Analysis of possible lubrication mechanism of radial shaft seals

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1. Introduction

It is widely accepted that radial shaft seals are working under elastohydrodynamic lubrication at the lip-shaft interface. However, frictional behaviour of actual seals cannot be explained by hydrodynamic lubrication theories. The authors have conducted numerical analysis of EHL and partial EHL with simple surface roughness models, and found that a possible mechanism is partial EHL where boundary film works at contact between a shaft and micro-asperities on lip surfaces.

2. Experiments

A shaft seal test rig was used to measure the friction force working between shaft and the seal lip in sealing and pumping conditions. Motor oil, bearing oil and base oil with particular additive were used. In addition to friction force, temperature in the vicinity of lip sliding surface was also measured simultaneously.

The results are plotted in Fig. 1 in the form of the Striebeck curves, i.e. the relationship between the coefficient of friction versus dimensionless duty parameter $G = \frac{\mu b}{Pr}$. The symbol $\mu$ is lubricant viscosity under lip, $u$ is shaft speed, $b$ is lip wear width and $Pr$ is radial load. Figure 1 shows that the coefficient of friction changes with speed at smaller gradient than what is predicted by EHL theory on the log-log chart. This suggests that full hydrodynamic lubrication is not established but mixed and boundary lubrication work even at higher speed.

3. Numerical analysis

In order to confirm this, numerical simulation of mixed lubrication was conducted. The simulation model assumed a moving smooth rigid surface for the shaft and a stationary rough elastic surface for the lip, where the surface consisted of a sinusoidal wave on a curved surface. The domain was divided into fluid and contact regions, and a boundary friction coefficient was assumed for friction in the contact region.

The result shown in Fig. 1 well depicts the characteristic dependence of the coefficient of friction on $G$ for a surface with shorter wavelength. This agreement cannot be obtained in full hydrodynamic analysis, suggesting that the partial boundary film contributes to friction in higher $G$ region.

4. Conclusion

From the simplified analysis, it is concluded that the radial shaft seals are in the mixed lubrication regime in a wide range of operating conditions.

![Fig.1 Striebeck curves obtained in pumping condition](image-url)