

Measurement of Oil Film Pressure in the Main Bearings of an Operating Engine Using Thin-Film Sensors

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ABSTRACT

We developed a technique to measure oil film pressure distribution in engine main bearings using thin-film pressure sensors. The sensor is 7μm in thickness, and is processed on the surface of an aluminum alloy bearing. In order to increase the durability of the sensor, a layer of MoS₂ and polyamide-imide was coated on thin-film sensors. This technique was applied to a 1.4L common-rail diesel engine operated at a maximum speed of 4,500r/min with a 100Nm full load, and the oil film pressure was monitored while the engine was operating. The measured pressure was compared with calculations based on hydrodynamic lubrication (HL) theory.

and a measurement using a thin-film sensor has been reported as one measurement method [6-14]. However, this method still has problems such as sensor durability, and there have been few examples of measurements on automotive engine bearings done at high surface pressures.

This paper describes a technique that was developed for creating a highly durable thin-film pressure sensor on the surface of an aluminum-alloy bearing, which is currently the predominant type of bearing for this application, and describes how the distribution of oil film pressure on the main bearing was measured and analyzed while the engine was operating.

INTRODUCTION

In recent years, engine power has increased while bearing size has been reduced in order to reduce friction and engine size, resulting in an increased need for optimized bearing design. The load generated on the piston by combustion is converted to a force that rotates the crankshaft via the connecting rod bearings and main bearings. During this process, the bearing is supported by an oil film that forms inside the clearance. Determining the distribution of pressure on this oil film while the engine is operating is an important issue for optimizing bearing specifications.

Many examples of analyses that are based on calculations have been reported [1-5] regarding the distribution of oil film pressure generating on the connecting rod bearing. However, because the main bearings tend to be affected by engine block deformation and crankshaft behavior, accurate calculations are difficult. Thus there are high hopes pinned on the development of measurement methods,

THIN-FILM PRESSURE SENSOR

Fig. 1 shows the cross-section of a metal bearing with a thin-film pressure sensor. After the surface of the metal bearing was polished to a mirror finish, an intermediate layer of Cr, an insulating layer of SiO₂, and a sensor layer of Cr-Al₂O₃ were sputtered one by one on to this surface. The electrical resistance of Cr-Al₂O₃ changes according to the pressure applied on it.

The sensor layer was etched to form a certain pattern, and then a protection layer (SiO₂) was added. To ensure the durability of the sensor, an overlay consisting of MoS₂ and resin was formed on the surface of the sensor as a buffer layer.

The sensor layer (Cr-Al₂O₃) has leads stretching to one axial edge of the bearing, and also has circular pressure-sensitive sections 20μm wide where they intersect the leads (see Fig. 2). The leads were made sufficiently wider than that of the pressure-sensitive section so that the resistance measured between the ends of the leads is almost equal to that of the pressure-sensitive section. The lead section extends to the side

surface of the metal bearing, and is connected to lead wires (enamel wire) on its side surface. The dimensions of the bearing including its width do not differ from those found in regular engines, and the bearing that the thin-film sensor was formed on for this measurement is one that is currently being manufactured.

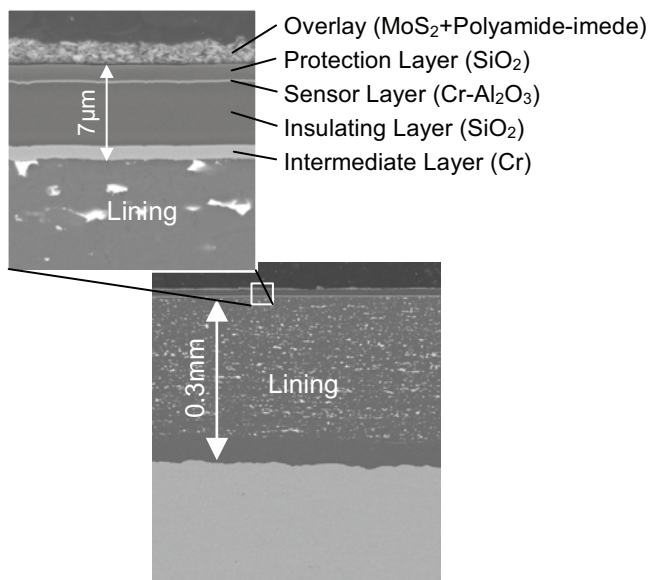


Fig. 1 Cross Section of the Thin-Film Sensor

By forming multiple pressure sensors on the surface of metal bearing as shown in Fig. 2, pressure distribution is obtained by measuring pressure on multiple spots simultaneously. Fig. 3 shows appearance of a metal bearing with seven pressure-sensitive sections formed at 2mm pitch in the axial direction at the center of the circumferential direction. Although it is not indication in the figure, a metal bearing with nine pressure-sensitive sections formed at 2mm pitch in the circumferential direction was also created.

