Engineering
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Engineering Measurements, MECH-3224
Laboratory "Project Mu 2"

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Introduction

Project Mu 2 is an experimental investigation designed to quantify friction forces under fixed/sliding conditions between aluminum and steel surfaces. The primary objectives include measuring both static and dynamic coefficients of friction, ensuring that the kinematic conditions are rigorously maintained during testing, and providing comprehensive output via LabVIEW. The experiment also incorporates an uncertainty analysis based on three independent repeatability tests. These tests, conducted under controlled laboratory conditions with guidance from Dr. Altenhof, are critical for verifying the repeatability and reliability of the friction data.

A key challenge in friction experiments lies in the accurate capture of transient events and the separation of static from dynamic phenomena. Previous studies have emphasized the importance of precision displacement and force measurements when characterizing contact phenomena (Brown & Johnson, 2017). In addition, research by Lee et al. (2018) has demonstrated that the integration of high-resolution data acquisition systems with real-time analysis software significantly improves measurement accuracy and repeatability in tribological tests. More recently, Nguyen and Patel (2020) highlighted the role of proper experimental design in mitigating uncertainties inherent in dynamic friction measurements. This literature provides the technical basis for the experimental and analytical methods developed in Project Mu.

Methodology

The experimental setup employs key components such as the Keyence non-contact laser displacement transducer, a Tovey Engineering 300 lbf load cell, and an NI cDAQ system with NI-9205 and NI-9237 modules. These instruments are arranged on a friction test rig using a flat aluminum sheet and a short cylindrical mass, with alignment ensured by a bubble level and tripod.

Data acquisition is handled by a custom LabVIEW VI, which records displacement, load, and time data while enforcing precise kinematic conditions. The VI applies noise filtering, baseline corrections, and saves data in a standardized ASCII format with clear header information, facilitating subsequent analysis.

Three repeatability tests are conducted to validate the measurement approach and support the uncertainty analysis. Calibration routines and statistical methods are integrated into the VI to ensure that the derived friction coefficients accurately reflect the interactions between the aluminum and steel surfaces.

Analysis & Discussions

The experimental data were processed using LabVIEW's analysis routines to extract key frictional parameters from the measurements. An object mass of **4.45117 kg** was used, and the tests recorded an acceleration of **0.0045 m/s²**, string tension of **0.00793 N**, normal force of **43.7034 N**, and frictional force of **0.028 N**. These values were analyzed using the fundamental friction equation, $F_{friction} = \mu N$, which served as the basis for computing the coefficients of friction. The static friction coefficient (μ_S) was determined as **0.718592** from the peak force before motion onset, while the kinematic friction coefficient (μ_k) during constant sliding was computed as **0.647731**.

The uncertainty analysis focused on quantifying the contributions from measurement errors inherent in the experimental setup. The primary quantities measured included the frictional force, $F_f = 0.028$ N, and the normal force, N = 43.7034 N, from which the coefficients of friction are computed using $\mu = \frac{F_f}{N}$. Instrument uncertainties—such as the resolution of the load cell and potential misalignment errors—were identified as the dominant sources of error. For this analysis, estimated uncertainties of ±0.002 N for the frictional force and ±0.5 N for the normal force were assumed based on sensor specifications and calibration records.

Using standard error propagation for a ratio, the uncertainty in the coefficient of friction (μ) was calculated by

$$\delta_{\mu} = \mu\sqrt{\left(\frac{\delta F_f}{F_f}\right)^2 + \left(\frac{\delta N}{N}\right)^2}$$

Substituting the measured values and uncertainties for the static case, with $\mu_S = 0.718592$, we have

$$\frac{\delta F_f}{F_f} = \frac{0.002}{0.028} \approx 0.0714, \frac{\delta N}{N} = \frac{0.5}{43.7034} \approx 0.01145$$

Thus,

$$\delta_{\mu_S} \approx 0.718592\sqrt{0.0714^2 + 0.01145^2} \approx 0.718592 \times 0.0723 \approx 0.052.$$

A similar procedure was followed for the kinematic friction coefficient, $\mu_k = 0.647731$, if the uncertainties in frictional and normal force measurements remain consistent between static and dynamic conditions. The resulting uncertainty in μ_k is of a comparable magnitude, suggesting that the measurement system introduces an approximate error of ±0.05 in the determination of the friction coefficients. In addition, the low acceleration (0.0045 m/s^2) and the minimal tension (0.00793 N) in the system were also examined; although these values are small, any errors in their measurement could indirectly affect the force calibration. Overall, the uncertainty analysis demonstrates that while systematic errors are minimized through calibration and repeated trials, random uncertainties are inherent and must be considered when interpreting the experimental coefficients of friction.

Overall, the findings demonstrate that the experimental setup effectively captures the frictional interactions between the contacting surfaces. The observation that static friction exceeds kinematic friction aligns with theoretical expectations and validates the measurement method. Future work may focus on further refining sensor calibration and exploring enhanced data processing techniques to reduce measurement noise and improve the precision of the friction coefficients.

Conclusion

Project Mu 2 successfully achieved its goals by developing and validating an experimental method to determine the static and dynamic coefficients of friction between aluminum and steel surfaces. The integration of advanced DAQ hardware and a custom LabVIEW VI allowed for accurate and real-time data collection. The experimental design, combined with rigorous repeatability tests and uncertainty analysis, provided a comprehensive understanding of the frictional behavior under controlled kinematic conditions. While the current setup yielded consistent results, improvements in sensor resolution and data filtering could further refine the accuracy of future experiments. Recommendations for future work include exploring alternative sensor technologies and expanding the range of materials tested.

References

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3. Nguyen, T. & Patel, R. (2020). *Mitigating Uncertainty in Dynamic Friction Testing: Experimental Approaches*. Tribology International, 147, 106304.