A Platinum Resistance Bridge Thermometer

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Keywords: Pt100. Bridge Circuit. Linear Temperature Measurement. Reference Table

Abstract. A platinum resistance bridge thermometer is introduced. It implements linear temperature measurement in -200~850 degrees with a bridge circuit. It consists of bridge circuit, multi-channel switches, amplifier, AD574, display, COM port, precision power supply, 89C51 etc. After the analysis of bridge circuit characteristic, a method is presented that the platinum resistance value is obtained by computing the current ratio of tow bridge circuit loop and then looking into the Pt100 reference table to obtain the measured temperature. So the linear temperature measurement is implemented without nonlinear compensation. The measurement error is less than 1.5 degrees.

Introduction

It is a most widely used method to measure the thermal resistance using a bridge circuit. In addition to the balanced bridge circuit used in laboratory the bridge circuit used to realize continuous measurement is work mostly in unbalanced state. It is a nonlinear relationship between the output voltage of the bridge circuit and the measured resistance. Generally we use a approximate linear method to complete the resistance measurement. This bring measurement error. The larger the measurement range the more the measurement error, sometimes up to 3~5%. It is very adverse for measurement accuracy. The measurement error will be larger considering the nonlinearity between the platinum resistance and temperature. For this point there are many nonlinear compensation methods by software or hardware technology that improved the measurement accuracy to a certain extent[1-5]. This paper presents a simple and practical method to measure the thermal resistance with a bridge circuit. The linear temperature measurement can be realized without nonlinear compensation.

Bridge Circuit

Single-arm Bridge Circuit. The simplest single-arm bridge circuit is shown in Fig. 1. R_t is the measured resistance, R_1, R_2, R_3 is fixed resistors, E is power supply, U_i is output, I_1, I_2 is the loop current of the two bridge loop at left and right. U_p is the voltage of the point a in left two arm branch and its value changes with R_t, U_s is the voltage of the point b in right two arm branch and its value is a constant. The output voltage U_i is

$$U_i = U_s - U_p = \frac{R_2}{R_1 + R_2}E - \frac{R_3}{R_3 + R_t}E = \frac{R_2 R_t - R_1 R_3}{(R_1 + R_2)(R_3 + R_t)}E \tag{1}$$

It is nonlinearity between U_i and R_t. Generally, let $R_t = R_{t0} + \Delta R_t$, $R_1 = R_2 = R_3 = R_{t0} = R$, Eq. 1 simplified as

$$U_i = \frac{\Delta R_t}{4R(1 + \frac{\Delta R_t}{2R})}E \tag{2}$$

Eq. 2 is the precise characteristic of U_i and R_t. when $\Delta R_t << R_{t0} = R$, ignore $\frac{\Delta R_t}{2R}$, Eq. 2 approximation as

$$U_i = \frac{\Delta R_t}{4R}E \tag{3}$$

Eq. 3 is a approximate linear relationship between U_i and ΔR_t when $\Delta R_t << R_{t0}$. It is the approximate characteristic of U_i and R_t. Let ΔR_t in 0 ~ 400 Ω, when R=1kΩ, 2kΩ, 3kΩ, the curve of Eq.2 and Eq. 3 is shown in Fig. 2. It is clear that the greater the R the smaller the error between Eq.2 and Eq. 3, and U_i range is reduced at the same time. The approximate value is greater than the precise value under the same ΔR_t. When R=3kΩ, ΔR_t=290Ω, the error is + 4.6% for the approximate value. For Pt100 the

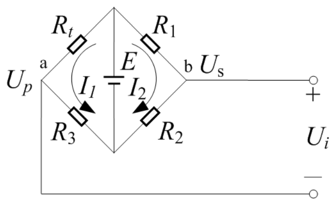

Figure 1. single-arm bridge circuit

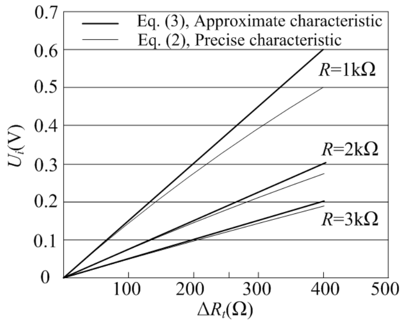

Figure 2. The curve of precise characteristic and approximate characteristic with different R

corresponding temperature error is about 35 ℃. The error will be larger coupled with the nonlinear characteristic of platinum resistance itself. Many nonlinear compensation methods was adopted to fix this error in instruments. This error include two aspects, one is the approximation error when using Eq. 3, the other is the inherent nonlinear error of platinum resistance. The two errors correction is tedious.

Platinum Resistance Bridge Circuit It is very easy to calculate the measured resistance ΔR_t with Eq. 2 based on microprocessor after measuring the U_i. But Eq. 2 is related to the power supply E and many factors can influence the stability of E, that is very bad for accurate measurement. In addition, it is necessary to do compensation for the impact of lead resistance when using platinum resistance to measure temperature. Usually use a three-wire connection. The improved bridge circuit is shown in Fig. 3. Here R_t is Pt100. The r is equivalent resistance of the three leads of R_t and its maximum value

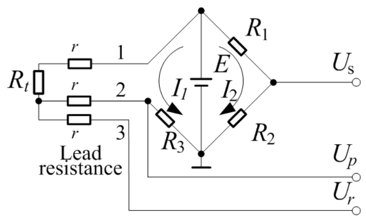

Figure 3. Platinum resistance bridge circuit

is 15 Ω. On both ends of R_t the lead 1 and 2 connected to the upper and lower arm of the bridge circuit left side respectively. Another lead 3 is used as a output terminal for U_r. U_r is compensation voltage signal of lead resistance. For the left loop, there is

$$E = (r + R_t + r + R_3)I_1 \tag{4}$$

Also, For the right loop, there is

$$E = (R_1 + R_2)I_2 \tag{5}$$

Because Eq. 4 = Eq. 5. there is

$$R_t = (R_1 + R_2)\frac{I_2}{I_1} - 2r - R_3 \tag{6}$$

Eq. 6 is the computing equation to realize the Pt100 measurement with bridge circuit shown in Fig. 3. It can be seen that the Pt100 value is obtained by computing the current ratio I_2/I_1 of tow bridge circuit loop. Eq. 6 not include the E so reducing its fluctuations. At the same time it corrects the effect of lead resistance r also. By Fig. 3 we have

$$I_2 = \frac{U_s}{R_2} \tag{7}$$

$$I_1 = \frac{U_p}{R_3} \tag{8}$$

$$r = \frac{U_r - U_p}{I_1} = \frac{U_r - U_p}{U_p} R_3 \tag{9}$$

Put Eq. 7, Eq. 8, Eq. 9 into Eq. 6, we can get

$$R_t = (R_1 + R_2)\frac{R_3}{R_2}\frac{U_s}{U_p} - 2R_3 \frac{U_r - U_p}{U_p} - R_3 \tag{10}$$

In this way, after R_1, R_2, R_3 selected and sampling the voltage signal U_s, U_r, U_p, the accurate value of Pt100 can be calculated by Eq. 10. That need not do any nonlinear compensation.

Platinum Resistance Data Processing Circuit

The platinum resistance signal processing circuit is shown in Fig. 4. It consists of the precision power supply E, bridge circuit, multi-channel switches M2, amplifier etc. MC1403 is used as precision voltage source E and its output reference voltage is 2.5V±25mV. here we take E = 2.525 V and its largest output current is 10 mA. A intermittent power supply way is used for the bridge circuit to minimize the influence of electro-thermal effect when the Pt100 is powered on long time. The Pt100

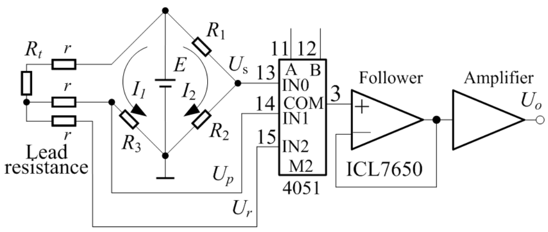

Figure 4 Platinum resistance data processing circuit

temperature range is -200~850ºC, its resistance range is 18.52Ω~390.48Ω, ΔR_t=371.96Ω. The manganin resistors are used for other resistors of bridge circuit in order to obtain stable temperature characteristic and precision resistance value. In order to let the U_p having sufficient range where Pt100 value changing, and limit the bridge circuit current within 10 mA, let R_1=18Ω, R_2=R_3=R=500Ω, so from the Eq. 10 we can get

$$R_t = 518\frac{U_s}{U_p} - 1000\frac{U_r - U_p}{U_p} - 500 \tag{11}$$

Eq. 11 is the precise computing equation to calculate the R_t with the measured voltage signal U_s, U_r, U_p. Let r=0Ω, U_s=2.437V, Eq. 11 as follow

$$R_t = 518\frac{2.437}{U_p} - 500 = \frac{1262.5}{U_p} - 500 \tag{12}$$

Now the Eq. 12 characteristic curve is shown in Fig. 5, it is a nonlinear curve.

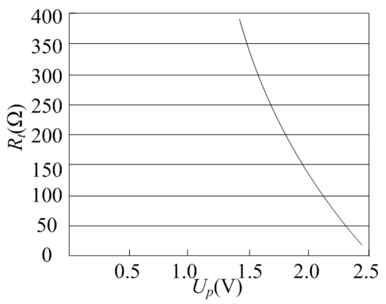

Figure 5. $R_t \sim U_p$ curve

From Fig. 4 ,U_s is

$$U_s = \frac{R_2}{R_1 + R_2}E = \frac{500}{18 + 500}2.525 \approx 2.437 \text{ V} \tag{13}$$

Let r=15Ω, when R_t=390.48 Ω, U_p is smallest, its value is

$$U_{p\min} = \frac{R_3}{R_t + R_3 + 2r}E = \frac{500}{390.48 + 500 + 2\times 15}2.525 \approx 1.372\ \text{V} \tag{14}$$

U_r is smallest also, its value is

$$U_{r\min} = \frac{R_3 + r}{R_t + R_3 + 2r}E = \frac{500 + 15}{390.48 + 500 + 2\times 15}2.525 \approx 1.413\ \text{V} \tag{15}$$

When R_t=18.52Ω, the U_p is biggest, its value is

$$U_{p\max} = \frac{R_3}{R_t + R_3 + 2r}E = \frac{500}{18.52 + 500 + 2\times 15}2.525 \approx 2.302\ \text{V} \tag{16}$$

U_r is biggest also, its value is

$$U_{r\max} = \frac{R_3 + r}{R_t + R_3 + 2r}E = \frac{500 + 15}{18.52 + 500 + 2\times 15}2.525 \approx 2.371\ \text{V} \tag{17}$$

The maximum effective output of bridge circuit is

$$\Delta U_{i\max} = U_{p\max} - U_{p\min} = 0.93\ \text{V} \tag{18}$$

Voltage signal U_s, U_r, U_p be sent to the amplifier through multi-channel switch M2 time-sharing, the voltage amplification factor K=4.1(V/V), so the U_s can be amplified to 10 V, the U_r and U_p less than 10 V, the amplifier output signals U_o be sent to AD converter. U_s is partial voltage of E on R_3 in the right side branch of the bridge circuit. Using sampling values in the Eq. 11 can play a role for power real-time self-calibration. The first level of amplifier adopts the follower in order to improve the input impedance and reduce the impact on the bridge circuit. here the follower is ICL7650, its input impedance is 10^{12} Ω, so the impact on the bridge circuit can be ignored completely.

Structure of Platinum Resistance Bridge Thermometer

The platinum resistance bridge thermometer, as shown in Fig. 6, consists of bridge circuit, multi-channel switch M1 and M2, amplifier, AD574, display, serial port, precision power supply E, 89C51 etc. The bridge circuit power supply E is powered by the reference voltage chip MC1403. Under the control of the 89C51 I/O port P1.1, multi-channel switch M1 turn on during the data collection to supply 10 V to the chip MC1403 and MC1403 output 2.5 V reference voltage as power

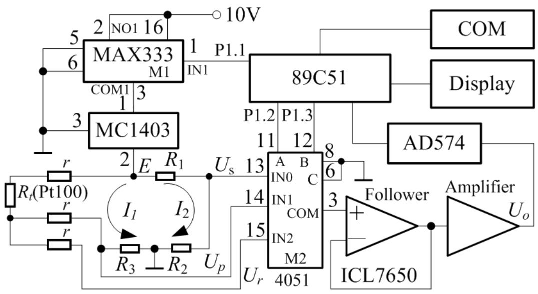

Fig. 6 The platinum resistance bridge thermometer structure diagram

supply E. After the data collection M1 turn off, MC1403 no output, no current flows through the Pt100, so the influence of electro-thermal effect on the measurement accuracy is reduced. The channel IN0, IN1 and IN2 of multi-channel switch M2 turn on time-sharing under the control of 89C51 I/O port P1.2, P1.3, sampling U_s, U_r, U_p respectively, calculating the value of Pt100 by Eq. 11, and then looking into the Pt100 reference table to obtain the measured temperature. So the linear temperature measurement is implemented [6,7]. From the Eq. 18 we can get the maximum digital signal range $D_{\max}$ as

$$D_{\max} = \frac{0.93}{2.437}\cdot 4096 = 1563 \tag{19}$$

The average resolution is 0.67 ºC in -200 ~ 850 ºC. The minimum resolution is 0.74ºC at 850ºCdue to the nonlinear, as shown in Fig. 5. Considering the calculating rounding error, look-up reference table error and the influence of the lead resistance, the measurement error is not more than 1.5ºC without considering the error of the Pt100 itself. The sampling period is 2s.

There are 1051 temperature dividing points in Pt100 reference table in -200~850 ºC. 10 milliohm is used as the unit for each dividing point value of Pt100. The value is converted into hexadecimal number and stored in tow memory cells. The assembly Pt100 reference table is shown in Fig. 7. The

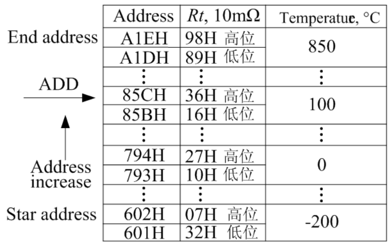

Fig.7 The assembly reference table diagram

assembly reference table occupying 2102 bytes and stored behind system programming. According to the Pt100 value calculated by Eq. 11 we can look into the assembly reference table to get its address. We use the high byte address and let it as ADD shown as Fig. 7. The temperature *t* can be get as

$$t = \frac{\text{ADD} - 602}{2} - 200 \ \ °\text{C} \qquad (20)$$

The look-up table rounding error is less than 0.5 ºC.

Conclusions

It is a important research topic in the temperature measurement field to implement the linear temperature measurement with platinum resistance. Many nonlinear compensation method is used in temperature measurement[1-5]. In the platinum resistance bridge thermometer a bridge circuit is used, the accurate measurement of the platinum resistance value is implemented by computing the current ratio of tow bridge circuit loop and then looking into the Pt100 reference table to get the measured temperature. The linear temperature measurement is realized without any nonlinear compensation. The measurement error is less than 1.5 ºC. It is a very practical linear temperature measuring method. The measurement accuracy can be further improved if using high resolution AD or 0.1 ºC Pt100 reference table.

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