Development of Fluids for Chain Type CVTs

Toshiaki Iwai 1)*, Keiichi Narita 1), Mitsugu Kudo 2) and Masato Ogawa 3)

1) Idemitsu Kosan Co., Ltd., Lubricants Research Laboratory, 24-4 Anesakikaigan, Ichihara-shi, Chiba 299-0107, Japan
2) Idemitsu Kosan Co., Ltd., Lubricants Department, 2, 1-1 Marunouchi 3-Chome, Chiyoda-ku, Tokyo 100-8321, Japan
3) Subaru Corporation, 3-9-6 Ohsawa, Mitaka-Shi, Tokyo 181-8577, Japan

*Corresponding author: Toshiaki Iwai (toshiaki.iwai@idemitsu.com)

Abstract

In the area of transmissions, continuously variable transmissions (CVTs) have been adopted for cars with various engine displacements mainly in Japan and North America because of their better fuel economy and smooth shift feeling. Continuously variable transmission fluids (CVTFs) with lower viscosity and optimal friction property for chain and pulley will be effective for improving fuel saving performance in CVT. In this study, compared with a market chain CVTF, the developed oil had a lower viscosity, a higher metal friction coefficient, and higher clutch transmission capacity, while its anti-seizure property was better than a market chain CVTF. As to higher metal friction coefficient, small islands were observed on friction surface by atomic force microscopy (AFM). It is supposed that those islands promote a shift to the boundary lubrication regime, contributing to a higher friction coefficient. The developed oil containing some additives demonstrated 10% higher variator torque capacity compared with a commercial CVTF.

Keywords

chain CVTF, AFM, metal friction, clutch friction, anti-seizure property

1 Introduction

Recently, awareness of global environmental problem has increased. Particularly due to issues of global warming and depletion of fossil fuels, automobile manufacturers are trying to reduce emission gases such as CO2 and increase the fuel economy of automobiles. In the area of transmissions, continuously variable transmissions (CVTs) have been adopted for cars of various displacements mainly in Japan and North America due to their higher fuel economy [1] and smooth shift feeling.

Chain CVTs as shown in Fig. 1 have excellent flexibility relative to push belt CVTs. Due to their wide range of transmission gear ratios, excellent transmission efficiency (about 5% higher than that of push belt CVTs) [2], and their ability to increase torque capacity by increasing chain width, these systems have attracted attention as the next generation of CVTs and are seeing practical application. They are also believed to increase fuel economy (10% relative to that of 4 speed automatic transmission cars) [3].

Chain CVTs transmit power via contact between the chain pin and the pulley, and are characterized by having higher surface pressure than push belt CVTs. Therefore, continuously variable transmission fluid (CVTFs) is required to have high anti-seizure property and high metal friction coefficient. It has been suggested that fluids giving a higher torque capacity have the potential to decrease the maximum required pulley clamping force, which results in the reduction of total power loss in the CVTs [4, 5].

There are some reports regarding the effects of Lubricants on the performance of a CVT. From these literatures, CVT torque capacity is founded to be dominated by boundary film formation derived from oil additives, and fluids with a higher metal-metal friction would give a positive outcome for achieving greater torque capacity.

In addition to giving higher torque capacity in the chain CVT, Chain CVTFs must be compatible with lock-up clutch fitted in the torque converter. Thus, CVTFs must have anti-shudder property. For the improvement of anti-shudder, friction modifiers are needed to be added into chain CVTFs.

Fig. 1 Chain CVT unit

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The Lubrication condition between the chain and pulley, the area which is the power transmitting portion of the CVT, is considered to be in the mixed/boundary lubrication regime. It is assumed that the friction coefficient is dependent on the shearing force based on the characteristics of the boundary lubrication film formed by the additives and the EHL (Elastohydrodynamic Lubrication) film.

This paper describes the performance of CVTFs developed exclusively for chain CVTs.

2 Experimental

2.1 Test oil

Table 1 shows the composition of the test oils. The lubricants used were a hydro-cracked mineral oil base blended to contain each additive.

