Research on electromagnetic interference protection of vacuum tank temperature acquisition system

Guo Shichao1*, Guo Dandan2, Zhang Qiongyu1, Wu Nankai1, Deng Jiaxin1
1Beijing Institute of Spacecraft Environment Engineering, Beijing, 100094, China
2Beijing Institute of Spacecraft System Engineering, Beijing, 100094, China
*Corresponding author’s e-mail: 357464199@qq.com

Abstract. Solving the electromagnetic interference problem of the vacuum tank temperature acquisition system has an important role in improving its field reliability. The interference coupling path is found by simulating the source of electromagnetic interference in the environment, and the component characteristics are analyzed. The problem of electromagnetic interference by improving its own anti-interference ability was solved, and a solution for verification was proposed again.

1. Introduction
The vacuum tank temperature acquisition system is used for real-time collection and high-speed transmission of the temperature in the tank. Its high resolution accuracy facilitates fine temperature collection and control data analysis. Its fast acquisition speed and wide collection points can realize multi-point parallel, real-time, and automatic monitoring of temperature data to ensure accurate positioning of temperature data in the ground simulation space and the scene. As some of the equipment under test works inside the tank, the electromagnetic environment inside the tank becomes complicated and severe, which even seriously affects the accuracy and stability of the data. The solution to the problem of electromagnetic interference is irregular and can only be achieved through step-by-step test verification. The electromagnetic environment outside the tank is also quite complicated, which will cause the accuracy of the vacuum tank temperature acquisition system to be challenged. These abnormal data will slightly affect the accuracy of the test results and severely may cause the entire test data to fail. In view of these phenomena and the characteristics of the vacuum tank temperature acquisition system itself, the system's own anti-interference ability is selected as a breakthrough point to find the coupling path and the solution to the interference.

This paper describes the verification and theoretical analysis of the temperature acquisition system by simulating interference sources and gives the corresponding solutions.

2. Interference source location and theoretical analysis
2.1. Interference coupling path
Detect the interference immunity of the system by simulating interference sources, locate and troubleshoot the frequency bands and items that are easily interfered by the system to ensure the stability and reliability of the vacuum tank temperature acquisition system during normal experiments [1].

[1]
There are hundreds of signals in the vacuum tank temperature acquisition system. Four of them are selected for simulation. A total of eleven different interference injection conditions are simulated: electrostatic discharge immunity, electrical fast transient pulse group immunity, lightning surge immunity, RF conducted immunity, power frequency magnetic field immunity, voltage drop and transient drop, cable bundle injection conduction sensitivity, cable bundle injection pulse excitation conduction sensitivity, cable and power line damping sinusoidal transient conduction sensitivity, magnetic field radiation sensitivity, and electric field radiation sensitivity. There are five kinds of interference that make the temperature acquisition system work abnormally, as follows:

a) ESD immunity: Test the anti-static interference ability of a single device or system, and simulate the discharge of an operator or an object when contacting the device, or the discharge of a person or an object to a nearby object. The temperature acquisition equipment multimeter front panel and wires have no effect during air discharge. There is no problem with horizontal coupling and vertical coupling during contact discharge.

b) Electrical fast transient burst immunity: The switching of an inductive load by a switching action in an analog circuit usually causes interference to other electrical and electronic equipment in the same circuit. In this test, the influence of the equipment power supply and the network is obvious only after the test level is greater than 3, but the temperature signal is severely interfered (The data change rate is too large and exceeds the accuracy range, and the communication is disconnected from the network).

c) RF conducted immunity: Electrical and electronic equipment's immunity to conducted emissions caused by RF field induction. The length of the network cable and temperature cable of the temperature acquisition device is equal to the wavelength of the indoor air conditioning and other equipment, which will cause interference on the network cable and temperature line, affecting the temperature line data changes and the network cable communication effect.

d) Cable and power line damped sinusoidal transient conduction sensitivity: Test the multi-frequency points of the power line, temperature line, and network cable of the temperature collection device. The main observations are whether the network communication is normal and the collected temperature data is stable. Repeated tests on the cable's multi-point frequency showed abnormalities in the network. It was judged that there should be packet loss in the network communication.

e) Electric field radiation sensitivity: For the housing and interconnecting cables of equipment and sub-systems, this test frequency range is tested according to the ground platform, and its test field strength is 50V / m. Temperature collection equipment is mainly affected by the interference of radio stations, communication towers and Bluetooth communication. Generally, the frequency band above 1GHz has less impact on the equipment, and the problem is generally concentrated in the frequency band below 1GHz. During the test at 50V/m field strength, only problems occurred in the 30MHz-200MHz frequency band, and other frequency bands were normal. This frequency band is more serious, and it is also the nearest source of interference that our general electrical equipment can generate, especially when there is a transient change in the space electromagnetic field caused by high current start-stop. This point is consistent with the actual situation at the application site, where high-power compressors, air conditioners, and motors will frequently start and stop, and the value will be disturbed at a certain instant of collection.

