MECH 420 – Lab Report 4

Kyle Ah Von #57862609

Part A

1. Find the actuator position (equilibrium) as a function of coil current $X_{VCA}(I_{coil})$. Provide a graph with the measured and predicted (pre-lab) position as a function of coil current. How do the curves compare?

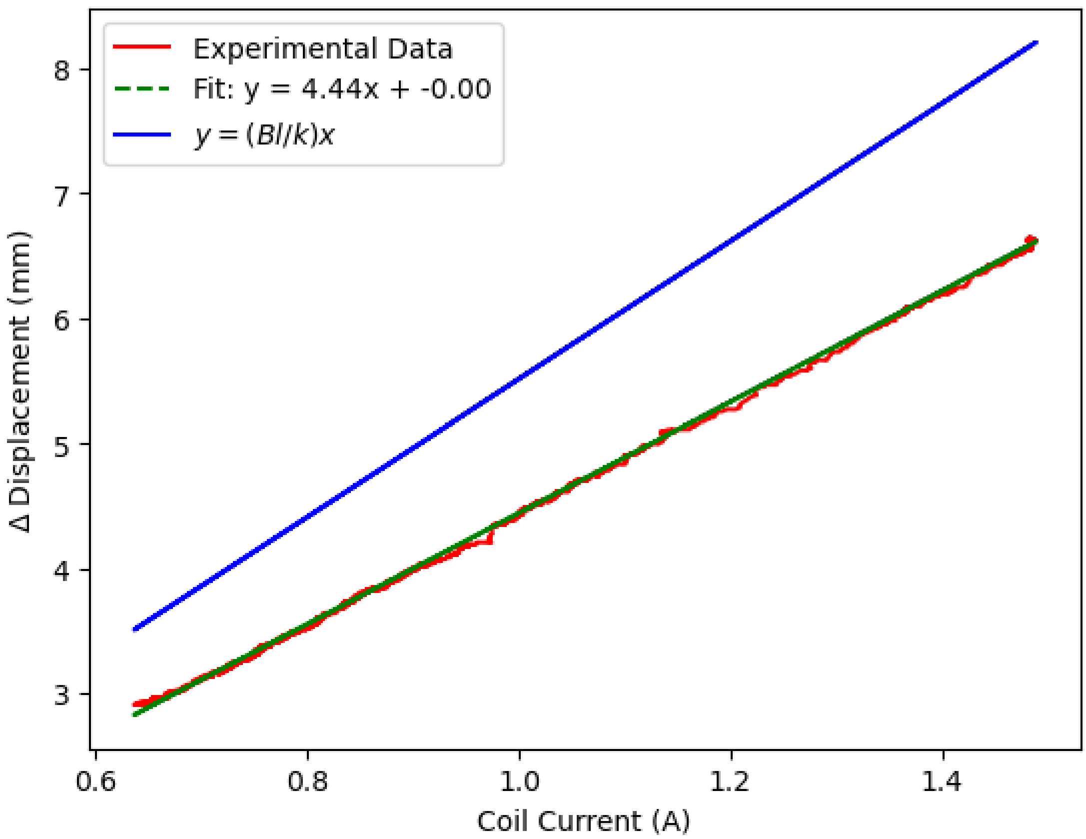

Figure 1: Displacement vs Coil Current

The equilibrium position as a function of coil can be obtained by solving the spring force and VCA force which gives us: $X_{VCA} = \frac{Bl}{k} I_{coil}$. Hence, the equilibrium position at each corresponding current value can be obtained as shown above. The measured relation shows only half of the total motion.

We can measure the deviation of the experimental value from the theoretical value using:

1. RMSE between fitted and theoretical line: 1.10
2. MAE between fitted and theoretical line: 1.06

The errors are small. The fitted line is centered on the point of origin and the displacement that I am considering is the change in displacement from the zero'd position.

Part B

1. Find and plot the amplitude and phase of $Vcoil$ and the position x for the different frequencies; consider the phase of the current as reference φI =0.

