

Research into Engine Friction Reduction under Cold Conditions - Effect of Reducing Oil Leakage on Bearing Friction

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ABSTRACT

Fuel efficiency improvement measures are focusing on both cold and hot conditions to help reduce CO₂ emissions. Recent technological trends for improving fuel economy such as hybrid vehicles (HVs), engine start and stop systems, and variable valve systems feature expanded use of low-temperature engine operation regions. Under cold conditions (oil temperature: approximately 30°C), fuel consumption is roughly 20% greater than under hot conditions (80°C). The main cause of the increased friction under cold conditions is increased oil viscosity.

This research used the motoring slipping method to measure the effect of an improved crankshaft bearing, which accounts for a high proportion of friction under cold conditions. First, the effect of clearance was investigated. Although increasing the clearance helped to decrease friction due to the oil wedge effect, greater oil leakage reduced the oil film temperature increase generated by the friction. Consequently, the friction reduction effect was less than that predicted by the lubrication calculation.

Next, the rate of friction used as heat energy was analyzed based on the oil film temperature and the leakage amount. In the test engine, approximately 20% of the total friction was used to increase the journal oil film temperature. Since the analysis found that raising the oil film temperature by reducing leakage may help to decrease friction under cold conditions, bearings with a sealing function were evaluated for verification. This sealing method can potentially reduce overall friction by 5%.

CITATION: Honda, A., Murakami, M., Kimura, Y., Ashihara, K. et al., "Research into Engine Friction Reduction under Cold Conditions - Effect of Reducing Oil Leakage on Bearing Friction," *SAE Int. J. Fuels Lubr.* 7(2):2014, doi:10.4271/2014-01-1662.

1. INTRODUCTION

The reduction of CO₂ emissions is important to help prevent global warming. Since the transportation sector is responsible for roughly 20% of total CO₂ emissions, improving vehicle fuel economy is a key aim for automakers.

Conventional measures to improve fuel economy have focused on fuel consumption after the engine is warmed up (i.e., once the oil and coolant temperature reaches roughly 80°C). However, from the standpoint of improving actual fuel economy, greater attention has been paid to fuel consumption under cold conditions in recent years. As a consequence of this trend, Europe, North America, and Japan plan to introduce cold-condition certification test cycles in 2015. Recent technological trends for improving fuel economy, such as hybrid vehicles (HVs) and engine start and stop systems, feature expanded use of low-temperature engine operation

regions. [Figure 1](#) shows the changes over time in coolant temperature in the New European Driving Cycle (NEDC). A vehicle with a hybrid system has a more gradual coolant warm-up curve compared to a conventional internal combustion engine (ICE) vehicle. In the case of this figure, the coolant temperature in the urban test cycle to 800 seconds is 60°C or less.

[Figure 2](#) shows the results of an investigation into the relationship between oil temperature and fuel consumption in previous NEDC tests [1]. In the case of 5W-30 engine oil, fuel consumption under cold conditions (oil temperature: 30°C) is approximately 20% higher than under hot conditions (oil temperature: 80°C). In contrast, fuel consumption under cold conditions is greatly improved when the ultra-low viscosity HTHS 1.7 engine oil is used. This demonstrates the major effect of engine oil viscosity on fuel consumption.

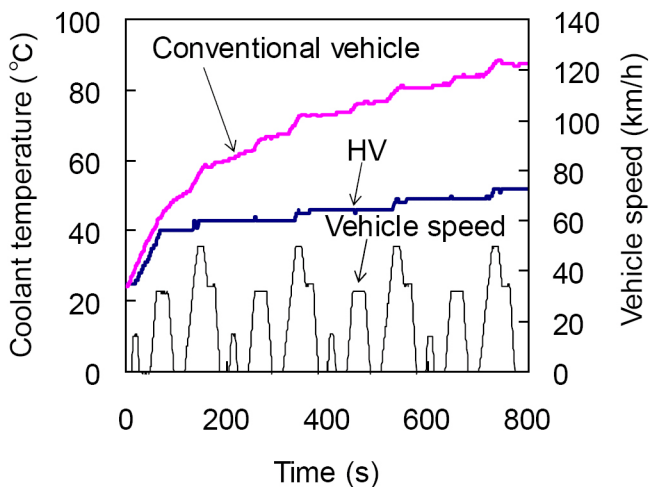


Figure 1. Changes in coolant temperature in NEDC.

