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Study of instantaneous starvation at a finite-length line contact

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KEYWORD

Lubrication
Starvation
Finite-length contact
High frequency

ABSTRACT

Starvation phenomenon widely exists in the non-conforming contacts when high-viscosity lubricating oil or greases are used. However, most of the work focuses on the steady state starvation, and the phenomenon of instantaneous starvation is not well explored by scholars. This paper experimentally studies the effect of speed, base oil viscosity and load on instantaneous starvation, and proposes some improvement measures to weaken the instantaneous starvation.

1.0 INTRODUCTION

Starvation often occurs in tribological contact due to reduced lubricant availability which generally accompanies with the decreased protective fluid film, and then even moderate surface roughness can lead to component damage. This is especially true with use of grease-lubricated or high-viscosity-oil-lubricated applications. Lots of theoretical and experimental works (Chevalier et al., 1998, Chen et al., 2015, Maruyama et al., 2015, Ali and Křupka et al., 2015) have been done to investigate the effects of the operating conditions and the lubricant properties on the starvation. Recently, some authors (Wang et al., 2017) used the multiple-contact optical EHL test rig to investigate the starvation of grease-lubricated finite line contact, and they found even in a short period of time there is a significant change in the thickness of the film, as shown in Figure 1.

The film-thickness interference images of one period are showed in Figure 2. Although this kind of high frequency fluctuations hasn't been appeared in previous literature, the low frequency fluctuations in grease lubrication have been discovered by (Kaneta et al., 2000) and (Cousseau et al., 2015). They believed that these low-frequency fluctuations are caused by the saponification material entering the contact area. This view seems difficult to explain the high frequency fluctuation, because the high frequency fluctuations are periodic and low frequency fluctuations are random. These high frequency fluctuations indicate "Instantaneous Starvation" phenomenon. Many factors may cause this phenomenon, such as the vibration of test rig, the variation of speed or the lubricant properties. In this paper, effect of speed, base oil viscosity and load on this

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phenomenon is firstly investigated with the elastohydrodynamic lubrication (EHL) test rig, and then some possible reasons are discussed, finally some improvement measures are proposed to weaken this phenomenon.

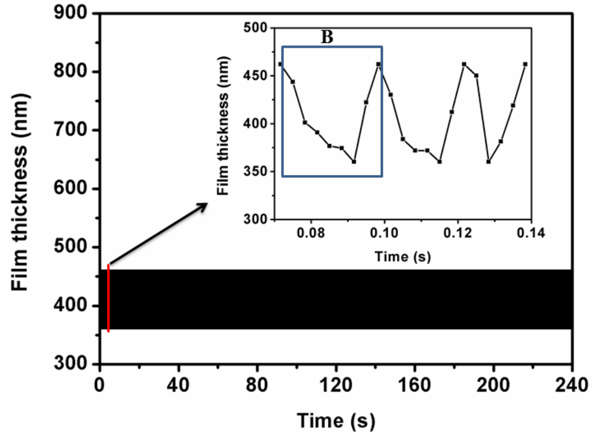


Figure 1: Change in film thickness over time. (From Wang et al., 2017).

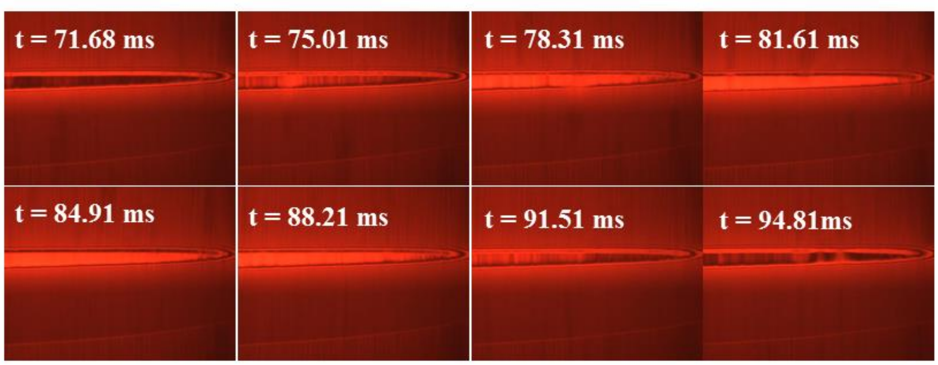


Figure 2: Variation of the oil film interference image in one cycle (corresponding to B in Fig. 1). (From Wang et al., 2017).

