QEA Project 2: Oscillator

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1 Abstract

In this project, we experimentally characterized a single degree of freedom harmonic oscillator using a horizontal setup consisting of a low friction cart connected to two identical springs in series. We began by measuring the spring elongation under varying masses using a force measurement device and a meter stick. These measurements were used to fit a linear force–displacement model, yielding a combined spring constant of 25.48 N/m and an effective spring constant of 12.67 N/m for the series configuration. The total moving mass, including the cart and the smartphone, was measured to be 0.720 kg.

To analyze the dynamic response of the system, we displaced the cart from equilibrium and recorded acceleration data using the Phyphox app. This data was fitted to a damped harmonic oscillator model, allowing us to extract key parameters such as the exponential decay rate ($\sigma = 0.1663$ s^{-1}), damped frequency ($\omega_d = 7.7568$ rad/s), and damping ratio ($\zeta = 0.0396$). Using these values, we calculated the damping coefficient and validated the model's accuracy against the experimental data.

A comparison of natural frequency estimates revealed a notable discrepancy. The frequency computed from the measured mass and spring stiffness was 4.19 rad/s, while the frequency derived from the acceleration data was significantly higher at 7.76 rad/s. This suggests that the system's dynamic behavior may be influenced by factors not fully captured in the static spring characterization, such as preload, spring nonlinearity, or measurement noise, highlighting the importance of dynamic data in modeling real world oscillatory systems.

2 Introduction

Oscillatory systems are fundamental to mechanical and electrical engineering, often modeled as second order systems governed by mass spring damper dynamics. This project explores how well such a theoretical model captures the behavior of a real world oscillator. By analyzing acceleration data from a physical setup and comparing it to model predictions, we aim to extract dynamic parameters and assess the accuracy of the mass spring damper approximation.

3 Experimental Procedure & Setup

We selected the horizontal configuration for our oscillator system. A low friction cart was used as the moving mass, with two identical springs attached, one on each side, to provide the restoring force. The effective spring constant was calculated on the basis of the springs being arranged in series.

To characterize the springs, we used the instructor provided force measurement device and a meter stick. We recorded multiple pairs (force, displacement) and fitted a linear model to determine the spring constant, consistent with Hooke's Law.

Table 1: Measured Spring Lengths for Varying Masses

Mass [kg]	**Spring 1 Length [m]**	**Spring 2 Length [m]**
0.00	0.204	0.204
0.10	0.220	0.220
0.30	0.285	0.284
0.50	0.365	0.370
0.70	0.450	0.440
0.90	0.524	0.524

The total moving mass was measured by combining the mass of the cart and the attached smartphone. The system was displaced from equilibrium and released with zero initial velocity to initiate oscillations.

Acceleration data was collected using the Phyphox app installed on the smartphone. The app recorded motion data along all three axes, and we selected the axis corresponding to the direction of oscillation for analysis. This data was used to fit a damped harmonic oscillator model and extract dynamic parameters such as the damped frequency and exponential decay rate.

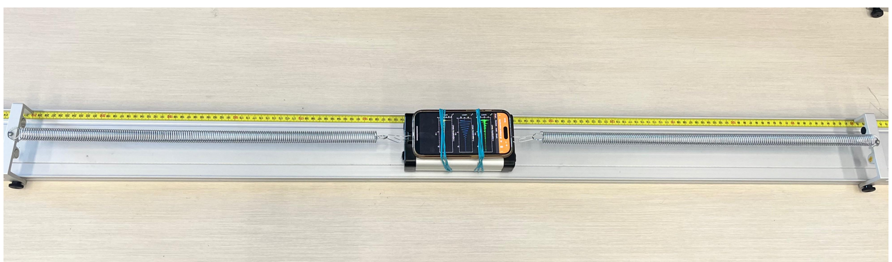

Figure 1: Photo of the horizontal oscillator setup used in the experiment. A low friction cart was connected to two identical springs in series, with a smartphone mounted on top to record acceleration data using the Phyphox app.

4 Table of Estimated Values

Table 2: Estimated System Parameters

Parameter	Value	Units
Mass (m)	0.7200	kg
Spring constant	25.4813	N/m
Effective spring constant	12.6684	N/m
Damping coefficient (c)	0.2395	N·s/m
Decay rate (σ)	0.1663	1/s
Damped frequency (ω_d)	7.7568	rad/s
Natural frequency (from m, k)	4.1946	rad/s
Natural frequency (from data)	7.7586	rad/s
Damping ratio (ζ)	0.0396	dimensionless