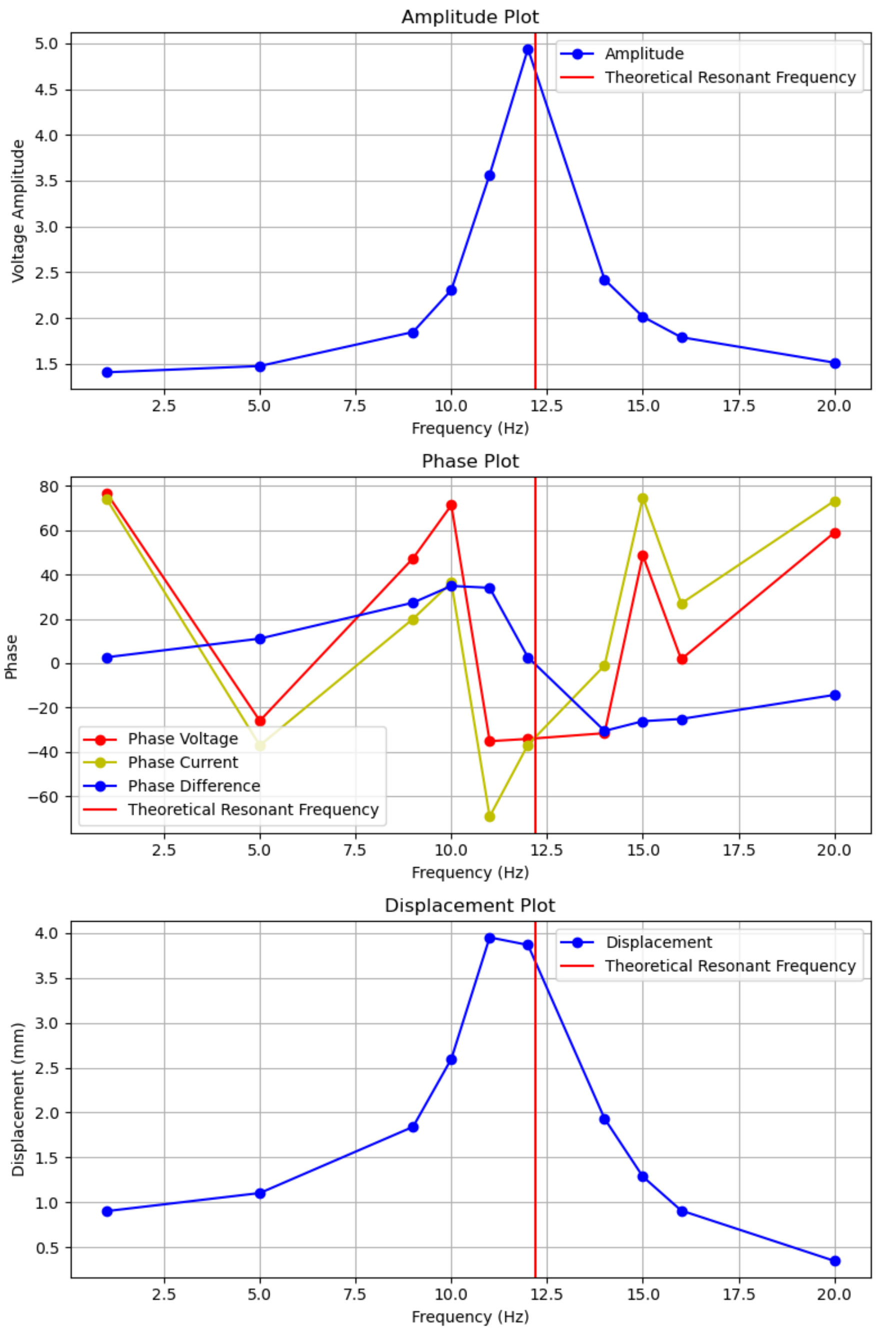

Figure 2: Amplitude, Phase and Displacement

The corresponding values of amplitude, phase and displacement with respect to different frequency values are extracted from fitting sine waves to the voltage and current signals. The phase can be obtained from the fitted values as well.

<u>Voltage Amplitude:</u> The amplitude signal shows that there is a typical harmonic response for amplitude with a clear resonant frequency at around 12 hz.

<u>Phase profiles:</u> Considering the profiles for voltage and current signals, there are no obvious trends, however, if we consider that the current phase is the base line, then the phase difference gives us a response that is as expected, where it increases until the frequency comes close to the resonant frequency where it falls, and then increases again.