2.0 TEST RIG AND CONDITIONS

2.1 Test Rig

Figure 3 and 4 show both the schematic diagram and in-kind shooting of finite line contact EHL test rig used in the work. Under the drive of variable frequency motor, the spindle drives race to rotate, ulteriorly keeping the tested roller moving. Owning to the condition that tested rollers are restrained by the fixed cage, there simply exists positioning movement. Then the positioning movement above make the glass disk rotate, and different workloads are obtained by applying load onto the glass disk. The beam emitted by the red light source shots to the refractive lens installed on the lower part of the microscope, and part of them refracts vertically downwards through the flat glass to the surface of the roller. The forming interference fringes can be observed from the microscope. Finally, the changes on oil film thickness and shape are observed by means of high-speed CCD camera.

The oil film thickness is calculated according to relative light intensity principle. The principle of this technique has been explained in detail by (Luo et al., 1996). The film thickness is given by the following expression:

$$h = \frac{\lambda}{4\pi k}\left[\left(n + \left|\sin\frac{n\pi}{2}\right|\right)\times\pi + arc\cos(\bar{I})\times\cos(n\pi) - arc\cos(\bar{I_0})\right]$$

where λ is the wave length of the incident light, k is the reflective index of the lubricant, n is the interference order, $\bar{I}$ is the relative interference light intensity, $\bar{I_0}$ is the relative light intensity when the film thickness is zero, and h is the film thickness.

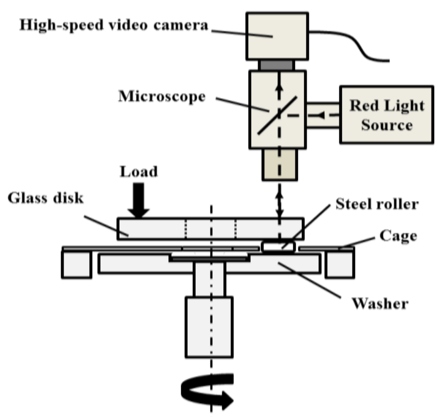


Figure 3: Schematic of EHL testing machine.

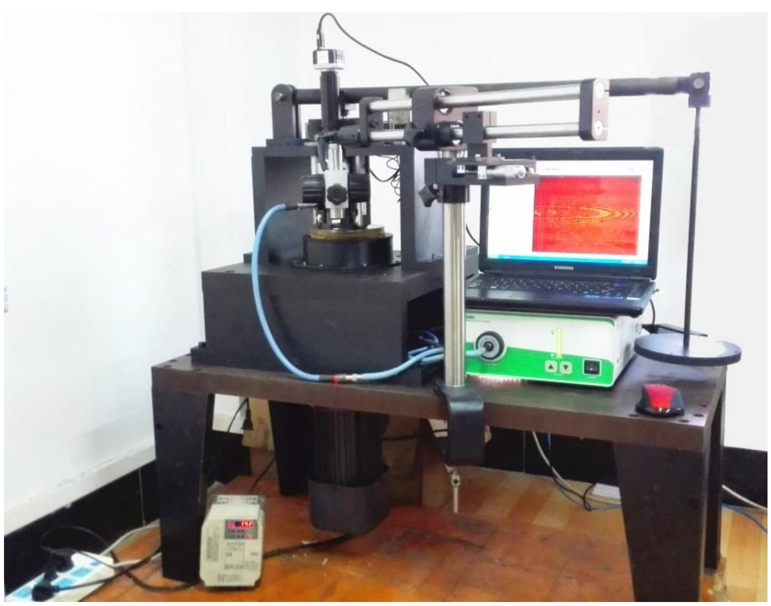


Figure 4: In-kind shooting of EHL testing machine.