2.2. **Theoretical analysis of interference phenomenon**

According to the above results, the interference is divided into three categories for analysis and resolution: electrostatic discharge immunity, common mode conductivity immunity, and differential mode conductivity immunity. The combination of practice and theory analyzes the essence of the EMC test and the EMC design principle of the temperature acquisition system itself.

2.2.1. **Theoretical analysis of electrostatic discharge immunity**. During the ESD electrostatic test of the vacuum tank temperature acquisition system, the network port and the USB port use contact discharge, and the network interruption occurs and cannot be recovered. This phenomenon affects the data acquisition result. In dry winter, people’s coats and hair have a strong electric charge, which is
likely to cause direct or indirect discharge, which has a certain impact on the actual application results, but it will not be the main source of interference. However, protection against static electricity is particularly important in production and electrical operations. If it is not handled properly, it will damage the equipment, disrupt production, and even cause a major disaster. In this project, static electricity will cause inaccurate temperature collection data, and the communication network cable will drop out. From its essence analysis, it can effectively find the source of the problem and the way to solve it.

During the ESD test, the ground wire of the ESD gun is connected to the safety ground through the reference ground plate. The EUT is placed on the reference ground plate (through a table or a 0.1m-high stand). The ESD gun head is pointed into the EUT and is easily contacted by humans. Where to go and vertical and horizontal coupling plates. Because the ESD current is concentrated on the reference ground plate, the ESD test is a test in which common mode interference is the source of interference. The ESD interference principle is analyzed from two aspects, as shown in Figure 1.

![ESD schematic diagram](image)

**Figure 1. ESD schematic diagram.**

When an electrostatic discharge phenomenon occurs in the place under test of the EUT, a discharge current will be generated. According to the analysis of the ESD discharge current waveform, ESD is a high-frequency influencing factor when the rising edge of the waveform is less than 1ns. The routing of the EUT circuit determines the current path of the ESD, and parameters such as its distributed capacitance will also be disturbed. And the current generated during the test will cause the appearance of a transient magnetic field, and the time-varying magnetic ring will cause the generation of induced electromotive force when passing through other loops, affecting the normal function of the circuit. When the range S of the magnetic ring is 2cm², the distance D from the ESD test loop current is 50cm, and the maximum peak current I of the ESD transient current I is 30A, then the magnetic field at the 0.5m ESD transient current is as shown in equation (1) show:

\[
H=\frac{I}{2\pi D} = \frac{30}{2\pi \times 0.5} = 10 \text{A/m}
\]  

(1)

The transient voltage in the loop of the induced current is U as shown in Equation (2). When the rising edge time \(\Delta t\) is 1ns and the air permeability is \(\mu_0\), the interference voltage 2.5V is easily affected compared to the normal operating voltage interference. According to the analysis, it can be concluded that the problems of the network port and the USB port are caused by poor grounding.

\[
U=S \times \mu_0 \times \frac{\Delta H}{\Delta t} e^{j\omega}
\]

\[
U=0.0002 \times \pi \times 10^{-7} \times 10^{4} \times 10^{-9} \approx 2.5V
\]

(2)

2.2.2. **Theoretical analysis of common-mode conducted immunity.** Disturbance signal paths of different frequencies sometimes fail in the specified test frequency band. It is particularly important to find out the cause and problem location of the test failure. According to the way and location of RF
interference entering the equipment, we identify the sensitive points that cause the failure and take targeted remedial measures.

The interference in the form of common mode voltage is applied to the power and communication ports of the device under test, and the internal mode of the device under test is interfered by the common mode current (Device structure design plays a key role in pulse group common mode current transmission path and current magnitude). At the same time, it is also possible to directly interfere with the internal circuit of the EUT through the common mode current. The common mode current will change to the differential mode voltage during the internal flow of the device, which will interfere with the normal working voltage of the device (Differential mode voltage in the device is the working voltage).

