ANOMALY ATTRIBUTED TO LOW EARTH ORBIT PLASMA ENVIRONMENT

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Abstract

This paper reports an anomaly on orbit of the solar array temperature measuring attributed to electrical ground floating resulted from LEO plasma environment for Chinese Meteorological Satellite. In order to determine the reason and repeat the anomaly on orbit, several simulating tests had been done in the ground. By analyzed the environments and its effects on orbit especially plasma effects on LEO spacecraft, the negative floating potential attributed to plasma was concerned. The potential would make the reference zero level of telemeter down to about -1V in the ground loop. Testing on simulating electrical ground floating for telethermomter repeated the anomaly and the data accorded with space. The results have being used for engineering improvement.

Introduction

The expectations to operating life and reliability of spacecraft have become increasing along with various spacecraft being launched. As we know, the natural space environments are characterized by many complex and specific phenomena that will be harmful to spacecraft. The effects of these phenomena will impact spacecraft design, development, and operations, thus understanding the space environment effects and the mechanism of spacecraft interaction with space environments are essential for spacecraft to accomplish overall mission in space[1].

Now, more and more new spacecraft being launched are placed in the region between 100 and 1000km termed Low Earth Orbit (LEO). These spacecraft are subjected to a variety of interactions with the orbital environment and notables among these are effects related to the plasma environment. During times of geomagnetic storms in the Geosynchronous(GEO), the plasma environment has charged spacecraft surface to a high level voltages, which may result in spacecraft systems anomalies. However, the LEO plasma is typically of much lower energy and higher density. Although the LEO spacecraft can not be charged to a high level voltages by plasma environment such as it is in GEO, the effects related to plasma environment are various, particular in floating potential, parasitic current losses, ion sputtering, and others. These effects that related to LEO plasma environment would make space science experiment and data detection difficult if they were not considered sufficiently in the engineering design[2].

Been launched in 1999 and was placed in a polar orbit, Chinese Weather Satellite are working well up to now. An anomaly event appeared after the satellite operating on orbit soon, according to the data from telethermomter could not estimate the true temperature of solar panel correctly. The data indicated that the temperature of solar panel during sunlight lower than the temperature of solar panel during it was in shadow, although the solar array output power was normal. Before launched, the satellite had been passed a series of strict ground testing items, and any anomaly did not experienced. The preparatory anomaly analysis addressed the reasons to the electrical ground loop damage during the satellite launching and starting to work on orbit or the effects caused by LEO plasma environment, especially the later were taken into account first. In order to determine the reason resulting in the anomaly and repeat the phenomena on orbit, charging/discharging experiments, electrical ground floating experiments had been done in laboratory. Results of grounding experiment indicated that the absolute value of measuring data accord with the data of orbit when the solar panel sample during sunlight and shadow if make the electrical ground of temperature measuring circuit floating below the absolute ground (it means the structure ground in satellite) –1.5V. In despite of other factors are being considered, the anomaly that attributed to negative floating of solar panel ground induced by LEO plasma environment is a reasonable explanation, and the improvements against it have been adopted and applied to others satellite.

The purpose of this paper was to report the experiments and explanations related to the anomaly, and make the spacecraft engineers to pay more attention to the LEO plasma environment effects on spacecraft.

LEO Plasma Environment and Floating Potential

The process of spacecraft interaction with LEO plasma environment is complex, the effects related to plasma environment involve many aspects, such as surface charging, floating potential, parasitic current losses, ion sputtering, arcing, contaminants accelerating, and many research works have been done in these fields. This paper will concentrate on discussing the floating potential, which is related to LEO plasma environment and how it make effect on spacecraft.

LEO plasma environment

Low Earth Orbit（LEO） is an orbit with altitude in the range from 100 to 1000km. The characteristics of LEO plasma environment are their lower energy and higher density, the electron/ion density is about 10^2—10^6/cm^3，the electron impact energy is about 0.3eV, and the ion impact energy is 5eV. In LEO plasma, the electrons and ions approximately have equal number density, it is equivalent to supply a neutral current in the surface charging process, so the LEO spacecraft couldn't be charged to a high level voltages in this plasma environment.

On the other hand, in LEO plasma, because of its much higher density, the current flux of reached spacecraft surface much larger than that of the secondary currents caused by secondary electron emission, back scattering and photoelectron emission. The LEO spacecraft will be charged to high potentials when it passes through the polar region and encounters an auroral electron environment[3].

Negative floating potential of LEO spacecraft

A spacecraft in the LEO plasma is subject to a current flux of the ions and electrons striking its surface. Although the electron current is equal to ion current in a plasma, in LEO，the spacecraft's orbital velocity, v_0 is larger than the ion thermal, v_{it}， but less than the electron thermal velocity, v_{et}. As a result, the electrons will be able to reach all surfaces of the spacecraft but the ions can't. Since the plasma is quasi-neutral, the spacecraft will charge to a negative potential, V_f when it facing the ram of the plasma flow, until the electrons are limited by an electrostatic repulsion.

