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Research on Uncertainty Evaluation of Measurement Results with Thermocouple Temperature Transmitter

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***Abstract*—In order to ensure the accuracy and reliability of the temperature transmitter measurement with thermocouple sensor, in this paper , the second-class standard platinum-iridium 10-platinum thermocouple was used as the reference standard in the teaching process. A temperature transmitter with a thermocouple sensor was calibrated in a thermocouple calibration furnace, and the uncertainty of the measurement was evaluated. The results show that the uncertainty of the measurement results of the thermocouple temperature transmitter is in accordance with JJF1094-2002 "Measuring Instrument Characteristics Evaluation", and the extended uncertainty is less than 1/3 of its maximum allowable error. The research methods and results of the uncertainty evaluation of measurement results have important theoretical significance and application promotion value in teaching and engineering practice.**

Keywords—Uncertainty, Standard platinum-10% rhodium/platinum thermocouple, Mathematical Model, Transmitter

I. INTRODUCTION

According to the measurement range of the sensor with the temperature transmitter and different types, the method of calibration and the uncertainty of the indication error are also evaluated. Calibration of thermocouples with thermocouples in the measurement range from 0℃ to 800℃.Below 300℃in a constant temperature bath compared to a standard mercury thermometer. Comparing with a standard platinum-10% rhodium/platinum thermocouple in a thermocouple calibration furnace above 300℃.In this paper, we use the second-class standard platinum-10% rhodium/platinum thermocouple as the standard. In the teaching process, the second-class standard platinum-iridium 10-platinum thermocouple is used as the standard, and the temperature transmitter with sensor thermocouple is calibrated at the temperature of 400 °C, and the uncertainty of the results of the indication error is evaluated.

II. MEASUREMENT METHOD

A. Evaluation Basis and Measurement Standards.

The assessment criteria are based on the National Metrology Technical Specifications of the People's Republic.[1-3]Measurement standards use a standard platinum-10% rhodium/platinum thermocouple as a standard to control the thermocouple to check the furnace temperature. Taking the the United States Keithley K2010-type,7-digit digital multimeter as the measurement standard. The annual allowable basic error is ± (500×10-6 ×reading + 80 ×10-6 ×range).

B. Environmental Conditions.

Temperature: 15℃~ 25℃;relative humidity: 45% to 75%;except for the earth's magnetic field around the transmitter, there should be no external magnetic fields that affect its normal operation.

C. Measured object.

Temperature transmitter with sensor, the sensor is a K-type II thermocouple, the signal converter is 0.5 level. measuring range: 0℃~ 800℃,output current: 4mA ~ 20mA, maximum allowable error: $\Delta tR + \Delta tC$ [2],in, $\Delta tR = \pm 0.75\% t$ the allowable error of the sensor thermocouple, $\Delta tC = \pm 0.5\% FS$ the basic error of the converter.

D. Measuring step.

Select not less than 5 points including the upper limit value, the lower limit value, and the vicinity of the range of 50% within the measurement range. Starting from the lower limit temperature, then measure from bottom to top, at each test point, the measurement is performed after the temperature in the furnace is stable enough. The measurement of the standard thermometer and the output of the transmitter are repeated 6 times in turn. Taking the average of 6 measurement data as the measurement result, this calibration point is 400℃as an example.[1] The temperature transmitter calibration system with thermocouple sensor is shown in Fig.1.

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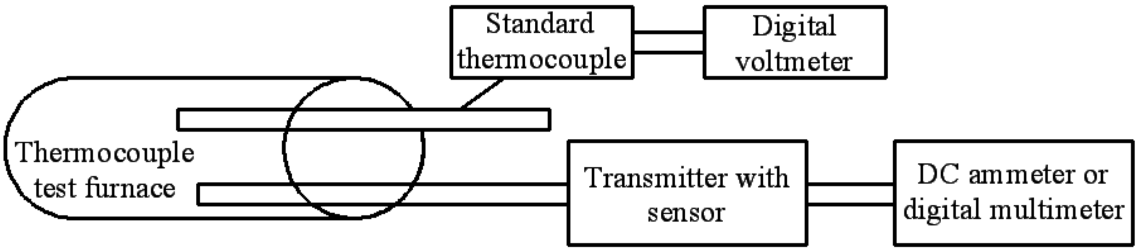

Figure 1. Temperature transmitter calibration system with thermocouple sensor

III. MATHEMATICAL MODEL

The following mathematical model can be obtained from "the temperature transmitter calibration specification". [1]

$$\Delta I_t = I_d - \left[\frac{I_m}{t_m}(t_s - t_0) + I_0 \right] \tag{1}$$

Where: ΔI_t the measurement error of the transmitter at temperature t, I_d the output current value of the transmitter, I_m the output range of the transmitter, t_m the temperature input range for the transmitter, t_s the input temperature value for the transmitter, t_0 the lower temperature value entered for the transmitter, I_0 the theoretical lower limit for the output current of the transmitter.

Variance and Sensitivity Coefficien

The variance and sensitivity coefficients are derived from "general measurement terms and definitions". [3]

$$c_1 = \partial \Delta I_t / \partial I_d = 1$$

$$c_2 = \partial \Delta I_t / \partial t_s = -I_m / t_m = -0.02mA/℃$$ Where, I_m =16mA, t_m =800℃

Evaluation of Standard Uncertainty

Standard Uncertainty $u(I_d)$ of Input Quantity I_d. There are two main sources of uncertainty $u(I_d)$ in the input volume, the repeatability of the measured output current of the transmitter and the measurement error of the K2010 digital multimeter.

