Friction characteristics of an oil-immersed clutches -Viscosity increase in thin films with additives

Hiroo TAURA
Yoshitsugu KIMURA
Insitute of Industrial Science, the University of Tokyo

1. Introduction

Recently, the automatic transmissions are becoming popular in automobiles. The automatic transmission have to be improved further in order to meet the requirements of new class of automobiles for better comfort. For making these improvements, it is important to achieve smooth engagement of a wet clutch.

Figure 1 shows a process of engagement of a wet clutch[1]. First, just at the start there is increase in the oil film pressure, which shows a hydrostatic action. But, Then, it caused little increase in the normal load nor the torque. This suggests its neglectable effect on power transmission. Then the oil film pressure decrease s rapidly and bubbles appear. This shows that a hydrodynamic action has come to work. Then, the normal load and the torque increase simultaneously. After a while, as the sliding speed decrease, the bubbles disappear, but the torque does not change. This shows that friction has taken place by solid contacts.

In summary, engagement of a wet clutch occurs in a transition from a hydrodynamic to a boundary regime. Therefore, friction characteristics of a wet clutch at the transition are very important for the smooth engagement.

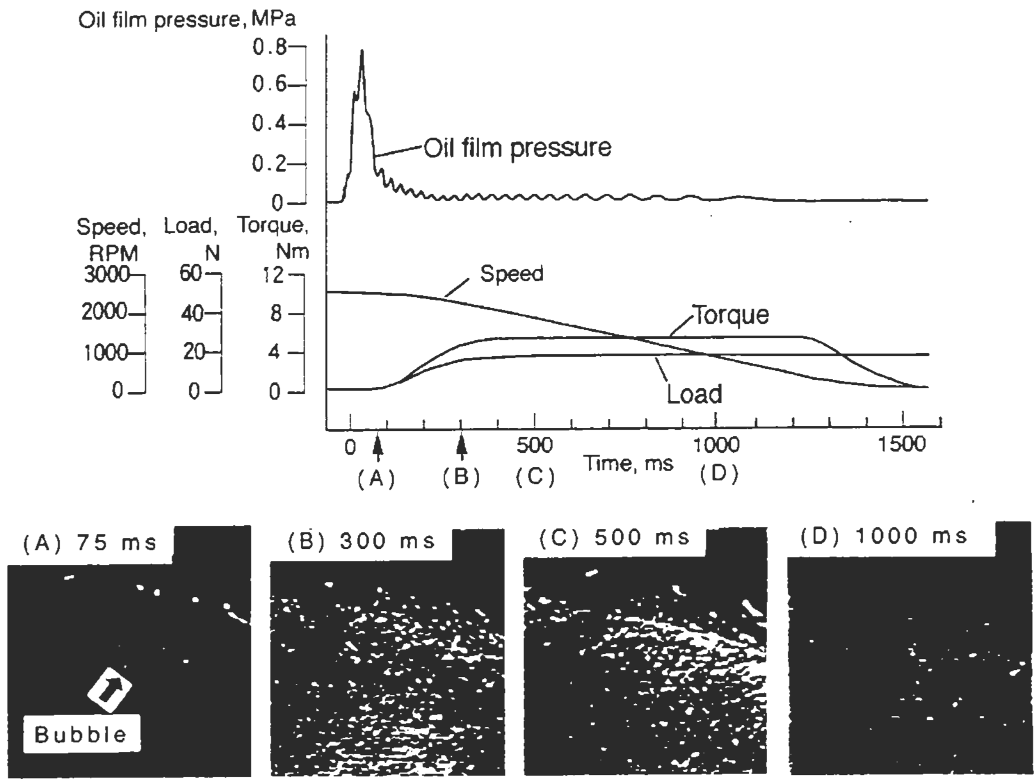

Figure 1 Process of engagement of a wet clutch

Wet clutches for automatic transmission is normally used with ATF which contains many kinds of additives. In general, friction characteristics of a wet clutch with ATF and the base oil are shown in figure 2[2]. As the sliding speed increases, the coefficient of friction for ATF increases to take a maximum at a higher speed. This feature is completely different from that of the base oil. The decrease in friction in comparison to the base oil at low speeds is understandable, but the increase at high speeds is mysterious.
Two possibilities can be considered as the reason. First is local viscosity increase caused by some additives[3]. The other is the prevalence of solid contacts. We consider that the former is more likely and try to examine hydrodynamic behavior of very thin oil films.

