

A Study of Reliability Evaluation of Main Bearings for Multicylinder Diesel Engines

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ABSTRACT

In recent years, although experiment technologies on real engines and simulation technologies has been improved rapidly, the tribology contributing factors have not been quantitatively well evaluated to reveal critical lubrication failure mechanisms.

In this study the oil film thickness of the main bearings in multicylinder diesel engines was measured, and the data was analyzed using response surface methodology, which is a statistical analysis methods used to quantitatively derive the factors affecting oil film thickness and the extent of their contribution. We found that the factor with the strongest effect on minimum oil film thickness is oil pressure. Lastly, as a verification test, bearing wear on the main bearings was compared under various oil pressure conditions. Clear differences in bearing wear were identified.

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INTRODUCTION

In recent years, measures such as improving combustion efficiency, downsizing, installing stop-start systems, and reducing friction have been applied to engines to satisfy the requirements for higher fuel economy and reduce emissions in commercial vehicles.

Downsizing, for example, is effective at reducing friction loss at identical levels of engine output. Although diesel engines produce higher torque at lower engine speeds than gasoline engines, downsizing means that high torque will be required at even lower speeds than before, and the cylinder pressure increases, leading to higher bearing surface pressure. Therefore, worse oil film formation as the engine bearing surface pressure increases is likely to be a one of key issue for reliability.

To solve the issues of reliability around the bearings, it is considered necessary to quantitatively derive the relationship between phenomena such as damage to the bearings, which is assumed to result from changes made in the engines to higher fuel economy and reduce emissions, and the factors affected by those phenomena. Appropriate control is also required.

Studies on the lubrication of engine bearings have long been actively conducted. In addition, in recent years simulation technologies has advanced rapidly, and tribology has become recognized as an important field that affects the basic performance and durability of the engine. For example, many studies that compare simulation results with the results of oil film evaluations carried out on test rigs

or in actual engines, or that improve the accuracy of the simulation based on actual measured results can be found [1,2,3,4,5,6,7,]. In contrast, there is a difference between evaluation results from actual engines and lubrication theory, and there are also many issues to address. Hence, there were no studies where the factors contributing to oil film formation on bearings in actual engines, or the extent of that contribution, were clearly indicated.

It should be possible to improve reliability and fuel efficiency by identifying the factors affecting bearing oil film formation from the engine operating conditions, and then applying countermeasures based on these factors.

In this study the oil film thickness of the main bearings in multicylinder diesel engines was measured, and the data was analyzed using response surface methodology [8,9,10,11,], which is a statistical analysis methods used to quantitatively derive the factors affecting oil film thickness and the extent of their contribution.

EXPERIMENT SETUP AND TEST CONDITIONS

1. Engine and Bearing Specifications

An in-line six-cylinder 8.9-L intercooler turbo diesel engine was used in this study. [Table 1](#) shows the engine and bearing specifications.

Table 1. Specifications of tested engine and bearing

Engine Type	6 Cylinder 4 Stroke Cycle Diesel OHC 4 Valves per Cylinder	
Bore × Stroke	φ 112 × 150 mm	
Compression Ratio	17.0	
Displacement	8.9 L	
Firing Order	1 → 4 → 2 → 6 → 3 → 5	
Fuel Injection System	Common Rail	
Air Intake System	Turbocharged with Cooled EGR	
Rated Power	265 kW / 1800 rpm	
Engine Oil	SAE 10W-30 JASO DH-2	
Main Bearing Size	φ 90.0 × W24.7 × L2.5 mm	
Main Bearing Type	Back Metal	Rolled steel
	Metal Layer	Cu-Sn-Bi alloy
	Over Layer	Bi-Ag alloy
Crankshaft Material	Carbon steel for machine structural use	
Oil Clearance at Main Bearing	0.068 mm (Diameter)	

2. Measurement Procedures

Studies on measuring the oil film thickness of journal bearings use various methods such as eddy current, capacitance, supersonic wave or optics. In this study, the distance between a gap sensor fixed to the main bearings and the crankshaft was measured. Taking the sensor acquisition characteristics, use environment within the engine, sensor mounting characteristics, as well as processing scale and yield for sensor mounting into account, an eddy current sensor (gap sensor hereinafter) was adopted for this study.

In addition, the effect of sensor installation on oil film formation was not considered in this study. The processing of the sliding surface is thought to create more severe oil film formation conditions than in the original shape, and the evaluation was conducted with those more severe conditions defined as its basis.

3. Choice of Gap Sensors

For general gap sensors with resin heads, poorer linearity and reduced sensitivity in the output due to the effect of the surrounding metal are concerns. Therefore, a shielded gap sensor where the side surface of the sensor head is covered in metal was selected for this study to account for linearity and reduced sensitivity in the output.

