Title	<Abstracts (PhD thesis)>Study on active spacecraft charging model and its application to space propulsion system
Author(s)	Hoshi, Kento
Citation	Sustainable humanosphere : bulletin of Research Institute for Sustainable Humanosphere Kyoto University (2018), 14: 35-36
Issue Date	2018-09-10
URL	http://hdl.handle.net/2433/235404
Right	
Type	Departmental Bulletin Paper
Textversion	publisher

ABSTRACTS (PH D THESIS)

Study on active spacecraft charging model and its application to space propulsion system

**(Graduate School of Engineering,
Laboratory of Space Systems and Astronautics, RISH, Kyoto University)**

Kento Hoshi

Introduction

Spacecraft charging is one of the most common problems in designing spacecraft. Although the amount of charging varies according to the surrounding environment and the material properties of the spacecraft surface, it is practically impossible to avoid charging because ambient plasmas are present everywhere in space. Recently, a variety of new space propulsion systems utilize spacecraft charging, that is, orbital control techniques that utilize electrostatic and electromagnetic forces have been proposed. These orbital control methods provide propellant-less spacecraft orbital control and a very lightweight propulsion system compared with conventional chemical and electrical propulsion systems. These previous works, however, studied the problem from the standpoint of orbital dynamics, and typically assumed some feasible value of surface charge and then computed orbital trajectories or relative motions between two spacecrafts. To evaluate the performance and feasibility of such systems, it is necessary to understand active spacecraft charging. The purpose of this thesis is to model active spacecraft charging and the related phenomenon for evaluating the performance under realistic conditions from the perspective of plasma physics.

Active spacecraft charging model

Active spacecraft charging is simulated with full particle-in-cell (PIC) simulation to investigate the potential characteristics of the actively charged spacecraft. The electrostatic potential characteristics with a geostationary plasma environment are revealed. A new active charging model that considers the velocity distribution of beam particles is then proposed. Figure 1 shows the concept of the new model. Due to the finite temperature, the velocity distribution of beam particles has a spread around a beam velocity which corresponds to the accelerating potential. To consider the returning current, we define the velocity which corresponds to the spacecraft's potential. If the particle's velocity is slower than it, the particle will return to the spacecraft's surface. The potential of active charging can be calculated numerically and quickly using the new model; in contrast, the conventional model can only express active charging qualitatively, and particle-in-cell simulations require a very high computational load. The numerical solution of the new model is in very good agreement with the results of the full PIC simulation for a cubic spacecraft model with electron beam emission.

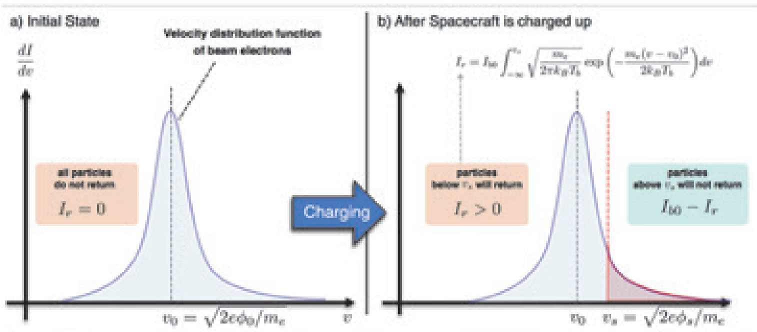

Fig.1: A new returning current model for active spacecraft charging.

