Research on improvement of vacuum gauge electrical connector in spacecraft

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Abstract. The vacuum gauge is the key equipment in the satellite thermal test process. During the test, the vacuum gauge resistance value will jump. This paper analyzes the fault mode for this condition, the cause of the vacuum connector's electrical connector failure, and proposes an improvement method. Finally, the improvement method is verified, which proves that the improvement effect is obvious and can be promoted and used.

1. Overview
The spacecraft will experience the space environment of vacuum, low temperature, cold black and external heat flow during orbital flight. In order to make the spacecraft work in the space environment for a long time, safely and reliably, and to complete the established tasks, we need to carry out the thermal design of the spacecraft reasonably [1]. Before the launch of the spacecraft, it is necessary to carry out relevant environmental simulation tests on the ground. The thermal balance test and the thermal vacuum test are key conditions for simulating the thermal design of the spacecraft and assessing its performance in a space environment simulator that simulates the cold black vacuum and external heat flow conditions of space. The vacuum environment is an indispensable environmental test state. It is generally required that the vacuum environment in the spacecraft test process be better than $1.3 \times 10^{-3} \text{Pa}$ [2].

2. Vacuum measuring device
The electrical components or equipment on some spacecraft are sensitive to the degree of vacuum when they are turned on, and need to be avoided by opening the vacuum discharge area. Therefore, it is necessary to monitor the vacuum degree in the vicinity, and generally use a hot cathode ionization gauge for measurement. The working principle is as follows: after the cathode is energized and heated, electrons are emitted, and the electrons fly to the positively charged electron acceleration pole, a part of the electrons are captured by the electron acceleration pole, and another part of the electrons passes through the electron acceleration pole. The electron collides with gas molecules during flight, causing a certain probability of ionization of the gas molecules. The number of positive ions generated by ionization is proportional to the gas density. Under the premise of a certain temperature, it is proportional to the pressure of the gas, so that the pressure value is indirectly obtained by measuring the magnitude of the ion current [3]. In actual use, it is found that the vacuum gauge value of the test will be bounced. For example, the vacuum gauge is tested before the test, and the vacuum gauge conduction test is performed in the return gauge outside the container. The cathode (filament) loop resistance test result is 2.25 $\Omega$, and the result is normal (usually at $2.1 \pm 0.1 \Omega$ range), but the
acceleration pole (gate) loop resistance jumps in the range of 10Ω ~ 15Ω, the result is abnormal, so this paper studies this situation.

3. Failure analysis

The level of reliability of the electrical connector has an important impact on the safe operation of the system [4]. The main fault in the use of the connector is poor contact. In addition to the unreasonable material and design of the connector, the appearance quality defect of the connector during the manufacturing process is also an important factor [5]. The reliable contact of the electrical connector is achieved by the stable contact force between the contacts (pins and sockets) [6]. In general, failure of electrical connectors is mainly concentrated in insulation performance degradation, poor contact and poor fixing [7]. The vacuum measurement system diagram is as follows.

![Vacuum Measurement system](image)

Figure 1. Vacuum Measurement system

The vacuum gauge is connected to the "porcelain octagonal" tailgate, and the analog signal is transmitted to the vacuum gauge through the transition cable network (the cable inside the container, the electrical connector through the wall, and the cable outside the container), and the vacuum gauge converts the analog signal into a vacuum digital signal.

Vacuum gauge plug connector (porcelain octagonal) a total of 8 contact parts, vacuum gauge only use NO.1, 2, 4, 5, 7 contact pieces, of which 1 is the collector; NO.2, 7 constitutes a loop, that is, the cathode (filament) loop; No. 4, 5 form a loop, that is, an accelerating pole (gate) loop. Test the vacuum gauge. The fault tree is shown below:

![System analysis fault tree](image)

Figure 2. System analysis fault tree

The resistance of the vacuum gauge circuit is tested when we removed the problem-free connector. The loop finds that the resistance of the cathode (filament) loop is about 0.7Ω, which is normal; but the resistance of the accelerating pole (gate) loop jumps obviously at 1.0Ω. In the range of ~29Ω, according to the analysis of this test result, it is very likely that one or two of the 4 or 5 contacts will be desoldered (the placement may be forced here), or 4, 5 contacts. One or two of them are not tightly
connected to the vacuum gauge, and the vacuum gauge is tested separately. The oscillating vacuum gauge or the cable has obvious jitter (gate) loop resistance, and the position is vacuum gauge. The resistance caused by the connector problem is bouncing. According to the current situation and specific analysis of the vacuum gauge, it is found that there is a problem in the connection of the vacuum gauge connector, and the process has defects. The simple loop resistance test in the test can not solve the process defects of the plug itself, and can only play a certain screening role on the vacuum gauge. There are hidden dangers in the test. Therefore, the corresponding improvement method is proposed in this paper.

4. Current vacuum gauge technology

Through the structural analysis of the vacuum gauge connector, the main research content is positioned to improve the vacuum gauge connector. The structural analysis of the vacuum gauge plugging found that its process defects are mainly reflected in the following four points

4.1 Connection method

As shown in Fig. 3, the porcelain octagonal is composed of two parts: the contact piece and the skeleton. The porcelain octagonal contact piece is a knife-and-fork type, and can be shaken in the skeleton, and the contact area with the vacuum gauge terminal has a certain randomness.

