Research and Application of Automatic Measurement of Resistance Value Based on a Thermal Control Device

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Abstract: The resistance measurement system of thermal control device is mainly composed of four parts: fixture, interface circuit board, switches module and data acquisition system. The main contents of the system design are as follows: To make the system realize the automatic resistance measurement function of thermocouple, heating belt and heating plate, and improves the measurement speed and robustness of the software; To achieve the friendliness of human-machine interface;
At room temperature, it can collect 40 output voltage signals of thermocouple, and judge whether the temperature collection of thermocouple is accurate or not.

1. Introduction
This paper briefly describes the development background and the main requirements of the system, and summarizes the function completion of the system design, if the main technical indicators are consistent with technical agreements and some technical problems encountered in the process of system design, solutions and results.

2. Overall Design for the System

2.1 System Overview
The system design requires the ability to measure multiple components under test at one time. Generally, the number of input channels of a single resistance measurement module cannot meet the requirements of the technical specifications. Multiple resistance measurement modules can meet the design requirements of the number of channels, but multi-card control requires more control resources, and there is a high complexity on the measurement and control. Therefore, this system design uses a resistance measurement module, with a group of 48 thermocouple measurement equipment and a multichannel matrix switch card. When the resistance (thermocouple) is measured, the computer serial port of the measurement and control is used to send the measurement instruction to the resistance measurement module (thermocouple measurement equipment). The instruction is to specify the measurement information such as the measurement channel. The measurement module analyzes the measurement instruction, controls the corresponding detection channel through the DO switch matrix, establishes the measurement loop of the specified channel. Then the channel resistance value Rx is measured by the resistance measurement module, and the measured values are fed back to the measurement and control computer through RS232 (USB) communication interface to complete the measurement of a channel. The measurement and control computer issues the measurement and control instructions in turn according to the condition of the measured parts until all the measurement channels
complete the measurement.

2.2 System Composition
The resistance measurement system of thermal control device is mainly composed of four parts: fixture, interface circuit board, switches module and data acquisition system. The main contents of the system design are as follows:

1). Optimize and improve the fixture structure of the existing automatic test system for thermistor acceptance, reduce the complexity of operation, increase the clamping function of heating belt and heating plate, and improve the clamping reliability of the fixture;

2). Optimize and improve the measurement software of the existing automatic test system for thermistor acceptance, and increase the thermocouple, heating belt, heating plate resistance measurement function through the optimization of software measurement algorithm to improve the measurement speed and robustness of the software.

3). Optimize and improve the man-machine interface of the existing measuring tools, and improve the user-friendly interface by improving the integration and reducing the weight of the tools and the number of parts;

4). Add measurement function for thermocouple. At room temperature, it can collect 40 output voltage signals of thermocouple, and judge whether the temperature collection of thermocouple is accurate or not.

2.3 Structural Design
The part of system structure is a design of integration, which integrates the measurement and control computer and its accessories, fixture, power module and resistance measurement module. The overall structure of the system is shown as follows:

![Figure 1: Overall Structure of the System (PANSINO SOLUTIONS/ measuring system for thermal control device organization)](image-url)
2.3.1 Thermistor and Thermocouple Fixture Design
The thermistor and thermocouple are connected by two scattered wires. The size of the scattered wires is about 3mm to 5mm. The system designs a special fixture for this connection.

2.3.2 Design of Heating Belt Fixture
The heating belt is different in size due to its mechanical size, and the measuring connection has three ways: two, four and six wire. The use of a thermistor fixture in section 5.2.2.1 is not convenient for the installation of the test piece. Therefore, the front panel of the system is designed with a six-core aviation socket and a six-core cable. The other end of the cable has six flat-mouth clips, three in black and three in red and all of them are to be paired for use. The renderings and mechanical dimensions of flat mouth clamps are shown as follows:

![Figure 2: Effect Diagram and Mechanical Dimensions of Flat Mouth Clamp](image)

When measuring, connect two ends of one heating belt to a pair of flat mouth clamps (black and red) respectively. If there are three ways, connect three pairs of measuring cables respectively.

2.4 Module Design for Resistance Test
The measured part and the measuring device are connected by cable. In order to accurately measure the resistance value of the measured part, the factors affecting the measurement accuracy such as the wire resistance value and the fixture contact resistance must be eliminated as far as possible. The system design uses four-wire to measure resistance, which can reduce the influence of the measurement route resistance on the measurement accuracy. For the lead resistance between the test piece and the test device, the lead terminal can be short-circuited to measure the lead resistance before measurement, and the lead resistance of each test piece can be deducted after the measurement.

