ME370: KINEMATICS & DYNAMICS OF MACHINERY LAB

Department of Mechanical Engineering
IIT Bombay

Lab 7: Vibration Data Acquisition and Analysis

Group: 5
Section: A

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1. **Aim of the Experiment**

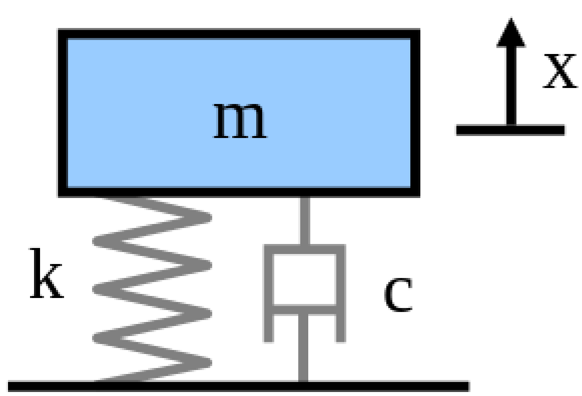
- **Investigate the dynamic behavior of a single-degree-of-freedom, second-order system:** We will achieve this by studying a real-world example – a simple spring-mass system.
- **Gain experience with data acquisition tools:** We will utilize Arduino IDE, Putty, and Phyphox software to collect data from the experiment.
- **Analyze the acquired data:** Employing appropriate signal processing techniques, we will identify the damping characteristics of the system.
- **Model the system:** Based on the data analysis, we will choose the most fitting mathematical model to represent the damping behavior of the spring-mass system.

2. **Apparatus Used**

- Smartphone with data acquisition app (Phyphox) installed
- Arduino for data acquisition
- Masses for spring characteristic measurement
- Laptop with MATLAB
- Spring
- Weighing machine
- Accelerometer (MMA7361)

3. **Introduction**

- The model of mass-spring-damper comprises individual mass nodes dispersed within an object and linked together through a system of springs and dampers. It is particularly effective in representing objects with intricate material characteristics, including nonlinearity and viscoelasticity.



$$-kx - c\dot{x} - mg = m\ddot{x}$$

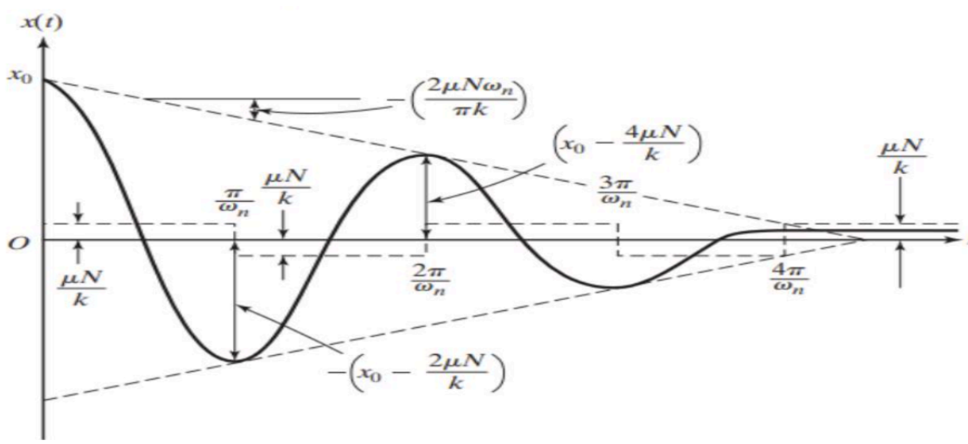
- Force Balance equation:-
  Rearranging this into the standard form we have: $\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2 x = u$
  Solution of this equation we get: $Ae^{-\omega_n t\left(\zeta+\sqrt{\zeta^2-1}\right)} + Be^{-\omega_n t\left(\zeta-\sqrt{\zeta^2-1}\right)}$

