Research Article

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Design of K Type Thermocouple Cold End Automatic Compensation Based on Single Chip Microcomputer

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Abstract

The K-type thermocouple is one of the most widely used temperature sensor in the industrial field, and its performance directly affects the accuracy of the sensor. As the most important measurement tools of detection technology and Instruments, the results' accuracy of the K-type thermocouple is very important. In order to improve the compensation accuracy, this design gets improvement on the methods of cold-junction compensation. According to the great data processing capabilities of single chip microcomputer, this paper designs the K-type thermocouple cold-junction compensation circuit by using the spot potential and the algebraic sum of environmental potential as thermocouple's standard potential.

Introduction

Research background and significance.

In order to reduce or eliminate the measurement error, it is necessary to compensate the temperature of the cold end of the thermocouple [1].

With the development of digital electronic technology and manufacturing process, it is possible to integrate cold end compensation device, measuring instrument and other components on a chip [2]. AD595 is such an integrated circuit, which has the advantages of high impedance differential input, wide power supply range, low impedance voltage output, and high disturbance rejection ability [3]. AD595 chip and K type thermocouple match very well, can achieve output linearization [4].

In order to further improve the precision of thermocouple cold end compensation, researchers at home and abroad are making continuous efforts. Recently, domestic high-precision digital thermometers have made the cold end of the isolation chamber [5], in order to minimize the influence of temperature changes in the surrounding medium [6]. The new development of cold end compensation technology will make thermocouple temperature measurement technology perfect day by day [7].

Background information on thermocouples

Principle of thermocouple.

There is a temperature difference between the connection points of two homogeneous conductors of different materials, and then there will be electromotive force in the loop, and at the same time there will be electric current in the loop, and this is what we call thermoelectric effect. The electromotive force generated in the loop is called thermoelectric potential, and its size has a functional relationship with the temperature of the contact, which is the temperature measurement principle of thermocouple [8].

Thermoelectric potential is composed of thermoelectric potential and contact potential, of which the proportion of contact potential is larger and the proportion of thermoelectric potential is smaller.

(1) Thermoelectric potential.

For the same section of metal conductor, when there is a temperature difference between the two ends, the electrons in the relatively high temperature region will drift to the relatively low temperature region. At this point, the cooler regions start to accumulate negative charges and the warmer regions start to accumulate positive charges, creating an electric field in the conductor that prevents electrons from drifting. The electric field will be enhanced with the drift of electrons. When the intensity of the electric field increases to a critical value, the situation of free electron drift will disappear. At this time, the dynamic balance is reached, and the electric potential of the relatively high temperature region is higher than that of the relatively low temperature region due to the accumulation of charges of different polarity at both ends of the conductor. This is the Thomson effect.

The thermoelectric potential of conductors A and B can be calculated by formula (1).

$$e_A(T,T_0) = \int_{T_0}^{T} \sigma_A \, dT \, , e_B(T,T_0) = \int_{T_0}^{T} \sigma_B \, dT \tag{1}$$

(2) Contact potential.

When two different metals contact each other, the free electrons will appear free diffusion because of the different concentration of free electrons in the two metals. That's when the two metals start to accumulate charges on the surfaces they touch, creating an electric field that prevents electrons from spreading. The electric field will be enhanced with the diffusion of electrons. When the intensity of the electric field increases to a critical value, the diffusion of free electrons will disappear. At this point, the dynamic balance is reached. This is the Perlpost effect.

The contact potentials of conductors A and B can be calculated by formula (2).

$$e_{AB}(T) = \frac{KT}{e}\ln\frac{n_A}{n_B}, e_{AB}(T_0) = \frac{KT_0}{e}\ln\frac{n_A}{n_B} \quad (2)$$

(3) Total potential of the thermocouple closed circuit.

