**Academic Journal of Science and Technology**
ISSN: 2771-3032 | Vol. 14, No. 2, 2025

# Electromagnetic Induction Sensor Design for Metal Oil Wear Particle Detection

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**Abstract:** When the mechanical equipment is working, the internal units interact with each other to produce different degrees of wear, wear will produce wear particles, the generated wear particles will flow around with the lubricating oil, if not timely detection and maintenance, it will aggravate the wear process, thus affecting the service life of the entire mechanical system. In this paper, a new high-precision three-coil electromagnetic induction sensor for metal oil wear in mechanical equipment is proposed, and Laval nozzle is innovarily applied to the oil inlet of the sensor. Firstly, based on the principle of electromagnetic induction, the physical characteristics of metal particles and their influence on magnetic field are analyzed, and the working principle and key parameters of the sensor are determined. Secondly, the overall structure of the sensor is designed, and the packaging and protection design are carried out according to the working condition. Finally, the coil schematic was established in Maxwell and boundary conditions and initial conditions consistent with the actual working conditions were set up for simulation verification under different types of wear particles at 1m/s. The results showed that the sensor's signal response was obvious under different particle sizes, which verified the rationality of the sensor design.

**Keywords:** Electromagnetic induction, metal abrasive particles, oil detection, sensor design, simulation verification.

## 1. Introduction

In the operation of mechanical equipment, the friction between rigid components inevitably leads to wear, and wear is often one of the key factors leading to equipment failure. During the wear process, a large number of metal abrasive particles will be produced, which will enter the lubricating oil and move with the oil, which may cause secondary wear of the mechanical equipment. There are rich tribological information in metal wear particles. The wear condition of friction pairs can be directly reflected by analyzing their size, type and quantity. This information is of great value for predicting the service life of mechanical equipment and fault diagnosis and location. Therefore, metal wear particles in lubricating oil are a key medium for studying tribological surface wear mechanism and identifying wear failure types [1].

Oil particle monitoring technology at present mainly divided into two major categories of on-line detection and an off-line testing. Offline detection usually uses spectral and ferrography methods. Although the detection accuracy is high, there are problems such as discrete sampling, long sampling period and limited range of analyzed particle sizes, which lead to low detection efficiency [2]. The on-line detection mainly depends on the induction, optical, capacitive and ultrasonic wear particle sensors. This research team has a certain research foundation in the detection technology of metal wear particles in oil, especially focusing on the research of inductive wear particle detection sensors [3]. Because of its easy installation, less environmental impact, and effective detection of ferromagnetic and non-ferromagnetic metal wear particles, inductive wear detection sensors have become a hot topic in recent years.

For example: the foreign research and development of electromagnetic detection sensor have GaSTOPS Canada MetalSCAN, techalerttm10 MA - COM companies in the United States, etc. The University of Akron conducted a study to detect metal particles by monitoring capacitance changes in a pair of microelectrodes in a microfluidic channel (width 100μm). The technique is able to detect metal debris particles about 10μm in size. The University of Akron in the United States detects metal particles by detecting capacitance changes in a pair of microelectrodes in a microfluidic channel (100μm), and can detect metal debris particles of about 10μm [4]. In China, Wang et al. proposed an improved induction sensor, which uses a saddle-shaped coil probe to generate a uniform magnetic field to improve the sensitivity of wear chip detection, and has a good ability to identify ferromagnetic and non-ferromagnetic wear chips with a diameter of less than 100μm [5]. Xie et al. proposed a three-coil sensor with both flux and detection accuracy, and optimized the coil design to improve the sensitivity [6]. YIN et al. designed a dual-channel wear particle detection sensor, which makes use of the correlation of dual-channel signals and can distinguish particle characteristics well through the cross-reference of dual-channel signals. A signal enhancement model is also proposed to enable it to extract pulse signals generated by wear particles more accurately [7].

Sensors of the face two problems: on the one hand, the sensor design is often smaller pipe is used to ensure the sensitivity of the sensor, which restrict the flow capacity of the sensor, may make the oil plug, and small pipe can only be installed in the bypass, usually cannot detect the entire oil; On the other hand, the use of large diameter circular pipelines may increase the flow rate but reduce the sensitivity [8].

