Research of a high voltage and high value resistors standard device

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Abstract. With the continuous increase of voltage class and the rapid development of electrical equipment, we need to design a new kind of intelligent high voltage and high value resistors standard metering device which can be used to a much larger range to complete daily verification work. Based on MSP430 single-chip microcomputer, this paper designed the temperature and humidity control module and the high voltage measurement module that the measuring range can be automatically switched. By using this standard device, the measurement of voltage and resistance can reach separately to 10 kV and 200 GΩ. At last by measuring the voltages and resistances and testing the temperature and humidity control system, it has indicated that the high voltage and high value resistors standard metering device in this paper meets the requirements.

1. Introduction
Electronic insulation resistance meter, megohmmeter and other high-resistance test equipment are frequently used in the power field and the safety performance test of factories and mines, these equipment are important measurement instruments forcibly verified by the country[1]. The verification and calibration of such electrical test equipment are mainly done by high voltage and high value resistors standard metering device[2-3]. However, the common standard metering device can not realize the automatic control of the calibration, the measurement range is small, the measurement result error is large, the operation is complicated, the calibration efficiency is low and it is difficult to meet the demand[4].

According to JJG1005-2005 "Electronic Insulation Resistance Meter Verification Regulations"[5], with the single-chip controller as the controller and based on the automatic control technology, the modules of the temperature and humidity acquisition and control and the high voltage measurement with automatic range switching have been designed which can effectively complete the 10 kV DC voltage measurement and the 100Ω~200 GΩ resistance calibration work.

2. Resistance calibration module design
In order to meet the calibration requirements of the metrology department for the insulation resistance meter, the standard resistance is divided into: (0~10)×10Ω, (0~10)×10²Ω, (0~10)×10³Ω, (0~10)×10⁴Ω, (0~10)×10⁵Ω, (0~10)×10⁶Ω, (0~10)×10⁷Ω, (0~10)×10⁸Ω, (0~10)×10⁹Ω, (0~10)×10¹⁰Ω and 200 GΩ. The maximum allowable error of the standard resistance is ±0.2% for 100Ω~0.1 MΩ, ±0.5% for 0.1 MΩ~10 MΩ, and ±1% for 10 MΩ~200 GΩ.
2.1. Standard resistor selection
The most important part of high voltage and high value resistors standard metering device design is to improve the accuracy of standard resistance, which is a key component to optimize the performance of the standard device and ensure the safe production of the power industry. The accuracy of the resistance will be affected by factors such as structure, materials, package and working environment. The actual resistance value will also be related to the temperature coefficient and voltage coefficient[6]. At present, most manufacturers producing high-voltage and large-resistance standard devices use the same material resistance in the design of standard resistance circuits. Although the characteristic of withstanding high voltage of all resistors is guaranteed, different resistance ranges have different demand of accuracy.

Therefore, in the process of designing the resistance circuit of the high voltage and high value resistors standard metering device, the resistance material is selected according to the specific resistance range. When the standard resistance value is small, the accuracy of the resistance is high. The precision resistors of RX70 series with high resistance precision, small temperature coefficient, firm structure and stable performance should be selected. When calibrating high resistance values, the resistance accuracy is relatively low but the resistance should withstand high voltage. The chip glass glaze-film low-sensitivity high-voltage resistors of RI82 series are widely used in high-voltage equipment because of its small size, light weight, high power and ability to withstand large overload capacity.

2.2. Standard resistance multi-gear design
After selecting the standard resistance that meets the requirements, the standard resistors and step switches are used to form a standard internal resistance measuring circuit for calibrating the resistors. The internal resistance network design of the high voltage and high value resistors standard metering device is shown in Figure 1.

![Fig.1 The internal resistance of reference device network diagram](image)

The resistance output is divided into two parts: adjustable resistance and fixed resistance. The 200GΩ resistance is a fixed resistance value and it is calibrated through two ports E and F. The adjustable resistance is calibrated through the E and L ports, and the resistance value of each magnitude is selected by the knob type gear selection switch. The resistance values of each magnitude are connected in series by the equivalent 10 standard resistors. In Figure 1, 9 sliding rheostats are used to replace the function of the step switch in the network, the terminal G is the shield port.

