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COMPUTER PROGRAM DEVELOPMENT PREDICTING ENGINE OIL CONSUMPTION

Sang Myung Chun

Department of Automotive Engineering, Hoseo University, Republic of Korea

ABSTRACT

The oil consumption and blow-by gas through piston-cylinder-ring crevices have to be minimized. Meanwhile, the friction losses in the piston ring pack need to be reduced in order to improve fuel economy and engine performance. In these two aspects, study on the optimized design of the piston ring pack has to be carried out. The amounts of oil consumption and blow-by gas are important factors to decide whether an engine is operating under good conditions or not during engine development and engine life cycle. The purpose of this study is to develop a computer program predicting engine oil consumption and blow-by gas by calculating the amount of oil flowing into the combustion chamber and gas flow down to the crankcase through the piston ring pack. Using this program, the condition of an engine can be predicted in advance.

INTRODUCTION

The status of piston ring-pack lubrication turns out to be fluid film lubrication or boundary lubrication by turns depending on ring profiles, piston motions and fluctuations in inter-ring pressure [1-7]. It is desired that fluid film lubrication is maximized for the reduction of friction and protection against piston ring wear. Meanwhile, the oil consumption and blow-by gas would be better in small amount in terms of saving of resources and engine efficiency. It is important in piston and ring-pack lubrication how these two aspects are combined.

During engine firing, the pressures in the combustion chamber and inter-ring pressures are required at every crank angle. A pressure transducer measures the cylinder pressure and the inter-ring pressures can be calculated by the crevice flow model. Assuming the lubrication between piston ring and cylinder wall is hydrodynamic lubrication, the Reynolds' equation is solved by finite difference method. Then oil film thickness and ring friction at the ring face are obtained. If the film thickness is sufficiently small to indicate boundary lubrication, the friction calculation follows the method for boundary lubrication. Furthermore, the blow-by gas and oil consumption can be calculated.

The purpose of this paper is to predict the lubrication status for the piston ring pack and thereby guide as optimum lubrication. Even if all the real firing states cannot be considered and the complicated physical phenomenon cannot be well modeled, it is useful to inform design through parametric study in a short time.

1. GOVERNING EQUATIONS

1.1. Piston ring motion equation

$$M_r \frac{d^2h}{dt^2} = F_p + F_f + F_i + F_s + F_{asp} \quad (1)$$

where M_r is the mass of each ring, h the oil film thickness, t time, F_p the pressure force, F_f the friction force, F_i the inertia force, F_s the radial hydrodynamic force and F_{asp} the radial contact force on the ring face.

1.2. Gas flow equations through piston ring pack crevice

$$\frac{m_{02}}{P_{02}}\frac{dP_2}{dt} = \dot{m}_{12} - \dot{m}_{23} \quad (2)$$

$$\frac{m_{03}}{P_{03}}\frac{dP_3}{dt} = \dot{m}_{13} + \dot{m}_{23} - \dot{m}_{34} - \dot{m}_{35} \quad (3)$$

$$\frac{m_{04}}{P_{04}}\frac{dP_4}{dt} = \dot{m}_{34} - \dot{m}_{45} \quad (4)$$

$$\frac{m_{05}}{P_{05}}\frac{dP_5}{dt} = \dot{m}_{35} + \dot{m}_{45} - \dot{m}_{56} - \dot{m}_{57} \quad (5)$$

$$\frac{m_{06}}{P_{06}}\frac{dP_6}{dt} = \dot{m}_{56} + \dot{m}_{76} - \dot{m}_{6c_2} - \dot{m}_{6c_1} \quad (6)$$

$$\frac{m_{07}}{P_{07}}\frac{dP_7}{dt} = \dot{m}_{57} - \dot{m}_{76} - \dot{m}_{7c_1} \quad (7)$$

where m_{oi} is the initial mass of i volume, $\dot{m}_{ij}$ the mass flow rate into j volume from i volume, P_i the pressure of i volume and P_{oi} the initial pressure of i volume. 1 indicates the top land clearance, 2 the volume behind the top ring, 3 the volume of second land clearance, 4 the volume behind the second ring, 5 the volume of the third land clearance, 6 the volume behind the oil ring and 7 the volume between the oil ring rails. c_1 and c_2 indicate the crankcase reached through the piston skirt clearance and oil drain hole respectively.

