Effect factor research on monitoring wear of piston ring based on magnetoresistive sensor

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Abstract

Piston ring is one of the important parts in diesel engine, and its excessive wear reduces the sealing performance of the combustion chamber, the method on monitoring wear of piston rings with the magneto-resistive sensor is researched from the simulation viewpoint, the research shows that the amplitudes reduce with the increase of the piston ring wear. The theoretical basis for monitoring piston ring wear with a MR sensor is provided.

Keywords: piston ring wear, magneto-resistive sensor, diesel engine

1 Introduction

Piston ring is one of the important parts in diesel engine, and its excessive wear reduces the sealing performance of the combustion chamber, which reduces the performance and the reliability of the diesel engine. In order to obtain the real-time operation status of the piston ring, the on-line monitoring methods should be researched. The wear of the piston ring can be measured by a magnetic sensor, and some monitoring system can achieve the monitoring function at present [1, 2].

Literature [3] studied the online monitoring method for the general piston rings based on the magneto-resistive sensor. On the research foundation of the literature [3], the effect of piston ring motion was researched in the paper, and it provides the theoretical basis for the practical application in the diesel engine.

2 Detection principle of magneto-resistive sensor

When a diesel engine works, the piston and the piston ring reciprocate within the cylinder and a magneto-resistive (MR) sensor is installed on cylinder liner to measure magnetic field intensity, as shown in Figure 1a. Figure 1b shows the distributions of the magnetic flux density when the piston ring passes the MR sensor. The change of the magnetic field intensity in Z direction can be found according to dealing with monitoring data. If the piston rings wear, the amplitudes of the magnetic field intensity on monitoring point would change respectively. And then the output amplitudes of the MR sensor change also, so that the wear of the piston rings can be detected.

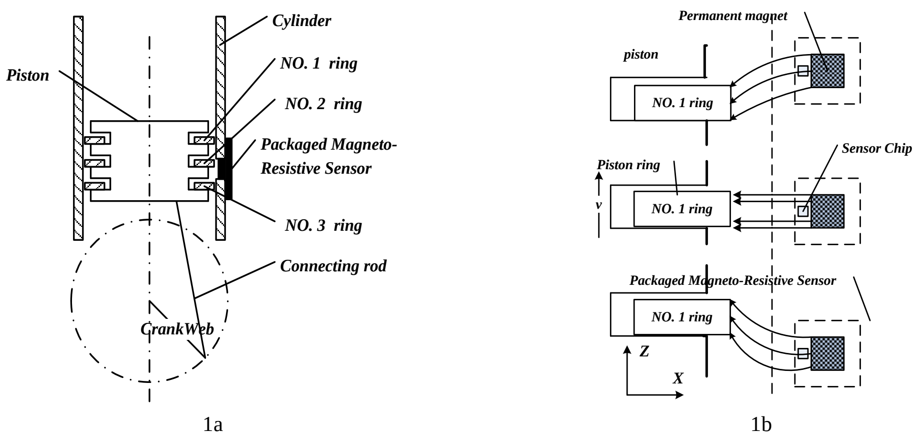

FIGURE 1 Sketch map of magnetic lines of force

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According to detection principle, the piston ring wear can be monitored with the amplitude change of magnetic field intensity, which may be bound up with its radial motion, including speed and acceleration, and has nothing to do with the axial movement, so the simulation must be finished to find out the relation between the radial motion and the wear of the piston ring.

3 Dynamics simulation on piston ring

3.1 DYNAMIC ANALYSIS ON PISTON RING

It needs to computer the balance equation of piston ring to find its radial motion. Figure 2 shows the force analysis of piston ring [4, 5].

The force of ring in axial direction includes:

$F_{a,con}$, the force between the ring groove and ring, including the oil film pressure $F_{a,oil,con}$ and the contact pressure between the ring groove and ring $F_{a,gro,con}$.

$F_g = mg$, the gravity of ring.

$F_{a,gas}$ the axial cylinder pressure.

$F_{a,fric}$ the friction force between the cylinder wall and piston ring.

