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Design of Oil Quality Tester Based on ARM

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ABSTRACT: *The military equipment reliability of hydraulic system, fuel system, lubricating oil system in submarines and aircrafts are greatly influenced by the water content of the oil, so the water content of the oil is often required less than 0.01％(0.01 Leve1). In order to develop such an instrument for detecting water content, this paper based on the dielectric constant principles to design a capacitance sensor for collecting the dielectric constant changing of the oil—water mixture and established the related mathematical model which is revised by temperature compensation for improving the measuring accuracy to 0.01. The S3C2412 ARM9 was used as the controller and WinCE as an op-crating system to manage multiple tasks，AD7745 for digital conversion of capacitance. It can be concluded from the experiments results that under the condition of —5 ℃ ~ 60 ℃ and 0 ~ 0.35％water content for detecting lubricating oil and light oil products, both of the accuracy reached 0.01 level, and has good repeatability, high reliability, etc. It can be used in the fields strict for oil water content such as military ships, electric power, and aerospace, to ensure the high reliability of military equipment.*
Key words: *oil of submarines and aerospace; water content of oil; dielectric constant; capacitance sensor model; reli-ability; ARM*

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I. INTRODUCTION

The water content in oil products has an important influence on the reliability and safety of high-performance hydraulic system, fuel system and lubricating oil system in submarines, airplanes and other equipment. These systems usually require water content less than 0.01%, that is, the quality reaches 0.01 grade [1-2]. At present, the domestic water content detection devices for 0.01-grade oil products are mainly imported from abroad. The main methods used to detect water content of oil products are: short wave absorption method and radio frequency method. Short wave method is a point-and-line sampling method for two-phase fluid in tubing, which cannot effectively express the situation of mixed two-phase flow, especially under working conditions, the mixing of oil and water cannot be completely uniform, so there is a large measurement error under working conditions. Radio frequency method is based on RF impedance theory, which has the characteristics of good repeatability, small size and fast response. However, the circuit of this method is complex, the cost is high, and the high-frequency circuit has a significant drift with the extension of working time under working conditions, so it is difficult to obtain the detection with the accuracy of 0. O1. Considering that the dielectric constant of water and oil is quite different, and the water content of oil is the main factor that affects the dielectric constant of oil, a small change can cause a large change in the dielectric constant of oil. After establishing a mathematical model of the change of capacitance corresponding to the change of dielectric constant, the water content j can be obtained by measuring the capacitance [3-4]. Therefore, this paper intends to use the dielectric constant method to study the methods and instruments for detecting the water content of oil products with the accuracy of 0. 01, so as to meet the demand for high-precision water content detection of oil products.

II. DESIGN OF OIL CAPACITANCE MODEL

PRINCIPLE OF DIELECTRIC CONSTANT METHOD

Dielectric constant is an electrical property of medium, which is related to the degree and process of polarization of medium in electric field. The dielectric constant ε_0 of vacuum is about 8.854×10^{-12}F/m, which is usually expressed by relative dielectric constant (hereinafter referred to as dielectric constant). It is defined as the ratio of dielectric constant to vacuum dielectric constant, that is, it accounts for $\varepsilon_r=\varepsilon/\varepsilon_0$, the dielectric constant of diesel oil is 2.1, that of gasoline is 1.9, and that of water is 80. The dielectric constant of oil and water is quite different, and a slight change in water content will cause a change in the dielectric constant of oil-water mixed emulsion [3]. According to the theory of dielectric physics, the expression of dielectric constant of oil-water mixed emulsion is:

$$\varepsilon = \varepsilon_H\left(1 + \frac{3W}{\frac{\varepsilon_0 + 2\varepsilon_H}{\varepsilon_0 - \varepsilon_H} - W}\right) \tag{1}$$

In formula (1), ε_0, ε_H, ε, which represents the water content of oil, represents the dielectric constants of pure water, pure oil and mixed emulsion, respectively.

When the capacitance sensor is used to detect the dielectric constant of the oil-water mixed emulsion, the output capacitance C_x of the sensor can be expressed as:

$$C_x = \varepsilon C_a + C' \tag{2}$$

In formula (2), $C_a$represents the capacitance of the sensor when the medium is vacuum (dry air), and C' represents the stray distribution capacitance of the sensor.