For ζ<1, this solution will have an oscillatory component

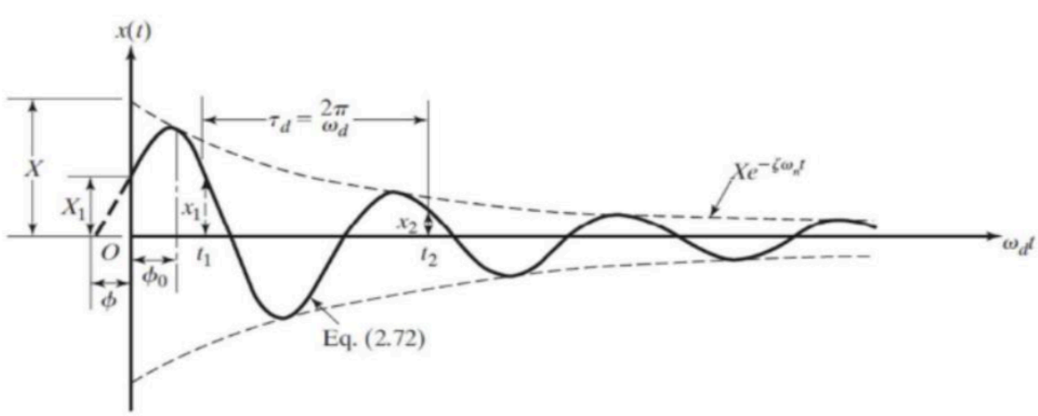
Natural Frequency(Hz) : $\omega_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

Damping Ratio : $\zeta = \frac{c}{2mw_n}$

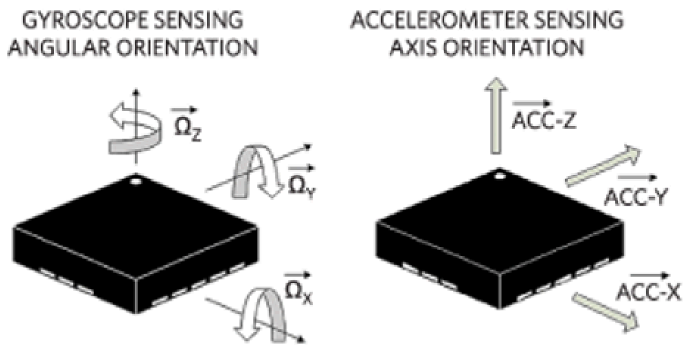
- The observed reduction in oscillation amplitude in the system can be modeled using one of the following damping representations:
  1. **Coulomb Damping Model** :
     Equation: $m\ddot{x}+kx=\mu mg$



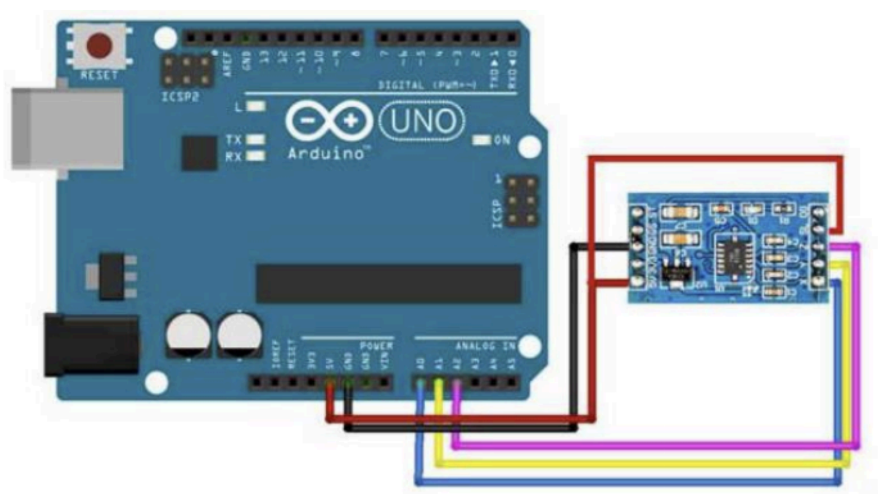
  2. **Viscous Damping Model** :



- The experiment will employ both a specialized accelerometer and the accelerometer found in a standard smartphone. These accelerometers are based on Micro-Electro-Mechanical System (MEMS) technology. The specific MEMS-based accelerometer utilized is the MMA7361, capable of providing acceleration measurements along all three axes. The sensor generates analog output for acceleration data acquisition.



