Research on structure design of thermocouple junction for spacecraft thermal vacuum tests

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Abstract. This paper investigates the structure design problem for the thermocouple junction in spacecraft thermal vacuum tests. Due to the different configurations during the tests, the length and the number of thermocouples are always different, which would lead to certain cost. As a result, a novel thermocouple integrated junction structure is developed and the thermocouple wire can be re-used. The experiment demonstrates that the proposed design method can save the spacecraft thermal vacuum test cost and considerably improve the test efficiency.

1. Introduction

During the past years, increasing attentions have been paid to the spacecraft thermal vacuum tests due to their importance of ground-based verification technology [1-4]. In particular, most spacecraft thermal vacuum tests such as spacecraft battery panels or antennas are based on the thermocouple measurement. Generally speaking, the traditional measurement procedure requires a specified thermocouple placement for each spacecraft thermal tests. However, this would lead to a considerable manpower and material cost for the corresponding test configuration. Moreover, with the rapid development and need of scientific research and spacecraft production tasks, the spacecraft thermal test frequency is greatly increased [5-6]. As a result, the traditional working process of thermocouple would restrict the test efficiency and the new technology for thermocouple measurement is needed.

Furthermore, it is worth mentioning that the traditional temperature measurement for spacecraft thermal tests based on thermocouple is very complicated. Much effort and time is spent on the thermocouple cable welding [7-8]. In addition, some thermocouple cable welding work need to be completed during the tests with poor welding conditions, which may cause quality problems such as wrong welding or missing welding. As such, in view of the shortcomings in the current temperature measurement process of thermal vacuum tests, it is reasonable to develop the optimized design technology and the selection of alternative thermocouples and the corresponding structure design of the integrated thermocouple junction are very important [9-10].

Based on the above discussions, this paper proposed a new design method for the thermocouple in spacecraft thermal vacuum test. Compared with traditional manufacturing and welding process of temperature measurement, the developed thermocouple junction structure design based on the new type TT-T-30 type repeatable thermocouple is more effective. In addition, by applying the new thermocouple temperature measurement testing process, the reliability and the efficiency of the spacecraft thermal vacuum tests can be effectively improved.

The following parts of the paper are arranged as follows. The thermocouple selection and verification for the spacecraft thermal vacuum tests is introduced in Section 2. The design details of the corresponding thermocouple junction structure are presented in Section 3. The experiment results are
provided in Section 4 to show the effectiveness and advantages of the proposed method. The conclusion of the paper is given in Section 5.

2. Thermocouple selection for spacecraft thermal vacuum tests

In this section, the new thermocouple selection strategy is presented with details, which is based on the new TT-T-30 type repeatable thermocouple.

2.1. Spacecraft thermal vacuum test temperature measurement system based on thermocouple

The structure of the spacecraft thermal vacuum test temperature measurement system based on thermocouple is shown in Figure 1.

![Figure 1: The illustration of thermocouple temperature measurement system](image)

Currently, the insulation layer of thermocouple is always thin such that the protective layer is easy to be damaged after repeated utilization. In addition, some tests are carried out in the complex environment such as protection treatment and thermocouple temperature measurement wire butt welding, which increase the working intensity. Because of the weak protection configurations, the thermocouple cannot be re-used, which greatly increases the test cost and would cause a waste of manpower. In order to improve the reliability of thermocouple temperature measurement, reduce the test cost and the repetitive work, it is necessary to carry out the type selection test of new thermocouple. The selection of new thermocouple mainly considers temperature measurement accuracy, wear resistance and flexibility. On the premise of meeting the temperature measurement accuracy of thermal test, the wear resistance and flexibility are comprehensively considered. Considering the inheritance of the existing thermocouples, the Omega TT-T-30 reusable thermocouple with the diameter close to the existing T-type thermocouple for thermal test is selected for testing, which can be seen in the Figure 2. The TT-T-30 thermocouple is manufactured according to IEC 584-1 standard. The performance of the physical characteristics of the thermocouple wire is good for use and it conforms to the national standard GB/T 16839.1 (adopted by IEC 584-1) [11-12].
On the other hand, the insulation layer of TT-T-30 thermocouple is made of Tetrafluoroethylene perfluoroalkyl vinyl ether copolymer materials (PFA). The thickness of the insulation layer is about 0.24mm, and it is double-layer insulation. The appearance is round and smooth. The insulation layer is tightly packed on the conductor and is easy to peel off without damaging the conductor. Compared with the traditional PTFE insulation layer of the original thermocouple, the PFA material is made of polytetrafluoroethylene, and its performance is better than that of polytetrafluoroethylene. The long-term service temperature of PFA material is -196 °C -200 °C. It has excellent chemical corrosion resistance. Its friction coefficient is the lowest among plastics. It also has good electrical properties. Its electrical insulation is not affected by temperature. Its creep resistance and compressive strength are better than that of PTFE, and the tensile strength is higher, and the elongation can reach 100% - 300%.

