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# Preliminary Discussion on the Spacecraft Electrostatic Discharge and Standards

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**Abstract.** The antistatic design of spacecraft is an important measure to improve the life and reliability of spacecraft in orbit. The standard and specification of spacecraft electrostatic discharge is an important guarantee for improving the reliability and long life of spacecraft. Analyzes the mechanism of electrostatic discharge effect of spacecraft, introduces the current status of electrostatic discharge test standards and specifications at home and abroad, and looks forward to the development direction of China's spacecraft electrostatic discharge standard, in order to improve the standards and specifications of spacecraft electrostatic discharge.

## 1. Introduction

Space-charged particle radiation is one of the spatial environmental factors that have a significant impact on spacecraft. It produces three important spatial effects, including spacecraft electrostatic discharge effects, single-event upset and blocking effects, total dose effects. Among these three effects, the electrostatic discharge effect on the spacecraft is particularly prominent, which will cause failure or damage of materials, components, components and single machines, and threaten the safe operation of the spacecraft in orbit. Therefore, in order to ensure the reliability of the spacecraft in orbit operation, in the process of design, manufacture, test, flight and return of the spacecraft, it is necessary to fully consider the influence of the electrostatic discharge effect on the spacecraft to improve the environmental resistance of the spacecraft and receptive and on-orbit stability.

Such as NASA and ESA, These foreign space agencies discovered the threat of electrostatic discharge to spacecraft very early. The study of electrostatic discharge effects has been carried out, which has been obtained from a large number of flight tests, various environmental parameters and the influence of surface charging on the instrument on the star, Since the 1960s and 1970s. And then research on antistatic design and reinforcement technology. At the same time, these space agencies have also established relatively complete standards and specifications for spacecraft electrostatic discharge, providing support for designers to design and test live space protection. Although China's research on the electrostatic discharge effect of spacecraft is relatively late, based on the successful experience of foreign countries, it has also explored a series of effective methods for antistatic, and gradually developed relevant enterprise standards and norms, but Electrostatic discharge test standards and specifications at the national or industry level and related space environmental standards and norms are still lacking. The mechanism of electrostatic discharge effect of spacecraft is preliminarily analyzed and the current status of electrostatic discharge test standards and specifications at home and abroad is summarized in this paper. Based on this, the development recommendations of the standards and specifications for electrostatic discharge test of spacecraft are given in China.



## **2. The nature of the electrostatic discharge effect of spacecraft**

The electrostatic discharge effect of spacecraft, also known as the charge-discharge effect, refers to the electrostatic charge accumulation and venting process that occurs when the satellite interacts with the environment such as space plasma and high-energy electrons. The essence of the spacecraft is the mutual interaction between space-charged particles and spacecraft materials effect.

### *2.1. Surface charge and discharge effect*

The surface charge and discharge effect is caused by the interaction between the surface of the spacecraft and the space environment. It is the process of charge accumulation and release in the surface material of the satellite. The spacecraft is orbiting in a low-energy plasma environment that interacts with the surface material of the spacecraft to accumulate charge on the surface of the spacecraft to cause surface charging. The surface potential difference will occur between the surfaces of the spacecraft, the surface and the deep layer, the surface and the satellite ground, due to the dielectric properties and geometrical shapes of the surface material. When this potential difference reaches the discharge threshold, the spacecraft will be triggered, Electrostatic discharge occurs [1], causing electromagnetic interference, surface contamination, etc. If there is an exposed power component such as a solar panel at the location where the electrostatic discharge occurs, a secondary arc may occur and cause a greater risk. In severe cases, even Threats to spacecraft safety caused various on-orbit anomalies[1].

### *2.2. Internal charging effect*

The internal charging effect is another satellite charging effect caused by the radiation of spatial high energy particles that is different from the surface charging effect. It refers to the process of establishing an electric field through high-energy charged particles passing through the surface of the satellite (the energy of these high-energy electrons is mainly in the range of 0.1-7 MeV, which has strong penetrating power), which is transmitted and deposited inside the dielectric material of the satellite component to establish an electric field. When the electric field generated by the deep charge of the medium exceeds the breakdown threshold of the dielectric material, a discharge occurs, and the electromagnetic pulse generated by the discharge may interfere with or even destroy the normal operation of the in-star electronic system, especially the poorly shielded cable, printed circuit board and the thermal protection layer is particularly vulnerable to damage. In severe cases, the entire star will fail [2]. The internal charging effect mainly occurs in the middle and high orbits, many spacecraft on-orbit faults have been classified as internal charging effects in recent year [2].

