2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Laboratory Experiment of Magnetoplasma Sail for Future Deep Space Missions

Yuki Murayama[1], Kazuma Ueno[2], Yuya Oshio[3], Hideyuki Horisawa[4] and Ikkoh Funaki[5]
[1] Department of Mechanical Engineering, Graduate School of Engineering, Tokai University,
[2] Chukyo University, [3]Tokyo University of Agriculture and Technology,
[4]Tokai University, [5]Japan Aerospace Exploration Agency

e-mail (speaker): yuki.murayama@ac.jaxa.jp

This paper summarizes experimental studies of the magnetic sail (MagSail) and the magneoplasma sail (MPS) by "Plasma Sail Working Group" in ISAS/JAXA and introduces the research plans of the experimental study after the group dissolution.

MagSail is a deep space propulsion system utilizing a large-scale interaction between the solar wind and artificial magnetic fields (Fig. 1). The solar wind is a high-velocity plasma flow constantly flowing out into interplanetary space from the sun. The artificial magnetic fields by the superconducting coil on the spacecraft, deflect the solar wind particles approaching the coil and produce a magnetosphere which is the cavity formed by the magnetic field in the solar wind flow. MagSail was proposed by R. Zubrin in 1991.[1] According to Zubrin's theory, it is estimated that the magnetospheric size of 100 km or more is necessary for a 20-N-class MagSail. However, it is difficult to launch a huge coil or make it in space. Therefore, R. M. Winglee proposed MPS using small coils and magnetosphere expansion by plasma assist. [2] (Fig. 2) The numerical analysis of MagSail was conducted in advance and clarified the thrust production mechanism. Those calculations are based on MagnetoHydroDynamics (MHD) model for small computation cost, however, the particle effect by ion and electron particle affects the thrust performance. It is difficult of calculation using full Particle In Cell (PIC) method considering the particle effects for whole MagSail area due to the limitation of computer resources. Therefore, the experiment including the particle effect is required.

Our research group conducted the experimental simulations of MagSail and MPS using MPS grand simulator, was developed in ISAS/JAXA. Three MagnetoPlasmaDynamic (MPD) arcjets were used as the solar wind simulator[3]. MPD arcjets can easily produce a high-velocity plasma stream. And the numerical analysis using MHD method was conducted in parallel. As a results, we have clarified the thrust characteristics and the particle effect of MagSail from the grand experiments[4] and numerical analysis on the MHD scale. Next, we conducted MPS grand simulation using plasma jets for magnetospheric inflation.[5] Furthermore, we confirmed thrust increment for MPS compared with MagSail in the laboratory experiment. However, finally, as a result of the experiment, our group could not confirm increasing the thrust gain, that $F_{MPS}/F_{MagSail}$, for practical use.

After the working group dissolution, the magnetic fields and induced current measurement was conducted to clarify the relation between thrust performance and the behavior of particles on magnetospheric boundary region of MPS. And to increase the limited of thrust gain, we came up with varying the magnetic field structure inside the magnetopause. We proposed and developed a new concept MagSail, multipole type, and conducted thrust measurement and magnetic fields measurement of the multipole MagSail.[6],[7]

Our group aimed to launch the technically demonstration satellite, however, it has not been realized yet, because MagSail could not find its advantage over other electric propulsion systems near Earth orbit. Thus, we came up with INTERSTELLAR FLIGHT as a new target of future missions. One of the most advantage of MagSail is what it is propellant-less system and MagSail can generate thrust from the interstellar wind, super-high-velocity plasma flow from the star, over 2000 km/s. We proposed that interstellar mission using MagSail. To realize interstellar flight, we have to make a large magnetopause and improve the performance of MagSail. We conducted multipolar MagSail experiment as the simulation of MagSail formation flight.

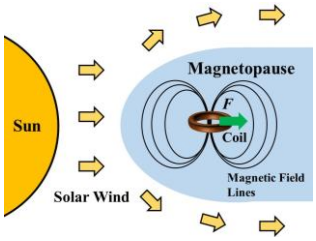

Fig.1 Concept of MagSail

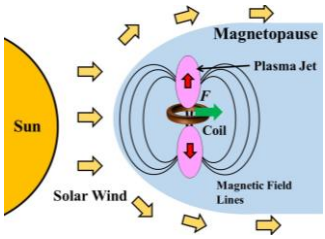

Fig.2 Concept of MPS

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