NUMERICAL AND INTERFEROMETRIC ANALYSIS OF STARVATION EFFECT ON OIL FILM THICKNESS IN EHL CONDITION

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A regression formula including the inlet film thickness as the parameter for the starvation factor in EHL condition is obtained by numerical analysis with Elrod's cavitation algorithm. In addition, an apparatus for starved film thickness measurement by use of the white light interferometry is developed in order to verify the proposed regression formula. From observation results by this apparatus, the proposed regression formula can predict the reduction of central film thickness caused by starvation in a ball-plate contact with an uncertainty up to 10%

Keywords : Starved Film, Regression Formula, EHL, Interferometry, Elrod's Algorithm

1. INTRODUCTION

Oil film reduction caused by starvation is observed in rolling element bearings lubricated with grease or lubricated by an oil and air lubricating system. An inlet meniscus position has been used as the parameter which is concerned with a starvation factor because the inlet meniscus position at which pressure commences directly relates to the oil film thickness. It is, however, difficult to apply this parameter to a prediction for the starved oil film thickness in the practical conditions. At first, the inlet meniscus position can not be directly controlled, that is, only the result from the starvation. In addition, measurement of the inlet meniscus position is difficult.

Because an immediate cause of the starvation is obviously deficiency of the lubricant flow volume into the contacts, the inlet oil film thickness can be taken as a principal factor governing the starvation. In this study, a regression formula for the starvation film thickness including the inlet oil film thickness as the parameter is obtained by use of an Elrod's cavitation algorithm[1]. Furthermore, interferometric measurements of central film thickness in a starved ball-plate contact are carried out in order to verify the proposed regression formula.

2. REGRESSION FORMULA FOR STARVED EHL FILM THICKNESS

To estimate the starved EHL film thickness, the Reynolds equation into which Elrod's cavitation algorithm is incorporated is numerically solved with elastic deformation in two dimensional steady state conditions. The central film thickness linearly increases with increaseing the inlet film thickness in the case of the severe starved condition. On the other hand, it asymptotically increases with increasing the inlet film thickness in the case of the nearly fully flooded condition. This characteristics is approximated by the following equation[2],

$$\phi = \frac{H_c}{H_{cf}} = \frac{r}{\sqrt[\gamma]{1+r^{\gamma}}} \tag{1}$$

where ϕ is a starvation factor, Hc and Hcf denote the central film thickness in the starved condition and fully flooded condition, respectively and r is a dimensionless inlet film thickness which is compensated by the density of lubricant.

$$r = \frac{H_{inlet}}{H_{cf}} \Big/ \frac{\rho(p_{max})}{\rho_0} \tag{2}$$

Numerical values of the parameter γ are obtained by fitting the equation (1) to the calculated values of the central film thickness with inlet film thickness in several conditions listed in table 1. From these calculated results, the following regression formula for the parameter γ is obtained,

$$\gamma = U^{-0.119} W^{0.100} G^{-0.049} \tag{3}$$

It is found that the parameter γ becomes smaller in the condition where the thicker film is generated if fully flooded. This is because the lubricant which flows into the contact has tendency to be squeezed out toward lateral directions by pressure induced flow in this situation.

3. INTERFEROMETRIC MEASUREMENT OF STARVED FILM THICKNESS

An apparatus for measurements of the starved film thickness by use of white light interferometry is developed as shown in figure 1. In this apparatus, the arrangement of the roller before the ball, of which the film thickness is observed in the contact, on the same rolling track can make the condition of lubrication of the ball be starved. Therefore, the inlet film thickness at the ball-plate contact is adjusted by load

Table 1

Velocity parameter $U \times 10^{-11}$	3	6	24
Load parameter $W \times 10^{-6}$	0.2	1	5
Material Parameter G	2200	3300	4400

Talbe 2

	Disk	Roller	Ball
Dimension	ϕ130	ϕ9 × 11	ϕ22.2mm
Material	BK7	JIS SUJ2	JIS SUJ2
Young's modulus	80.2GPa	206GPa	206GPa

applying the front roller. More two balls are placed followed by the roller and ball, not shown in figure 1. Details in dimensions, materials, etc are shown in table 2.

Paraffinic oil(ISO VG68) is supplied as lubricant. A pressure-viscosity coefficient of lubricant used in this apparatus is estimated by comparing the film thickness calculated by the regression formula for the fully flood condition with that measured in the same condition.

Figure 2 shows observation results on variations of the film thickness and inlet meniscus shape with the ball passing. It is found that the meniscus position comes close to the front edge of a plateau film area with the ball passing.

