

An Experimental Study on Relationship between Lubricating Oil Consumption and Cylinder Bore Deformation in Conventional Gasoline Engine

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ABSTRACT

It is well known that lubricating oil consumption (LOC) is much affected by the cylinder bore deformation occurring within internal combustion engines. There are few analytical reports, however, of this relationship within internal combustion engines in operation.

This study was aimed at clarifying the relationship between cylinder bore deformation and LOC, using a conventional in-line four-cylinder gasoline engine. The rotary piston method developed by the author et al. was used to measure the cylinder bore deformation of the engine's cylinder #3 and cylinder #4. In addition, the sulfur tracer method was applied to measure LOC of each cylinder. LOC was also measured by changing ring tension with a view to taking up for discussion how piston ring conforms to cylinder, and how such conformability affects LOC. Their measured results were such that the cylinder bore deformation was small in the low engine load area and large in the high engine load area. In particular, it was shown that there was a different tendency in deformation between cylinder #3 and cylinder #4 around the top dead center. Whereas there was not a large difference between cylinder #3 and cylinder #4 in LOC, as ring tension was lowered and overall LOC was on the increase.

We then made a calculation of ring oil film thickness, using a model to predict a ring's conformability considered cylinder bore deformation. The results were used to calculate the rate of oil flow into a combustion chamber, and the rate of evaporation of oil from a cylinder wall. This verified that a low tension ring conformed to a cylinder less, while ring oil film got thicker. In addition, as oil film got thicker, the rate of oil flow increased, however, there was not a noticeable change in the rate of evaporative oil. From the above, we can conclude that changes in ring tension are affected when a ring conforms to a deformed cylinder, which in turn affects LOC.

INTRODUCTION

It is understood that a reduction in piston friction is an effective way to reduce fuel consumption in engines. And many efforts have been made to develop lower tension piston rings [1]. Once we recognize that the more ring tension goes down, the more lubricating oil is consumed [2,3], then we must also see that the limit of lowering ring tension depends on how much we can control LOC. One reason why lower ring tension involves increase in LOC is that such a ring conforms to cylinder less. Accordingly, it will be possible to control the increase in LOC resulting from lower ring tension by

demonstrating the relation of a ring's conformability with LOC. We used a conventional in-line four-cylinder gasoline engine in this study, and made the measurements of the engine for cylinder deformation and LOC. Using a model to predict a ring's conformability considered cylinder bore deformation, we calculated the rate of oil flow into the combustion chamber and that of evaporative oil. We then analyzed the relationship of ring's conformability with LOC on the basis of such measured results.

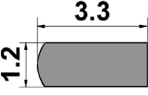
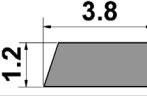
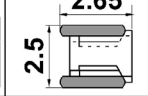
TEST ENGINE AND PISTON RINGS

We used an in-line four-cylinder gasoline engine with natural aspiration (NA) as a test engine. The main specifications included a displacement of 2 liters, a bore of 89mm, and a stroke of 80.3mm, which are shown in Table 1. The cylinder block is aluminum, open-deck type, where the number of head bolts is four per cylinder. We chose cylinder #3 and cylinder #4 to measure the cylinder deformation of the engine being operated. And LOC was measured on each cylinder, from cylinder #1 to cylinder #4, and on all the cylinders taken together (LOC of the overall engine). Table 2 shows the piston ring specifications. In order to measure cylinder deformation, we used a standard tension ring (STD ring). And for the measuring of LOC, we used two types of specifications (STD ring and low tension ring) to verify how ring tension conforms to the cylinder.

