International Core Journal of Engineering Volume 7 Issue 7, 2021
ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0015

A Non-metal Thickness Measurement Method Based on Capacitive Sensing

Chao Zhang, Qingyan Zhao

ZhongShan Polytechnic College, GuangDong, China.

Abstract

Based on the analysis of the main methods of non-metallic thickness measurement, a non-metallic thickness measurement method based on capacitive sensor is proposed. This paper analyzes the basic principle of capacitance sensor, uses Schmidt multivibrator for capacitance frequency conversion, and how to use high-performance 32-bit microcontroller for accurate frequency measurement. Through the experiment of measuring the number of 1-40 sheets of A4 paper, the results show that the non-metallic thickness measurement method described in this paper is simple in principle, high in accuracy and easy to realize.

Keywords

Capacitance Sensor; Thickness Measurement; Multivibrator; Microcontroller.

1. Introduction

At present, in the field of non-metal thickness measurement, ultrasonic, ray or microwave measurement methods are commonly used[1]. Ultrasonic measurement method has high accuracy, but it needs couplant when measuring, and has certain requirements for the thickness to be measured. Generally, the thickness to be measured is required to be greater than 2mm; the accuracy of radiographic measurement method is high, but it requires the use of a radioactive source, which is complicated and complicated. Additional protection measures against radiation are required, and the measurement cost is high and it is not easy to promote. Microwave thickness measurement technology has also made some progress in the research and application of these years. It has outstanding performance in the measurement of metal thickness, but there are still some in the measurement of non-metal thickness. These status quo show that there are still great technical challenges in the field of non-metal thickness measurement.

Capacitive sensors have a series of advantages such as good stability, simple structure, fast response, and high precision. According to the different methods of changing the capacitance of the capacitor, the capacitance sensor can be divided into a pole-distance change type capacitance sensor, an area change type capacitance sensor, and a medium change type capacitance sensor. This paper proposes a method of using a capacitance sensor with variable pole pitch and Schmidt multivibrator to convert the capacitance change into a frequency change, and then measure the thickness of non-metal, and use the 32-bit single-chip STM32F407 to build the thickness measurement Device.

2. Capacitive sensor

Capacitive sensors use various types of capacitors as sensing elements. Through capacitive sensing elements, changes in the measured physical quantity are converted into changes in capacitance. Capacitive sensors use the basic principles of plate capacitors. The composition of plate capacitors is shown in Figure 1.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0015

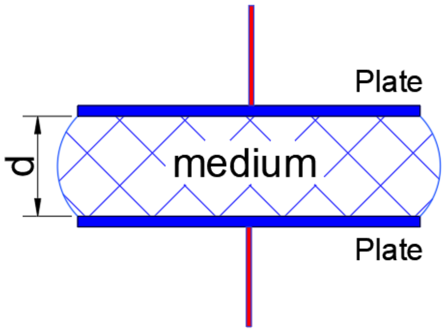

Figure 1. Flat capacitor

In the case of ignoring the fringe electric field effect, the capacity of the capacitor can be calculated by the following formula:

$$CX = \frac{\varepsilon s}{d} \tag{1}$$

Among them, ε is the comprehensive permittivity,

$$\varepsilon = \varepsilon r \times \varepsilon 0 \tag{2}$$

ε_r is the relative dielectric constant, which is related to the material to be measured, ε_0= 8.85*10^{-12}F/m is the vacuum dielectric constant, s is the effective area between the two plates of the flat capacitive sensor, and d is the distance between the two plates.

It can be seen from the formula (1) that when the plate area s and the material to be tested are selected, the capacitance of the capacitor has a linear relationship with the plate distance d. When the thickness of the measured object changes, it will cause the change of the capacitance, thus The thickness of the object can be calculated by measuring the change in the capacity of the capacitor C_X.

3. Capacitance frequency conversion

In acturaly, measuring the thickness of an object does not need to know the specific size of the capacitor, and it is not easy to accurately measure the size of the capacitor. This article uses an indirect method to achieve thickness measurement. The Schmitt trigger and the measured capacitance form a multivibrator, which converts the change of the measured capacitance into a frequency change. The capacitance change is detected by measuring the frequency. Calculate the thickness of the measured object.

