

Development of Low-friction Manual Transmission Fluid

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ABSTRACT

Efforts have been made for some time to lower the viscosity of automotive lubricants as a way to improve fuel economy. Manual transmission fluid (MTF) in particular is expected to increase product appeal by enhancing shift feel at low temperatures. Various studies have also been conducted to lower the viscosity of lubricating oil.

The authors of this study optimized the base oil blend and Viscosity Index Improvers (VII), which are the constituent elements of MTF, with the objective of reducing viscosity at low temperatures without lowering durability at high oil temperatures, which is an issue when attempting to lower the lubricating oil viscosity. The results confirmed that the new oil reduces friction in terms of temperature conversion by 10 °C, compared to that of the current oil, and effectively enhances shift feel at low temperatures. The developed oil was also confirmed to have durability equivalent to that of the current oil, even at high oil temperatures.

1. Introduction

In recent years, as measures for responding to environmental issues have gained public attention, the enhancement of fuel consumption in automobiles, designed to reduce CO₂ emissions, has become a major issue. In line with this, there has been increased demand for drive train lubricating oils that help enhance fuel economy performance^{(1)–(3)}. With manual transmissions (MT), there are several related issues. One is an increase in shift load, caused by the increase in agitation and rotation resistance that accompany an increase in oil viscosity at low temperatures. Another issue is the deterioration in shift feel due, for example, to double bumping.

This means that a manual transmission fluid (MTF) with low friction performance is required.

In response to these issues, Honda developed a low viscosity MTF using high viscosity index (HVI) mineral oils. This low viscosity MTF has been in mass production since 1994. However, because of the increase in friction elements due to the increased use of multiple gears and multicone synchronizer rings, the need for a lower friction MTF has increased. Generally, lowering the viscosity of the lubricating oil is an effective way to reduce friction in the transmission. However, when the viscosity of the oil is drastically reduced, its durability at high temperatures becomes an issue^{(4),(5)}.

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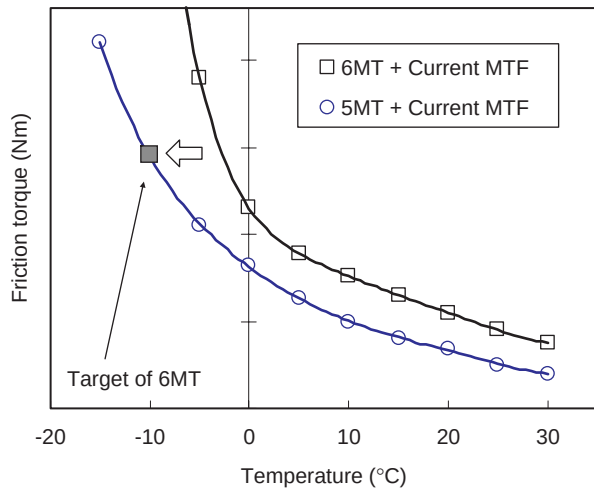


Fig. 1 Characteristic of MT friction torque

Research was conducted on developing an MTF with reduced viscosity at low temperatures that maintains its durability at high oil temperatures. This was accomplished by blending base oils and optimizing the viscosity index improvers (VII). The results are reported in this paper.

2. Development Goals

For this research, the principle focus was on maintaining the function and durability of the MT while lowering the friction of the MTF. The following development targets were set:

(1) Enhancing shift feel at low temperatures

The target of development was to provide a shift feel at an oil temperature of -10°C that was equivalent to the shift feel with the current oil at 0°C . As shown in Fig. 1, this development target was set because to attain a shift feel in a 6-speed MT, which has many friction elements, that was equivalent to that in a 5-speed MT, which has few friction elements, the amount of friction reduction necessary was slightly less than 10°C in the low temperature region of 0°C or less.

(2) Ensuring transmission function and durability

With respect to the durability of the gears and the bearings, and the function and durability of the synchronizer, which is unique to MTs, the development target was set to ensure performance equal to that provided by the current oil.

3. Method of Attaining the Targets

Based on the development targets for the function and durability of the MT, the targets for the MTF were set as shown in Table 1, and research on base oils and VIIs was carried out.