2.2 Roller placement

Figure 5 shows the steel rollers placement. There are three rollers with the same specification under the glass disk. They are evenly distributed at 120° perpendicular to the circumferential direction.

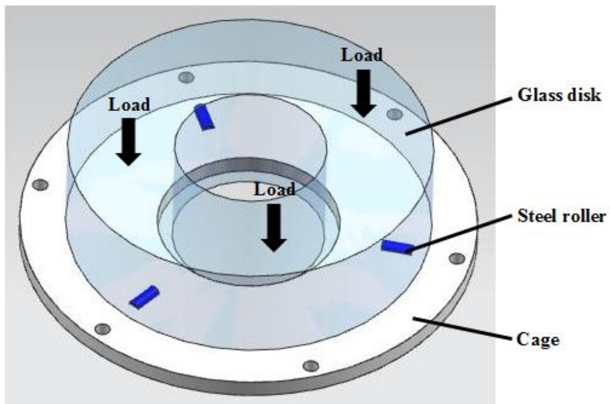


Figure 5: The steel rollers placement.

2.3 Test conditions and lubricants

All measurements are taken at ambient temperature of 25℃. Table 1 shows the test conditions used in this study. The kinematic viscosity of PAO at 40℃ varies from 30.5mm^2/s to 1000mm^2/s. The oil is uniformly smeared on the disk, and no additional lubricant is added during the test.

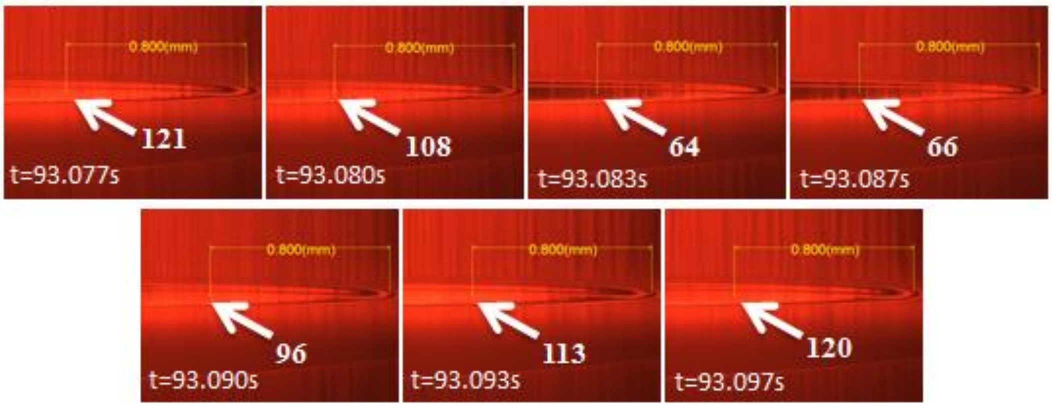
Table 1: Test conditions.

Condition	Parameter
Needle roller	6 mm ×12 mm
Load	293N ~ 672 N
Speed	0.107 m/s ~ 0.321 m/s
Experiment time	4 min
Frame rate	300 frames/s
Lubricant (Synthetic oil)	Poly Alpha Olefin (PAO)

