Experimental Study on Monitoring the Wear of Journal Bearings of Diesel Engine by Thermoelectric Method

Jun ZHU, Hong-liang GAO, Chen LIU, Li-guang WANG and Jun YU
College of Mechatronics and Control Engineering, Hubei Normal University, Huangshi, 435002, China

Keywords: Diesel engine, Main journal bearing, Thermoelectricity, Wear.

Abstract. The experimental research on monitoring wear of main journal bearings by thermoelectric method for a diesel engine is introduced mainly in the article. The measured thermoelectric signals is related to intensity of the friction and the rotational speed on a sliding bearing test bench. The thermoelectric effect and the weak signals caused by the friction between the eccentric rotor and the sliding bearing are detectable. The thermoelectric signal peaks are pointed to the different cylinder ignition points on a diesel engine test bench. It is shown that the wear of the different main journal bearings is localizable.

Introduction

Main journal bearing is the critical and vulnerable component of diesel engine, and its damage shows wear-resistant alloy layer destruction. The causes of damage of main journal bearing are bad oil purification, crankshaft neck's low surface roughness grade, its geometric difference being too large, crankshaft deformation, frequent start-stop of diesel engine, over-speed and overload for a long time, etc. The uneven excessive wear of main journal bearing will enlarge the gap between bearing and journal, cause rapid wear of cylinder liner, piston and piston ring, lead to incomplete combustion and fuel consumption rate increase, even the crankshaft deflection, melt fracture and crankcase explosion and all these malignant accidents.

Currently the ways monitoring wear status of diesel engine journal bearing mainly includes oil analysis, temperature monitoring and vibration monitoring method et al[1-7]. Due to some reasons like the complexity of diesel engine excitation source, transmission path and signal interference and low SNR, the engineering application of these methods is difficult. In this article, through experimental study of thermo-electric method on monitoring the wear state of main journal bearing of diesel engine, it is proposed to con-firm that the thermoelectric signal produced by the friction between crankshaft and journal bearing can be detected, and the consistency of the wear state of main journal bearing and some of the characteristic parameters such as thermoelectric signals’ fluctuation amplitude, and to lay technology foundation for engineering applications of thermoelectric method monitoring the wear state of main journal bearing of diesel engine.

The Principle of Thermoelectric Method Monitoring the WEAR State of Main Journal Bearing of Diesel Engine

The thermoelectric method monitors journal bearing wear condition by measuring thermoelectric potential produced by friction between crankshaft and journal bearings. Figure 1 is the monitoring principle diagram of thermoelectric method. The monitoring system mainly includes the crankshaft adapter 5, slip ring 6, sampling resistance 7, regulating amplifier unit 8 and the thermoelectric potential 9. Due to local damage of lubricating oil film between journal bearing and journal, journal bearing and crankshaft rub each other and produce heating. Different journal bearings’ wear conditions result in the difference of friction heat produced. It drives active free electrons in journal tunneling into main bearing, so an electrical potential difference between crankshaft and frame
(land) forms. The free electron flow is exported by crankshaft adapter and slip rings, then received by sampling resistance. Like this the thermoelectric potential is gained at both ends of sampling resistance. By processing of conditioning and amplifying unit, the thermoelectric potential signal of less interference, its amplitude and waveform being easy to measure is available. By analysis of relationship between thermoelectric potential signal's feature and journal bearing wear degree, online monitoring of journal bearing wear can be realized.

![Diagram](image)

Figure 1. Thermoelectric method monitoring schematic diagram.

**Experimental Researches on Sliding Bearing Test-bed**

Due to complex structure inside diesel engine and a great many of moving parts, thermoelectric signal is interfered by other factors seriously. Therefore the author designed a single rotor of sliding bearing test bed, in order to eliminate the influence of other factors. The liner material of radial sliding bearing was copper; the material of axis was 45# steel. The servo motor drove shaft, rotor and eccentric block to rotate. Lubricating oil was injected through oil pipe from the top of bearings, and then returned to oil box from both sides and bottom of the bearings. Thermoelectric signal passed through the mercury slip ring firstly, then enlarged and acquired by acquisition card and measurement software. By the elastic support, support and electrical insulating elastic coupling, the influence of electric shock and vibration from sliding bearing and servo motor to the thermoelectric signal was reduced. The speed of the rotor was controlled by the servo motor, and bearings’ lubrication and wear condition were adjusted through oil supply. By controlling the rotation of the rotor with eccentric block on test bed, the rotating shaft and bearing were made to rub each other and then thermoelectric effect would happen.