3.1. Selection of the Base Oils and VIIs

Base oils can be broadly classified into two types: synthetic oils and mineral oils. Among these, it is known that when compared in terms of identical base oil viscosities, the viscosity indexes of the synthetic oils are higher than those of the mineral oils. Esters and poly- α -olefins (PAOs), which have a structure identical to that of mineral oils, are representative synthetic oils. Because esters affect rubber components and the solubility of the performance additives, it would be difficult to use them in vehicles that have already been sold. Therefore, base oil was investigated using PAOs. Research

Table 1 MTF development target

Properties	MTF development target
Low-temperature viscosity (-10°C)	Equal to current MTF kinematic viscosity at 0°C
High-temperature viscosity (100°C)	Equal to current MTF kinematic viscosity at 100°C
Shear stability	Equal to current MTF

Table 2 Formulation of tested oil

Test oil	Base oil	Viscosity Index Improvers (VII)
Current MTF	Mineral oil High-viscosity	Low molecular weight type
A	PAO High-viscosity	High molecular weight type
B	PAO High-viscosity	Low molecular weight type
C	PAO Low-viscosity	High molecular weight type
D	PAO Low-viscosity	Low molecular weight type

was carried out using two types of VII: one with high molecular weight and the other with low molecular weight.

As shown in Table 2, test oils were made by varying the blend of the base oil and the VIIs, and formulations that fell within the temperature targets were studied. The results of the temperature characteristics for the test oils are shown in Fig. 2. Formulation C fell within the targeted viscosity range. Formulations B and D both used a low molecular weight VII. The low temperature viscosity of Formulation B deviated greatly from the target values. While Formulation D fell within the target values for low temperature viscosity, viscosity at high temperatures decreased. Formulation A did not satisfy any of the target values.

Shear stability was also confirmed for the above formulations. The fluctuation rates for viscosity during the shear stability test are shown in Fig. 3. The shear stability tests were carried out using ultrasonic tests. Only Formulation D fell into the target area for shear. Formulation C, which satisfied the viscosity target in Fig. 2, exhibited the greatest viscosity fluctuation, and did not satisfy the target values. Formulations B and A also did not satisfy the target values. Formulations A and C, which exhibited high viscosity

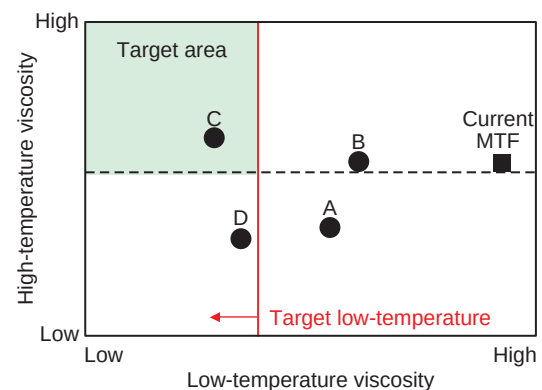


Fig. 2 Viscosity characteristics of tested oil

fluctuation due to shear, used high molecular weight VIIs, and from these results it can be understood that the reduction in viscosity can be lessened by using a low molecular weight VII. When considering lubrication function in a drive train, an MTF that exhibits little fluctuation in viscosity over time is preferable in terms of maintaining performance. Thus, the low molecular weight VIIs were used for the formulation specifications.

It can be understood from the above results that a formulation that satisfies the target range including fluctuation in viscosity due to shear is not possible. To attain the targeted low temperature viscosity, it is necessary to use a base oil with a low viscosity and to reduce the kinematic viscosity at 100 °C with respect to the initial target. Because the development target for an MTF at high temperatures was to achieve a durability equivalent to that of the current MTF, it was decided to examine a procedure in which durability would not deteriorate even when the kinematic viscosity at 100 °C was reduced. A low viscosity base oil and a low molecular weight VII were used as a base for this procedure. As shown in Fig. 4, when selecting low viscosity base oils, there are mineral oils, such as HVI mineral oils, that have viscosity indexes equivalent to those of PAOs. Considering availability and cost, investigation of the base oils was carried out using mineral oils.

3.2. Setting High Temperature Durability Targets

Although the development target at high temperatures was to maintain durability equivalent to the present durability, reducing the kinematic viscosity at high temperatures may shorten the fatigue life of gears and bearings. Therefore, in the present research, durability was evaluated in terms of gear fatigue life.

