Preliminary Study on Sustained Arc due to Plasma Excited by Debris Impact on the Solar Array Coupon

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Abstract

Recently solar array has become higher in potential and larger in capacitance. Therefore, possibility of collision between space debris and enlarged solar array has been pointed out. Actually, a lot of debris and dust impacts were confirmed on fuselage of retrieved satellite SFU and solar array paddle of satellite Eureca. If space debris collides with solar array of an orbit satellite, it causes generation of high-density plasma by debris impact induced dielectric breakdown of satellite component and the phenomenon called discharge. This discharge short circuit and current does not flow into a load of the satellite. And the very worst event by this discharge is operational end of the satellite. However, any events of discharge phenomenon by debris impact cannot be yet confirmed. But we cannot ignore such possibility of discharge by debris impact.

The purpose of the present paper is to investigate discharge condition due to debris impact which yields us reduction of electric power of solar array, and to reduce influence of the impact on satellite missions. In this study, a solar array coupon was tested under hypervelocity impact in which a projectile was launched by a two-stage light gas gun installed in KIT. As a result, we verified discharge event in the hypervelocity impact ground test.

Introduction

Recently, long duration of operation of spacecraft, higher in power, higher in potential, and the solar array especially higher in potential are advanced for the actualization of the large space platform for industrial use in space such as the space factory, the space hotel, and solar power satellite. The use of high power in future space missions calls for high voltage power generation and transmission to minimize the energy loss during power transmission and the cable mass. The satellite at life end and upper stage of a rocket and the parts and fragment from them are called space debris. It is suggested that the possibility of collision between space debris and solar array is large. Moreover, the possibility of collision will increase further when the future solar array is operated for the long duration.

If space debris collides with solar array of the satellite, it causes generation of high-density plasma by debris impact induced. Then plasma grows up by surrounding plasma and the phenomenon called discharge. Moreover, it is possible for the debris to wear plasma and to collide. For example, the discharge phenomenon called sustained arc as a cause of trouble of geostationary satellite Tempo-2 is suggested[1]. But it is not cause debris

impact.

This discharge shorts circuit and current does not flow into a load of the satellite. And this fact yields us reduction of electric power of solar array, and the impact influences on satellite missions. Actually, a lot of debris and dust impacts were confirmed on fuselage of retrieved satellite SFU and solar array paddle of satellite Eureca. Generation of the discharge phenomenon by debris impact is not yet confirmed, but such possibility will be progressively large.

Solar array coupon

Figure1 shows the solar array coupon used in this study. This solar coupon consists of only P electrodes and the current will not flow between the P electrodes. Moreover, symbol of A~H shown in Fig.1 stand for each pair of cells. Voltage is applied to cell 2, while it is not applied to cell 1. Next, the cross section of the solar array coupon is shown in Fig.2. Kapton (insulator) is put on the 3.2mm thick Al substrate. And P electrode, cell and coverglass are stacked on the kapton as shown in Fig.2. Moreover, the cable is connected with P electrode and it bonds with the adhesive that is called RTV. Kapton is used insulator between substrate and cell.

Fig.1 Solar Array Coupon

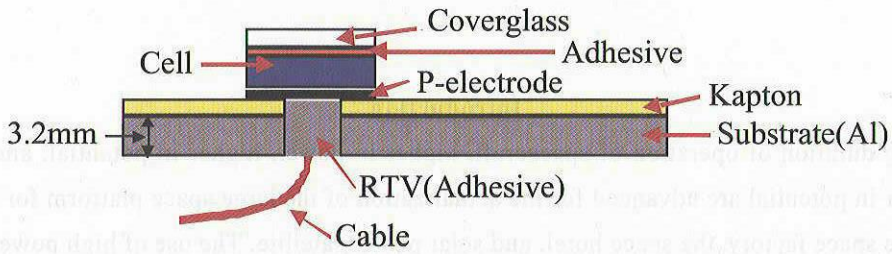


Fig.2 Structure of Solar Array Coupon

Experimental set-up and Experimental condition

Hypervelocity impact tests in this study were conducted using a two-stage light gas gun, installed at hypervelocity impact test facility, laboratory of spacecraft environmental interaction engineering, Kyushu Institute of Technology. A smokeless powder charged in a powder chamber with a black powder is ignited and a pressure in the powder chamber rises. A piston is pushed by the pressure of the combustion gas and compresses a light gas which is charged into a pump tube preliminarily. The light gas is compressed suddenly by a reflection of a shock wave in the pump tube, ruptures a diaphragm, flows into a launch tube and accelerates a

projectile at once. The projectile is accelerated in the launch tube by the light gas which is compressed by the progress of the piston after rupture of the diaphragm and projected into a vacuum chamber. The piston is stopped for a taper section which is located between the launch tube and the pump tube. The projectile simulated debris is cylinder's polycarbonate (PC) with the diameter 10mm and mass 1g. The experimental parameters are vacuum value 533MPa, smokeless powder 45g, light gas (helium) 0.8MPa and diaphragm 30MPa. It experimented four times by the parameters and the average velocity became 4.2km/sec.