4. **Methodology**



Spring Characterization:

1. We varied the weight attached to the spring and measured the resulting displacement.

2. A best-fit line was then drawn through the collected data points (load vs. displacement) to determine the spring stiffness and the system's natural frequency.
3. To minimize errors, multiple data points were used in the analysis.

Data Acquisition Setup:

1. An MMA7361 accelerometer was connected to the Arduino board following a provided circuit diagram.
2. The Arduino board was connected to a laptop via USB cable. The Arduino Uno software was launched, and the appropriate port (COM10 in this case) was selected.
3. The provided data acquisition code was uploaded to the Arduino, and the Serial Monitor tool was opened to observe real-time data output.

Smartphone Setup and Data Collection:

1. A smartphone with Phyphox running was placed in a sealed Ziplock bag.
2. An accelerometer was attached to the phone using double-sided tape.
3. The smartphone and Arduino were configured with the same sampling frequency (50 Hz, at least 15 times the estimated natural frequency).
4. Putty software was launched on the laptop for automated data storage, and logging settings were adjusted. Voltage readings were collected until both Arduino and Phyphox reached a constant zero voltage and acceleration respectively.

Data Analysis:

1. The collected data was transferred to an Excel sheet, excluding initial readings due to time lag.
2. Six sets of readings were collected.
3. A Fast Fourier Transform (FFT) was performed on the data to compare the experimentally obtained natural frequency with the theoretical estimate.
4. For Arduino readings, voltage values were converted to acceleration units (g) using the provided conversion factor (800 mV/g) based on the accelerometer datasheet.
5. Data from both Arduino and Phyphox were compared to identify an appropriate Damping Model for the system.

5. **Results**

- We performed 3 sets of experiments to calibrate the spring provided to us. The values of spring constants obtained by linear curve fit are -