Based on previous research, on the basis of the principle of electromagnetic induction and the innovative laval nozzle structure domain sensor combination of inlet, we design a high precision three radial induction coil structure monitoring sensor, oil grits after laval nozzle of oil will be faster, the oil carried by abrasive particle velocity also rose, The more obvious the induced voltage signal is generated by the metal wear particles through the sensor. The reliability of the sensor structure design is verified by detecting the induced voltage change trend caused by the metal wear particles passing through the sensor.

# 2. The Structure of The Sensor Structure Design and Test Principle

## 2.1. Sensor structure

A high-precision three-coil structure radial induction type oil wear particle monitoring sensor, its structure is shown in Figure 1, the oil inlet is Laval nozzle structure, Laval nozzle structure is shown in Figure 2, the sensor consists of two excitation coils and an induction coil, the induction coil evenly wound on the oil pipe, two excitation coils symmetrical distribution on both sides of the induction coil.

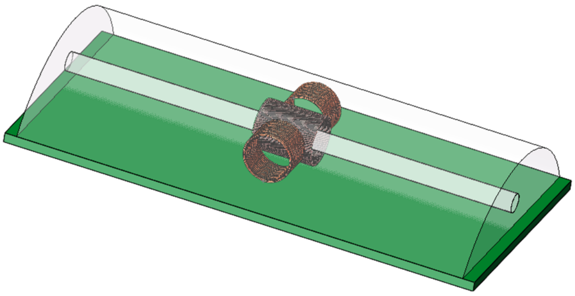

**Figure 1.** Schematic diagram of sensor

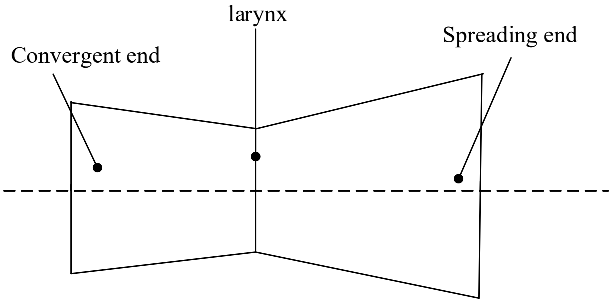

**Figure 2.** Laval nozzle structure diagram

Laval nozzle is composed of convergence section, throat section and expansion section. Its working principle is to use the acceleration process of the fluid in the nozzle to convert the pressure energy of the fluid into kinetic energy. In the oil wear particle sensor, the expansion section of the Laval nozzle is the acceleration end, which can accelerate the wear particles in the oil to a higher speed, so that the induced voltage signal is more obvious [9].

## 2.2. Detection Principle

When AC excitation is applied to both excitation coils, equal but opposite magnetic fields are generated. These magnetic fields cancel each other at the center of the induction coil, leaving the induction coil in a zero magnetic field state. When the metal particles enter the alternating magnetic field, magnetization effect and eddy current effect will be produced. The magnetization effect will enhance the original magnetic field, while the eddy current effect will weaken the original magnetic field. When the ferromagnetic particles enter the sensing area, they are mainly affected by the magnetization effect, and the original magnetic field will be positively enhanced, resulting in a trend of positive increase in the induced voltage signal. When the ferromagnetic particles leave the sensing area, the original magnetic field will be enhanced in reverse, and the induced voltage signal will show a negative trend. Therefore, the complete ferromagnetic particle signal shows the characteristics of first decreasing and then rising; When non-ferromagnetic particles enter the sensing area, they are mainly affected by eddy current effect, which weakens the original magnetic field in a positive direction and increases the induced voltage signal in a negative direction. When the non-ferromagnetic particles leave the sensing area, the original magnetic field will be weakened in reverse, and the induced voltage signal will show a trend of positive increase. The complete non-ferromagnetic particle signal shows the characteristic of first rising and then falling, which is completely opposite to the characteristic of ferromagnetic particle signal. As shown in Figure 3 and 4, iron and copper mill grinding grain respectively by induction coil when the induction voltage signal change trend chart. According to the changing trend of the signal, the metal particles can be accurately judged whether they are ferromagnetic particles or non-ferromagnetic particles.