2.4.1 Resistance Measurement
The schematic diagram of four-wire resistance measurement is as follows:

![Figure 3: Schematic Diagram of Four-Wire Resistance Measurement](image)

The constant current source Is outputs the excitation current, the current through Rx produces a voltage drop Ux, the voltmeter measures the voltage drop Ux at both ends of Rx, and then according to ohm's law Rx=Ux/Is. Since the RL is much smaller than the voltmeter input resistance, the voltage drop UL on the RL is negligible. The constant current source module outputs constant current excitation Is, and the output of Is varies slightly with the ambient temperature or the resistance value of the measured component. In order to accurately obtain the constant current excitation size in a single measurement,
the system design measures the constant current excitation size of the constant current source output each time. In this way, the influence of constant current output instability caused by environment and other factors on the measurement results can be avoided.

Based on the previous design experience of resistance testing hardware, it is estimated that the resistance measurement accuracy of the system is between ± 0.5%, which can meet the resistance measurement accuracy requirements of the Technical Specifications.

2.4.2 Design of Current Source
The constant current source circuit design is a voltage control current source based on dual operational amplifier structure of Howland current source, and as shown in the figure:

![Schematic Diagram of Constant Current Source Circuit](image)

When $R_1 \times R_3 = R_2 \times R_4$, $I_{out} = R_4 \times \frac{V_{IN}}{R_1 \times R_s}$.

Stable test current output can be achieved by setting appropriate resistance value and selecting operational amplifier with excellent performance. Before the resistance test, the system measures the output current of the constant current source, and then the voltage at both ends of the bridge of the tested item is collected for several times, and some digital filtering is carried out. Finally, the bridge resistance of the tested item is calculated according to ohm's law.

The system design chooses to use the high-precision DAC output voltage as $V_{in}$, which is used to generate different current excitation. The system control chip controls the DAC output through the SPI interface. According to the resistance value of the measured object, the control chip controls the DAC output matching voltage, and then generates matching excitation current.

2.4.3 Protection Circuit
The design idea is as follows: the current value applied to the measured resistance is monitored, and the high precision resistance $R_s$ is used to convert the current signal into voltage signal. The voltage signal is fed into a high-speed voltage comparator with a pre-set reference voltage $V_{ref}$. The output signal of the comparator is formed through the self-locking control circuit to form the relay control signal, which controls the on-off of the resistance test loop and feedback the control state signal to the upward machine.

When the test current on the resistance being measured exceeds the set value, the voltage on $R_s$ increases and exceeds the reference voltage $V_{ref}$. At this time, the output signal of the voltage comparator changes from low level to high level, and the high level signal triggers the operation of the self-locking control circuit. On the one hand, the self-locking control circuit locks the alarm state, and feedback the alarm signal to the MCU related IO; On the other hand, the output control signal is given to the reed relay on the test loop. The relay disconnects the test loop and the test current on the measured resistance is cut off.

The voltage comparator for protection in the current scheme selects high-speed AD8561R with the maximum delay time of 7ns, which triggers the relay for fast operation. Pickring's quick response reed relay 111P-1-A-5/1D was used as the relay.
2.4.4 Automatic Resistance Measuring Range
The resistance measurement module is used to measure the resistance of heating belt and thermistor. The resistance of the heating belt is in the range of about 100 ω, and the resistance of the thermistor varies according to the model at room temperature. The resistance measurement module needs to determine the appropriate measurement range according to the resistance value of the component under test.

The range selection method of resistance measurement: the resistance measurement module uses a small excitation current output to roughly measure the resistance value, select the appropriate measurement range according to the measured resistance value, and then accurately measure to get the final resistance value. The measuring range of resistance can be 0~100 ω, 100 ω ~1K ω, 1K ω ~100K ω, and 100K ω ~1M ω.

2.4.5 Zero calibration of resistance measurement
After the system is powered on and the testing software is started, the system automatically calibrates the zero point of resistance measurement.

Zero calibration method: the system design a standard reference channel CHref. When the equipment is inspected, the loop resistance Rref of CHref is steadily measured, which is used as the reference. The relative difference Δrx between loop resistance Rx and CHref in all other channels was measured and recorded.

The loop resistance of each channel is mainly affected by the temperature, and the relative difference between each channel is basically unchanged. Therefore, the resistance Rref of the reference channel CHref is only checked once before each measurement, and then the loop resistance Rx of each channel is calculated from Δrx and is subtracted from the resistance values measured later.

2.5 Module Design for Thermocouple Measurement
The system uses NI 9213 thermocouple measurement kit, which includes a 16-channel thermocouple measurement module and a 4-slot CompactDAQ case, to complete thermocouple measurement. The measurement kit communicates with the measurement and control computer through the USB interface of the chassis to exchange measurement instructions and data.