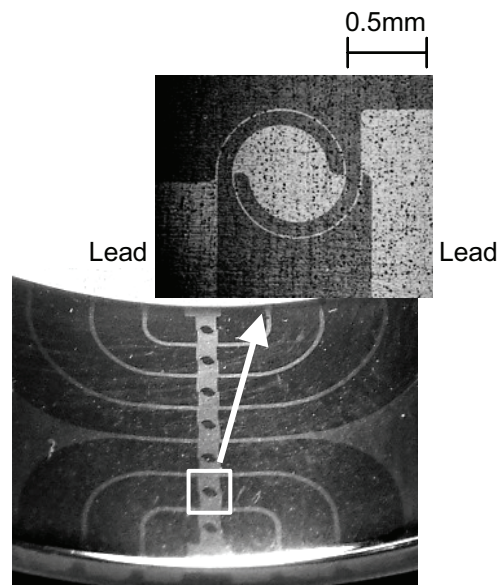


Fig. 3 Appearance of Bearing before Overlay was Formed

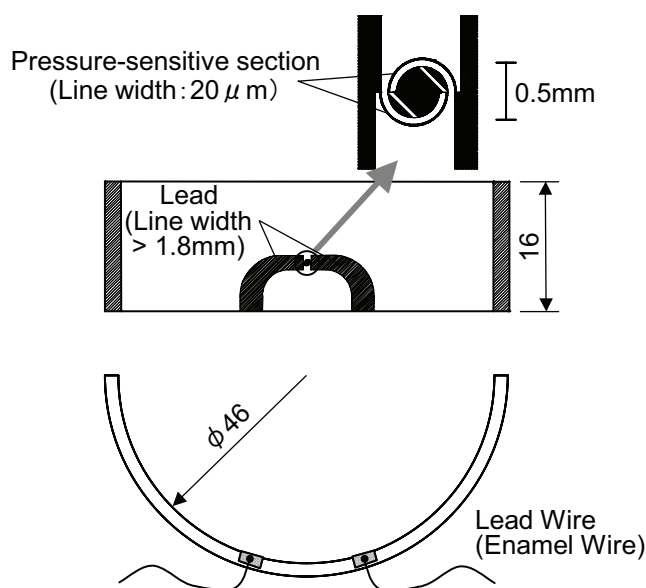


Fig. 2 Sensor Layer Pattern

Fig. 4 shows a property of the thin-film pressure sensors that were used. The bearings on which the sensors were formed was placed in an oil tank, and the resistance change of the sensors was measured as the oil pressure was raised from 0 to 200MPa. It was confirmed that the resistance changes almost linearly with increasing pressure without any hysteresis.

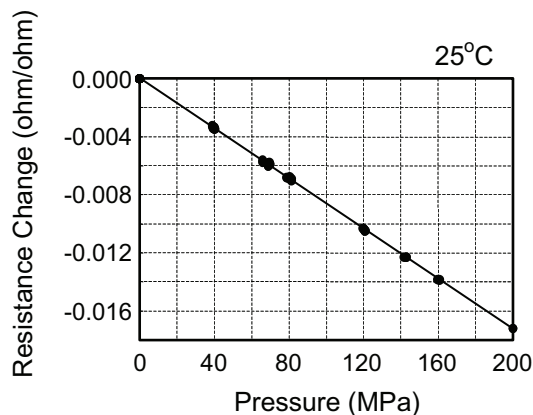


Fig. 4 Property of the Thin-Film Sensor

The measurement of the pressure-related property above was carried out on every sensor created, and it was after the pressure sensitivity of each sensor was measured that they were used in engine tests.

Because the resistance of the sensors ($\text{Cr-Al}_2\text{O}_3$) changes not only with pressure, but also with temperature and strain, the effect of these other factors must also be taken into account.

