The Lubrication Oil Wearing Particles Monitoring System with Three-coil Inductive Sensor

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Abstract. In the lubrication oil of the machinery devices, metal wearing particles reflect the wearing state in real time. Therefore, lubrication oil wearing particles monitoring system can identify the health state of the machinery devices. Based on the three-coil inductive sensor, this paper proposes the monitoring system including the exciting circuit, the detection circuit, the MCU system circuit and the host PC software. Experimental result shows that the proposed monitoring system can captures the output signal of the metal wearing particle.

Introduction

Most mechanical malfunctions are caused by mechanical wearing. Those particles produced by wearing debris in lubrication oil of mechanical equipment can reflect the working condition of the machine. Among the equipment failures, the wearing failure caused by metal debris is more than 70\%. Therefore, the wear debris of lubricating oil reflects the health status of the equipment, as well as an important basis for the diagnosis and the prediction of equipment failures. Lubricating oil debris detection technology includes off-line detection and on-line detection \cite{1}. The former needs to extract wearing debris from the lubrication oil system, analyze the debris with ferrograph, spectral or scanning electron microscope, etc. \cite{2,3,4}. The latter needs to directly install the sensor onto the lubrication oil pipeline to detect the debris in real-time. The on-line detection sensor includes the MetalScan sensor developed by GasTops \cite{5}, the lazer sensor developed by Y. Iwai \cite{6}, the optical online debris monitoring sensor jointly developed by Takusosato and M. Linzer \cite{7} and some other researches \cite{8,9}.

Considering that the metal wearing debris particles are the important factor in equipment wearing, this paper studies the three-coil inductive sensor for lubrication oil debris detection and proposes the on-line monitoring system with the exciting circuit, the detection circuit, the MCU circuit and host PC software.

The Principle of the Three-Coil Inductive Sensor

Based on electromagnetic induction law, the magnitude of induction electromotive force in circuit is proportional to the changing rate of the magnetic flux in the circuit loop. Induction electromotive force is determined by the magnetic field direction and its changing direction. The conventional inductive sensor for lubrication oil debris detection generally applies the scheme with three coils in which three coils wound around the same magnet inert tube. As the driving units, two of the coils are in serials with each other and wounded reversely around the tube keeping symmetry on both sides. As the sensing unit, the third coil is in the middle of the two reversely wounded coils. When alternating current passes the driving coils, the induced electromagnetic force in the center of the sensing coil is canceled because of their same numbers of windings and opposite directions, so that the output of the sensing coil is almost zero \cite{10}. When metal debris enters the sensor, the disturbance is involved into
the magnetic field inner the inductive coils. The sensing coil converts the disturbance into a voltage signal for monitoring, where the amplitude of the output voltage determines the volume of metal debris. According to the different effects on the magnet field between ferromagnetic and diamagnetic metal debris, the phase of the output signal determines the magnetic type of metal debris [11]. The scheme of the three-coil inductive sensor is shown in Figure 1.

![Figure 1. The scheme of the three-coil inductive sensor.](image)

**The Overall Design of the On-line Monitoring System**

The exciting circuits mainly consist of the driving circuit, the unipolar-bipolar conversion circuit, the filter circuit and the voltage-current conversion circuit. The detection circuits mainly consist of the amplifying circuit and the demodulation circuit. Besides that, the monitoring system includes the central MCU circuit, the communication circuit and the Host PC. The schematic diagram of the monitoring system is shown in Figure 2.

![Figure 2. The schematic diagram of the monitoring system.](image)

The driving circuits generate sinusoidal exciting voltage signals required by sensitive element. Then the signals are converted from unipolar to bipolar. After they are filtered by the analog low-pass filter, the driving signals are converted from voltage to current in order to excite the two driving coils. The output voltage signals from the sensing coil are amplified and rectified accurately, and then they are extracted by the demodulated circuit. Finally, the signals are acquired by the microcontroller after they are converted from analog signals to digital signals by the microcontroller's built-in A/D conversion. Finally, the digital signals are transmitted to the host computer through the communication circuit.

**Central MCU Circuit**

C8051F060 is an advanced microcontroller with built-in A/D converter which provides 16-bit resolution and up to 1Mbps conversion rate. Therefore, C8051F060 microcontroller is chosen as the
central unit to control the driving circuit, collect the output signal and communicate with PC. The designed circuit is shown in Figure 3.

Figure 3. The central MCU circuit with C8051f060.

A/D conversion uses the internal 2.5V reference voltage of C8051F060. Since the 16-bit resolution of the A/D converter, the signal quantization error is only ± 0.038mV.

The Test Results

We wound the 1200 driving coils and the 1000 testing coils with pack pain copper line whose diameter is 0.33mm. Finally, the testing system is established with the coils and the circuit as the Figure 4.

Figure 4. The proposed testing system.
Before the small icon particle passes through the testing system, it is measured by electron microscope and the result is shown in Figure 5. Its length is about 258 μm.

![Figure 5. The measurement of the small icon particle.](image)

The host PC software is developed with NI LabVIEW which is a kind of graphical programming language. The test result is shown in Figure 6, in which the output voltage signal is nearly 0.6V.

![Figure 6. Result of the detection system.](image)

After different size of particles are measured by this monitoring system, the curve describing the relationship between the metal particle diameter and the output voltage is shown in Figure 7.

![Figure 7. The detection signals for different diameter.](image)

Wherein, the result curve presents the mathematical model in which output signal approximately has linear relationship with the square of the metal particle diameter.
Summary

With three coils, the schematic of the inductive sensor is presented. This paper proposes the monitoring system with the inductive sensor is proposed with exciting circuit, detection circuit, MCU circuit and host PC. Finally, the effectiveness of the monitoring system for detecting the metal wear particles is demonstrated in the test section. Therefore, the monitoring system can be conveniently used to detect the working states of the machines.

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References