The main technical specifications of the kit are described as follows:
- Differential input channels: 16 channels
- Resolution: 24bit
- Maximum voltage range: -78.125mV~78.125mV
- Accuracy of voltage measurement: 38μV
- Sample frequency: 78Hz

Except for the number of channels, other main performance indicators of the kit meet the requirements of system design and technical indicators. System requirements require that the number of system design channels is not less than 40. Therefore, three sets of thermocouple measurement channels with a total of 48 channels are selected in this scheme to meet the system design requirements.

2.5.1 Line-connecting Method.
The NI 9213 can be connected to the thermocouple input signal. The positive thermocouple is connected to the TC+ terminal, and the negative thermocouple is connected to the TC- terminal. It connects the shield layer to the COM end when using a shielded thermocouple. The shielded end is connected to the common mode reference voltage of the thermocouple. Common-mode reference voltage refers to the voltage within the range of the thermocouple common-mode voltage ±1.2V. When the floating thermocouple or the potential difference between the thermocouple and ground is within ±1.2V, ground the COM terminal and the shield terminal.
2.5.2 Cold End Compensation and Measurement Error

The NI 9213 measurement module multiplexes 16 thermocouple input channels, 1 cold end compensation (CJC) channel and 1 automatic zeroing channel to ADC.

Devices or heating devices near the NI9213 will increase the terminal temperature of the NI9213, that means the terminal temperature will be different from the temperature of the cold end compensation sensor, which will affect the measurement error of the thermocouple. Terminal thermal gradient can lead to terminal temperature differences. In this case, the measurement result not only has the determining measurement error, but also has the relative accuracy error between channels. Therefore, it is necessary to minimize the influence of thermal gradient on the measurement results. The system mainly includes the following points:

1). The system needs to be preheated for 15 minutes before measurement;
2). Try not to measure the thermocouple in an overly cold or overheated environment;
3). Minimize the flow of heat or air around the terminals and keep the ambient temperature as stable as possible;
4). Use a smaller diameter cable to complete the thermocouple conductor.

2.5.3 Thermocouple Qualification Judgment

The system thermocouple measurement is performed at room temperature. Multiple temperature points cannot be measured. It is impossible to determine whether the thermocouple is working on its temperature curve. In order to initially judge whether the thermocouple works normally, the system chooses to use DS18B20 temperature measurement module to measure the room temperature as the standard temperature value T0. Then the output voltage of the thermocouple is measured and converted to the corresponding temperature Ttc. Comparing T0 with Ttc, the thermocouple is considered to work normally if the following relationship is satisfied:

\[ \left| \frac{T_{tc} - T_0}{T_0} \times 100\% \right| \leq 10\% \quad \text{OR} \quad |T_{tc} - T_0| \leq 2^\circ C \]  \hspace{1cm} (1)

2.5.4 Multi-way Switchover

The system needs to be able to collect 40 thermal control devices, including thermistor, heating plate, heating band resistance and thermocouple output voltage values.

The thermistor, heating plate and heating belt are resistive devices. Their resistance value under normal temperature conditions needs to be measured only. The system design uses custom resistance test cards for measurement; The output voltage system of thermocouple is measured by NI 9213 thermocouple test module. Since the output of thermistor and thermocouple will not be measured at the same time, the system design uses a set of fixtures. According to the different measurement objects, the data acquisition equipment corresponding to the measurement objects is selected through the multi-way switch.

The tested components are connected to the system through fixtures. According to the different types of the tested objects, the software controls the switch matrix to switch and select, and the tested components are connected to the corresponding acquisition equipment. In the figure above Thermocouple Measurement Module consists of 3 NI 9213 thermocouple measurement cards, and each card has 16 channels, so there is a total of 48 channels. 48 thermocouple output voltages can be measured simultaneously. Resistance Measurement Card is a custom resistance test card and multi-way switching card composition. The resistance test card consists of a resistance measurement path and a 12-way multi-way switching unit and can measure up to 48 channel resistors through four sets of 12 switch switches each.

3. Software Design

3.1 Software Function

The system software mainly includes four modules: measurement configuration, data acquisition, data
management and file management. Each module separately contains several functional modules.

3.2 System Software Functions
The system software mainly consists of four parts. The following sections describe in detail the functions of each component, organizational unit and the detailed design scheme.

3.2.1 Measurement Configuration
The software measurement configuration function consists of two functions: parameter import and export and parameter configuration. The system configuration parameters are as follows:

- Model code: satellite model code;
- Product code: code of the product under test;
- Measurement time: start time based on the system time;
- Location of survey: Record the location of survey;
- Surveyor: The name or code of the person who performs the measurement;
- Qualification criteria: resistance measurement qualification criteria and thermocouple qualification criteria;
- File storage path setting: includes configuration parameter path, test data storage path, and report generation path.

