講演番号	292

Influence of Lubrication Direction on Cooling Performance in High-Speed Traction Drives and Observation of Oil Film Behavior

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KEY WORDS: **Traction drive・Lubrication direction・Cooling performance・Oil-film visualization・Meniscus behavior・Particle Image Velocimetry・Pressure estimation・High peripheral velocity**

This study examines the influence of lubrication direction on cooling performance and oil-film behavior in a high-speed traction drive intended for electric vehicle reduction systems. Traction drives are promising for high-speed applications because they generate less vibration and lower churning loss than gears. However, under high peripheral velocity conditions, the lubricant behavior around the elastohydrodynamic lubrication (EHL) contact region and its relationship to cooling performance have not been sufficiently clarified. To address this issue, the authors experimentally investigated the effects of lubrication direction, oil supply conditions, and local oil-film flow on roller temperature rise. The study combines temperature measurement, high-speed flow visualization, Particle Image Velocimetry (PIV), and pressure estimation.

The experiments were carried out using a roller-on-disk testing machine designed to reproduce conditions relevant to actual automotive systems. Temperature measurements were performed at a disk peripheral speed of 20 m/s and a roller peripheral speed of 18 m/s, corresponding to a 10% slip ratio, under a normal load of 1,000 N. The oil supply temperature was maintained at 25°C, and cooling performance was evaluated from the roller surface temperature rise after 60 minutes. The oil supply position was calibrated for each nozzle condition before the measurements. As shown in Fig. 1, the disengagement direction exhibited better cooling performance than the engagement direction, even after supply position calibration. In addition, the disengagement direction showed greater robustness against deviations in oil supply position. Increasing the oil supply rate tended to improve cooling in the engagement direction, whereas in the disengagement direction a higher oil supply did not necessarily enhance cooling. These results indicate that simply supplying more oil is not always effective and that the disengagement direction provides efficient cooling even without increased flow rate.

To clarify the mechanism behind this difference, the lubricant behavior near the contact region was visualized using a high-speed camera, fluorescent tracer particles, and a mirror-based optical system. The visualization results showed that the lubricant flow bifurcated just before the EHL contact zone. This suggests that the flow avoids the highly pressurized contact region. The meniscus shape also depended on lubrication direction: it spread more widely in the engagement direction and remained relatively smaller in the disengagement direction. PIV analysis further revealed the local flow field around the meniscus. Based on the measured velocity distribution, pressure was estimated using the incompressible Navier–Stokes equations and a pressure Poisson equation. The estimated results, presented in Fig. 2, showed that a negative-pressure region formed behind the meniscus after the oil film bifurcated.

This negative pressure is considered important because it may draw lubricant back toward the downstream side of the contact, promoting oil-film rejoining and cavitation. In fact, visualization confirmed that the ruptured oil film could merge again after passing through the contact region. The authors suggest that the superior cooling performance of the disengagement direction is supported not only by direct delivery of cooler oil to the heated area, but also by reflow of the separated oil film behind the contact. Overall, the results demonstrate that lubrication direction strongly affects both cooling and oil-film behavior in high-speed traction drives. The study concludes that effective cooling design should consider not only oil supply quantity but also lubrication direction and downstream reflow behavior.

Acknowledgement : This work was supported by TRAMI（Transmission Research Association for Mobility Innovation）Grant of 2025.

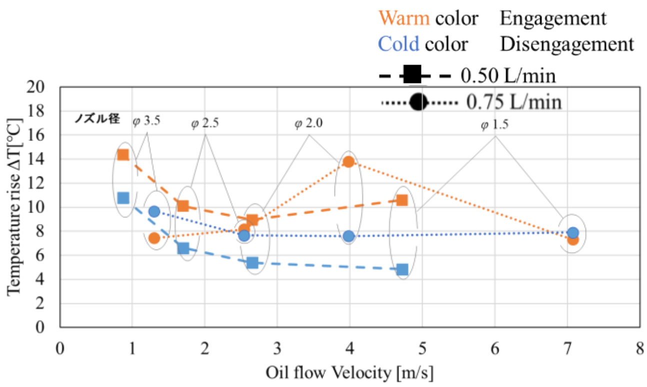
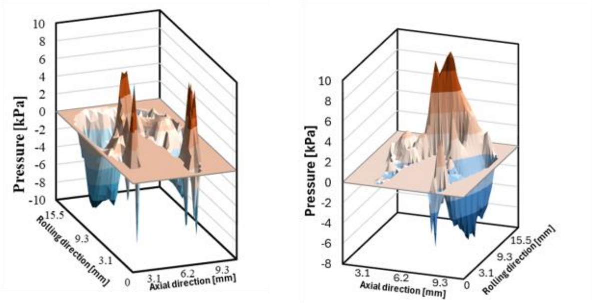


Fig. 1 Relationship between roller temperature rise and supply oil speed



(a) Engagement 10m/s (b) Disengagement 10m/s

Fig. 2 Results of pressure estimation