

Development of a Long Life Continuously Variable Transmission Fluid

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ABSTRACT

With the purposes of making the maintenance interval of continuously variable transmission (CVT) fluid as long as that of automatic transmission (AT) vehicles and of making its use common to AT vehicles, an ester friction modifier and high FW amide were used to develop a fluid that is optimally adjusted to friction characteristics by means of a metallic detergent. This fluid has at least 4 times the longevity of current products with respect to friction characteristics.

The initial vehicle quality such as the shift quality of AT vehicles, which is affected by the friction characteristics of a wet clutch transmission, and acceleration smoothness from stop of CVT vehicles are maintained by this new fluid, which has made it possible to extend the maintenance intervals of CVT vehicles. Also, the extended maintenance schedule has occasioned improved convenience for the user and contributed to reduction in the amount of liquid waste disposal because of the reduced frequency of fluid change. Therefore, it is expected that this new fluid will contribute to the prevention of pollution of the global environment.

1. Introduction

Automobile development has long been focused on the satisfaction of demands for both performance and environmental protection, together with the goals of more economical use of fuel and resources, as well as higher quality. Against this background, the automatic transmission fluid (ATF) used in automatic transmission vehicles has been the subject of continuous research in the attempt to improve friction characteristics, low-temperature viscosity characteristics, and oxidation stability.⁽¹⁾⁻⁽⁶⁾

Fig. 1 illustrates the progress of research into the improvement of automatic transmission fluid.

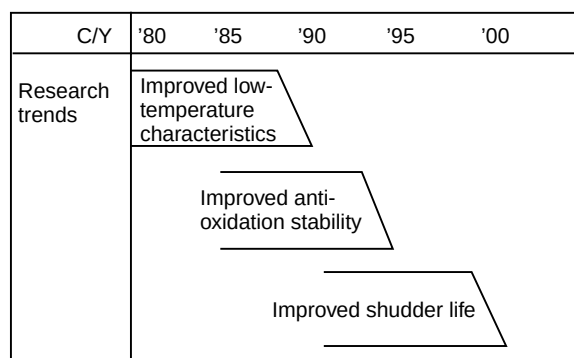


Fig.1 Research trends for ATF

On the other hand, global concerns for the protection of the environment have led to demands for the reduction in the amount of oils and fluids discarded, and the desire to respond better to increasing user needs have led to calls for longer service lifetimes for the various oils and fluids used in automobiles.

In response to such social concerns and the need to enhance the commercial competitiveness of continuously variable transmission (CVT) vehicles, we have engaged in the development of a new continuously variable transmission fluid (CVTF) for such CVT vehicles. Our aim has been to improve vehicle performance characteristics, including the shift quality of conventional automatic transmission vehicles, and the acceleration smoothness from start of vehicles with continuously variable transmissions.

In the development project discussed here, we analyzed the mechanism of deterioration whereby friction characteristics deteriorated in the start clutch of CVT vehicles as a result of the use of automatic transmission fluid. To counter such deterioration, we worked to develop a friction modifier that led to a means of extending the service life of the fluid. Further, we studied how that fluid might be adopted not only in CVT vehicles, but also to those with conventional automatic transmissions. By adjusting the friction characteristics that would allow application to conventional automatic transmissions, we achieved an extension of the maintenance interval of both continuously variable transmission and automatic transmission vehicles.

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2. Development Objectives

With the ultimate aim of extending the service life of automatic transmission fluid, we set the following development objectives, focusing on improving the durability of the friction characteristics (particularly μ -V values) which have an important influence on product appeal:

- (1) To improve the durability of μ -V characteristics by a factor of 4 times or more compared to current automatic transmission fluids.
- (2) To provide the fluid friction characteristics usable in conventional automatic transmission vehicles.
- (3) To maintain low-temperature viscosity characteristics, anti-oxidation stability, and abrasion resistance performance at or above levels currently available in automatic transmission fluids.

3. Maintenance Intervals for Continuously Variable Transmission and Automatic Transmission Vehicles

Fig. 2 displays a comparison of current maintenance intervals for continuously variable transmission and automatic transmission (AT) vehicles commercially available in Japan.

As indicated by this chart, the maintenance interval for CVT vehicles is set lower than that for conventional AT vehicles.