According to the thermocouple temperature measurement principle, the total electromotive force of the thermocouple closed circuit is the algebraic sum of the total contact potential and the total temperature difference potential, whose formula can be expressed by formula (3).

$$E_{AB}(Tn, T_0) = (T - T_0)\frac{k}{e}\ln\frac{n_A}{n_B} + \int_T^{T_0}(\sigma_B - \sigma_A)dT \quad (3)$$

Through the above analysis, we can draw the following conclusions:

1. The size of thermocouple thermoelectric potential depends on the material of the two homogeneous conductors and the temperature of the thermoelectric ends and has nothing to do with the length and thickness of the thermal electrode.
2. A thermoelectric potential can occur only when the homogeneous conductors of the thermocouple are of different materials.
3. Thermoelectric potential can be generated only when there is a temperature difference between the two ends of the thermocouple.
4. When the two thermal electrode materials of the thermocouple are selected, the size of the thermoelectric potential will only depend on the temperature of the two ends of the thermocouple.

The fundamental law of thermocouples.

(1) Intermediate conductor law.

The thermocouple closed circuit is connected by two homogeneous conductors of different materials. When another homogeneous conductor is connected in the circuit, if there is no temperature difference between the two contacts of the homogeneous conductor in the circuit, the thermoelectric potential generated by the thermocouple will not be affected.

(2) Thermocouple electrode law.

It is known that the thermoelectric potential generated by the thermocouple composed of conductor A and conductor C at contact temperature T and T_0 is $E_{AC}(T_0)$, and the thermoelectric potential generated by the thermocouple composed of conductor B and conductor C at contact temperature T and T_0 is $E_{BC}(T_0)$, then the thermoelectric potential $E_{AB}(T_0)$ generated by the thermocouple formed by conductor A and conductor B at contact temperature T and T_0 is the algebraic sum of $E_{AC}(T_0)$ and $E_{BC}(T_0)$, as shown in formula (4).

$$E_{AB}(T, T_0) = E_{AC}(T, T_0) + E_{BC}(T, T_0) \quad (4)$$

(3) Intermediate temperature law

$E_{AB}(T, T_n)$ is the thermoelectric potential of a thermocouple at contact temperature T and T_n, and $E_{AB}(T_n, T)$ is the thermoelectric potential of a thermocouple at contact temperature T and T_0. Then $E_{AB}(T, T_0)$ is the algebraic sum of $E_{AB}(T, T_n)$ and $E_{AB}(T, T_n)$ at contact temperature T and T0. Formula is shown in formula (5).

$$E_{AB}(T, T_0) = E_{AB}(T, T_n) + E_{AB}(T_n, T_0) \quad (5)$$

Classification of thermocouples.

Thermocouple can be divided into standardized thermocouple and non-standard thermocouple; standardized thermocouple can be divided into inexpensive metal thermocouple and precious metal thermocouple according to the cost. Precious metal thermocouple generally refers to platinum rhodium thermocouple, S, R, B three models, usually used for temperature measurement in high temperature places. Low temperature metal thermocouple refers to nickel-chromium-nickel-silicon thermocouple used for temperature measurement in low temperature places, there are K, T, J, E four models.

Factors of temperature measurement error

(1) Influence of insertion depth.

If the temperature of the thermocouple is low, the measurement error may occur due to heat loss in the heat transfer process of the protective casing. The error caused by heat loss in the process of heat transfer is related to the depth of thermocouple insertion, so the measurement error is affected by the depth of thermocouple insertion.

(2) Impact of response time.

The response time of the thermocouple is related to the time when the two objects in contact with each other reach the same temperature, so the thermal electrode composed of the thermocouple is required to have good thermal conductivity, and the material composed of the protective sleeve is required to have good thermal conductivity.

(3) Influence of thermal impedance increase.

If the thermocouple measures a high-temperature gas medium, the thermal impedance of the protective casing will increase as particles in the gas medium adhere to and melt on the casing surface. The increase of thermal impedance of protective casing will affect the heat transfer process and make the measured temperature lower than the actual temperature.

(4) Thermoelectric heterogeneity effect.

Degradation of material may occur when thermocouple works in high temperature environment for a long time. When the degraded part of thermal electrode works in an environment with temperature difference, there will also be parasitic potential, causing errors in measurement results.

