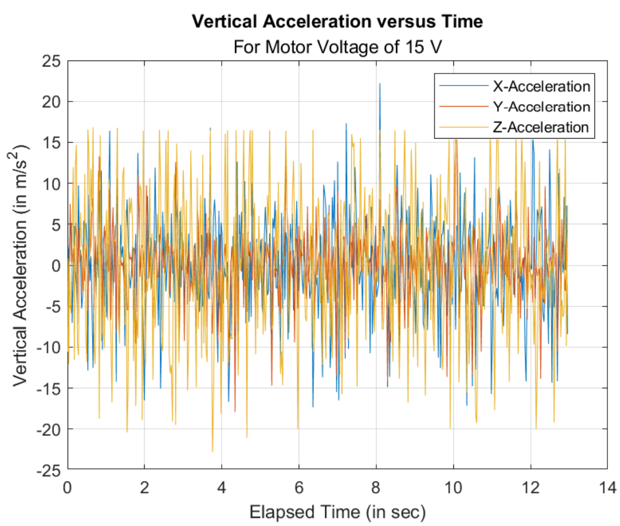


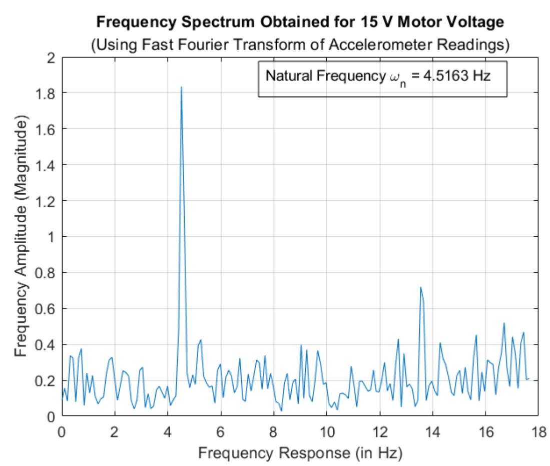

Vertical Acceleration versus Time
For Motor Voltage of 11 V
X-Acceleration
Y-Acceleration
Z-Acceleration
Vertical Acceleration (in m/s^2)
Elapsed Time (in sec)

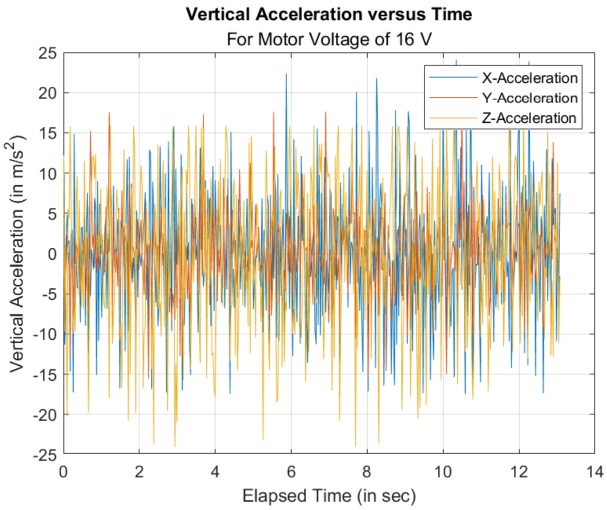

Frequency Spectrum Obtained for 11 V Motor Voltage
(Using Fast Fourier Transform of Accelerometer Readings)
Natural Frequency ω_n = 3.2525 Hz
Frequency Amplitude (Magnitude)
Frequency Response (in Hz)

