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Lubricating Oil Pollution Detection Sensor Design

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Abstract: Metal abrasive particle content in lubricating oil is an important index to judge the degree of deterioration of lubricating oil. Established a spiral electrode capacitance sensor by the finite element software ANSYS, the simulation result shows that the sensor is sensitive to the content of metal abrasive particle in lubricating oil, not affect by the metal abrasive particle itself. According to the simulation optimization model to make the real sensor, and designed lubricating oil pollution degree measurement system with the MS3110 capacitance detection circuit and MCU. Experiments show that it can distinguish metal abrasive particle from the change of 0.1 %-0.5 % content, this change can determine the degree of pollution of metal abrasive particle in lubricating oil, provides a simple and feasible method for the oil pollution detection. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Micro capacitance detection, ANSYS, MS3110, Lubricating oil degradation degree.

1. Introduction

Lubricating oil has an irreplaceable role in daily life, and it is the necessary condition to ensure the normal operation of production equipment and prolong the service life. In the monitoring system to maintain the normal operation of the equipment, usually the working state of the equipment through detecting deterioration degree of lubricating oil [1], the correct state of lubricating oil can provide better maintenance of equipment. The monitoring system designed in this paper realized the monitoring of particles in oil liquid pollution, it can determine the reasonable changing period, it also can forecast potential faults so as to avoid catastrophic damage, or to reduce unnecessary repair in the normal operation of the equipment, or reduce downtime save repair costs. Through the design of the actual sensor device and circuit, realize the system to monitor the oil parameters.

In order to realize the system good and accurate operation, need to determine the normal work of each function module, this system, sensor design will determine whether the system can determine the lubricating oil correctly in the detection process, simulation and so many parameters on sensor. Firstly, to create the sensor simulation model, then calculate the capacitance value relationship between the content of grinding grain and metal, according to the simulation results, test the actual optimization design of a sensor model of new practical sensor, sensor, meet the measurement requirements, according to the characteristic of sensor, the MS3110 capacitance detection circuit design, and microcomputer control technology to produce lubricating oil contamination measurement system. The system can effectively measure capacitance parameters. The measurement system is calibrated by using a precision HPS2817A meter. Measurement of capacitance change by adding metal in the fresh of wear particles in lubricating oil, the conclusion achieved through the relationship between oil pollution simulation and actual measurement.

2. Sensor Simulation and Physical Design

In this paper, by using finite element software ANSYS12.0 modeling and Simulation of the sensor, the software has powerful model building and grid partition function, and is common in fluid, thermal, acoustic and electromagnetic. Mainly used the electromagnetic method that solves capacitance with the CMATRIX command macro solution [2-3]. The applied potential of the CMATRIX default is 100 V.

The ANSYS12.0 simulation process consists of three stages: preprocessing, solving and post processing.

1. Pre processing module.

Pre processing module mainly defines the simulation data needed. Which contains the definition of coordinate, node and element types, the real constant unit is determined by the properties of element types, constants and different unit has not. Model is established after the need to define material properties, which is mainly divided into linear and nonlinear. The software provides a solid modeling and direct modeling in two ways. Here mainly adopts the entity modeling, meshing loading condition and constraint equations in the completed model.

2. Solution module.

Solution module helps users define analysis type, analysis options, load data and load step options, and then began to solve the finite element. A direct solution method for solving module processing default includes Sparse Solver, the Frontal Solver, JCG method. The former 2 is direct elimination method, the latter is the iterative method.

3. The post-processing module.

After ANSYS through the pretreatment and after treatment solution, obtained the solution process through a user friendly interface results and calculation of these results, and the results to display graphics or data. The graph can be output to the display device on-line or off-line output to the plotter.

The electromagnetic simulation, are exact solution and approximate solution method, finite element method is an accurate method for solving numerical method, is based on the variational principle.

In the simulation, sensor adopts the double helix structure, it has the characteristics of a uniform electric field distribution, and high sensitivity. The sensor model is established by APDL language. The two electrode simulation structure as shown in Fig. 1, the actual production of four kinds of structure such as the appearance of Fig. 2, the left one has the same structural parameters with the simulation model, and the experimental results show that it has high sensitivity. The inside radius is 2.1 cm, the Outer radius is 3 cm, the inner tube wall thickness is 0.3 cm, the outer shield layer thickness is 0.2 cm. The outermost layer between the shielding electrode and the spiral electrode shielding layer thickness is 0.2 cm. The inner tube wall material is defined as the polymethyl methacrylate (PMMA) dielectric constant in the range of 2.75~2.85, in simulation it set as 2.8, between the electrode and the insulating layer is full of epoxy resin. The pure oil relative dielectric constant is 2.5 [4], Iron particle as a component, and the double electrode, grounding shielding layer consist a component with four nodes.

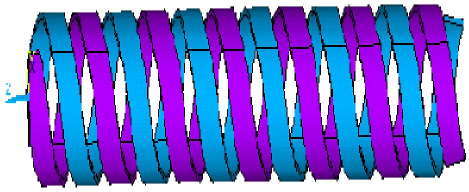

Fig. 1. Spiral electrode capacitance sensor structure simulation diagram.