![Graphs](image)

Figure 2. Different rotational speed and friction strength of thermoelectric signal.

Figure 2 is different rotational speed and friction strength of thermoelectric signal curve. The right signals are for increase of eccentric of the left side thermoelectric signal. When rotation speed in 480 r/min (fig. 2 a)), adjust bearing to half dry friction condition and leaping parts appear, with the base amplitude value of the signal being zero; Increase the weight of the eccentric block, the signal amplitude increases obviously. When axis rotates in 600 r/min (fig. 2 b)), adjust bearing to dry friction condition, friction produces 10 cycles’ fluctuation per second, the zero base of the
amplitude is absent; increase the weight of the eccentric block, the signal’s average and rotary amplitude increase. To a certain extent, the increase of rotation speed affects friction strength, thermoelectric effect gradually intensifies. By tests of sliding bearing bed it is confirmed that the friction between eccentric rotor and sliding bearing produces thermoelectric effect and the weak signal can be detected.

Experimental Researches on Diesel Engine Test Stand

The Test Objects and Test System

Considering the limitation of sliding bearing test-bed, on the basis of above-mentioned tests, some experimental studies were carried out on the 4120 SD1 diesel engine test stand. Test system consists of thermoelectric sensor, magneto-electric sensor, cylinder pressure sensor, data acquisition card and industrial computer. The diesel engine test stand is shown as in figure 3. The signal of top dead center (TDC) is time reference for thermoelectric signal, and the signals of cylinder pressure and instantaneous speed act as its auxiliary analyzing signals.

Main Journal Bearing Fault Simulation and Test Conditions

Main bearing fault simulation and test conditions are shown as in table 1 and table 2. All bearings were artificially polished from factory default to set value. When journal bearing was polished to 0.3 mm, the lubricating oil pressure dropped to 0.34 MPa, but the normal was 0.55 MPa. When the lubricating oil leakage amount became larger in bearings, the further increase of wear might lead to low lub oil pressure and tile burning accident of main journal bearing.

<table>
<thead>
<tr>
<th>Item</th>
<th>Main bearing state</th>
<th>Wear/ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All normal</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>The third tranche only</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>The third tranche only</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>The third tranche only</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>The fourth tranche only</td>
<td>0.1</td>
</tr>
<tr>
<td>6</td>
<td>The fourth tranche only</td>
<td>0.2</td>
</tr>
<tr>
<td>7</td>
<td>The fourth tranche only</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Table 2. Test working conditions of diesel engine.

<table>
<thead>
<tr>
<th>Item</th>
<th>Speed/ r/min</th>
<th>Power/kW</th>
<th>Load/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standstill</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Motor drive</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>900</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1500</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>1500</td>
<td>22</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>1500</td>
<td>33.1</td>
<td>75</td>
</tr>
<tr>
<td>8</td>
<td>1500</td>
<td>39.7</td>
<td>90</td>
</tr>
<tr>
<td>9</td>
<td>900</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>Standstill</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The Processing Method of Thermoelectric Signal

To determine the location and degree of wear of bearing wear, the thermoelectric signals are processed and analyzed as follows:

**Sampling.** Extract specific sampling sequence from the thermoelectric, cylinder pressure, TDC and instantaneous rotation speed signal, as the length of the 240 k sampling points, if sampling rate is 60 KHZ, the interception time is about 4 s. When diesel engine has a rotating speed of 1500 r/min, the sampling length is about 50 working cycles of diesel engine. To intercept a diesel engine work cycle one by one from the zero crossing point of every 2 turns of TDC signal, determining the sampling sequence number is important.

**Cycle Averaging.** Because of some random factors such as diesel engine fuel injection at work and the characteristics of discontinuous work cycle, its instantaneous speed often fluctuates. In order to improve the reliability of analysis, to count thermoelectric signal average with the appropriate work cycles.

