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Design of Inductance Micrometer Based on Multiplicative Phase Sensitive Detector

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Abstract

Inductive sensors are widely used because of their high resolution, reliable operation, simple operation, and long service life. In this paper, based on a full comparison of the development status of inductance micrometers at home and abroad, for the current situation of low accuracy and stability of domestic products, a multiplicative phase sensitive detection circuit is used to design an inductor with relatively high accuracy and relatively good stability Micrometer. Mainly adopts the combination of software and hardware. According to the selected German TESA GT21 03210904 standard half-bridge, differential self-sensing sensor probe, the excitation signal generation circuit, signal amplification circuit, multiplying type matched with it Phase-sensitive detection circuit, low-pass filter circuit, analog-to-digital conversion circuit and display circuit,and write a program to develop an inductance micrometer system with relatively high measurement accuracy and relatively good stability after system calibration and error processing.

Keywords

Inductance micrometer; Multiplicative phase sensitive detection; Error handlingr.

1. Introduction

With the development of the times, new products and new technologies in the field of national basic manufacturing are actively appearing. At the same time, the products manufactured are more sophisticated. This has prompted people to develop higher-precision measuring instruments, and people pay more and more attention to it. Sophisticated equipment that can measure tiny amounts, so the micrometer has entered the public's field of vision. In short, a micrometer is a measuring device that can measure various high-precision physical quantities. At present, the micrometer is widely used in precision machinery manufacturing, transistor and integrated circuit manufacturing. It has the characteristics of high accuracy, low cost, long service life, and small size, and is favored by various manufacturing industries [1]. The development of micrometers is very rapid. It used to be mainly used for contact measurement, but now it has developed to non-contact measurement. Among various micrometers, the inductive micrometer has a position that cannot be ignored. With its simple structure, the inductive micrometer can achieve high-precision and high-stability measurement results. It is currently mainly used for the measurement of small dimensional changes [2].

2. Overall Scheme Design

The overall scheme of the entire inductance micrometer is shown in Figure 1. Under the action of the excitation voltage, the inductive sensor measures the small displacement, the sensor converts the small displacement change into a weak voltage, and the measurement amplifier circuit changes the output of the sensor The weak voltage is amplified, and the amplified signal is processed by the multiplication phase-sensitive detector circuit and the filter circuit, and then enters the microcontroller through the analog-digital conversion circuit, and finally the measured data is displayed on the LCD through the MCU control. And the amplifying circuit used in this design can reduce the interference of the common signal. The output DC signal can be directly read by the A/D converter after being screened by the detection circuit and the filter circuit, and controlled by the MCU circuit. Display displacement data through LCD. The purpose of this design is to build an inductance micrometer with a measuring range of ±200μm and a resolution of 0.1μm, based on the multiplication phase-sensitive detection.