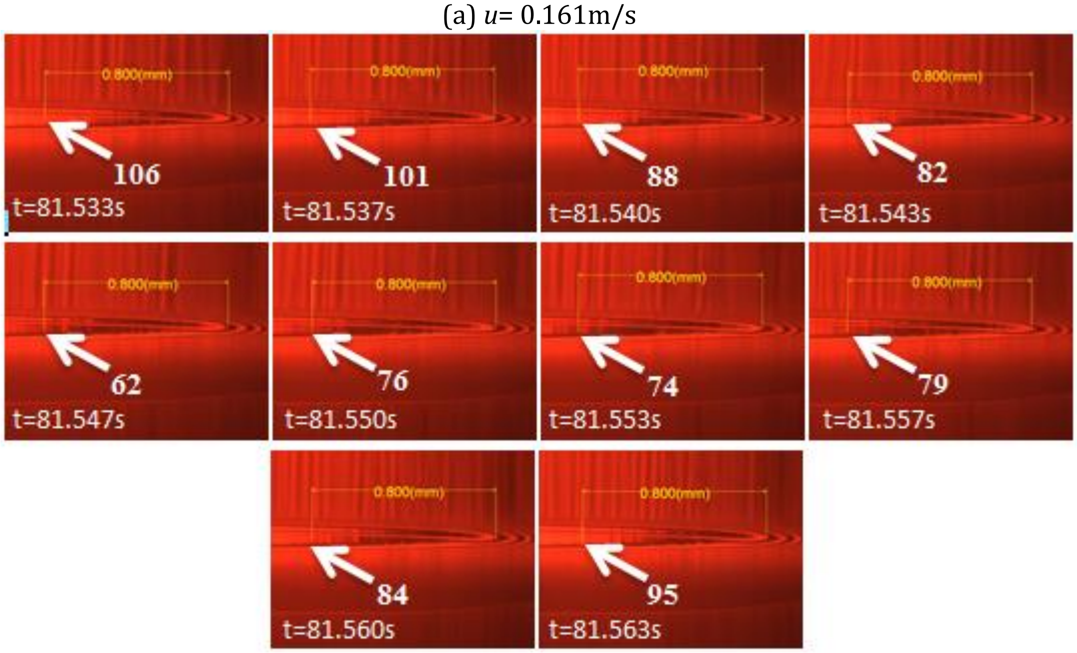
3.0 EFFECT OF OPERATING CONDITIONS ON INSTANTANEOUS STARVATION

3.1 Effect of speed on instantaneous starvation

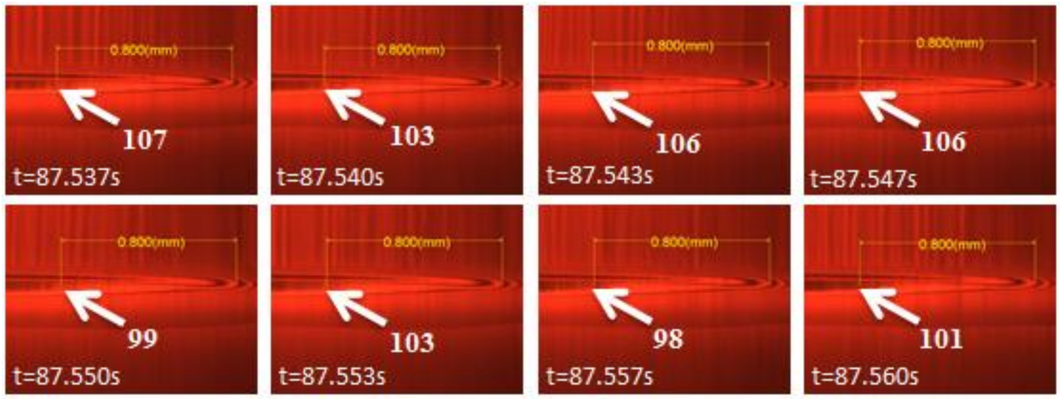
Figure 6 gives the oil film interference images at different speeds and the light intensity at the specified point. In this case, the load is equal to 200N, corresponding to the maximum Hertzian pressure 0.50 GPa. And the viscosity of lubricant is equal to 1000 mm^2/s at 40℃. It can be found that the light intensity varies periodically at the specified point when the speed is equal to 0.161 m/s and 0.214 m/s. And as the speed increases, the light intensity trends to stable. Figure 7 gives the film thickness at the specified point. It can be found that when the high-viscosity base oil is used, as the speed increases, the film thickness increases, and the high frequency fluctuation of film thickness weakens and finally disappears. This is because the quantity of lubricating oil involved in the contact area increases corresponding to the increase of speed, and the volume of lubricant passing contact areas per unit of time also increases, which may weaken instantaneous starvation. Under this working condition, when the speed is larger than 0.321 m/s, the instantaneous starvation phenomenon disappears.



