

# Thermal Flow Analysis of Hybrid Transaxle Surface Using Newly-Developed Heat Flux Measurement Method

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## ABSTRACT

This research developed a new measurement technology for thermal analysis of the heat radiation from a hybrid transaxle case surface to the air and improved the heat radiation performance. This heat flux measurement technology provides the method to measure heat flux without wiring of sensors. The method does not have effects of wiring on the temperature field and the flow field unlike the conventional methods. Therefore, multipoint measurement of heat flux on the case surface was enabled, and the distribution of heat flux was quantified. To measure heat flux, thermal resistances made of plastic plates were attached to the case surface and the infrared thermography was used for the temperature measurement. The preliminary examination was performed to confirm the accuracy of the thermal evaluation through heat flux measurement. The oil in the transaxle was heated and the amount of heat radiation from the case surface was measured. The input energy and heat radiation amount were compared. As a result, it was found that the measurement was accurate to be within about 13%. In addition, thermal analysis with conditions simulating an actual vehicle was performed. The surface temperature distribution and heat flux distribution were measured and results were obtained that reflected the effects of internal oil flow path layout and cooling air flow. Based on these results, locations with a large potential for improved heat radiation performance were identified and it became possible to effectively improve heat radiation performance by installing fins at those locations to enlarge the heat radiation surfaces.

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## INTRODUCTION

In order to improve the heat radiation performance of hybrid transaxles, it is effective to take measures based on the surface temperature distribution and the distribution of the amount of heat radiation from the case surface. It is necessary to measure the distribution of heat flux, or heat radiation energy per unit surface area and per unit time, to quantify the amount of heat radiation from the case surface. Until now, various heat flux sensors were proposed. For example, thermopiles [1, 2, 3, 4, 5], which consisted of thermoelectric elements connected in series, and thin-film temperature sensors [6] were used. These electrically measure the temperature difference between the surface and back side of a thin plate, or thermal resistance, which had low thermal conductivity.

However, conventional heat flux sensors required the installation of sensor wiring. The sensor wiring should be fixed on the case surface in the air flow to prevent blowing off. The sensor wiring and clamps affect the temperature field and flow field of the measuring object. Especially, if they were located on the windward side of the heat flux sensing element, their disturbing effect on the measurement would be

larger. Therefore, these are unsuitable for multipoint measurement which has many wires and clamps. To solve this issue, a heat flux measurement method without wires was developed.

With the heat flux measurement method developed in this research, thermal resistances, which were plastic plates, were attached to the case surface. The temperatures of the thermal resistance surfaces and the case surface were measured by infrared thermography to measure the heat flux without wires. The thermal resistance had a diameter of 6 mm and a thickness of 0.3 mm. Even if multiple thermal resistances were attached on the case surface for thermal analysis, they would have few side effects on the measurement, which made it possible to measure the heat flux distribution.

The thermal analysis of the hybrid transaxle was performed by using this heat flux measurement method. First, the accuracy of the thermal evaluation of the transaxle was quantified by comparing the input energy with the heat radiation amount obtained from the heat flux. Next, evaluation was conducted with conditions simulating an actual vehicle. As the measurement result of the heat flux and the case surface temperature, the locations with a large potential for improving the heat radiation performance were identified. Furthermore, fins

were installed on locations with large potential for improvement in heat radiation performance. It was confirmed that the heat radiation performance improvement effect was 2.4 times larger than that for setting up fins on other locations.

## HEAT FLUX MEASUREMENT METHOD

### Measurement Principles

Figure 1 shows the method for measuring the heat flux. Thermal resistance ( $t = 0.3$  mm) made of plastic plate was installed on the case surface, which radiated heat energy to the air, with thermally conductive double-coated adhesive tape ( $t = 0.1$  mm). The thermal resistance surface temperature  $T_1$  and the case surface temperature  $T_2$  adjacent to the thermal resistance were measured with infrared thermography. Then, the temperature  $T_3$  of the case surface at the back side of the thermal resistance was interpolated linearly from the case surface temperature  $T_2$ . If the thermal flows in one dimension in the thickness direction of the thermal resistance, the temperature difference  $\Delta T (= T_3 - T_1)$  between the temperature  $T_3$  of the case at the back side of the thermal resistance and the temperature  $T_1$  of the thermal resistance surface is proportional to the heat flux  $q$  (Fourier's Law). The heat flux  $q$  was obtained from  $\Delta T$  based on this relationship.