As mentioned above, if secondary current is ignored, an equilibrium potential on spacecraft surface is established when the electron current, I_e is balanced by an equal ion current, I_i. The equilibrium potential is floating potential, V_f relative to the LEO plasma. I_e, I_i is given by

$$I_e = e n_i v_0 A_i \qquad (1)$$

$$I_i = (1/4)\, e n_e v_{et} A_e \exp(eV/kT_e) \qquad (2)$$

Where V is the potential of the spacecraft, measured relative to the plasma potential, A_i, A_e is ion and electron collection area respectively, e is elementary charge, n_i, n_e is ion and electron density respectively, T_e is electron temperature and k is Boltzmann's constant. When $I_e=I_I$, the floating potential is given by

$$V_f = -(kT_e/e)\ln(4 n_i v_0 A_i / n_e v_{et} A_e) \qquad (3)$$

For a solar array, considering the case when the solar panel is normal to the plasma flow, the collecting areas of ion and electron will be essentially equal, i.e. $A_i=A_e$, since $v_{et} >> v_0$, so the array potential will float about -1V from equation (3).

For an actual spacecraft, this means that if there is a floating potential between the solar array and spacecraft structures which typically provide the electrical ground, a floating ground is exist. In general, a floating ground will makes some parameters detecting on orbit difficult.

Experiments and Procedures

The purpose of the experiments is to discover what's the reason to induce the anomaly of solar panel temperature measuring by ground simulating tests. The sample of solar array used in the experiments has same electrical state and structures as the actual solar array on orbit, the size of sample is 200mm×300mm×20mm, the solar panel substrate is carbon fiber aluminum honeycomb, the top side is solar cells, and the back side are wiring circuit and coating with white paint for thermal controlling. Two temperature sensors are placed below the solar cells for detecting the temperature of solar panel.

Solar array charging experiment

Testing was done in the SCF-900, the combined spacecraft charging ground simulation facility at Lanzhou Institute of Physics[4]. The test chamber offers a cylindrical volume 0.9m in diameter by 1.6m long. The background pressure in chamber is 2×10^{-4}Pa. The facility can simulate plasma environment, geomagnetic storms charging environment and auroral electron environment by a hollow cathode discharge plasma source and two dispersing electron guns. During the testing, the solar array sample is placed in the middle of the chamber, the back side of solar panel is exposure to the plasma source and electron guns, and the side with solar cells facing a sun simulator. The distance between the solar array sample and sun simulator or plasma source/electron guns is approximately 0.6m. The experiment configuration is illustrated as figure 1.

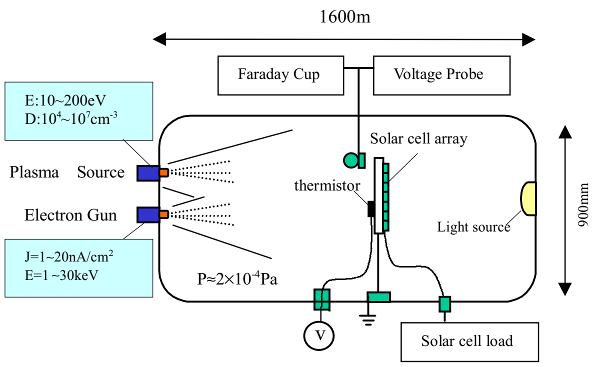

Figure 1. Configuration of solar array charging experiment

Electrostatic discharging test

The electrostatic discharging (ESD) evaluating test system for spacecraft electronics is used for observing and surveying the variation of temperature sensor's temperature coefficient[5]. Two types of ESD simulators, a arc ESD simulator and a sphere-flat capacitor ESD simulator were used in the test, the ESD pulses were injected to the circuit loop of temperature measuring by the methods of single point injection, radiation field, and capacitance coupling injection. The output data were recorded when the ESD voltages changed from low level to high level.

Electrical ground floating experiment

Since the electrical ground of solar panel is connected with temperature measuring circuit and conducted to spacecraft ground by a 68kΩ resistance. Considering some unexpected errors are possible on orbit, the negative floating potential of solar panel may effect the telemetering data. In order to simulate the effect of negative floating potential, an electrical ground floating experiment was designed as figure 2. For testing convenience, a dry battery was in series to the circuit loop and made the solar panel electrical ground floating below the spacecraft ground –1.5V. The difference between the experiment circuit and the actual circuit on orbit only is –1.5V voltage source in series to the ground loop.