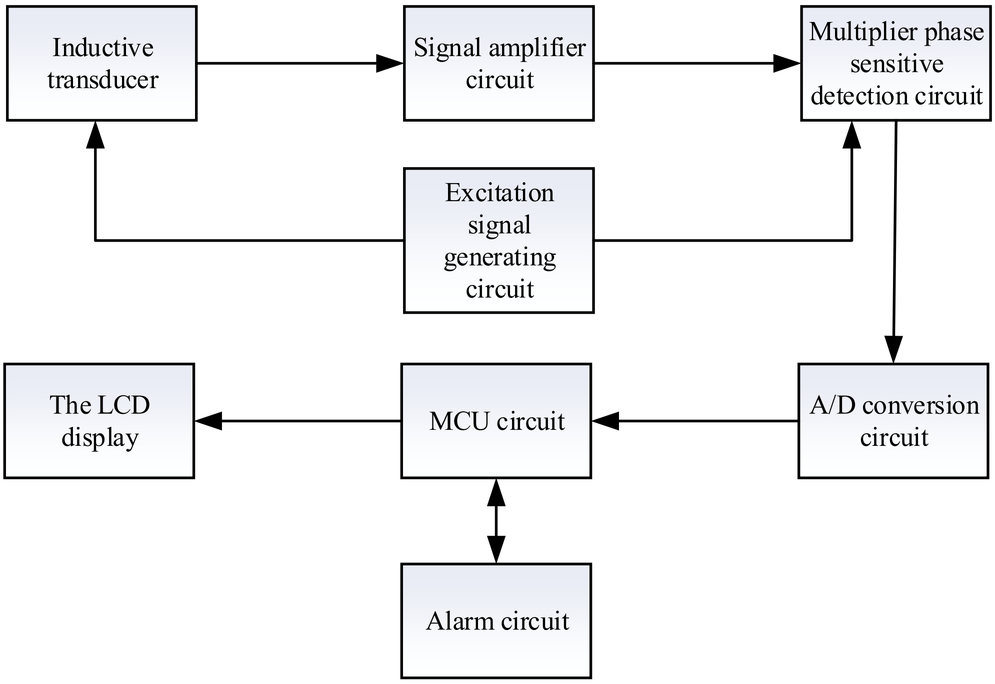

Figure 1. Overall block diagram of the system

2.1. Signal Conditioning Circuit Design

2.1.1 Sinusoidal signal generating circuit

Since the selected inductive probe TESA GT21 03210904 requires a single stable sine wave with a frequency of 13KHz and an amplitude of 3V, the design of the sine wave signal generating circuit in this design can use the principle of a Wien bridge, but the most basic Wien bridge The sine wave generated by the bridge oscillation circuit is prone to stop vibration or distortion, and the resulting waveform is unstable [3]. Therefore, it needs to be improved on the basis of the Wien bridge. The improved circuit diagram is shown in Figure 2. The improvement idea is to ensure that the magnification is greater than 3 (R3≥3R5) when the circuit starts to oscillate. This can make the circuit easy to oscillate. When the oscillation amplitude of the circuit increases to a certain extent, the magnification is automatically switched to less than 3, so that the maximum amplitude of the oscillation can be limited, thereby avoiding clipping and distortion of the oscillation waveform.

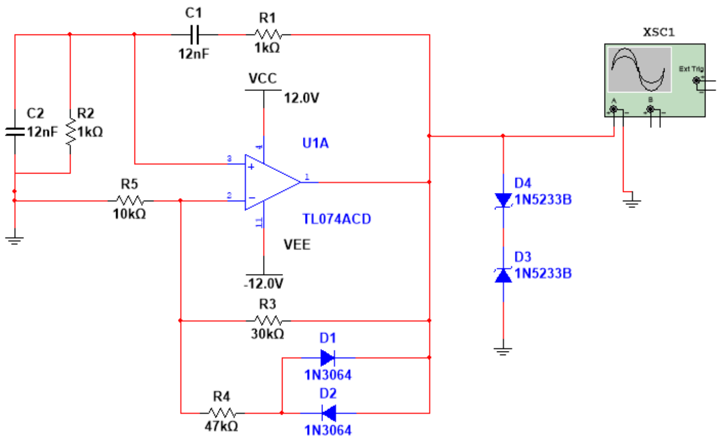

Figure 2. Sine wave signal generating circuit

As shown in the circuit diagram of Figure 2, in order to ensure that the magnification of the circuit is greater than 3, and at the same time to avoid serious distortion of the waveform caused by too deep positive feedback after start-up, R4, D1, and D2 are added here. When the oscillating signal is relatively small, the diode is not turned on, so the R4, D1, and D2 branches are equivalent to not. At this time, the amplification factor is greater than 3. When the oscillating signal is relatively large, the diode is turned on, which is equivalent to R3 and R4 in parallel. The magnification will be smaller (a reasonable setting of the resistance of R4 can make the magnification less than 3), so as to achieve the effect of stabilizing the amplitude and reducing the distortion. According to the requirements of the probe TESA GT21 03210904, in order to ensure the best measurement effect, the output voltage is about 3V and the output frequency is 13kHz. Analyzing the circuit in Figure 2, the output frequency calculation formula can be obtained as shown in equation (1).

$$f = \frac{1}{2\pi R_3 C_1} \tag{1}$$

It can be calculated that the output frequency is about 13kHz, which meets the requirements.