The axial equation is given as:

$$m\frac{d^2y}{dt^2} = F_{a,con} + F_{a,gas} + F_{a,fric} + mg \text{ .} \quad (1)$$

The force in radial direction includes:

$F_{r,con}$, the force between the cylinder wall and ring, including the oil film pressure $F_{r,oil,con}$ and the contact pressure between the cylinder wall and ring $F_{r,cyl,con}$

$F_{tension} = k_r(h' + h_0)$ the tension of piston ring, where k_r is the radial elastic coefficient of the piston ring.

$F_{r,gas}$ the radial cylinder pressure.

$F_{r,fric}$ the friction force between the ring and groove,

$F_{rl,gas}$ the gas force acting on the ring surface near cylinder wall due to the less lubricating oil.

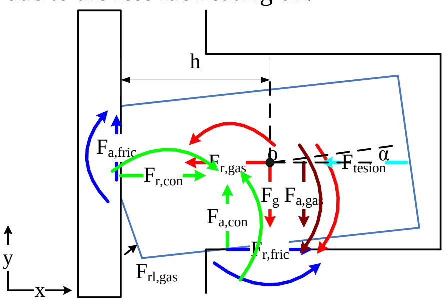

FIGURE 2 Force diagram of piston ring

The radial Equation is given as:

$$\begin{aligned} m\frac{d^2h}{dt^2} &= F_{r,con} + k_r(h' + h_0) + F_{r,gas} + F_{r,fric} + F_{rl,gas} \\ &= F_{r,oil,con} + F_{r,cyl,con} + k_r(h' + h_0) + F_{r,gas} + F_{r,fric} + F_{rl,gas} \end{aligned} \text{ .} \quad (2)$$

The Torque equation is given as:

$$I\frac{d^2\alpha}{dt^2} = M_{a,con} + M_{a,gas} + M_{a,fric} + M_{r,con} + M_{r,fric} + M_t \text{ ,} \quad (3)$$

where $M_t = k_t\alpha$, $k_t = \dfrac{Eb^3 \ln\left(\dfrac{D}{d}\right)}{3(D+d)}$.

I is the moment of inertia, α the angle of inclination, E the modulus of elasticity, b the axial height, D the outer diameter, d the inner diameter.

The axial motion equations of the piston and piston ring can be described as:

$$y = y_p + y_{rp} \text{ ,} \quad (4)$$

$$\frac{dy}{dt} = \frac{dy_p}{dt} + \frac{dy_{rp}}{dt} \text{ ,} \quad (5)$$

$$\frac{d^2y}{dt^2} = \frac{d^2y_p}{dt^2} + \frac{d^2y_{rp}}{dt^2} \text{ ,} \quad (6)$$

where y is the axial displacement of piston ring centre of gravity, y_p the axial displacement of piston, y_{rp} the axial displacement between piston ring and piston.

According to the relationship between y_p and crank angle, piston ring motion trajectory can be found.

3.2 THE RADIAL MOTION SIMULATION ON PISTON RING

The wear limit of the piston ring is 4 mm for the marine diesel RTA52U, so the wear rage of the piston ring was set from 0 mm to 4 mm with a 1 mm step, thus the piston ring motions were simulated in various wear conditions according to the previous equations.

The radial velocity and displacement of piston rings were found during a working cycle of diesel engine. Figure 3 shows the radial velocity and displacement curves of the piston rings without wear.

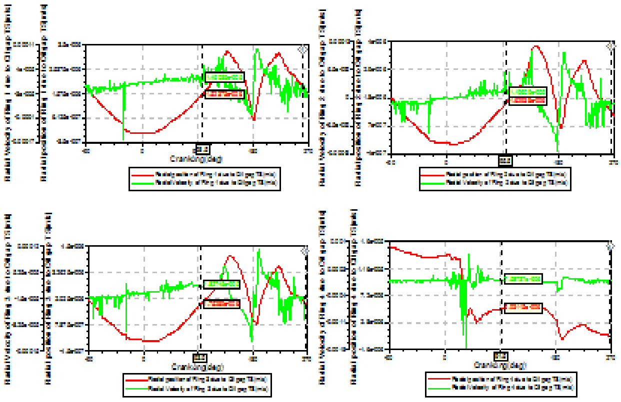

FIGURE 3 The radial velocity and displacement of piston rings

According to simulation results, it can be found that the change tendencies of the radial velocity and acceleration are almost the same for the piston rings except NO.4 ring (oil ring), and the minimal radial displacement occurs at the maximum combustion pressure.