When the structure and geometric dimensions of the capacitance sensor are determined, its output capacitance C_x is a single-valued function of water content W in oil. At this time, when the sensor is relatively pure oil, the capacitance change ΔC is:

$$\Delta C = \frac{3W}{\frac{\varepsilon_0 + 2\varepsilon_H}{\varepsilon_0 - \varepsilon_H} - W} C_H \tag{3}$$

In formula (3), C_H is the output capacitance of the sensor when the oil is pure.

It can be seen from Formula (3) that when the water content in the oil is low, the ΔC of the capacitance sensor has a linear relationship with the water content W. It can be seen that under the condition of small water content, the water content in oil measured by the sensor has good linearity, and the relationship between water content and capacitance can be expressed as follows:

$$W = \mu C_x + \eta \tag{4}$$

Dielectric constant method uses the principle that the dielectric constant of oil-water mixed emulsion is related to the water content to measure the water content in oil. Usually, in order to facilitate the analysis and calculation, it is considered that the dielectric constant of oil-water mixed emulsion is only related to the water content, but the influence of hydrocarbon composition, pressure, density, gas content and temperature is often ignored. For potential diesel oil, the influence of temperature cannot be ignored. For light oil such as diesel oil, the dielectric constant decreases with the increase of temperature. This is because the thermal motion of molecules in oil-water emulsion is strengthened when the temperature rises, which makes its polarization more difficult. According to the test, when the water content is less than 10%, if the temperature factor is ignored, the measurement error of about 0.15% will be introduced when the measured oil temperature changes by 10℃.

For diesel oil with good working conditions (such as stable hydrocarbon composition, slight gas content, uniform flow, constant density and pressure), temperature changes have a great influence on the measurement results of water content of oil products. Therefore, after considering the temperature compensation of medium, the mathematical model of capacitance sensor is established as follows:

$$W = \mu C_x + \beta(t - t_0) + \gamma \tag{5}$$

In formula (5), W is the water content in oil, μ, β, γ is the coefficient, t_0 is the reference temperature, t is the medium temperature, and C_x is the actual capacitance value. When the standard moisture content and medium temperature are known, the mathematical model of the required capacitance sensor can be obtained by calibrating the above formula.

According to formula (5), among the relevant factors for calculating water content W, C_x and t are two variables of W . According to the principle of least square method, the problem of determining parametersμ^*, β^*, γ^*, finally boils down to finding the minimum point of the following ternary linear function.

$$S(\mu, \beta, \gamma,) = \sum_{i=1}^{m}[\mu C_{xi} + \beta(t_i - t_0) + \gamma - W_i]^2 \tag{6}$$

According to the necessary conditions of extreme value of multivariate function μ, β, γ are the solutions of the following equations.

$$\frac{\delta S}{\delta \mu} = 0, \frac{\delta S}{\delta \beta} = 0, \frac{\delta S}{\delta \gamma} = 0 \tag{7}$$

The following equations can be obtained:

$$\begin{cases} \sum_{i=1}^{m}[\mu^* C_{xi} + \beta^*(t_i - t_0) + \gamma^* - W_i]C_{xi} = 0 \\ \sum[\mu^* C_{xi} + \beta^*(t_i - t_0) + \gamma^* - W_i]C_{xi}(t_i - t_0) = 0 \\ \sum[\mu^* C_{xi} + \beta^*(t_i - t_0) + \gamma^* - W_i]C_{xi} = 0 \end{cases} \tag{8}$$

If the reference temperature t is takent_0=20℃, under the condition of standard water content W_i, the output capacitance C_{xi} and the medium temperature t_i of the capacitive sensor are measured, and the experimental data are replaced by the above formula, so that the parameter μ^*, β^*, γ^* can be obtained, and thus the mathematical model of temperature compensation of the capacitive sensor can be established.

It can be seen from the model that the dielectric constant method adopts the average value of the mixed fluid in the pipeline, which is suitable for the complex flow pattern of two-phase flow under working conditions. Even if there is a small amount of free gas in the pipeline, it will not cause large measurement error, and it is easy to meet the requirements of measurement accuracy under working conditions. And the range of dielectric constant method is small, which is especially suitable for detecting the case of small water content.