3. High voltage measurement module
The standard device designed in this paper has a nominal voltage range of 250V~10kV, and the six range gears are 250V, 500V, 1kV, 2.5kV, 5kV and 10kV. In order to ensure the measurement range of high voltage and the measurement accuracy of voltage, this paper proposes a high-voltage measurement module with automatic range conversion. The design of the voltage measurement circuit is shown in Figure 2. It consists of the following three parts: input voltage dividing circuit, range automatic conversion circuit, signal processing and amplification circuit, the dot in the figure indicates the remaining three relay control circuits.
As shown in Figure 2, the measured voltage is input from the E and L ports, then select the range after passing through the voltage dividing circuit. The voltage dividing circuit is mainly composed of two 500MΩ resistors as high voltage side, and then six precision resistors of 5 MΩ, 2.5 MΩ, 1.5 MΩ, 500 KΩ, 250 KΩ, and 250 KΩ are connected in series as low voltage side. The voltage of the full-scale range is reduced to about 2.5V. When the over-range or under-range occurs, the MCU will automatically match the appropriate measurement range through the measurement data. In order to eliminate high frequency interference in high voltage environment, a high voltage ceramic capacitor is connected in series between the high voltage measurement input terminals L and E. At the same time, the voltage output from the relay switch is isolated and buffered by the voltage follower and the linear optocoupler to enhance the stability of the measurement system[7].

The range adaptive function is realized by controlling the six-way relay through the P2.6~P2.1 port level signal of the MCU, and the control port should be low level after the initialization of the MCU, so that the initial state of the relay is normally open, and the circuit is not connected. When the level signal of the MCU port is high, the base of the transistor is input to a high level, so that the transistor is in a saturated conduction state, and the collector becomes a low level. Therefore, the relay coil is energized and the switch is closed. At this time, the measuring circuit works in the corresponding range. In order to prevent the relay from changing from the closed state to the open state and the transient back electromotive force generated by the relay coil will break through the switching device, a diode is connected in parallel on the coil to provide a discharge circuit which increases the safety performance of the system. The output of the voltage dividing circuit is connected with the respective relay control circuit, and the MCU sequentially scans from the high-grade position to the low-level position through the software program until the gear position matching the measured voltage value is found, and then the measurement data is processed and displayed.

4. Temperature and humidity acquisition and control module

The temperature and humidity of the standard device working environment will directly affect the accuracy of the standard resistance and may reduce the insulation performance of the box. Therefore, it is necessary to design the temperature and humidity acquisition and control module to improve the overall performance of the system. This paper adopts a temperature and humidity integrated chip AM2302, which has the characteristics of fast response, low power consumption and strong anti-interference ability. It can collect temperature and humidity detection data at the same time, which simplifies the system hardware design. The system block diagram of the temperature and humidity acquisition and control module is shown in Figure 3.
4.1. The design of AM2302 temperature and humidity detection circuit

The interface circuit between the AM2302 sensor and the MSP430F149 microcontroller is shown in Figure 4.

The external 5.1kΩ pull-up resistor is designed to keep the high level when the microcontroller is not transmitting data and the bus is idle. The device works in a high voltage environment for a long time. Therefore, a 380Ω resistor and a 10pF capacitor are added between the SDA port and GND to enhance the anti-interference ability. The single bus communication mode is adopted between the sensor and the MCU: after the system is initialized, the AM2302 starts to wait for work and automatically goes to the sleep state; after the user sends a start signal through the master controller, the sensor immediately responds from the sleep mode to the high speed mode. At this time the data line port is kept high, it is ready to detect the external signal when it is in the input mode; after the start signal sent by the MCU is finished, the sensor starts to send the response signal and outputs 40-bit data from the single-bus SDA serial port, in the order: the high digits of humidity data, the low digits of humidity data, the high digits of temperature data, the low digits of temperature data and check digit; complete message collection, measure and record the temperature and humidity data of the environment. After the acquisition, the chip will enter the sleep mode and wait for the next signal to wake up.

4.2. Driving relay circuit design

The peripheral circuit design of the solid-state relay SAI4002D and its interface with the microcontroller are shown in Figure 5. The temperature and humidity control system needs to drive the cooling fan and the heating chip to work separately, so the two solid-state relays are selected to be divided into two circuits for circuit design. The drive function of the SAI4002D is completed by the new three-channel relay driver chip ULN2001D. In this design, channel 1 and channel 3 are used to drive the solid state relays. The control signal of the ULN2001D is the active level signals transmitted from the P6.3 and P6.4 ports of the master.

