

The study of water capacitance for single electric cable in precision measurement

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A high precision water capacitance measuring system is designed by using a water capacitive sensor, which carries on non-contact measurement in a single electric cable in water. System's fundamental and electric data processing methods have been illustrated through the analysis of object's features. The factor of influenced sensor's measurement accuracy and stability is analyzed as well. Then the paper proposes a technical means to utilizing electronic and digital signal filtering technology for enhancing accuracy of sensors. It provides a means of measuring the quality of high speed data communication cables. The experimental data analysis shows that the measurement range of the system is 10-300pF, the resolution is better than 0.2pF, which can meet the needs of the water capacitance detection in the production of insulated wire electric cable.

Keywords: Water Capacitance; Single Electric Cable; Precision Measurement; Electric Bridge.

1. Introduction

Among all the parameters of the electric cable, the water capacitance is the most representative parameter, which can synthesize the heterogeneity of the core line. The change of capacitance in water can reflect the process parameters of electric cable production process changes and changes in environmental conditions. By detecting changes in cable capacitance in water, the electric cable production conditions can be controlled well. So water capacitance testing for single electric cable is very important significance in the production of the electric cable [1].

In this paper, a particular single electric cable in water is used as the main research object, and a measuring system is built by using National Instrument (NI) data acquisition board and Personal Computer (PC) [2]. A high accuracy capacitive sensor is applied to the single electric cable to measure the various

changes. Moreover, temperature sensors are also applied to the water tank. Then, the relation curve between the temperature and capacitance is obtained.

2. The Design of Measuring System

The measurement system is consisted by the following: single electric cable in water, high precision capacitive sensor, NI multichannel data collection board, PC and other accessory device and testing software et al. The multichannel data collection instrument is based on high performance of Digital Signal Processing (DSP) processor and computer technology. With the support of low-level control procedure and data acquisition software, it accomplishes collection, processing, and display of the water copacitance data. The whole system organization is illustrated in Fig.1.

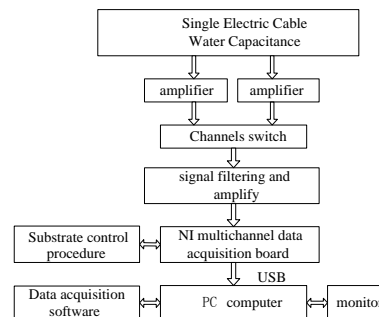


Fig. 1. The structure chart of measurement system

And the test equipment installation is shown in Fig.2^[3].

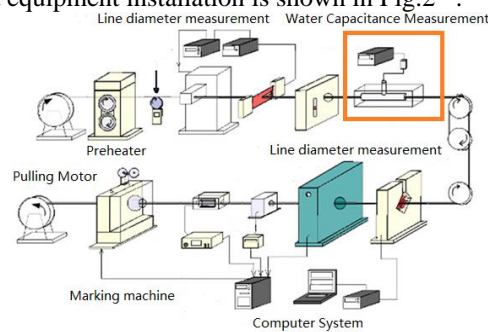


Fig.2. Test equipment installation in the cable production

3. The Optimization Design of Capacitance Sensing Circuit

Water capacitance sensor is commonly used at tiny capacitance measurement [4-5]. Because of temperature, noise and null drift of capacity sensor, a greater measuring error will be led. Simultaneously, bridge form is adopted commonly

at the measurement of the circuit layout. The amplified power supply error has an influence on the output signal. Therefore overcoming these two influencing factors is the key point to improve the accuracy of capacitive sensor. This paper will analysis and reduce these two source error in two aspects. The whole measuring circuit functional scheme is shown in Fig.3.

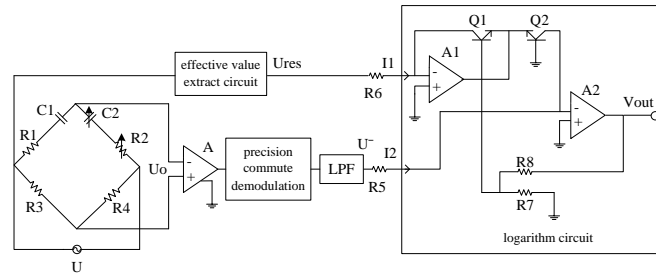


Fig. 3. The schematic of capacitance sensing circuit

3.1 .The measuring principle of capacitive sensor

The principle of capacitive measurement is based on the principle of the parallel plate capacitor. For conductive targets, the sensor and the target opposite form the two plate electrodes. If neglect the fringe effect of capacitive sensor, the measurement capacitance C can be expressed by the following simple equation.

$$C = \frac{\epsilon_r \epsilon_0 S}{\delta} = \frac{\epsilon S}{\delta} \quad (1)$$

Where S is the area of electrode, δ is the distance between the two electrodes, ϵ_r is the relative permittivity, ϵ_0 is the permittivity of vacuum, and ϵ is the dielectric constant.

The dielectric constant between the electrodes changes when the material is not the same, and then the capacitance changes as well. The capacitance change $\Delta \epsilon$ is presented as.

$$\Delta C = C_o \Delta \epsilon \quad (2)$$

Where C_o is the initial capacity, when the electrode distance was δ .

Since the changes of capacitance change are very small, the dedicated measuring circuit is needed to set up to get proportional voltage signal to the capacitance change. Capacitive sensor switches in an arm of the alternating current bridge, while the other arm is steady resistance and capacitance. The remaining arms are constant resistance. The alternating current bridge is excited by constant amplitude sinusoid, $U = U_m \sin \omega t$ as carrier wave, which drives the bridge circuit.