CAPACITOR STRUCTURE DESIGN

Capacitance sensor is the key component of the detector. In order to simplify the manufacturing process and facilitate the installation, the coaxial cylindrical capacitor structure is adopted, and the probe of the capacitance sensor is made of 1C:8Ni9Ti stainless steel. The outer electrode plate of the capacitor is provided with a certain regular round hole, which can play the role of self-equalizing. The inner electrode is coated with PTFE insulation layer, and the surface is smooth, so as to eliminate the conductive effect of moisture, and also enhance the mechanical strength of the probe, increase the compression resistance, and make the output signal basically stable [5-8].

Let the radius of the inner electrode of the coaxial circular simple capacitance sensor probe be r, the radius of the outer electrode be R, the thickness of the insulating layer of the inner electrode be 6, the dielectric constant of the insulating material be 81, the electrode length be L, and the dielectric constant of the oil-water mixed emulsion be 2. The capacitance C of the capacitance sensor is equivalent to the series value of the insulation layer and the oil-water mixed emulsion capacitor. C expression is:

$$C_p = \frac{2\pi\varepsilon_1\varepsilon_2 L}{\varepsilon_1 \ln\left(\frac{R}{r+\delta}\right)+\varepsilon_2 \ln\left(\frac{r+\delta}{r}\right)} \tag{9}$$

Because the value of δ is small (about ten Am), much less than r and R (about several tens of millimeters), the above formula can be transformed into:

$$C_p = \frac{2\pi\varepsilon_2 L}{\ln(R/r)} \tag{10}$$

It is also known that G, the capacitance increment ΔC of pure oil is:

$$\Delta C = \frac{3W}{\frac{\varepsilon_0+2\varepsilon_H}{\varepsilon_0-\varepsilon_H}-W} C_p \tag{11}$$

In the formula, ε_H , ε_0 , ε respectively represent the dielectric constants of pure oil, pure water and mixed emulsion, and W represents the water content in oil.

Take L =100 mm, R =40 mm, r =20 mm. In the case of pure oil, $C_p \approx 16.82pF$. If W is 0~3%, $\Delta C \approx 1.44pF$ can be obtained by substituting into the above formula.

The sensor adopts fully enclosed armored structure to ensure its good shielding performance, and can be installed at the bottom or side of the fuel tank.

The system scheme of oil moisture detector is shown in Figure 1, which is mainly composed of sensor and measurement and control [9-13].

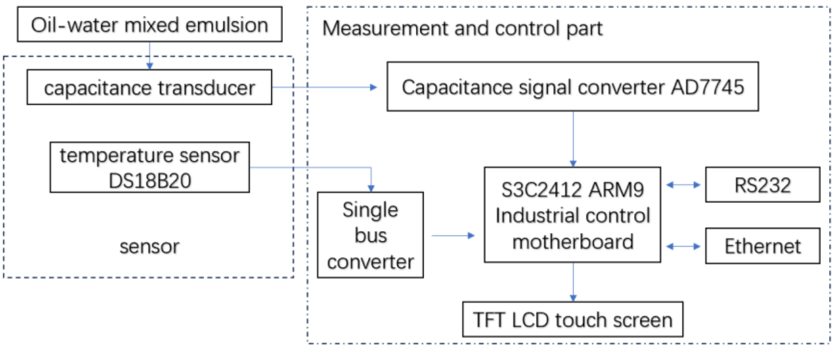

Fig. 1 composition schematic diagram of detection device

In Figure 1, the capacitance sensor converts the dielectric constant of oil-water emulsion into capacitance, which realizes the online real-time measurement of water content in oil, the temperature sensor realizes the real-time temperature measurement of oil-water emulsion, the capacitance and temperature information are input to the measuring device, and the measurement and control device completes the functions of data acquisition and processing, temperature compensation processing, result display and remote information output.