(a) u= 0.161m/s



(b) u= 0.214m/s



(c) u= 0.321m/s

Figure 6: Oil film interference images at different speeds.

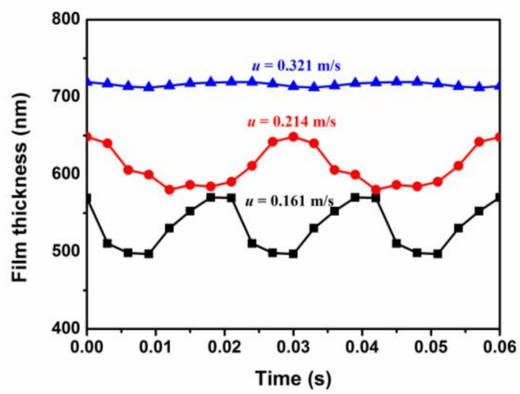
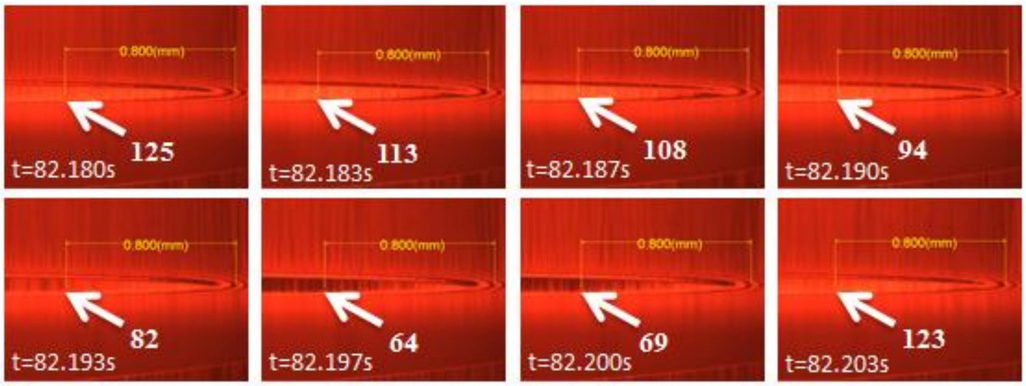


Figure 7: Variation of film thickness with time at different speeds (w = 200 N, v = 1000 mm^2/s).

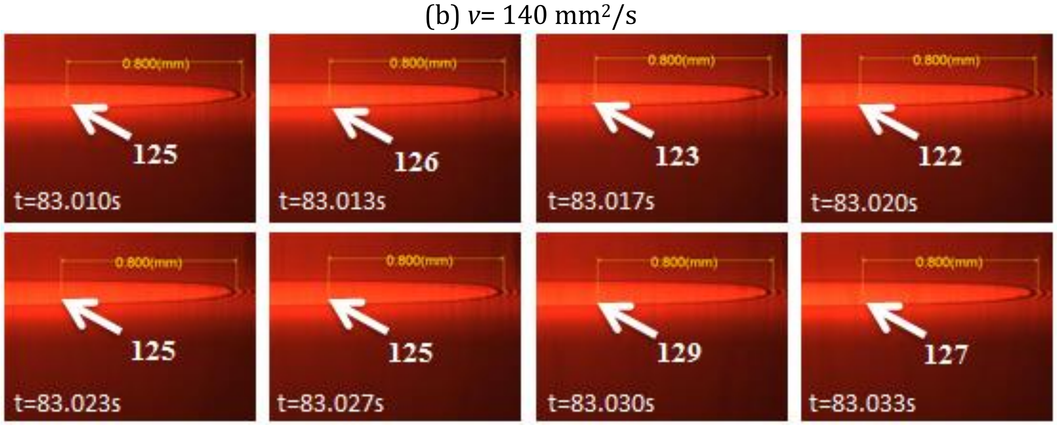
3.2 Effect of base oil viscosities on instantaneous starvation