k_1	k_2	k_3
161.54 N/m	142.28 N/m	147.28 N/m

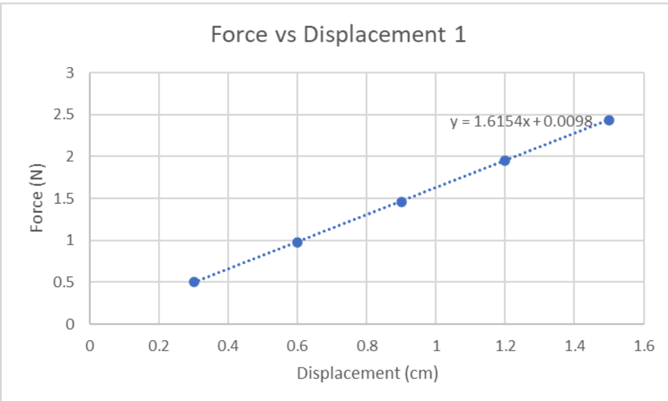


Figure 1: Linear fit for first dataset

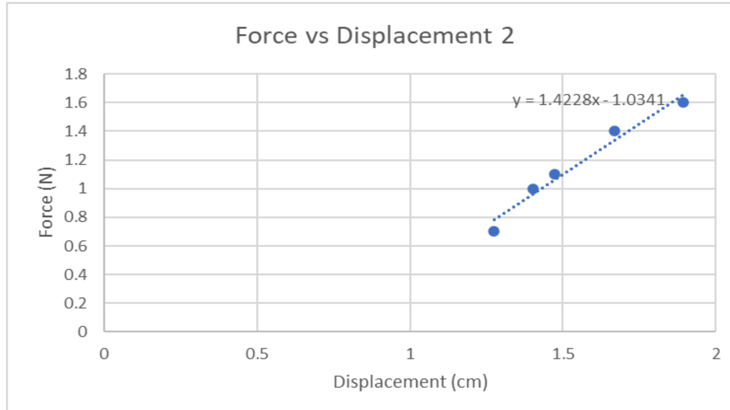


Figure 2: Linear fit for second dataset

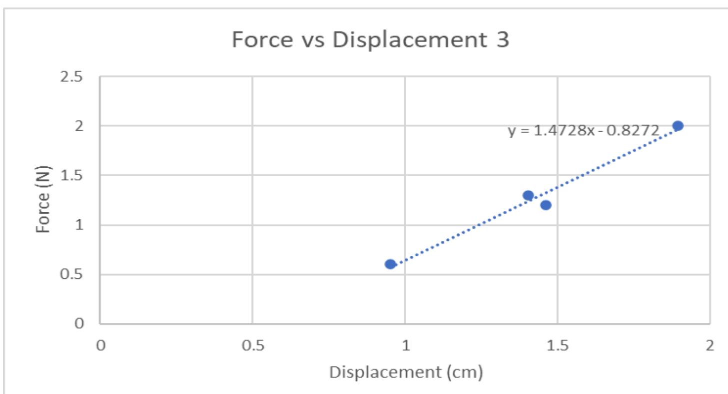


Figure 3: Linear fit for third dataset

The slope of the linear fit is in N/cm, therefore you need to multiply it with 100 to get the value of k in SI units (N/m).

- The average value of k obtained is 150.367 N/m. This value will be used for further analysis. Other parameters of the spring and system are -

Natural Length	Sample Rate	Mass of Phone	Natural frequency
12 cm	50Hz	248 gm	3.92 Hz

