Research on Calibration of Short Base Metal Thermocouples

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Abstract: Short and cheap metal thermocouple is a general term for detachable short base metal thermocouple (electrode length is about 300mm-500mm)¹ and short base metal armored couple (metal sleeve length is about 300mm-500mm)². Their electrodes are short in length. Traditional measuring equipment often fails to accurately measure the indication deviation in the high temperature region (above 300 ℃). By studying the principle of short couple temperature measurement, this paper designs experiments to find out the reasons for its inaccuracy. According to the reason, this paper designs and manufactures the terminal thermostat, which is used to calibrate the short couple in tubular furnace. In this paper, the following two places will be kept constant temperature. Firstly, the thermocouple electrodes are exposed in the tube furnace and the thermocouple reference end; secondly, the compensation wire wiring. The experimental results show that the influence of heat loss on measurement accuracy can be reduced, which reduces the extended uncertainty of calibration of short even value deviation.³

1. Introduction
Short and cheap metal thermocouple is a general term for detachable short base metal thermocouple (electrode length is about 300mm-500mm)¹ and short base metal armored couple (metal sleeve length is about 300mm-500mm)². Their electrodes are short in length. Traditional measuring equipment often fails to accurately measure the indication deviation in the high temperature region (above 300 ℃). By studying the principle of short couple temperature measurement, this paper designs experiments to find out the reasons for its inaccuracy. According to the reason, this paper designs and manufactures the terminal thermostat, which is used to calibrate the short couple in tubular furnace. In this paper, the following two places will be kept constant temperature. Firstly, the thermocouple electrodes are exposed in the tube furnace and the thermocouple reference end; secondly, the compensation wire wiring. The experimental results show that the influence of heat loss on measurement accuracy can be reduced, which reduces the extended uncertainty of calibration of short even value deviation.³

2. Measuring principle
Five kinds of short base metal thermocouples with national standards in China are indexed as "K, N, E, J, T".⁴ In the field of measurement, it is also called short base metal thermocouple for work, in which the armored thermocouple with metal casing outer layer is also called armored thermocouple. Short base metal thermocouples for work are widely used in industrial production, which is the most important temperature sensor in medium and high temperature zone. It is mainly used in temperture control and environmental temperature field measurement equipment.

The thermocouple is mainly composed of two kinds of alloy materials. If there is a temperature difference between the measuring end and the reference end, the Seebeck thermoelectric effect will be produced and the potential will be generated in the loop.⁵ Thermoelectric potential and temperature difference have a certain functional relationship. Using the digital multimeter to measure the thermoelectric potential in the circuit, we can get the temperature of the measuring end. According to different types of scale, we can measure temperature. Thermocouples are generally used in high temperature, oxidation, reduction and other environments. After a period of use, the pollution and aging of the electrodes will cause the drift of the scale.⁶ Therefore, we need to calibrate the thermocouple regularly, which will ensure that the indication deviation is within a certain allowable range.

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3. Research background
The calibration principle of the thermocouple is as follows. Firstly, the measuring end of the couple and the measuring standard is placed in the heat source under the state of heat balance, and the reference end is placed at the freezing point. Secondly, we measure the thermoelectric potential of the digital multimeter. Thirdly, by comparing with the measurement standard and the scale, we can get the indication deviation of the couple at a certain temperature point. According to the national standard JJF1637-2017, the measuring principle is shown in Figure 1.

![Figure 1: Principle diagram of thermocouple measurement](image)

The traditional calibration method is only applicable to the removable short base metal thermocouple whose electrode length is not less than 500 mm. There is no relevant standard for thermocouple calibration under 500 mm at home and abroad. This kind of thermocouple with shorter size is often widely used in construction, petrochemical, military and aerospace fields. It can not guarantee the accuracy of indication deviation.

In the current verification regulations of thermocouples, only precious metal thermocouples for working use involve short size. JJG668-1997 Pt-Rh 10-Pt or Pt-Rh 13-Pt short thermocouples for working use \(^7\). However, the measurement methods, relevant standards and technical indicators of supporting equipment are not suitable for the measurement of short and cheap metal thermocouples and armored thermocouples. There is no uniform requirement for standard appliances and supporting equipment for short-type short base metal thermocouples in all statutory metrology and verification institutions throughout the country.

4. Reasons for inaccuracy

4.1 Theoretical analysis
In practice, the material of thermocouple wire is reliable, and the manufacturing process also meets the relevant standards \(^8\). We have manufactured short base metal thermocouples of common size, whose indication deviation is in accordance with its accuracy. Its length is greater than or equal to 500 mm. However, the length of the short-sized metal thermocouple is less than 500 mm. After calibration, the indication deviation often appears over-error, and the indication deviation is mostly negative. This problem has not been well solved. Many equipment using short couples can not guarantee its accuracy, and its value can not be traced back to the national benchmark \(^9\).