## **3. Effect of electrostatic discharge on spacecraft reliability**

The electrostatic discharge effect of spacecraft is closely related to the disturbance of space environment. Different track heights will have different electrostatic discharge effects. The space environment is complex and unique. It includes parameters such as charged particles, plasma, electric field, solar radiation, space debris. Each space environmental parameter will have a fatal impact on the spacecraft, resulting in reduced product performance, shortened working life, and static electricity in the orbit. The failure and damage caused by the discharge effect has become one of the main causes of the failure and damage of the spacecraft in orbit.

### *3.1. Different track charge and discharge effects*

In the earth orbit space, there is a great difference in spatial particle radiation, space plasma and high-energy electrons change with height and latitude.

The surface charge and discharge effect is related to the temperature of the plasma. The LEO orbital plasma has a high density and a low temperature. The surface charge and discharge problem of the spacecraft is not serious. It is only necessary to consider the surface charge and discharge problems of a high voltage system exposed to the outside of the spacecraft and larger than 150V. The spatial plasma of the GEO orbits, MEO orbits and polar regions have high temperature and low density, is

often accompanied by geomagnetic sub-explosion activities, therefore, spacecraft operating in these two regions will face serious surface charging problems.

The internal charging effect is related to the energy and total fluence of high energy electrons. High-energy electrons have two distribution peaks of the inner radiation band and the outer radiation band. Spacecraft operating in MEO orbits face the worst-case orbital environment at the center of the outer radiating zone and therefore face the most severe internal charging effects. The GEO orbit is close to the outer edge of the outer radiating zone. When the space environment is disturbed, the high-energy electron flux will change by an order of magnitude, and the electrified electric effect in the orbit can not be ignored. The LEO orbiting spacecraft does not have an internal charging effect.

### *3.2. The effect of discharge on the reliability of spacecraft*

In 1996, the Marshall Space Flight Center (MSFC) published a statistical data on the failure and anomaly of the spacecraft system caused by the space environment. Among the 114 spacecraft faults and anomalies, the charge and discharge abnormalities caused by plasma and high-energy electrons were 41. There are 39 faults caused by particle radiation effects, 12 faults caused by thermal environment, and 11 faults caused by micrometeor/space debris. These four environmental incentives account for about 90% of the total faults. The main influencing factors of anomalies. In particular, the electrostatic discharge effect caused the spacecraft to account for 36% of the total number of failures, which is the biggest killer of spacecraft anomalies. Therefore, for the electrostatic discharge effect and the particle radiation effect, the importance of the reliability work of aerospace products is unquestionable.

The most important effect of the spacecraft's electrostatic discharge effect is caused by electrostatic discharge (ESD). The main hazards of spacecraft surface charge and discharge effects include: the discharge current causes the power supply and distribution system to burn out and short circuit, destroying the satellite energy system; the electrostatic discharge will break through the components and destroy the satellite electronic system; the electromagnetic pulse generated by the discharge will cause the circuit The device flips; the electrostatic discharge will break the surface material and affect the material performance; the satellite charging will cause the structure potential to drift, affecting the measurement system; the surface of the satellite material will also enhance the surface pollution, affecting the performance of the sensor, window glass, lens and so on. The internal charging effect is different from the surface charging. Internal charging and discharging often occur inside the in-star electronic system, which is very close to sensitive devices, such as printed circuit boards. The surface charge occurs on the surface of the satellite, and the discharge pulse it causes must be coupled to the internal sensitive component, but will decay due to the presence of the coupling factor. Compared with the surface charging, the internal charge and discharge pulse is directly coupled into the electronic system with almost no attenuation, so the internal charging is more harmful to the in-star electronic system. The occurrence of internal charging is often accompanied by a large space radiating environmental disturbance event, and the probability of occurrence is relatively small, but once it occurs, the impact on the satellite will be fatal.

### *3.3. Antistatic Strengthening Technology*

In order to resist the impact of harsh environment on spacecraft materials, components, subsystems, etc. during on-orbit operation, antistatic reinforcement is required. The criterion for surface discharge effect reinforcement design is to control the grounding of the surface material and make the surface potential of the aerospace product within a safe range. Its guiding principle is to select materials with good electrical conductivity and ensure that the surface material is well grounded. The starting point of the foundation. Therefore, its design focus includes three points: surface material control, grounding requirements and capacitance requirements. The criterion for the internal charging effect reinforcement design is to reduce the discharge occurrence as much as possible by carrying out the deep charge and discharge protection design; however, when the discharge is unavoidable, the damage caused by the discharge should be reduced as much as possible. Therefore, the goal of the internal

charging effect reinforcement design is to reduce the deposition current by shielding measures, limit the electric field between the insulating material or the isolated conductor and the local ground, and select the material with high conductivity as much as possible.