One reason for the shorter maintenance interval for CVT vehicles is the fact that while automatic transmissions achieve a power-transmission efficiency of around 95%, the efficiency of continuously variable transmissions is only around 85%, meaning that a range exists within which efficiency is lower than with conventional automatic transmissions under conditions of a high stable speed. This lower efficiency produces higher fluid temperatures, thus adversely affecting the working life of the fluid.

As a result, use over long periods of time results in a deterioration of the friction characteristics of the automatic transmission fluid, leading to the potential for a lowering of the product value of CVT vehicles, and thus necessitating the setting of a routine maintenance schedule with shorter intervals.

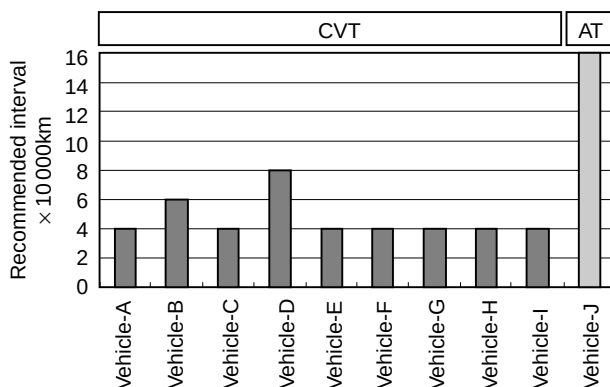


Fig.2 Maintenance interval recommended in Japan

4. Analysis of Deterioration of Friction Characteristics

In order to study the factors leading to the deterioration of friction characteristics over long periods of use, a vehicle endurance test was performed followed by an analysis of the vehicle's oil, in an effort to study ways of extending life.

4.1. Analysis of the Deterioration of Friction Characteristics

Fig. 3 shows the results of analysis of the friction characteristics of transmission fluid after a vehicle endurance test. As demonstrated on the chart of friction characteristics, the μ -V characteristics, which are measured in the low sliding velocity range, change over the course of the vehicle endurance test. The results shown here are the actual measurements of μ -V characteristics resulting from the combination of the automatic transmission fluid and wet clutch material recovered from the vehicle following the endurance test. The friction characteristics prior to the test in general demonstrate an inclination (upslope), but following the test, the μ -V characteristics of the aged material products indicate a down sloping or declination.

Specifically, when comparing the ratios of the two friction coefficients at the sliding velocities 2 rpm and 50 rpm (μ ratio: μ_2 / μ_{50}), the μ ratio of the new product (μ_2 / μ_{50}) is 0.92 and the μ ratio of the deteriorated product (μ_2 / μ_{50}) is 1.1, indicating that as the μ -V characteristics deteriorate, the μ ratio grows larger (greater than 1.0).

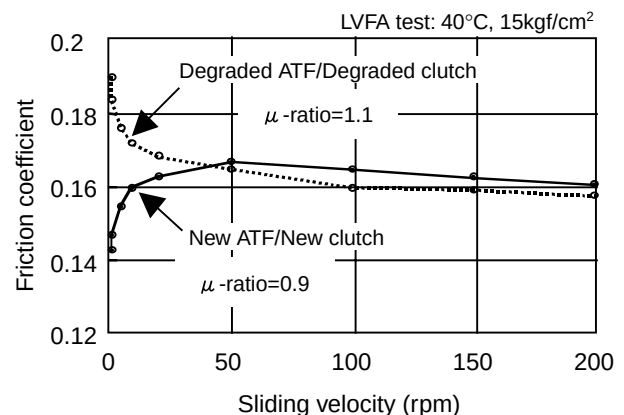
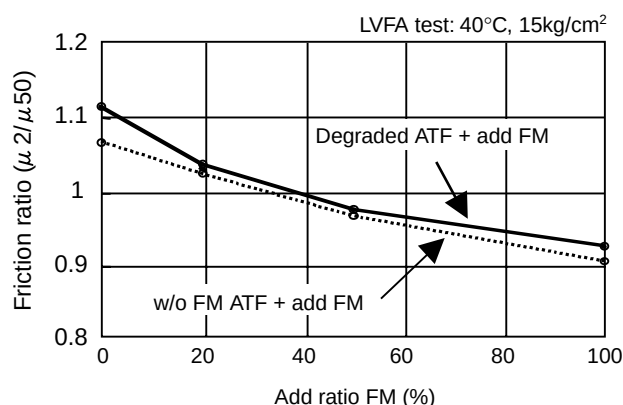


