

# In-Situ Measurement and Numerical Solution of Main Journal Bearing Lubrication in Actual Engine Environment

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## ABSTRACT

A simple method is frequently used to calculate a reciprocating engine's bearing load from the measured cylinder pressure. However, it has become apparent that engine downsizing and weight reduction cannot be achieved easily if an engine is designed based on the simple method. Because of this, an actual load on a bearing was measured, and the measured load values were compared with a bearing load distribution calculated from cylinder pressure. As a result, it was found that some of actual loads were about half of the calculated ones at certain crank angles. The connecting rod's elastic deformation was focused on as a factor behind such differences, and the rod's deformation due to the engine's explosion load was studied. As a result, it was found that the rod part of the engine's connecting rod was bent by 0.2 mm and became doglegged. Additional investigation regarding these findings would allow further engine downsizing.

In this paper, the authors mainly report that an actual load on a bearing during the engine's combustion could not be determined by simplified calculation based on the engine's cylinder pressure, and that it is necessary to take into account a connecting rod's deformation as well as a piston ring's friction and a crank shaft's deformation which were not measured at this time. As a follow up of this report, the authors plan to report minimum oil film thickness and the distribution of oil film thickness with respect to an engine's individual rotation speed when Elastohydrodynamic Lubrication (EHL) is used.

**CITATION:** Matsumoto, K., Harada, H., Ono, Y., and Mihara, Y., "In-Situ Measurement and Numerical Solution of Main Journal Bearing Lubrication in Actual Engine Environment," *SAE Int. J. Fuels Lubr.* 9(2):2016, doi:10.4271/2016-01-0894.

## INTRODUCTION

In recent years, Computer Aided Engineering (CAE) analyses have been used frequently, allowing a lower number of prototype tests and speedier automobile development. It is anticipated that such a trend will continue. When calculations are made for the CAE analyses, it is often the case that sliding surface data tend to be insufficient and experimental values are used instead. The authors paid attention to such sliding surfaces, and have been collecting sliding surface data of actual engines for the last few years.

The distribution of an actual load on a reciprocating engine's main journal(1),(2),(3),(4) is an example of such data. Normally, the simple method will be used to calculate an engine's bearing load from the measured data of the engine's cylinder pressure. However, more accurate data of bearing loads are required when engine downsizing and weight reduction are studied.

Therefore, the authors selected thin film sensors which are proven to measure oil film pressure distribution(5), and attached them to an engine to measure the load distribution during the engine's combustion. Furthermore, the measured load distribution was

compared with that obtained by using the simple method based on measured cylinder pressure values, which is a proven and frequently used method in bearing design activities.

This time, a horizontally-opposed engine for General Aviation (GA), which is characterized by its capability to nullify second and higher vibrations, was used to collect data.

## CALCULATED BEARING LOAD

This study used a 4-cylinder horizontally-opposed engine with 230 hp output power, 3500 cm<sup>3</sup> displacement and water cooling. Unleaded premium gasoline for automobiles was used as the engine's fuel. Honda pure Ultra engine oil Mild 10W-30 was used as the engine's lubricant.

A 6061B pressure sensor with water cooling manufactured by Kistler was attached to the engine's #1 piston to measure the engine's cylinder pressure at the Wide Open Throttle (WOT). Figure 1 shows the engine's waveform data during its combustion with respect to its crank angle.

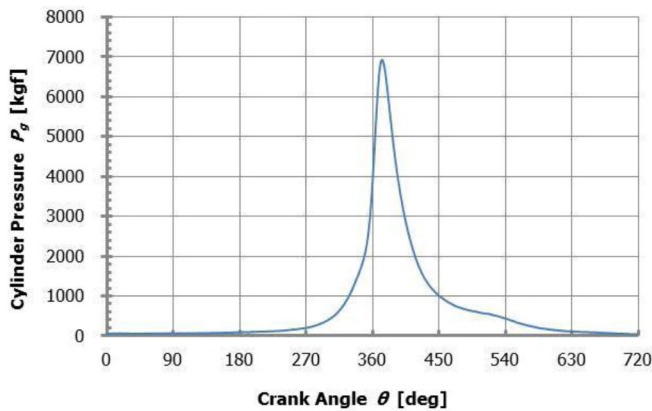


Figure 1. Waveform Data (at WOT)

Following equations by Gross et al.<sup>6)</sup> were used to calculate the composition load of the engine's inertia force and explosion load on the engine's bearing based on the waveform data shown in Figure 1.

$$F = P_g \frac{\pi d^2}{4} - m_e r \omega^2 \left( \cos \theta + \frac{\cos 2\theta}{\lambda} \right)$$

$P_g$  = Cylinder pressure

$D$  = Bore diameter

$m_e$  = Piston mass weight + Connecting rod mass weight

$r$  = Crank radius

$\omega^2$  = Angular acceleration

$\theta$  = Crank angle

$\lambda$  = Connecting ratio

Figure 2 shows the composition load of the explosion load and the inertial force calculated from the measured cylinder pressure values per cylinder.