Fig. 2. Four sensor electrode structure.

The sensor volume is =227 cm^3. Set free space dielectric constant 854E-06. According to the lubrication oil quality standard, it is Scrap when abrasive content reached 0.5 %. According to the proportion of conversion to the volume fraction of the simulation, the capacitance of the filled with pure lubricating oil is 0.18970E+02 pF. The inside radius of the model is 21000um, take abrasive normalized to the middle cylindrical conductor, Volume ratio is:

$$\pi r^2 H / \pi R^2 H = r^2 / R^2 \quad (1)$$

The wear particle content percentage is the square of the ratio of particle radius (r) and pipe radius (R). The gear oil density is, the 90 % pure iron grain density is. When grain impurity content in the oil liquid reaching 0.5 %, like:

$$\pi (\mathrm{R} - r)^2 H\rho_{oil} / \pi r^2 H\rho_{metal} = 0.5\% \quad (2)$$

The particle diameter (r) of this volume model is 631um. The calculated simulation capacitance values as shown in Table 1. The simulation data shows that when the full sensor size oil dielectric constant change of 2 pF, the abrasive particle content to be scrapped. Paragraph format: spacing before 0 pt, after 0 pt, line spacing: single.

Table 1. Different percentage capacitance value (um, pF).

Content	0.5 %	0.4 %	0.3 %	0.2 %	0.1 %
R	631	569	495	406	289
C	21.29	20.85	20.31	19.86	19.51

3. Capacitance Detection Circuit Design System

Designed by Micro Sensor company, specifically for the MEMS sensor MS3110 micro capacitance detection chip, its detection range is 0.25~10 pF. MS3110 has the characteristics of: set the capacitor voltage into one; with the internal EEPROM, real-time change related parameters; low power, low noise; C-V conversion time is short, and as a fixed value; the capacitance resolution up to 4aF/rtHz [5].

3.1. Detection System Design

The MS3110 block diagram shown in Fig. 3.

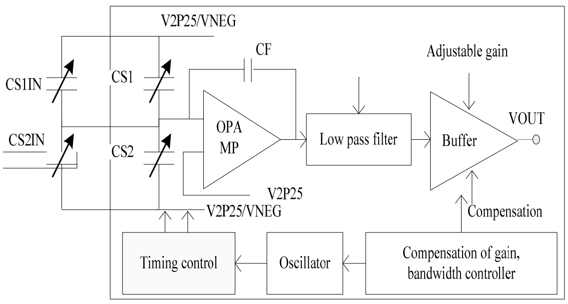

Fig. 3. MS3110 principle diagram.

The MS3110 block diagram shown in Fig. 3. MS3110 is mainly composed of a capacitance compensation circuit, charge integration circuit, low-pass filter and an operational amplifier. Among them, CS1N, CS2N as the measured capacitance, CS1, CS2 as the internal MS3110 tunable capacitor. The calculation formula of pin output voltage V_{out} voltage as follows: The text of figure captions should be 9 points high, Times New Roman. For the words "Fig." and "Table" use Bold. For example:

$$V_{out} = \frac{G_{AIN} \times V2P25 \times 1.14 \times (CS2T - CS1T)}{CF + V_{REF}} \quad (3)$$

Among them,

$$CS1T = CS1N + CS1 \quad (4)$$

$$CS2T = CS2N + CS2 \quad (5)$$

V2P25 is the reference voltage output, the default value is 2.25 V. The reference voltage VREF has the option of 0.5 V and 2.25 V two values. When SOFF=0, VREF=2.25 V, the typical no-load output value is 2.25 V; When SOFF=1, VREF=0.5 V, Working in a differential mode, the output is 0.5 V.

The main control chip of measurement system chooses the AVR series single-chip microcomputer ATMEGA16. ATMEGA16 Integrated 10 bit A/D. When VREF=0.5, CF=9.728 pF, GAIN=2, then:

$$\pi r^2 H / \pi R^2 H = r^2 / R^2 \quad (6)$$

$$V_{out} = (A / D_{Samplingvalue} / 1023) \times 2.25 \quad (7)$$

At this time, the capacitance of the resolution is 4.171fF that meets the data acquisition application. Measurement scheme as shown in Fig. 4, the measured capacitance use differential access mode that can eliminate the influence of environmental temperature, and the effect of input parasitic capacitance. In addition to the method of differential measurement, as long as the sensor and a reference sensor (reference capacitor) difference in measurement range within the chip, the measurement is not affected by size effect the measurement sensor based on capacitance. The system program provides a host interface which offers the convenience for the capacitance acquisition further processing. All the figures, graphs and photographs should be numbered and referred in the main text. Abscissas and ordinates of all graphs should be labeled with symbols and units.