Fig.3 Friction characteristics of degraded ATF

4.2. Analysis of Deterioration Factors

Next, in order to make an analysis of factors involved in deterioration, we investigated the μ -V characteristics when 20%, 40%, 60% and 100% of the amount of friction modifier added to automatic transmission fluid was added to non-additive fluid (fluid to which no friction modifier had earlier been added), and the used fluid. The results are shown in Fig. 4. As friction modifier was added to the non-additive fluid and to the used oil, both came to produce the same kind of μ ratio as the new automatic transmission fluid with its additives.

From these facts, it became clear that the deterioration

Fig.4 Relationship of μ -ratio and FM

of friction characteristics was caused by reduced performance of the friction modifier added to the fluid.

5. Extending the Life of Friction Characteristics

Based on the understanding gained in the previously described factor analysis, we next studied how to extend the service life of the friction modifiers.

5.1. Oxidation and Friction Modifiers

First, we performed a study to find friction modifiers whose products would still demonstrate high friction characteristics even when oxidized.

Conventional carboxylic acid additives perform well at controlling friction characteristics, but they are also known for the friction performance they bring about as the result of oxidation reactions. In contrast, as indicated in Fig. 5, the Indiana Staring Oxidation Test (ISOT) demonstrates that ester additives maintain friction characteristics for more than twice as long as carboxylic acid additives.

In order to clarify the factors behind these results, we studied the heat-degradation products of oil treated with an ester friction modifier and detected carboxylic acid with the same structure as that possessed by carboxylic acid friction modifiers. From this fact, we deduced that the thermal cracking substance of ester additives may also function as friction modifiers.

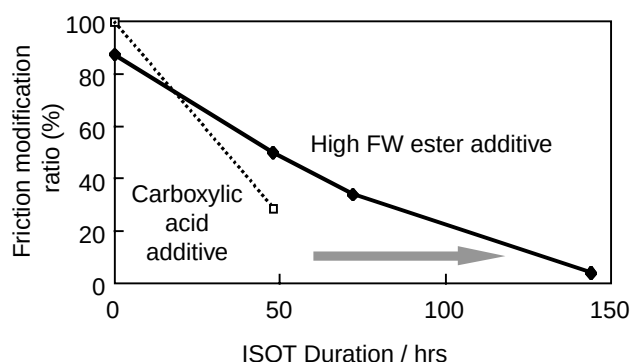


Fig.5 Durability of friction modification

5.2. Slow-Oxidizing Additives

Amide radicals are compounds produced as the result of the acid-base reaction between amines and carboxylic acid. While demonstrating lower polarity and adsorption than the group's amines and carboxylic acid, they have low reactivity since they are produced through a neutralizing reaction. As a result, they have less ability to modify friction characteristics, but are able to maintain those friction characteristics for an extended period of time.

We thereupon measured these radicals' life-extending properties by means of a part heating deterioration test apparatus equipped with a local heater as shown in Fig. 6.

The results of the test are shown in Fig. 7.

From our test we learned that of all the additives considered, the high-polymer amide compound possessed the greatest ability to extend longevity, extending the life some two times longer than conventional carboxylic acid additives.