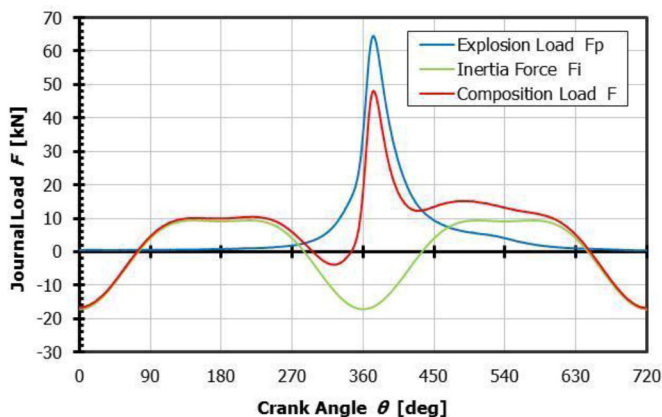


Figure 2. Composition Load of Inertial Force and Explosion Load Calculated from Measured Value

Such composition loads were calculated for each bearing, and the loads of the 4 cylinders were added. Figure 3 shows the changes of the added loads on individual bearings.

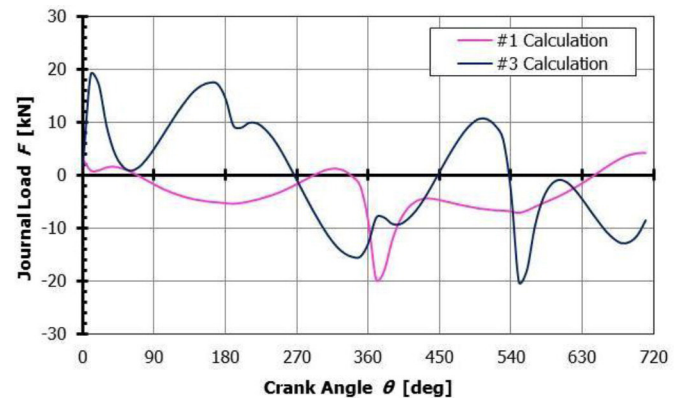


Figure 3. Change of Calculated Load on Individual Bearing With Respect To Crank Angle

Characteristically the opposed-pistons in a horizontally-opposed engine cancel out each other's loads, and its load change is smaller than that of an in-line 4-cylinder one. However, it was found that the #2 bearing was subjected to a large load whose maximum value would be  $\pm 56$  kN. In order to verify how the bearings were subjected to actual loads, thin film sensors were attached to the bearings to measure the actual loads on the bearings during the engine's combustion.

## MEASUREMENT OF OIL FILM PRESSURE DISTRIBUTION OF BEARING BY THIN FILM SENSOR

Several papers have reported results of pressure distribution measurement on sliding surfaces by thin film sensors<sup>7),8),9),10)</sup>. The authors also manufactured similar thin film sensors, and measured the distribution of the load to which the sliding surface of the main journal bearing was subjected.

Figure 4 shows the engine the authors used and locations where the thin film sensors were installed. The red marks on the bearings indicate the locations where the thin film sensors were installed.

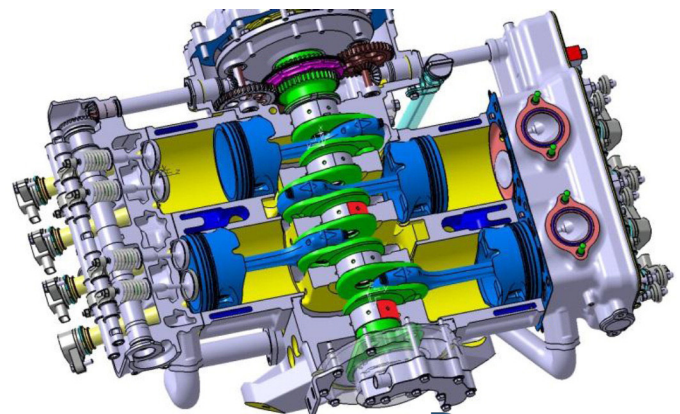


Figure 4. Engine Used for Measurement and Locations of Thin Film Sensors