Comparative Research on Temperature Measurement Methods in Vacuum and Low Temperature Environment

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Abstract—In this paper, two kinds of temperature sensors (platinum resistance and thermocouple) commonly used in vacuum and low temperature (below 100k) are compared. The same data collection method is used. The temperature measurement results are analyzed to obtain some differences in the temperature measurement of platinum resistance and thermocouples under vacuum and low temperature conditions. At the same time, the differences between the two temperature measurement methods are sorted out, and the temperature measurement methods in different environments are given. Some suggestions, and some prospects for future research directions are given.

1. INTRODUCTION
Space environment simulator is the key equipment for spacecraft to carry out vacuum thermal test. Through the thermal vacuum test in the space environment simulator, the simulator provides a vacuum low temperature environment for the test piece[1].Generally speaking, the temperature measurement of the test equipment mainly includes the shroud temperature and the temperature of some parts of the chamber execution mechanism, shroud temperature measurement generally uses copper-constantan thermocouples, and individual test equipment uses platinum resistance[2].In the application of low-temperature engineering, it often involves the accurate measurement of temperature. The commonly used low-temperature thermometers are thermocouple, thermal resistance and low-temperature diode thermometers. Because the time constant of thermocouple is small and there is no self heating of current, they are widely used in the measurement of transient low-temperature[3].Thermocouple is the most widely used temperature sensor in spacecraft thermal test because of its high sensitivity, stability and reliability, good interchangeability and low price[4].In addition, there is a commonly used temperature sensor, platinum resistance, which is widely used to measure the temperature in the range of - 200 °C - + 800 °C. It has the characteristics of high measuring accuracy, high sensitivity, good stability, wide measuring temperature range, strong anti vibration and anti impact, no need for cold end compensation[5], and it has fast response speed and temperature line under low voltage[6].

The space environment simulator uses thermocouple and platinum resistance as two kinds of commonly used temperature measuring equipment. Its use environment is mainly vacuum and low temperature environment, and the use environment is in the alternating state of vacuum and low temperature and normal pressure. The comparative study of these two temperature measuring methods
is conducive to the in-depth understanding of the thermal test system and better analysis of the thermal test temperature measurement state.

2. MEASURING PRINCIPLE

2.1 Principle of thermocouple temperature measurement

The thermocouple is called "couple" because he must appear in pairs. That is, two ends of metal materials with different compositions are connected to form a loop. If the temperatures of the two connection ends are different, a thermal current is generated in the loop to form a thermoelectric potential. The thermoelectric potential generated by this loop consists of contact potential and thermoelectric potential.

The thermocouple in this article only involves copper-constantan thermocouple, also known as T-type thermocouple, referred to as T-couple. The positive electrode is pure copper, and the negative electrode is constantan, which is an inexpensive metal thermocouple that is best measured in the low-temperature region. The temperature range can be (-200 ~ 350) °C according to the diameter of the wire. Under the premise of good uniformity of the wire, the accuracy of the T-couple is the highest among metal thermocouples.

2.2 Principle of resistance thermometer

Generally, metals have crystal structure. Metal ions form lattice according to their arrangement and combination. The free electrons move in the lattice irregularly. This kind of electrons is called free electrons in metals. The movement of free electrons is irregular and fast. In motion, it often collides with vibrating ions to produce scattering. Because of scattering, the negative acceleration of the electrons in the metal in the opposite direction of the electric field can not be increased indefinitely, so there is resistance.

It has been proved theoretically that the resistivity is directly proportional to the thermodynamic temperature at high temperature and to the quintic of the thermodynamic temperature at low temperature [7].

The thermal resistance in this paper only involves PT100 in the platinum thermal resistance (RTD) of the industrial thermal resistance (IPRT).

3. TEST DESIGN AND IMPLEMENTATION PROCESS

3.1 Experimental design

In this paper, through the arrangement of real temperature measurement points in the space environment simulator, two kinds of temperature sensors, thermocouple and platinum resistance, are compared and analyzed. The distance between the two sensors is controlled within 1cm. During the operation of the space environment simulator, the local temperature can ensure its temperature consistency. In view of the space environment simulator in the process of operation, the heat sink is full of liquid nitrogen working medium, in a small local range, it can be considered that the temperature is uniformity, through the measurement of two kinds of temperature sensors, it can be compared.

The whole measuring range including the whole process of simulated thermal test is shown in the figure below:

![Figure 1 Full process comparison test](image-url)
3.2 Implementation process
The entire sensor layout process should follow the following process:

1) Determine the sticking position, use medical gauze dipped in anhydrous ethanol to wipe the surface of the sticking position to ensure that the sticking surface is clean, flat and free of protrusions and burrs;

2) One end of the insulating tape is folded into a triangle shape (as shown in the figure below) and pasted on the cloth point of the test piece. As the adhesive substrate of the sensor, it should be noted that the insulating tape should be close to the surface of the test piece, which should be flat and free of bubbles;

3) Stick the sensor head on the insulating substrate with adhesive tape, and the platinum resistance head is exposed at the edge of the adhesive tape.

