EHL OIL FILM THICKNESS UNDER ROLLING-SLIDING CONTACT

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Abstract: The Elastohydrodynamic lubrication (EHL) minimum oil film thickness is theoretically investigated under rolling with sliding contact. The effects of contact pressure, rolling speed and slip ratio on the EHL minimum oil film thickness are calculated numerically. It is found that for a range of contact pressure from 0.5 to 3.5 GPa, the minimum oil film thickness gradually decreases with the increase in contact pressure. As the rolling speed increases from 3500 to 4500 rpm, oil film thickness is increased. It is also found that the oil film thickness is not much influenced by the slip ratio.

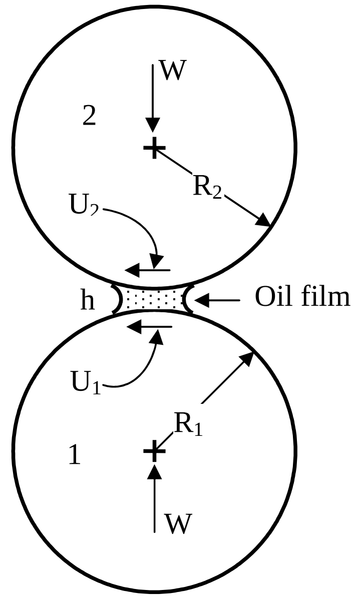
Keywords: EHL oil film thickness, Contact pressure, Rolling speed, Slip ratio.

INTRODUCTION

Elastohydrodynamic lubrication (EHL) occurs in machine components with nonconforming heavily loaded contacts such as gear teeth, rolling element bearings, cams and tappets, etc. In these applications, the solid surfaces operate so close to each other that some surface asperities come into contact despite the presence of a thin film of lubricant oil in the interface. In the EHL regime, the elastic deformation of the bounding solids is large to an extent that affects the lubrication process[1,2]. The deformation may be either plastic or elastic depending on the magnitude of the applied load and the material's hardness. In EHL, the maximum contact pressure is about 3–4 GPa. The change in viscosity of the lubricant oil due to high pressure is crucial in the EHL analysis[3,4].

The pioneering work in EHL was conducted by Dowson and Higginson[5] and was continued by Crook[6]. Crook initiated a revolution in disk machine experiments and found that the thickness of the oil film is inversely proportional to load whereas directly proportional to speed. One of his major conclusions is that the viscosity of the lubricant oil at the surface temperature of the disks greatly affects the oil film thickness. Other researchers like Cameron and Gohar[7], Johnson et al.[8] continued to make progress towards a complete understanding of the mechanism of EHL. Significant development in the analysis of EHL contacts have taken place in the last 10-15 years.

In EHL, the properties of the lubricant oil play a significant role in the forming of an oil film and reducing friction between the contacting surfaces. The properties of a number of lubricating oils of mineral, vegetable and synthetic origin are described in Hogland[9]. Theoretical solutions of various EHL problems of a finite line contact between a plane and an axially profiled cylinder are discussed by Liu and Yang[10]. The pressure profile and the oil film shape in the middle part of the roller are very different from those at the ends. It is revealed that in a finite line contact the maximum pressure and the minimum film thickness occur at the end regions of the roller. The behavior of point contact EHL films under pure rolling short stroke reciprocating motion is investigated using both optical interferometry technique and theoretical analysis by Wang et al.[11]. In addition, general tribo-characteristics of EHL under fully flooded and starved conditions are discussed by them.



$$u = \frac{U_1 + U_2}{2}$$

Figure 1: Oil film developed between loaded discs.

In the present report, the effects of contact pressure, rolling speed and slip ratio on the minimum oil film thickness are investigated. After calculating the dimensionless material parameter, load parameter and speed parameter numerically, the minimum oil film thickness is calculated for a range of contact pressure, rolling speed and slip ratio.

CONTACT OF TWO ROLLERS

In heavily loaded contacts, high pressure can lead both to changes in the viscosity of the lubricant oil and elastic deformation of the bodies in contact, with consequent changes in the geometry of the bodies bounding the oil film.