4. PREDICTION OF STARVED EHL FILM THICKNESS

Predicting the reduction of the starvation factor with the ball passing by use of the proposed regression formula is carried out. The oil films sticking to the ball and glass plate flow into the contact together. Therefore it is assumed that inlet film thickness is estimated by a sum of values of the two films. The value of the oil film thickness on a certain ball is assumed to be half as much as that of the central film thickness in the contact between its ball and plate. On the other hand, the value of the oil film on the plate depends on the ball passed through ahead as shown in figure 3. Consequently, the dimensionless inlet film thickness is assumed to be following equation.

$$ {}^{(i)}r = \frac{{}^{(i-1)}H_c + {}^{(i)}H_c}{2 \times {}^{(i)}H_{cf}} \qquad (4)$$

The reduction of the starvation factor with the ball passing can be predicted by solving the equations from (1) to (4) and the regression formula for the fully flood central film thickness simultaneously. A prediction result and a measurement result in the same lubricated condition are plotted in figure 4. In this case, the magnitude of the film thickness of lubricant that flows into the first ball from the roller is 0.209μm.

This result demonstrates the proposed regression formula gives a good prediction for the progress in starvation with successive ball passing. Same investigations in several velocity conditions show that an error in prediction is less than 10%.

5. CONCLUSION

A regression formula including the inlet film thickness as the parameter for the starvation factor in EHL condition is obtained by numerical analysis with the Elrod's cavitation algorithm.

$$\phi = \frac{H_c}{H_{cf}} = \frac{r}{\sqrt[\gamma]{1 + r^{\gamma}}}, \text{ where } \gamma = U^{-0.119} W^{0.100} G^{-0.049}$$

By use of the interferometric measurement apparatus, it is verified that the progress in starvation with the ball passing can be predicted by this formula.

6. REFERENCES

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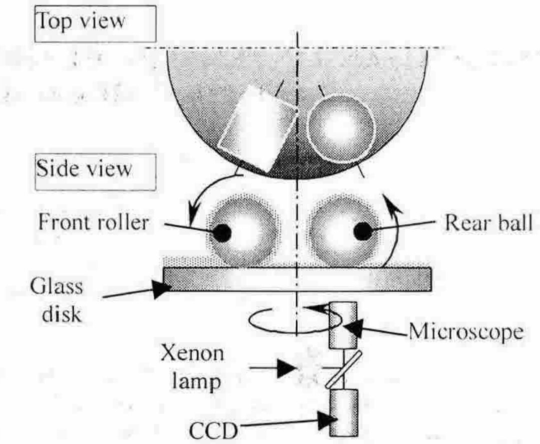

Fig. 1 An apparatus for measurement of starved film thickness

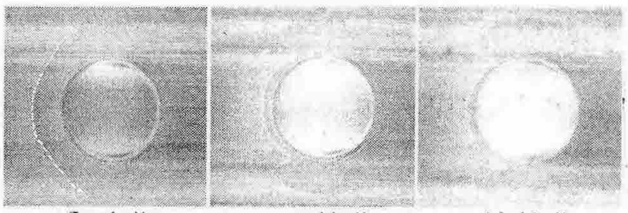

Fig. 2 Progress in starvation with ball passing (normal load: 74N, linear velocity: 0.267m/s, normal load applied to front roller: 28N)

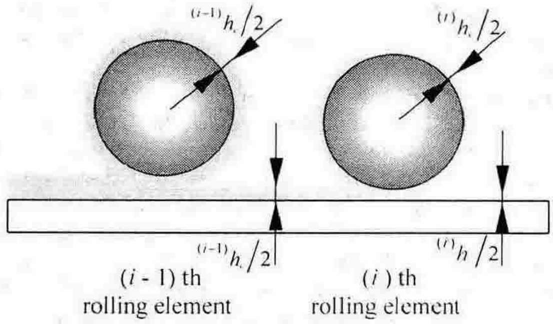

Fig. 3 Schematic illustration of inlet film thickness

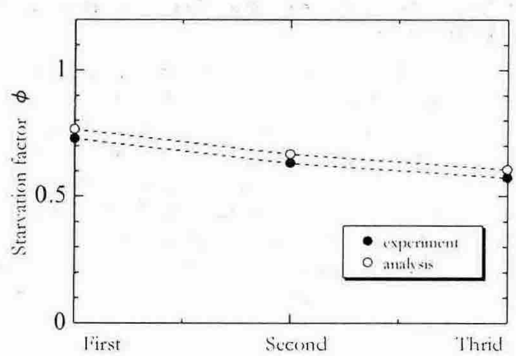

Fig. 4 Comparison of reduction in starvation factor with ball passing between experiment and analysis