4) Paste the platinum resistance. It is required to paste the sensor to fold one end into a triangle shape, and the insulating tape used shall be compacted and flattened without bubbles.

![Schematic Diagram](image1.png) ![Actual Measuring Point](image2.png)

Figure 2. Sticking process & Measuring point layout

Through the implementation of the measurement and fixation process, ensure that the test points have the same sticking process, and avoid the systematic error caused by the difference of sticking process. Three groups of comparison groups are arranged for measuring points to avoid errors caused by single measurement.

After the sensor layout is completed, data processing and data analysis are carried out through the data collection system, and the working principle of the data collection system is shown in reference[8].

In this comparative test, Keithley 3706 is used. The measurement program sends instructions through the LAN interface to drive the 3706 digital measurement instrument. At the same time, it reads the voltage or resistance value of the measurement channel of the 3706 meter, calculates the temperature value of the measured point through the fitting formula, displays and stores the data value in real time[9].

4. Data Analysis
Through a cycle of rising and falling temperature cycle to simulate the actual test environment state, the temperature measurement state of thermocouple and platinum resistance is analyzed, among which the measurement point 01-03 is platinum resistance measurement point, and the measurement point 04-07 is thermocouple measurement point. Through the analysis of test measurement curve, we can get the following measurement results.
Through curve analysis, we can easily find:

1) Under normal temperature and pressure conditions, the temperature measurement consistency of the two types of sensors is good;

2) Under vacuum conditions, the measurement consistency of the two types of sensors begins to deviate;

3) In the process of cooling down and under low temperature, thermocouples are more sensitive to temperature, and platinum resistance responds to temperature more slowly;

4) In the low temperature state, for the current bonding process, the temperature value of the platinum resistance measurement is higher than that of the thermocouple, but as time goes by, the temperature consistency becomes the same;

5) During the heating process, the measurement consistency of the two types of sensors is getting better and better;

6) After returning to normal temperature and pressure, the measurement results of the two types of sensors are the same as before the test, and there is almost no difference in the measurement results.

At the same time, according to years of test data, the temperature errors of the two temperature sensors discussed in this article are negative under vacuum conditions. The working T-type thermocouple has a larger error value than the industrial Pt100 platinum resistance and the value keeps changing with the pressure.
TABLE I. COMPARISON ANALYSIS TABLE

| Items                        | Two kinds of sensors comparison analysis                                                                 |
|------------------------------|-----------------------------------------------------------------------------------------------------------|
|                              | Thermocouple                                                                                               |
| Response time                | Unshield and fast response                                                                                   |
| contamination                | Easily influenced                                                                                           |
| Alternating temperature      | Basically no effect                                                                                         |
| Test channel                 | 1 channel                                                                                                   |
| Economy                      | Positively related to measurement length                                                                    |
| Sensor damage                | reused after re-welding                                                                                     |
| Ease of use                  | Need to match temperature reference point                                                                    |
|                              | Platinum resistance                                                                                            |
|                              | Shield and Slow response                                                                                    |
|                              | Not easily affected                                                                                         |
|                              | Easy to produce zero drift, has a certain impact                                                            |
|                              | 2 channel                                                                                                   |
|                              | Mainly the price of platinum resistance, the measurement line has little influence                           |
|                              | Sensor scrapped                                                                                             |
|                              | Obtained directly through the data acquisition system                                                        |

5. CONCLUSION AND FUTURE OUTLOOK

Through the comparison and analysis of thermocouple and platinum resistance in the previous section, we can find the main advantages and disadvantages of the two temperature measurement methods and their response conditions. We should combine the actual use environment and use accuracy to selectively use the two temperature sensors, and promote the selection of platinum resistance temperature measurement method under the condition of low demand for temperature change sensitivity measurement and repeated using. When the temperature measurement is sensitive and there are many measuring channels, it is recommended to use thermocouple for measurement.

The existing data acquisition instruments are mainly digital multi-purpose meter and multi-channel data acquisition switch, which can not take into account the data acquisition time and accuracy. The time and method of data acquisition determine the impact of environmental changes on data, and the accuracy of data acquisition is an important component of data error analysis or uncertainty evaluation. How to solve the problem of high accuracy and high-speed data collection is also a problem to be solved in the future. The installation process of the temperature sensor and the source of the measurement error of the temperature sensor in the vacuum environment will also be topics for continued exploration.

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