Engineering Measurements, MECH-3224

Laboratory “Project Omega”

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Introduction

Project Omega investigates the dynamic behavior of a one-degree-of-freedom (1DOF) mass-spring system subjected to free (undamped) vibrations. The objectives include determining system mass and stiffness, analyzing displacement and force responses, and computing the natural frequency. LabVIEW is utilized for data acquisition and analysis, ensuring precise measurement and uncertainty evaluation.

Experimental vibration analysis is critical in engineering applications. Figliola and Beasley (2019) emphasize precision in mechanical measurements [1], while De Silva (2007) highlights real-time data acquisition strategies for dynamic systems [2]. Brüel and Kjær (2004) discuss transducer-based vibration measurement techniques, validating the use of non-contact displacement sensors [3].

This study applies these methodologies using advanced instrumentation, including the Keyence laser displacement transducer, NI cDAQ modules, and LabVIEW software, to derive fundamental vibration characteristics and assess measurement accuracy.

Methodology

The experiment utilized a Keyence laser displacement transducer and a Tovey load cell to measure displacement and force, respectively. These sensors were connected to an NI cDAQ chassis with NI-9205 and NI-9237 modules, interfacing with LabVIEW for data acquisition. A spring-mass system was subjected to controlled displacements, and corresponding forces were recorded. The data was analyzed to determine the stiffness constant and the system's natural frequency. Multiple trials were conducted to minimize errors, and calibration techniques ensured accuracy.

Analysis

The experiment investigated the dynamics of a mass-spring system, adhering to Hooke's Law $F_s = -kx$. Displacement was measured using the laser sensor, and force was captured by the load cell. Data acquisition was performed via the NI cDAQ system, processed through LabVIEW.

- The **spring stiffness (k)** was computed from the slope of the force-displacement graph, validated against theoretical values.
- The **natural frequency** of the system was derived from the time-domain oscillation data, compared with the analytical expression $w = \sqrt{\frac{k}{m}}$.
- A frequency response analysis confirmed expected damping effects, with slight deviations due to experimental limitations.

Results indicate that measurement uncertainties influenced stiffness estimation and oscillation frequency, necessitating refined calibration techniques for improved precision.

Uncertainty Analysis

Uncertainty in measurements originates from sensor limitations, environmental factors, and data processing. The total uncertainty is determined using root-sum-square (RSS) propagation:

$$U_{total} = \sqrt{U_x^2 + U_F^2 + U_{env}^2 + U_{proc}^2}$$

- **Displacement (U_x)**: Laser transducer resolution error:

$$U_x = \sqrt{U_{res}^2 + U_{align}^2}$$

where is sensor resolution and is misalignment error.

- **Force (U_F)**: Load cell error:

$$U_F = \sqrt{U_{cal}^2 + U_{noise}^2}$$

where is calibration uncertainty and is signal noise.

$$U_x = 0.0005 \times 10mm = 5\mu m$$

$$U_F = 0.00005 \ \times 300lbf = 0.015lbf$$

- **Data Acquisition (U_{DAQ})**: NI cDAQ sampling and quantization errors:

$$U_{DAQ} = \frac{FSR}{2^n}$$

$$U_{DAQ} = \frac{20V}{2^{16}} \approx 0.000305\ V$$

where FSR is the full-scale range and is bit resolution.

Reducing uncertainty involves sensor calibration, noise filtering, and improved alignment.

The computed refines experimental precision and validates Hooke’s Law analysis.

Discussion

The experiment effectively demonstrated Hooke's Law and simple harmonic motion, with data aligning closely with theoretical predictions. However, minor deviations were observed due to sensor precision limits and environmental factors. The displacement and force measurements were affected by system noise, highlighting the importance of calibration and proper data filtering. The computed natural frequency showed reasonable agreement with theoretical values, validating the methodology. Future improvements could include higher-resolution sensors and more robust mounting techniques to minimize misalignment errors.

Conclusions

This study successfully analyzed a mass-spring system, confirming the relationship between force and displacement while evaluating system oscillations. Despite minor uncertainties, the results aligned well with theoretical models, demonstrating the effectiveness of the employed measurement techniques. Enhancing precision through improved instrumentation and calibration would further refine the accuracy of future experiments.

References

1. Figliola, R. S., & Beasley, D. E. (2019). *Theory and Design for Mechanical Measurements (7th ed.)*. Wiley.
2. De Silva, C. W. (2007). *Vibration and Shock Handbook*. CRC Press.
3. Brüel & Kjær. (2004). *Measurement of Vibration in Engineering Systems*. Brüel & Kjær Technical Review.