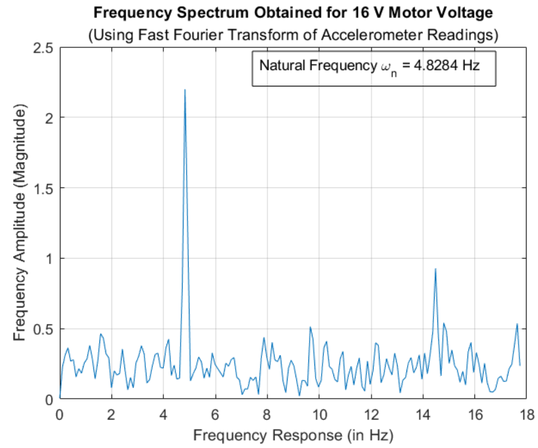

Vertical Acceleration versus Time
For Motor Voltage of 13 V
X-Acceleration
Y-Acceleration
Z-Acceleration
Vertical Acceleration (in m/s^2)
Elapsed Time (in sec)

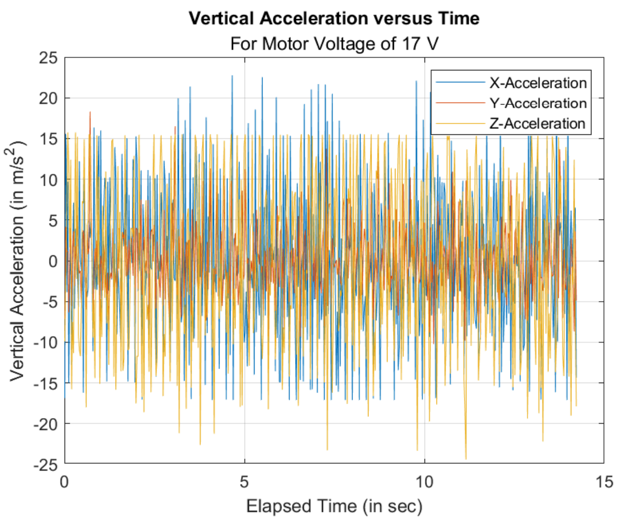

Frequency Spectrum Obtained for 13 V Motor Voltage
(Using Fast Fourier Transform of Accelerometer Readings)
Natural Frequency ω_n = 3.8845 Hz
Frequency Amplitude (Magnitude)
Frequency Response (in Hz)

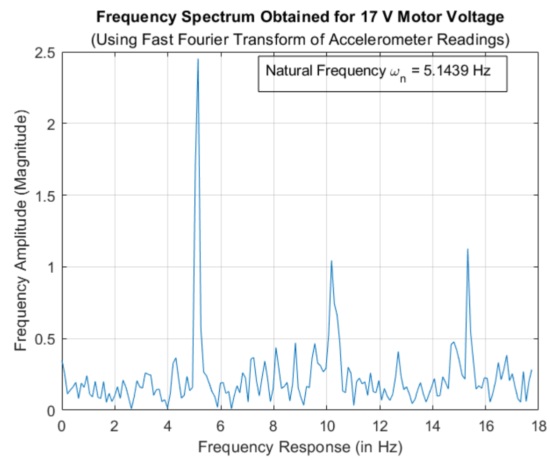

Vertical Acceleration versus Time
For Motor Voltage of 15 V
X-Acceleration
Y-Acceleration
Z-Acceleration
Vertical Acceleration (in m/s^2)
Elapsed Time (in sec)

