frontiers | Frontiers in Mechanical Engineering

TYPE Editorial
PUBLISHED 18 March 2025
DOI 10.3389/fmech.2025.1588494

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OPEN ACCESS

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RECEIVED 06 March 2025
ACCEPTED 11 March 2025
PUBLISHED 18 March 2025

CITATION
Maruyama T, Maegawa S, Okubo H, Reddyhoff T and Vlădescu S-C (2025) Editorial: Visualization techniques in tribology.
Front. Mech. Eng. 11:1588494.
doi: 10.3389/fmech.2025.1588494

Editorial: Visualization techniques in tribology

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KEYWORDS

computer simulation, tribology, visualization, condition monitoring, EHL, electrical method, optical method, surface analysis

Editorial on the Research Topic
Visualization techniques in tribology

Introduction

"Seeing is believing" is a phrase that conveys the idea that people tend to believe something more strongly and confidently when they can actually see it with their own eyes. It suggests that visual evidence or firsthand experience holds a significant level of conviction and trustworthiness, often surpassing what is merely heard or described. The phrase implies that when you witness something directly, you are more likely to accept its reality or truthfulness compared to when you rely solely on descriptions or explanations. In short, the act of seeing something with your own eyes can be a powerful way to persuade and convince yourself or others of its existence or validity. For this reason, techniques to visualize phenomena that are normally invisible are very effective in elucidating phenomena and are utilized in a variety of academic fields. Of course, various visualization techniques are also used in tribology to contribute to the better understanding of complex phenomena. Tribology is a scientific and engineering discipline that studies friction, wear, and lubrication of surfaces in relative motion. Tribology plays an important role in understanding and optimizing the performance, durability, and efficiency of mechanical systems and components, from small-scale equipment to large-scale industrial machinery. That is, tribology aims to investigate the complex interactions between materials under various conditions and to minimize friction and wear through the use of lubricants, coatings, and surface treatments. However, since tribology deals with severe contact conditions that result in thin film thickness (nm order) and high contact pressure (GPa order), the development of visualization techniques is very important to elucidate the phenomena. Moreover, visualization of actual complex phenomena not only verifies existing theories but also provides opportunities for new discoveries and hints for the construction of new theories that emerge from such discoveries. Therefore, in this Research Topic, we have compiled various themes on the visualization techniques developed to elucidate tribological phenomena. The Research Topic consists of 16 papers, which are broadly categorized into two groups: 1) optical methods (10 papers) and 2) electrical methods (6 papers).

Optical methods

The first group focuses on optical methods, which leverage light to visualize tribological interactions. Techniques such as high-speed imaging, laser-induced fluorescence, and optical interferometry have been instrumental in capturing real-time data on friction and wear processes. These methods allow researchers to observe surface changes at the micro and nano scales, providing insights into the mechanisms of lubrication and wear.

This Research Topic of articles begins with a review article titled “Visualization techniques of grease fluidity” authored by Sakai. It introduces visualization techniques using advanced optical methods such as fluorescence, particle image velocimetry (PIV), infrared spectroscopy, X-rays, and neutron beams.

Following this, Yamashita and Hirayama present a paper titled “A method for simultaneously measuring friction and gap at metal–lubricant interface by combined use of atomic force microscopy and line-and-space patterned metal films.” They propose a method to simultaneously measure friction and gap at the metal-lubricant interface under boundary lubrication conditions using atomic force microscopy. They also visualize the state of adsorption film formation using neutron reflectometry.

Okubo et al. investigated the friction reduction mechanism of 100% cellulose nanofiber (CNF) molded bodies using an *in-situ* Raman tribometer in their paper titled “*In-situ* vibrational spectroscopic observation for thermally activated structural changes of 100% cellulose nanofiber molding with ultralow friction.” The *in-situ* Raman observation results during friction visualized the structural changes of the CNF molded body and identified key factors contributing to the ultra-low friction phenomenon observed at high temperatures.

Shiomi and Obara have published a paper titled “An *in-situ* experimental method for monitoring viscosity change and oil amount during sliding test.” They propose a method to predict the viscosity and oil amount during sliding tests by visualizing the shape of the meniscus formed ahead of the EHD (elastohydrodynamic) contact area, and found that it can be applied even in vacuum friction tests without returning to atmospheric pressure.

In addition to the above paper, two papers have been published on visualization technology using high-speed cameras. Takeshima et al. have published a paper titled “Mechanisms of Cage Noise Generation in Machine Tool Bearings,” where they conducted observation tests using a high-speed camera to visualize the behavior of the cage in ball bearings under grease lubrication. By detailed image processing of the obtained observation results, they clarified specific cage behaviors that affect cage noise. Ochiai and Ohya have published a paper titled “The effect of inner ring groove on leakage reduction in dry gas seals and its visualization verification,” investigating the impact of introducing an inner ring groove (IRG) on the leakage characteristics of dry gas seals widely used in turbomachinery such as gas turbines and compressors. They obtained important insights into the optimal design guidelines for seals by applying PIV to visualize the gas flow within the seal gap using images obtained with a high-speed camera.

