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Research on the Influence of Cold End Junction Compensation on the Measurement Accuracy of Temperature Calibrators

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Abstract. As a widely used portable measurement and control instrument in the power system, the accuracy and reliability of temperature calibrators are of great significance for ensuring the stable operation of the power system. However, in the calibration process of temperature calibrators, different connecting methods and the selection of cold junction compensation modes will have a significant impact on the calibration results. Therefore, conducting research on laboratory calibration of temperature calibrators and exploring the impact of different cold end compensation methods on calibration results is of great significance for improving the accuracy of calibration results. This paper aims to compare and analyze the application effects of different cold end compensation methods in the calibration process of temperature calibrators, and explore their specific impact mechanism on the calibration results. Through experimental verification and data analysis of different compensation methods, a calibration method that is conducive to improving the accuracy of calibration results is proposed, providing theoretical support and practical guidance for the precise calibration of temperature calibrators.

Keywords. Temperature calibrators, cold end junction, measurement

1. Summary

A temperature calibrator is a multifunctional and comprehensive instrument used for calibration, testing, and debugging of temperature sensors and measurement and control systems. Temperature calibrators generally have two functions: output and measurement. According to the primary temperature measurement element used to match them, they can be divided into three types: thermocouple temperature calibrators, thermal resistance temperature calibrators, and thermocouple thermal resistance multifunctional calibrators [1]. The calibration instrument with thermocouple temperature calibration function generally has two compensation methods: internal compensation (automatic compensation) and external compensation (manual compensation).

The performance of temperature calibrators will affect many aspects of temperature measurement and control in power grids and power plants, thereby

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affecting the safety of the power system. Therefore, regular calibration of temperature calibrators is necessary.

1.1. Operating principle of temperature calibrator

The temperature calibrator consists of a signal setting/receiving module, a signal conversion module, a signal output module, and a display module. Through the functions of these modules, the function of signal output or signal measurement is realized [2]. The calibrator can receive the set signal through the digital keyboard, convert the set temperature value into electrical signal output, and display the output temperature value on the calibrator screen. Figure 1 shows the signal output principle. The calibrator can also receive input electrical signals from thermocouples and thermal resistors through its wiring terminals. After processing by the signal conversion module, the temperature display of the measured signal is achieved. Figure 2 shows the signal measurement principle.

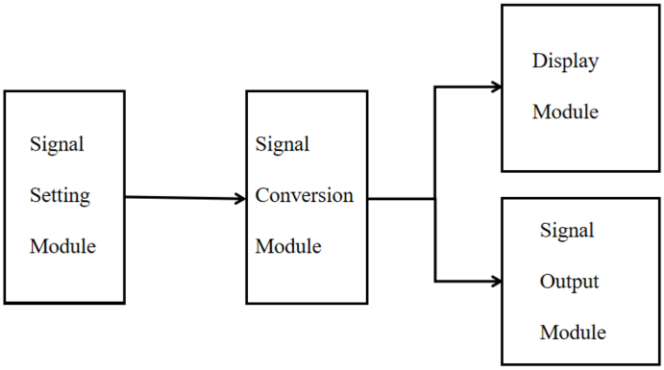

Figure 1. Schematic diagram of calibrator output signal.

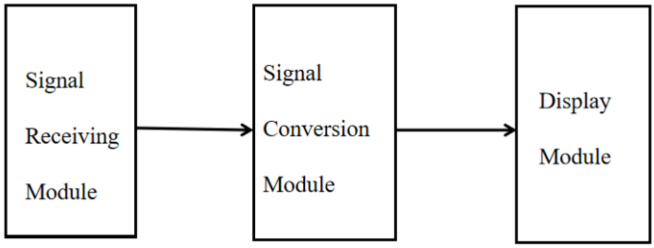

Figure 2. Schematic diagram of calibrator input signal.

1.2. Cold end compensation method for temperature calibrators

When combining a temperature calibrator with a thermocouple for temperature measurement, the compensation function of the temperature calibrator can be used to correct measurement errors caused by environmental factors or equipment characteristics, and its compensation function is important particularly. The compensation of temperature calibrators can be divided into two types: internal compensation and external compensation.

(1) Internal compensation

Internal compensation is an automatic correction function of the temperature calibrator. It's mainly used to reduce errors caused by changes in the temperature characteristics of internal components of the instrument. Internal compensation is usually achieved through the following methods:

Hardware design optimization: By improving the hardware design of the temperature calibrator and selecting components and materials with excellent temperature stability, the impact of temperature on instrument performance is reduced.