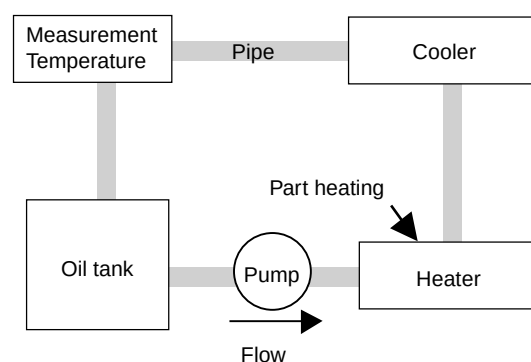


Fig.6 Part heating deterioration test device

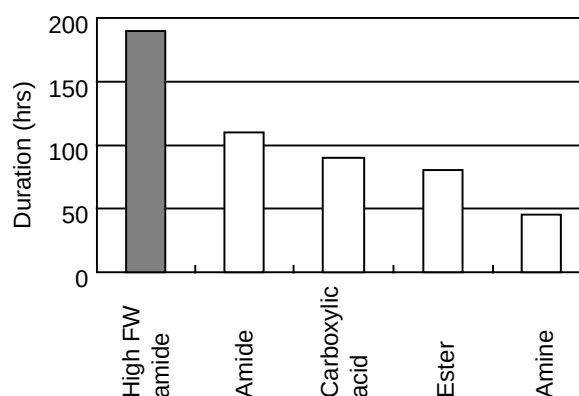


Fig.7 Durability of friction modification

6. Optimization of Friction Characteristics

The foregoing studies oriented us to the proper direction necessary for achieving our goal of anti-judder life, with the result that we now turned our attention to studying the optimum formulation of a friction modifier which would satisfy our friction characteristics, including application to conventional automatic transmission requirements.

6.1. Modification of Friction Characteristics

While attempting to achieve our goal of extended life by addition of a friction modifier, we discovered that the static friction coefficient μ_s , an index of transmission torque capacity, was lower than that produced with conventional automatic transmission fluid.

As a result, we reconsidered the composition of additives for automatic transmission fluid. We focused on the fact that in general, lowering the amount of friction modifier raises the μ_s , but since that method would not permit us to reach our goal of anti-judder life, we considered how to formulate an additive which would raise the μ_s while minimizing any fluctuations in friction modifier. An example of our formulation investigation procedure is shown in Table 1.

The results of our compounds and their friction characteristics are shown in Fig. 8.

The horizontal axis indicates the μ ratio (μ_0/μ_d), a general index of product appeal when used with a wet clutch, while the vertical axis indicates the wet clutch's transmission torque capacity, μ_s .

Compared to conventional automatic transmission fluid, prototype B has a lower friction ratio (μ_0/μ_d), thus indicating higher product appeal, but the μ_s value is also lower, thus giving it lower transmission torque capacity.

As a result of considering the various prototype fluids as listed in Table 1, we found that adjusting the ratio of friction modifiers and metallic detergents to produce prototype D resulted in a formulation which was capable of fulfilling our desired requirements for both μ ratio and μ_s .

Table 1 Optimal additive combination and volume

Evaluation fluid	Prototype B	Prototype C	Prototype D	Prototype E
FM-A	○	○	Increase	Decrease
FM-B	○	○	Decrease	Decrease
Detergent-A	○	Increase	○	Decrease
Detergent-B	○	Decrease	○	Decrease

○ : basic

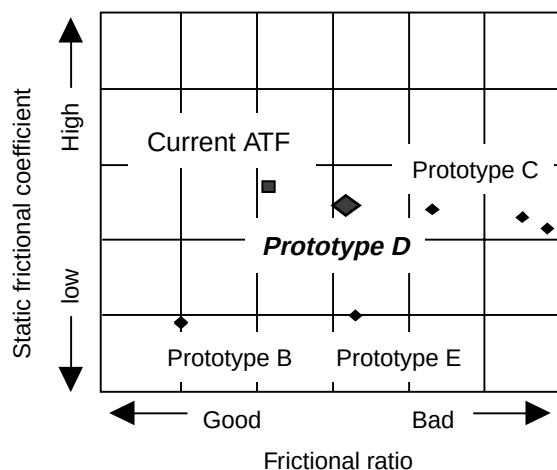


Fig.8 Friction characteristics of prototype ATF

7. Specifications for the Developed CVTF

Table 2 shows the final specifications which we arrived at based on the above studies. These specifications are for a continuously variable transmission fluid which possesses viscosity characteristics and shear stability performance equaling that of current automatic transmission fluid, while also achieving our goals of anti-judder life and friction characteristics.

8. Effects Extending the Life of Friction Characteristics

8.1. Results of Bench Evaluation

The newly developed continuously variable transmission fluid was used in an anti-judder life evaluation test using the start clutch from a continuously variable transmission automobile. The bench test conditions are shown in Table 3. The test involved use of an actual engine and continuously variable transmission, adopting engine firing to measure mode operation, and checking the continuously variable transmission fluid's friction characteristics (μ -V characteristics) after each elapsed operation cycle. The results of this test are shown in Fig. 9. Compared to conventional automatic transmission fluid, the newly developed continuously variable transmission fluid demonstrated an effect of extended life represented by an approximate four-fold increase in μ -V characteristics.