Minimum Oil Film Thickness: Oil film thickness h varies according to the geometry defined by the two circular arcs of the discs as shown in Fig. 1. The effects of contact pressure, rolling speed and slip ratio on the minimum oil film thickness are calculated numerically. EHL minimum oil film thickness, h_m is calculated by the following relation:

$$\frac{h_m}{R} = 2.65\{\alpha E'\}^{0.54}\left\{\frac{\eta_0 u}{E'R}\right\}^{0.7}\left\{\frac{W}{E'Rb}\right\}^{-0.13}$$

where,

$\frac{h_m}{R}$ = Dimensionless minimum oil film thickness

$\alpha E'$ = Dimensionless Material Parameter

$\dfrac{\eta_0 u}{E'R}$ = Dimensionless Speed Parameter

$\dfrac{W}{E'Rb}$ = Dimensionless Load Parameter

Here, α is the pressure viscosity coefficient in GPa^{-1}, E' is the reduced elastic modulus in GPa, R is the combined or reduced radius of contacting solids in mm, η_o is the lubricant viscosity at atmospheric pressure in Pa.s, u is the average surface speed of the contacting solids in mm/s, W is the load calculated from Hertzian contact pressure in N and b is the contact width in mm.

The reduced elastic modulus E' is defined by the following relation:

$$\frac{1}{E'} = \frac{1}{2}\left(\frac{1-\varepsilon_1^{\,2}}{E_1} + \frac{1-\varepsilon_2^{\,2}}{E_2}\right)$$

where, $E_1=E_2=E$ is the elastic modulus of the two contacting solids, MPa. For steel, E = 2.061x10^4 MPa. ε_1 and ε_2 are the Poisson's ratio of the contacting solids. For steel, $\varepsilon_1 = \varepsilon_2 = \varepsilon = 0.3$.

Average Speed of the Contacting Solids:

$$u = \frac{U_1 + U_2}{2} = \frac{1}{2}\left(\frac{\pi d_1 n_1}{60} + \frac{\pi d_2 n_2}{60}\right) = \frac{\pi}{60}\left(R_1 n_1 + R_2 \frac{z_1}{z_2} n_1\right)$$

where, U_1 and U_2 are the surface speeds of the two contacting solids in mm/s and n_1 and n_2 are, respectively, the driving side and the driven side speeds in rpm. The reduced radius R of the contacting solids is defined as:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

where R_1 and R_2 are radii of the contacting solids.

After calculating the non-dimensional EHL groups such as material parameter, speed parameter and load parameter numerically, the minimum oil film thickness, h_m is calculated.

RESULTS AND DISCUSSION

Figure 2 shows the variation of minimum oil film thickness, h_m with the contact pressure, P_H for rolling speed = 3500 rpm, slip ratio =-16% and combined roughness = 0.1414 µm. From the figure, it can be seen that at contact pressure P_H = 0.5 GPa, minimum oil film thickness is about h_m = 0.65 µm. Results are shown for a range of contact pressure from P_H = 0.5 to 3.5 GPa. From the figure it is apparent that as the contact pressure increases, oil film thickness gradually decreases.

Figure 3 exhibits the effect of contact pressure on oil film thickness for speed = 4500 rpm, slip ratio =-28% and combined roughness = 0.1414 µm. From the figure it is clear that at P_H = 0.5 GPa, oil thickness is very near to 0.8 µm which is higher than the oil thickness at 3500 rpm. Moreover, the variation of oil film thickness with contact pressure shows that it gradually decreases with the increase of contact pressure and this variation is almost similar as before.

Figure 4 illustrates the effect of contact pressure and rolling speed on minimum oil film thickness for slip ratio =-16% and combined roughness = 0.1414 µm. Results are shown for contact pressure ranging from P_H = 0.5 to 3.5 GPa and rolling speed =3500, 4000 and 4500 rpm. From these results it is clear that with the increase of contact pressure, oil film thickness is decreased. Moreover, it is very clear that with the increase of rolling speed, oil film thickness is increased.

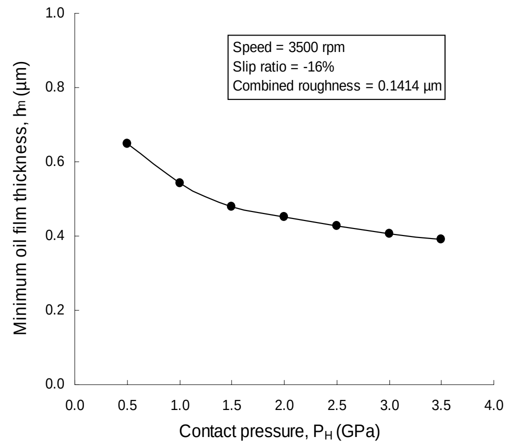


Figure 2: Effect of contact pressure on minimum oil film thickness (3500 rpm).