<u>Displacement:</u> Displacement is obtained through the LED sensor and corresponds to the voltage signal.

2. Find the complex input impedance $Z(f)$ of the system as measured at the VCA and provide a graph of its magnitude.

I first converted the voltage and current signals to their complex number equivalents found the impedance by using: $Z = \frac{V}{I}$ and found the magnitude of the impedance.

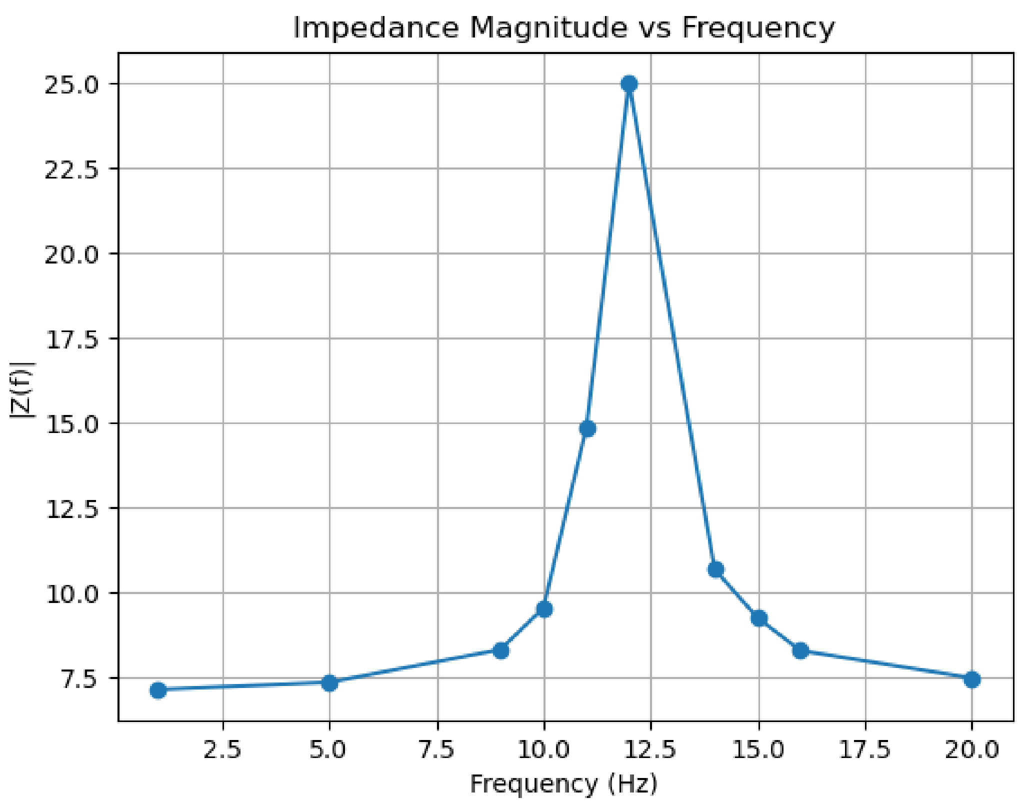

Figure 3: Complex Impedance

Code to obtain Impedance:

```
voltage_magnitude = np.array(amplitude_array)
voltage_phase = np.array(phasevoltage_array)
current_magnitude = np.array(amplitudecurrent_array)
current_phase = np.array(phasecurrent_array)

# Convert phase angles from degrees to radians
voltage_phase_rad = np.deg2rad(voltage_phase)
current_phase_rad = np.deg2rad(current_phase)

# Calculate complex voltage and current
voltage_complex = voltage_magnitude * (np.cos(voltage_phase_rad) + 1j *
np.sin(voltage_phase_rad))
current_complex = current_magnitude * (np.cos(current_phase_rad) + 1j *
np.sin(current_phase_rad))

# Calculate complex impedance Z(f)
impedance_array = voltage_complex / current_complex

# Get the magnitude of impedance for plotting
impedance_magnitude = np.abs(impedance_array)

print(impedance_magnitude)

plt.plot(frequency_array, impedance_array, marker = 'o')
plt.xlabel("Frequency (Hz)")
plt.ylabel("|Z(f)|")
plt.title("Impedance Magnitude vs Frequency")
plt.grid(True)
plt.show()
```

After converting the current and voltage signal to their complex form, we can divide the values to find the corresponding impedance as shown in the code above.