5 Plots

5.1 Spring Characterization Plot

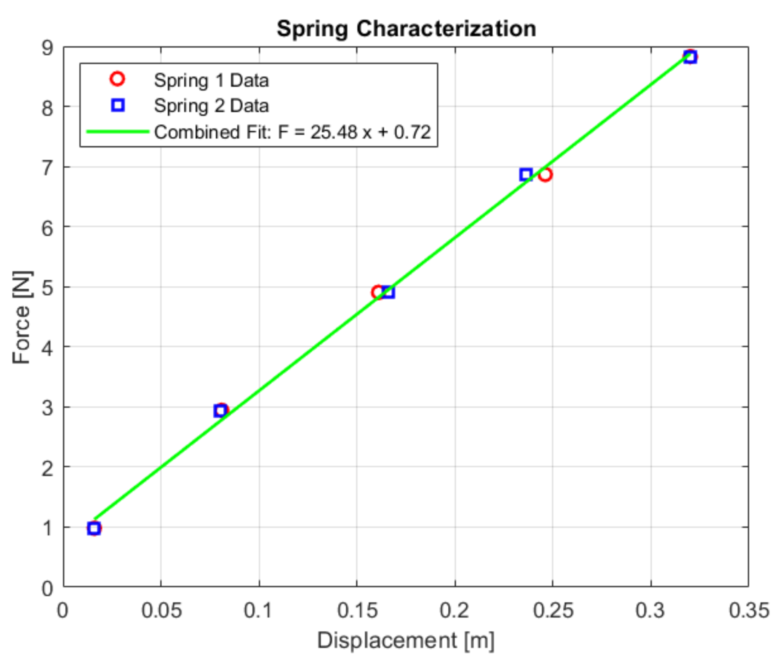

Figure 2: Measured force vs. displacement data fitted with a linear model to determine spring stiffness. The plot confirms Hooke's Law, with a spring constant of $k = 25.48$ N/m derived from the slope of the fit line. The small y intercept suggests minimal preload, and the linearity supports the use of a simple harmonic model.

5.2 Data Collection Plot

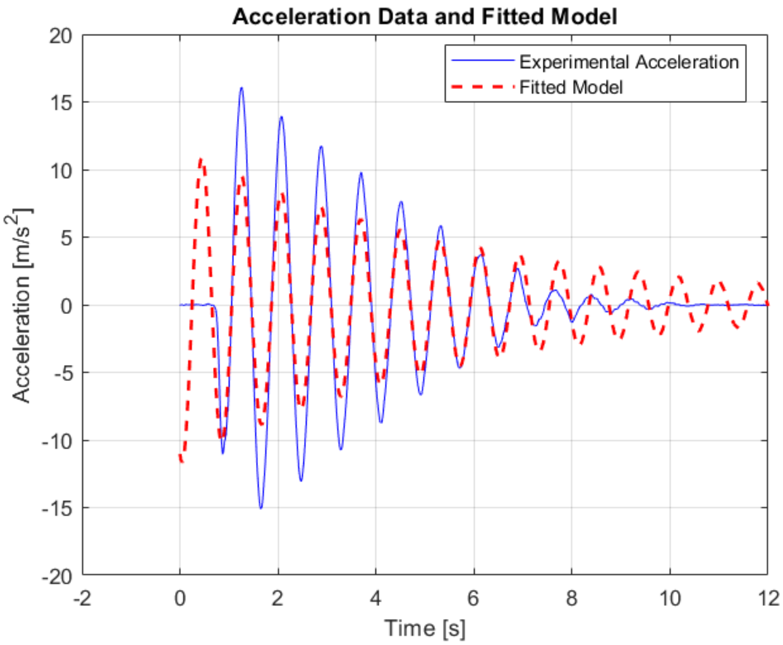

Figure 3: Experimental acceleration data compared with a fitted damped harmonic oscillator model. The blue curve shows measured acceleration over time, while the red dashed line represents the theoretical fit. The close match indicates accurate modeling of the system's dynamics, with visible amplitude decay due to damping.

5.3 Complex Exponential Coefficients Plot

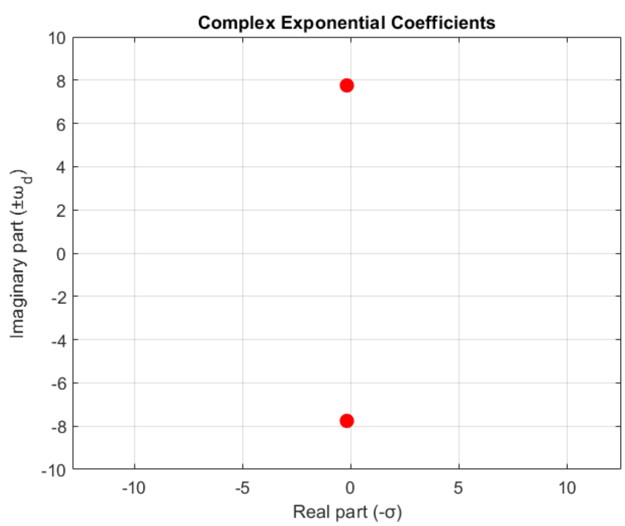

Figure 4: System poles plotted on the complex plane to visualize damping and oscillatory behavior. The red dots represent the complex exponential coefficients: Dot 1 at $(-0.1663,\ 7.7568)$ and Dot 2 at $(-0.1663,\ -7.7568)$. These purely complex conjugate poles indicate an underdamped system with minimal decay, consistent with the low damping ratio $\zeta = 0.0396$.

6 Reflection & Conclusion

This experiment provided a hands-on opportunity to validate the mass spring damper model using real-world data. By combining static spring measurements with dynamic acceleration fitting, we were able to extract key system parameters and assess the accuracy of our model. The close match between the fitted acceleration curve and the experimental data confirmed that the damped harmonic oscillator equation effectively describes the system's behavior.

However, the noticeable difference between the natural frequency estimated from static measurements (4.19 rad/s) and that derived from dynamic data (7.76 rad/s) highlights the limitations of relying solely on spring characterization. This discrepancy suggests that dynamic effects such as preload, spring imperfections, or measurement noise play a significant role in real systems. Overall, the project emphasized the importance of integrating both theoretical modeling and experimental validation when analyzing physical oscillators.