Table 1. Engine specifications

Engine Type	Four-cylinder, in-line NA Gasoline Engine
Displacement	1.998L
Bore × Stroke	89mm × 80.3mm
Max Power	108kW / 6000rpm
Max Torque	198Nm / 4000rpm

Table 2. Piston ring specifications

	Top ring	2nd ring	Oil ring
Shape			
STD tension [N]	7.85	7.85	35.3
Low tension [N]	5.9	5.4	13.3

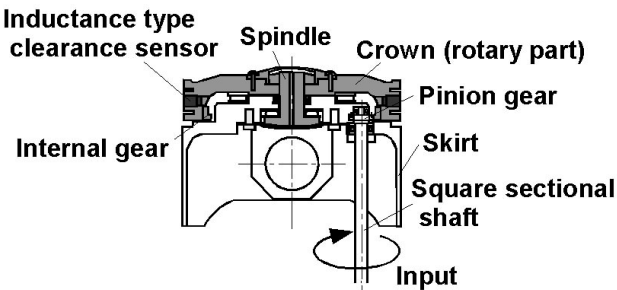


Figure 1. Sectional view of rotary piston

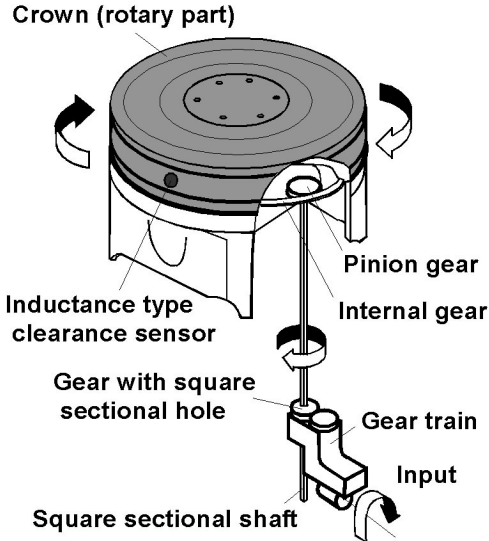


Figure 2. Schematic structure of rotary piston

ROTARY PISTON METHOD

Figure 1 shows a sectional view of our developed rotary piston [4] to measure cylinder deformation in this study. The rotary piston is divided into two parts, the crown and the skirt, both of which are coupled with each other by means of the spindle. As shown in Figure 2, the crown can be rotated voluntarily, by turning a spindle from outside the engine, using a square sectional shaft and a train of gears. The crown is equipped with an inductance type clearance sensor to measure the clearance between cylinder wall and crown. Therefore, by turning the crown 360 degrees centering on the spindle shaft, it is possible to measure clearances between clearance sensor and cylinder all the way around the cylinder.

SULFUR TRACER METHOD

In order to analyze the relationship between cylinder deformation and LOC, it is necessary to measure both cylinder deformation and LOC per cylinder. With a conventional method of LOC measurement, such as the gravimetric method or level method, it is difficult to measure LOC per cylinder in a multi-cylinder engine. We applied, therefore, the sulfur tracer method to measure LOC in this study. Figure 3 shows a systematic view of the sulfur tracer method used for our LOC measurements. Exhaust gas sampled from the exhaust pipe of each cylinder is measured for SO₂ concentration using an SO₂ analyzer, and LOC is calculated according to the formula (1) shown in Figure 3. Since it is difficult to measure the flow rate of exhaust gas here, we measure the intake air flow, assuming that the flow rate of exhaust gas is equivalent to intake air flow. As mentioned earlier, with the sulfur tracer method we are able to measure LOC per cylinder by measuring SO₂

concentration of exhaust gas from each cylinder and intake air flow.