4. Examination of the Measurement Journal

Figure 1 shows the results of theoretical calculations based on three-dimensional Reynolds equation of the oil film thickness of the main bearings. The preconditions of calculations are main gallery oil temperature of 100°C at 1100 rpm, operating under a full load. A hydrodynamic lubrication calculation where actual cylinder pressure wave patterns were entered for each crank angle was used, yielding a motion characteristic calculation that accounts for inertial forces. Based on this result, main bearing No. 4 was used to make the measurements.

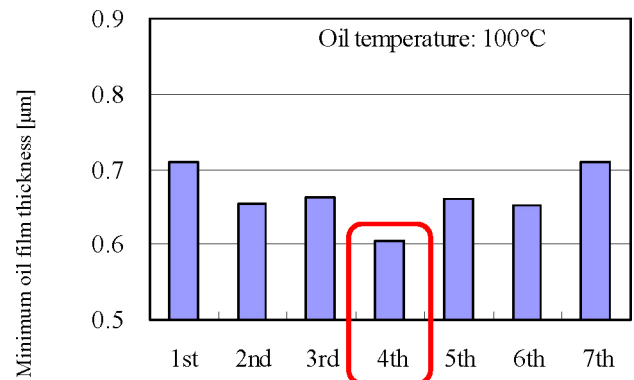


Figure 1. Minimum oil film thickness (hydrodynamic lubrication calculation)

5. Gap Sensor Mounting and Output Verification

Figure 2 shows the mounting positions of the gap sensors. Sensors A, B, and C were at the bottom of the front side, and sensors D, E, and F at the bottom of the rear side, of the 4th journal. Since the theoretical calculation results indicated that oil film is thinnest near the lower end of the main bearing, sensors A and D were placed there.

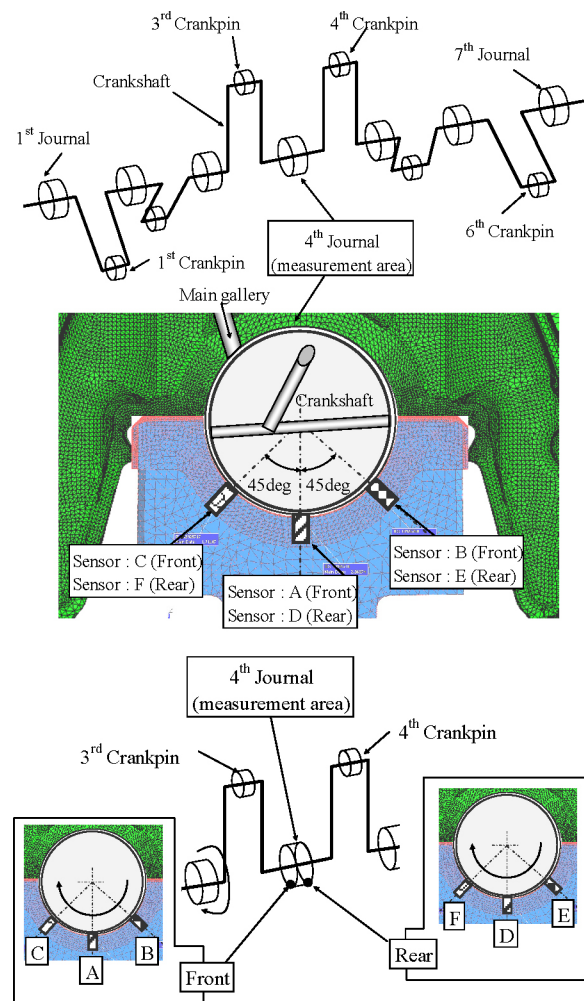


Figure 2. Installation of gap sensors on main cap

In addition, the rotary inertial force of combustions and the crankshaft peripheral components are thought to cause deformation in the cylinder block and the main cap in actual engines. Therefore, sensors B and E, as well as sensors C and F, were placed as shown in Figure 2, and the experiment was conducted by calculating the locus of the shaft center from the results of the sensor output, confirming the position where the oil film becomes thinnest. Figure 3 shows the actual mounting conditions.

This study used two kinds of verification results to convert output levels into oil film thickness. First the temperature properties of all sensors were obtained from the sensor maker before they were delivered. At this point, the same material as the main shaft was set as the material for the verification measurements. After delivery, a jig of the same material as the crankshaft was set as the measured material, and with the sensors mounted on the main cap, set the clearance between the sensor and target to 0 mm and adjusted the voltage to 0 V with SHIFT of converter, the point 0 and output characteristics were verified.

