

Thermal Analysis of Traction Contact Area Using a Thin-film Temperature Sensor

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ABSTRACT

The purpose of this paper is to construct the thermal analysis model by measuring and estimating the temperature at the traction contact area. For measurement of temperature, we have used a thin-film temperature sensor. For estimation of temperature, we have composed the thermal analysis model.

The thin-film temperature sensor was formed on the contact surface using a spattering device. The sensor is constituted of three layers (sensor layer, insulation layer and intermediate layer). Dimensions of the sensor were sufficiently smaller than the traction contact area. The sensor featured high specific pressure capacity and high speed responsiveness.

The thermal analysis model was mainly composed of three equations: Carslaw & Jaeger equation, Rashid & Seireg equation and heat transfer equation of shear heating in oil film. The heat transfer equation involved two models (local shear heating model at middle plane, homogeneous shear heating model).

The accuracy of the thermal analysis model was verified by two methods. First, we measured the temperature individually by using several different shapes of the sensor. Second, we measured the temperature individually by using several different insulation layers' properties (thickness and thermal conductivity). As a result, the measured and estimated temperatures agreed closely.

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1. INTRODUCTION

Recently, for reduction of environmental load and saving energy, automakers have been developing fuel-efficient vehicles. The transmission of the vehicles is required to have higher efficiency. In addition, for operating engine at high efficiency, the transmission is required to be multistage or continuous and to shift speed in wide range. For example, Toyoda, et al [1] has reported that a double cavity Half-Toroidal CVT showed an efficiency rate of 97% at the overdrive ratio and a ratio-coverage of 7.5. Clamping force, one of factor for higher efficiency operation, in the CVT should be controlled by the maximum traction coefficient estimated from input conditions. The maximum traction coefficient is the functions of temperature and pressure. The temperature - an important factor - is difficult to be measured because the measurement area is subjected to a high pressure. Miyata, et al. [2-3] has overcome the difficulties by using a thin-film sensor and has succeeded to measure the temperature of traction contact area. They have used a two

roller experimental apparatus for measurement. In addition, measurement of the temperature was compared with results from a traction numerical analysis model. They have reported that the calculation of the temperature was qualitatively in good agreement with measurement.

In this paper, we have developed the thin-film sensor to measure the temperature rise of the traction contact area. The sensor was installed on a test roller of a four-roller experimental apparatus. The accuracy of the thermal analysis model was verified by two factors (sensor shapes and insulation layer properties). As a result, we have acquired a close agreement between the estimated and measured temperature.

2. EXPERIMENTAL METHOD

2.1. Model Test Apparatus

The four-roller experimental apparatus (Fig.1) consisted of three driving rollers and one driven roller. We have

measured the temperature of the contact area between the driving and the driven roller. Slip ratio of the contact area is controlled with rotational speed of the driving and the driven roller. A contact load is determined by pressing one of driving rollers (left side roller in Fig.1). We have determined to install the thin-film sensor on the upper right roller because of its easiness of replacement. The contact shape of this apparatus was designed in agreement with that of the actual CVT. The driving roller was cylindrical form and the driven roller was crowned cylindrical form. The diameter of the driving and driven rollers was 100mm. The crowning radius was 150mm.

