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Special issue on thin film lubrication

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Published in:
Friction

Published: 01/12/2016

Document Version:
Final Published version, also known as Publisher's PDF, Publisher's Final version or Version of Record

Published version (DOI):
10.1007/s40544-016-0137-3

Publication details:
Guo, F., Wong, P., & Luo, J. (2016). Guest editorial: Special issue on thin film lubrication. *Friction*, *4*(4), 277-279. https://doi.org/10.1007/s40544-016-0137-3

Friction **4**(4): 277–279 (2016)
DOI 10.1007/s40544-016-0137-3
ISSN 2223-7690
CN 10-1237/TH

EDITORIAL

Guest editorial: Special issue on thin film lubrication

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It has been well accepted that the lubrication in tribo-pairs is dominated by different regimes under different conditions, mainly involving hydrodynamic lubrication (HDL), elastohydrodynamic lubrication (EHL), thin film lubrication (TFL), and boundary lubrication (BL). Thin film lubrication is a lubrication regime with lubricant film thickness ranging from a few nanometers to tens of nanometers, which bridges the gap between boundary lubrication and elastohydrodynamic lubrication. In fact, TFL can be influenced by many factors, such as the hydrodynamic effect, the size and polarization of lubricant moleculars, and surface energies of bounding solids. The film thickness and tribological properties in TFL regime are therefore different from those in both EHL and BL regimes. The typical film thickness of TFL is large when compared to that of BL such that the bulk flow properties of the liquid cannot be ignored, and it is small when compared to that of HL or EHL such that some seem-to-be minor issues, e.g., surface energy or interfacial slippage between the solids and the liquid, can have significant effect. TFL cannot be modeled merely based on the principles of continuum mechanics. Since TFL was first recognized by tribologists, it has gained substantial interests in the tribology community, and a lot of works have been presented in the fields of theoretical, instrumental and experimental researches. However, TFL regime is a rather young area in tribology and still facing many unresolved issues and challenges, particularly in understanding its fundamentals and exploring innovative experimental techniques and instrumentation.

This special issue of ***Friction*** is intended to report the state-of-the-art research progresses in thin film lubrication, covering not only the fundamentals of TFL but also its applications to industrial practices. 1 review paper and 8 research articles are included to demonstrate the breadth and the timeliness of the subject and to provide an opportunity for the publication of new findings. 9 papers by tribologists and scientists in mechanical engineering have been invited to achieve these aims, including one review article on the history of thin film lubrication in past twenty years, one research paper on the study of grease starvation and replenishment from the evolution of grease fingers, central film thickness and the wettability of the rolled track with deposited thickener film, one on the investigation of the mechanisms for stable superlubricity of poly(vinylphosphonic acid) coatings, one on the optical technique purposely for a ball-on-ring test rig for oil film thickness measurement, one on the optimization of a piston ring profile considering mixed lubrication, one on indentifying the optimal interfacial parameter correlated with hydrodynamic lubrication, one on the study of the behaviors of lubricant droplets both spreading around a static contact and passing through a rolling contact with an optical ball-on-disk EHL test rig, one on the relevance of analytical film thickness elastohydrodynamic (EHD) equations for isothermal point contacts and exploring whether they can be used as qualitative or quantitative predictions, and one on the lubricant flow in thin-film elastohydrodynamic contact under extreme conditions. The above contributions cover the historical view of TFL, the micro-mechanisms, technical studies and analysis of yet unsolved problems. Some studies are not strictly limited in the TFL regime, but show that some dominating factors in TFL still work in other regimes.

The first paper by Liran Ma et al. offers a comprehensive review on the history and progress of thin film lubrication during the 20 years since 1996, from both of the theories and the experiments. This review paper begins with the description and definition of TFL, followed by the state-of-the-art studies on experimental techniques, fundamental researches and applications. Future prospects of relevant researches and applications are also highlighted in details.

