Study on effect of space environment on surface charging of spacecraft

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Abstract. The effects of space environments on the surface charging of spacecraft include space plasmas environment and space magnetic sub-storm environment. The investigation on these space environments is essential for analysing spacecraft surface charging mechanism, Electrostatic Discharge (ESD) safety and for research on deep dielectric charging and discharging in spacecraft. Furthermore, analysis of charging mechanism can provide basic guidelines to ESD protection for spacecrafts, which is important to the safety of spacecrafts.

1. Introduction
In modern times, the battlefield environment is the complex of sea, land, air, space, electromagnetism, in which the space means being preponderant in spaceflight domain. The development and martial application of spaceflight technology and equipment have impacted the modern wars deeply. As we know, 70 satellites were used in Gulf War, which reached to 50 respectively in Kosovo War and Afghanistan War. They offered all-sided information support and guaranteed to equipments in the sea, land and air.

In 1960s, along with the running of geostationary orbit satellites, many failures appeared in the spacecraft in and abroad, which interfered the functions. The unconventionality could not be explained correctly in the near 10 years. By analyzing the failures happened aboard, it is known that the space environment is the main causation rather than other reasons. And in the failures caused by space environment, 75% were relative with spacecraft’s surface charging and discharging. The ratio reached to 83% in the failures of satellites of our country. The hazard can be seen clearly. The process was simulated and demonstrated in the laboratory by De Forest, proving that static was the main reason for the failures.

In such case, it is very necessary to research the spacecraft’s surface charging in the space environment for military affairs. Furthermore, it is very important for spacecraft’s anti-jamming ability, which means spacecrafts can play more important roles in modern wars.

2. The space environment influencing spacecraft’s surface charging
Spacecraft runs on many kinds of orbits and faces many space environment basics, including electromagnetic radiation from the sun, neutral atmospheric globosity ionosphere, space plasmas globosity magnetic field, space electrification particle radiation and so on. These basics work on the

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spacecraft running on the orbit by influencing the materials and electron devices of the spacecraft. And then the safety of the spacecraft is impacted.

In all basics, space plasmas environment and magnetospheres sub storm environment influence spacecraft’s surface charging intensively. While running in such environment, the spacecrafts act with the plasmas, and surface charging/discharging effect come forth[1-2]: Potential differences between the near surfaces, surface and deep medium, surface and terra appear because of the differences in dielectric properties, light and geometry. Along with the rise of potential differences, charging by corona, flash-over, breakdown, and EMP appears. Besides, grounded system may immit the charging current into the electron system which causes the failures. Even the whole spacecraft would be in danger, as shown in figure 1.

![Figure 1. Charging and discharging on spacecraft’s surface.](image)

### 2.1 Space plasmas environment
Plasma sphere starts from about 60 km upside from the ground. The density, component, and energy of the plasmas change as the altitude changes. While sun activity is in the range of 60 km~3000 km, the relation is shown in table 1[3-4].

### 2.2 Space magnetic sub storm environment

| altitude (km) | density (cm$^{-3}$) | energy (keV) |
|---------------|---------------------|--------------|
| 60            | $2 \times 10^2$     | 0.05         |
| 85            | $1 \times 10^4$     | 0.05         |
| 140           | $2 \times 10^5$     | 0.08         |
| 200           | $5 \times 10^5$     | 0.19         |
| 300           | $2 \times 10^6$     | 0.22         |
| 400           | $1.5 \times 10^6$   | 0.23         |
| 500           | $1 \times 10^6$     | 0.24         |
| 600           | $6 \times 10^5$     | 0.25         |
| 700           | $4 \times 10^5$     | 0.26         |
| 800           | $3 \times 10^5$     | 0.27         |
| 900           | $2 \times 10^5$     | 0.28         |
| 1000          | $1 \times 10^5$     | 0.30         |
| 2000          | $2.5 \times 10^4$   | 0.35         |
| 3000          | $1.5 \times 10^4$   |              |
| 10000         | $2 \times 10^3$     | 1.00         |
Earth’s magnetosphere is the finite space area which is restricted and inhibited by solar wind and interplanetary magnetic field and controlled by geomagnetic field.

Magnetosphere sub storm is regularly disturbed which occurs in magnetosphere. The disturbance to magnetosphere occurs while stored energy about $1 \times 10^{14} - 1 \times 10^{15}$J is released by it in about 1000 s.