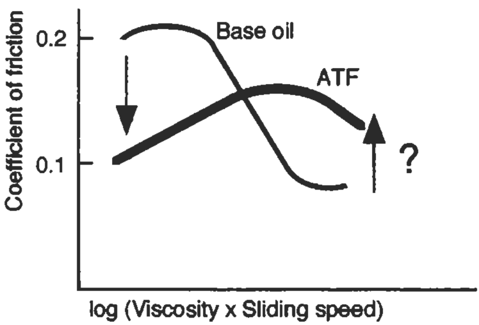

Figure 2　Friction characteristics of a wet clutch with ATF and the base oil

2. Experiments

2.1 Experimental apparatus

Figure 3 shows the experimental apparatus that can measure friction and oil film thickness. This apparatus is basically a pin-on-disk type. The pin is cut out from a 1.5" bearing ball. Friction between the pin and the glass disk is calculated from the lateral displacement of the double cantilever. Oil film thickness is measured by using a point contact optical interferometry which has been often used in EHL contacts. But, an EHL is not preferable here, because of pressure-viscosity effects. Therefore, low sliding speeds and a light load are employed.
Figure 4 shows the concept of the slider support. Bold lines represent solid structures. The guide is pushed to the glass disk by the weight to reduces the effect of undulation of the glass disk and to keep the distance between the disk and the arm constant. Owing to this slider support, the pin can be made a light load stably by the loading spring.

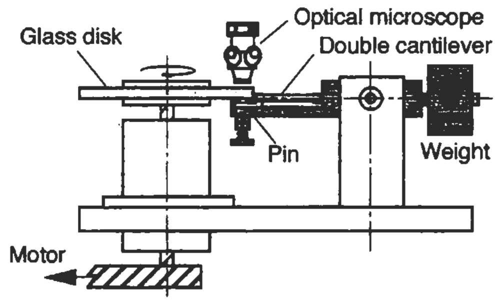

Figure 3　Experimental appratus

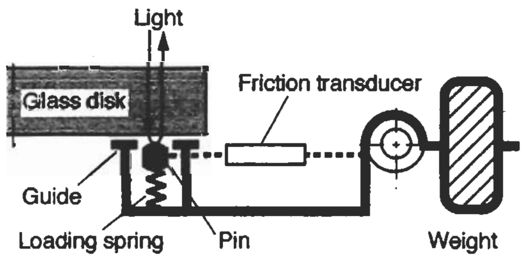

Figure 4　Concept of slider support

2.2 Measurement oil film thickness

In this experiment, we intend to measure oil film thickness less than 0.1 μm, but normal optical interferometry technique can not measure this range. So, an optical interferometry with stepped spacer layers was used.
A spacer layer technique that can decrease the minimum film thickness was proposed by Westlake4). On the basis of this technique, we used a glass disk with a stepped spacer layer as shown in figure 5. We call the thinnest part step 1, and the thickest part step 4. Figure 6 shows colors of the fringe at each step for varying oil film thickness. From this figure, different thickness of the spacer layer at each step shifts differently the color band to the thin side. By comparing color at each steps, we can improve the resolution.
Thus, the optical interferometry with a stepped spacer layer enables the measurement of very thin films and improves the resolution.

2.3 Experimental conditions

Table 1 shows the properties of the oils used. The base oil is paraffinic one and additives are the typically used in ATF. Though the viscosities are slightly different, these values are higher than that of ATF in market.

Table 2 shows the experimental conditions. The meniscus force can not be ignored because of a light load. So, the meniscus force was measured under static conditions, and it was added to the spring load to give a real load.

According to the Hamrock-Dowson's map of lubrication regimes for a point contact EHL[5], these conditions are in the Isoviscous-Rigid region. It is confirmed that the experimental conditions are hydrodynamic, not EHL.

3. Results

Figure 7(a) shows the minimum film thickness against the product of bulk viscosity and sliding speed both on a logarithm scale. Data for all oils fall on straight lines which have slopes of about 1.8 over this range which is close to the value given by the Isoviscous-Rigid theory i.e. 2.0. It is clear that the additives increased the minimum film thickness. In this figure, since the sliding speed is multiplied by the bulk viscosity, increases are not caused by the different bulk viscosity.

Figure 7(b) shows the friction against the product of bulk viscosity and sliding speed, both on a logarithm scale. The effect of additives on friction is similar to that on minimum film thickness. Ashless dispersant and metallic detergent additives gave high friction, but the friction modifier seemed to have little effect.

Table 3 shows the relative increase in minimum film thickness and friction with additives to the base oil. The effect of bulk viscosity of each oil on

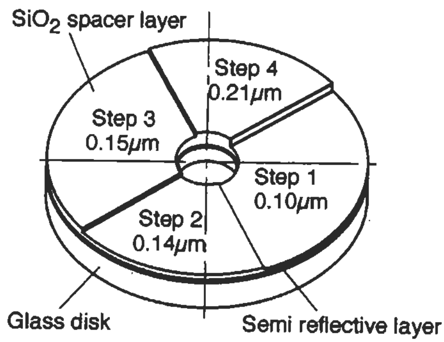

Figure 5 Glass disk with stepped spacer layer

Table 1 Properties of oils

Additives	Viscosity, mm²/s 40 °C	100 °C	Refractive Index
Base oil	81.72	10.03	1.48
+ Metallic detergent	86.01	10.41	1.48
+ Ashless dispersant	93.69	11.19	1.48
+ Friction modifier	81.34	10.01	1.48