3. Identify the mechanical resonant frequency of the system from the input impedance Z(f).

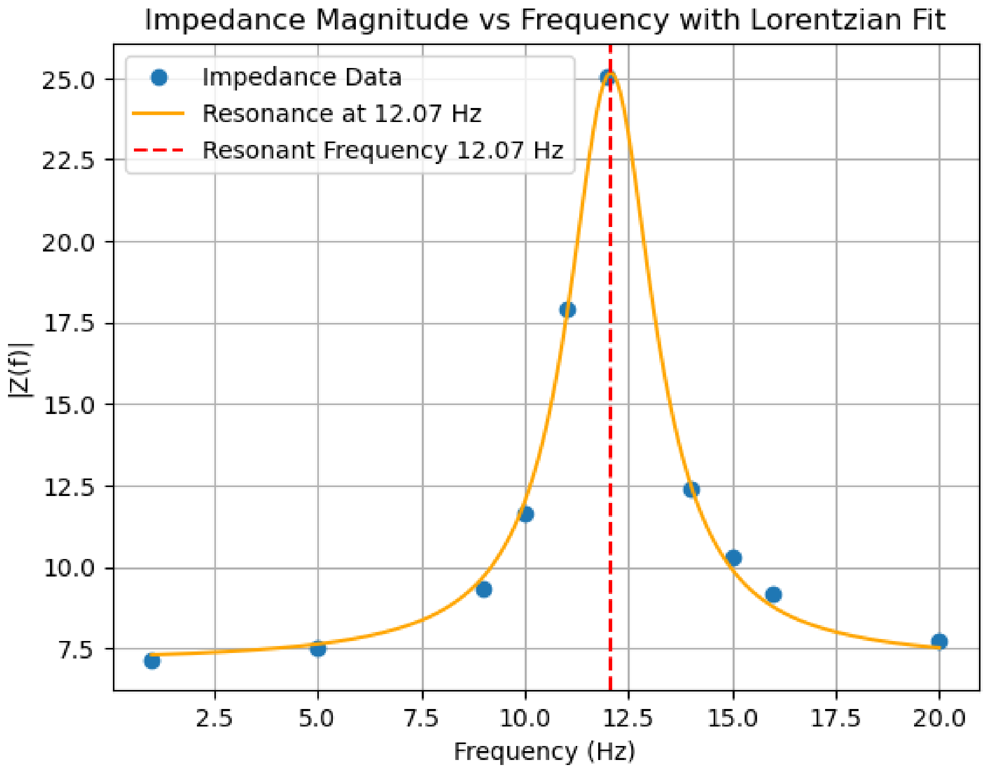

Figure 4: Fitted Lorentzian curve

After fitting a lorentzian curve to the magnitude of the impedance, we can see that the mechanical resonant frequency is 12.07 Hz based on the parameters of the curve.

4. Determine the total moving mass using the mechanical resonant frequency.

Resonant Frequency is obtained from $f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

Given that k has been experimentally determined to be 1.642 N/mm.

Mass is thus calculated to be 0.285 kg.

5. Knowing all the parameters of the system, derive the transfer function for a coil current input and a displacement (position) output and plot the magnitude of this transfer function as a function of frequency along with the measured position. Compare the two curves.