In CVTFs, various kinds of additives are blended in base oil to meet required performances. For reducing viscosity of fluid, the selection of base oil and viscosity index improver (VII) is important. To higher metal friction coefficient, detergent, dispersant and extreme pressure agent will be contributable.

Developed chain CVTF’s (use Group III base oils and low molecular weight polymethacrylate) kinematic viscosity, an important physical property of CVTFs, is 7.1 mm²/s at 100°C lower than that of market chain CVTFs (7.5 mm²/s). This would suggest some effect in terms of fuel economy effects due to the reduction in agitation loss.

<table>
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<tr>
<th>Table 1</th>
<th>General properties of test oil</th>
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<tr>
<td></td>
<td>Belt CVTF</td>
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<tr>
<td>Viscosity</td>
<td>@40°C</td>
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<tr>
<td>Kinematic Viscosity</td>
<td>33.9</td>
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<tr>
<td>Viscosity Index</td>
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<tr>
<td>Element</td>
<td>Ca</td>
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2.2 Block on ring tribometer (LFW-1)

The friction characteristics between the metals were evaluated by using a block on ring tribometer (Falex LFW-1) as shown in Fig. 3. The friction characteristics between the metal were evaluated by varying the sliding speed from 0.02 to 0.5 m/s with a constant load of 1,112 N and constant oil temperature (110°C). Under the conditions listed in Table 2 [6]. This type of tester is widely used for conducting evaluations.

2.3 Surface analysis

Atomic force microscopy (AFM) (Veeco Caliber AFM) is used to investigate the morphology of tribofilms. Before surface analysis, the test specimens were washed by immersion in hexane in order to remove residual oil and wear debris.

AFM allows a real surface investigation of tribofilm morphology at the nanometer scale. In this study, AFM images were recorded in contact mode with a V-shaped Si3N4 cantilever. To ensure consistency, the same probe was used for scanning each sample and the specified resolution in the normal direction lm. It is unlikely that the AFM tip would damage the surface because this contact force level is extremely low compared with contacting force during the friction tests and the expected mechanical properties of the tribofilm.

2.4 Pin-on-V block type friction tester (the FALEX tester)

The anti-seizure property was evaluated by using a pin-on-V block type friction tester (the FALEX tester) as shown in Fig. 3. To test pieces mimicking a real machine, with the pin revolving at a constant speed (0.096 m/s), the load added to the V block was gradually increased until it reached the maximum level of 10,000 N. The friction force was monitored while the load was being increased, and the load at which the friction force suddenly increased was deemed to be a seizure load. This test implies that using a greater load results in a better anti-seizure property for the test oil.

2.5 Chain box tester

A variator, contain chain and pulley, torque was evaluated by using a chain box tester as shown in Fig. 4.

2.6 Low velocity friction apparatus (LVFA)

Low velocity friction apparatus (LVFA) based upon JASO M349 was used for anti-shudder properties for lock-up clutch composed of friction plate and steel plate. This test as shown in Fig. 5 is widely used for evaluating friction behavior for the wet clutch...
system in the transmissions. The friction coefficient between the friction plate and steel plate was continuously recorded with decreasing sliding speed from 1.5 to 0 m/s at a constant pressure of 1.0 MPa. Fluids showing a positive μ-V curve which means that the friction coefficient increases with sliding speed would be able to prevent uncomfortable vibration which is called shudder phenomenon.

3 Results and discussion

3.1 Evaluation of metal friction coefficients

When examining a chain CVT, the relative sliding between the chain and pulley, which it the area that serves as the power transmission portion, gradually increases as the input torque increases. Because a chain CVT transmits power between the chain and the pin and pulleys, CVTFs is required to have a higher metal friction coefficient.

This type of tester is widely used for conducting evaluations. Figure 6 shows the results. The developed oil contains a calcium detergent and a boron type dispersant to increase the coefficient beyond that of market chain CVTFs.