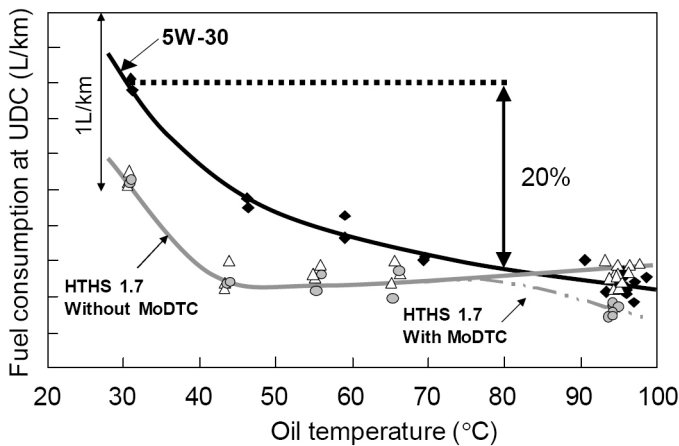


Figure 2. Effect of oil temperature on fuel consumption.

Reducing the viscosity of engine oil is one way of improving fuel economy under cold conditions and research is being carried out to take advantage of this relationship. A new viscosity standard has also been incorporated into the next-generation oil standards approved by the International Lubricant Standardization and Approval Committee (ILSAC).

Other key ways of improving fuel economy under cold conditions include thermal management and reducing friction at low temperatures. Figure 3 shows an example of a study into thermal management. Each line shows the changes in cylinder liner temperature over time under different conditions: line (a) shows a normal cold start in the NEDC test cycle; line (b) shows a hot start, i.e., when the engine has been intentionally warmed up before the NEDC cycle); and line (c) shows the trend when flow control is applied to the coolant to speed up the increase in coolant temperature. Figure 4 shows the results of fuel consumption measurement under these conditions (a) to (c). Condition (a) makes greater use of cold engine operation regions than condition (b) and consumes 5.3% more fuel. Condition (c) speeds up the increase in liner temperature compared to condition (a) by the adoption of coolant flow control. This control improves fuel consumption by 1.5%.

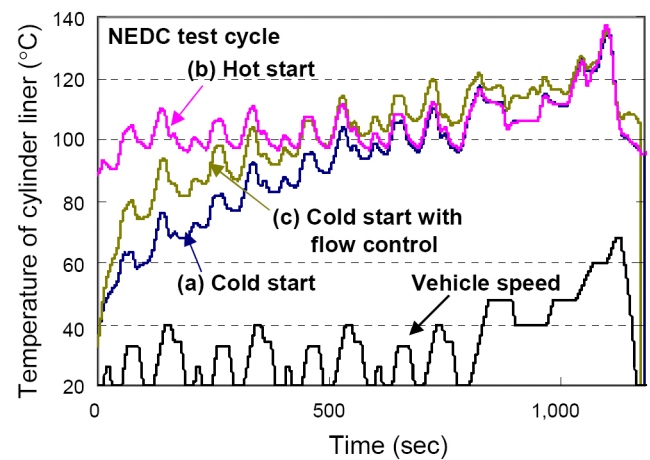


Figure 3. Effect of thermal management on cylinder liner temperature.

