ME Seminar

Tribology under Extreme Conditions- Lubricant Levitation, Film Instability and Droplet Deformation in High-Speed Bearings

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ABSTRACT

Tribological performance under extreme operating conditions is governed by complex near-surface interactions that can extend beyond conventional lubrication regimes. At high surface speeds, such as those encountered in electric vehicle drivetrains, aerospace turbomachinery, and precision machinery, fluid inertia and air entrainment can significantly alter lubricant behavior. These effects can produce unstable lubricant films and loss of surface adhesion, directly affecting friction, wear and lubrication reliability in rolling-element bearings. This work investigates these phenomena through a combination of experiments and physics-based modeling. Experiments were conducted using a custom-developed test rig and high-speed imaging to investigate lubricant behavior, lubricant-film levitation, and droplet deformation at high surface speeds. A striking phenomenon observed in this regime is the Aerodynamic Leidenfrost Effect (ALE), in which a rapidly moving surface generates a thin air layer that can separate and levitate lubricant droplets from the surface above a critical speed. A soft-Elastohydrodynamic Lubrication (soft-EHL) numerical model was developed to simulate droplet deformation and levitation over the entrained air film and provide a mechanistic interpretation of the observed behavior. The results show that above specific speed thresholds, reduced lubricant adhesion results in severe starvation and altered lubricant distribution within the bearing. These findings also demonstrate how integrated experimental and computational approaches can reveal and explain complex interfacial phenomena. The work provides a foundation for developing more reliable lubrication strategies for high-speed and next-generation mechanical systems.

ABOUT THE SPEAKER

Dr. Ujjawal Arya is currently a Senior Research Associate at the Computational Solid Mechanics and Advanced Packaging (CoSMAP) Lab at Purdue University, where his research focuses on the experimental characterization of thermo-mechanical and mechanical reliability in advanced semiconductor packages and heterogeneous material systems. His work involves developing new experimental methods to understand localized deformation, damage initiation, and failure near critical material interfaces. He has also led the establishment of a new reliability characterization lab at Purdue for testing emerging semiconductor packaging technologies.He earned his M.S. and Ph.D. in Mechanical Engineering from Purdue University, where he developed novel visualization methods and computational models to investigate complex lubrication phenomena in high-speed rolling element bearings. Earlier, he completed his B.Tech. in Mechanical Engineering from IIT Kharagpur. He has also received multiple awards and recognitions for his research and teaching. Drawing on expertise in experimental mechanics, tribology, and interface metrology, Dr. Arya's research addresses fundamental questions at the intersection of interfacial mechanics and reliability. His future research will explore electrified and extreme-environment tribology, engineered and adaptive interfaces, and interfacial fracture mechanics and reliability, with a broader goal of developing experimental and computational frameworks to understand and control interfacial behavior across diverse engineering systems.

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