Figure 8 gives the oil film interference images at different viscosities and the light intensity at the specified point. In this case, the load is equal to 200N and the speed is equal to 0.107m/s. It can be found that the fluctuation of light intensity exists in the figure 8(a) and 8(b), while the light intensity is relatively stable in figure 8(c). Figure 9 gives the effect of base oil viscosity on the film thickness at the specified point. It can be found that as the viscosity decreases, the film thickness decreases, and the high frequency fluctuation of film thickness weakens and finally disappears, since reducing the viscosity of base oil will decrease the internal friction of lubricant, which can improve the mobility of the lubricant and weaken instantaneous starvation. Thus, the instantaneous starvation phenomenon disappears. In this working condition, when the base oil viscosity is lower than 58mm^2/s, the instantaneous starvation phenomenon disappears.



(a) v= 500 mm²/s

(b) v= 140 mm²/s



(c) v= 58 mm²/s

Figure 8: Oil film interference images at different viscosities.

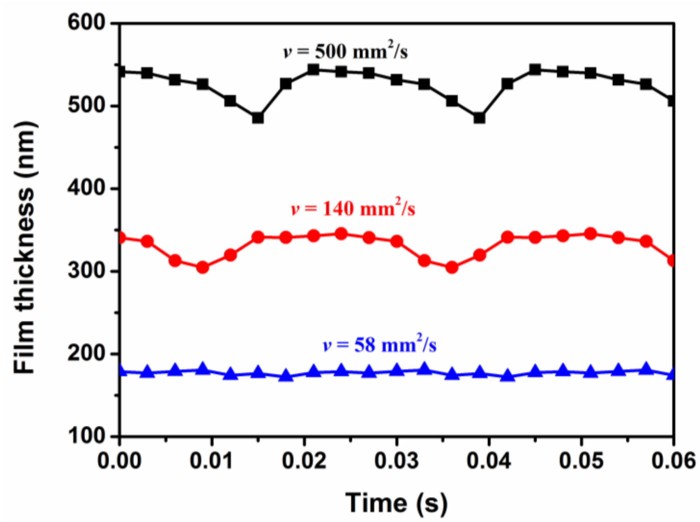
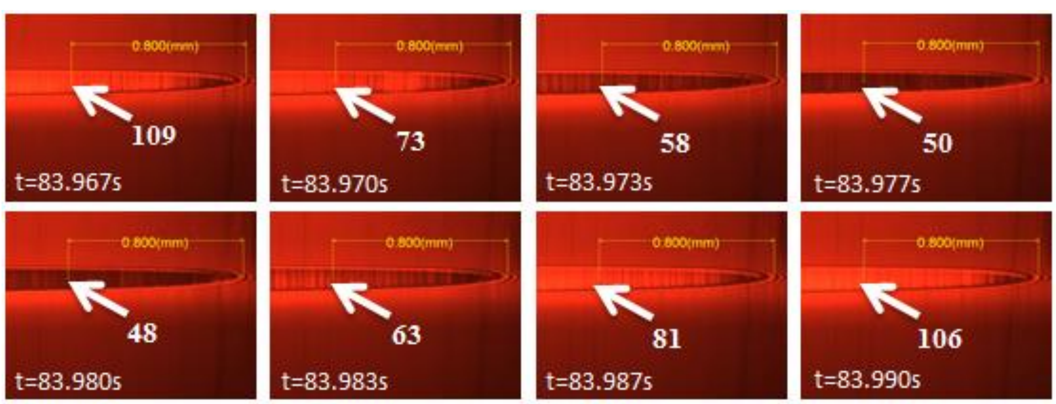