The solar array coupon of Fig.1 was used as target and set up in a chamber. An external circuit that simulated the electric power of an actual solar array was connected with the coupon. Moreover, high-speed camera was used high-speed photography before and after the collision of projectile. Velocity, the discharge current, and the discharge voltage of the projectile were measured by using four oscilloscopes in this study. The current source used solar array simulator (SAS) that had high-speed respond as shown in Fig.3. In the experiment, the voltage was set to 60V and the current was set to 1.3A. The current does not flow because this coupon is P electrode only. And it is the cell with voltage. In this condition, when the projectile collides with coupon, the discharge is generated between cell and substrate or between cells. This phenomenon is called short circuit. At this time, the blocking diode of Fig.3 is used to restrict the direction of the current for one direction. The current flowing in this external circuit is measured by the three current probes (CP1～CP3) as shown in Fig.3. The current probes CP1, CP2 and CP3 are employed to judge short circuit, in the whole circuit, short circuit between cell and substrate, short circuit between cells, respectively.

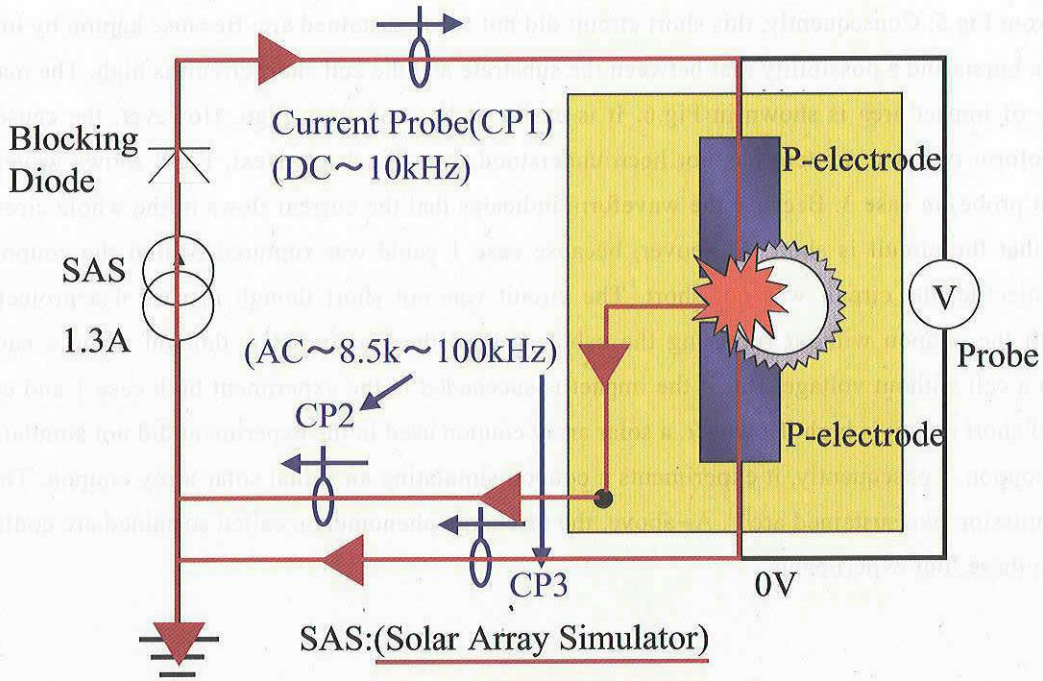


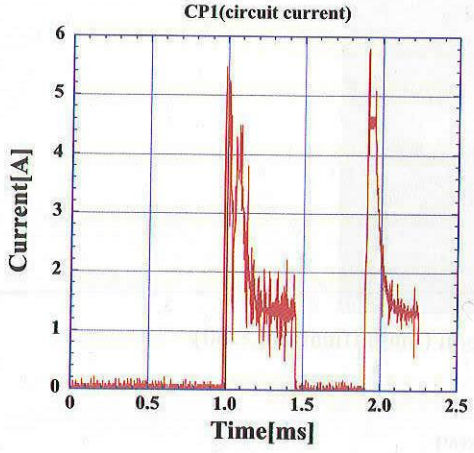
Fig.3 External Circuit

Experimental results and discussion

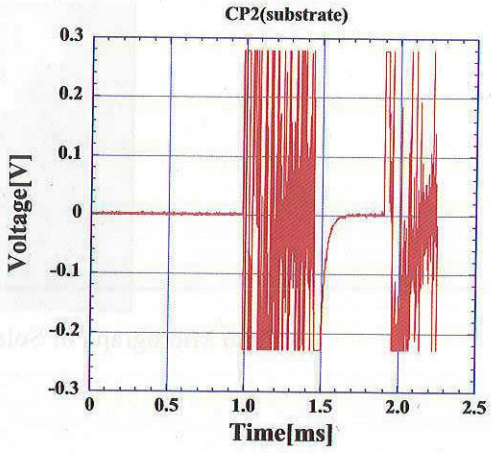
Table 1 Experiment Results

Case No.	1	2	3	4
Velocity[km/sec]	4.08	4.20	4.25	4.27
Short	×	○	○	×
Remarks	Rupture of Cables			Impact on a Cell without Voltage

