ABSTRACTS (MASTER THESIS)

Thrust Evaluation of Magnetic Sail by Using Plasma Particle Simulation

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Magnetic sail is spacecraft propulsion that produces an artificial magnetosphere to block solar wind particles, and thus impart momentum to accelerate a spacecraft. In the present study, we conducted full particle-in-cell simulations on small-scale magnetospheres (Electron inertial scale) and Flux-Tube simulation on large-scale magnetospheres (Ion inertial scale) to investigate thrust characteristics of magnetic sail and its derivative, Magneto Plasma Sail (MPS), in which the magnetosphere is inflated by an additional plasma injection.

First, the simulations with the various magnetospheric sizes were performed to obtain the thrust level of the each magnetic sail. In Electron inertial scale, the Full-PIC simulation that treats both ions and electrons as particles is performed since the electron's finite Larmor radius effect and the charge separation between ion and electron become significant. In Ion inertial scale, the Flux-Tube model is performed, which neglects wave propagation and solves only a steady state of a plasma flow including the ion's finite Larmor effect. Therefore, the Flux-Tube model is expected to quickly estimate a thrust level with the low capacity of the computational memory. However, the Flux-Tube models developed for hall thrusters and ion engine grid do not include the effect of induced magnetic field. In the case of magnetic sail, the induced magnetic field has to be considered. Therefore, we constructed a new Flux-Tube model including the induced magnetic field [1]. As a result, the experimental formula for the thrust estimation is obtained and the thrust level from Electron scale to MHD scale is revealed. It is also shown that the MPS demonstrator spacecraft ($L\sim500$ m) can obtain the larger thrust by the magnetosphere inflation since the drag coefficient rapidly becomes larger in the scale.

In addition, the simulation for MPS was performed and the increase of the thrust was analyzed. We revealed that the plasma injection on the condition that the kinetic energy of plasma is smaller than the local magnetic field energy ($\beta\sim10^{-3}$) can significantly inflate the magnetosphere by inducing diamagnetic current in the same direction as the onboard coil current. As a result, the MPS thrust is increased effectively by an additional plasma injection: the MPS thrust (15 μN/m) becomes up to 7.5 times larger than the original thrust of the magnetic sail (2.0 μN/m). In addition, we found that the thrust gain of MPS defined as "MPS thrust / Magnetic sail thrust + plasma injection thrust" becomes up to 2.2 [2].

As a result, the thrust of the magnetic sail from Electron inertial scale to Ion inertial scale and the attitude stability were revealed. These enable us to design the orbit of the magnetic sail supposing deep space missions. In addition, MPS with thermal plasma injection in 2D achieved to generate the high efficient thrust.

References

[1] Ashida, Y., Funaki, I., Yamakawa, H., Kajimura, Y. and Kojima, H., "Thrust Evaluation of a Magnetic Sail by Flux-Tube Model," Journal of Propulsion and Power, Vol. 28, No. 3, 2012, pp. 642-651.

[2] Ashida, Y., Funaki, I., Yamakawa, H. and Kajimura, Y., "Two-Dimensional Particle-In-Cell Simulation of Magnetic Sails," 32nd International Electric Propulsion Conference, Wiesbaden, Germany, September, 2011.