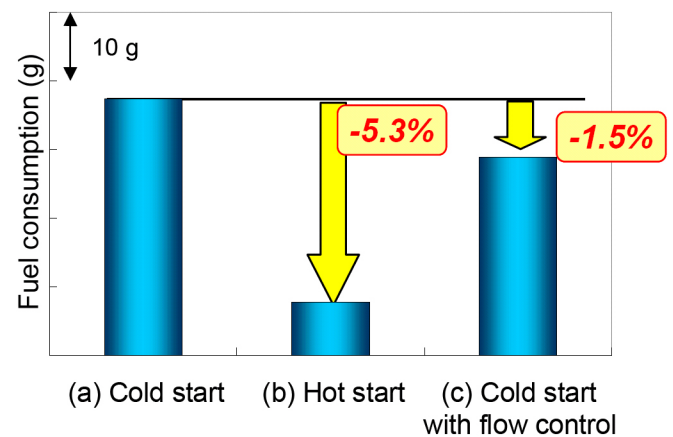


Figure 4. Effect of thermal management on fuel consumption.

Several studies into friction reduction under warm conditions have been carried out [1][2][3], however, few reports have been published describing friction reduction under cold conditions.

Therefore, research was carried out to measure and examine the characteristics of friction under cold conditions [4]. Figure 5 shows the friction torque of various engine parts at oil temperatures 45°C and 80°C. Friction torque at 45°C was 1.6 times greater than at 80°C. The research found that friction was particularly high at the pistons and crankshaft.

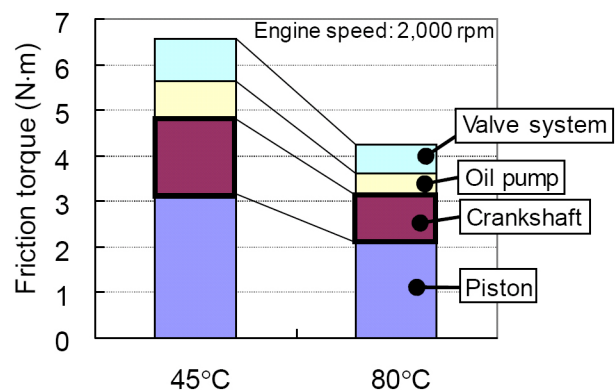


Figure 5. Effect of oil temperature on friction torque.

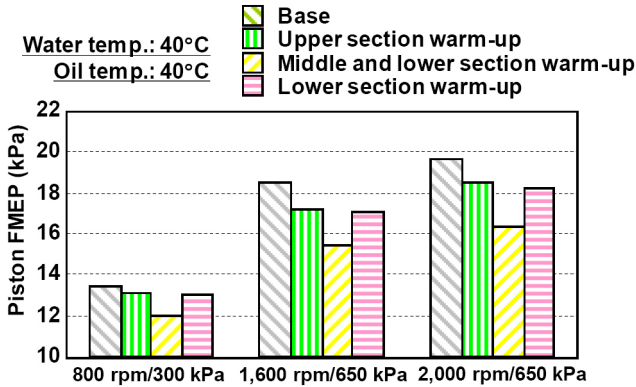
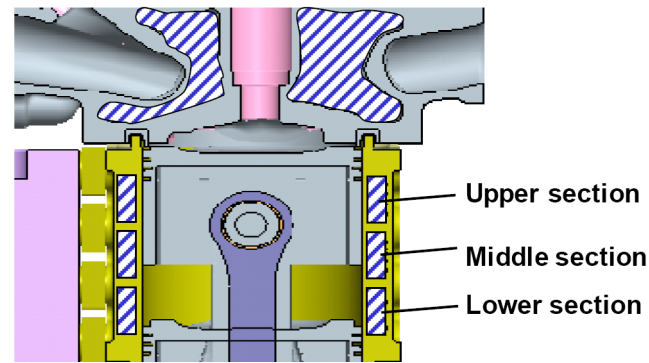


Figure 6. Research into effects of cylinder liner temperature.

The next phase in the research focused on piston friction [5]. It was found that controlling the cylinder liner temperature distribution was an effective means of reducing friction (Fig. 6).