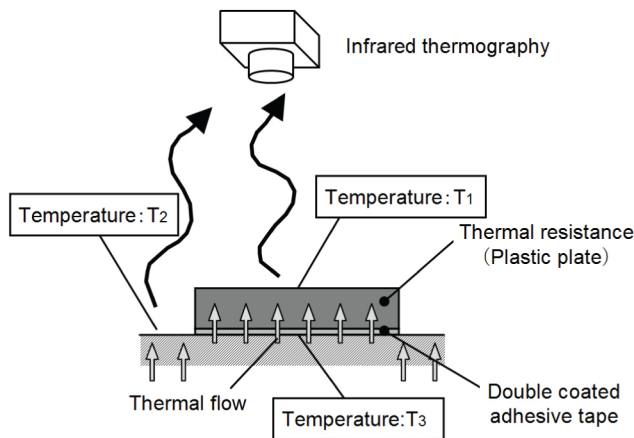


Figure 1. Measurement method

### Thermal Resistance

The specifications of the thermal resistance were determined by the perspective of securing thermostability and measurement accuracy. Table 1 shows the specifications of the thermal resistance. The material used for thermal resistance was polyimide. Polyimide has thermostability under operating temperature and its thermal conductivity is relatively low among plastic materials.

The thermal resistance should be as small as possible. The reason is that the multiple point installation of thermal resistances was required to measure heat flux distribution.

The size of the surface area measured per pixel was determined by the number of thermal image pixels (Figure 2) and the distance  $L$  between the transaxle and the infrared thermography. In this case, the distance  $L$ , where whole transaxle view came into sight, was 0.6 m and the view size of one pixel was as shown in Figure 3. Based on this, the thermal

resistance size was decided making it possible to measure the thermal resistance surface temperature with multiple pixels. There were two reasons for measuring the thermal resistance surface temperature with multiple pixels. One was to facilitate the distinction of the thermal resistance positions on the thermal images. The other was to improve the accuracy through averaging the processing of the measured values. Figure 4 shows the positional relationship between pixels and thermal resistance. The number of pixels fitted into the thermal resistance image varied with the relative positions of the pixels and thermal resistance. However, at least 4 pixels were included.

Table 1. Specification of thermal resistance

|                              |                        |
|------------------------------|------------------------|
| Material                     | Polyimide              |
| Thermal conductivity         | 0.18 W/m·K             |
| Glass-transition temperature | 250 °C                 |
| Dimensions                   | $\phi 6$ mm $t=0.3$ mm |

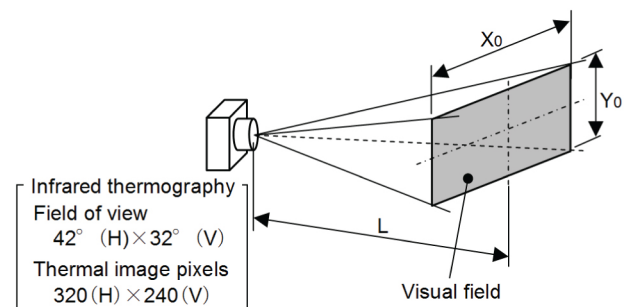


Figure 2. Specification of infrared thermography and visual field

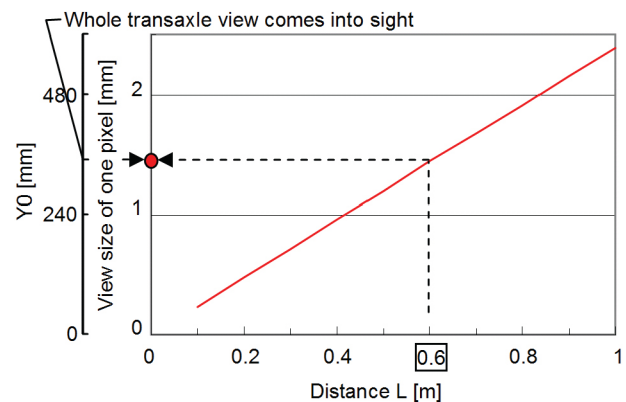


Figure 3. View size of one pixel

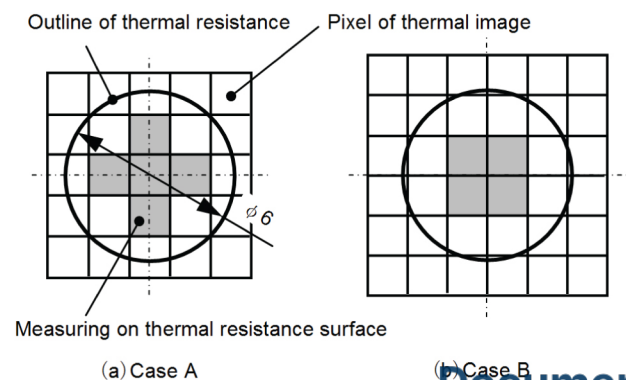


Figure 4. Pixels measuring thermal resistance surface temperature

The thickness of the thermal resistance was set to 0.3 mm from the heat flux measurement range in this study and the thermal conductivity of the thermal resistance.

### Estimating the Temperature T3

In order to obtain the heat flux from the temperature measured with infrared thermography, it was necessary to estimate the temperature T3 of the thermal resistance back side. With this method, the temperature T3 was interpolated linearly with the least-squares method from the temperature T2 of the case surface around the thermal resistance, which was measured with infrared thermography. It was noted that the case was made of aluminum which had high thermal conductivity and the surface temperature distribution in directions along the case surface was approximately linear in the range size of the thermal resistance. However, since this method could not be applied at locations where the case surface temperature had a non-linear distribution, for example at edge sections of uneven case surface and at rib boundary sections, such data was excluded from the interpolation. In order to make it easy to measure temperatures with infrared thermography, black paint with an emissivity of 0.94 was applied to the surface to give the polyimide and the case surface the same emissivity.