Figure 4 shows an example of the verification results. No problems were found in the linearity and sensitivity of the output levels. In addition, the presence or absence of lubricant between the sensor heads and the measured material was confirmed to produce no changes in the output.

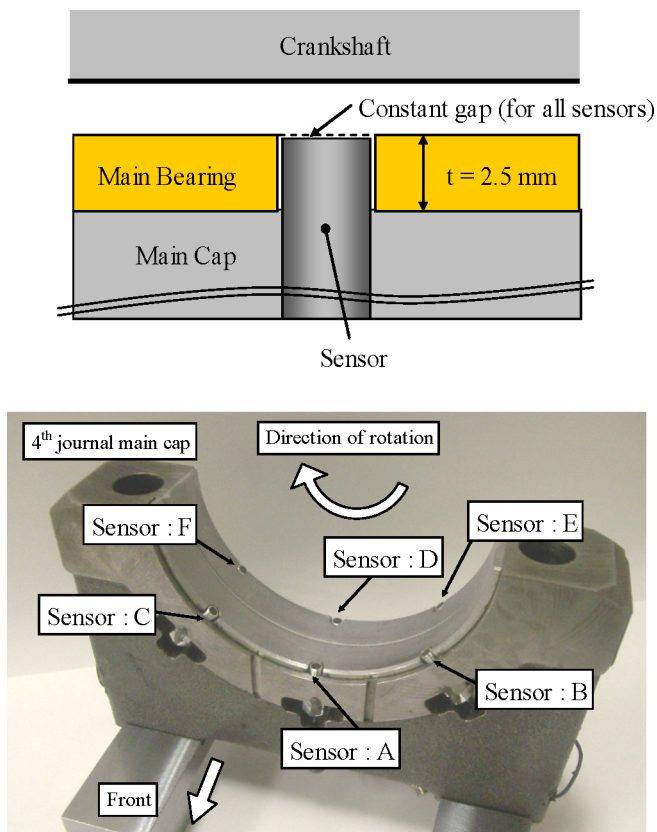


Figure 3. Photograph of oil film thickness measurement device

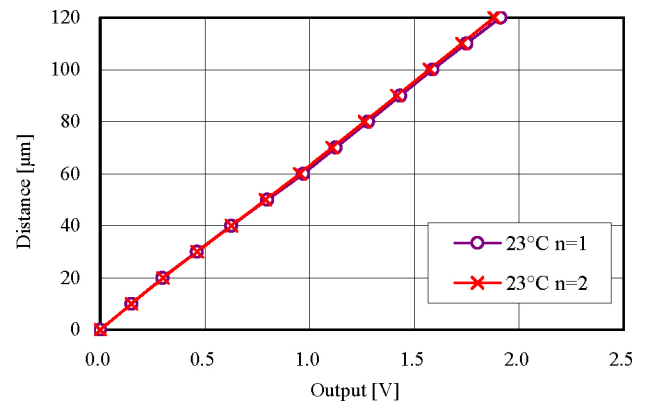


Figure 4. Relationship between voltage and distance of gap sensor (after the voltage adjustment)

6. Measurement Circuits

Figure 5 shows a measurement circuit. Thermocouples were placed at the rear of the metal near each gap sensor and the output of the sensors and the temperature at the rear of the metal in the same crank angle period were measured. The temperature data was used in the conversion of temperature characteristics and thermal expansion in peripheral components, including the gap sensors, relative to the output levels of the sensors, and then converted into oil film thickness.

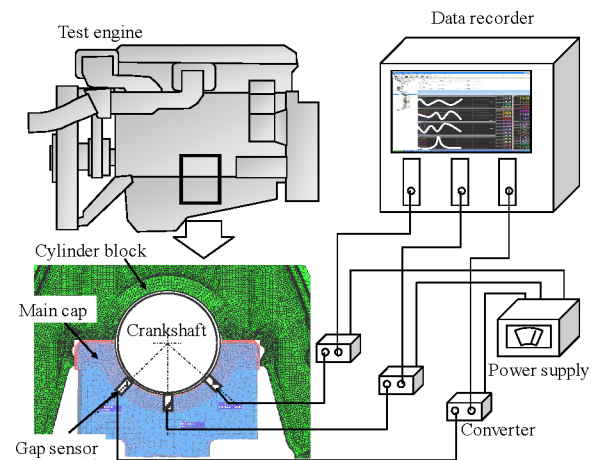


Figure 5. Measurement system

7. Experiment Conditions

Table 2 shows the conditions applied in the experiment.

Table 2. Test conditions

Engine speed [rpm]	Engine load [%]	Main gallery oil temperature [°C]
600 to 2200	0 to 100	80, 100, 110
(every 200 rpm)	(every 12.5 %)	-