Dataset 1

Arduino Data -

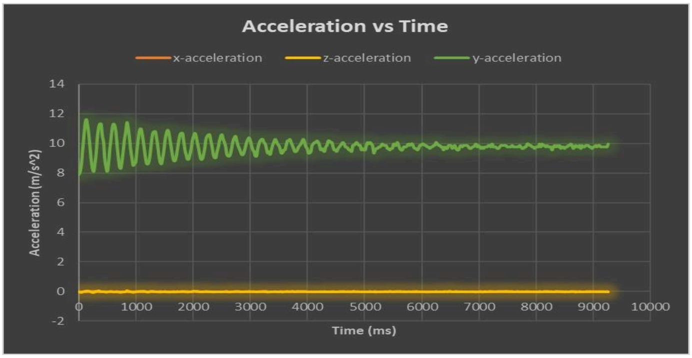


Figure 4: Acceleration vs Time plot

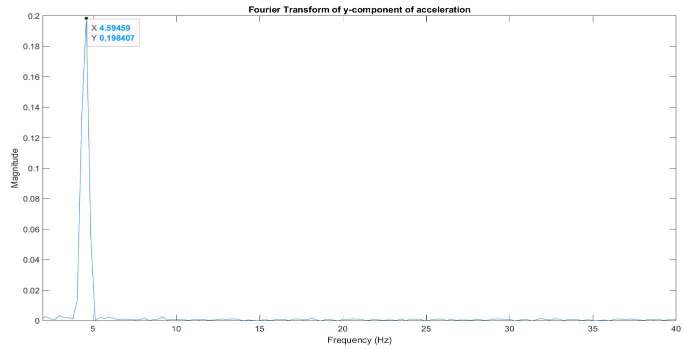


Figure 5: FFT of the acceleration data with Hann windowing

Phyphox Data -

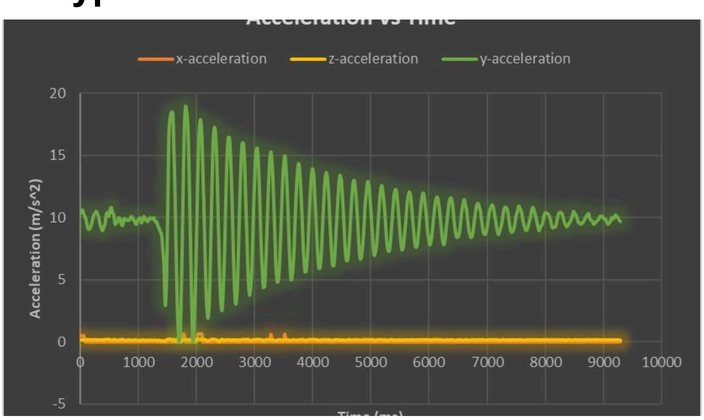


Figure 6: Acceleration vs Time plot

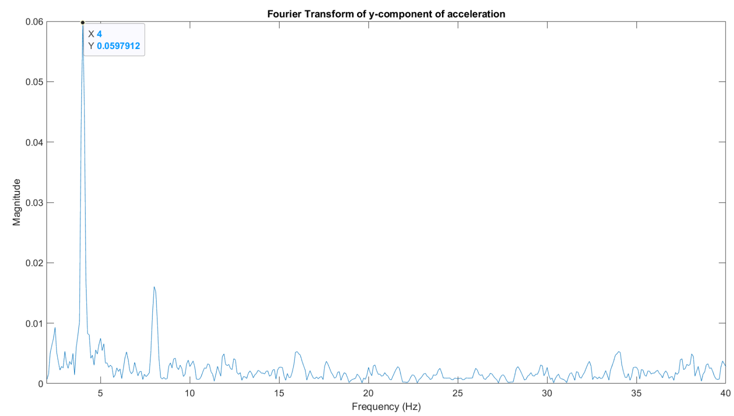


Figure 7: FFT of the acceleration data with Hann windowing

Dataset 2

Arduino Data -

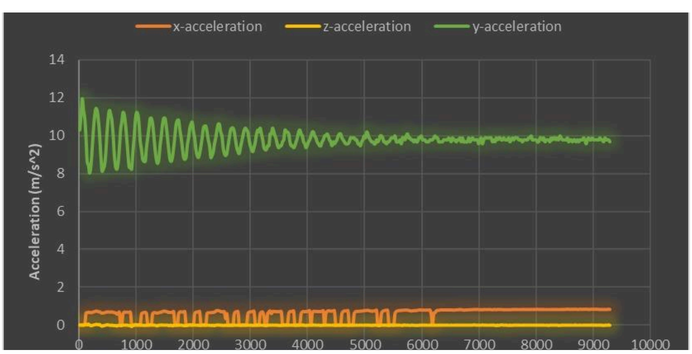


Figure 8: Acceleration vs Time plot

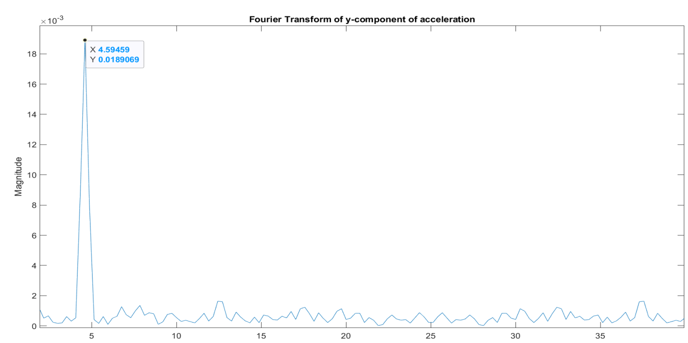


