GREASE FLOW BEHAVIORS IN ELASTOHYDRODYNAMIC POINT CONTACTS

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（点接触弾性流体潤滑におけるグリースの流れ挙動）

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論　文　内　容　の　要　旨

The flow behavior of greases is one of the dominating factors for the performance of the grease-lubricated machine elements such as rolling-element bearings. However, because of its complexity, the lubrication mechanism of greases is still poorly understood, and it is necessary to investigate flow of greases in detail. Because of the semi-solid composition and the complex rheological properties, the features of grease flow are different from those of oils, and different for different grease types and different conditions. The unique flow characteristics should contain a lot of important information: the interactions between the thickener and the base oil, the lubricating conditions, the rheological properties and the mechanisms of redistribution and transportation. By knowing the details of these interactions, the lubrication mechanisms of greases will become clearer and the design of grease lubrication will be improved.

The purpose of this work is to find the information behind the flow behavior through a systematic observation of the features of grease track patterns. The focus is on the grease flow behaviors in elastohydrodynamic (EHL) point contacts. It includes the features of visual pattern produced around the contact point and the lubricating conditions.

The thesis is composed of seven chapters.

Chapter 1 introduces the research background, and describes the motivation for carrying out the research.

In Chapter 2, various different types of greases used in this study are introduced, and the rheological properties of the grease are determined by the tests of yield stress and apparent viscosity.

In Chapter 3, a ball-on-disk test rig equipped with an optical microscope is used to observe grease flow and track patterns through dynamic observation and static observation of the remaining greases on the track on the disk specimens. The features of grease flow and contact tracks for different greases are observed under different entrainment speed, test duration and slide-to-roll ratio. The features of track pattern are different for different grease types and different operating conditions. The track pattern after rolling/sliding tests preserves the most features of grease flow, and eight characteristic parameters are defined to characterize the patterns. The variation of the pattern parameters represents the grease flow behaviors, regardless of the type of grease. It is found that lithium-12-hydroxy stearate grease shows clear track patterns, whereas di-urea grease shows obscure track pattern and heavy thickener deposition in the center of the track. The thickener type and base oil viscosity are more important than base oil among the factors that affect the area of grease fingers at the sides of the tracks. The features of the track patterns are not only related to the constituents of grease, but the changes in rheological properties also produce changes in the patterns. For example, the grease with smaller yield stress and higher viscosity tends to have larger finger area. The grease with better flow ability at low shear rates tends to have a clearer finger pattern. It is proposed that the formation and maintenance of grease fingers in the track pattern are dependent on the state of lubrication.

In Chapter 4, the optical interferometry is employed to determine grease EHL film thickness in the ball-on-disk test rig. A pair of scoops is also used for artificial replenishment in additional tests in order to understand the changes occurring in lubricant starvation without the artificial replenishment. Through the film thickness data, the relationships between the track patterns and lubrication mechanisms are found. At higher speed, lubricant starvation and finger-loss occur. The starvation speeds are always lower than the finger-loss speeds. The apparent viscosity of the grease at low shear rate in the inlet zone has a great impact on the resupply of the greases and the starvation speed. The results suggest that the grease finger provides supply to the contact area and the side reservoir, and one part of grease finger that lies near the center of track plays the main role. In addition, the thickener deposition in the center of track plays a positive role in the film formation with some types of greases, especially the urea greases.

In Chapter 5, on the basis of the results in Chapters 3 and 4, covariance analysis is conducted to find out whether there exists correlation among all these factors including characteristic parameters, operating conditions, rheological properties and film formation. In addition, principal component analysis is conducted to find the most representative parameters that represent the change in the features of grease flow when the entrainment speed, test duration and slide-to-roll ratio change. The covariance analysis shows that the eight characteristic parameters are more or less correlated with each other, and the principal component analysis suggests that some of them are strongly related and some are not in terms of their relationships with operating conditions, rheological parameters and film formation. The near finger area, the degree of contrast of ridges and the wavelength contain similar information regarding lubricating conditions. Each of the degree of finger contrast, the number of finger split joints, and the degree of thickener deposition separately reflects other characteristics including grease properties. These quantitative relations clearly represent the relationships found in Chapters 3 and 4.

In Chapter 6, an attempt is made to observe *in-situ* the behaviors of greases with a wider observation range by using a fluorescence technique. It is shown that the technique is capable of studying the replenishment of grease by the grease from the side reservoir merging with grease left in the form of the fingers at sides of the track. It is also shown with fluorescence that, in the case with di-urea grease, EHL film thickness first decreases with time due to weak supply of the grease and subsequently increases due to thickener deposition on the track.

Chapter 7 describes conclusions and further works.

In summary, this study develops a new method to describe visual characteristics of flow and tracks around the contact in rolling/sliding point contact EHL with greases, finds dependence of the flow characteristics parameters on various factors including operating conditions, rheological properties of greases and the state of fluid film formation, and proposes mechanisms of grease supply to the contact which depend on these factors.