The four arms of bridge impedance are

$$Z_1 = R_1 - j \frac{1}{\omega C_1}, Z_2 = R_2 - j \frac{1}{\omega C_2}, Z_3 = R_3, Z_4 = R_4$$

,and the output voltage is,

$$\Delta U_o = U \frac{Z_1 Z_4 - Z_2 Z_3}{(Z_1 + Z_2)(Z_3 + Z_4)} \quad (3)$$

The initial alternating current bridge is assumed to be balanced. When the working capacitance C_1 changes ΔC , it makes impedance Z_1 changes ΔZ_1 . The output voltage ΔU_o can be written,

$$\Delta U_o = U \frac{\frac{Z_4 \Delta Z_1}{Z_3 Z_1}}{(1 + \frac{Z_2}{Z_1} + \frac{\Delta Z_1}{Z_1})(1 + \frac{Z_4}{Z_3})} \quad (4)$$

In respect that the initial symmetry bridge is balanced, the denominator of ΔZ_1 item is the factor caused by nonlinear. Considering its value is relatively small that can be omitted, the linear output can be described as following equations:

$$U_o = \frac{U}{4} \frac{\Delta Z_1}{Z_1} \quad (5)$$

$$\Delta Z_1 = \frac{\Delta C}{j\omega C_o(C_o + \Delta C)} \quad (6)$$

The initial values of parameters are

$$C_1 = C_2 = 1nF, R_1 = R_2 = R_3 = R_4 = 300\Omega.$$

Inserting the values of parameters into (5) and (6), the relationship between output voltage U_o and capacitance changes ΔC can be obtained, as shown in the following table 1. The measuring range of ΔC is 0-300pF

Table 1. The relationship between the output voltage U_o and capacitance variation ΔC

ΔC (pF)	10	20	30	40	50	100	150	200	250	300
U_o (mV)	1.9	3.7	4.5	5.3	6.2	10.9	14.8	18.6	22.5	30.3

3.2 The method of reduce measurement error

The capacitive sensor circuit has two main errors. The first one is from voltage supplying, and another is thermal noise which is from bridge circuit. Reducing the impact of these two errors is the key point to improve the capacitive bridge precision.

The method of reducing the error of voltage supply can be solved by the logarithmic circuit. The principle of circuit is shown in Fig.4.

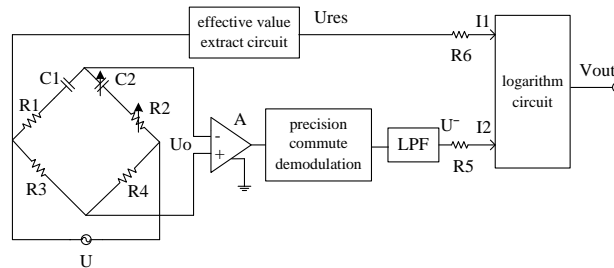


Fig. 4. Eliminate the error of voltage supply in capacitance sensing circuit

Assuming the offset voltage of voltage supply is σ , and then the power supply U can be described as $U = (U_m + \sigma) * \sin \omega t$.

Through the effective value extract circuit,

$$U_{res} = \sqrt{\frac{1}{T} \int_0^T (U_m \sin \omega t)^2 dt} = \frac{U_m}{\sqrt{2}} \quad (7)$$

The output voltage of logarithmic circuit is,

$$V_{out} = L \log \frac{I_1}{I_2} = L \left(\log \frac{2\pi}{PAV} + \log \frac{\beta}{\alpha} - \log \varepsilon \right) \quad (8)$$

The L is constant. And the letter α and β are the top and bottom boundary of the input current value of I_2 and I_1 in logarithmic circuit.

According to the above equations, the output signal of bridge through the logarithmic operation can be acquired from the uniform function relationship between the output function and changes in capacitive.

4. The Result of Test Measurement

After the original electric bridge data is collected by DAQ board, a curve can be got just like Fig.5.

Through the test data, water capacitance value from 10pF-300pF can be measured by this bridge circuit. Under the data processing and analysis, the resolution of system comes up to 0.2pF, and linearity is superior to 0.1mV/pF..

5. Conclusions

According to the analyses of source noise in the capacitance sensor, the measuring circuit, the data processing means are improved, and the precision is raised as well. The capacitive sensing circuit has a non-linear error. In order to reduce the non-linear error exploiting the differential capacitive sensors is the best choice.

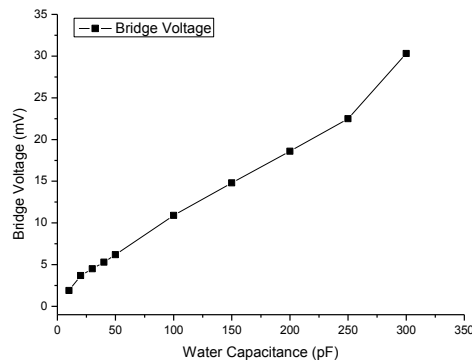


Fig.5. Curve of original electric bridge data

After all, the measurement system is designed by high accuracy capacitive sensor. And through using the logarithmic circuit, it satisfied the requirements of single electric cable production, and has a great reference for the capacitive sensor in the similar non-contact, high-precision applications.

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