Figure 9: FFT of the acceleration data with Hann windowing

Phyphox Data -

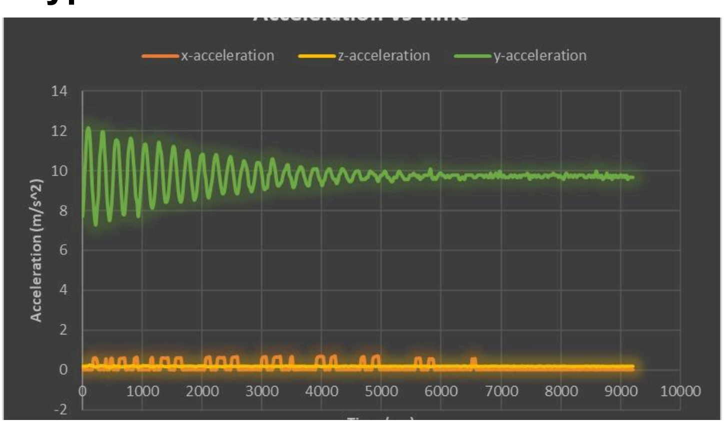


Figure 10: Acceleration vs Time plot

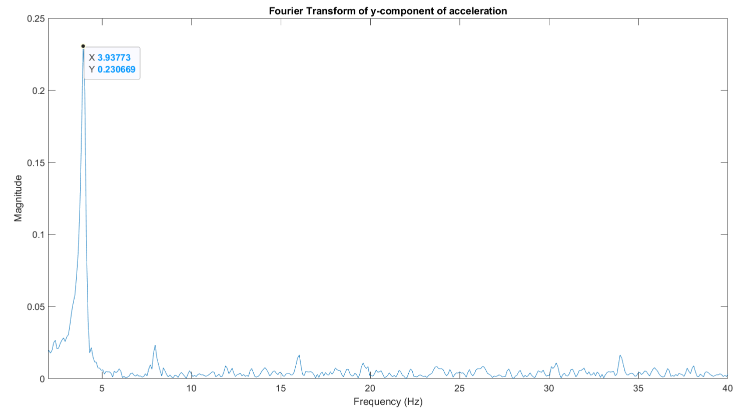


Figure 11: FFT of the acceleration data with Hann windowing

Dataset 3

Arduino Data -

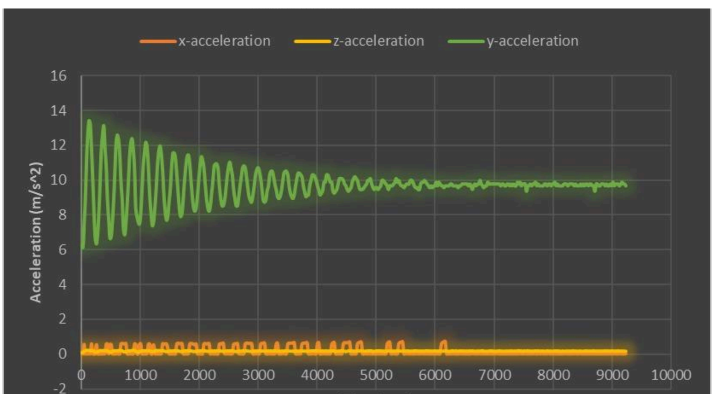


Figure 12: Acceleration vs Time plot

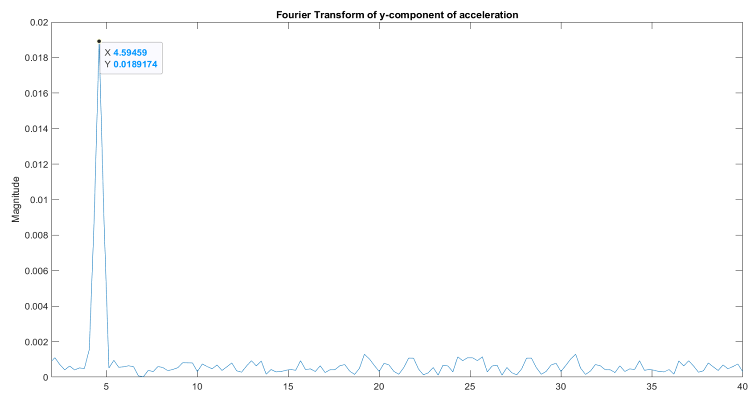


Figure 13: FFT of the acceleration data with Hann windowing

Phyphox Data -

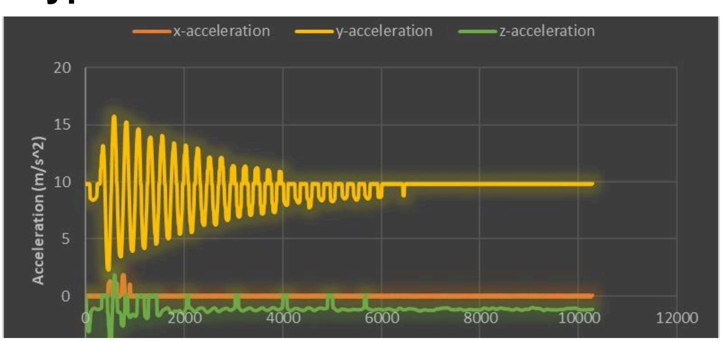


Figure 14:Acceleration vs Time plot