Table 2 General characteristics of new CVTF

		Current ATF	New CVTF
Kinematic Viscosity cst	40°C	29.51	29.55
	100°C	7.285	7.208
Low Temp. Viscosity cp	-40°C	6800	8550
TAN	mgKOH/g	0.51	0.73
TBN	mgKOH/g	3.72	4.12
Aniline point	°C	95.2	100.7
Metal contents ppm	Ca	800	400
	Mg	—	230
	P	200	170

Table 3 Bench endurance test condition

Item		Condition
Transmission		CVT mission
Engine		1.6L SOHC
Test mode		High speed endurance mode
1 Cycle	Distance	60 km
	Av. speed	150 km/hr
	Max. speed	180 km/hr

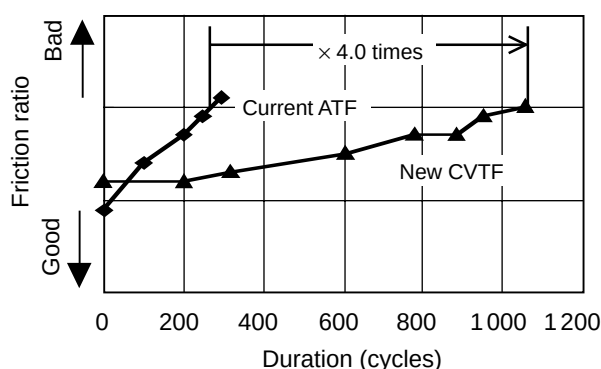


Fig.9 Bench endurance test result

8.2. Results of Road Testing

Next, an actual vehicle was used to road test the endurance effects of the fluid under conditions of high-speed driving. Utilizing a 1996 model automobile equipped with continuously variable transmission, an evaluation was performed involving high-speed driving conditions on an expressway, focusing on a measurement of μ ratio values of the used CVT fluid. As shown in Fig. 10, the results of the test indicate that the newly developed continuously variable transmission fluid achieves roughly a three-fold anti-judder life compared to current conventional automatic transmission fluids.

In short, the newly developed continuously variable transmission fluid possesses the hoped-for effects of extended friction characteristics and applicability to conventional automatic transmission vehicles, while also allowing continuously variable transmission vehicles to be given maintenance schedules equivalent to those for conventional automatic transmissions.

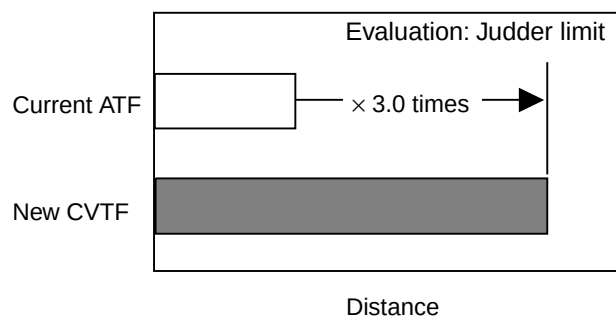


Fig.10 Vehicle endurance test result

9. Conclusions

The continuously variable transmission fluid development project discussed here achieved the following goals:

- (1) clarified that the cause of deterioration of automatic transmission fluid friction characteristics is the degraded performance of the friction modifier due to oxidation;
- (2) extension of the life of friction characteristics, to a

maximum 4 times can be achieved by a compound additive formulated from ester friction modifiers with excellent heat-resistance, and high-polymer amides;

- (3) by adjusting the formula of friction modifiers and metallic detergents, a continuously variable transmission fluid was produced which possesses friction characteristics equivalent to those of conventional automatic transmission fluid, and which can be applied to current automatic transmission vehicles.

Plans are being made to apply the newly developed continuously variable transmission fluid to new automobile models which will be marketed this fall. Adoption of this long-life continuously variable transmission fluid will not only improve vehicles' product appeal, but also extend their maintenance intervals, thus enhancing convenience for owners, and reducing the amount of waste fluid, to thereby contribute to lower loads being placed on the global environment.

Acknowledgments

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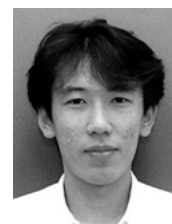
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