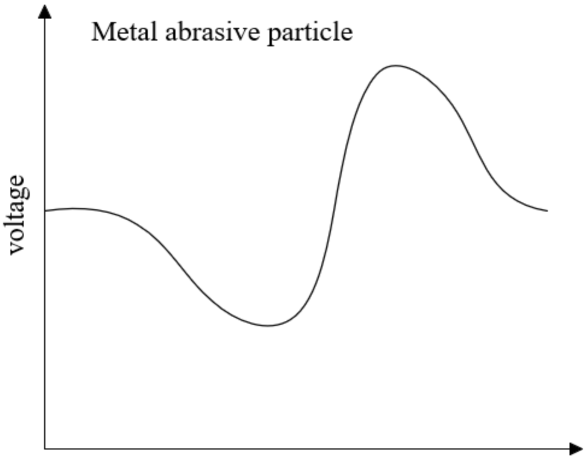

**Figure 3.** Iron wear through the induction voltage trend diagram

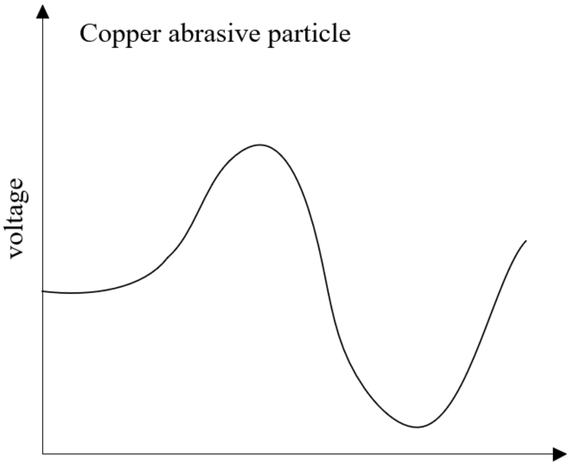

**Figure 4.** Copper wear through the induction voltage trend diagram

# 3. Finite Element Simulation Analysis

In this paper, 3D finite element analysis module of ANSYS Maxwell 2022 version is used to simulate and analyze the sensor. Because of the simple structure of the sensor's excitation and induction components, modeling can be done directly in ANSYS Maxwell. In the simulation process, the transient field solver is used for analysis. The specific modeling and simulation process is shown in Figure 5.

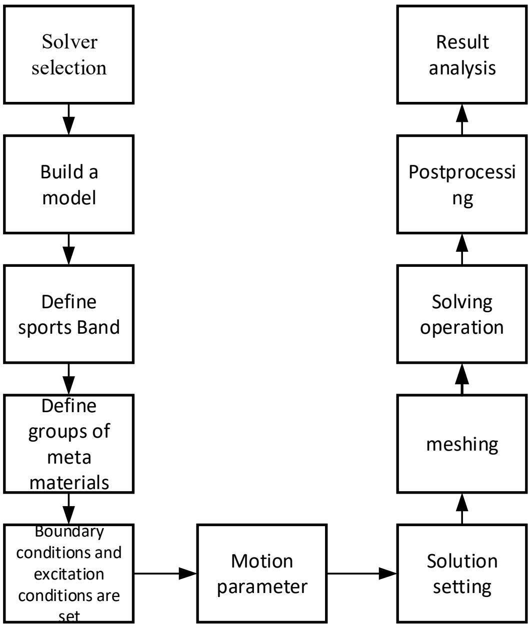

**Figure5.** Transient magnetic field simulation flow chart

The size and shape of the coil have a great influence on the detection effect. The coil selected in this paper is made based on the existing conditions in the laboratory, and the material is copper. The coil is taken as the research object to explore the detection effect of this type of sensor. The parameters used in sensor simulation in this paper are shown in Table 1.

**Table 1.** Simulation parameter setting

| Number | name of parameter | parameter values |
|---|---|---|
| 1 | excitation current | 2A |
| 2 | excitation frequency | 1000Hz |
| 3 | Inside diameter of excitation coil | 3.6mm |
| 4 | Outside diameter of excitation coil | 8mm |
| 5 | Excitation coil height | 2 mm |
| 6 | Number of turns of excitation coil | 500 |
| 7 | Inside diameter of induction coil | 3.6 mm |
| 8 | Induction coil outside diameter | 7.2 mm |
| 9 | Induction coil height | 8 mm |
| 10 | Number of turns of induction coil | 1600 |
| 11 | Wire diameter of excitation and induction coil | 0.07 mm |

Because the magnetic field simulation of the sensor has nothing to do with other structures except the coil, the mode of the sensor in Maxwell is simplified to the excitation coil and induction coil, and the three coils are set as coils during the simulation setting. The modeling diagram in Maxwell is shown in Figure 6. The cuboid area with the outer border is the air domain.