When injecting the common-mode interference on the signal line and GND into the circuit of the device at the same time, at the signal port of component 1, the impedance of signal 1 is higher than the impedance of GND, so that the common-mode interference signal becomes differential mode, thus interfering with the signal input port of component 1. The filter capacitor for ground at the input side protects the interference of component 2. The differential mode interference signal of the input of component 1 and the ground is filtered by the capacitor. The interference signal will be transmitted to the other end through the low impedance in the PCB. The second stage, the interference signal will be generated when the interference current passes through GND. The principle is shown in Figure 2 below:

![Figure 2. Schematic diagram of common mode conduction.](image)

2.2.3. *Theoretical analysis of differential mode immunity.* In the EMC test project, the low frequency conduction test is mainly based on differential mode interference. The principle of differential mode conduction test is to superimpose the differential mode interference voltage on the EUT and judge by observing whether the equipment works normally. Because the differential mode conduction test is a test of low-frequency transient interference, through analysis of the transmission interference path, smaller parasitic parameters will not interfere with the communication of low-frequency data.

The surge test is divided into wire-to-wire test and wire-to-ground test. It is a kind of conducted interference test with coexistence of differential mode and common mode, and it is also a low-frequency EMC test [4]. From the perspective of the frequency domain, its energy is concentrated in the tens of kilohertz, and the surge test is a high-energy immunity test. The surge interference signal is injected into the EUT port, which interferes with the normal operation of the device. Cause damage to some devices in the equipment. The surge test requires separate common-mode and differential-mode tests. The essence of interference is to superimpose the surge signal on the normal working state of the EUT. Due to the low frequency, there is no need to consider the interference of parasitic parameters such as parasitic capacitance.

3. System interference solution
Through data analysis, it is concluded that there are certain problems with the overall immunity of the product, and there are certain problems with both power and communication or signal paths. The electrical fast pulse group immunity test and the RF conducted immunity test, which have serious
problems, have two main problems: the internal common-mode filtering and the ground design of the circuit are problematic. The problem with the radiation immunity of RS103 just shows that the temperature acquisition system is not in place in the grounding design and shielding measures. In response to the above problems, it is necessary to combine the device interface to do the corresponding filtering circuit or signal conversion transmission method, and at the same time to take measures such as filtering, shielding and strong and weak galvanic isolation for field wiring, and grounding the collector and cabinet.

3.1. ESD immunity solution
In the previous bottoming test, network disconnection occurred frequently when the contact discharge caused the USB and LAN ports on the back. After the super-type 7 network cable was replaced in the reproduction test and the USB and LAN ports were grounded, the local network did not experience network interruption, and the temperature data received was stable, and the temperature variation was within the specified range.

The replacement type VII network cable is a twisted pair cable with double shielding layer, which is used in the field of 10 Gigabit engineering applications. Its communication rate is 10Gbps, and it can provide a comprehensive attenuation of 500MHz and an overall bandwidth of 600MHz, which is more than twice that of a Category 6 line [5]. From the physical structure point of view, the extra shielding layer makes the type 7 wires have a larger diameter.

3.2. Immunity solution for electrical fast transient burst
In the previous test, the network frequently dropped, and the data collected by the temperature line changed greatly beyond the specified range. A pulse group suppressor is added to the power line, and a level 3 injection is performed on the power port and the PE. When the voltage peak is 2000V, the untreated power line is tested [6]. The temperature fluctuation is very strong and reaches a range of 0.200. After adding a pulse group suppressor on the power line, the test is repeated three times, and the temperature change is stable to achieve the purpose. During the level 4 injection, the network was interrupted when the voltage peak was 4000V. The reason was that the network was interrupted due to the contact between the power cable and the network cable. Repeated experiments were performed to verify and reproduce successfully. Replace the ultra-type 7 network cable and continue the test. The temperature change amount is controlled to fluctuate within the range of 0.002 and meet the specified requirements.

A ground wire and a heat shrinking sleeve were added outside the temperature line, and then the temperature line was subjected to a coupling clip injection for a three-stage 1000V experiment. The maximum temperature change is 0.125, and the large value deviation causes the program to report an over-limit error, and the network is dropped. Adding a 104PF capacitor on the temperature line is invalid, and continuing to increase the capacitor to 106PF is invalid. The existence of junction capacitance between the two lines makes the isolation at high frequencies invalid, and it is concluded that adding capacitance cannot effectively suppress it. Add a ground wire to the temperature line and perform grounding treatment. First, perform grounding at one end, and control the temperature change within 0.050. After grounding at both ends, the change is small and the data is stable.

