From macro to micro thermal performance design —Estimation of lubricant temperature inside a CVT—

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Summary

In the process of lubricating internal transmission parts, the lubricant is heated and then partially cooled by the oil cooler before being returned and recirculated through the transmission. The lubricant temperature has traditionally been estimated at the oil cooler exit, but heat is transferred to the lubricant inside the transmission, presumably raising its temperature from the cooler exit before it is supplied to the parts. This article describes a method of modeling heat transfer and estimating the lubricant temperature in the passage from the oil cooler exit to the lubricated parts. Experimental results validating this method are also presented.

1. Introduction

Transmissions have traditionally been designed for macro thermal performance in order to ensure durable quality in real-world driving. The macro design includes the temperature in the oil pan, at the oil cooler exit and other parts based on the total amount of heat generated and radiated by the transmission. However, despite managing the oil temperature based on prior experience, it was found that there were driving situations where part temperatures exceeded the envisioned levels.

In order to improve the durable quality of all the parts inside the transmission, it is necessary to estimate part temperatures from a micro perspective and not just from a macro viewpoint. As one activity for estimating part temperatures, the lubricant temperature supplied to transmission parts was estimated and the estimation was validated in this study. This article describes the validation of the method used.

2. Transmission of interest and scope of lubricant temperature estimation

The transmission selected for investigation in this study was the Jatco CVT8 (CVT8), one of JATCO's representative products. Forced lubrication to the variator was selected for investigation. Because the variator is the most heat of all the CVT parts, managing its temperature is critical. Lubrication to the variator was treated as the main lubricant flow in the lubricant circuit of interest and lubrication to each part as branch lubricant flow. The dashed lines in Fig. 1 show the flow of the lubricant as seen from the side of the transmission. Figure 2 shows the lubricant passage extracted from Fig. 1. The actual path of lubricant flow from the oil pan to the parts to be lubricated is shown in Fig. 3. The transfer of lubricant from one part to another is divided into individual sections. Section number (i) indicates the traditional scope of temperature estimation and section numbers (ii) to (v) represent the scope of interest in this study.

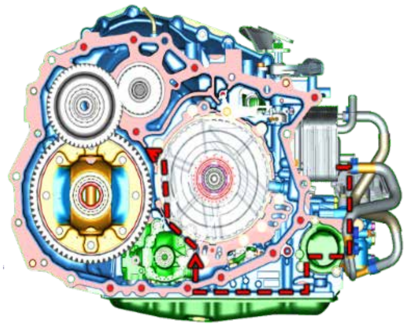

Fig. 1 Flow of lubricant in a side view of the transmission

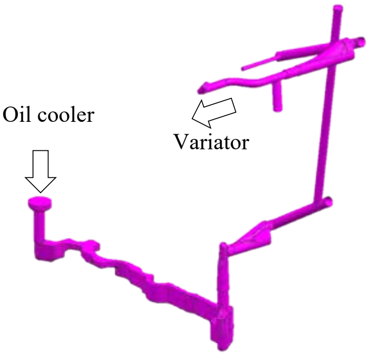

Fig. 2 Lubricant passage of CVT8

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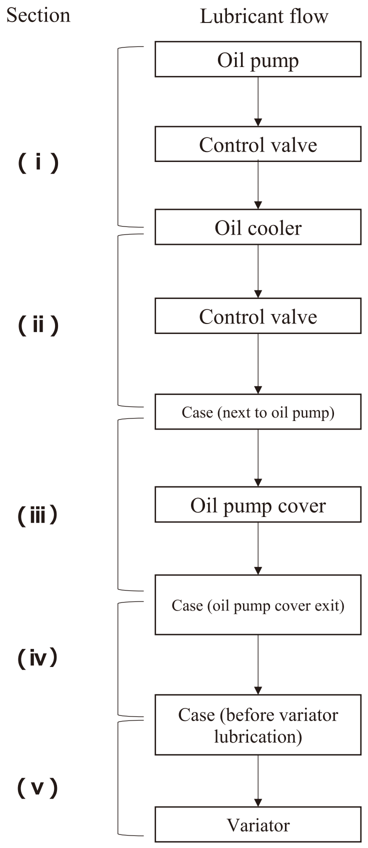

Fig. 3 Lubricant flow path and sectional divisions

3. Method of estimating lubricant temperature

In order to estimate the lubricant temperature, the change in the temperature in each section, dT, is found with the following equation.

$$\mathbf{dT} = \frac{Q}{G\times\gamma\times C} \qquad (1)$$

dT: change in lubricant temperature
G: lubricant flow rate Q: amount of heat transferred
C: specific heat of lubricant γ: lubricant density

The amount of heat transferred Q to the lubricant received in each section must also be estimated in order to estimate the lubricant temperature. To do that, the lubricant passage shown in Figs. 1 and 2 was represented in a simple configuration, and the heat transfer paths to the lubricant were modeled (Fig. 4). It was considered that heat was transferred to the lubricant in the following ways:

I. heat transfer from heat-generating parts and
II. heat transfer due to the temperature difference between the passage inner wall and lubricant.

Ways I and II were defined as follows.