A new probability-based secondary electron emission model

Secondary electron emission (SEE) was also investigated, which is one of the dominant factors that affect spacecraft charging. To realistically simulate an interaction between an electron and a material, three different processes of SEE should be considered in the simulation model. However, to correctly include all processes in charging simulations requires some computational techniques. Particularly, probability-based SEE models enable realistic simulation, but these models are difficult to use in a general particle simulation code due to their complexity and because they include experiment-dependent parameters. Since these models were mainly developed to be used for the simulation of an interaction between mono-energetic electron beam and an object's surface, they require experimental data of emission energy distribution and yield by electron beam impact to fit the parameters. Here we propose a new probability-based SEE model that is suitable for particle-based simulations. Figure 2 depicts the concept of the new SEE model. The new model has flexibility in the use of yield models of each emission process and can be easily implemented for particle-based simulations. This model was employed for a spacecraft charging simulation using a three-dimensional (3D) PIC code and its effect on charging was investigated. As a result, the secondary electron current significantly was varied depending on the ambient plasma temperature because the amount of elastic and inelastic backscattering current was strongly dependent on the temperature. The model enables the ratio of each secondary current to be automatically adjusted without any experimental parameter fittings.

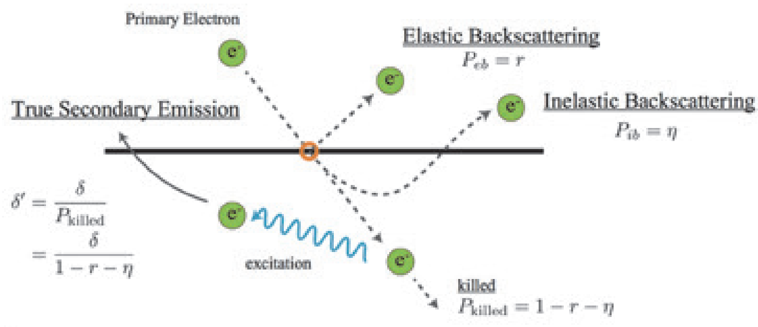

Fig. 2: A new probability-based SEE model for particle simulations.

Thrust Evaluation of Electric Solar Wind Sail

An electric solar wind sail, called E-sail, is a recently proposed propulsion device that consists of 50–100 conductive tethers with lengths of 10–20km and thicknesses of 0.1–1µm, as shown in Fig. 3. The E-sail was first proposed by Janhunen 2004 [1]. The main body of the spacecraft expands the tethers to form a sail-like structure. E-sail has electron guns to maintain a positive surface potential on the order of several kilovolts, in order to deflect solar wind protons. The tethers obtain the momentum of these deflected protons via Coulomb scattering and use it as their propulsive force. The system requires electron sources and electrical power for the electron guns to produce thrust. The E-sail is expected to be used as a new propellant-less space propulsion device. In this thesis, the thrust characteristics of the E-sail are investigated. The thrust obtained from the PIC simulation was lower than the thrust estimations obtained in previous studies. The PIC simulation indicated that ambient electrons strongly shield the electrostatic potential of the tether of the E-sail, and the strong shield effect causes a greater thrust reduction than has been obtained in previous studies. In addition, previous expressions of the thrust estimation were modified using the shielded potential structure derived from the present simulation results. The modified thrust estimation agreed very well with the thrust obtained from the PIC simulation.

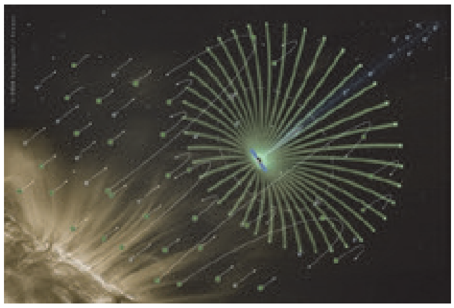

Fig. 3: An artistic image of E-sail. [©www.electric-sailing.fi]

Acknowledgements

The present study was supported by a JSPS Kakenhi Grant-in-Aid for JSPS Fellows No. 15J08941. The computations in the present study were performed using the Kyoto-daigaku Denpa-kagaku Keisanki-jikken (KDK) system at RISH of Kyoto University.

References

[1] Janhunen, P., "Electric Sail for Spacecraft Propulsion," Journal of Propulsion and Power, vol. 20, pp. 763-764, 2004.