Software algorithm calibration: Embed software algorithms inside the temperature calibrator to automatically adjust measurement values based on temperature changes to eliminate errors caused by temperature.

The advantage of internal compensation lies in its automation and real-time performance, which can correct errors caused by temperature in real time and improve measurement accuracy. However, the effectiveness of internal compensation is limited by the level of instrument design, manufacturing, and calibration, and may not be able to completely eliminate errors for certain complex environments and measurement requirements [3].

(2) External compensation

External compensation is a method of correcting errors by adding auxiliary equipment or taking specific measures outside the temperature calibrator. Common external compensation methods include:

Using a temperature compensator: A temperature compensator is a device specifically designed to correct temperature errors, which can automatically adjust the output signal based on changes in ambient temperature to compensate for the impact of temperature on measured values.

Environmental control: By controlling the usage environment of temperature calibrators, such as thermostats, air-conditioned rooms, etc., the stability of environmental temperature is maintained to reduce the impact of temperature on measurement [4].

External calibration: Regularly calibrate the temperature calibrator externally, use higher precision standard equipment to calibrate and adjust the instrument, and ensure the accuracy of measurement results.

The advantages of external compensation lie in its flexibility and applicability, and suitable compensation methods can be selected based on specific application scenarios and needs. However, external compensation requires additional equipment or measures, which may increase costs and operational complexity.

1.3. Cold junction compensation principle of temperature calibrator

The output and measurement of the thermocouple range of the temperature calibrator utilize the cold junction compensation principle of the thermocouple. Inside the calibrator, the cold junction compensation temperature sensor is generally installed in the temperature equalization block next to the output (measurement) socket. In the output and measurement process of thermocouples, it is necessary to measure the cold junction compensation temperature first, and then add or subtract the electric potential corresponding to the measured cold junction temperature during the output or measurement process to correctly obtain the measured value or output signal [5][6].

When the calibrator is output as a temperature source, the signal conversion module first converts the measured cold junction compensation temperature into a DC millivolt electrical signal, while also converting the set temperature value into an electrical signal, subtracting the former, and finally outputting it in the form of an electrical signal. During measurement, the calibrator first converts the measured cold junction compensation temperature into a DC millivolt electrical signal, which is then superimposed on the millivolt signal directly measured at the measurement terminal, and then converts the electrical signal into a temperature signal for display as the final measurement result.

1.4. Calibration method of temperature calibrator

The calibration of temperature calibrators is mainly in accordance with JJF1309-2011 "Calibration Specification for Temperature Calibrators". According to the requirements of the regulations, DC resistance boxes and DC low potential instruments can be used to simulate the output of thermal resistors and thermocouples to calibrate the measurement functions of temperature calibrators; A digital multiinstrument can be used to calibrate the output function of the temperature calibrator [7].

However, with the development of science and technology, the standards used to calibrate temperature calibrators are continuously improving, gradually shifting towards intelligence and automation. Currently, the standard instrument used in the laboratory of State Grade Zhejiang Electric Power Co. LTD is the 5520A multi-function calibrator, with a measurement accuracy of 0.02 level, which can replace traditional standard instruments and measure and output multiple signal types such as current, voltage, thermal resistance and thermocouple.

The calibrator has a temperature measuring probe inside, which can compensate for the cold end temperature of the connected thermocouple, so that the converted temperature value can reflect the measured temperature at the hot end of the thermocouple more accurately. Generally, when using a temperature calibrator, you can select the "Internal Compensation" or "External Compensation" function. Internal compensation refers to the use of the measured ambient temperature by the temperature probe inside the thermocouple in the calculation of electrical temperature conversion; External compensation refers to the fact that the cold junction temperature of the thermocouple used for calculation during the electrical temperature conversion of the instrument is derived from the external input temperature value, or that the thermocouple signal input by the instrument by default has received physical cold junction compensation (such as ice bottles, etc.) from the outside, without requiring special processing of the data during data conversion.

2. The necessity of cold junction compensation for temperature calibrators

When using a calibrator to calibrate the thermocouple range of a temperature calibrator, many laboratories use copper wires to connect the calibrated calibrator and standard calibrators directly, and there are also questions about whether to set internal or external compensation for the calibrated and standard calibrator. Whether different wiring methods and compensation methods will have an impact on the calibration results of temperature calibrators, the author analyzed the impact of different calibration methods on the calibration results through theoretical and experimental methods.