I. Heat transfer from heat-generating parts

This was defined as the transfer of energy loss incurred by heat-generating parts.

$$\mathbf{Q = EnergyLoss} \qquad (2)$$

The oil pan is the heat-generating part that affects the lubricant passage in this transmission. In addition, since the lubricant passage goes through the transmission interior, it has no sections with a lower temperature than the lubricant temperature. Accordingly, it was assumed there was no heat radiation from the lubricant passage.

II. Heat transfer due to temperature difference between passage inner wall and lubricant

Assuming the flow in the lubricant passage was turbulent, heat transfer was defined using the Dittus-Boelter equation (Eq. (5)) for heat transfer of turbulent pipe flow.

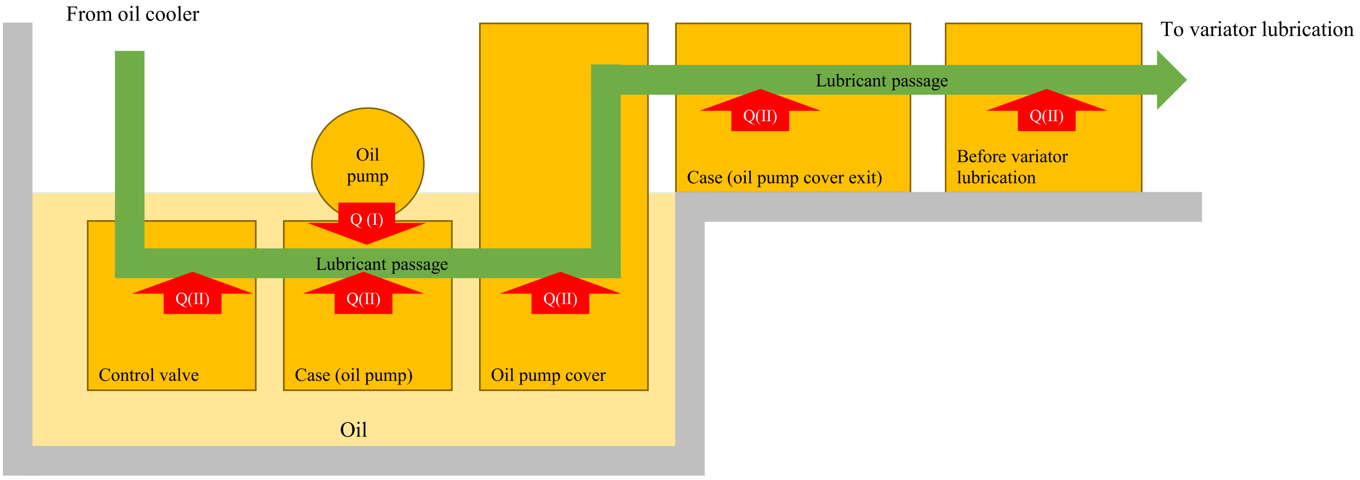

Fig. 4 Model of heat transfer to lubricant

$$\mathbf{Q} = \mathbf{A} \times \mathbf{h} \times (T_s - T_o) \tag{3}$$

$$\mathbf{h} = \frac{Nu \times \lambda}{d} \tag{4}$$

$$\mathbf{Nu} = 0.023 \times Re^{0.8} \times Pr^{0.4} \tag{5}$$

A: surface area of lubricant passage inner wall
Ts: temperature of lubricant passage inner wall
Nu: Nusselt number
d: pipe diameter
Pr: Prandtl number
h: coefficient of heat transfer
To: lubricant temperature
λ: thermal conductivity of lubricant
Re: Reynolds number

Oil remaining in the oil pan is considerably scattered by churning inside the transmission. For that reason, the temperature of the oil passage inner wall was assumed to be the same as that of the lubricant in the oil pan.

The equations defined above were applied to each section of the lubricant passage to formulate an equation for estimating the change in the lubricant temperature from the oil cooler exit until it was supplied to the variator.

4. Experimental validation

The lubricant flow rate and the temperature of each part were measured using an actual CVT, and the results were compared with the estimated change in the lubricant temperature. The factors affecting changes in the lubricant temperature are the amount of heat generated by the