![Figure 3. Connector](image)

The direct cause of the resistance of the accelerating pole (gate) circuit is that the vacuum gauge terminal is not in close contact with the fork-type contact, and the contact resistance changes when the cable or vacuum gauge is shaken, causing the acceleration loop resistance to jump.

![Figure 4. Connection method](image)

4.2 Clamping structure

As shown in Fig. 5, the tail of the vacuum gauge plug is a circular hole, which is not a tailgate clamping structure of a conventional plug. After the cable is soldered, it is taken out from the round hole and cannot be fixed. The unfixed cable may cause the porcelain octagonal solder joint to be stressed, and there is a risk of the solder joint falling off or the virtual joint.
4.3 Excess material
The ceramic skeleton used in the vacuum gauge will generate some detachment debris during the octagonal contact process and during the insertion process, which will generate excess material in the plug. The accumulation of these excesses may also cause contact problems of the connectors, affecting the resistance of the loops, and thus affecting the measurement effectiveness of the vacuum gauges.

4.4 Docking problem
In the process of docking, the connector is simply inserted into the link, and there is no locking limit device. If it is used repeatedly and is inserted and removed, the loosening may occur during use.

5. Improved method research
In view of the structural insufficiency and defects of the 4-point vacuum gauge connector mentioned above, it is proposed to propose relevant improvement measures as follows:

1) For the octagonal structure of porcelain, the structure of the knives and forks is abandoned. Analyze and study other tightly connected structures to ensure that the contact area is large enough to increase contact reliability; eliminate related jitter problems caused by cable sway and poor contact.

2) For the cable-free clamping structure at the end of the connector, improve the tail structure of the connector, increase the clamping function, and ensure that the force of the external cable of the vacuum gauge plug is not transmitted to the solder joint inside the plug, ensuring the solder joint Safe and reliable.

3) We abandon the ceramic skeleton structure in the vacuum gauge for the problem of excess material in the ceramic skeleton. It is proposed to replace the polyimide skeleton with similar ceramic structure performance, solve the problem of ceramic shedding in the connector, and improve the reliability of the overall vacuum gauge.
4) For the docking problem of the connector, it is planned to add design to the docking end, and develop the plug locking mechanism. In the docking process, the connector can be firmly connected to avoid loosening.

![Figure 7. Improved clamping and locking mode](image)

6. Performance Testing

After the vacuum gauge is improved, it is tested to verify its reliability. The main evaluation index of the test is the resistance of the two circuits of the vacuum gauge. Determine if the resistance has a beating condition.

Test method: Perform a loop resistance measurement before use to confirm that there is no jitter. In order to simulate the influence of various factors such as external force, we apply the centrifugal force in the test (the distance in the table is characterized). The measurement is carried out using five sets of vacuum gauges. The specific measurement data is as follows:

|                  | 1#gauge | 2#gauge | 3#gauge | 4#gauge | 5#gauge |
|------------------|---------|---------|---------|---------|---------|
| **Before test**  |         |         |         |         |         |
| loop1            | 2.4     | 2.4     | 2.3     | 2.1     | 2.4     |
| loop2            | 2.1     | 1.9     | 2.1     | 2.3     | 2       |
| **After test**   |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.4     |
| loop2            | 2.1     | 1.9     | 2.1     | 2.3     | 1.9     |
| **10cm**         |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.3     |
| loop2            | 2       | 1.9     | 2.1     | 2.3     | 2       |
| **After test**   |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.3     |
| loop2            | 2.1     | 1.9     | 2.1     | 2.3     | 2       |
| **20cm**         |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.3     |
| loop2            | 2       | 1.9     | 2.1     | 2.3     | 2       |
| **After test**   |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.3     |
| loop2            | 2.1     | 1.9     | 2.1     | 2.3     | 2       |
| **30cm**         |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.3     |
| loop2            | 2.1     | 1.9     | 2.1     | 2.3     | 2       |
| **After test**   |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.3     |
| loop2            | 2.1     | 1.9     | 2.1     | 2.3     | 2       |
| **40cm**         |         |         |         |         |         |
| loop1            | 2.4     | 2.3     | 2.3     | 2.1     | 2.3     |
| loop2            | 2.1     | 1.9     | 2.1     | 2.3     | 2       |

Through the measurement of the five sets of vacuum gauges, it was found that the vacuum gauge resistance did not jump, which fully satisfied the requirements. Eliminate the phenomenon of resistance bounce, meet expectations, and can be well used for spacecraft star vacuum measurement.

7. Summary

Through the failure analysis of the vacuum gauge resistance value, the failure reason is obtained, and the failure mechanism is improved, the connection performance is effectively improved, the vacuum degree measurement inside the spacecraft can be performed, and good application effect has been achieved. In the next step, relevant electrical and mechanical connectors in the spacecraft test process can be carried out in a targeted manner.

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