Cheap metal thermocouples of the same material are truncated from 1000mm to 300mm in size. Each dimension uses traditional calibration methods to calibrate its indication error. The variation of indication deviation is shown in Table 1.
It can be seen from the table that the maximum variation is -1.33 °C, which has seriously affected the determination of the accuracy level of the calibrated thermocouple. There are many reasons for this result, the most important of which is related to the size of thermocouple. First, we exclude the two reasons of human operation and repeatability of equipment measurement. The reliability of thermocouple material is an important reason for large deviation of indication value. Other reasons should occur in the measurement end and the reference end. The errors at the measuring end may be related to the uniformity of temperature field in the tubular furnace. The errors at the reference end may be related to the compensating conductor, the switch, the reference end and the digital multimeter. For a thermocouple with a length of about 300 mm, only less than 150 mm is exposed outside the furnace after it is inserted into the center of the furnace. Because the metal material of the thermocouple itself is also an efficient heat conductor, this will cause the change of the cause of the error. The temperature of thermocouple measuring end is difficult to keep balance with the measuring standard and furnace temperature. Heat is continuously transmitted to room temperature through thermocouples. However, the standard thermocouple is still the normal size required in the specifications, and the thermal conductivity efficiency is not high by the couple. Therefore, the actual temperature of the calibrated couple is lower than the measuring end of the standard thermocouple.

4.2 Measuring end temperature difference experiment
The heat loss is due to the shorter size of the thermocouple being calibrated. This is more evident in armored thermocouples. The result is that the negative deviation of the thermocouple with reliable material after calibration often does not meet the requirements of national standards. Therefore, through the following experimental verification, this paper can speculate whether the above views are correct. Thus, we can find out the reasons for the short-term accidental uncertainty.
As shown in Figure 2 and Figure 3, the measuring end of precious metal thermocouple is welded to the measuring end of cheap metal thermocouple in this experiment. By measuring the precious metal thermocouple with higher accuracy, we can measure the actual temperature of the measuring end of the cheap metal thermocouple in the calibration process. By comparing the display value with the actual value, we can find out the reason why the indication deviation of the short-type short base metal thermocouple is larger in the calibration process.

The experimental results are shown in Table 2. Figure 4 is obtained after sorting out.

| Temperature point /℃ | Long stove N-S | 500mm N-S Short stove | 300mm N-S Short stove |
|-----------------------|----------------|-----------------------|-----------------------|
| 300                   | -1.91          | -0.14                 | -0.51                 |
| 400                   | 0.03           | -0.12                 | -0.42                 |
| 500                   | 0.22           | -0.29                 | -0.34                 |
When calibrating the short couple, the difference between the display temperature and the actual temperature of the measuring end will increase with the decrease of the tubular furnace size. Details are shown in Figure 4. The uniformity of temperature field of thermocouple verification furnace is affected by its size. The longer the size, the better the uniformity. The closer the result of calibrating thermocouple is to the true value. It increases with the decrease of the length and size of the couple. The variation is often negative, which verifies the correctness of the speculation on the cause of short-type occasional uncertainty.

Because of the different material, the heat conduction rate of the calibrated thermocouple is usually faster than that of the standard thermocouple. This will result in a certain temperature difference between the calibrated thermocouple and the standard thermocouple. Standard thermocouples need to use protective tubes in the furnace, so this problem can not be solved by full contact of the measuring end. It is impossible to compensate for the temperature difference between the two by a longer time of stabilizing temperature. There is little room for technical improvement on temperature field uniformity of short thermocouple calibration furnace and tubular furnace. In the absence of major innovations in heat source equipment, we can introduce thermostats near the thermocouple terminals, which will cause heat loss problems.

| Temperature (℃) | Difference | Temperature (℃) | Difference | Temperature (℃) | Difference |
|-----------------|------------|-----------------|------------|-----------------|------------|
| 600             | 0.53       | 700             | 0.68       | 800             | 0.94       |
|                 | -0.06      |                 | -0.51      |                 | -0.67      |
|                 | -0.39      |                 | -0.69      |                 | -0.96      |
| 1000            | 1.18       |                 | -0.74      |                 | -1.08      |

5. Solutions

5.1 Terminal temperature experiments
Thermocouple terminals are generally composed of thermocouple wires, compensation wires and signal lines. The equipment that keeps the terminal temperature constant is called "terminal thermostat". It is necessary to determine the constant temperature before joining the terminal thermostat. Through the following experiments, we can find that the thermostat should control the temperature in practical application.
Figure 5: schematic diagram of terminal temperature experiment

Using digital thermometer and surface thermometer, this paper can measure the relationship between the external temperature, the terminal temperature and the furnace temperature. Firstly, a short thermocouple is inserted into the verification furnace of the short thermocouple, as shown in Fig. 5. The measuring end of the thermocouple is located at the highest temperature of the uniform temperature field in the furnace, and the furnace mouth is sealed with fire-proof cotton. The thermocouple calibration furnace is heated and measured from the lower limit temperature to the upper limit temperature (300℃, 400℃, 600℃, 800℃, 1000℃).