2.2. **Extreme high temperature and extreme low temperature test**

Take three thermocouple samples of 1m each and put the samples into the high-temperature test box. The test temperature is set by 200 °C. After holding for 2 hours, the samples are taken out from the high-temperature box and the thermocouple wire is restored to normal temperature. The withstand voltage test is carried out, and the insulation layer state is observed, and there is no adhesion or crack.

In addition, take 9 thermocouple samples of 1m each, and conduct the storage test according to GJB150.4. Put the sample into the thermos bottle containing -196 °C liquid nitrogen, and the sample is completely immersed in liquid nitrogen. The 9 samples were divided into 3 groups, and each group was placed for 48 hours, 72 hours and 96 hours, respectively. After the test, take out the sample, restore to room temperature and conduct voltage test. It can be observed that the insulation layer state has no adhesion or crack phenomenon.

The sample is put into the low temperature test box, and the test temperature is set by -90 °C. After holding for 1 hour, take out the sample and put it into the high temperature that has been heated to 200 °C within 5 minutes. Keep it for 1 hour and cycle 25 times according to the above steps, then take out the sample after the test, and conduct the withstand voltage test. The insulation performance is good, and the appearance is not damaged. The low temperature test site of thermocouple is shown in Figure 3.

![Figure 2: The illustration of Omega TT-T-30 reusable thermocouple](image1)

![Figure 3: The illustration of low temperature test of thermocouple](image2)
Through the extreme high temperature test, extreme low temperature test and temperature shock test, the Omega TT-T-30 thermocouple is selected with good performance. This type of thermocouple is of T-type thermocouple. Its temperature measurement range is -270 °C ~ 400 °C, the temperature measurement accuracy is 0.1 °C, and the wire diameter is 0.25 mm. The insulation material is PFA, which has good wear resistance and flexibility. The test results show that the physical characteristics of TT-T-30 thermocouple does not change significantly after high and low temperature test and temperature shock test, and the electrical performance is good, which meets the requirements of spacecraft thermal test. In order to verify the compliance of temperature measurement index of TT-T-30 thermocouple, the comparison testing data is shown in the following Table.

### Table 1: Comparison of coefficient between TT-T-30 thermocouple and 15-08-18 thermocouple

| Graduation | TT-T-30 thermocouple | 15-08-18 thermocouple |
|------------|----------------------|-----------------------|
| Voltage -> Temperature | | |
| Temperature | 200℃~0℃ | 0℃~100℃ | -100℃~200℃ | 200℃~0℃ | 0℃~100℃ | -100℃~200℃ |
| A | 0.03299 | -0.01008 | 53.29479 | 0.03644 | -0.01222 | 54.27465 |
| B1 | 25.73893 | 25.92077 | 69.51943 | 25.64842 | 26.02237 | 70.44423 |
| B2 | -0.63749 | -0.56787 | 11.37946 | -0.61194 | -0.56000 | 11.62856 |
| B3 | 0.02000 | 0.15409 | 1.25412 | 0.01884 | 0.15758 | 1.28225 |
| Temperature -> Voltage | | |
| Temperature | 200℃~0℃ | 0℃~100℃ | -100℃~200℃ | 200℃~0℃ | 0℃~100℃ | -100℃~200℃ |
| A | 0.00029 | -0.00017 | 0.0137 | -1.86673E-05 | 9.6712E-05 | 0.02703 |
| B1 | 0.03849 | 0.03878 | 0.03914 | 0.03867 | 0.03863 | 0.03933 |
| B2 | 0.00005 | 0.00005 | 0.00005 | 4.40738E-05 | 4.5170E-05 | 5.1335E-05 |
| B3 | -3.1642E-08 | -4.2758E-08 | -3.0965E-08 | -2.8927E-08 | -4.3583E-08 | -2.5585E-08 |