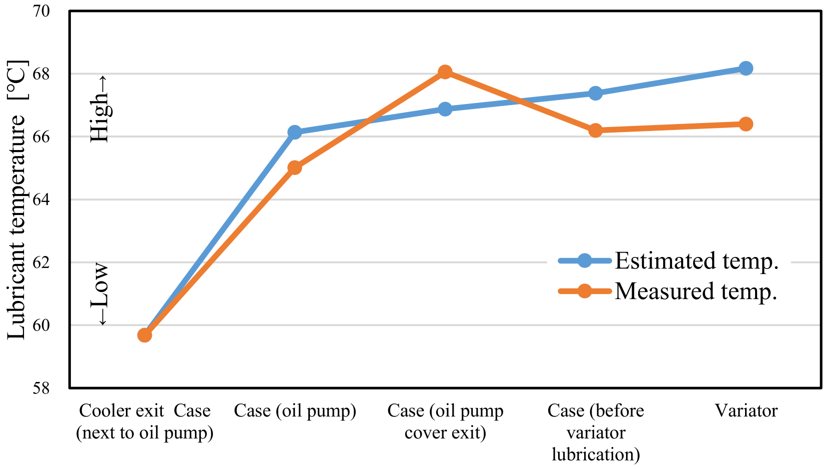

Fig. 5 Validation results

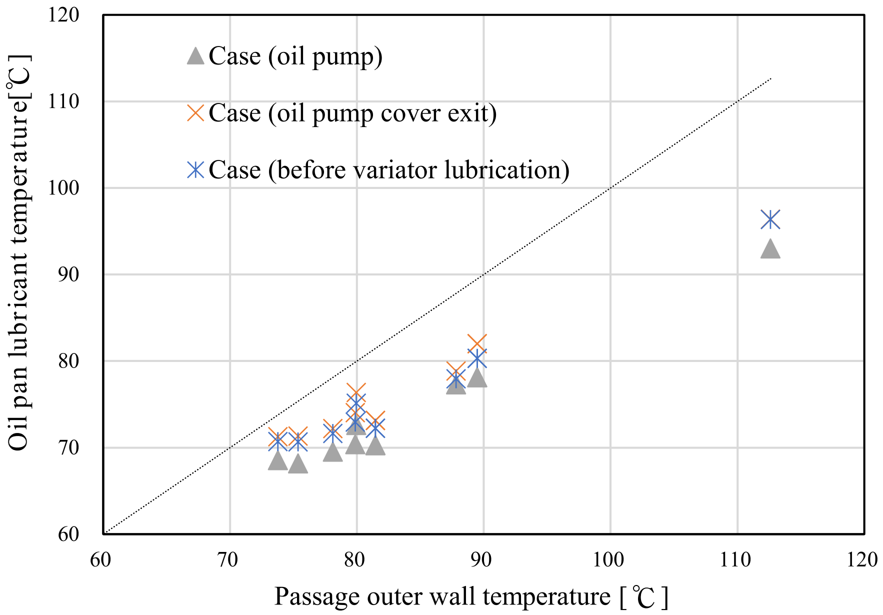

Fig. 6 Comparison of passage outer wall temperature and oil pan lubricant temperature

oil pump, the lubricant temperature in the oil pan and the lubricant flow rate. These factors were varied as the experimental conditions in the validation exercise in order to make a comparison with the estimated temperatures. The amount of heat generated by the oil pump is influenced by its rotational speed and discharge pressure.

5. Validation results

The difference between the estimated and measured temperatures for each part was a maximum of 2.4°C and a mean of ±1.0°C under each section. The oil pump displayed large heat generation in the validation exercise and the oil temperature in the oil pan was high. Figure 5 presents the experimental and estimated results for the highest rise in the lubricant temperature from the oil cooler exit to the variator under such conditions.

6. Discussion

A comparison of the measured and estimated results revealed that the lubricant temperature was often estimated higher than the actual measured temperature. As mentioned earlier, there are many places in the lubricant passage where heat is transferred to the lubricant from the passage inner wall. Among the variables in Eqs. (3) to (5) defined for heat transfer, the inner wall temperature (Ts) was assumed to be the same as the oil temperature in the oil pan. Therefore, the relationship between the passage inner wall temperature and the oil temperature in the oil pan was investigated. Because it was difficult to measure the inner wall temperature without blocking the lubricant flow, the temperature of the passage outer wall was measured. The results showed that the outer wall temperature tended to be lower than the oil pan lubricant temperature (Fig. 6).

It was thought that even places on the inner wall that were not submerged in the lubricant because of churning would have a temperature close to the oil pan lubricant temperature. However, it was found that the wall temperature was actually lower than the oil pan lubricant temperature. That difference was applied to Eqs. (1) to (5) and converted to the change in the lubricant temperature. The effect was found to be approximately 1°C. Accordingly, if the inner wall temperature was separately defined, it could further improve estimation accuracy. However, considering the resultant effect on durable quality, it was decided that the current level of accuracy within ±1.0°C was sufficient. Moreover, increasing the complexity of the estimation method would not be a good idea for its future use, so it was concluded that the present definition of the inner wall temperature should be left as it is.

7. Conclusion

Previously, macro temperature estimations were made using the overall heat generated and radiated by an entire CVT. In this study, a micro approach was taken to estimate the temperature of the lubricant supplied and the validity of this method was verified. This was undertaken as one activity for estimating the lubricant temperature at each part for the purpose of improving durable quality.

Modeling heat transfer to the lubricant made it possible to estimate the lubricant temperature to within a mean accuracy of ±1.0°C of the measured values, taking into account the passage inner wall temperature and heat-generating parts. Simplifying the equations and concept suppressed the additional volume to be studied, resulting in a method fully capable of practical application.

Since the estimation concept does not pertain uniquely to the CVT8, it can also be applied to estimate the lubricant temperature in other transmissions.

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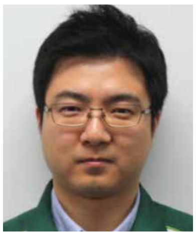

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