Subsequently, the research described in this paper describes the reduction of crankshaft friction, which also accounts for a large percentage of friction under cold conditions. Previously, Zammit et al. examined the reduction of crankshaft friction by pre-heating oil supplied to the main bearing using an external heat source [6]. However, a major issue of this method is securing the external heat source. Therefore, this research examined the feasibility of increasing the temperature of the oil film by reducing the amount of oil leakage as a means of lowering friction under cold conditions.

2. EXPERIMENTAL EQUIPMENT AND PREDICTION CALCULATION METHOD

This research used the motoring slipping method to measure friction. A system was constructed to accurately control the oil and coolant temperature (Fig. 7).

This system is capable of controlling the air temperature within a range of 0°C to 25°C with a tolerance of ±1°C, and can also control the oil and coolant temperature and transmission oil temperature within a range of 0°C to 40°C with a tolerance of ±1°C. Subsequently, friction can be measured with a tolerance of ±0.1 N·m. A 1.3-liter gasoline engine was used in the experiment. Table 1 shows the experiment start conditions.

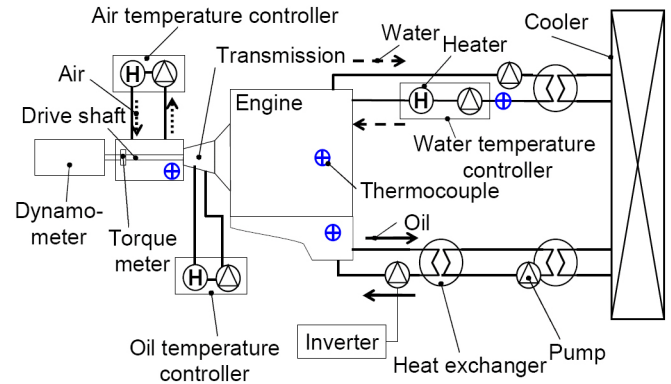


Figure 7. Experiment setup

Table 1. Start conditions.

Engine speed (rpm)	Oil pressure at main oil hole (kPa)	Air temperature (°C)	Coolant temperature (°C)	Oil temperature at main oil hole (°C)	Oil temperature at transmission (°C)
1,000	332	0	0	0	26
2,000	381	0	0	0	26
3,200	422	0	0	0	26
1,000	332	25	20	20	40
2,000	381	25	20	20	40
3,200	422	25	20	20	40

This experiment also predicted friction through a hydrodynamic lubrication (HL) calculation to analyze the friction characteristics under cold conditions. Equation (1) shows the Reynolds equation used for the calculation.

$$\frac{1}{R^2} \frac{\partial}{\partial \theta} \left(\frac{h^3}{12\mu} \frac{\partial P}{\partial \theta} \right) + \frac{\partial}{\partial z} \left(\frac{h^3}{12\mu} \frac{\partial P}{\partial z} \right) = \frac{1}{R} \frac{\omega}{2} \frac{\partial h}{\partial \theta} + \frac{\partial h}{\partial t} \quad (1)$$

Figure 8 illustrates the meaning of the terms used in this equation. R is the radius of the bearing, h and P are the oil film thickness and pressure, respectively, μ is the oil viscosity, and θ and z are the positions in the bearing circumference and width directions, respectively. This research applied this prediction technique to the crankshaft journal.

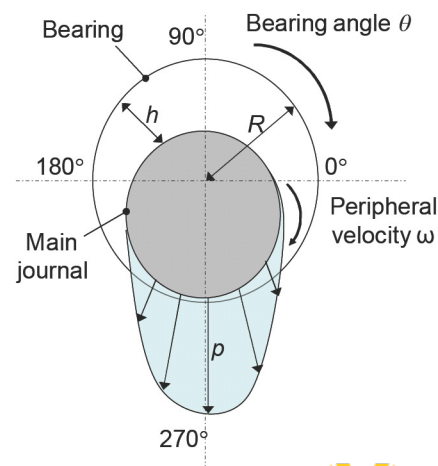


Figure 8. Diagram of main journal and bearing