2.1.2 Operational amplifier circuit

The purpose of designing the operational amplifier circuit is to amplify the weak signal output by the sensor to facilitate subsequent signal reception and processing. However, since the output voltage of the inductive sensor used is not only very weak but also accompanied by a large common-mode voltage, in order to improve the accuracy of the circuit, it is necessary to suppress the common-mode voltage while amplifying the signal. In order to meet this requirement, a differential input integrated operational amplifier is generally used. When designing the circuit, in order to better suppress the common mode error and achieve higher accuracy, an operational amplifier with ideal characteristics should be used, and the ratio of external resistors should follow the principles of equal size, balance and symmetry. Generally, the higher the symmetry accuracy of the external resistor, the stronger the common-mode rejection capability of the operational amplifier, and the smaller the output common-mode voltage. The common mode rejection capability of our commonly used ordinary op-amp circuits is not strong and generally reachable; but if several op-amp circuits are used to cooperate with each other to form a high common-mode rejection ratio amplifier circuit, the common-mode rejection capability will be significantly improved. Up. Therefore, in order to amplify the signal while improving the common-mode rejection capability, this design will adopt a high common-mode rejection ratio amplifier circuit with strong common-mode rejection capability.

2.1.3 Multiplier phase sensitive detection circuit

The signal modulation of this circuit belongs to sensor modulation, so there is no need to design the signal modulation circuit in the future, and the purpose can be achieved by demodulating the circuit modulated in the sensor. The purpose of using the multiplicative phase-sensitive detection circuit is to realize high precision demodulation by using its characteristics of frequency selection and phase discrimination. Demodulation is the process of stripping out the weak signal attached to the high frequency carrier signal and restoring it to its original state. In various information transmission or processing systems, the sender modulates the weak signal intended to be transmitted onto a high-frequency carrier signal to produce the signal carrying the message; The receiving end separates the signal it wants to transmit from this signal, which is demodulation. Demodulation is corresponding to modulation. Demodulation is the inverse process of modulation. Different modulation methods are different. Correspondingly to the classification of modulation, demodulation can be divided into sine wave demodulation (sometimes referred to as continuous wave demodulation) and pulse wave demodulation. In general, the demodulation process consists of two main steps: firstly, the frequency spectrum near the carrier carrying useful information is moved to the baseband, and then the baseband signal is filtered out by the corresponding filter to complete the demodulation task [4].

This is the use of sine wave demodulation, design chip selection simple and high precision AD633 chip. The differential X and Y inputs of AD633 chip are converted into differential currents through the voltage-current converter. The product of these currents is generated by the multiplication kernel. The value of the product is added to the high-impedance input Z through the adder, and the total transfer function is shown in Equation 2.

$$W = \frac{(X_1 - X_2)(Y_1 - Y_2)}{10} + Z \tag{2}$$

The circuit designed based on the use method of AD633 chip and the principle of multiplicative phase-sensitive detection circuit is shown in Figure 3.

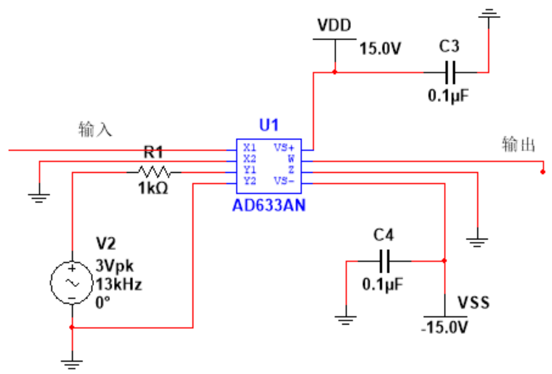

Figure 3. Multiply phase sensitive detection circuit based on AD633

The demodulation circuit mainly adopts the synchronous detection mode, using the multiplication function of AD633 to realize the product type synchronous detection. In this detection, the local mediating wave is required to be in the same frequency and phase with the modulated carrier signal at the transmitting end. If there is a certain deviation in frequency or phase, the recovered signal will be distorted. Synchronous detection consists of an analog multiplier and a low pass filter, which is used to demodulate the two-sideband amplitude modulated wave with carrier suppression. As shown in figure 3, the modulation signal input from the X1, Y1 connected sine wave signal generating circuit, the input and the same excitation signal sensor, X2, Y2, Z side grounding, thus realizing the sine wave signal generator excitation signal and directly to the X1 input end of the same frequency and phase modulation signal multiplication, realizes synchronous detection product type, The low impedance output terminal W will output the demodulated signal. Finally, a low pass filter is needed to extract the low frequency useful signal.