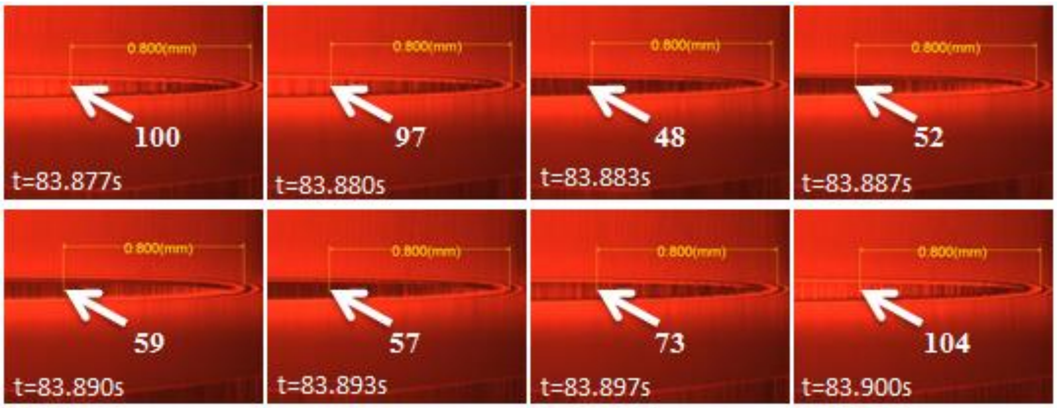
Figure 9: Variation of film thickness with time at different viscosities (w = 200 N, u =0.107 m/s).

3.3 Effect of load on instantaneous starvation

Figure 10 gives the oil film interference images at different loads and the light intensity at specified point. In this case, the speed is equal to 0.107m/s and the viscosity of lubricant is equal to 242 mm²/s at 40℃. It can be found that the fluctuation of light intensity exists in three different loads. Figure 11 gives the corresponding film thickness at specified point. It can be found as the load increases, the film thickness slightly decreases, the fluctuation of film thickness still exists, which indicates that the load has little influence on the instantaneous starvation.



(a) w= 300 N



(b) *w*= 200 N

(c) *w*= 100 N

Figure 10: Oil film interference images at different load.

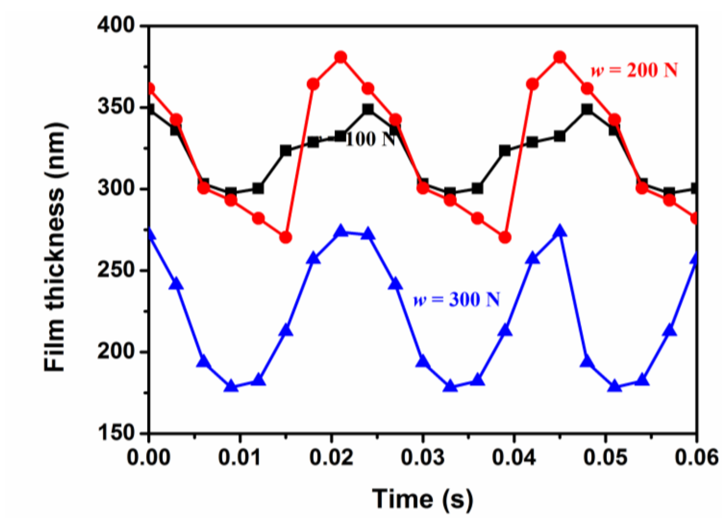
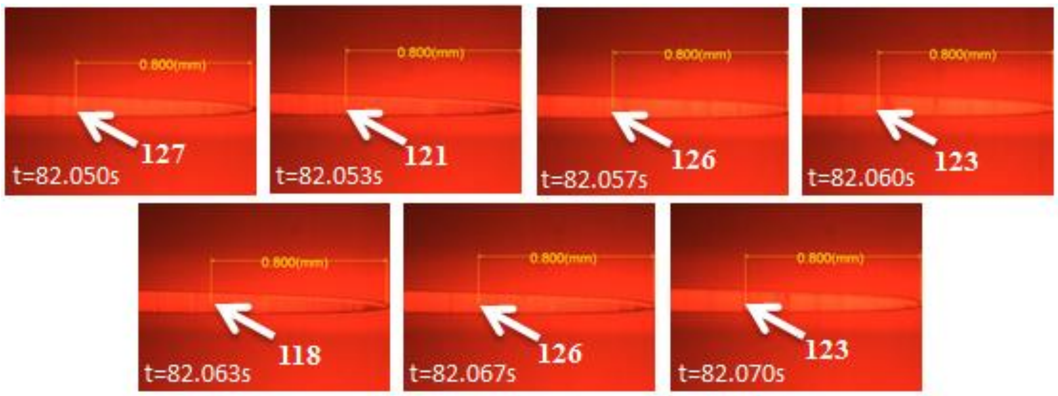