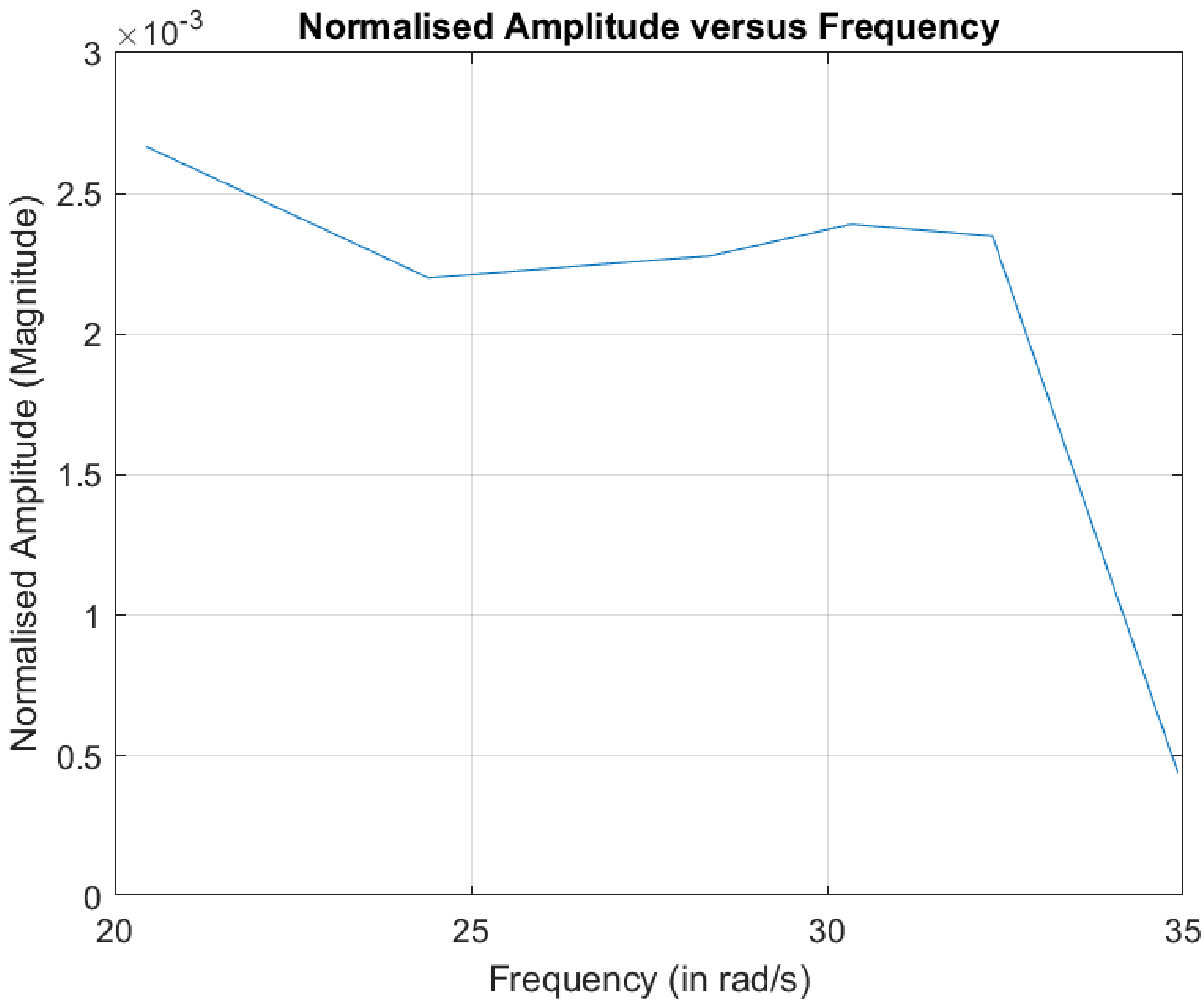

Frequency Spectrum Obtained for 15 V Motor Voltage
(Using Fast Fourier Transform of Accelerometer Readings)
Natural Frequency ω_n = 4.5163 Hz
Frequency Amplitude (Magnitude)
Frequency Response (in Hz)


Vertical Acceleration versus Time
For Motor Voltage of 16 V
X-Acceleration
Y-Acceleration
Z-Acceleration
Vertical Acceleration (in m/s^2)
Elapsed Time (in sec)


Frequency Spectrum Obtained for 16 V Motor Voltage
(Using Fast Fourier Transform of Accelerometer Readings)
Natural Frequency ω_n = 4.8284 Hz
Frequency Amplitude (Magnitude)
Frequency Response (in Hz)


Vertical Acceleration versus Time
For Motor Voltage of 17 V
X-Acceleration
Y-Acceleration
Z-Acceleration
Vertical Acceleration (in m/s^2)
Elapsed Time (in sec)