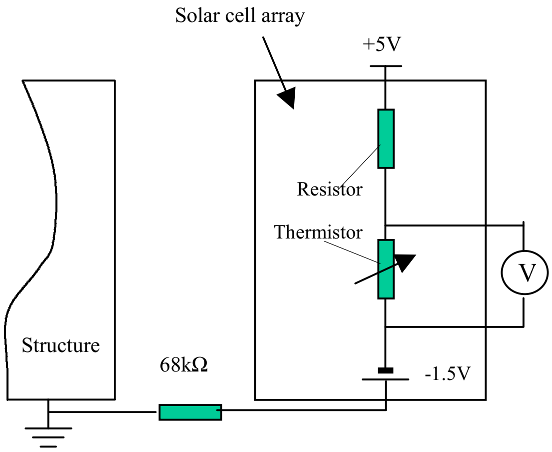

Figure 2. Circuit diagram of electrical ground floating experiment

Results and Discussion

Solar array charging experiment

The output voltages corresponding to the solar array temperature under sunlight and shadow were measured for three cases, the first, no electrons and plasma environment in chamber, secondly, charged the solar back side to approximately –400V voltages, and the third, the solar array immersed the simulating plasma environment. The results are shown in the figure 3 and presented in graphical form in curves 1, 2, and 3 respectively.

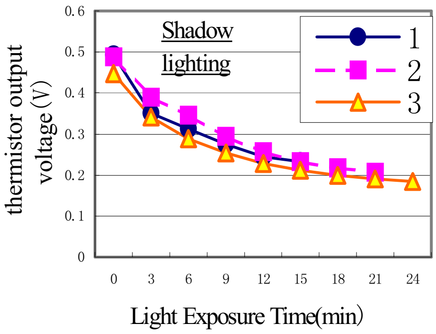

Figure 3. The results of solar array charging experiment

As showing in figure 3, the output data were consistent under three testing conditions and any anomaly was not appeared. The experiment results indicate that the plasma environment and surface charging can't induced the anomaly of solar array temperature measuring if the electrical ground floating of measuring circuit loop is absence.

Electrostatic discharging test

Under the electrostatic discharging testing, the output data of solar panel temperature measuring voltammeter was overflow during a electrostatic discharging pulse was injected in the wiring circuit, and the data were normal when the

ESD pulse coupling stopped. By the testing, it is clear that space electrostatic discharge can't change the negative temperature coefficient of temperature sensors to the positive coefficient, and the reason which the anomaly attributed to the reverse of temperature sensor's temperature coefficient induced by ESD can be left out of account.

Electrical ground floating experiment

The experiment results are showed in figure 4 (in solid line). Obviously, the result difference with other experiments is the value of voltage less than zero voltage. In the testing, although the temperature sensor presented a negative temperature coefficient as like it in other tests, the absolute value of measuring voltage present a positive temperature coefficient (line of dashes in figure 4). If the negative symbol was unconsidered by the telemetering device, this means that the solar panel temperature under sunlight is lower than it is in shadow according to the test data, and the phenomenon is agreement with the anomaly on orbit.

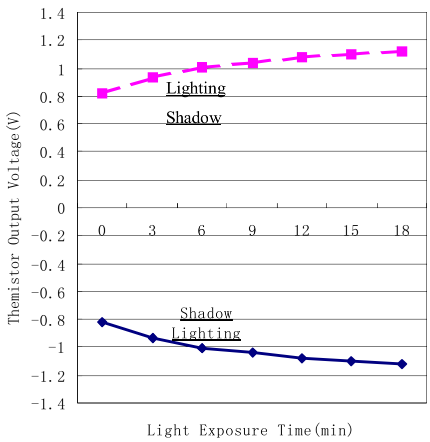

Figure 4. Electrical ground floating experiment data

From the test results, if the ground loop of the measuring circuit was changed or the telemetering circuit was not read the negative value correctly, the negative floating potential of solar array induced by LEO plasma environment may affect the correct distinguish of telemetering data. The explanation that the anomaly attributed to the negative floating potential was reasonable and it should be taken into account.

Conclusions

It is possible for a spacecraft in Low Earth Orbit to have significant interactions with ambient plasma environment. Understanding the plasma environment and its effects on spacecraft are important for spacecraft design, development, and operation.

The experiments and theoretical analysis results indicate that the surface charging and electrostatic discharge pulse of solar array in LEO satellite don't effect the characteristic temperature coefficient of solar panel temperature sensors. It is possible that telemetering data of solar array temperature will give a wrong explanation due to the negative floating potential induced by the LEO plasma. Careful attention must be given to the plasma environment effects during spacecraft design. In order to do this, spacecraft ground wiring loop should be improved and optimized, in addition, the output level of telemeter should be increased from 0~5V to 0~12V, and the output voltage value below 1V should be avoid as far as possible for some important measuring data.

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