**Homogenizing of Crankshaft Angle.** The corresponding flywheel tooth waveform obtained by magneto-electric speed sensor is similar to sine wave, and its corresponding sampling time is the sampling interval of a gear turned by a fixed angle of the flywheel (360° / Z, Z for flywheel gear number). By capturing the beginning and end of the sine wave, we can obtain a fixed angle of flywheel gear signal sequence index. Choosing the corresponding points of thermoelectric data sequence to constitute a new set of thermoelectric data sequence, and then the data sequence is interpolated to 720 points (depending on angle resolution), finally the thermoelectric signal with crankshaft angle can be accomplished.

**Signal filtering.** To analyze thermoelectric signals and the running characteristics of diesel engine, and combine with actual effect, finally select 6 order of Butterworth IIR low-pass filter.

**Faulty Bearing Localizing.** To make thermoelectric signal amplitude of a cycle of sampling sequence as polar radius, the crankshaft angle as angular coordinate, and input cylinder number by firing order, the faulty main bearing localizing map can be drawn.

Analysis of Experiment Result

Figure 4 is thermoelectric signal’s change curve of motor dragging with the fourth journal bearing of 0.2 mm wear, which is divided into two periods: starting phase and steady state operation phase. Motor dragging is to control the fuel rack by zero, and hold down the start button by dc starter motor dragging diesel engine to rotate with duration of 3 ~ 5 s. Compared with sliding bearing test-bed test, the starting phase can simulate bearing state of dry friction, and the steady state operation phase can simulate the boundary lubrication condition. Because the crankshaft of diesel engine directly drove pump to supply lubricating oil, the lubrication of main bearing became lagged. In starting phase main bearing was under oil-free dry friction condition. About 2 s after diesel engine
started lubricating oil reached main bearing, and main bearing went into a state of boundary lubrication. As you can see from figure 4 a): In 0 ~ 2 s thermoelectric signal is very densely arranged and its amplitude is very large; After 2 s the signal tends to be thin and smooth. In figure 4 b), the corresponding thermal signal amplitude is also big, but cyclical changes are more obvious. In figure 4 the cylinder pressure signal comes from the fourth cylinder; the timing is based on the fourth cylinder top dead center signal; Speed signal was measured from the flywheel gear ring. The time between each two TDC points corresponds to one work cycle of diesel engine; in each work cycle thermoelectric signal has a crest, and peak position lies in the TDC point for firing of the fourth cylinder.

![Thermoelectric signal of cyclical change curve in motor dragging working condition.](image)

Figure 4. Thermoelectric signal of cyclical change curve in motor dragging working condition.

Put the thermoelectric signal amplitude as polar radius, the crankshaft angle as angular coordinate, and input the cylinder number by firing order, the localizing map of faulty main bearing can be drawn (figure 5). These jumps of signals are obvious at the ignition points of four cylinders of diesel engine one by one.

![Thermoelectric signal location map with main bearing in normal state.](image)

Figure 5. Thermoelectric signal location map with main bearing in normal state.
Conclusion

1) The sliding bearing test shows that thermoelectric potential is related with the rotating speed and the frictional strength. The thermoelectric signal is detectable. The higher the rotating speed and the more intense the friction, the thermoelectric effect would be more obvious. The thermoelectric effect and the weak thermoelectric signals of friction between eccentric rotor and sliding bearing could be detected.

2) The diesel engine stand test shows that with the same diesel engine speed, load and the abrasion loss of main bearing of diesel engine, the thermoelectric signal peaks point to different cylinder ignition points. The wear state of main bearing of diesel engine can be located by thermoelectric signals. There exists dry friction, boundary lubrication, and normal lubrication condition when main journal bearing of diesel engine is at work. When in the dry friction, the thermoelectric signal peak value is greater than that of the boundary lubrication. Thermal signal peak value is associated with the degree of wear of bearing.

Acknowledgment

Funded projects: Hubei province education department science fund projects (B2017148), Hubei province natural science fund projects (2016CFC735), Hubei Engineering Laboratory of intelligent logistics transportation equipment fund projects.

References