The multivibrator circuit composed of Schmitt triggers and capacitors is shown in Figure 2, and the input and output waveforms of the composed multivibrator are shown in Figure 3.

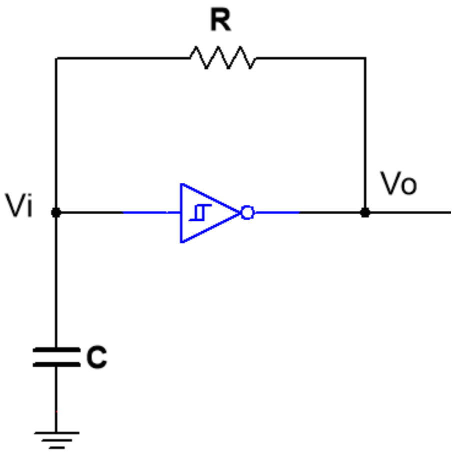

Figure 2. Schmidt multivibrator

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0015

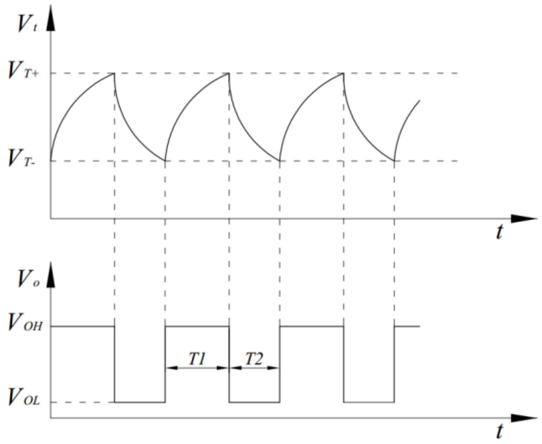

Figure 3. Schmidt multivibrator input and output waveforms

It can be seen from Figure 3 that the oscillation period of the multivibrator $T=T_1+T_2$:

When using CMOS Schmitt trigger, the output high level is approximately equal to the power supply voltage, and the output low level is close to 0, that is $V_{OH}\approx V_{CC}$, $V_{OL}\approx 0$. Suppose V_0 is the initial voltage value on the capacitor, V_1 is the voltage value that the capacitor can finally be charged or discharged, and V_t is the voltage value on the capacitor at time t. T_1 and T_2 can be calculated from the capacitor charge and discharge formula 4.

$$\text{Charging voltage}\ \ Vt = V0 + (V1 - V0) \times (1 - e^{-t/RC}) \tag{4}$$

$$\text{Discharge voltage}\ \ Vt = V1 + (V0 - V1) \times e^{-t/RC} \tag{5}$$

From equations (4) and (5), the charging period T_1 and the discharging period T_2 can be calculated to obtain the oscillation period T. The reciprocal of the period is the oscillation frequency, which corresponds to the thickness of the measured object.

$$T = RC\ ln(\frac{VCC-VT-}{VCC+VT+} \times \frac{VT+}{VT-}) \tag{6}$$

The capacitance-frequency conversion circuit is shown in Figure 4. The SN74LVC1G14 Schmitt trigger U2, the measured capacitor C6, and the charge and discharge resistor R5 constitute a multivibrator, which converts the thickness of the measured object into a change in the oscillation frequency. In order to make the output of the circuit have a higher driving capability, an inverter is added as a buffer output, which is shaped and buffered by the SN74LVC2G14 Schmitt trigger U3 in Figure 4[2-5].