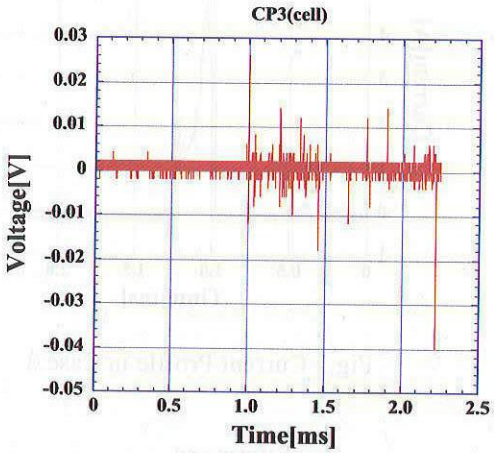
The four experiments were done in the same condition, where measured velocity is listed in Table 1. The circuit was short in cases 2 and 3 as shown in Table 1. Figure4 (a) shows waveform of CP1 (current probe) in case 2. Because the current flows from this waveform, it is understood that the circuit was short. Moreover, it is understood that the short circuit was between cell and substrate. The short circuit was not observed between cell and cell. Because this fact is understood from waveform of Fig.4 (b), (c) and resistance after short circuit is 22Ω. The high-speed photography (2000frames/sec) was taken to verify whether this short circuit is due to sustained arc or not. Fig.5 shows this three frames in photography. Emission of sustained arc can not be confirmed from Fig.5. Consequently, this short circuit did not cause sustained arc. Because kapton by impact of the projectile bursts and a possibility that between the substrate and the cell short circuit is high. The magnified photography of impact area is shown in Fig.6. It is easily understood from Fig6. However, the cause of the current waveform type intermittent has not been understood from Fig.4 (a). Next, Fig.7 shows waveform of CP1 (current probe) in case 3. Because the waveform indicates that the current flows in the whole circuit, it is understood that the circuit is short. Moreover, because case 1 cable was ruptured behind the coupon when colliding projectile, the circuit was not short. The circuit was not short though in case 4 a projectile had collided with the coupon without rupturing the cables behind the coupon. It is thought to be a cause that impacted on a cell without voltage. But if the impact is succeeded in the experiment both case 1 and case 4, a possibility of short circuit is high. However, a solar array coupon used in the experiment did not simulate actual solar array coupon. Consequently, it experiments a coupon simulating an actual solar array coupon. The result confirmed emission like sustained arc[2]. As above, the discharge phenomenon called sustained arc could not be confirmed in these four experiments.



(a) CP1



(b) CP2



(c) CP3

Fig.4 Current Profile Case 2

(a) at 1.0msec after impact (b) at 1.5msec after impact (c) at 2.0msec after impact

Fig.5 High-Speed Photography

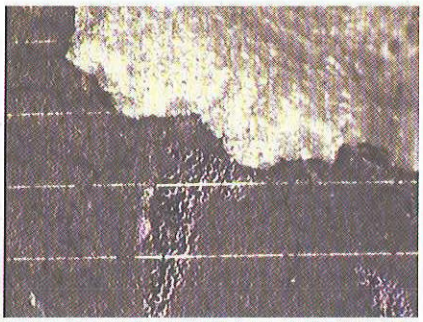


Fig.6 Micrograph of Solar Array Coupon (magnification: × 60)

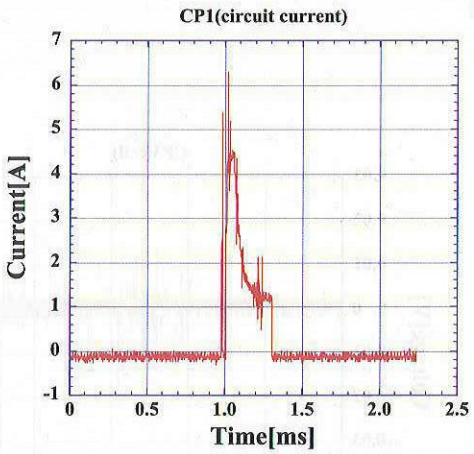


Fig.7 Current Profile in Case 3

Summary

When the debris collides with the solar array, it has been understood the circuit is almost short. Experiment should be done using the solar array coupon to simulate an actual solar array. Moreover, it is thought that the electric power of the solar array is reduced by short circuit when the debris of 10mm in diameter penetrates the solar array. However, the collision probability of the debris of this size is very small. Consideration of existence or nonexistence of discharge induced by micro debris is necessary where a projectile is made of Al and is smaller than 1mm in diameter.

Acknowledgement

It is noted that the present experiments were done at laboratory of spacecraft environmental interaction engineering.

References

[1] I.Katz, "Mechanism for Spacecraft Charging Initiated Destruction of Solar Arrays in GEO", AIAA paper 98- 1002, 36th Aerospace Science Meeting, Reno, (1998-11)

[2] S.Hosoda,T.Okumura,K.Toyoda and M.Cho, "Development of High Voltage Solar Array in LEO Plasma Environment", International Symposium on Space Technology and Science, (2004)