2.1.4 Second order low pass filter

The most important characteristic indexes of the filter are characteristic frequency (turning frequency, natural frequency), gain and consumption, damping coefficient and quality factor. Since the driving frequency of the selected sensor is 13KHz, the turning frequency of the designed low-pass filter can be set as 500Hz, and the remaining data can also be calculated according to the turning frequency [5].

The low-pass filter adopts the second-order infinite gain multi-channel feedback Butterworth low-pass filter, and the calculation formulas of the second-order low-pass filter's transfer function, gain, natural frequency and quality factor are respectively shown in Equations 3, 4, 5 and 6.

$$H(s)=\frac{K_p\omega_0^2}{s^2+\alpha\omega_0 s+\omega_0^2} \tag{3}$$

$$K_P=-\frac{R_3}{R_1} \tag{4}$$

$$\omega_0=\frac{1}{\sqrt{R_2R_3C_1C_2}} \tag{5}$$

$$\frac{\omega_0}{Q}=\frac{1}{C_1}\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right) \tag{6}$$

The designed second-order low-pass filter is shown in Figure 4.

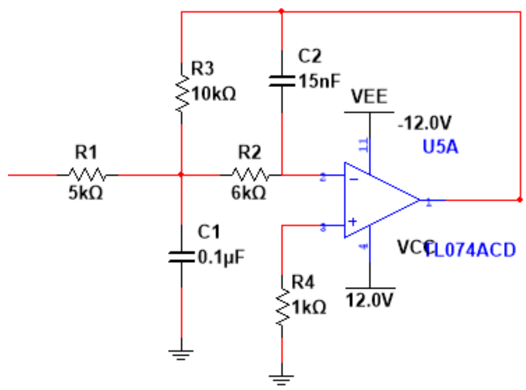

Figure 4. Second order low pass filter

Because there is no positive feedback in the infinite gain multichannel feedback filter circuit, it is always stable. The disadvantage of this circuit is that it requires high ideal degree of operational amplifier, and sometimes it is very inconvenient to adjust [6].

2.1.5 MCU circuit design

MCU circuit selection STC89C52 chip, MCU in the system is mainly responsible for the following parts of the content: A/D acquisition circuit control and data reading, LCD screen control and display.

The word length of AD converter is related to the resolution of the data acquisition system and even the whole system. Therefore, when choosing AD converter, it is necessary to ensure that the word length is enough to reduce the error from the converter as far as possible. We commonly used AD converter word length for 8 bit, 12 bit or 16 bit three, according to the design requirements, the design of the system resolution is 0. L μm, the system range is ±200μm, taking into account the actual voltage range of 0 to 5V, so you can calculate the resolution of A/D converter should be greater than 1.25mV. If the 16-bit AD converter is selected, the resolution of the converter is about 0.08mV when the unipolar input is used, which meets the design requirements. If the 12-bit AD converter is selected, the resolution of the converter is about 1.22mV when the unipolar input is used, which also meets the design requirements. However, when the 8-bit converter is selected, the resolution of the converter is about 19.53mV for unipolar input, which does not meet the requirements. Therefore, this topic needs to choose 12 bit or 16 bit AD converter to meet the design requirements. The chip used by STC89C52 microcontroller to realize AD conversion is XPT2046, which is A 12-bit successive approximation A/D converter, meeting the requirements [7].

This design uses the LCD1026 liquid crystal display that matches with STC89C52 chip. The output voltage, which is converted into digital signal by A/D, is displayed on the LCD screen, which is easy to read.

2.2. Software System Design

For the whole system, in order to complete the realization of its functions, in addition to the hardware circuit introduced before, but also need a matching software system to cooperate. The software design is through the microcontroller control AD converter and LCD1062 LCD, A/D converter to convert analog signals into digital signals, and then through the LCD1062 LCD display data measurement.