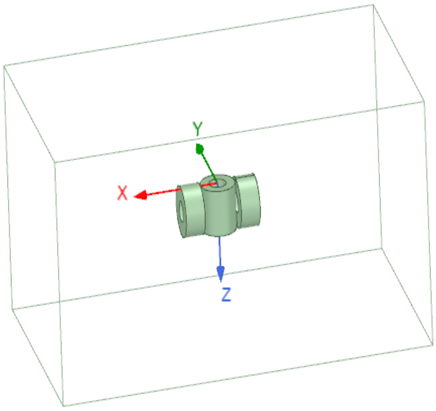

**Figure 6.** Schematic diagram of sensor magnetic field modeling

When the excitation coil is configured, the initial direction of the excitation voltage of the two coils is set to be opposite, so as to produce two magnetic fields in opposite directions. Then the whole model was divided into grids, and the specific partitioning results were shown in Figure 7. Figure 8 shows the band domain set by the abrasive particle movement.

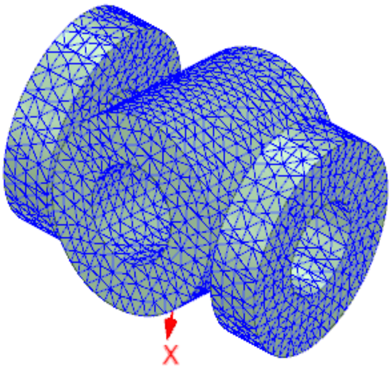

**Figure 7.** Grid division diagram

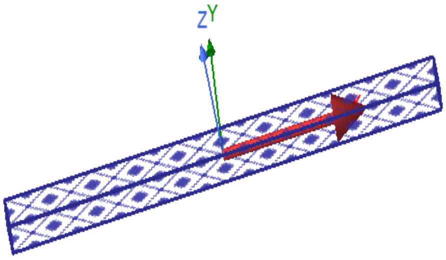

**Figure 8.** band domain Settings

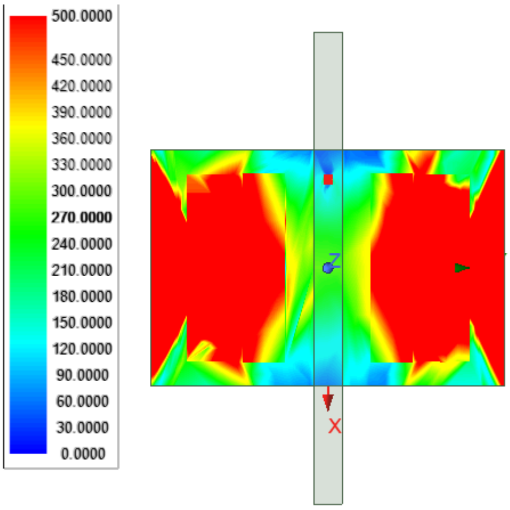

**Figure 9.** Cloud map of axial magnetic induction intensity

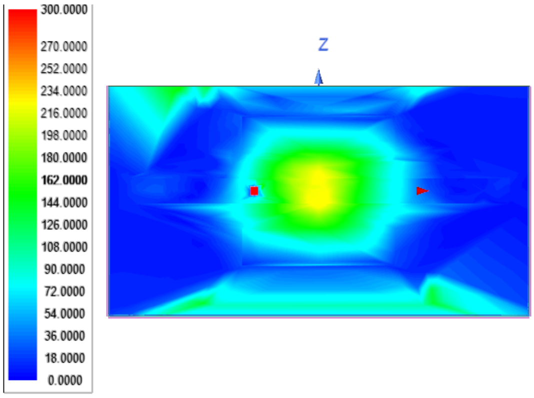

**Figure10.** Cloud image of radial magnetic induction intensity

Based on the induction coil, take axial and radial screenshots, view the magnetic field intensity cloud map,FIG. 9 is the axial magnetic induction intensity diagram of the iron wear particle moving through the induction region in the band domain. According to the diagram, it can be analyzed that the magnetic induction intensity of the axial section of the induction coil presents a significant symmetric characteristic, and the magnetic induction density distribution along the flow channel axis fluctuates from 0 to 500μT. This symmetry feature also exists in Figure 10 of the radial magnetic induction intensity when the iron wear particle moves through the induction region in the band domain, and its value fluctuates in a stable range from 0 to 300μT. The numerical analysis of the magnetic field cloud map shows that high intensity magnetic flux accumulates at the edge of the hole in the excitation coil, and its spatial distribution is consistent with the Biot-Savart law.