Moreover, four papers on visualization techniques using fluorescence methods have been reported in this Research Topic. Tokoroyama et al. have published a paper on the visualization of wear particles titled “The 1 μm wear particles entrainment *in situ* observation via fluorescent staining silica particles by silane coupling with Rhodamine B.” Specifically, they experimentally investigated the capture of imitation wear particles in the contact area under boundary lubrication conditions. To address optical limitations, they implemented fluorescent staining on these particles. Furthermore, Tokoroyama et al. have also submitted a paper titled “The mechanism of small wear particles entrainment in friction under boundary lubrication.” These two studies are expected to provide important insights into the behavior of wear particles under boundary lubrication and form the basis for a more detailed understanding of the impact of particles on friction phenomena. Tadokoro et al. have published a paper titled “Controlling windscreen wiper vibration through yaw angle adjustments: a study of dynamic contact behavior using fluorescence observation,” which elucidates the mechanism of friction-induced vibration in passenger car wiper systems. By conducting fluorescence observations, they successfully measured the exact position of the rubber blade tip and the water film thickness at the contact area during operation. Tohyama et al. have submitted a methods article titled “Visualization of oil-lubrication ball bearings at high rotational speeds.” They observed the oil film thickness in the contact area of deep groove ball bearings rotating at high speeds and the oil distribution inside the bearings using three-wavelength optical interferometry and fluorescence methods, respectively. The results of this study are expected to contribute to the development of ball bearings used at high speeds required for electric vehicles.

Electrical methods

The second group encompasses electrical methods, which utilize electrical signals to infer tribological behavior. Techniques such as piezoelectric sensors, capacitance measurements, and electrical resistance monitoring provide valuable data on contact conditions and wear rates. These methods are particularly useful in environments where traditional optical techniques may be limited due to surface roughness or opacity.

In this Research Topic, five papers on visualization techniques using electrical impedance have been submitted. The first is a review article by Becker-Dombrowsky and Kirchner titled “Electrical impedance based condition monitoring of machine elements–a systematic review.” It introduces various studies on condition monitoring using electrical impedance and identifies research challenges to be addressed in future studies. The second is a paper by Puchtler et al. titled “Impedance measurement of rolling bearings using an unbalanced AC wheatstone bridge.” They indicated that their developed impedance measurement can be used as a sensor for condition monitoring when the bearing is operated in the hydrodynamic lubrication. The third paper, by Koetz et al., is titled “Visualising the lubrication condition in hydrodynamic journal bearings using impedance measurement.”

By measuring the electrical characteristics of journal bearings with applied AC, it suggests the possibility of detecting deformation and damage of bearings in mixed lubrication conditions. The fourth paper, by Maruyama et al., is titled "Application of the electrical impedance method to steel/steel EHD point contacts." It discusses the electrical impedance method that can simultaneously measure the thickness and breakdown ratio of oil films in EHD contacts, particularly mentioning the impact of wear generated in mixed lubrication on the accuracy of oil film measurements. The fifth paper, by Iwase et al., is titled "Studies on dielectric spectroscopy of oxidatively degraded Poly (α-olefin)." By sweeping the frequency of the AC applied to the lubricant, they verify the practicality of dielectric spectroscopy (DES) for condition monitoring and predictive maintenance of lubricants.

Finally, as an electrical visualization method other than electrical impedance, Tamae et al. have presented a paper titled "A study of measurement of raceway direct measurement of rolling bearings." The authors developed a method called "dynamic thermocouple method" to measure the temperature of bearing raceways by applying the Seebeck effect, which generates an electromotive force when different metals are in contact and subjected to a temperature difference. Furthermore, this study is unique in that it correlates the temperature rise of the bearing with the behavior of the rolling elements by combining the dynamic thermocouple method with high-speed camera observations.

Conclusion

The visualization techniques discussed in this Research Topic are essential for advancing our understanding of tribological phenomena. By making the invisible visible, these methods not only validate existing theories but also pave the way for new discoveries that can transform the field of tribology. As we continue to refine these techniques and develop new ones, we can expect significant improvements in the performance of mechanical systems across various industries. This Research Topic of papers serves as a testament to the importance of visualization in tribology and highlights the ongoing efforts to explore and elucidate complex interactions at play in friction, wear, and lubrication.

At the end of this editorial article, we would like to express our heartfelt gratitude to all the authors who have made valuable contributions to this Research Topic of papers on visualization techniques in tribology. We hope that this Research Topic will contribute not only to the field of tribology, which deals with complex phenomena, but also to various other research fields.

Author contributions

TM: Writing–original draft, Writing–review and editing. SM: Writing–review and editing. HO: Writing–review and editing. TR: Writing–review and editing. S-CV: Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Acknowledgments

This Research Topic was done with the collaboration of Florian Becker-Dombrowsky, M. Sc. from the Technical University of Darmstadt. We acknowledge his dedicated contributions.

Conflict of interest

Author TM was employed by NSK Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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