

Analysis of Piston Friction – Effects of Cylinder Bore Temperature Distribution and Oil Temperature –

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ABSTRACT

Hybrid vehicles (HVs) are becoming more widely used. Since HVs supplement engine drive with motor power, the lubricant oil temperature remains at a lower level than in a conventional gasoline vehicle. This study analyzed the effect of cylinder bore temperature and lubricant oil temperature on engine friction. The results showed that, although the lubricant oil temperature was not relevant, the bore temperature had significant effect on piston friction. It was found that raising the temperature of the middle section of the cylinder bore was the most effective way of reducing piston friction.

1. INTRODUCTION

Many countries are strengthening CO₂ emissions regulations in an effort to reduce global warming. Consequently, improving the fuel economy of vehicle engines has become an important issue. Reducing engine friction is one important technique for improving fuel economy. In particular, a great deal of research has been carried out to reduce friction in the piston system, which accounts for a large percentage of total engine friction[1][2][3]. However, this research has mainly focused on methods to reduce friction after engine warm-up has completed and there has been almost no research into friction during the warming up process. Therefore, the aim of the research described in this paper was to identify parameters that are effective at reducing piston friction during the warming up process.

As a result, it was found that the most effective way of reducing piston friction during the warming up process is to increase the cylinder bore temperature in the section near to the point where maximum piston speed is reached.

2. TEST DEVICE AND METHOD

2.1. FRICTION MEASURING DEVICE USING FLOATING LINER METHOD

Figure 1 shows an image of the device used in the test, and its specifications are shown in Table 1. The single-cylinder engine used in the test simulated a port injection, spark ignition gasoline engine and had a bore diameter of 86 mm and a stroke of 86 mm. Furthermore, eight 3-force component sensors were placed on the liner in the thrust direction to measure the thrust force and friction force. This device was constructed so that only the friction between the piston and the liner would be measured using the floating liner method[4].

2.2. LINER COOLING METHOD

Figure 2 shows the configuration of the liner cooling system used in the test. To control the distribution of the cylinder bore temperature during the test, the water jacket of the liner was divided into three independent sections and then water was pumped through each of these sections. A valve was placed on the exit side of each of the water jackets so that the flow rate of the coolant could be adjusted. Below, these three water jacket sections are referred to as (from the top dead center side) the upper, middle, and lower sections of the water jacket.

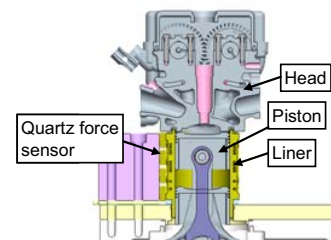


Fig. 1 Floating Liner Method Test Device

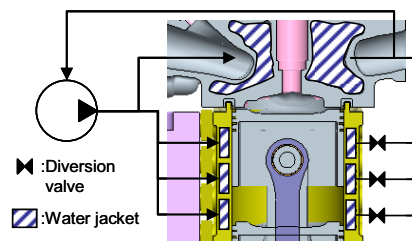


Fig. 2 Cooling System

Table 1 Test Engine Specifications

Bore x stroke	Single-cylinder, $\phi 86 \times 86$
Displacement	500cc
Ignition system	4-stroke, spark ignition
Sensors	Piezoelectric quartz crystal 3-force component sensors (Friction force, Thrust force, pin-direction force)
Lubricant oil	SAE 0W-20

3. MEASUREMENT CONDITIONS

The increase in temperature of the parts around the piston is not uniform during the engine warming up process. Therefore, to reduce piston friction, it is necessary to determine the sections at which the temperature should be increased, as well as the optimum temperature to achieve the greatest effect. This research focused on the temperature of the lubricant oil supplied between the piston and the cylinder bore, and the cylinder bore temperature as important parameters for reducing piston friction. These parameters were evaluated in combination under the conditions shown in Tables 2 and 3.

Table 2 shows the evaluation conditions where only the temperature of the lubricant oil was changed. This evaluation was conducted with a constant coolant temperature of 80°C and lubricant oil temperatures of 30°C, 45°C, and 80°C. The engine speed and load were set to 800 rpm/300 kPa, 1,600 rpm/650 kPa, and 2,000 rpm/650 kPa.

Table 3 shows the different combinations of test conditions in accordance with the sections of the water jacket where the water coolant was applied. The condition under which the coolant was applied through all three sections of the water jacket (i.e., the upper, middle, and lower sections) was used as the base for comparison. The condition under which the flow of coolant was stopped only in the upper section is referred to as upper section warm-up. The condition under which the flow of coolant was stopped in the middle and lower sections is referred to as middle and lower section warm-up. Finally, the condition under which the flow of coolant was stopped only in the lower section is referred to as lower section warm-up. Furthermore, two different conditions were adopted for the combination of lubricant oil temperature and coolant temperature: first one where both were set at 40°C and second one where both were set at 80°C. In addition, six conditions were set for the engine speed and load: 800 rpm/300 kPa, 800 rpm/650 kPa, 1,600 rpm/650 kPa, 1,600 rpm/900 kPa, 2,000 rpm/650 kPa, and 2,000 rpm/900 kPa. These combinations of engine speed and load were selected because of their relationship to fuel economy during actual vehicle use. In addition, these combinations were used to measure whether the effect of the cylinder bore temperature on friction would change due to the load.

Table 2 Test Conditions A

Oil temperature	Coolant temperature	Engine speed (rpm) and load (kPa)		
		800/300	1,600/650	2,000/650
30°C	80°C	(1)	(4)	(7)
45°C	80°C	(2)	(5)	(8)
80°C	80°C	(3)	(6)	(9)

Table 3 Test Conditions B

Section of water jacket	Base	Upper section warm-up	Middle and lower section warm-up	Lower section warm-up
Upper section	ON	OFF	ON	ON
Middle section	ON	ON	OFF	ON
Lower section	ON	ON	OFF	OFF

4. PISTON FRICTION MEASUREMENT RESULTS

4.1. EFFECT OF LUBRICANT OIL TEMPERATURE ON PISTON FRICTION

In the test device, the lubricant oil supplied to the piston is injected at the cylinder bore rather than toward the piston. However, the oil is injected at the piston near to the bottom dead center.

Figure 3 shows the friction mean effective pressure (FMEP) for each of the conditions. No reduction in piston friction was confirmed by increasing the lubricant oil temperature under any of the test conditions. Figure 4 shows the distribution of the cylinder bore temperature under each of the test conditions. The results indicate that, when the lubricant oil temperature is increased, the temperature at the middle section of the cylinder bore increases by 5°C. As a result, it was concluded that increasing the lubricant oil temperature at an early stage during the warming up process has only a minor effect on reducing piston friction.

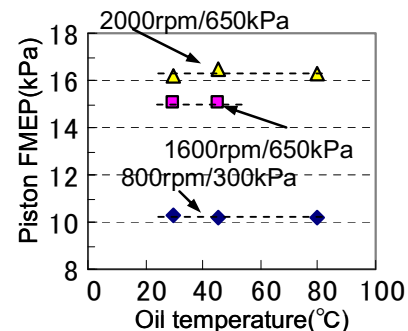


Fig. 3 FMEP with Different Oil Temperatures