4.3. The analysis of temperature and humidity control module

The working process of the temperature and humidity control system is as follows: After the system is powered on, the chip port initialization is first completed, and the predetermined temperature and humidity value is set. Then the sensor AM2302 detects the temperature and humidity in the box and transmits the data to the microcontroller. Then, the MCU compares the collected data with the initially set value. When the measured temperature and humidity are not exceeded, the MCU stores the data in the data storage unit and drives the LCD to display the data; when the measured data exceeds the set range, the microcontroller drives the relay control circuit to work. If the temperature is lower than the set value, the controller will drive the heating chip to work and if the detected temperature is higher than the set value, the controller will drive the cooling fan to work. The humidity of the measuring environment is mainly controlled by the humidifying device of the laboratory. When the humidity in
the box is higher than the set value, the controller will drive the heating chip and the fan to work at the same time, and place a desiccant in the box to absorb the water vapor.

5. System performance test results

5.1. The voltage measurement module test
After the system debugging work is completed, the test is performed by a standard DC voltage source. The indication error of the standard device high voltage measurement is within the range of ±1% of the maximum allowable error. The test results are shown in Table 1.

| Range (V) | Standard values (V) | Measurement (V) | Error of indication |
|-----------|---------------------|-----------------|---------------------|
| ×250      | 250.00              | 248.75          | -0.5%               |
| ×500      | 500.00              | 498.05          | -0.4%               |
| ×1000     | 1000.00             | 996.28          | -0.4%               |
| ×2500     | 2500.00             | 2514.98         | 0.4%                |
| ×5000     | 5000.00             | 4975.36         | -0.5%               |
| ×10000    | 10000.00            | 9972.17         | -0.3%               |

5.2. The temperature and humidity control module test
The goal of the simulation test in this paper is to change the internal environment of the standard box to a temperature of 25°C and a humidity of 70% RH. In a relatively closed laboratory environment, the ambient temperature and humidity are adjusted to 15°C and 90% RH with air conditioning and humidifiers to perform the performance test of the temperature and humidity module, and the standard device is placed more fully in the environment. We set the parameters through the software program and start to record the temperature and humidity measurement data within half an hour. Collect valid data every minute for the first ten minutes, and every two minutes after twenty minutes. The test results are shown in Fig. 6.

As can be seen from the curve in the figure 6, the designed system takes about 10 minutes to reduce the temperature and humidity of the test environment in the box to a preset value to complete the state transition. After 20 minutes temperature and humidity control, the temperature and humidity indications began to stabilize and the change was small. At the end of the simulation experiment, the state is stable, the error between temperature value and the predetermined value is not more than ±0.3 °C, and the humidity error is not more than 3% RH, indicating that the design of the system meets the requirements.
5.3. Resistance calibration module test

In the standard resistors test, the measured values of all the resistors we get are in the error-allowed range after comparing the measured results with the standard values. The partial verification results are shown in Table 2.

| Indicating value (GΩ) | Permissible minimum (GΩ) | Standard value (GΩ) | Permissible maximum (GΩ) | Indicating value (KΩ) | Permissible minimum (KΩ) | Standard value (KΩ) | Permissible maximum (KΩ) | Conclusion |
|-----------------------|--------------------------|---------------------|--------------------------|-----------------------|--------------------------|---------------------|--------------------------|-------------|
| 5.000                 | 4.950                    | 5.013               | 5.050                    | 4.990                 | 4.9941                   | 5.0100              | P                        |             |
| 8.000                 | 7.920                    | 8.024               | 8.080                    | 7.9840                | 7.9947                   | 8.0160              | P                        |             |
| 50.00                 | 49.50                    | 49.72               | 50.50                    | 49.90                 | 50.025                   | 50.100              | P                        |             |
| 80.00                 | 79.20                    | 79.80               | 80.80                    | 79.840                | 80.014                   | 80.160              | P                        |             |

6. Conclusion

Compared to most insulation resistance meter calibration devices, the design of high voltage and high value resistors standard device in this paper has following advantages:

1) Selecting the corresponding resistance model with consideration for the standard resistance structure, material, working environment and specific resistance range can improve the accuracy of the calibration resistor; 2) Using MSP430 single-chip microcomputer as the controller and adding a set of temperature and humidity automatic control module in the standard device can improve the measurement accuracy of the system; 3) Design of high voltage measurement module which can automatically convert the range gear makes the measurement system more intelligent. The test results show that the maximum allowable error of the device designed in this paper is ±0.2% for 100Ω~0.1MΩ, ±0.5% for 0.1MΩ~10MΩ, and ±1% for 10MΩ~200GΩ.

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