In order to verify the effectiveness of the design of the wear particle monitoring sensor, it is necessary to study whether the influence of different metal wear materials on the sensor output induced voltage is consistent with the theoretical model. Therefore, in this simulation, copper metal wear particles and metal wear particles are selected respectively for simulation analysis and research, and the shape of wear particles is set as square. The magnetic particles with different properties were simulated by adding 200μm iron particles and 200μm copper particles to the detection area of the sensor, and the induced voltage generated by the copper and iron particles was obtained through the parametric sweep function.

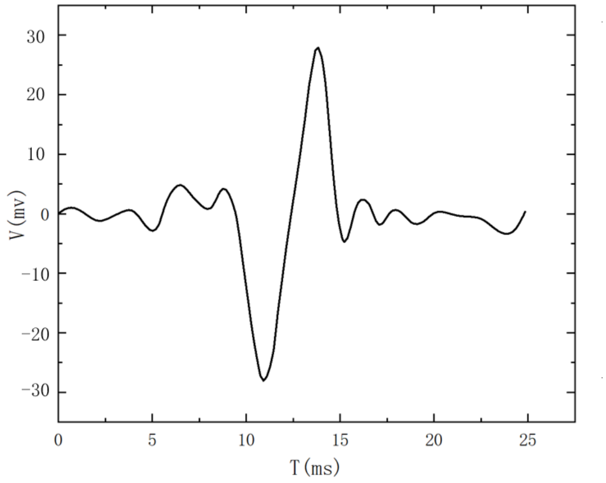

**Figure 11.** Induced voltage generated by iron abrasive particles in simulation experiment

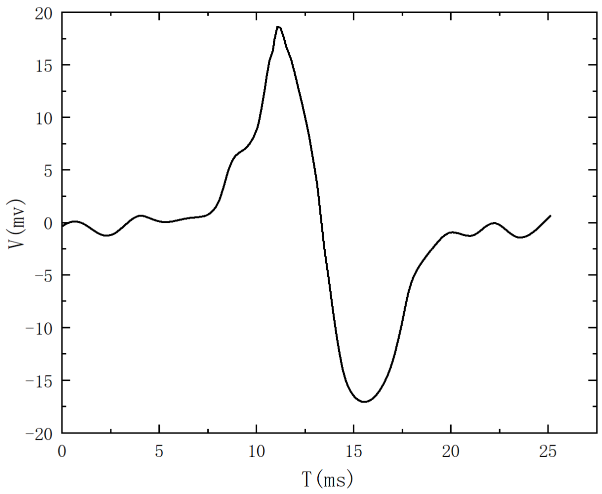

**Figure 12.** Induced voltage generated by copper abrasive eparticles in simulation experiment

## 4. Conclusion

In this paper, a new type of electromagnetic induction type oil wear particle sensor is proposed, and the effectiveness of the sensor structure design is verified by electromagnetic simulation. The experimental results show that at a speed of 1m/s, 200μm copper and iron abrasive particles pass through the induction region to produce a significant induction voltage signal. This phenomenon proves that the sensor can effectively detect the abrasive particles in the oil. Secondly, the Laval nozzle structure is innovatively applied to the entrance of the sensor. The acceleration effect of Laval nozzle on the measured oil can make the abrasive particles in the oil flow through the detection area faster, thus obtaining a stronger induced voltage signal. This improvement significantly improves the detection accuracy of the sensor and makes its performance better in actual working conditions.

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