This software system mainly consists of two parts: A/D acquisition module and LCD display module. The program design structure is mainly divided into the following parts: I/O port initialization setting, A/D conversion initialization setting, A/D conversion acquisition, filtering algorithm, data conversion, key setting and liquid crystal display. The flow diagram of the main program is shown in Figure 5.

3. System Test and Validation

In order to obtain accurate data, calibration should also be carried out under standard conditions. The standard conditions calibrated in this topic generally refer to no vibration, acceleration, impact force and so on, the ambient temperature is about 20℃, the relative humidity is less than 85%RH, the pressure is one atmosphere and so on.

The calibration of this topic adopts absolute method calibration, and the calibration steps are as follows:

(1). Connecting the sensor of the system with the standard measuring system, the measuring range of ±200μm is divided into 20 equidistant interval points.

(2). According to the 20 equal points of the whole measuring range, from small to large, the system is used to measure the length of the measured point by point, and record the output voltage corresponding to the measured point.

(3). On the contrary to 2, the output voltage corresponding to the input value at each point is recorded in turn as the measured voltage decreases from large to small.

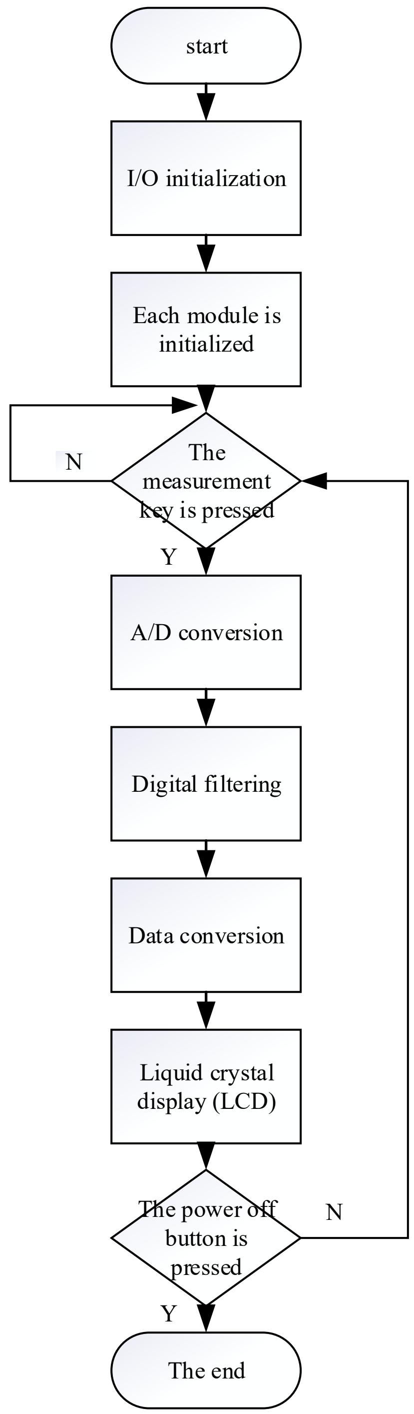

Figure 5. Main program flow chart

(4). According to the process described in Step 2 and Step 3, carry out multiple cycle tests of forward and backward travel of the measuring system, process the measured data at each point, eliminate invalid values, and then average the data at each point.

(5). Draw the output value -- input test data curve with the average value of each point, according to the test data curve, the characteristic index of the system can be obtained [8].

Because the measuring range of the sensor probe is 400μm, through the above method, select 20 different measuring lengths in this range for several measurements, observation of the measured data, we can know that with the linear change of displacement, the output voltage is roughly linear change, so you can take the linear fitting method to draw the fitting curve. Finally,

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the relationship between the output voltage y(V) and the displacement (μm) was obtained by fitting the experimental data with the least square method

$$y = 83.6303x - 216.3238 \tag{6}$$

Finally, the standard measuring parts were measured for 20 times in the measuring range, and the obtained voltage value was substituted into the formula to obtain the maximum error of 0.6μm.

4. Summary

It can be seen from the experiment that the current inductance micrometer based on multiplicative phase sensitive detection has high stability and precision in the range, and can be used for precision measurement. Moreover, using the reasonable collocation of hardware circuit and software system to process signals also has a certain practical value in theory, which provides some help for the realization of high-precision measurement and processing operations within my ability.

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