![Image](http://www.tribology.jp/)

**Fig. 5** Schematic view of

![Image](http://www.tribology.jp/)

**Fig. 6** Results of block on ring test

In general, the thickness of the additive film generated by friction is only several tens of nanometer. Thus, it is difficult to evaluate the nano structure directly. AFM was used, and the topographic image of the surface was observed at the nanometer scale. The AFM analysis technology employs a probe attached to the cantilever that is either attracted to or repelled by the sample surface. Applying the principle that the mutual action (attraction, repulsion) between the probe and the sample surface abruptly increases or decreases, it becomes possible to observe the surface image of the friction surface at the nanometer scale [7].

![Image](http://www.tribology.jp/)

**Fig. 7** AFM photograph (low friction)

![Image](http://www.tribology.jp/)

**Fig. 8** AFM photograph (high friction)

Figures 7 and 8 are photographs of wear scars on test pieces taken using AFM after the block on ring test. The sample with a low friction coefficient has a smooth appearance (Fig. 7), while on the sample with high friction coefficient small islands were observed (Fig. 8). It is supposed that those islands promote a shift from the fluid lubrication area to the boundary lubrication area, contributing to a higher friction coefficient [8].

3.2 Evaluation of anti-seizure property

One of the primary performance requirements of chain CVTFs is that the friction coefficient between the metals of the chain and pulley must be high. In addition, chain CVTFs must also work with the other lubricated parts. Along with the high friction between metals, the anti-seizure property of the oil solution is also important because the chain CVTs has a single point of contact between the pulleys and the pin, and thus has higher surface pressure compared to belt CVTs, which have a linear contact. Thus, CVTFs for chain CVT is required to have high anti-seizure property.

![Image](http://www.tribology.jp/)

**Fig. 9** FALEX test results
Figure 9 shows the results of the test. The friction force was monitored while the load was being increased, and the load at which the friction force suddenly increased was deemed to be a seizure load.

The developed oil achieved high anti-seize property because it contained a sulfur-phosphorus extreme pressure agent, which provides excellent extreme pressure properties.

When using the developed oil for the test chain CVTs, post-test surface analysis of the test pieces using. We examined the correlation of the anti-seizure property and friction surfaces by using the information about the composition inside the lubrication film, which was obtained by using analysis methods that employ beams, such as electron probe micro analysis (EPMA) showed the presence of phosphorus and sulfur all over the surface, as can be seen in Fig. 10. It is supposed that formation of such a stable phosphorus and sulfur film resulted in excellent anti-seize property.

3.3 Chain box tester
This consisted only of the pulleys and the chain CVTs in order to measure torque capacity. It enabled us to successfully measure the torque capacity of lubricants with high precision. Figure 11 shows the torque capacity limits as measure with the device. The developed oil was determined to have increased torque capacity (by 10% relative to the market oil).

3.4 Anti-shudder property for lock-up clutch
Figure 12 shows anti-shudder property on test oils evaluated at 120°C by using LVFA. Time until the μ ratio (μ1/μ50) - a general index of judder resistance in durability tests - exceeded the criteria, achieving better than 600 hours, indicating better durability than market belt CVTF. The chain CVT developed oil is better anti-shudder property than the belt CVT market oil.

Optimized friction modifiers (FMs) were formulated to provide satisfactory friction properties for the clutches.

4 Conclusions
In this study, the developed chain CVTFs must be able to produce a higher metal-metal friction coefficient, an excellent anti-seize property and good anti-shudder property for lock-up clutch. Lubricant additives such as anti-wear additive, detergent, dispersant and friction modifiers were optimized for improving these performance of chain CVTs. Compared to market chain CVTF, the developed oil had lower viscosity, a higher metal friction coefficient, and higher clutch transmission capacity, while its anti-seizure property was comparable to that of market chain CVTF. As to higher metal friction coefficient, subtle projections were observed on friction surface by atomic force microscopy (AFM). It is supposed that those projections promote a shift from the fluid lubrication area to the boundary lubrication area, contributing to a higher friction coefficient. The developed oil containing multifarious additives demonstrated 10% higher torque capacity compared with a commercial CVTF.

References