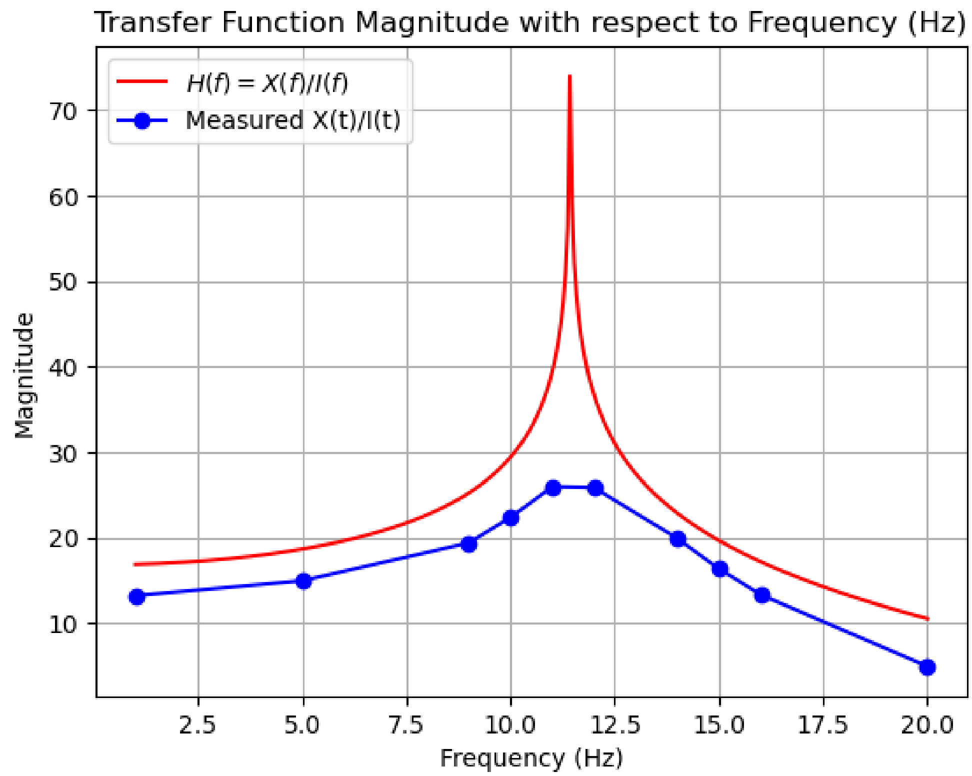

Figure 5: Theoretical vs Measured Transfer Function

The theoretical transfer function of $\frac{X(t)}{I(t)} = \frac{Bl}{k-\omega^2 m}$ where $\omega = 2\pi f$.

The measured transfer function is given in blue.

The two graphs have similar shapes with similar resonant frequency at around 12 hz. The measured transfer function is of smaller magnitude and does not show the peak magnitude due to resolution of our measurement. The lower magnitude can be explained by the electrical side and experimental errors.

Part C

1. Convert V_{coil} to a velocity signal and plot $u(t)$.

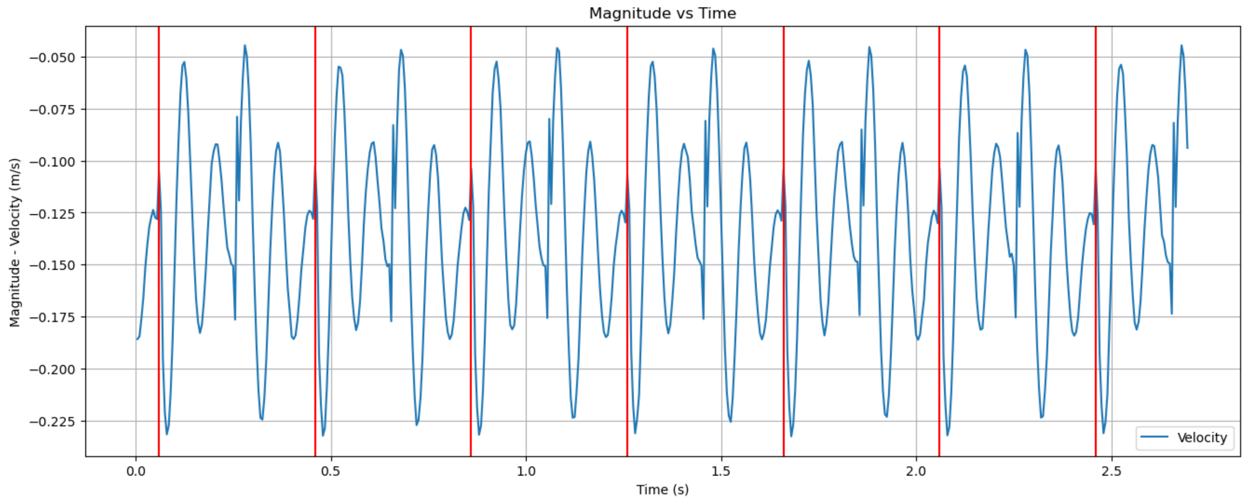

Figure 6: Velocity vs Time (from Coil Voltage)

We can observe oscillations when the current stabilizes – Oscillation when the current is at 0.8 A and when the current is at 0.4 A.