By measuring the surface temperature of the insulating beads and the temperature of the couple wires, the relationship between the furnace temperature and the temperature of the short thermocouple electrode is obtained. The arrangement is shown in Figure 6.

Figure 6: Experimental results of terminal temperature
5.2 Structure of terminal thermostat

The terminal thermostat consists of heating component, thermal cycle component, thermal insulation material, temperature controller and so on. The heating medium is air. By means of air convection, the heat exchange and temperature control of the end part of the thermocouple were completed. One side has an opening and the other side is closed. The structure diagram is shown in Fig. 7. The heating module is composed of eight resistance heaters, which can rapidly raise and lower the temperature. The heat-resistant fan is responsible for convection circulation. Thermal insulation curtain and cover can ensure that the thermostat has a 200 mm long axial uniform temperature field in its working area. The temperature deviation of any point in the temperature field is not more than (±1℃).

The temperature controller adopts Bott BT10S double channel temperature indicator controller. The accuracy of temperature control instrument is 0.5 grade and the resolution is 0.01 ℃. It has thermal resistance and thermocouple dividing meter. The temperature controller can record 10 sets of PID adjustments [11]. Thermal insulation materials should ensure that the constant temperature range is (40-120) ℃. The insertion depth is not less than 300 mm. The total length is about 500 mm. In the working area, the temperature deviations from the temperature control point in each position of the axial temperature field are not more than ±2℃.

![Structure design of terminal thermostat](image)

6. Experimental verification

6.1 Terminal temperature experiments

In this test, a terminal thermostat is added to the calibrated short couple. In this experiment, truncation experiments are carried out to verify the validity of the cheap metal thermocouple, which is made of the same material. In this paper, the variation of the demonstrative deviation from 1000 mm to 300 mm is obtained.
The first standard platinum rhodium 10-platinum thermocouple is used in this test. The calibrated thermocouple adopts N-type with better stability. The accuracy level is superior to the working level 1, and the indication deviation is calibrated by the thermocouple. After 1000mm manufactured by the manufacturer, the test uses the traditional method to calibrate the indication deviation of each temperature point, referring to JJF1637-2017 "Calibration Specification for Short base Metal Thermocouples". This value serves as a reference value for comparison of experimental data.

From 1000mm to 300mm in turn, the indication deviation of each temperature point is taken as the comparison value. The values that comparisons minus reference values is the variation of thermocouple indication deviation at a certain temperature.

After processing and revising the data, this paper compares the variation between the use of thermostat and the non-use of thermostat. If the change is less than or equal to 1/3 of the 2 stage allowable difference of the cheap metal thermocouple, which proves the validity of the terminal thermostat. In addition, the best temperature control point of the thermostat is found in this experiment from (40-100) degrees Celsius.

6.2 Data processing and results analysis
The experimental data are calculated as shown in Table 3.

Table 3: Effect of terminal thermostat on experimental results

| No. | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10     |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Temperature | No thermostat | | | | | | | | | 300mm Thermostat |
| mm  | m     | 40℃   | 50℃   | 60℃   | 70℃   | 80℃   | 90℃   | 100℃  | 300℃  |
| 1000| 300m  | 1.05  | -0.12 | 1.01  | 1.35  | 1.25  | 0.79  | 0.90  | 1.64  | 0.64   |
| 800℃|       | 1.05  | -0.12 | 1.01  | 1.35  | 1.25  | 0.79  | 0.90  | 1.64  | 0.64   |

After sorting out, it is shown in Figure 9.
The following results are obtained from the above experiments. The terminal thermostat has a good positive effect on the calibration of short couples. At the junction end, the thermostat is constant at (40-60 °C), and the deviation of the short-type short base metal thermocouple is closer to the traditional method. Therefore, the uncertainty of the terminal thermostat can be reduced by calibrating the short and cheap metal thermocouple, which also proves that the terminal thermostat is more accurate.

7. Conclusions
The short couple is calibrated by the thermocouple calibration furnace above 300 °C. The reasons for the inaccuracy are as follows. The thermocouple size is too short, and the couple wire as a heat conductor has a great influence on the temperature field balance of the furnace. Couple wires continuously transmit heat from the furnace to the outside of the furnace, which makes it unable to reach thermal equilibrium with standard thermocouples. Therefore, there is a large negative deviation in the indication deviation of the couple under test. Under the existing technical means, the use of terminal thermostat in short-type couple furnace can reduce the heat loss at the measuring end. If the temperature is controlled at (40-60 °C), the measured results are closer to the true values, and the expanded uncertainty of the calibration results is smaller.

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