(5) Shunt error of armoured thermocouple.

When the armored thermocouple is used to measure the temperature in the furnace, if there is more than 800°C area near the middle part of the thermocouple, the temperature measurement result will be abnormal due to the decrease of insulation resistance, which is called shunt error.

Cold end compensation method.

The common cold end compensation methods are listed below, and their working principles and advantages and disadvantages are briefly introduced.

(1) Ice bath method.
Place the ice water mixture in an insulated container at standard atmospheric pressure and force at 0°C. The advantages are simple and easy, high compensation precision. Disadvantage is susceptible to external environment.

(2) Bridge method.
The principle is to use the voltage generated by the unbalanced bridge to compensate the influence of the temperature change of the cold end of the thermocouple on the output potential. Advantage is simple line, low cost. The disadvantage is poor applicability.

(3) Diode compensation method.
The principle is to use the diode voltage with temperature change characteristics of thermocouple temperature compensation. The disadvantage is that the discrete type of compensation element is large, which affects the compensation accuracy.

Main Research Contents

Thermocouple in the junction temperature of T, T_n field generated by the potential for E_1, the junction temperature is generated when the T_n, T_0 environment potential for E_2, then by the laws of the intermediate temperature, thermocouple in junction temperature T, T_0 the standard electric potential E to spot potential potential E_2 algebra and E_1 and the environment, the formula as shown in formula (6).

$$E = E_1 + E_2 \qquad (6)$$

Therefore, as long as the designed hardware circuit can complete the measurement of field potential E_1 and environmental potential E_2, the standard potential E can be calculated, and then query the thermocouple indexing table can get the hot end temperature.

Design and analysis of cold end compensation circuit.

Traditional cold end compensation circuit.

Bridge method is a method to compensate the temperature of cold end of thermocouple by using the voltage generated by unbalanced bridge.

The cold end compensation method is simple in principle and low in cost, but it can only realize the complete compensation when the cold end temperature is the equilibrium temperature and the complete compensation temperature, and there are compensation errors at other temperatures.

Environmental potential measurement circuit.

We can use copper thermal resistance, platinum thermal resistance and other temperature sensors to measure the ambient temperature, and then through the functional relationship between the ambient potential and the ambient temperature can be calculated. The data corresponding to thermoelectric potential and temperature can be obtained by querying k-type thermocouple indexing meter, and the function relation between environmental potential and ambient temperature is determined by using least square method to fit the data. The calculation formula is shown in formula (7).

$$E_1 = 0.0392 \text{ X } T_n + 0.0340 \qquad (7)$$

Figure 1 is the environmental potential measurement circuit designed to achieve formula (7). R18 is PT100 platinum thermal resistance, which can linearly reflect the change of temperature to the output V_{o1}. The data corresponding to the ambient temperature and the output voltage V_{o1} can be obtained through the test, and the least square method is used to fit the data, and the functional relationship between the ambient temperature Tn and the output voltage V_{o1} is obtained, as shown in formula (8).

$$T_n = 33.6080 \text{ X } V_{o1} - 76.8451 \qquad (8)$$

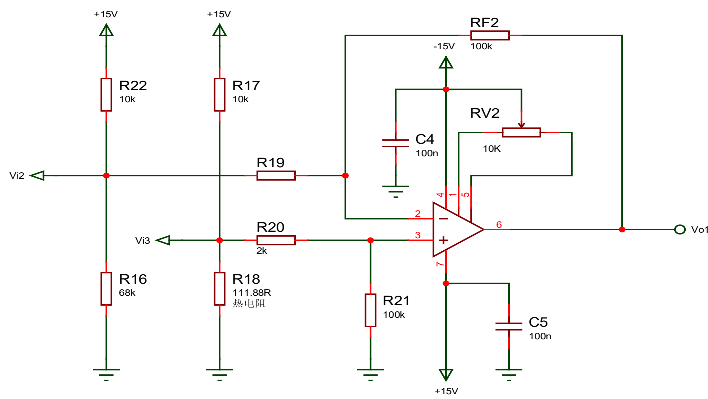

Figure 1: Ambient temperature measurement circuit

Field potential measurement circuit.