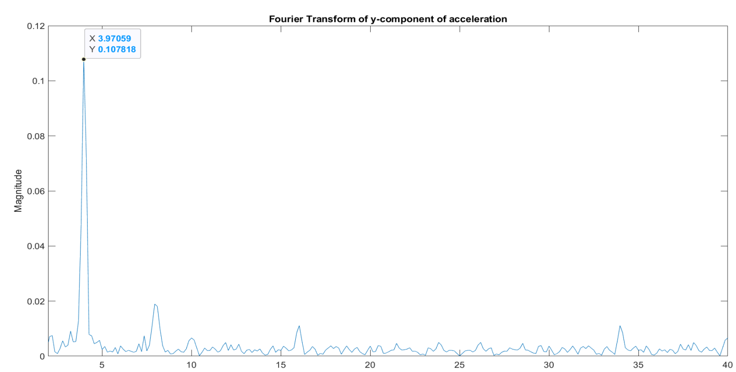
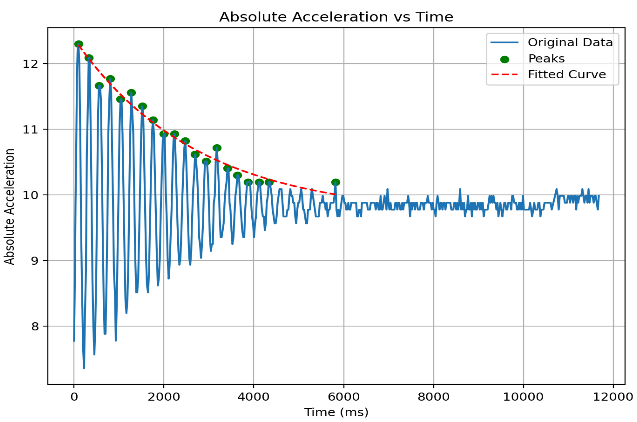


Figure 15: FFT of the acceleration data with Hann windowing

- Clearly, the y-component values are dominant over x and z-component values of acceleration. So the initial assumption of ignoring x and z components is valid.
- All three datasets used a sampling rate of 50 Hz which is approximately 12.5 times the natural frequency to avoid aliasing in signals acquired
- Performing curve-fit on the maximas in the y-acceleration signal gives the value of ζ