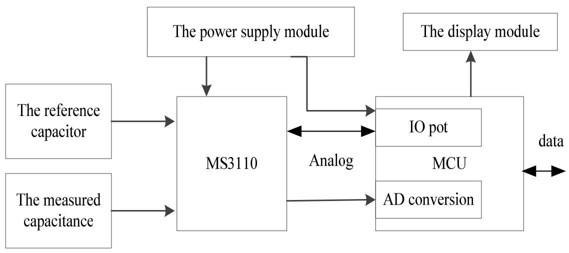

Fig. 4. System principle diagram as a whole.

The 60 bit register of MS3110 have two ways to write [6]: A EEPROM write mode, it needs to put HAV16 pin with voltage 16 V; A shift register write mode, this mode does not need to be added with high voltage, the power could not be saved, so every time the power to register the re initialization. Because the circuit does not need to provide extra high voltage, to choose second program to write into the register configuration, Fig. 5 is an eight bit MS3110 data is actually written to timing diagram. The Blue line is clock signal and the yellow line is data signal. Font sizes to be used in various parts of the article are summarized in Table 2 below.

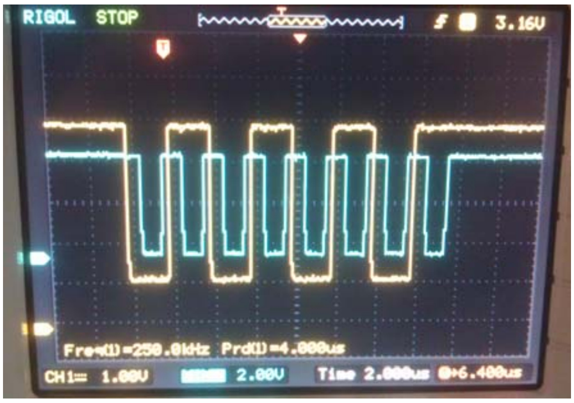

Fig. 5. MS3110 sequence diagram.

Table 2. Measurement error form.

The 3110 capacitance variation ΔC (pF)	Digital bridge calculation $\Delta C1$ (pF)	Measurement error $(\Delta C1-\Delta C)$ (pF)	Digital bridge measurement CS2T $(15.354\,pF)$
1.657	1.723	-0.066	17.077
2.188	2.201	-0.013	17.555
3.003	2.957	0.046	18.311
3.855	3.861	0.006	19.215
4.517	4.433	0.085	19.787
5.231	5.188	0.043	20.542
6.745	6.829	-0.084	22.183
8.900	8.839	0.061	24.193

3.2. The Experimental Measurement Error

HPS2817A is the impedance measuring instrument Helpa Science and Technology launched a high precision, high stability, wide measurement range. It has the advantages of powerful function, superior performance, and the use of liquid crystal display with simple operation. The measurement includes the measurement stability, temperature coefficient, linearity, repeatability of measurement error. It can measure inductance, capacitance, resistance and other parameters, capacitance measurement precision of 0.05 % [7] it meets the test requirements, to use HPS2817A to proof accuracy on MS3110.

In the accuracy test, access to a 30 pF continuously tunable external capacitors CS1T, CS2T, as shown in Fig. 6. According to the formula, when the CS1T values is fixed value, the capacitance variation of CS2T equal to. Record the measurement results, after each record, and then use the precision digital bridge to measure this results, digital bridge and MS3110 comparison of the measurement results as shown in Table 2, from the table can be seen both measurement error about within 0.1 pF. When access the actual sensor, and then by function fitting curve to reduce the error between the MS3110 and the digital bridge measurement.

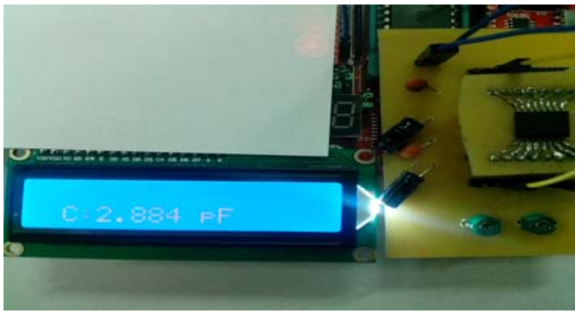

Fig. 6. MS3110 test system diagram.

4. Lubricating Oil Contamination Measurement Experiment

Make two sensors with the same structure parameters, one of them as reference capacitance internal to 20 cm height fresh oil, with an external capacitor fine-tuning the two sensor capacitance value difference is zero. When measuring, put 253.8 g oil in the sensor, the 1.26 g iron powder is 0.5 % of the total quality. Put accurate weighing iron powder and added oil into the sensor to record the variation of dielectric constant, as shown in Table 3.

Table 3. Grind grain content and dielectric constants Change form.

Iron quality (g)	0.252	0.504	0.756	1.008	1.26
Capacitance change (pF)	0.455	0.890	1.327	1.78	2.301

5. Conclusions

Methods using capacitance sensor differential in the system can eliminate the measurement error caused by the temperature fluctuation of the external environment, improve the lubrication oil dielectric constant detection accuracy. Experimental results show that the system can accurately distinguish iron grit from the change of 0.1 %-0.5 % content. This change can determine the degree of pollution of lubricating oil, provides a feasible idea and method for the detection of metal wear particles in lubricating oil content.

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