The shield layer of the shielded cable should be grounded at both ends and connected to the metal case of the product at the same time, but the shield layer on the right side of the shielded cable will increase the interference current flowing through the PCB in the temperature acquisition device after being connected to the case[5]. The final solution is to change the interconnection relationship between the working board of the PCB board and the metal case in the temperature acquisition device, and realize the equipotential interconnection of the working board of the temperature acquisition device in the metal case. The interference current entered by the cable on the left will be bypassed on the outside of the metal case of the computer host, and the interference current will no longer flow to its PCB board. The shield layer on the right side of the shielded cable will not be a problem. The entire temperature is collected The EMC problem of the equipment system is perfectly solved.
The network interruption phenomenon occurred when the level 3 voltage peak of 1kV was performed on the ordinary network cable. Replace the super-type 7 network cable and effectively ground the temperature cable to solve this problem.

3.3. RF conducted immunity solution
The original network cable and untreated temperature line were used for testing. After the ordinary network cable is replaced with a super-category seven network cable, the data is stable and reaches a specified range of change.

3.4. Cable and power line damped sinusoidal transient conduction sensitivity solution
According to the analysis of the previous test data, it was found that the local network communication at 30MHz and 100MHz frequency was interrupted. The local network interruption was solved after replacing the super-type 7 network cable. The data is disturbed when the current probe is injected into the temperature line, and the temperature line is shielded and grounded to be solved [7]. After replacing the ultra-type 7 network cable, the temperature line plus the ground wire at both ends was grounded, and the change amount was stable within 0.005, which met the specified requirements.

3.5. Electric field radiation sensitivity solution
During the test, the problem occurred in the range of 30MHz-200MHz. During the test, the mouse drifted, the keyboard failed, and the network was interrupted. The original mouse and keyboard interface uses the PS / 2 interface. The common mode current generated will interfere with the internal circuit of the mouse and keyboard. The USB 3.0 bidirectional data transmission mode can avoid problems. Logitech's wireless mouse and keyboard can also effectively avoid wiring harness Interference caused by coupling [8].

Because the two ends of the temperature line shield are not grounded, the temperature change is large, and an over-temperature alarm occurs. Add a ground wire for the temperature cable and ground it at both ends. Replace the super-type 7 network cable with a normal network cable. Add a ferrite absorption ring to the power cable to absorb high-frequency radiation interference, which can effectively suppress it.

4. Conclusion
The vacuum tank temperature acquisition system is an important part of the entire vacuum tank system. It is responsible for the temperature acquisition, transmission, monitoring and control. The stability and accuracy of the system are related to the success or failure of the vacuum test. In this paper, the interference immunity capability of the system is tested by simulating interference sources, and an effective solution is obtained through theoretical analysis and rectification verification, which greatly improves the anti-interference capability of the temperature acquisition system and ensures its stability and reliability in normal experiments. The foundation for electromagnetic protection of other systems was laid in the future.

References
[1] Gung-Ho Sun. The summarization of the ship EMC development. Ship Electric Engineering. 2007, 27(5):20-22.
[2] Dong-Lin Su, Bing-Qie Wang, De-Kun. The topside EMC pre-design techniques for the special airplane. Journal of Beihang University. 2006, 32(10):1239-1243.
[3] SHAN Ming, CHOU Yu-xue, HAO Xin-jing. Spacecraft vacuum tank support technology—multi-point, real-time, automatic monitoring and display technology of environmental data [J]. Spacecraft Environmental Engineering. 2008, 25(06): 580-583.
[4] ZHANG Lan-tao, WEI Chuan-feng, BAI Fan-lu. Microbial distribution characteristics in the center of a vacuum tank of a manned spacecraft [J]. Spacecraft Environmental Engineering. 2014, 31(04): 415-419.
[5] WANG Chuan. Research on acquisition and calibration method of thermocouple temperature signal [D]. North University. 2016.

[6] TANG Zhao-ting. Design of Thermocouple Thermometer for Spacecraft [D]. Xidian University. 2011.

[7] ZHANG Ling. Detailed explanation of electromagnetic compatibility (EMC) technology and application examples [M]. BEIJING. Electronic Industry Press. 2014.

[8] WANG Zhi-cheng. Analysis of three factors of electromagnetic interference in spaceborne electronic equipment test [J]. Radio engineering. 2009, 39(06): 49-54.