2.1. Comparison between internal compensation choice and external compensation choice during calibration

The standard instrument 5520A temperature calibrator of our laboratory was selected as the standard instrument, and the 7526A temperature calibrator was selected as the calibrated instrument. The internal compensation mode and external compensation mode were selected for calibration tests. Table 1 shows the calibration results for two different modes.

Table 1. Comparison of calibration results between internal compensation mode and external compensation mode.

Calibration temperature（℃）	Internal compensation		External compensation	
	Measured status[a]	Output status	Measured status	Output Status
0	0.20	-0.20	0.11	-0.01
400	400.18	399.85	400.10	400.00
600	600.18	599.82	600.10	599.96
800	800.17	799.84	800.10	799.95
1000	1000.18	999.84	1000.10	999.96

[a] Various states refer to the state of the calibrated instrument.

During this internal compensation mode calibration test, the laboratory room temperature was 20.21 ℃, the compensation temperature of the calibrated instrument was 20.92 ℃, and the internal compensation temperature of the standard instrument was 20.39 ℃.

Results in Table 1 imply that when selecting the internal compensation mode, the calibration result is somewhat worse than when selecting the external compensation mode.

According to the analysis of test data, the main reason for the difference in calibration results is the inconsistency in the cold end compensation temperature of the calibrator. The cold end compensation temperature sensor inside the calibrator is generally installed in the temperature equalization block next to the input/output terminals. Due to the installation location of the cold end compensation sensor of the calibrator and the self-heating of the equipment, the temperature measured by the compensation temperature probe is not completely consistent with the ambient temperature [8]. This results in a difference in the compensation temperature between the standard instrument and the calibrated instrument, making the instrument calibration results different between using the internal compensation mode and using external compensation.

2.2. Comparison of calibration using copper conductors and using compensation conductors

In order to compare the impact of using copper conductors and compensating conductors to calibrate a temperature calibrator on the results, the author used a 5520A temperature calibrator as a standard and selected a M8918 calibrator as the calibrated instrument. Firstly, under normal laboratory environmental conditions, the instrument was calibrated using copper conductors and compensating conductors connected separately, and then placed in a ventilated position at the window to make the ambient temperature fluctuate significantly, Once again, copper wire and compensation wire were used to perform calibration work respectively. Table 2 shows the calibration results for Different calibration environments and different connection methods.

Table 2. Comparison of calibration measurement status calibration results using copper wire and compensation wire connections.

Calibration temperature（℃）	Stable ambient temperature		Ambient temperature fluctuations	
	Connection by copper conductor	Connection by compensation wire	Connection by copper conductor	Connection by compensation wire
0	0.09	0.05	0.13	0.07
400	400.12	400.05	400.39	400.13
600	600.15	600.11	600.23	600.14
800	800.14	800.10	800.26	800.13
1000	1000.11	1000.06	1000.31	1000.10

Results in Table 2 imply that when the calibration ambient temperature is stable, the calibration results using compensation wires are basically consistent with those using copper wires, and the calibration results using compensation wires are slightly better; if calibration is carried out under large fluctuations in ambient temperature, the results of calibration using compensation wires will be more stable.

The main reason is that when using a compensation wire for calibration, the function of the compensation wire is equivalent to a thermocouples of the same type. The temperature difference between its two ends exactly forms a thermoelectric potential superimposed on the loop, offsetting the error caused by the different compensation temperatures at the cold ends of the standard instrument and the calibrated instrument. Therefore, in actual calibration work, even if the electrical signals are output from different thermocouple ranges, matching thermocouple compensation wires are still used to connect the calibrated instrument instead of copper wires. The main reason is to reduce the errors introduced in the measurement process.

3. Conclusions

Based on the above tests and analysis, the following conclusions can be drawn:

When performing calibration under unstable ambient temperatures, use compensation wires to connect the standard instrument and the calibrated instrument, and the calibration results can more objectively reflect the performance of the calibrated instrument.

When conducting calibration in a laboratory with stable ambient temperature, it is preferred to use compensation wires to connect the standard instrument and the calibrated instrument for calibration, or copper wires can be used for calibration, provided that sufficient stabilization time is experienced.

The measurement results using the internal compensation function may be worse than those using the external compensation function. However, considering the situation of on-site use of the instrument, the external thermocouple sensor of the instrument generally does not have external temperature compensation measures. Therefore, during on-site use, the internal compensation function of the instrument is generally selected. According to the principle that instrument calibration should reflect the actual working conditions of the instrument on site as much as possible, and compensating for temperature errors is also a part of the measurement error of the calibrated instrument. The author believes that internal compensation functions should be selected in laboratory calibration.

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