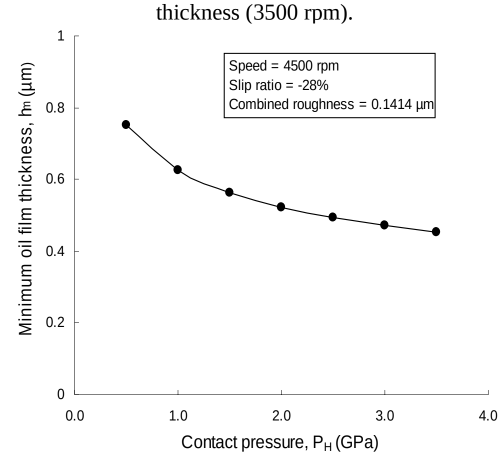


Figure 3: Effect of contact pressure on minimum oil film thickness (4500 rpm).

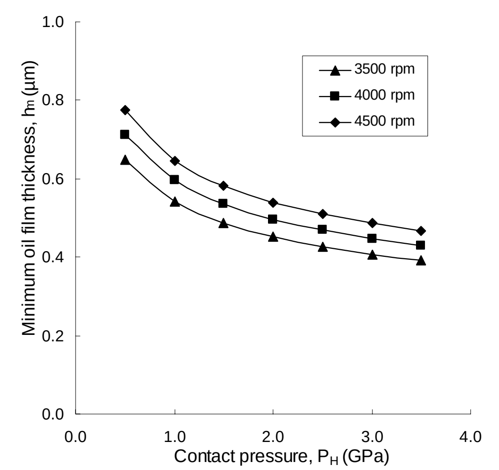


Figure 4: Effect of contact pressure and speed on minimum oil film thickness (slip ratio =-16%, combined roughness = 0.1414 µm)

Figure 5 shows the effect of contact pressure and slip ratio on minimum oil film thickness for rolling speed = 3500 rpm and combined roughness = 0.1414 µm. Results are shown for contact pressure ranging from P_H = 0.5 to 3.5 GPa and slip ratio =-16%, -24% and -28%. From the

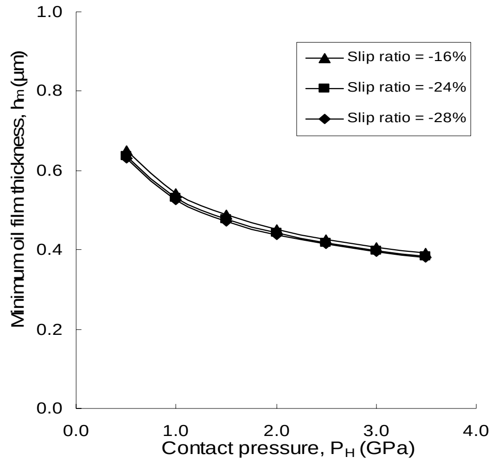


Figure 5: Effect of contact pressure and slip ratio on minimum oil film thickness (speed = 3500 rpm, combined roughness = 0.1414 μm)

obtained results, it is seen that for slip ratio =-16% and P_H = 0.5 GPa, oil film thickness is about 0.65 μm and oil thickness decreases gradually with the increase of contact pressure. From the obtained results it is also apparent that oil film thickness is slightly decreased for higher slip ratio -24% or -28%, and the trend in variation of oil film thickness is same as before. On the whole, it can be concluded that oil film thickness decreases with the increase of contact pressure and it is hardly influenced by the slip ratio.

CONCLUSION

The effects of contact pressure, rolling speed and slip ratio on the minimum oil film thickness are calculated numerically. It is found that minimum oil film thickness gradually decreases with the increase in contact pressure ranging from 0.5 to 3.5 GPa. As the rolling speed increases from 3500 to 4500 rpm, oil film thickness is increased. On the whole, oil film thickness is much influenced by the contact pressure and rolling speed. Moreover, with the increase in slip ratio, the oil film thickness is slightly decreased and it is concluded that oil film thickness is hardly influenced by the slip ratio.

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