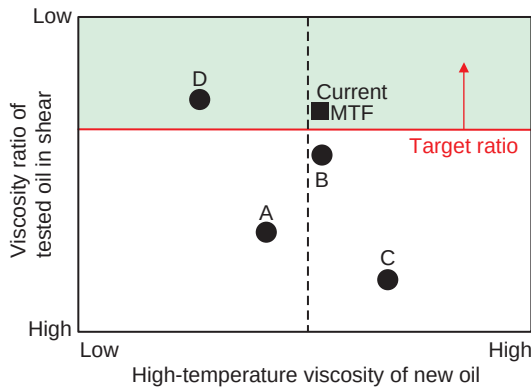


Fig. 3 Viscosity decrease after shear test

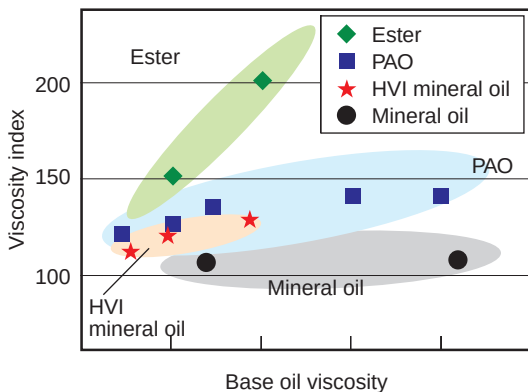


Fig. 4 Viscosity index characteristics with differences in base oil viscosity

3.3. The Mechanism of Gear Fatigue Life

One form of damage to a gear is pitting, and pitting occurrence life serves as a measure for evaluating fatigue life. There are various theories that explain the mechanism behind pitting. In the oil penetration theory⁽⁶⁾, as shown in Fig. 5, oil pockets that form a closed system occur between two surfaces when two gears that have fine asperities mesh. In this situation, the oil penetrates into micro-cracks present in the gear surface, the cracks propagate due to the high oil pressure generated when the gears mesh, and finally surface peel, that is, pitting, occurs.

Therefore, in order to extend the pitting life, it is thought that interposing an oil film to relatively reduce metal-to-metal contact, and suppressing the propagation of micro-cracks are important. Based on the above idea, parameter studies were carried out.

3.4. Development and Testing of Gear Durability

To help ensure the durability of a gear, the influence of the viscosity of the base oil and of the high viscosity base oil blend were clarified.

The IAE gear tester shown in Fig. 6 was used to test gear durability, and the durability was evaluated in terms of time until