In this system, the signal conversion of capacitance sensor is realized by using special integrated circuit AD7745 [14-15]. AD7745 is a 24-bit $\sum -\Delta$ capacitance-to-digital converter (CDC) introduced by American analog devices, which can be directly connected with a capacitance sensor to realize measurement. Its characteristics are: high resolution (minimum 4 aF), high linearity ($\pm$0.01%) and high precision ($\pm$4 factory calibration), etc. Have a two-wire serial interface compatible with I^2C;It can be powered by a single power supply of 2.7V~5.25 V, and its rated working temperature range is -40℃~125℃.

Set the AD7745 to work in single-ended bias mode, and the capacitance input range is 13 pF~21 pF. According to the above analysis, when the water content is 0~3%, the variation range of the capacitance sensor is about 16.82 pF~18.26 pF, which obviously meets the input requirements of AD7745. Assuming that the measurement result of the capacitance sensor is ideal in the measurement range, the measurement accuracy is R_M, and the measurement dynamic range is $\Delta M = 3\%$. Given that the maximum absolute error of the AD7745 in the whole measurement range is $R_C = |\pm 4aF| = 4 \times 10^{-3} pF$, and the measurement range is $\Delta C \approx 1.44pF$, the conversion accuracy of water content can be $R_M = \pm 8.3 \times 10^{-6}$ according to $\frac{R_M}{\Delta M} = R_C / \Delta C$.

In the temperature compensation circuit, the digital temperature sensor DS18B20 with strong anti-interference ability is selected to collect temperature data.

The embedded industrial control motherboard is realized by S3C2412 with "ARM9+WinCE" architecture, which is produced by Samsung and has built-in WinCE embedded operating system. TFT LCD with touch screen is selected as the display screen to display data information such as moisture content and temperature in real time.

When the system works, the ARM processor is connected with the temperature single-bus converter through the C-interface capacitance signal converter to realize data acquisition. Ethernet interface host debugging interface, through which the execution code is downloaded; RS232 serial port realizes the connection with other extended intelligent serial port devices; The display screen mainly completes the interface display function; Matrix keyboard is an input device, which mainly realizes the functions of parameter input and control.

III. SYSTEM SOFTWARE DESIGN

The embedded operating system of this system is WinCE 5.0, and the development environment is embedded VC++4.0.

The structure of functional program modules in the system is shown in Figure 2. Multi-thread structure is adopted, and tasks such as data acquisition, data processing, data display and data storage are completed by using multiple threads.

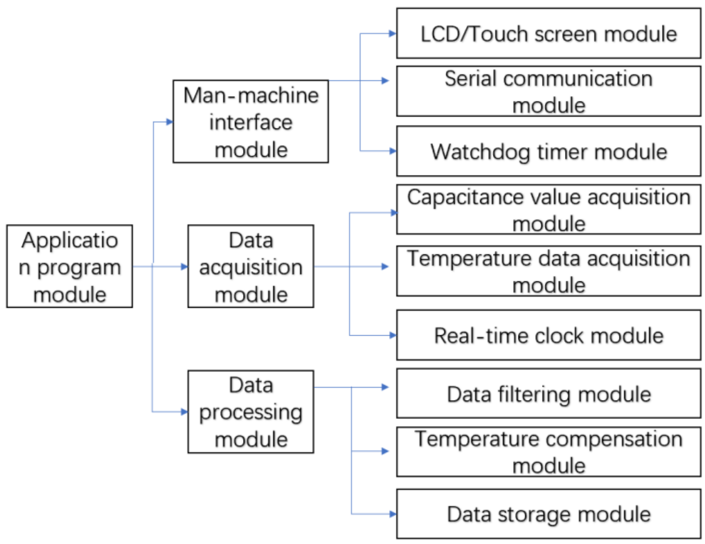

Figure. 2 Application Software Function Module

The system makes full use of the multithreading characteristics of Windows CE operating system to distribute different tasks to each thread, so that each task can be carried out synchronously and harmoniously. The main thread is responsible for man-machine interface, including LCD real-time display of data, timing transmission of serial data, touch screen input response and watchdog WDT response. In order to ensure that data acquisition is not interrupted by other threads, a thread with higher priority is set to manage data acquisition, which ensures that all task threads (human-computer interface thread, data acquisition thread and data processing thread) can complete their respective work in coordination. The communication between threads is realized by message response function.