When magnetic sub storm occurs, the plasma of high density (10 cm$^{-3}$ –100 cm$^{-3}$), low energy (less than 1 eV) in geosynchronous orbits environment were replaced by that of low density (less than 1 cm$^{-3}$), high energy (1 keV~50 keV). Statistic shows that sub storm can be observed at 30% of the time, and 8%~10% of them can influence the spacecraft in geosynchronous orbits. With the environment data basic obtained by ATS-5, ATS-6, SCATHA (STP P78-20), the USA presents the average and extremely hard condition plasma environment in geosynchronous orbits for design and evaluation by computer [5].

**Table 2.** The average plasma environment in geosynchronous orbits while magnetic sub storm occurs.

| model | ATS-5 | ATS-6 | P78-20 |
|-------|-------|-------|--------|
| particle | electron | ion | electron | ion | electron | ion |
| density (cm$^{-3}$) | 0.80 | 1.30 | 1.06 | 1.20 | 1.09 | 0.58 |
| current density (nA·cm$^{-2}$) | 0.065 | 5.1 | 0.096 | 3.4 | 0.115 | 3.3 |
| average energy (keV) | 1.85 | 6.8 | 2.55 | 1.20 | 2.49 | 11.2 |

**Table 3.** The extremely hard condition plasma environment in geosynchronous orbits while magnetic sub storm occurs.

| particle | electron | ion |
|----------|----------|-----|
| density (cm$^{-3}$) | 1.12 | 0.236 |
| average energy (keV) | 12 | 29.5 |

3. **The main influence factors and complexion of spacecraft’s surface charging**

3.1 **While magnetism serenity without illumination**

In magnetism serenity, the spacecraft is surrounded by plasma whose electron energy is about several eV. The high energy ion is so unwonted that it is out of consideration. Suppose that the speed distributing of the electron and ion abide Maxwell distributing, their average speed is [6~8]:

$$v_e = \left(\frac{8kT_e}{\pi m_e}\right)^{1/2}, \quad v_i = \left(\frac{8kT_i}{\pi m_i}\right)^{1/2} \quad (1)$$

$v_e$, $v_i$ stand for the average speed of the electron and ion; $T_e$, $T_i$ stand for the temperature of the electron and ion; $m_e$, $m_i$ stand for the quality of the electron and ion; $k$ stands for Boltzman constant, the cost of which is $8.617 \times 10^5$ ev °C$^{-1}$.

While the ion stands for proton, $T_e \approx T_i$, because the quality of proton is about 1840 times of that of electron. So

$$\frac{v_e}{v_i} = \left(\frac{m_i}{m_e}\right)^{1/2} \approx 44 \quad (2)$$

It means that as the densities of electron and ion are pretty much the same thing, the electron falling on the surface of the spacecraft is much more than that of the ion. The electron piles up at the surface of the spacecraft so that the negative potential is formed. When it is in magnetism serenity, the energy
of electron on the GEO is only about 1 eV, the surface potential of spacecraft in the shadow of the globosity is only some volts and it does not work on the regular operation.

3.2 While magnetism serenity with illumination

While spacecraft gets in the illumination area, the photoelectron will be excited by photons. Although the energy of photons is quite low, its speed always exceeds the plasma. The photoelectron plays an important role because the amount is big. The photoelectron can get out of the surface when it is irradiated by the sun. When the summation of the ion current, electron current and photoelectron current is around zero, the surface in the irradiation gets in balance, namely

\[ J_p + J_{ph} = J_e \]  \hspace{1cm} (3)

There \( J_p, J_e \) and \( J_{ph} \) stand for the ion current, electron current and photoelectron current which arrive at the space of spacecraft.

Ignore the ion current \( J_p \), the balance potential can be gotten as

\[ \varphi_s = \frac{kT_e}{e} \ln \frac{J_e}{J_{ph}} \]  \hspace{1cm} (4)

While magnetism serenity with illumination, on the GEO, \( J_e \approx 1.5 \times 10^{-11} \text{ A (cm)}^{-2}, J_{ph} \approx 5.4 \times 10^{-10} \text{ A (cm)}^{-2}, \) so the potential can be estimated as some positive volt.

3.3 While magnetic sub storm

While in magnetic sub storm, thermal plasma immits to the GEO, and the scope of the energy is from some thousand to some ten thousand. \( J_e \) can reach to 1 nA cm\(^{-2}\). \( J_p = (1/20-1/50)J_e \), so the balance potential can be deduced as

\[ \varphi_s = (\text{(-3)} \sim \text{(-4)})E_e / e \]  \hspace{1cm} (5)

As that, \( E_e \) can be 1 keV ~ 30 keV, so the balance potential will be estimated to be some thousand votes to some ten thousand.

4. Conclusion

The paper summarized the investigations on spacecraft surface charging, in which the space environment resulting in surface charging of spacecraft was mainly studied. The investigation can provide the basic to spacecraft ESD protection, which is important to the safety of spacecraft.

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