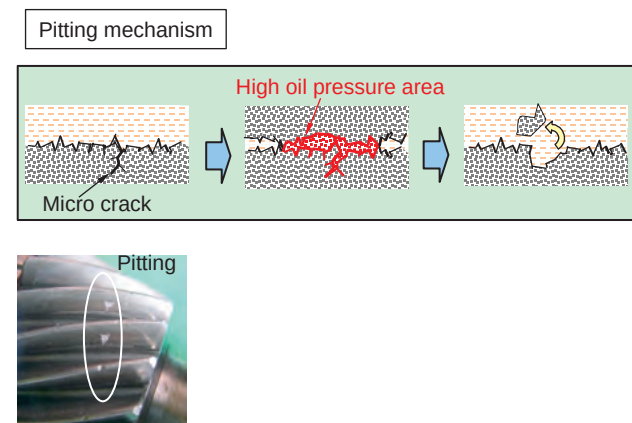


Fig. 5 Mechanism of pitting on gear

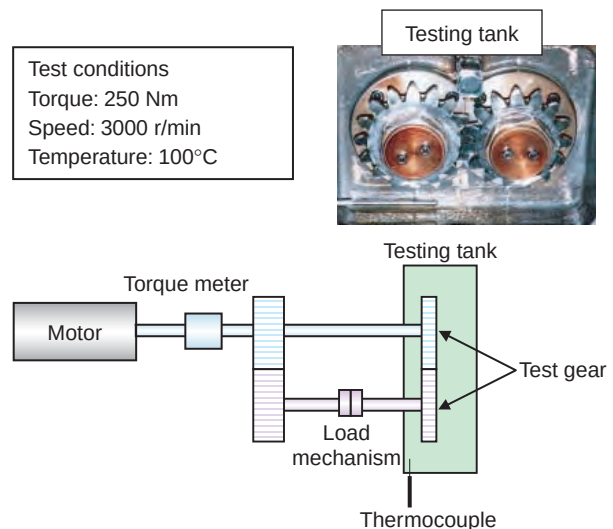


Fig. 6 IAE gear tester and durability test conditions

Table 3 Test piece specifications for durability test

	Current T/P	New T/P
Number of teeth drive/driven	15/16	30/32
Module	5.00	2.65
Face width (mm)	5.2	12.7
Material	SNCM415	SCr420
Heat treatment	Carburizing	Carburizing
Tooth surface finishing	Grinding	Shaving
Tooth surface PV (N/mm ² ·m/s)	9660	11900

pitting occurrence. As shown in Table. 3, a gear test piece (T/P) was specially prepared, taking into account the dimensions of an actual gear.

(1) Influence of the base oil viscosity

The durability of the gears was confirmed for test oils E, F, and G, which have the same kinematic viscosity as the product, by varying the base oil viscosity using a single grade HVI mineral oil formulation. As a result, it was understood that the fatigue life of the gear was extended as the base oil viscosity increased (Fig. 7).

(2) Influence of a high viscosity base oil blend

Test oil H was a blend of high viscosity base oils and had the same base oil viscosity and product kinematic viscosity as test oil G, which was a 100% HVI mineral oil. Both test oils were used to examine the durability life of the gear, and it was found that the test oil H extended pitting life (Fig. 7).

This method of blending high viscosity base oils is widely and empirically known. There have been a variety of reports about the mechanism by which it works^{(7),(8)}, and in fact it is thought that depending on various conditions, multiple phenomena are complexly interlinked. Under these circumstances, as shown in Fig. 8, we considered that because the oil film is ensured due to the three-dimensional structure of the high viscosity base oil, the number of contacts of micro-structures between surfaces that accompany sliding is reduced.

From the results of the above tests, a base oil viscosity that could maintain durability was set by preparing a high viscosity base oil while setting the base oil viscosity to the highest possible value that satisfied the low temperature viscosity.

3.5. Results of Confirming High Temperature Durability of the Developed MTF

The high temperature durability of the low viscosity MTF formulated based on the results of the tests described above was compared to the current MTF, and confirmed. The results are shown in Fig. 9. The developed MTF has a life equivalent to the pitting occurrence life of the current MTF, and a duration life equivalent to current oils was obtained even after lowering the viscosity.

In addition, duration testing of a gear was carried out for the MTF recovered after completing the duration bench test using a transmission. As a result, it was confirmed that the durability was 1.5 times the current oil degradation life, and was better than current oils after duration.

It was thus confirmed that the developed MTF is a formulation that helps ensure an oil film that does not reduce the durability even at a low viscosity.

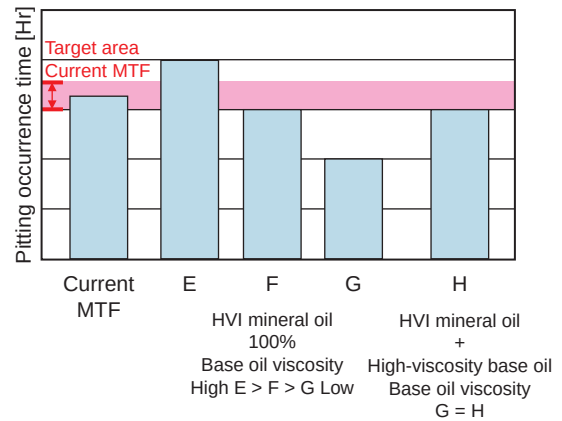
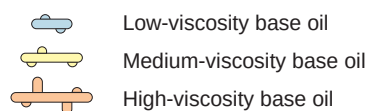