#### **4. Status of electrostatic discharge standards for spacecraft at home and abroad**

With the development of spacecraft technology, long life and high reliability have become the basic capabilities that future spacecraft need. International standards organizations and aerospace powers have developed a series of international standards, national standards and industry standards, which provide a good description of the threat and protection design of electrostatic discharge to guide spacecraft design and ground test. These standards are mainly formulated around the antistatic reinforcement of spacecraft, which can solve the problems of failure or damage of materials, components, components and single machines caused by electrostatic discharge. Aerospace practices over the past half century have shown that spacecraft electrostatic discharge standards (or specifications) have played an important role in the design and operation of spacecraft.

##### *4.1. Foreign spacecraft electrostatic discharge standard*

NASA has released the Spacecraft Charge Effect Evaluation and Control Design Guide (NASA TP-2361) since 1984. This document has been the authoritative document for GEO's spaceborne analysis and protection design. It is used in GEO spacecraft live analysis and protection design. Play an important role[3]. In 2007, NASA released the Design Standard for Low Earth Orbiting Spacecraft (NASA-STD-4005), which provides a design standard for high-voltage space energy systems (>55 volts) that must be used in low-Earth plasma environments, followed by The "Low Earth Orbiting Spacecraft Design Manual" (NASA-HDBK-4006) was released, which provides a detailed design for the charging of low-Earth orbit spacecraft and provides design guidance for NASA-STD-4005[4]. In 2011, NASA released the NASA-HDBK-4002A "Guide to the Protection of Spacecraft's Charge Effect", which became an important basis for the current US spacecraft's electrification protection design[5]. The Space Engineering - Spacecraft Charged (ECSS-E-ST-20-06C) developed by European ESA is the European standard for the design, protection and testing of spacecraft charging effects. ESA has also released space electrostatic discharge sensitivity test. Standard methods such as the method and the environmental induction effect of electrostatic behavior of aerospace systems, how to carry out spatial electrostatic discharge sensitivity test and space electrostatic effects are described. Japan JAXA has developed the "Design Standard for Charge and Discharge" (JERG-2-211A), which is based on ECSS-E-ST-20-06C and specifies the surface charge simulation analysis and protection design[6]. In addition, the ISO standard "Space System - Solar Panel - Spacecraft Electrostatically Induced Electrostatic Discharge Test Method" (ISO-11221) drafted by Japan, the surface charge calculation is described in the appendix, and the surface is given. Software example of charging effect calculation. The relevant content of these standards represents the advanced level of current international charge and discharge tests, and can be better used in the design and development of spacecraft.

##### *4.2. Domestic spacecraft electrostatic discharge standard*

Domestic and spacecraft static-related standards are mostly for the electronic component level and electronic products to develop electrostatic protection requirements and electrostatic discharge related factors test methods, these standards mainly focus on electrostatic protection of electronic components and stand-alone products, as well as some static electricity The protection standard is a universal electrostatic protection standard, which mainly includes: GB/T 1410-2006 "Test method for volume resistivity and surface resistivity of solid insulating materials", GB/T 17626.2-2006 "Electromagnetic compatibility test and measurement technology electrostatic discharge resistance Disturbance test", GB/T 32304-2015 "Aerospace electronic products electrostatic protection requirements", QJ 1693-89 "electronic components anti-static requirements" and so on.

The standards related to spacecraft charging and discharging are mainly GB/T 15463-2008 "Static safety terminology", GB/T 32452-2015 "Spacecraft space environment terminology", QJ 20409-2016 "Spacecraft surface material charging and discharging characteristics parameter test method" and QJ 20422.1-2016 "Spacecraft component environmental test method Part 1: Surface charge and discharge test". There are also some enterprise-level and below standards, such as the yard standard of the Spacecraft Five Institutes, "Satellite Surface Discharge Effect Test Method", "High-altitude Spacecraft Surface Charge and Discharge Protection Design Guide", "Spacecraft Component Environmental Test Method Part 8" : Magnetic layer substorm environment surface charge and discharge test" and The company standard of Beijing Institute of Spacecraft Environment Engineering, "Spacecraft solar cell array electrostatic discharge test method", "Spacecraft surface charging effect simulation analysis requirements", "Spacecraft surface charging effect simulation analysis method" and so on.