Frequency Spectrum Obtained for 17 V Motor Voltage
(Using Fast Fourier Transform of Accelerometer Readings)
Natural Frequency ω_n = 5.1439 Hz
Frequency Amplitude (Magnitude)
Frequency Response (in Hz)



Discussions:

1. There is a large amount of variation in ω_n over the readings from 1.5 to 17 V, and this doesn't follow any particular trend.
2. In Voltages under 9.5 V, many frequencies have peaks close to the height of ω_n, ie, there is no clear natural frequency. Above 9.5 V we can see a clearer single peak, but even this doesn't follow a trend.
3. X,y and z direction acceleration plots all show similar amplitudes of vibration, indicating the motor did not follow a clean up and down path. This is probably because there was sufficient space for x-y plane movement between the rails guiding the motion and the holes in the platform.
   We identified the z direction as the required direction of motion based on our placement of the accelerometer and the fact that it has maximum amplitude in these plots.
4. The amplitude of acceleration increases with Voltage, which makes sense as higher Voltages mean higher motor speeds, which is a higher frequency forcing function (response depends less and less on k)

5. We have not reached resonance in the given range of voltages

Conclusions:

1. The experiment conducted highlights the significance of selecting the appropriate driving voltage to prevent instability in vibrations and the role of choosing the correct auxiliary mass value to adjust the system's amplitude.
2. Vibration absorbers are extensively used to reduce vibrations in various applications such as machine tools, overhead transmission cables affected by wind-induced vibrations, and propeller vibrations in helicopters.
3. Resonance, capable of causing severe vibrations that may result in failure, must be prevented in numerous applications to ensure operational safety. The experiment draws our attention to this fact.
4. The amplitude of oscillations of the primary system have reduced significantly when the spring-mass auxiliary system or the dynamic balancing mechanism is used.
5. In situations where the attenuation mechanism can be mounted in the interior of the forcing system (motor in this case), dynamic balancing is a good option, whereas the auxiliary system is useful when the attenuation mechanism can only be mounted externally

Limitations and Possible Improvements to the Current Experimental Setup:

1. Noise in the acceleration data obtained using the dedicated accelerometer can be reduced by improving the adhesion between the accelerometer and the plate. It can also be improved by creating a proper structure for the accelerometer that can be mounted using nuts and bolts.
2. Ensure the power supply remains on when opening the Putty Terminal to avoid loss of initial voltage readings due to a rapid rate of voltage drop. We must acknowledge the fluctuations in supplied voltage during the execution of the experiment.
3. The springs are mounted at the top in such a way that they are prone to spring jump-off. This can be improved by mounting the tops of the springs using a suitable structure with nuts and bolts or by using a structure with a hole through which the top portion can be inserted into and firmly put in place.
4. Properly attach the Accelerometer and eccentric mass to prevent them from coming off during the experiment, leading to data loss.
5. Noise and errors in data acquired from the dedicated accelerometer due to movement of the wires connecting the accelerometer. This can be avoided if the acceleration data can be transmitted to the Arduino in a wireless manner.
6. Reduce damping effects caused by friction or air resistance in the system to maintain the desired amplitude of vibrations and ensure a consistent frequency response.
7. Minimise external mechanical vibrations, such as those from nearby equipment or people learning on the table, to maintain the precision and accuracy of measurements in the experimental setup.

8. Address any nonlinear behaviour in the springs to ensure that the amplitude and frequency of vibrations are directly proportional to the applied force or voltage, enhancing the experiment's reliability and consistency.

Contributions:

1. Introduction and Objectives - Vora Jay Bhaveshbhai
2. Methodology - Saukhya Telge
3. Data Plotting - Arnav Kalgutkar
4. Results and Discussions - Nayantara Ramakrishnan
5. Conclusions (Including Limitations and Improvements) - Aryan Bhosale