The thermoelectric potential E_2 measured by the thermocouple is connected to the differential integrated op amp µA741 via resistor R14. The data corresponding to the field potential and the output voltage V_{o2} can be obtained through the test. The least square method is used to fit the data and the functional relationship between the field potential and the output voltage V_{o2} is obtained, as shown in formula (9).

$$E_2 = 16.3017 \text{ X } V_{o2} - 1.2603 \qquad (9)$$

Software simulation of cold end compensation.

The basic operation process of Proteus is to start the program, which can enter the operation page. The operation page is mainly composed of schematic diagram editing window, preview window, mode selection toolbar, component list, simulation toolbar and direction toolbar.

In the mode selection toolbar, we mainly use component mode and terminal mode. Click the 'P' button in select component mode to enter the select component dialog box, where you can find the component we need.

In the case of known required component model can directly enter the keyword in the keyword search, you can find the required component in the results, double-click the component, the component will appear in the component list for us to choose at any time. Terminal mode can provide us with the required terminal interface.

The simulation.

Proteus software is used to simulate the cold end compensation circuit before and after the improvement, and the compensation effect is compared to verify whether the improved cold end compensation circuit can improve the accuracy of cold end compensation.

By comparing the cold end compensation methods before and after the improvement, it can be found that although the compensation effect of the bridge method is better when the cold end temperature compensation is below 20°C, the improved cold end compensation method can obtain better compensation accuracy in the whole temperature range and is more suitable for industrial production.

Microcomputer compensation scheme

Figure 2 shows the temperature signal processing circuit at the hot end, which is mainly composed of A/D conversion device, single chip microcomputer, LIQUID crystal display, pull-up resistor, etc. Below, we make A brief introduction to these components.

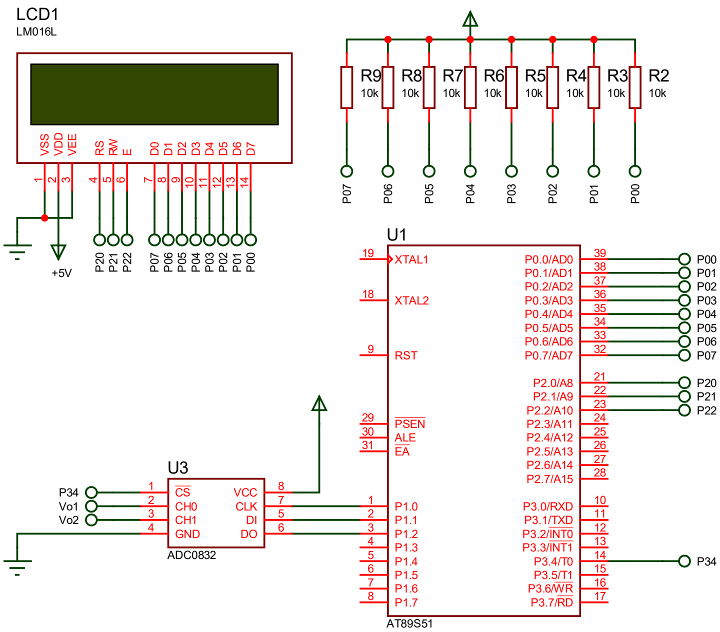

Figure 2: Signal processing circuit

Signal processing circuit components.

(1) A/D converter.

Analog quantity has continuity in both time and value, and unlike analog quantity, digital quantity has discreteness in both time and value. A/D converter can convert analog quantity into digital quantity.

In this design, the analog input channel CH0 of THE ADC0832 chip is connected with the voltage signal V_{o1} output by the environmental potential measurement circuit, and the voltage signal V_{o2} output by the field potential measurement circuit is connected with the microcontroller through the 5th pin of the ADC0832 chip to control the collection sequence of the field potential and the environmental potential. The analog quantity is converted into digital quantity by THE ADC0832 chip and output to the single chip from pin 6. The functional relationship between the analog signal Vi before the chip conversion and the digital signal VAL after the conversion can be expressed by the formula (10).

$$VAL = 51 \text{ X } V_i \quad (10)$$

(2) Display.