### 3. Structure design of thermocouple junction for spacecraft thermal vacuum tests

In this section, the new structure design procedure of thermocouple junction box for the spacecraft thermal vacuum tests based on the TT-T-30 thermocouple is given with details.

The Thermocouple integrated multiplex junction box is designed to collect thermocouple wires in the box, which can be reused through the retraction and release of thermocouple wires. It is composed of a box body, a winding unit in the box and a thermocouple wire. As shown in Figure 4, the junction box body is the connection link between thermocouple wire storage and external measuring instrument. It is composed of six sides processed by aluminum alloy plate. The thermocouple winding unit is arranged and fixed on the back panel of the transfer box. The front panel corresponding winding unit is provided with thermocouple wire measuring point lead-out hole, and the hole edge is provided with anti-wear sleeve, and the bottom of the outlet hole is provided with anti-retraction buckle. Moreover, a thermocouple wire welding plug is installed on one side of the box, and a common wire outlet hole is opened under the plug. The other side of the box is designed with a fixed interface for heat sink installation, and the upper part of the box is provided with a handle which is easy to carry. The material of the box should be resistant to high and low temperature, and the back panel should have enough rigidity to prevent deformation after the winding unit and thermocouple wire are installed.
Figure 4: The illustration of thermocouple integrated multiplexing transfer box

The thermocouple wire is wound on the winding shaft of the box body. One end of the thermocouple of each spool is pulled out to the special position, and the wiring is fixed in the wiring groove of the box. The thermocouple copper wire and the Kang copper wire are welded into the plug end according to the number. The heat shrinkable cloth is used to protect the outlet end. The electrical connector passes through the special position of the box and is fixed in the box with screws Special location. Connect the temperature measuring cable plug in the test tank with the plug end on the box. The two pairs of common lines are led out from the hole of the common line protection sleeve of the box. The whole box body is insulated with aluminized film. After the test, the common line and electrical connector are not disconnected. The thermocouple is retracted and reversely wound back into the winding shaft through the handle connected with the thermocouple winding shaft outside the tank for reuse. The wiring of the transfer box in thermal test is shown in Figure 5.

Figure 5: The illustration of transfer box wiring

4. Experiment illustration

In this section, the experiment results are provided to demonstrate the correctness of the proposed design method.

Based on the designed new equipment, the comparison of thermocouple control temperature curve between new and traditional temperature measurement from -170 °C to 80 °C is shown in Figure 6. It can be seen that the new thermocouple integrated reusable transfer box has no effect on the internal
temperature field and the measurement results of TT-T-30 thermocouple has good consistency, and the test temperature is evenly distributed around ± 1.5 ℃ of platinum resistance temperature.

Furthermore, the new design of thermocouple installation based on the thermocouple integrated reusable transfer box can lead to lower test cost, reduce repeated labor, and improve quality and efficiency for the spacecraft thermal vacuum tests.

5. Conclusions
In this paper, we developed a new structure of thermocouple junction for spacecraft thermal vacuum tests. Furthermore, based on the designed structure, the new thermocouple selection strategy based on TT-T-30 type repeatable thermocouple for spacecraft thermal vacuum tests is presented instead of the traditional single-use thermocouple approaches. Finally, the experiment results can verify that our proposed method can effectively increase the test efficiency and considerably decrease the test configuration cost.

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