IV. SYSTEMATIC EXPERIMENT

In order to test the performance of the detector, 5 W-40/SM lubricating oil and 93# light product oil were used for testing experiments, respectively. At a temperature of -5℃ ~ 60℃, the changes of capacitance and dielectric constant corresponding to different water contents were shown in Figures 3 and 4.

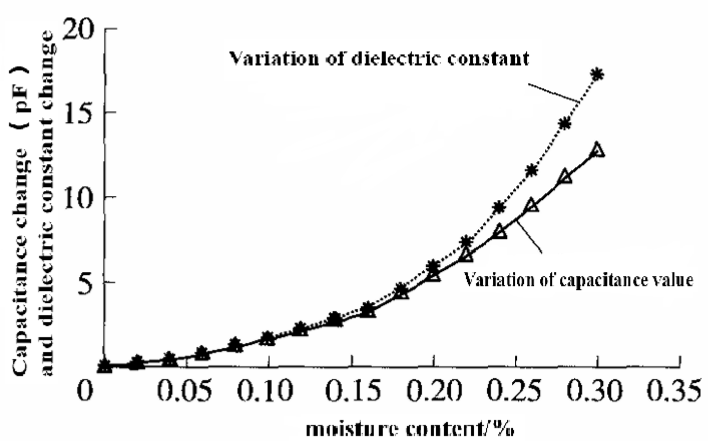

Fig. 3 Relationship between capacitance and dielectric constant of lubricating oil and water content

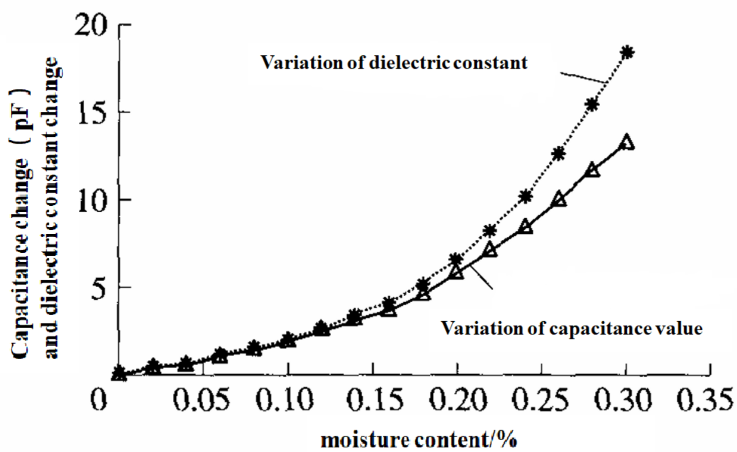

Fig. 4 Relationship between capacitance and dielectric constant of light finished product and moisture content.

As can be seen from Figure 3 and Figure 4, with the increase of water content in two kinds of oil products, the dielectric constant of oil products changes significantly, which makes the detected capacitance value change accordingly. Within the accuracy requirement of 0.01, the relationship between capacitance value and water content is linear.

V. CONCLUSION

According to the dielectric constant method, the mathematical model of capacitor for water content detection of oil-water mixture is established, and the capacitive sensor is designed and realized. The dielectric constant method adopts the average method to measure the mixed fluid in the pipeline, which is especially suitable for the complex flow pattern of oil-water two-phase flow under working conditions. The dielectric constant method has a small measuring range, which is very suitable for detecting the low water content of oil products in submarines and aviation equipment. The moisture content detector based on ARM embedded system has been tested on lubricating oil and light oil, and the relationship between moisture content and oil dielectric constant and the correctness of the established capacitance mathematical model have been verified. The relationship is linear within the range of 0.01-level detection accuracy, which makes the accuracy of the detector reach 0.01-level, which can meet the needs of submarine and aviation equipment for detecting oil moisture content accuracy, ensure the reliability and safety of the system, and can also be applied to other fields with strict requirements on oil moisture content. It has the advantages of high measurement accuracy, good repeatability, high reliability, simple equipment, convenient installation and maintenance, etc., and provides a technical scheme for realizing the localization of 0.01-level precision oil water content detector.

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