When the piston rings passed the monitoring point in various wear conditions, the radial motions of piston rings were found, as shown in Table 1.

TABLE 1 Motion parameters for ring passing sensors (100 r/min)

Piston ring	Wear value 0mm		Wear value 1.0mm	
	Radial speed(m/s)	*Radial displacement (m/s2)*	*Radial speed(m/s)*	*Radial displacement (m/s2)*
NO.1	1.5e-5	1.5e-6	1.5e-5	1.8e-6
NO.2	1.2e-5	1.68e-6	1.2e-5	2.2e-6
NO.3	1.8e-5	1.8e-6	1.8e-5	2.1e-6
NO.4	7.6e-6	5.0e-6	7.6e-6	5.0e-6
Piston ring	**Wear value 3.0mm**		**Wear value 4.0mm**	
	Radial speed(m/s)	*Radial displacement (m/s2)*	*Radial speed(m/s)*	*Radial displacement (m/s2)*
NO.1	1.5e-5	1.6e-6	1.5e-5	1.6e-6
NO.2	1.3e-5	1.9e-6	1.3e-5	1.9e-6
NO.3	1.8e-5	2.1e-6	1.8e-5	2.1e-6
NO.4	6.9e-6	2.4e-5	6.9e-6	2.4e-5

4 Simulation on magnetic field intensity

A finite element model consisting of a piston, piston rings, a cylinder liner, and a magneto-resistive sensor was established on the basis of actual size, the magnetic field intensity of the monitoring point could be simulated. The piston ring motions of finite element model were set according to the previous results. Thus, the magnetic field intensity was simulated under different wear conditions, as shown in Figure 4. The relation between the amplitudes of the magnetic field intensity and the piston ring wear is shown in Figure 5. It shows that there is corresponding relationship between the amplitudes and the ring wear, and the amplitudes decrease with the increase of the ring wear.

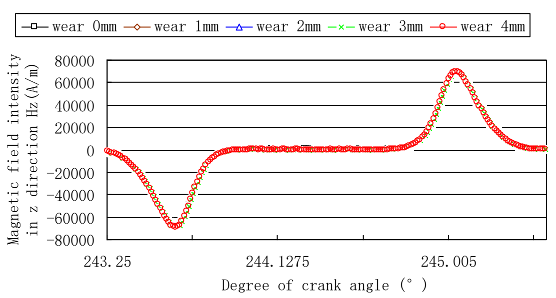

FIGURE 4 Calculation waveform

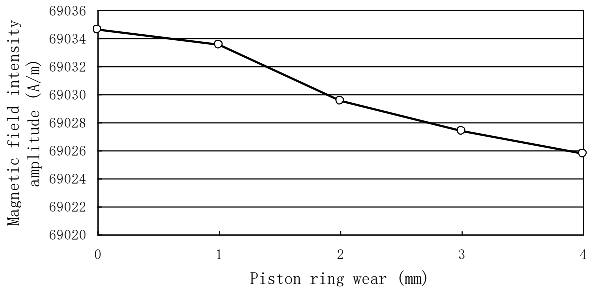

FIGURE 5 The relation between amplitudes and ring wear

5 Conclusions

The magnetic field intensity on the monitoring point is simulated for RTA52U marine diesel engine during a working cycle, the method on monitoring wear of piston rings with the magneto-resistive sensor is researched from the simulation point of view, it can be found the ring radial movements do not affect the amplitudes of the magnetic field intensity, and there is corresponding relationship between the amplitudes and the ring wear. Furthermore, the amplitudes reduce with the increase of the piston ring wear. It provides the theoretical basis for monitoring piston ring wear with a MR sensor.

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