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Overview of Spacecraft-Charging Study in Japan

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***Abstract* — In Japan, many spacecraft charge -related activities are performed. We will report details of those concerning satellite design guideline, charging analysis tools, on-orbit investigation and laboratory experiments.**

Keywords — design guideline; charging analysis tools; on orbit investigations

I. Introduction

After the failure of ADEOS-II, many satellite charging studies were established in Japan. It is important to establish mutual links among satellite design, on-orbit measurements and laboratory experiments to mitigate anomalies caused by charging. For satellite design, spacecraft-charging design guidelines and MUSCAT (Multi-Utility Spacecraft Charging analysis tools) were developed and applied to the satellite after ADEOS-II and have since been continually revised. Moreover, the material properties used in MUSCAT are also important and their database is updated as part of the work of the spacecraft-charging design guideline committee. A new work item of the ISO standard “Spacecraft potential estimation in worst case environment” was proposed by Japan, and has been discussed in the working group and international workshop. For on-orbit measurement, SEDA-AP (plasma and potential measurements on the ISS), QZS (charging measurements of cover glass samples), Atoti-mini (potential measurements on HTV-4), Horyu-II (High Voltage Technology Demonstration Satellite) and PASCAL (discharge current measurement at ISS) were successful, and some missions continue to perform measurements. With regard to future launches, Horyu-III, IV, KASPER (plasma and potential measurement at HTV-5) have been under development in recent years and with regard to laboratory experiments, many components, such as solar array coupon panels, are tested for charging mitigation at LaSEINE (Laboratory of Spacecraft Environment Interaction Engineering) in KIT (Kyushu Institute of Technology) and at the space chambers in JAXA (Japan Aerospace Exploration Agency). Material properties for use in MUSCAT are measured by KIT, TCU (Tokyo City University), NNCT (Nara National College of Technology) and JAXA. We report on these activities and the current status of the spacecraft-charging study in Japan.

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II. Design Guideline And Charging Analysis Tools

A. *Spacecraft-Charging Design Guideline*

In 2005, JAXA established a working group to compile a spacecraft-charging design guideline and the first edition of the “Satellite Design Guideline for Charging and Discharge” (JERG-2-211) was published in 2009. Rev. A of this document was published in 2012, and an English version is also available. The design guideline has been continuously revised. In addition, the activity of this working group has included measuring material data used to charge analysis tools. JAXA, KIT, NNCT, and TCU have cooperated to make a database of the same.

B. *Charging analysis tools*

The development of MUSCAT (Multi-Utility Spacecraft Charging analysis tools) [1] [2] commenced in 2006; aiming to allow the person having designed the satellite to calculate the charged analysis within half a day. MUSCAT was completed with cooperation from the researcher in 2006. The computer code used with MUSCAT is a hybrid of PIC (Particle In Cell) and PT (Particle Tracking). This program allowed repeated improvement according to user suggestions, and was applied to the satellite after ADEOS-II.

C. *ISO Activity*

ISO-11221 “Space systems -- Space solar panels -- Spacecraft-charging induced electrostatic discharge test methods“ was published in 2011. A new work item of the ISO standard “Spacecraft potential estimation in worst case environment” was proposed by Japan, and has since been discussed in the working group. An international workshop concerning this standard was also held twice in January 2013 and 2014 respectively. Round-robin simulation tests using selected worst-case environments are ongoing using MUSCAT, NASCAP-2K and SPIS.

III. On Orbit Investigation

For on-orbit measurement, SEDA-AP, QZS, Atoti-mini, Horyu-II, PASCAL were successful, and some missions are still making measurements. With regard to future launches, Horyu-III, IV and KASPER have been under development in recent years.

A. *SEDA-AP*

Space Environment Data Acquisition equipment – Attached Payload (SEDA-AP) [3] was developed to measure the space environment around the International Space Station (ISS) and is one of the first missions of the Exposed facility (EF) of the Japanese Experimental module "Kibo". Space environmental data is crucial to avoid risks posed by the space environment, such as total dose, single event anomalies, surface charging, and material degradation. SEDA-AP measures these aspects of the space environment using eight types of instruments. SEDA-AP was attached to Kibo on July 25 using Kibo's JEM Remote Manipulator System (JEMRMS). PLAM (PLasma Monitor) [4], one of the eight instruments, measures the plasma density, temperature, and floating potential using a Langmuir probe. The data of PLAM is used for charging analysis of the ISS compared to FPMU (Floating Potential Measurement Unit) data.