The gas mass flow rates between adjacent lands are calculated using the orifice flow equation such that

$$\dot{m} = C_d \rho A c \eta \,. \quad (8)$$

where C_d is the discharge flow coefficient, ρ the gas density, A the flow area associated with the orifice, c the speed of sound and η the compressibility factor.

The blow-by gas flow, $\dot{m}$ is

$$\dot{m} = \dot{m}_{7c_1} + \dot{m}_{6c_1} + \dot{m}_{6c_2} \ . \qquad (9)$$

1.3. Reynolds equation for film lubrication

$$\frac{\partial}{\partial x}\left(h^3 \frac{\partial P}{\partial x} \right) = -6\mu U \frac{\partial h}{\partial x} + 12\mu \frac{\partial h}{\partial t} \qquad (10)$$

where P is the oil film pressure, μ oil dynamic viscosity, U the velocity of piston-ring, h the oil film thickness and x the axial coordinate.

1.4. Friction calculation

1) Friction for film lubrication, F_f

$$F_f = \int \left[\frac{h}{2} \frac{\partial P}{\partial x} + \mu \frac{U}{h} \right] (\pi D_b) dx \qquad (11)$$

where D_b is the diameter of cylinder bore.

2) Friction for boundary lubrication, $F_{f,asp}$

$$F_{f,asp} = c_f F_{asp} \qquad (12)$$

where c_f is the friction coefficient and F_{asp} the radial contact force on the ring face.

1.5. Oil consumption

According to the puddle theory of oil consumption [8], the oil consumption can be expressed with the correction factor of oil loss, α, as follow.

$$Oil\_Consumption = 3 \times 10^4 \alpha RPM \rho h_i h^* A_{ref} A^* \left(\frac{g}{hr} \right) \qquad (13)$$

where ρ the density of oil, A_{ref} the area of second land oil puddle beneath top ring gap, A^* the non-dimensionalized second land puddle area, h_i the second land oil film thickness before top ring reversal, $h^* = (h_i - h_f)/h_i$ the non-dimensionalized change in second land oil film thickness, where h_f is the final height of the oil film, and RPM the speed of engine.

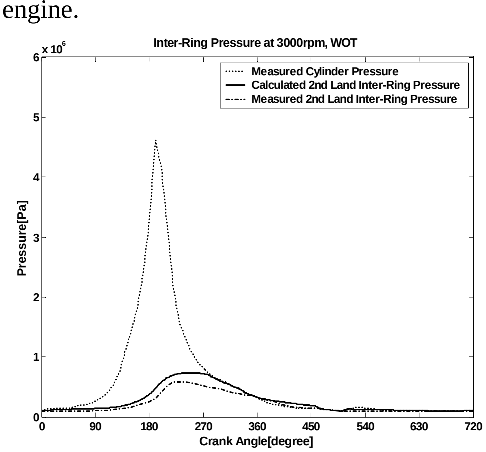

Fig. 1 Comparison between measured 2nd land pressure [9] and calculated 2nd land pressure of a 2V-MPI engine

2. RESULTS

In order to examine the reliability of this developed computer program, the measured 2nd land pressure [9] was compared with the calculated value. For example, in a case operating at 3000rpm and full load, the result showed quite a good correlation, Fig. 1. Also, for several firing engines, the calculated values of oil consumption are compared to the ranges of measured values in Fig. 2. The calculated oil consumption was well correlated with the measured range, except in a few cases.

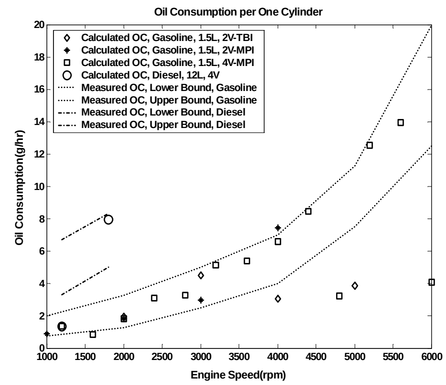

Fig. 2 Oil consumption calculation results at various speeds.

3. CONCLUSION

The calculated values of oil consumption are well correlated with the ranges of measured values for several firing engines. Using the developed computer program, the real time condition of an engine in terms of oil consumption can be predicted with good reliance.

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