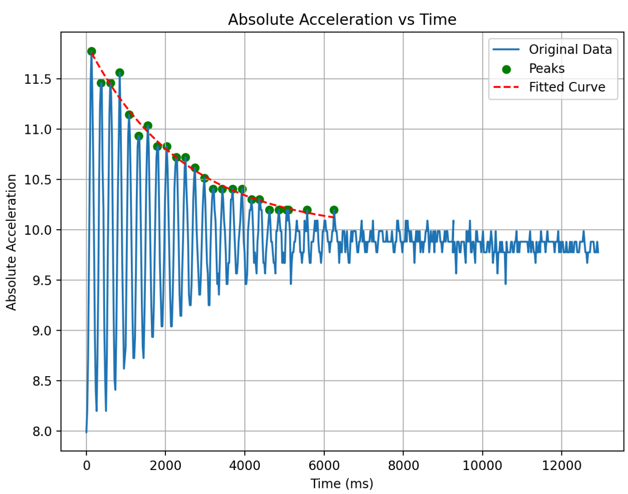
Dataset 1 (Arduino)-



ζ = 0.0138

c = $2\zeta\sqrt{km} \;=\; 0.16854\ Ns/m$

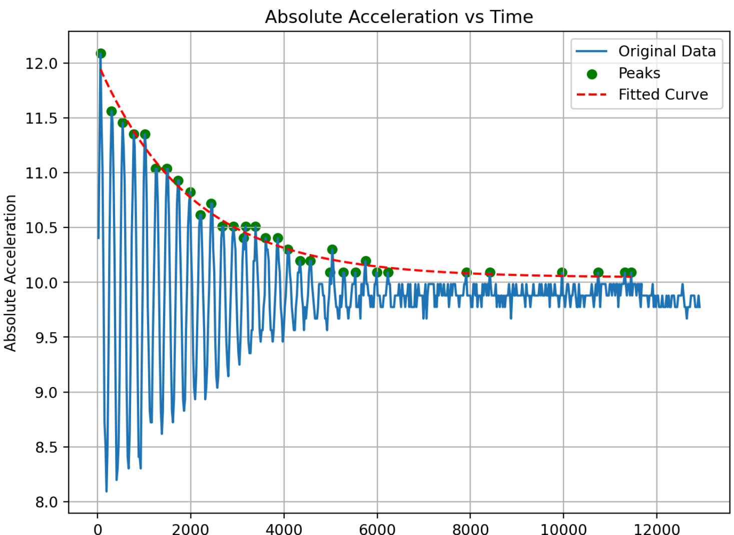
Dataset 2 (Arduino)-



ζ = 0.00826

c = $2\zeta\sqrt{km} \;=\; 0.10088\ Ns/m$

Dataset 3 (Arduino)-



ζ = 0.00971

c = $2\zeta\sqrt{km} \;=\; 0.1186\ Ns/m$

Phyphox datasets weren't considered for this fitting as some parts of the data are incomplete
Average damping coefficient = **0.12934 Ns/m**

- The damped natural frequencies obtained(in Hz) from FFTs were as follows -

Software	Data 1	Data 2	Data 3	Mean
Arduino	4.59459	4.59459	4.59459	4.59459
Phyphox	4	3.93773	3.97059	3.96944

Relaxation time τ_s = 0.545 secs (time between two peaks, calculated using python)

Experimental damped frequency = $\frac{2\pi}{0.545}$ = 11.53 Hz

6. Discussion

- The spring used in the experiment was not a linear spring, hence best linear fit was used to model its stiffness.
- The mean values of the experimental damped natural frequency(from FFT) are 4.59459 and 3.96944 Hz for Arduino and Phyphox respectively, which is close to the analytical natural frequency of 3.92 in the Phyphox data.
- The part of the Phyphox data where the sampling is complete was used to perform FFT. Taking incomplete, aliased parts may lead to error.
- Hann windowing was performed on the acquired signal. Other windowing functions like Hamming, Tukey can also be used to see the frequency content.
- The mean damping coefficient is 0.12934 Ns/m
- Viscous damping model provides a relatively good fit to the data, thereby serving as a valid estimate for modeling the decay in amplitude of acceleration of the system.
- The experimental damped frequency(11.53 Hz) is very far from the natural frequency (3.92 Hz) which is a 66% relative error in values.

7. Conclusion

- The employed vibration data collection instruments proved effective in acquiring dependable data regarding the spring's vibrational characteristics.

- Phyphox data acquired is incomplete in the 1st and 3rd datasets. Possible reasons for this include misalignment of the phone as well as a low sampling rate. Increasing sampling rate may reduce aliasing.
- Upon analyzing the frequency response, it can be seen that the spring system possesses a low damping ratio, suggesting prolonged vibration persistence post-excitation force cessation.
- The FFT graphs do not contain any other major spikes. Thus the data is dependable as other spikes would have been indicators of high noise.

8. Sources of Error

- Predicting the precise value of sample frequency is not possible because the graphs' shapes can only be seen with the naked eye.
- There is a greater likelihood of errors in the FFT technique if the slopes of the curves near peaks are very large.
- The electrical circuit's component parts have loose connections.
- When the accelerometer is not properly attached to the mobile phone, it may fall off during the experiment and cause measurements to be lost. Additionally, one must only apply a little amount of displacement to the smartphone because a larger displacement could cause the spring to leap off the hook and damage the device.
- Human errors in the application of the methodology, such as software usage, voltage adjustments, or computation round-off errors.
- Due to approximations made during estimation, such as using a best-fit curve and assuming zero current, the calculated damping coefficients are not accurate.

9. Contributions

No.	Name	Contribution
1	Yash Salunkhe	Results, Discussion
2	Sanika Wagh	Aim, Introduction
3	Kavan Vavadiya	Methodology, Formatting,Conclusions
4	Shreya Biswas	Sources of error
5	Samiksha Patel	Apparatus
6	Mudit Sethia	Methodology

10. **Bibliography**

- https://en.wikipedia.org/wiki/Viscous_damping
- https://en.wikipedia.org/wiki/Mass-spring-damper_model
- Arduino, MATLAB scripts and slides shared by Prof. Salil Kulkarni
- http://mechanicsmap.psu.edu/websites/16_one_dof_vibrations/16-2_viscous_damped_free/16-2_viscous_damped_free.html