## CALIBRATION OF HEAT FLUX MEASUREMENT

### Calibration Method

Figures 5 and 6 show the configuration of the calibration apparatus. The apparatus formed a 26 mm width by 10 mm high rectangular closed channel and was configured to heat air from the bottom surface of the rectangular channel. The heating surface was an aluminum plate and the electric heater was installed on the surface of the aluminum plate opposite from the channel. The thermal resistance was set on the heating surface. The heat flux radiating from the heating surface to the air flowing in the rectangular channel was measured. The installation position for the thermal resistance was set 500 mm from the electric heater inlet side end. The position of thermal resistance was not affected by the entrance region, which is about 20 times the equivalent diameter of the channel cross-section, to evaluate properly. Figure 7 shows the distribution of temperature in the direction of flow on the heating surface. It could be seen that the installation position of the thermal resistance was away from the entrance region and it had no temperature gradient along the direction of flow. At the position of thermal resistance, the heat transfer along the heating surface could be ignored due to uniformity of temperature. Therefore, the heat flux  $q$  [W/m<sup>2</sup>] from the heating surface to the air was obtained by Equation (1).

$$q = \frac{W_{air}}{S}$$

(1)

Where  $W_{air}$  is the amount of heating of the air [W] and  $S$  is the heating surface area [m<sup>2</sup>].

The cover of rectangular channel had the infrared transmissive window in order to measure the temperature around the thermal resistance with infrared thermography. The window was made of germanium ( $t = 2$  mm) coated with antireflection film and transmitted the infrared wavelengths 8 to 14  $\mu$ m used in these measurements.

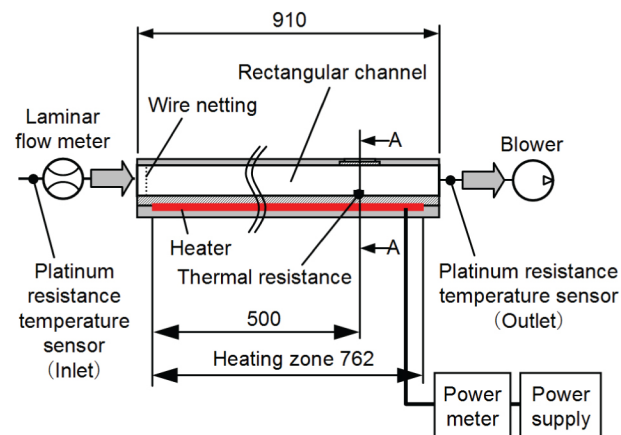


Figure 5. Experimental apparatus

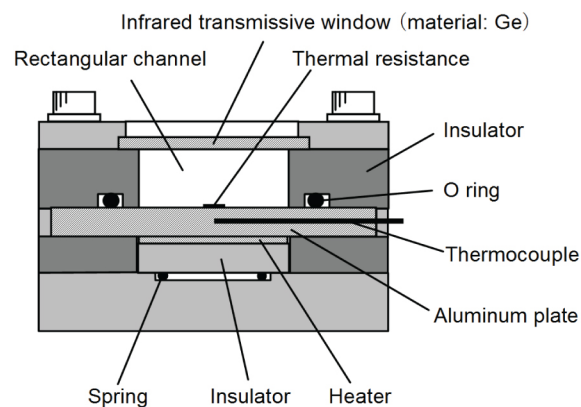


Figure 6. Cross-section view (A-A in Figure 5)

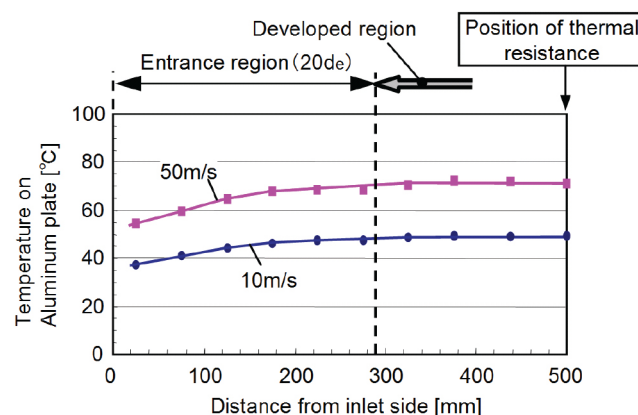


Figure 7. Temperature distribution of aluminum plate

### Results of Calibration

Figure 8 shows the results of evaluating with the thermal resistance thickness as a parameter. The horizontal axis is  $\Delta T (= T_3 - T_1)$ . The solid lines show the measured values. The broken lines show the calculated values under the assumption that thermal conduction is