Lu Huang et al. revealed the mechanism of starved grease lubrication, especially how grease is replenished under starved conditions. The evolution of grease reservoir, central film thickness and the wettability of the rolled track with deposited thickener film were studied together to explain grease replenishment mechanism. The results showed that during the operation most of the bulk grease was pushed outside the contact, and grease fingers along the rolling track were the main source of grease supply under starved lubrication conditions. And these fingers could bleed base oil out of the thickener to provide lubricant to the contact after a period of operation. The superlubricity phenomena of the poly(vinylphosphonic acid) (PVPA)-modified Ti6Al4V/polytetrafluoroethylene (PTFE) interface in various lubricants and the corresponding mechanism were investigated in details by Caixia Zhang et al. Step by step, a pH buffer solution, salt solutions with buffer ions (Na_2HPO_4, $(NH_4)_3PO_4$ and $NaHCO_3$) and salt solutions without buffer ions (NaCl, $NaNO_3$ and Na_2SO_4) were examined. Based on the experimental results, pH and ions were confirmed to be the two factors influencing the tribological behaviors. The firm PVPA coatings and the compatibility with lubricant are critical factors for the perfect tribological properties of PVPA coatings.

An original test rig for measuring oil film thickness based on ball-on-ring mode was presented by Yaoguang Zhang et al. Different from the classical ball-on-disc contact, a ball-on-ring configuration was used for better simulation of EHL in a rolling bearing. Due to the light bending by the ring surface, the previous optical system cannot provide sharp interference images. An optical ray tracing model was given and a correction lens was introduced, and the proposed test rig is validated by preliminary experimental results.

To reduce friction loss between the piston ring and cylinder liner, Zhinan Zhang et al. used the reverse method and sequential quadratic programming algorithm to determine the optimized profile of the piston ring. Different from existing work, the effects of the mixed lubrication, the variation of piston speed and gas pressure, as well as the characteristics of the lubricant with temperature along the engine stroke on the optimization were all taken into account. And based on the proposed approach, the effects of shapes of piston ring on friction and oil film load-carrying capacity were also discussed in details.

An effective interfacial parameter correlated with hydrodynamic lubrication was identified by Liang Guo et al. This paper explored the best parameter for correlating slippage effect in hydrodynamic lubrication. Some interfacial parameters including surface tension, contact angle, contact angle hysteresis and a spreading parameter were compared with the film thickness measured in hydrodynamic lubrication tests, and the best interfacial parameter was found to be the contact angle hysteresis under the working parameters in the study.

The interaction between an oil droplet and lubricated contact has been recognized to have significant effect on thin film lubrication. Xinming Li et al. explored the behaviors of lubricant droplets in terms of spreading around a static contact as well as passing through a rolling contact using an optical ball-on-disk EHL test rig. The influences of oil droplet size, viscosity and surface tension on droplet spreading were examined and the lubricating film formation was investigated when droplets traveled through the EHL contact region. The experimental results indicated that droplet size and running speed significantly influenced film profiles.

Jean-David Wheeler et al. evaluated the validity and accuracy of some existing analytical formulae for the central film thickness and the minimum film thickness in both circular and elliptic EHL contacts by comparison with full numerical solutions. The purpose of this comparison is indeed not to rank the models against each other, but to evidence whether they can be considered sufficiently quantitative or just qualitative, in the domains investigated in this work. This topic is an interesting and important work since the most widespread analytical formulae are usually used to predict film thickness without any doubt on their accuracy.

The closing paper by Petr Sperka et al. presented four kinds of experiments about EHL film thickness measurement under extreme conditions. Some particular film profiles, different from the traditional steady-state horse-shoe shape, were obtained and used to infer the lubricant flow across the film gap based on Couette flow continuity. Moreover, some experiments were carried out at high sliding speeds introducing a significant temperature rise into a lubricant film. And the understanding of lubricant flow inside contact may give answers to fundamental questions about the origin of limiting shear stress found in traction experiments.

To gain a comprehensive understanding of TFL with considerations of different attributes needs more tribologists willing to take up the challenges and utilize the Journal—***Friction*** as a platform for the share of results and the exchange of ideas.

Finally, the guest editors would like to offer our gratitude to all the authors of this special issue for contributing the high quality papers, and all reviewers for their critical evaluation and invaluable help.