TEST METHOD

Pressure sensors were created on the bearing, and the properties of these pressure sensors were measured. This bearing was installed as the main bearing of a 1.4-liter straight-4 common-rail direct-injection diesel engine. The bearing clearance at this time was $30\mu\text{m}$. The enamel wires connected to the sensor's leads were extended to the outer surface of the engine, and were then connected to a bridge circuit to carry out measurement by converting resistance change to voltage change.

10W-30 engine oil was used, and the oil and water temperature was kept at 80°C for approximately five minutes under the specified conditions before the measurement was carried out.

MEASUREMENT/ANALYSIS RESULTS

OIL FILM PRESSURE CHANGE (MAIN BEARING)

Fig. 5 shows the resistance change in the thin-film sensor at the center of the lower bearing for journal #2 when the engine was operated at 3,000r/min, and Fig. 6 shows the pressure change obtained from the resistance change. It was confirmed that the oil film pressure increases during the compression and combustion cycles of the cylinders located adjacent on both sides of the bearing measured, and that pressure change reaches approximately 80MPa at full load.

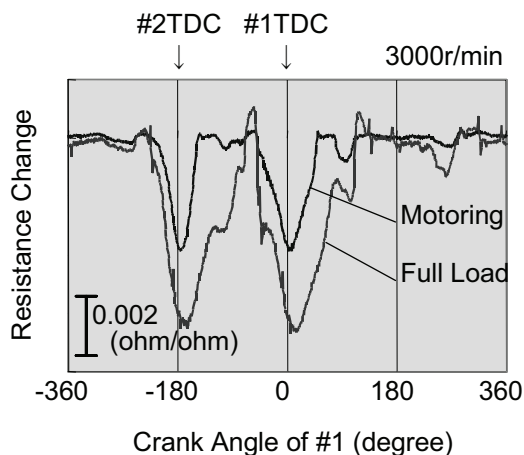


Fig. 5 Resistance Change of a Thin-Film Sensor

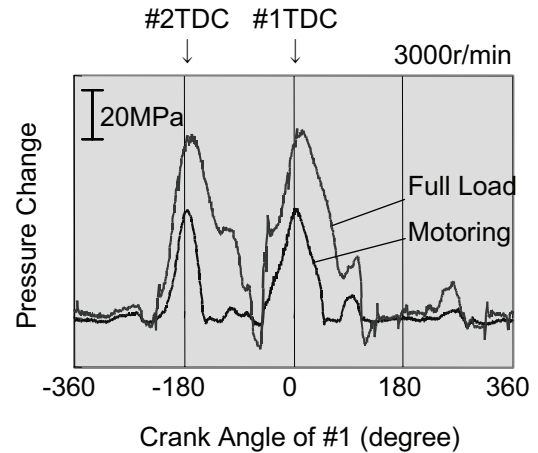


Fig. 6 Pressure Change of Oil Film in the Main Bearing

In Fig. 6, it can be seen that the oil film pressure drops suddenly at around -60°CA . This is caused by the crankshaft oil hole passing by.

What can be measured using this method is pressure change, not absolute pressure. Therefore, the oil film pressure, for instance at around 180°CA where the pressure can be assumed to be low, was converted to 0MPa in absolute pressure. The following argument is based on this assumption.

It was explained earlier that the output of thin-film pressure sensors is affected by temperature and by strain. It has been confirmed that the effect of temperature on the measured pressure values can be ignored by measuring the temperature change using a thin-film temperature sensor with the same structure.

Additionally, a thin-film strain sensor was used to measure strain, and it was found that the pressure measured was up to 15% less than the actual value due to the effect of strain. Therefore, strain was also measured in addition to pressure under all conditions so that the effect of strain could be corrected for when the pressure conversion was carried out.

COMPARISON OF CALCULATED PRESSURE AND BEARING LOAD

To verify the quantitative correctness of this oil film pressure measurement method that uses thin-film sensors, the load on the bearing obtained by integrating the measured oil film pressure was compared with the one estimated based on the pressure inside the cylinders. Assuming that there is no inertia in the piston/connecting rod, that crankshaft rotation is well balanced, and that the load is exerted uniformly on both the main bearings beside the cylinders, the load on the main bearings can be calculated as follows: