

# High Precision Earth-Temperature Detection System Based on Platinum Resistance

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**Abstract**—According to the measurement precision requirements during geothermal testing process, optimize the circuit design and segmented curve fitting were used, discussed the feasibility of realize high precision temperature detection. Platinum resistance were used as temperature sensing element, matched with high precision constant current source bridge in order to improve the precision of the hardware and the quadratic polynomial fitting and cubic polynomial fitting were analyzed and compared. Final experimental results show that the system made up the deviation intermediate detection process and achieved the purpose of high precision testing.

**Keywords**—Earth temperature; High Precision; Platinum resistance; segmented curve fitting

## I. INTRODUCTION

In the hydrological geological science, agricultural environmental science and other fields, earth temperature is very meaningful data. Layers of thermal parameters include the formation of thermal conductivity and specific heat capacity and thermal diffusion rate, water parameters formation including moisture content, seepage velocity and so on, and these parameters acquisition, are directly or indirectly with soil temperature of the precision measurement<sup>[1]</sup>. Study soil temperature measuring, Help to study plant growth habit, ensure the quality of crops, and improve the agricultural production. On the environment geology, hydrogeology, soil science, and many other areas have very important significance<sup>[2]</sup>.

Based on platinum resistance as temperature medium, combined with high precision temperature measurement circuit, the low power consumption modulus conversion unit, through the single chip microcomputer control, segmented curve fitting the temperature sampling value, get the corresponding D-t curve, and compensate the nonlinear relationship of platinum resistance in the practical work, to achieve the purpose of accurate measurement of the temperature.

## II. SYSTEM'S DETECTION STRUCTURE

Commonly used method of soil temperature measurement is using special thermal resistance or other temperature sensor for temperature measurement. It's measurement accuracy in the 0.1℃, At present, this kind of method was most used to soil parameter measuring equipment in domestic and foreign<sup>[3]</sup>.

The detection scheme of this system was shown in figure 1. Temperature sensing element use EL - 700 (100 Ω)

platinum resistance, the thermal resistance using thick film structure, in low temperature range has good stability and accuracy of measurement, in 259.34 ~ 630.74 ℃ range was identified as standard measuring devices by international scale IPTS - 68. Platinum thermal resistance of input/output characteristic in 0 ~ 850 ℃ range expressed as:

$$R_t = R_0(1 + At + Bt^2) \quad (1)$$

In range of -200 ~ 0℃ expressed as:

$$R_t = R_0(1 + At + Bt^2 - 100Ct^3 + Ct^4) \quad (2)$$

The  $R_0$  for sensor calibration value 100 Ω, temperature coefficients was:

$$A = 3.97 \times 10^{-3} / ^\circ\text{C}, B = -5.85 \times 10^{-7} / ^\circ\text{C}^2, C = -4.22 \times 10^{-12} / ^\circ\text{C}^4.$$

Platinum resistance feels soil temperature variables, convert to resistance signal  $\Delta R$  and output to the measurement circuit. The constant current source driver bridge converted the  $\Delta R$  signal to voltage signal  $\Delta U$ , after amplification and low pass filtering (filtering out-of-band noise) unit, at last, got the analog signal which proportional relation to temperature variable.

In the design process, the temperature-sensing element, temperature measurement circuit, data conversion unit as a whole to be consider. Based on the overall accurate function and described digital quantity expression of D, through piece wise fitting and inversion to series of discrete data D, to obtain the function close to formula (1) and (2). Fitting error was controlled by the least square method. This kind of fitting method made D and T as parameters, compensated the signal deviation generated each of the intermediate links from platinum resistance to A/D conversion process, and made more accurate in temperature measuring<sup>[4]</sup>.

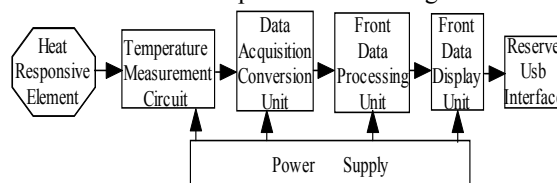


Figure 1. Temperature measurement system solutions

## III. PRECISION ANALYSIS OF HARDWARE DETECTION CIRCUIT

Figure 2 showed the hardware structure of detection circuit. Platinum resistance uses the three-wire system access measuring bridge.

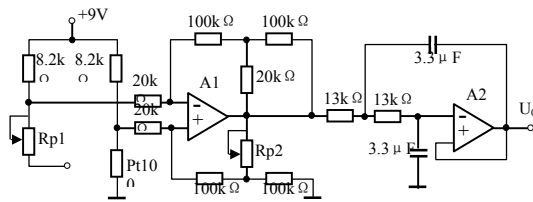


Figure 2. Hardware structure of detection circuit

It can eliminate the influence of lead resistance on the accuracy of measurement, the operational amplifier A1 to signal amplification (Amplifier gain  $K$  can be controlled), A2 and capacitance constitute a high order low-pass active filter. Filter out the useless clutter (Cut-off characteristic steep, Cut-off frequency set to 40 Hz, to eliminate the interference of circuit power frequency effectively). Before the temperature measurement circuit working, Make the relative bridge arm resistance equal to the product, Make bridge in a state of balance, Output voltage  $\Delta U$  was zero, When platinum resistance began to temperature, the change of the resistance capacity for  $\Delta R$ , the amplifier gain of  $A_1$  for  $K$ , the amplifier output voltage  $\Delta U'$  as flow:

$$\Delta U' = K \Delta U = K \frac{(R_0 + \Delta R)R_3 - R_1R_2}{(R_0 + \Delta R) + R_1 + R_2 + R_3} I \quad (3)$$

The output voltage  $\Delta U'$  was sent into data acquisition conversion unit for  $n$  bit modulus conversion, assuming the switching voltage reference  $V_{REF}$  for 5 v, Then the voltage accuracy of converter  $\Delta V_{REF}$  can be expressed as  $V_{REF}/2^n$ , The converter output digital quantity as flow:

$$D = \frac{\Delta U'}{V_{REF}/2^n} = \frac{K \Delta U}{\Delta V_{REF}} \approx \frac{K I \Delta R}{4 \Delta V_{REF}} \quad (4)$$

$(\Delta R \ll R_0, R_1, R_2, R_3)$

Form the equation can see that through the lower voltage reference, improving conversion digits or increasing the amplifier gain  $K$  and bridge circuit current  $I$  can make

TABLE 1 Part of the sampling results of 10°C~20°C temperature range

Actual Temperature (°C)	16 Times Sample Value of One Temperature Point	Final Result D	Temperature Estimated Value (°C)	Measurement error(°C)
	D1 ..... D16			
10	12847 12855 12843 12876 12865 12843 12854 12872 12846	12855.25	9.9871	-0.0059
10.5	13494 13482 13502 13508 13490 13501 13510 13486 13407	13493.89	10.5024	+0.0024
11	14140 14149 14126 14128 14131 14121 14113 14114 14130	14133.56	10.9861	-0.0139
11.5	14786 14790 14767 14762 14771 14788 14781 14759 14780	14773.08	11.4856	-0.0144
12	15442 15439 15378 15380 15430 15412 15397 15424 15435	15416.61	12.0183	+0.0183
...	...	...	...	...
18.5	23768 23711 23762 23735 23754 23739 23733 23733 23774	23742.13	18.4936	-0.0064
19	24378 24346 24387 24393 24377 24355 24379 24381 24375	24381.11	19.0142	+0.0142
19.5	25038 25009 25042 25051 25003 24987 25034 25012 25003	25024.72	19.5095	+0.0095
20	25665 25641 25668 25677 25641 25663 25650 25655 25640	25662.67	19.9941	-0.0059

#### V. CURVE FITTING PROCESS ANALYSIS OF D TO t

During the temperature range of -20°C to 60°C, every 10°C was divided as a piecewise fitting in order to ensure fitting precision. A fitting function expression for:

A/D converter to improve sensitivity. Assuming the system A/D conversion digits as  $n=16$ , the amplifier gain  $K=200$ , the bridge circuit current  $I=5 \times 10^{-3}A$ , then:

$$D = 2^n \times \frac{K I \Delta R}{4 V_{REF}} = 2^{16} \times \frac{200 \times 5 \times 10^{-3}}{4 \times 5} \Delta R = 2^{16} \times 50 \times 10^{-3} \Delta R \quad (5)$$

For the platinum resistance of EL-700(100Ω), the ideal mathematical model of the I/O relationship is as follows:

$$R_t = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \dots + a_n t^n \quad (6)$$

In the case of not affecting the measurement precision, using formula (1), (2) to approximate alternative, and substitution formula (5), can get:

$$D = 327680 (At + Bt^2) \quad (0 \leq t \leq 850^\circ C) \quad (7)$$

$$D = 327680 (At + Bt^2 - 100 Ct^3 + Ct^4) \quad (-200^\circ C \leq t \leq 0)$$

#### IV. ORIGINAL DATA COLLECTION

For each specific temperature  $t$  should have a unique  $D$  to corresponding, with the  $D$  value, then looking for the relationship between temperature and the temperature point and the voltage signal which is converted by the A/D<sup>[5]</sup>. by using of least squares method piecewise fitting  $D - t$  curve, combined with the collected digital quantity  $D$  can get practical temperature.

Using constant temperature tank to simulate 0°C~60°C temperature field when testing, every 0.1°C as a temperature sampling point, for each sampling point sample 16 times. Eliminated the maximum and the minimum sample in the group of 16 samples, and the remaining 14 value take average as the sampling results, so that we can effectively remove bulky error and random error influence. Part of the sampling results of 10°C~20°C range were intercepted and shown as table 1, the interval for 0.5°C.

$$t = a_0 + a_1 D + a_2 D^2 + \dots + a_m D^m \quad (8)$$

Above  $a_0, a_1, a_2 \dots a_m$  to stay for coefficient. From engineering view, deviation of fitting curve mainly comes from the following aspects: First, uneven experiment data. Second, data density. More density data will increase of

the curve constraint, thus reduce the interval experimental data deviation of fitting curve. Third, suitable interval of fitting curve. Generally, in the experimental data interval has small deviation, while outside interval, deviation will far from the prediction and higher order fitting lead to the greater error [6].

Comprehensive consideration the above factors, decided to use quadratic polynomial and cubic polynomial to go fitting processing separately, and compare the measurement accuracy they can reach. In temperature range of  $10^{\circ}\text{C} \sim 20^{\circ}\text{C}$ , under the quadratic polynomial fitting, the measurement error was shown in figure 3, it clear that the error in  $-0.04^{\circ}\text{C}$  to  $0.04^{\circ}\text{C}$  range; However, under Cubic polynomial fitting, the measurement error showed in figure 4, the error range form  $-0.02^{\circ}\text{C}$  to  $0.02^{\circ}\text{C}$ , measuring precision had be increased remarkably. Therefore, the system decided to select cubic polynomial fitting.

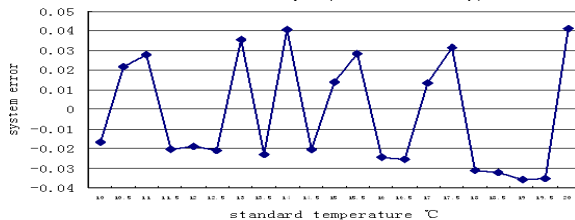


Figure 3. Error distribution curve under quadratic polynomial fitting

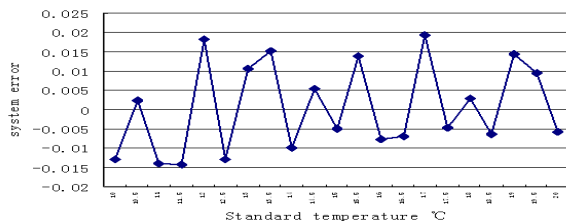


Figure 4. Error distribution curve under cubic polynomial fitting

In the formula (8), m value for 3, the D and t value of  $10^{\circ}\text{C} \sim 20^{\circ}\text{C}$  temperature range substituted in it and got:

$$\begin{bmatrix} 1 & D_1 & D_1^2 & D_1^3 \\ 1 & D_2 & D_2^2 & D_2^3 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & D_n & D_n^2 & D_n^3 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix}^T = \begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_n \end{bmatrix}^T \quad (9)$$

Namely the type:  $A\alpha = T$

Above equation, the sampling number n is greater than the number of unknown quantity, so it is an inconsistent equation. Used the least square method to solve it in order to ensure fitting accuracy, The total mean square error  $\delta$  was  $\|T - A\alpha\|_2^2$ . Make it the minimum, and the could get the  $\alpha$  value, so must solve the following equation:

$$\frac{\partial \delta}{\partial \alpha} = -2A^T T + 2A^T A \alpha = 0 \quad (10)$$

Above, the A and T was known, solve the vector  $\alpha$ , namely determined the fitting polynomial coefficient.

Fitting process can use the polynomial fitting function provided in MATLAB software  $p = \text{polyfit}(xdata, ydata, n)$ .

Above, n said the highest order number of polynomial; xdata, ydata said the data will be fit, they were input with

the way of array; the output P was a row vector of a polynomial coefficient.

From table 1 it's clear that sampling results D value was complex relatively, in order to simplify fitting process, normalizing method was used before fitting. Such as formula (11) shown.

$$D' = (D - D_{\min}) / (D_{\max} - D_{\min}) \quad (11)$$

After derivation, Got the fitting function of  $10^{\circ}\text{C} \sim 20^{\circ}\text{C}$  temperature range as flow:

$$T(D) = a_3 D'^3 + a_2 D'^2 + a_1 D' + a_0 \quad (12)$$

Above,  $a_0 = -0.0651, a_1 = 0.000776, a_2 = -1.0174e-10, a_3 = 1.9623e-15$ . According to the fitting-function the D-t fitting curve shown as figure 5.

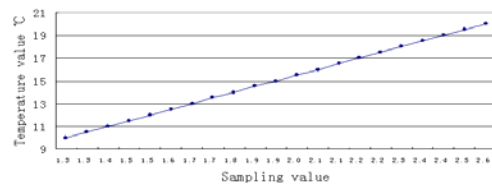


Figure 5. D-t fitting curve of  $10^{\circ}\text{C} \sim 20^{\circ}\text{C}$  temperature range

## VI. EXPERIMENTAL CONCLUSION

In the high precision temperature detection system, through improving measurement circuit structure and using least squares D-t segmented curve fitting, improved the accuracy of detection effectively. The detection error was controlled in the range of  $-0.02^{\circ}\text{C}$  to  $0.02^{\circ}\text{C}$ , reached the accurate detection requirements. In the actual use process, the heat element can design into differential structure, reduce the influence of nonlinear error further more, and improve the detection sensitivity.

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