Table 2 Experimental conditions

Sliding speed	0.003 - 0.013 m/s
(Revolution speed)	(0.4 - 1.4 rpm)
Load	0.0567 N
(Spring load)	(0.049 N)
(Meniscus force)	(0.0077 N)
Temperature	room temperature(22.5°C)

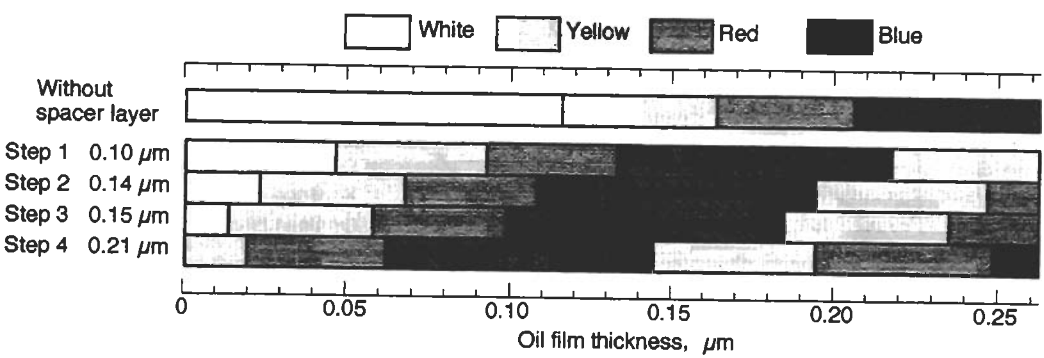

Figure 6 Fringe color chart (Refractive index = 1.48)

these value has been removed by normalizing by their respective bulk viscosities. Increase of 10 to 20% in the film thickness and 10% in friction is obtained.

Assuming that the increases in the film thickness and friction presented so far are caused by local viscosity increase in very thin films with additives, we can estimate the local viscosity increase from the measured values. From table 4, it is concluded that the metallic detergent and the ashless dispersant increased the local viscosity by about 10% over the base oil, and the effect of the friction modifier is less than that of others.

4. Conclusions

◆ An optical interferometry technique with stepped spacer layers is able to measure lower minimum oil film thickness and has an improved resolution.

◆ Some additives increased minimum hydrodynamic film thickness and friction over a measured film thickness range of 0.01 to 0.2 μm.

◆ The results are related to local viscosity increase of about 10% caused by a metallic detergent and an ashless dispersant.

Acknowledgments

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References

1) N. Takakura, J. Takahasi, J. J. Gil, H. Sugiyama and T. Arai : Proc. ITC Yokohama '95 Satellite Forum, "Tribology of Wet Friction Materials", (1995) 27.

2) M. Kuroiwa, Y. Nagasawa, A. Suzuki and K. Hayashi : Proc. of JAST Tribology Conference Kanazawa,(in Japanese), (1994-10) 915.

3) S. Shirahama : J. Jpn Soc. Tribologists, (in Japanese), 39, 12 (1994) 1037.

4) F. J. Westlake : Ph. D. thesis, Imperial college, Unversity of London, 1970.

5) B. J. Hamrock and D. Dowson : Proc. 5th Leeds-Lyon Symp. on Tribology, (1978) 22.

Table 3 Relative value to the base oil

	Minimum film thickness	friction
Base oil	1.00	1.00
+ Metallic detergent	1.18	1.10
+ Ashless dispersant	1.20	1.08
+ Friction modifier	1.11	1.00

Table 4 Relative viscosity increse in thin films estimeted from the measured values.

	Minimum film thickness	friction
Base oil	1.00	1.00
+ Metallic detergent	1.09	1.10
+ Ashless dispersant	1.09	1.08
+ Friction modifier	1.05	1.00

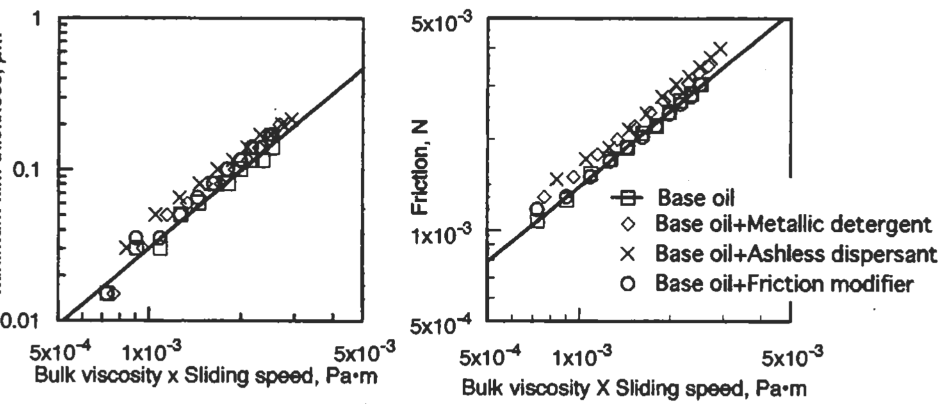

Figure 7 Experimental results