Since the surface charge and discharge problem of spacecraft is one of the main reasons for the anomaly of the spacecraft in orbit, it is not uncommon for the spacecraft to experience electrostatic discharge in the early stage. The research on the electrostatic charging and discharging effects of spacecraft was carried out abroad earlier, and relevant standards and norms were formed according to the research results to guide the antistatic design of spacecraft. China started relatively late. The domestic research on the electrostatic discharge effect of spacecraft began in the mid-1980s. The first unit to carry out satellite charging and discharging experiments was Beijing Institute of Spacecraft Environment Engineering, National Space Science Center, CAS, Lanzhou Institute of Physics.

They have also achieved many results in the mechanism of electrostatic discharge effects, simulation analysis and ground test [2]. In particular, Beijing Institute of Spacecraft Environment Engineering is the first to break through the three-dimensional simulation method of charged medium in arbitrary configuration under complex boundary conditions, and developed the internal simulation analysis software ATICS (Assessment Tool of Internal Charging for Satellite) in China. In the process of external cooperation of satellites such as NIGCOMSAT-1 and PAKSAT-1R, the supervisory party entrusted the simulation analysis and risk assessment of the charging effect in the spacecraft, which was well received by the supervisory party. Although China has made certain achievements in the study of electrostatic discharge effects, it is still lacking in standards and norms, and there are no relevant top-level standards and norms. In the research, China usually draws on foreign standards and norms, but the adaptability of key indicators needs to be studied.

## 5. Future prospects

The failure and damage caused by the spacecraft's on-orbit charging and discharging effect has become one of the main causes. At present, there is no unified standard specification for spacecraft electrostatic discharge protection design. In the spacecraft design, ground simulation test evaluation, on-orbit fault analysis and on-orbit prediction and early warning process, each unit carries out its work according to its own understanding, lacks a unified reference standard specification to constrain, and aerospace material space environment adaptability test method. The relevant standards are also relatively scarce.

In addition to the research and work on the mechanism, test and evaluation technology of the spacecraft's electrostatic discharge effect, the standards and specifications related to the electrostatic discharge of spacecraft cannot be delayed. First, improve the national standards and norms related to the electrostatic discharge source of spacecraft, and formulate relevant national standards for solar cosmic rays, galaxy cosmic rays, and space plasma on the basis of existing environmental standards and norms related to electrostatic discharge of spacecraft. Standards for solar electromagnetic radiation, earth radiation belts, etc. The second is to learn from NASA, ESA and some of Japan's protective design standards and impact assessment standards to improve the surface charge and discharge effects and internal charging effects standards and specifications. Establish relevant standard specifications and general standards and specifications for surface simulation tests of spacecraft surface charge and discharge effects and internal charging effects, and fully test and verify at the

design stage to ensure that space materials can adapt to them without adequate application of antistatic design. Space environment.

Beijing Institute of Spacecraft Environment Engineering has a series of space charging and discharging environmental test equipments such as large-scale geomagnetic substorm charging and discharging test equipment, 1.2m surface charging and discharging equipment, plasma charging and discharging equipment, and participated in a number of satellite model discharge verification tests. It has a group of experts and technicians who have been engaged in the analysis and research of spacecraft charging effects for a long time, and has conducted many exchanges on electrostatic discharge tests with internationally advanced units with relevant test technology (such as Japan KIT, France ONERA, etc.). Since the "Eleventh Five-Year Plan", the research on electrostatic discharge of spacecraft in Beijing Institute of Spacecraft Environment Engineering has been supported by national defense basic scientific research projects, technical basic projects, key technical research projects, national defense 973, etc., and has one set of software copyrights and corresponding patents. The results have been analyzed and evaluated many times on the internal charging effects of key components such as Nixing and Baxing, and good results have been achieved. In recent years, Beijing Institute of Spacecraft Environment Engineering has led and participated in the preparation of several GB, GJB, and QJ standards, including Spacecraft Space Environmental Terminology, Spacecraft Thermal Control Coating Test Method Part 7: Vacuum-Electronic Irradiation Test, and Aerospace Environmental testing methods for components (Part 1: Surface charge and discharge test), etc., with the ability to write the corresponding standard specifications, I believe that in the future, we can continue to deepen theoretical, methodological and application research, and establish environmental national standards related to electrostatic discharge. Contribute to the national military standards or industry standards related to the test.

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