Uncertainty component introduced $u(I_{d1})$ by output current repeatability.[3,5]10 sets of independent repeated measurements were taken at 400℃,the indication of the standard platinum-10% rhodium/platinum thermocouple and the output of the transmitter in turn. The measured value is the average of 6 times of data for each set of calibration records. The measurement results are shown in Table 1.

TABLE 1 REPEATABILITY MEASUREMENT VALUES

measurement number	measurements standard platinum-10% rhodium/ platinum thermocouple /[℃]	transmitter/ [mA]
	400.00	12.007
1	400.08	12.006
2	400.10	12.007
3	400.09	12.003
4	400.05	12.000
5	400.06	11.998
6	400.10	11.995
7	400.11	11.994
8	400.09	11.995
9	400.08	11.996
10	400.07	11.997
average value	400.083	11.9991

The combined sample [4] deviation is, $S=\sqrt{\frac{\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2}{\text{n - 1}}}=0.0047mA$.

The actual measurement takes 6 measurements as the measurement result.

$$u(I_{d1})=\frac{s}{\sqrt{6}}=0.0019mA$$

Uncertainty component introduced $u(I_{d2})$ by measurement error of K2010 digital multimeter. The maximum allowable error of the K2010 digital multimeter at the calibration point of 12 mA is ±0.0084 mA, Containing factors, k= $\sqrt{3}$, $u(I_{d2})=0.0048mA$.

Calculation of standard uncertainty $u(I_d)$. [6,7] I_{d1} and I_{d2} are independent of each other ,so $u(I_d)=\sqrt{u^2(I_{d1})+u^2(I_{d2})}=0.0052mA$.

Uncertainty Introduced $u(t_s)$ by Input t_s. The uncertainty of the input t_s is mainly derived from the measurement error of the standard platinum-10% rhodium/platinum thermocouple, calibration uncertainty, stability drift and thermocouple check furnace temperature field changes.

Uncertainty component introduced $u(t_{s1})$ by standard platinum-10% rhodium/platinum thermocouple measurement repeatability. Multiple measurements are usually used, from Table 1,the combined sample deviation of the standard platinum-10% rhodium/platinum thermocouple at 400℃. [3,8]

$$S=\sqrt{\frac{\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2}{\text{n - 1}}}=0.019\ ℃$$

The actual measurement takes 6 measurements as the measurement result,

$$u(t_{s1})=\frac{s}{\sqrt{6}}=0.0078℃.$$

Uncertainty component introduced $u(t_{s2})$ by the extended uncertainty of standard platinum-10% rhodium/platinum thermocouple verification results. According to the volume transfer system, the extended uncertainty of the second-class standard platinum-10% rhodium/platinum thermocouple is 1.0 ℃ (k=2).According to the differential rate of thermoelectromotive force of the thermocouple, the standard uncertainty at 400℃can be obtained.[3,9]

So 400℃, $u(t_{s2})$ =4.78μV (add up to 0.50℃).

Standard uncertainty component $u(t_{s3})$ is introduced standard platinum-10% rhodium/platinum thermocouple stability drift. The standard platinum-10% rhodium/platinum thermocouple has an internal thermoelectric potential drift of no more than 10μV.the half interval is 5.0μV,evenly distributed.[5]

Standard uncertainty is $u(t_{s3})=\frac{5.0}{\sqrt{3}}=2.88$ μV(add up to 0. 31℃).

The uncertainty component $u(t_{s4})$ introduced by the furnace temperature change checking.

Checking the temperature change of the furnace also affects the actual furnace temperature of the standard platinum-10% rhodium/platinum thermocouple, it is unreliable at 0.25℃. After conversion to the thermoelectric potential value, the half-interval value is calculated, and the inverse sinusoidal distribution is used. [10]

$$u_{400} = \frac{9.57 \times 0.25}{\sqrt{2}} = 1.7$$ μV (add up to 0.18℃)

Calculation of standard uncertainty $u(t_s)$. t_{s1}, t_{s2}, t_{s3}, t_{s4} independent of each other,

$$u(t_s) = \sqrt{u(t_{s1})^2 + u(t_{s2})^2 + u(t_{s3})^2 + u(t_{s4})^2} = 0.62$$ ℃.

Synthetic Standard Uncertainty

The input quantities I_d and t_s are independent of each other, and the synthetic standard uncertainty can be obtained as follows.

$$u_c(\Delta I_t) = \sqrt{[c_1 \times u(I_d)]^2 + [c_2 \times u(t_s)]^2} \tag{2}$$

$u(\Delta I_{400})$=0.0133mA.

IV. Extended Uncertainty Assessment

Inclusion factor k=2, $U = 2 \times u_c(\Delta I_t)$,as shown in Table 2.

TABLE 2 EXTENDED UNCERTAINTY AND MAXIMUM ALLOWABLE ERROR SUMMARY FOR TRANSMITTER AT 400℃ CALIBRATION POINT

Calibration point/[℃]	Extended uncertainty U /[mA](k=2)	MPEV/[mA]	Extended uncertainty U / [℃](k=2)	MPEV/[℃]
400.0	0.027	0.14	1.4	7.0

V. Conclusion

It can be seen from Table 2 that the obtained extended uncertainty is less than 1/3 of the absolute value of the maximum allowable error. According to "Measuring Instrument Characteristics" [5],It can be judged that the above uncertainty evaluation is qualified, the method used is effective and feasible. The uncertainty assessment of other calibration points of the temperature device is transmitted, refer to the above method. This method is not only applied to the teaching process, but also has been well verified in the practical application of engineering, and its applicability is very strong. Therefore, this method has important theoretical guiding significance and wide application and promotion value.

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