Parameter Import and Export Function
Parameter import: the user can edit and save the configuration file in Excel. The software reads the specified configuration file, loads the configuration parameters into the system. And it only needs to select the specified model code and product code when measuring.

Parameter export: the user can edit parameters on the parameter configuration interface. After editing, click “Save”. The software will update or add the configuration parameters to the configuration file for the next import.

Parameter Configuration
Software design for parameter configuration interface is used to import parameters or add parameters to edit. This interface has the following functions:

- Parameter loading: The user selects the specified code product, loads the existing configuration data, and can edit it;
- New parameters: The user can add and edit a new set of configuration parameters for new product measurements;
- Parameter storage: After editing the parameters, save the new parameters to the configuration file and update the software configuration data.

3.2.2 Data Collection
Data acquisition module is mainly composed of: thermocouple measurement, resistance measurement (thermistor and heating band) measurement, matrix control, measurement display, qualification judgment, sound and light alarm and data storage and other functional units.

Thermocouple Measurement
The thermocouple measurement unit mainly performs the following functions:

- NI 9213 self-test, zero calibration;
- Measure the thermocouple temperature of the specified channel according to the measurement configuration;
- Collect the RTD temperature data;
- Judge whether the thermocouple is normal according to the measurement parameters, highlight the state of the product, and make sound and light alarm when defective products occur;
- Store measurement data.
Resistance Measurement
The resistance measurement unit mainly performs the following functions:
- Resistance measurement hardware self-check, zero calibration;
- Measures the resistance value of the resistance of the specified channel according to the measurement configuration;
- The resistance measurement process is divided into three main steps:
  - Output minimum test current, preliminary measurement resistance value, and adjust the measurement module gear according to the resistance value;
  - Output suitable excitation current, delay appropriate time according to the different gear selection, and wait for the measurement circuit voltage stability;
  - Collect the resistance value of the measured resistance frequently, and the sampling results are processed to obtain the stable and effective resistance value
- Judge whether the resistance value is normal according to the measurement parameters, highlight the state of the product, and make sound and light alarm when defective products occur;
- Store measurement data

Matrix Control
According to the measurement selection, the software sends a switch command to the matrix switch module to switch the measurement signal to the thermocouple measurement hardware or the resistance measurement hardware.

Qualified Judgement
The qualification is judged according to the measurement parameter configuration for each measurement of the thermocouple temperature value or resistance value of a channel, and output the indication information whether the status is qualified or not.

Sound-light Alarm
If the qualified Judgement determines that a product meets the parameter requirements, it is a defective product. The software controls the acousto-optic alarm device to output acousto-optic indication signal, and flashes the measured data of the channel on the interface.

Data Storage
After the measurement is complete, the measurement data is saved to the specified file. If no file is specified, the file is saved with a specific string as the name. The data is also recorded in the database.

3.2.3 Data Management

Database Management
During the software installation, the system database and corresponding data tables are automatically created. The software provides a database management module, where the user can create new tables or delete existing tables.

Data Query
The users can query the test data of a specific product through the data query interface. Or they can specify search conditions to query test data that meet the search conditions.

3.2.4 File Management

System Log
During the running of the software, the system automatically records work logs in the background, including measuring basic information and system running status. When a fault occurs, the system can be queried and located. The system log file is in “*. Log” format and can be opened using an application program such as Notepad.

Configuration Files
Users can edit and input parameters through the parameter configuration function unit, update the existing parameters or add new parameters, and update the configuration file.
Data Report
The Software designs the generation interface for data report. The user can generate the measurement data report of the specified product through this interface. After the measurement report is completed, the software stores it in the specified path and stores it as “a *.xls” file with the specified name or customized name.

4. Test Application
After testing, the system design function is complete and is in line with the functional requirements of the project. Thermistor measurement, thermocouple measurement, heating sheet measurement and room temperature measurement accuracy meet the technical requirements.

| No. | Path | Standard Resistance Value R0(kΩ) | Measure Resistance Rx(kΩ) | Error =(Rx-R0)/R0*100% |
|-----|------|----------------------------------|---------------------------|-------------------------|
| 1   | 1    | 1                                | 1.01                      | 1%                      |
| 2   | 2    | 1                                | 1.01                      | 1%                      |
| 3   | 3    | 1                                | 1.01                      | 1%                      |

Note: If all measurement errors meet the Technical Specifications, the test passes.

Figure 5: the functional requirements of the project

5. Conclusion
At present, the research and application of this set of system fill the blank in the field of thermal control device resistance value on batch automatic measurement and increase the accuracy of resistance value measurement, and save the time and labor cost of batch measurement. There is a broader market prospect at the aspect of application.

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