2. Convert $V_{position}$ to a position signal and plot $x(t)$.

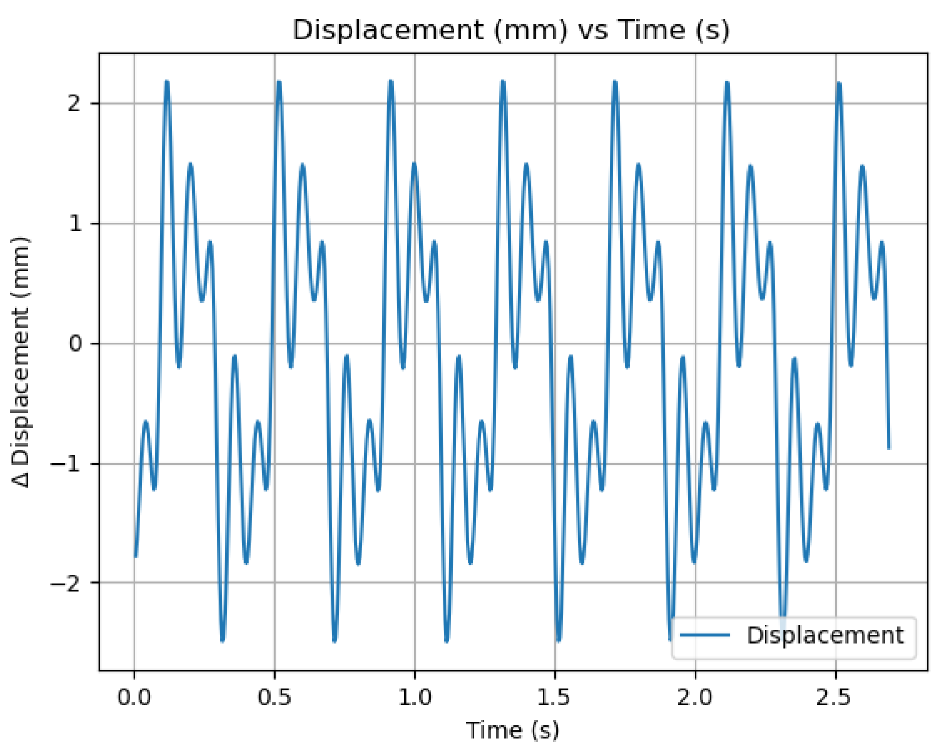

Figure 7: Displacement vs Time (from LED sensor)

3. Integrate the acceleration signal once & twice, integrate or differential velocity once, differentiate the position signal once & twice. Provide a plot for acceleration over time obtained from the position, velocity and acceleration measurements. Provide corresponding plots for velocity and position. Compare the curves in each plot.