Figure 11: Variation of film thickness with time at different loads (u = 0.107 m/s, v = 242 mm^2/s).

3.4 Effect of non-Newtonian fluid

In order to weaken the instantaneous starvation phenomenon, the non-Newtonian fluid was investigated. The viscosity improver additive (PMA) was added to base oil (PAO), which can form non-Newtonian fluid. Figure 12 gives the oil film interference images of Newtonian and non-Newtonian fluid. In this case, the speed is equal to 0.107m/s and the load is equal to 200N. As shown in figure 12, it can be found that the fluctuation of light intensity apparently weakens for non-Newtonian fluid, although two kinds of lubricants have the similar kinematic viscosity before experiment. Figure 13 gives the film thickness at the specified point, it can be found that the film thickness of non-Newtonian fluid is apparently lower than that of Newtonian fluid. This is because shear-thinning behavior exists in non-Newtonian fluid under high shear stress which can cause temporary loss of viscosity. In addition, air–oil meniscus didn't appear for the non-Newtonian fluids which indicate that the oil supply volume of non-Newtonian fluid is larger than that of Newtonian fluid. This is because the effective kinematic viscosity of non-Newtonian fluid didn't fully recover during operation. Therefore, non-Newtonian fluid can weaken the instantaneous starvation.

(a) Newtonian fluid



(b) Non-Newtonian fluid

Figure 12: Oil film interference images of Newtonian and non-Newtonian fluid.

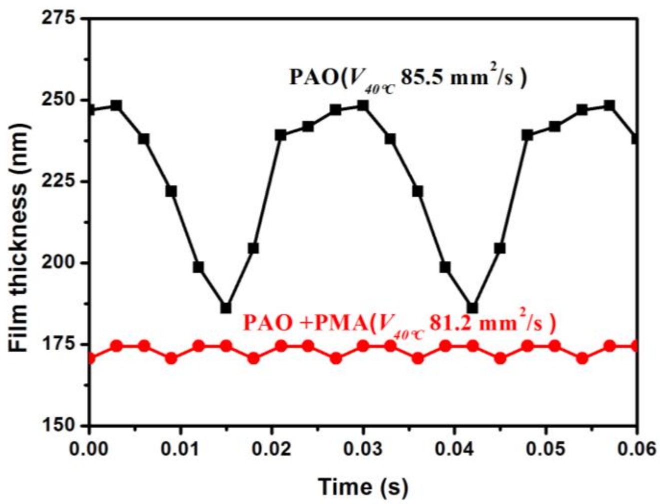


Figure 13: The influence of non-Newtonian fluid on instantaneous starvation (w = 200 N, u =0.107 m/s).

4.0 CONCLUSION

The instantaneous starvation phenomenon is experimentally investigated by using the multiple-contact optical EHL test rig. It can be found that the operating speed and the base oil viscosity are the two primary factors in the instantaneous starvation phenomenon. The load has little influence on the instantaneous starvation. Increasing the speed, reducing the viscosity, and using the Non-Newtonian fluid can effectively weaken the instantaneous starvation phenomenon which may be useful for the design of bearing lubrication.

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