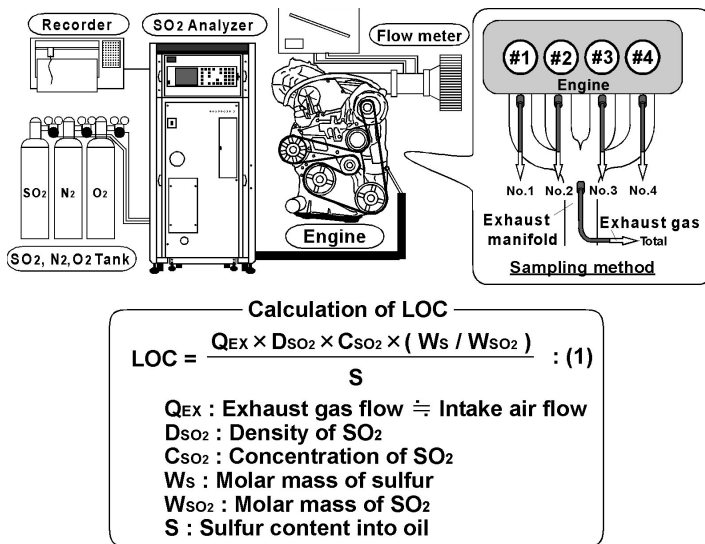


Figure 3. Measurement of LOC in sulfur tracer method

Figure 4 shows the method for measuring intake air flow per cylinder in a multi-cylinder engine [5]. The intake manifold is vertically divided into two, top and bottom. And there is a spacer built between them in order to divide and render each independent from the others. As well, each cylinder is provided with a hot-wire flow meter to measure intake air flow for that specific cylinder. Also, there is a laminar flow meter at the intake manifold inlet, which simultaneously measures intake air flow of all the cylinders combined. Figure 5 shows the results of a comparison made between the intake air flow of each cylinder and that of all the cylinders combined. It can be seen that there is a large difference of 10% at 2000rpm between the sum of each cylinder flow rate as measured by hot wire flow meter and the flow rate of all the cylinders as measured by laminar flow meter. However, the intake rates are almost equal to each other at 3000rpm, and 4000rpm. It is acceptable, therefore, to use such methods in measuring intake air flow in each cylinder of a multi-cylinder engine, as we have done here.

MEASURED RESULTS

CYLINDER DEFORMATION

Figure 6 shows measured results on cylinder deformation with no load, and full load, at 3000rpm, in connection with the upper (UPR), middle (MID) and lower (LWR) parts respectively. Figure 6 (a) shows the measured results of cylinder #3 and (b) that of cylinder #4. A comparison of cylinder deformation between the

case of no load and the case of full load shows that deformations of both cylinders become large as engine load increases, and the cylinder deformation is caused by thermal expansion. Another comparison of cylinder #3 and cylinder #4 at full load shows that cylinder #3 meets with bigger secondary deformation, and tends to deform into an oval in a TH-ATH direction. This is because cylinder #3 is located between cylinder #2 and cylinder #4 and so cannot deform in a Front-Rear direction. In contrast, cylinder #4 can expand flexibly in a Rear direction and form into a triangle. As seen from above, cylinder #3 and cylinder #4 have been measured for cylinder deformation in an in-line four-cylinder engine [6], the measurements of which are considered reasonable.

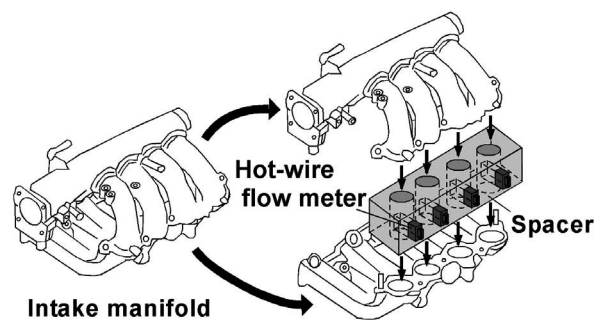


Figure 4. Measurement method of intake air flow

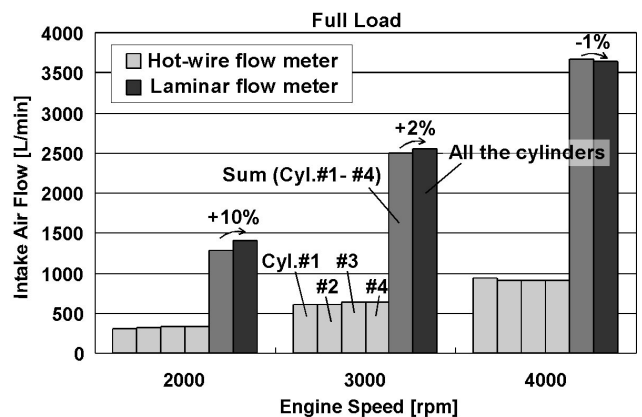


Figure 5. Comparison of each cylinder and all the cylinders in intake air flow