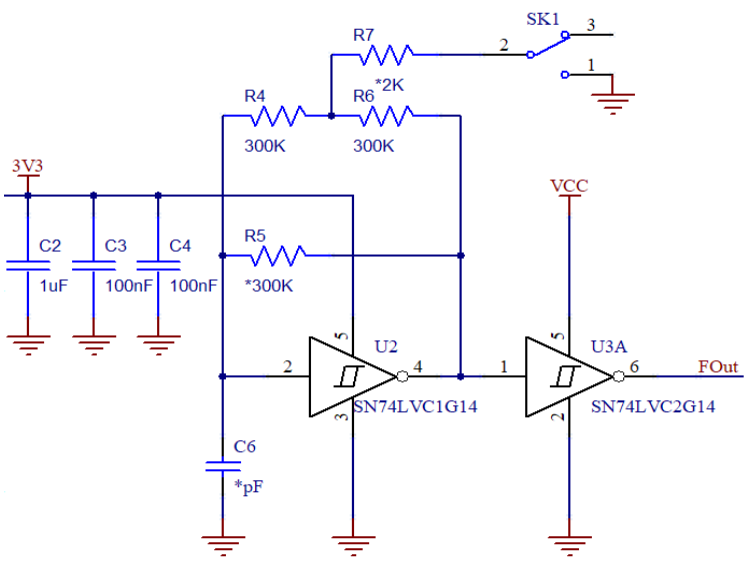

Figure 4. Capacitor-frequency conversion circuit

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0015

4. Frequency measurement

When the thickness of the measured object changes greatly, the capacitance formed between the plates also changes greatly, and the frequency after conversion by the Schmitt circuit has a large range. This requires that the subsequent frequency measurement must have a very high Accuracy also have a very wide bandwidth. For this reason, the STM32F407VE single-chip microcomputer is selected as the detection core. The square wave signal generated by the Schmidt multivibrator is input to the external counting pin of the single-chip timer TIM2 through PA0. The other single-chip timer TIM3 is used to generate accurate time base signals. Count the pulses input to TIM2 under the time base signal to calculate the thickness of the measured object. The timer TIM2 of the STM32F407VE single-chip microcomputer is a 32-bit timer counter, which can be used with the TIM3 time base unit to accurately measure a wide range of frequency signals. The frequency measurement circuit is shown in Figure 5.

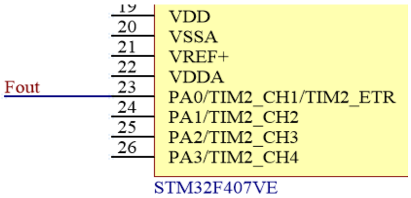

Figure 5. Frequency measurement circuit

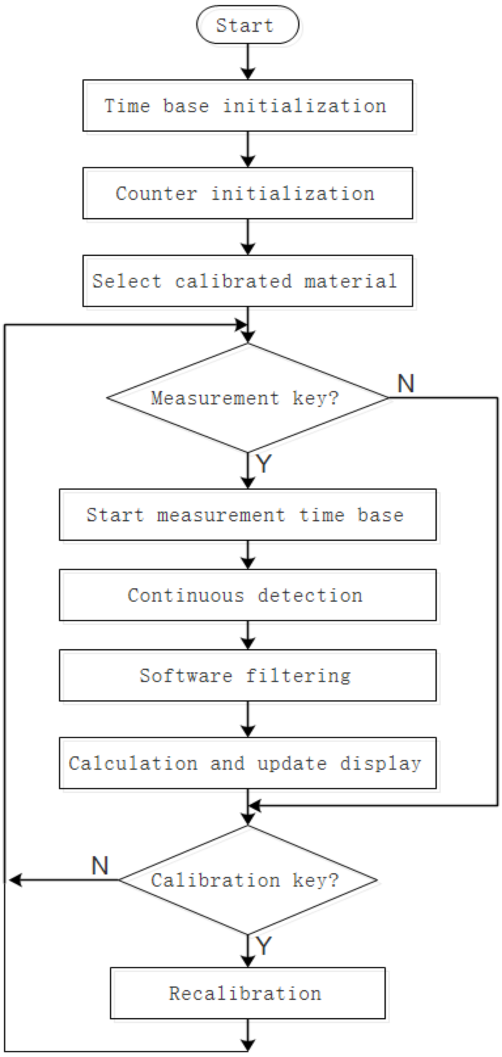

Figure 6. Main program flow

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0015

5. Program flow chart

Two timers, TIM2 and TIM3, are enabled. TIM3 is used to generate precise time base signals. TIM2 is configured in external counting mode. In one time base signal period, square wave signals are counted. The selection of the period of the time-base signal should be able to satisfy the highest frequency measurement. At the same time, the appropriate widening of the time-base period will help improve the measurement accuracy. The main program flow chart is shown as in Figure 6.