Fig. 7 Pitting durability characteristics by different oil specifications

Molecular structure image



Oil film performance

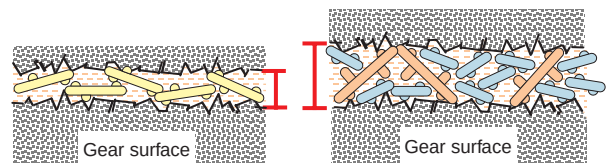


Fig. 8 Mechanism of oil film performance enhancement

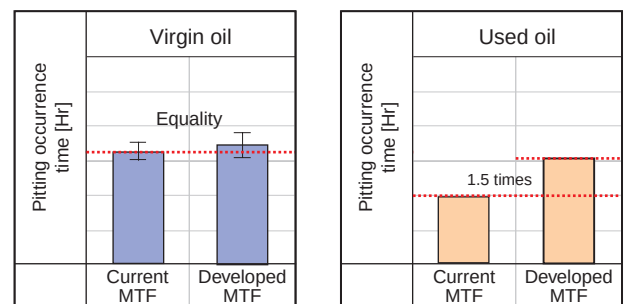


Fig. 9 Comparison of pitting durability by MTF

4. Transmission Test Results

4.1. Friction Reduction Effect

By lowering the viscosity, agitation resistance in the transmission was reduced, and a reduction in friction torque can be expected.

The effect of reducing friction during low temperatures by reducing the viscosity of the developed oil was confirmed by a bench test using a compact vehicle-class 6-speed MT. Under test conditions of 25 km/h speed, no-load, and neutral gear, the change in friction torque with respect to the transmission oil temperature

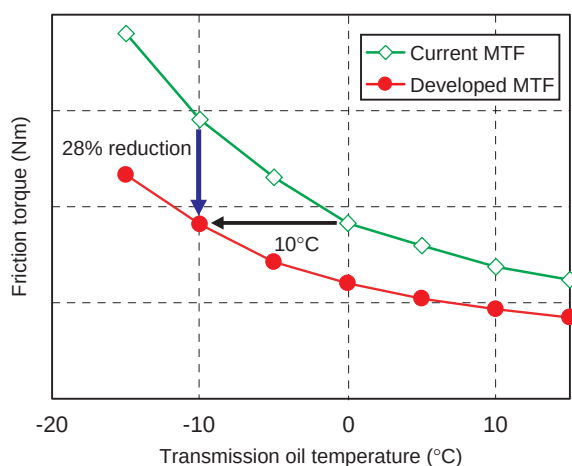


Fig. 10 Comparison of transmission friction torque

was measured. The results of the measurement are shown in Fig. 10. The developed oil was compared to the current oil, and a 28% reduction in friction torque and a friction reduction effect of about 10 °C in terms of the oil temperature were confirmed.

4.2. Shift Feel Enhancement

In MT, an increase in friction torque due to an increase in viscosity at low temperatures may lead to a reduction in the double bump feel and an increase in shift operation load. These are factors related to a deterioration of shift feel.

The effect of enhancing shift feel by lowering the viscosity of the developed oil was confirmed in a compact vehicle-class 6-speed MT vehicle. In the test conditions, the speed was fixed at 20 km/h, and the double bump load when shifting from first speed to second speed and shift operating load when shifting from second speed to first speed were measured.

As a result, in comparison to the current oil, it was confirmed that for the developed oil, at 0 °C, the double bump load was reduced by 18%, the shift operating load was reduced by 15%, and a reduction effect of about 10 °C in terms of oil temperature was confirmed.

4.3. Durability at High Temperature

Durability at high temperatures was the main issue when lowering the viscosity of the lubricating oil. In addition to the evaluation of the gear unit described above, durability evaluation using a transmission was carried out. It was confirmed that the newly developed MTF attains characteristics that are equivalent to or better than the current oils, satisfies in-house standards for the metal fatigue life of the gear and bearings, and has sufficient durability under field conditions.

In addition, in relation to the synchronizer ring, which is an important structural element unique to MTs, it was confirmed that the influence on synchronization performance and friction characteristics equals those of the current oil.

5. Conclusion

- (1) By blending high viscosity base oils with low viscosity base oils and optimizing the VIIs, durability at high temperatures was achieved and the viscosity was lowered at low temperatures.

- (2) The results confirmed that at 0 °C the friction torque in terms of temperature conversion was reduced by 10 °C in comparison to the current oil, and thereby the shift feel was enhanced.
- (3) It was confirmed by the results of unit testing and engine testing that the durability at high temperatures, which is an issue when lowering the viscosity, maintained a performance equal to the current oil.

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