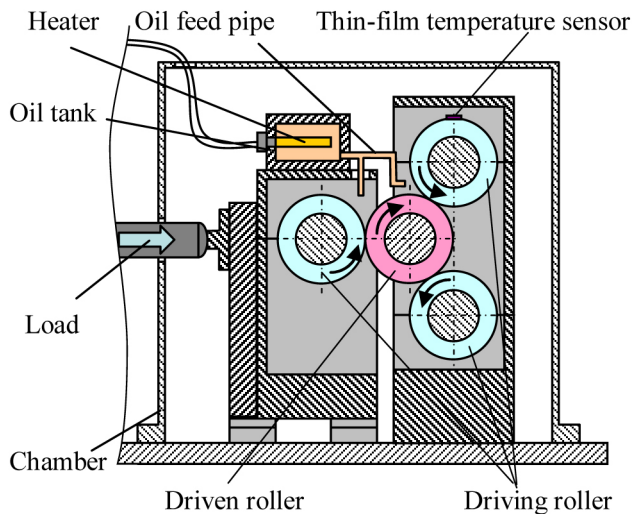


Figure 1. Schematic view of four-roller experimental apparatus

2.2. Thin-Film Temperature Sensor

Fig.2 shows the shape and structure of the thin-film temperature sensor. The sensor has been processed in three ways. First, the roller is polished similar to a mirror surface. Second, we sequentially mount intermediate layer (Ti), insulation layer (SiO_2) and sensor layer (Pt) using RF magnetron sputtering. Third, the sensor shape is formed within the boundary of $0.2\text{mm} \times 0.5\text{mm}$ by using etching treatment. The sensor has been designed smaller than the contact area at Hertzian pressure of 1GPa. In addition, a lead part (10mm $\times$ 20mm) transmitting the sensor signal has been formed around the sensor.

The thin-film temperature sensor requires greater strength for being subjected to higher pressure iteratively. In severer conditions, the load may concentrate the edge of sensor bulging from the surface resulting in destruction of the sensor. To reduce the concentrated load, the lead part is located around the sensor forming a flush surface.

The thin-film temperature sensor was required to have sufficient responsiveness for detecting the temperature rise and decline in extremely short time. Usually, the sensor is located under a protection layer for securing insulation. On

the other hand, our sensor was located for contacting the oil film directly for the high speed responsiveness. In steady operation, the oil film was generated between the sensor on the driving roller and the surface of the driven roller, and then the insulation of the sensor is secured.

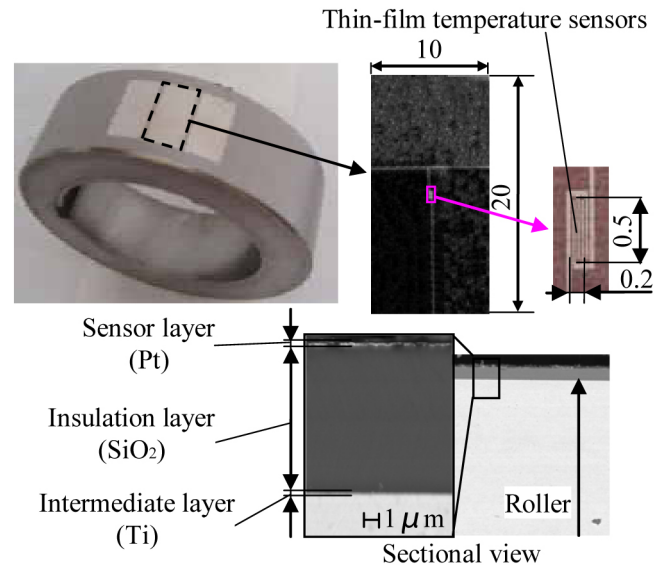


Figure 2. Overview and cross-section view of thin-film sensor

The thin-film sensor can measure the temperature because of its resistance variation proportional to the temperature. The variation of the resistance is detected by a circuit illustrated in Fig.3. The sensor signal is measured by four steps. First, a voltage is measured through the sensor part, the lead part and conductive wires by applying constant current. Second, the output of voltage is amplified primarily. Third, the output signal is transmitted through a slip ring. Fourth, the output of voltage is amplified secondary and measured. The output signal includes effects of the pressure and the strain. Therefore, the output signal is transformed into the temperature after revised. The transformation from the voltage into the temperature depends on the calibration curve prepared.

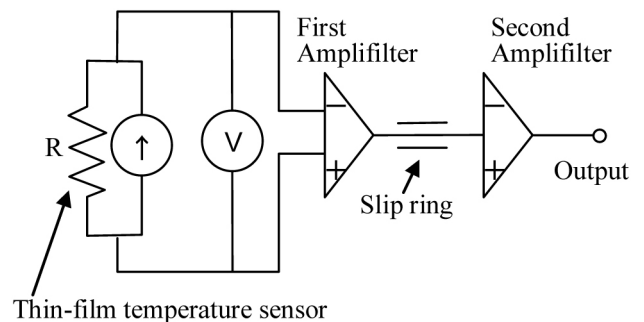


Figure 3. Resistance detection circuit