ME – PhD Thesis Defense

Noise, Vibration and Harshness (NVH) and Energy Efficiency Analysis of Lubricant Oils in Boundary Lubrication Using Force-Controlled Tribometers

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ABSTRACT

Tribological performance and the Noise, Vibration, and Harshness (NVH) characteristics of lubricants are critical to ensuring the durability and comfort of mechanical systems, especially under boundary lubrication. Despite the growing importance of NVH in applications such as electric vehicles, a standardised test method to evaluate the NVH and energy efficiency of lubricants is currently lacking, making formulation and screening difficult. Conventional tribometers often fail to capture dynamic tribo-contact behaviour due to their inability to account for contact stiffness, damping, and inertia of the tribosystem. Stiffness-altering sensors and motor-driven actuation also introduce self-generated noise and vibrations, making it difficult to isolate friction-induced NVH responses. This research focuses on developing force-controlled tribometers that eliminate sensor-induced stiffness effects and operate without motors, enabling accurate evaluation of both frictional energy dissipation and NVH behaviour.

In the first phase of this thesis, a Lateral Force-Controlled Parallel Pendulum (LaFCoPP) tribometer was used to assess the boundary lubrication performance of saturated fatty acids (C6–C18). Operating in force-controlled mode, it allowed precise frictional energy dissipation measurement without altering contact stiffness. Longer-chain fatty acids, especially C18 (stearic acid), showed better boundary lubrication properties due to better molecular adsorption and surface coverage. The LaFCoPP tribometer's parallel pendulum design restricted it to rolling-sliding contacts. It also lacked pure sliding motion and precise temperature control. To overcome these limitations, the setup was modified into a single-pendulum pin-on-disc tribometer capable of pure sliding and lubricant temperature control. Tests with a Group II base oil and a 0.03 M stearic acid blend were conducted at 27 °C, 60 °C, and 100 °C. The stearic acid blend showed better boundary lubrication properties across all temperatures attributed to tribofilm formation. FTIR analysis identified a 1713 cm^{-1} peak for the carboxylic acid group, while XPS confirmed increased intensity of C=O and O–C=O peaks at elevated temperatures, indicating a thermally enhanced tribofilm chemically bonded to the steel surface.

In the second phase, a pendulum-based pin-on-disc force-controlled NVH tribometer was developed to evaluate NVH characteristics. The pendulum provided sliding motion without motors, eliminating the system-generated vibration and noise significantly. The tribometer was placed in a hemi-anechoic chamber to minimise background noise. The tribometer validation tests at 100 °C with a Group II base oil and a 0.03 M ZDDP blend showed that the blend reduced peak noise by up to 15 dB, V_{rms} from 0.63 to 0.04 milli-g, and COF from 0.2–0.25 to 0.05–0.08. SEM and TEM confirmed a ~35 nm thick ZDDP tribofilm containing Zn, P, and S. The presence of this tribofilm minimised direct metal-to-metal contact, thereby reducing friction and significantly suppressing dominant vibration modes at 140 Hz and 280 Hz, contributing to enhanced NVH performance. After validation, eight lubricant formulations were tested to evaluate the tribometer's ability to compare commercially used lubricants. Samples with two Group II base oils (B1 and B2 with different viscosities) and AW, EP, and FM additives were tested at 60 °C and 100 °C. Base oils alone exhibited higher friction, noise, and vibration levels. The B2+FM blend showed the best performance, with COF ~0.045 (60 °C) and ~0.05 (100 °C), LEQ ~35.9 dB and ~34.2 dB, and V_{rms} ~0.025 milli-g and ~0.01 milli-g, respectively. While AW and EP additives improved NVH characteristics, their effectiveness was lower compared to FM. These trends suggest that FM additives may promote more stable sliding conditions and reduce stick-slip oscillations, thereby improving damping behaviour across a wide frequency range, as supported by Continuous Wavelet Transform (CWT) analysis. These results validated the tribometer's capability for lubricant screening and highlighted the role of base oil viscosity and additive chemistry in achieving optimal NVH and tribological performance.

ABOUT THE SPEAKER

Adarsh D is a PhD student in the Department of Mechanical Engineering at the Indian Institute of Science, Bangalore. He works under the supervision of Prof. Satish Vasu Kailas and is a recipient of the Prime Minister Fellowship for Doctoral Research (PMFDR). His research investigates the impact of lubricants on friction, noise, and vibration in tribological contacts. His PhD work includes designing unique force-controlled tribometers and developing testing methods to evaluate how friction influences Noise, Vibration, and Harshness (NVH) in the boundary lubrication regime. He holds a Master's degree in Ocean Engineering and Naval Architecture from IIT Kharagpur and a Bachelor's degree in Mechanical Engineering from Govt. Engineering College, Kozhikode.