6. Experimental verification

Objects with different materials and the same thickness have different relative permittivity ε_r, the capacitance formed at the two ends of the plate will be different, and the frequency after Schmidt conversion will also be different, which makes the calibration of the instrument difficult. This article uses the standard thickness comparison method to achieve calibration. Set the calibration button on the tester. Before testing, put the standard thickness sample into the tester, press the calibration button, and enter the corresponding standard on the screen. Thickness, and then the thickness measurement of insulating objects of the same material can be carried out.

Experimental process: select 40 sheets of 100g A4 paper, first put 10 sheets of A4 paper into the instrument for calibration, then start with 1 sheet and continue to 40 sheets, and the number of paper measured by the instrument and the actual number of papers put into one Check and verify, as shown in Figure 7.

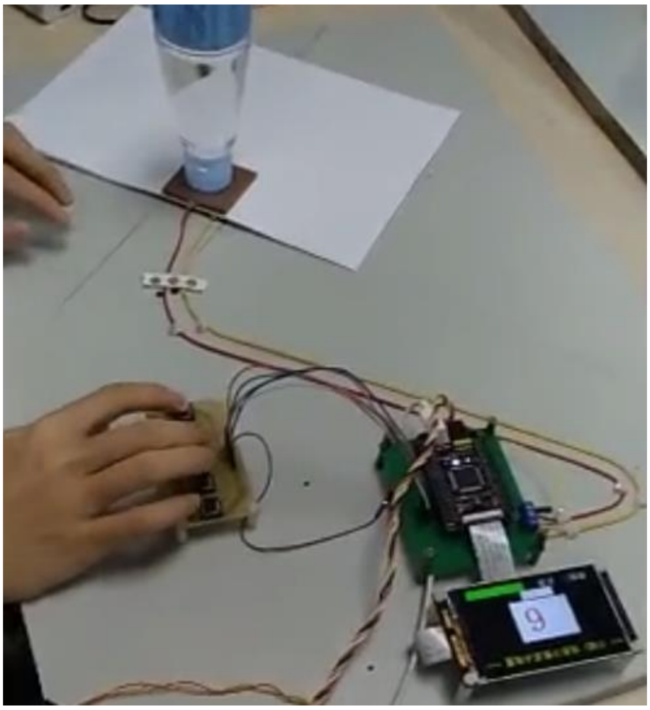

Figure 7. The number of sheets of paper is measured to verify the thickness measurement

Experiments show that the number of 1-40 A4 papers tested are all correct, which verifies the feasibility and accuracy of the thickness measurement method described in this article.

7. Concluding remarks

The capacitance-sensing non-metal thickness measurement method proposed in this paper uses the change of the plate capacitance caused by the measured object, and indirectly measures the thickness of the object by measuring the frequency output by the Schmidt multivibrator. Experimental results show that the method is simple in principle, easy to implement, and high in measurement accuracy.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202107_7(7).0015

The disadvantage is that the measured object can only be non-metal, and the surface is required to be very flat.

References

[1] Qiang Song, Huichao Shi.Design and Simulation of Capacitive Non-metallic Material Thickness Measuring Device[J]. Sensor World, 2018, 24(05):14-16.

[2] Chao Zhang, FangGe Yuan , Lin Ye. rapid detection technology and Realization of automobile lubricating oil quality [J]. Computer and Telecom, 2019 (06): 38-41

[3] Peng Zhang, Seng Li, JianQiang Han.The design of the waveform conversion circuit of the micro-resonant sensor detection system[J]. Science and Technology Bulletin, 2016, 32(11):184-187.

[4] Wei Zhang, Zhenlong Yang, Yuehong Chen.Application of Schmitt Trigger in Communication Indicator Circuit[J]. China's New Technology and New Products, 2018 (18):14-15.

[5] Jianguo Cui, Yongxiang Ning.Single pulse and continuous pulse dual-mode generator based on Schmitt trigger[J]. Industrial Technology Innovation, 2018, 05(05):33-36.