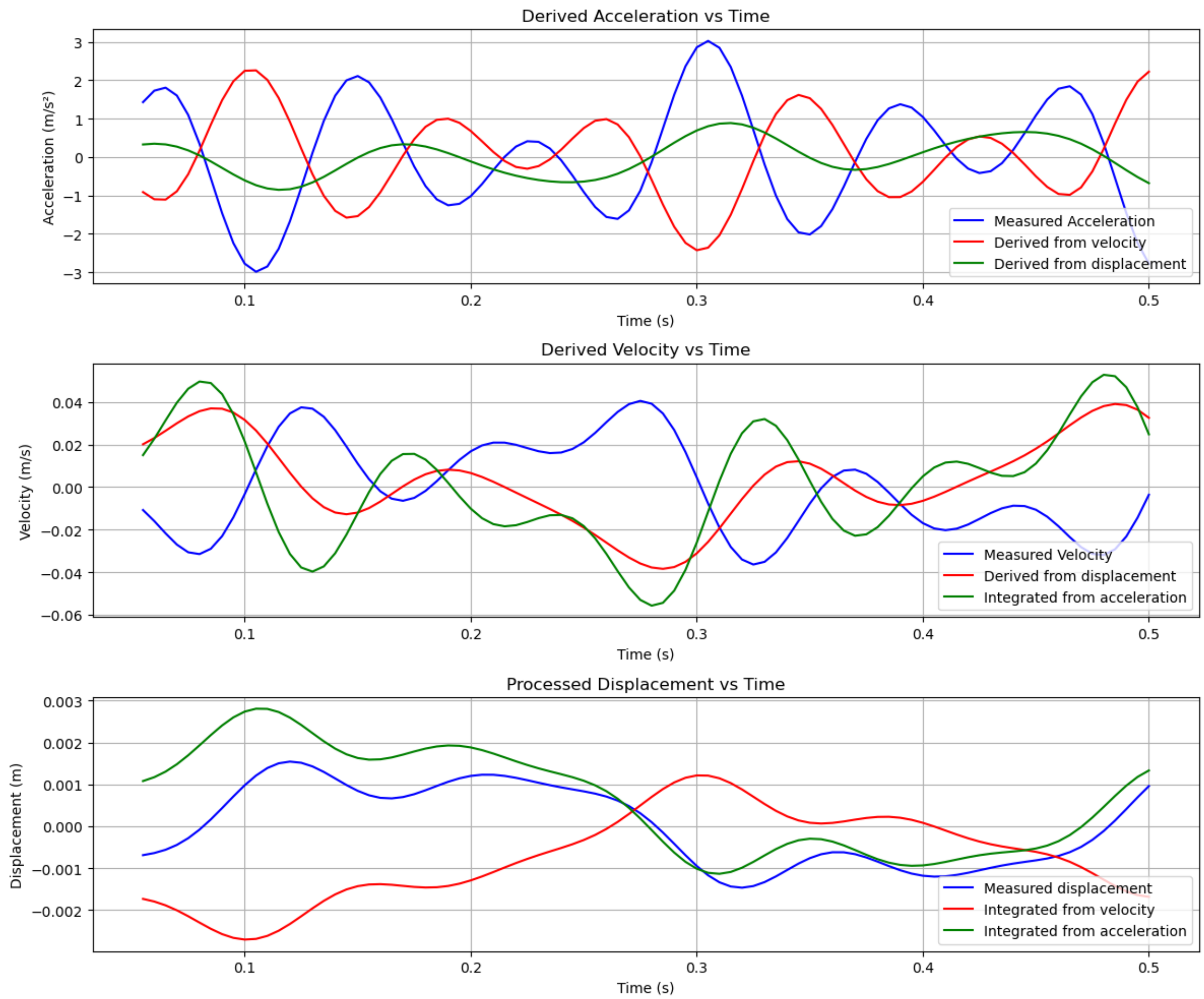

Figure 8: Acceleration, Velocity and Displacement vs Time

Looking at these three graphs showing acceleration, velocity, and displacement measurements over time, I notice several important points:

1. Measurement Discrepancies:

    - There are notable differences between measured values and derived values across all three quantities
    - The measured acceleration (blue line in top graph) shows higher frequency oscillations and larger amplitudes compared to the derived values

- The measured velocity shows phase differences compared to both the integrated acceleration and derived displacement curves

2. Signal Quality:

   - The acceleration measurements appear to be noisier than velocity and displacement measurements
   - This is typical since acceleration measurements are more sensitive to high-frequency noise
   - The displacement measurements appear smoothest, which is expected due to the integration process acting as a low-pass filter

3. Integration Effects:

   - There's drift visible in the integrated values (particularly noticeable in the displacement graph)
   - The green lines (integrated from acceleration) show systematic deviation from measured values over time
   - This is a common issue with numerical integration due to accumulation of small errors

4. Calibration/Offset Issues:

   - There appear to be baseline offsets between the different measurement methods
   - This could indicate calibration issues or DC offset problems in the sensors
   - The displacement graph shows the most obvious offset between methods

5. Recommendations:

   - Consider implementing a high-frequency filter on the acceleration data
   - Calibrate sensors to reduce baseline offsets
   - Use sensor fusion techniques to combine the strengths of each measurement type
   - Implement drift compensation for integrated values
   - Consider using a Kalman filter to optimally combine these different measurements