B. QZSS

The Quasi-Zenith Satellite System (QZSS, "MICHIBIKI") is a positioning system using multiple satellites with the same orbital period as geostationary satellites and some orbital inclinations (their orbits are known as "Quasi-Zenith Orbits"). The MICHIBIKI was launched by the H-IIA Launch Vehicle No. 18 on September 11, 2010. Technical Data Acquisition equipment (TEDA) is mounted on QZS. The mission equipment of TEDA includes an LPT (Light Particle Monitor), which measures radiation and a POM (Potential Monitor), which measures the differential charge of material sample. TEDA continues measuring now.

C. ATOTIE-mini

The Advanced Technology On-orbit Test Instrument for space Environment-mini (Atotie-mini) is a trial instrument used to measure the potential of HTV against ambient plasma. The Atotie-mini comprises two sensors, a spacecraft-charging monitor (SCM) and an electrostatic voltmeter (TREK-3G). TREK-3G measures the dielectric potential against the chassis. In low Earth orbit, the ionosphere plasma charges the HTV. When HTV has potential against ambient plasma, the potential of the dielectric material on the surface, such as MLI and Ag-Teflon, is approximately equal to that of ambient plasma, which means the Atotie-mini can measure the HTV potential and has done so since being launched on 4 August.

D. Horyu-II

The HORYU (High Voltage Technology Demonstration Satellite)–II is a small 30cm cube 7kg satellite; developed by students of the Kyushu Institute of Technology. Its main mission is to demonstrate high-voltage (300V) solar array technology. It is the first time a solar array has been used to generate 300V without a DC/DC converter. Other equipment includes a solar array with arc mitigation, surface charging sensor, ELF (Electro-emitting Film for Spacecraft-charging Mitigation), a debris impact sensor and camera. HORYU-II was launched on 18 May. 350V photovoltaic power generation was successfully demonstrated. Experiments to demonstrate arc mitigation solar array designs were carried out. Electron emission from ELF was confirmed over the southern polar region.

E. PASCAL

An on-orbit experiment instrument, called PASCAL (Primary Arcing effects on Solar Cells At LEO), has been developed to perform ESD testing in orbit. The key job of the orbital ESD test is to characterize the threshold voltage of discharge, discharge frequency and degradation of state-of-the-art solar cells. PASCAL is essentially a miniature equivalent of a typical ground experiment system. Pre-launch functional testing shows that PASCAL has sufficient performance to successfully meet the goals of the ESD test on-orbit. Several environmental tests have been performed and the PASCAL experiment is now ready to start operation.

F. Horyu-III,IV

Horyu-III is a 3U-size cube sat, which is set to be released from the ISS. Its main mission is to measure electric discharge current on the high voltage solar array. Horyu-IV is a 30cm cubic-size small satellite. Its main missions include measuring discharge electric current and acquiring electric discharge images. The project of Horyu-III got underway as an educational satellite for undergraduate students, and Horyu-IV, as a research satellite for the astronautical engineering international course.

G. KASPER

A space environment monitor, KASPER, will be installed on HTV5 and measure the space environment while the HTV is flying and mooring to the ISS. KASPER comprises 4 sensors; TREK-3G to measure the charge potential of the HTV body, LP to measure the plasma current, SDM to measure micro-meteoroid and orbital debris (MMOD) from 100um to a few millimeters in size, and CDM to measure MMOD of size below 100um. KASPER is under fabrication and will be launched in 2014.

IV. Material Properties for Charging Analysis

The material properties used in MUSCAT are important and their database is updated by the spacecraft-charging design guideline committee. The material properties are measured by KIT (Kyushu Institute of Technology), TCU (Tokyo City University), NNCT (Nara National College of Technology) and JAXA.

For the SEE (Secondary Electron Emission) coefficient, we performed a round-robin examination of representative materials and the influence on electrostatic charge investigation by simultaneous irradiation with the electron beam and UV. For the photoemission coefficient, we established a deterioration confirmation system and performed a preliminary evaluation examination in representative materials. For volume resistivity, we established an examination environment matching the current density in orbit and repeatedly measured the influence on volume-specific resistance for irradiation and temperature changes.

V. Electro Charge and Discharge research in Laboratories

For laboratory experiments, many components, such as solar array coupon panels, are tested for charging mitigation at

LaSEINE (Laboratory of Spacecraft Environment Interaction Engineering) in KIT and at the space chambers in JAXA. The scope includes the following topics:

- Development of a sustained electric discharge restraint technique
- Development of a technique to control creeping discharge.
- Development of ELF to prevent static charge
- A current-collection performance test and electric discharge examination of EDT (Electro Dynamic Tether)
- Charged and discharge examination of the new solar array panel

VI. CONCLUSION

Most of the malfunctions due to electrostatic charges have been eliminated thanks to establishing a design standard and developing MUSCAT since the ADEOS-II accident. Constant and continued efforts to acquire material parameters for MUSCAT will be important. In addition, it is important to cooperate with efforts to establish standards of the ISO as an international contribution.

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