Spacecraft-Charging Study in Japan

K. Koga, T. Okumura, M. Ohhira, S. Kawakita, K. Toyoda, M. Cho and H. Miyake

Colleagues in Japan

***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

It is important to mutually link satellite design, on-orbit measurements, and laboratory experiments to mitigate anomalies caused by charging. For satellite design, spacecraft charging design guidelines and a MUlti-utility Spacecraft Charging Analysis Tool (MUSCAT) were developed and applied. These guidelines and MUSCAT have been continuously revised according to user requirements. Moreover, it is important to measure charging-related material properties used in MUSCAT. The material property database used in MUSCAT is updated by the committee on spacecraft charging design guidelines. Spacecraft potential estimation in worst-case environment was raised as a new work item proposal for an ISO standard by Japan and has been discussed by work groups and in international workshops. For on-orbit measurements, SEDA-AP (plasma and potential measurements on ISS), QZS (charging measurement of cover glass sample), Atoti-mini (potential measurement on HTV-4), KASPER (potential and plasma measurements on HTV-5), Horyu-II (High Voltage Technology Demonstration Satellite), and PASCAL (discharge current measurement at ISS) were successful, and some missions continue measuring. Moreover, Horyu-IV, and KITE (electrodynamic tether demonstration at HTV-6) are under development and intended for future launch. Concerning laboratory experiments, many components such as solar array coupon panels are tested for charging mitigation at Kyutech (Kyushu Institute of Technology) and space chambers in JAXA (Japan Aerospace Exploration Agency). Material properties of spacecraft surface that need to be used in MUSCAT are measured by Kyutech, TCU (Tokyo City University), NNCT (Nara National College of Technology) and JAXA. Herein, we report activities and the current status of spacecraft charging study in Japan

K. Koga, T. Okumura, M. Ohhira and S. Kawakita are with the Japan Aerospace Exploration Agency, 2-1-1 Sengen, Tsukuba city, Ibaraki prefecture, 305-8505, Japan (e-mail: koga.kiyokazu@jaxa.jp)

K. Toyoda and M. Cho are with the Kyushu Institute of Technology, 1-1 Sensui-cho, Tobata ward, Kitakyushu city, Fukuoka prefecture, 804-8550, Japan

H. Miyake are with the Tokyo City University, 1-28-1 Tamazutsumi, Setagaya-ku,Tokyo, 158-8557, Japan

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, Kyutech, 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 2009. 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. Current status of this item is CD Voting phase by April 30th, 2016

III. On Orbit Investigation

For on-orbit measurement, SEDA-AP, QZS, KASPER, Horyu-II, Horyu-IV were successful, and some missions are still making measurements. With regard to future launches, KITE 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. 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, 2012. 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.

D. Horyu-IV

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. HORYU-IV flight model has been completed in December 2015 and launched by a H-IIA rocket to an orbit of 575 km altitude in February 2016.

E. KASPER

A space environment monitor, KASPER is installed on HTV-5 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 launched at 2015 August.

F. KITE

JAXA plans demonstration test of the electrodynamic tether experiment on HTV-6. The name of experiment is Kounotori Integrated Tether Experiment, KITE. For the experiment, the potential monitor and electron emission module are developed. The electron emission module generates the electric circuit through the tether and ambient plasma. The field emission cathode type electron emitter is used for this function. The potential monitor measures the potential of HTV-6 to check the influence of electrodynamic teter.

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 Kyutech (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 Kyutech and at the space chambers in JAXA. The scope includes the following topics:

- Comparison between ultraviolet light and electron beam as charging source for ESD
- Simulation of flashover discharge on solar array by using plasma impedance model
- Effect of insulation film thickness on durability against sustained ark
- Simulation of power generation system of debris removal tether

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VI. CONCLUSION

Most of the malfunctions due to electrostatic charges have been eliminated thanks to establishing a design standard and developing MUSCAT. 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.

ACKNOWLEDGMENT

We thank all researchers having cooperated in the working group of JAXA design guidelines and ISO-related activity.

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