At present, the commonly used display components are digital tube, dot matrix screen, LIQUID crystal display, LED and LCD, this design uses the 14-pin LCD1602 chip as a display.In this design, LCD1602 chip is used to display the temperature of the hot end.

(3) single chip microcomputer.

Single-chip microcomputer is a kind of single-chip microcomputer with powerful data processing function. it has been widely used because of its small size, low price, perfect function, real-time measurement and control system and so on. AT89S51 and AT89C51 these two kinds of chips both belong to 51 series single-chip microcomputer, which is a good choice for this design.

Calculation of hot end temperature of thermocouple.

The data corresponding to the standard potential E and the temperature T of the hot end can be obtained by querying the K-type thermocouple indexing meter. The least square method is used to fit the data and the functional relationship between the standard potential E and the temperature T of the hot end is obtained, as shown in formula (11).

$$T = 24.5020 \text{ X } E - 4.40446 \quad (11)$$

Software design and simulation

(1) measure the field potential E_2 of the thermocouple. The A/D conversion module is used to convert the voltage analog quantity into the voltage digital quantity and send it to the single-chip microcomputer. The calculation formula between field potential and digital signal VAL is shown in formula (12).

$$E_2 = 8 \text{ X } VEL / 25 - 1 \quad (12)$$

(2) Measure the environmental potential   of the thermocouple. A/D conversion module is used to convert analog voltage into digital voltage and then send it to the single-chip microcomputer. The calculation formula between environmental potential and digital signal VAL is shown in formula (13).

$$E_1 = VEL / 40 - 3 \quad (13)$$

(3) According to the intermediate temperature law, the standard potential E can be obtained by summing the environmental potential E_1 and the on-site potential E_2

(4) The hot end temperature T is calculated by using the functional relationship between standard electric potential E and hot end temperature. The calculation formula between the standard potential and the temperature of the hot end can be derived, as shown in formula (14).

$$T = 24 \text{ X } E + E / 2 - 4 \tag{13}$$

Figure 3 is the circuit schematic diagram of the cold end temperature compensation system of type K thermocouple.

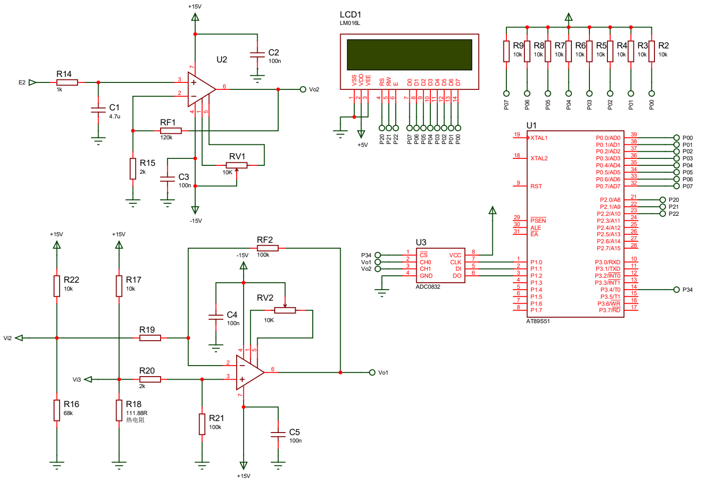

Figure 3: Schematic diagram of cold end compensation system

Conclusion

K type thermocouple indexing meter is established in the cold end temperature of , but the temperature of the thermocouple working environment is usually not 0°C, so we have to design the cold end compensation system based on the intermediate temperature law. The A/D converter converts the output voltage signal of the ambient temperature measuring circuit and the field temperature measuring circuit into digital signal and then sends it to the single chip microcomputer. The powerful data processing power of the single chip microcomputer is used to process the two input signals, and the processing results are displayed on the display.

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